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RELATION OF THE CRETACEOUS FORMATIONS TO THE ROCKY MOUNTAINS IN COLORADO AND NEW MEXICO.

By Willis T. Lee.

PURPOSE OF THIS PAPER.

Some time ago, while working on a problem that involved the question of the presence or absence of islands near the close of the Cretaceous period in the region now occupied by the southern part of the Rocky Mountains, I was forced to the conclusion that no land masses or islands of any considerable size persisted there throughout the Cretaceous period, for I found no sedimentary rocks that were clearly derived from such islands. This result led to a reexamination of available information to see what evidence the sedimentary rocks in other areas near the present mountains could furnish, and I found rather unexpected confirmation of my conclusion. In the course of this study it became evident that there is apparent conflict of testimony between different classes of fossils and that the physical evidence, including lithology, structure, and sequence of beds, is at variance with some of the commonly accepted correlations. In this state of uncertainty I tried to apply physiographic principles to see if they would throw any light on the interrelations of the Cretaceous formations of the Rocky Mountain region and on the events that opened and closed the period. This led me to a conclusion similar to that reached by the paleontologist C. A. White [1] many years ago, namely, that the Upper Cretaceous formations up to and including the Laramie extended across the site of the mountains.

I believe that the principles of physiography, as well as those of lithology, paleontology, and structure, may be used to good advantage in the correlation of sedimentary formations, and that they may prove effective in some problems where the others fail. I propose to attempt an application of these principles to some phases of the stratigraphy of the Rocky Mountain region of Colorado and New Mexico, although I recognize that to do this adequately much more information must be gained, especially in areas that are now very imperfectly known. The most that can be accomplished at the present time is to point out some of the relations that seem to exist, in the hope that observation may thus be stimulated.

A study of this kind naturally leads into many byways, and the paper might be expanded indefinitely. I propose, however, at this time to confine the discussion to such facts as may have a direct bearing on the correlation of some of the Cretaceous formations in the Rocky Mountain region and to such facts as will throw some light on the physical conditions of this region at the close of the Cretaceous. The significance of the unconformity separating the Cretaceous and Tertiary systems in this region—that is, the post-Laramie, post-Vermejo unconformity—is very largely dependent on the question whether any considerable parts of the Rocky Mountain area remained above sea level throughout Cretaceous time.

The sections used in this paper were measured independently, most of them for the purpose of showing the stratigraphic relations of the coal-bearing rocks. Hence the coal-bearing formations have been described more fully than others. The measurements and descriptions were made by different men, and the personal equation must be considered; also due allowance must be made in the interpretation of results.

[1] U. S. Geol. and Geog. Survey Twelfth Ann. Rept., p. 50, 1883.

REASON FOR THE INVESTIGATION.

COAL BEDS AT MANY HORIZONS WITHIN THE CRETACEOUS.

During the investigations of the Rocky Mountain coal fields coal beds have been found at so many horizons within the Cretaceous that it seems probable that conditions favorable to their accumulation existed over extensive areas in one place or another from Dakota to Laramie time. There seems to be a tendency on the part of some geologists to explain these numerous coal beds on the assumption that the land underwent repeated oscillations which carried it sometimes above and sometimes below sea level, whereas it seems equally possible to account for them on the assumption that sedimentation was going on contemporaneously with the advance of the sea, due either to subsidence of the basin or to rise of sea level, and that the apparent withdrawal of the sea at a given locality as shown by brackish or fresh water sediments was due to the relatively rapid accumulation of sediments in that portion of the basin which was thereby filled to the existing sea level. The relation of marine to non-marine beds would thus depend on the rate of sedimentation relative to the rate of subsidence. For example, in some parts of western New Mexico and eastern Arizona no Cretaceous rocks younger than Colorado have been found. This has been attributed to the "emergence" of these parts, whereas it may as rationally be interpreted to mean that during Colorado time, without any oscillation of the land, these parts of the basin received alternately brackish-water and marine deposits, and that during later time sediments were carried seaward over these deposits to parts of the basin not yet filled, just as the Mississippi is now filling the Gulf of Mexico without materially building up the surface of its delta.

In the region with which this paper deals the evidence seems to point to an intermittent downward movement of the surface (or an intermittent upward movement of the sea level) during early Cretaceous time and practical stability during later Cretaceous time rather than to oscillations that produced so-called islands in the region of the present Rocky Mountains. (The term Rocky Mountains in this paper refers to the ranges of central Colorado extending southward into New Mexico and northward into Wyoming.)

In correlating the sedimentary formations of the several localities which are now more or less disconnected because of erosion there is a tendency to correlate rocks that are lithologically similar and to neglect the obvious fact that a coal-bearing sandstone may have been in process of formation at one locality at the same time that marine beds were being formed at another locality.

CORRELATIONS: LITHOLOGY VERSUS PALEONTOLOGY.

There is a tacit understanding among geologists, more or less precise according to the individual, that a formation name implies a definite age relation. The application of a formation name, however, is dependent on correlation and is subject to all the uncertainties attendant on correlation. For example, coal-bearing sandstones of middle Upper Cretaceous age at several of the localities described in the following pages have been called Mesaverde. There are reasons for believing that the so-called Mesaverde of the several localities may occupy very different places in the time scale, ranging from upper Colorado to a position well toward the top of the Montana group. A sedimentary formation is usually defined as a lithologic unit, but this definition is not closely adhered to in practice, and in reality formational boundaries are often drawn on fossil rather than on lithologic evidence. Moreover, it is not possible to adhere to this definition in all cases, inasmuch as beds formed at the same time may change laterally from sandstone of fresh-water origin, through brackish-water beds, to shale or limestone of marine origin. If the rocks can be traced through these transitions, a fresh-water sandstone and a marine shale may be proved to be of the same age; but if for any reason connection can not be established by actual tracing and the correlation must depend on lithology and sequence or on paleontology, it seems to be practically impossible to determine whether certain fresh-water, brackish-water, and marine beds are of the same age or are more or less widely separated in time.

NEAR-SHORE VERSUS OFFSHORE DEPOSITS.

It is obvious that in a basin which is being filled with sediment the finer material is likely to be carried far out and the coarser material to accumulate near shore and that swamp conditions favorable to the formation of coal are likely to prevail along the coast. As the shore migrates, either because of the accumulation of sediments or because of a change in sea level, the conditions of sedimentation are likely to remain constant with respect to the shore but to vary with respect to given localities. It is possible that in a filling sea like the interior Cretaceous sea of North America brackish-water and fresh-water conditions favorable to the accumulation of coal persisted near shore throughout the life of the sea, while marine conditions existed continuously in the center of the basin. It is conceivable, therefore, that a coal-bearing sandstone, were its continuity unbroken by erosion, might be traceable without interruption through the Cretaceous beds and yet vary in age from place to place, as is illustrated in figure 12. For example, the basal sandstone at A may be the homogenetic equivalent of the basal sandstone at B, but it is not the time equivalent.

This illustration is intended to represent some of the possible relations of the sedimentary rocks formed in a sea that advanced from the right, spreading over a land mass toward the left. A basal sandstone is formed at A and is soon covered with marine shale as the sea advances. The same thing then takes place at B. Later a retreat of the sea, a temporary halt in advance, or an increase in the amount of sediment causes a second sandstone to form at A′ and a little later at B′. If now the rocks are exposed at A and at B and the intervening rocks are eroded away or covered, the sections A-A′ and B-B′ appear alike in that each shows a sandstone separated by a marine shale from a basal sandstone. The sections may be so near each other that correlation by lithology would seem to be admissible, and such fossils as happen to have been found may not be adequate to show difference in age. There is little doubt that under these conditions the formations of the two sections would be erroneously regarded as time equivalents, whereas they are only homogenetically equivalent and really differ in age.

Sediments accumulating near shore may contain fossil plants, fresh-water or brackish-water invertebrates, or certain kinds of marine invertebrates, according to local conditions at the time of sedimentation. But the fossils in the sandstone at B′ are likely to be so different from the open-sea forms at C that there is little possibility of recognizing them as being of the same age.

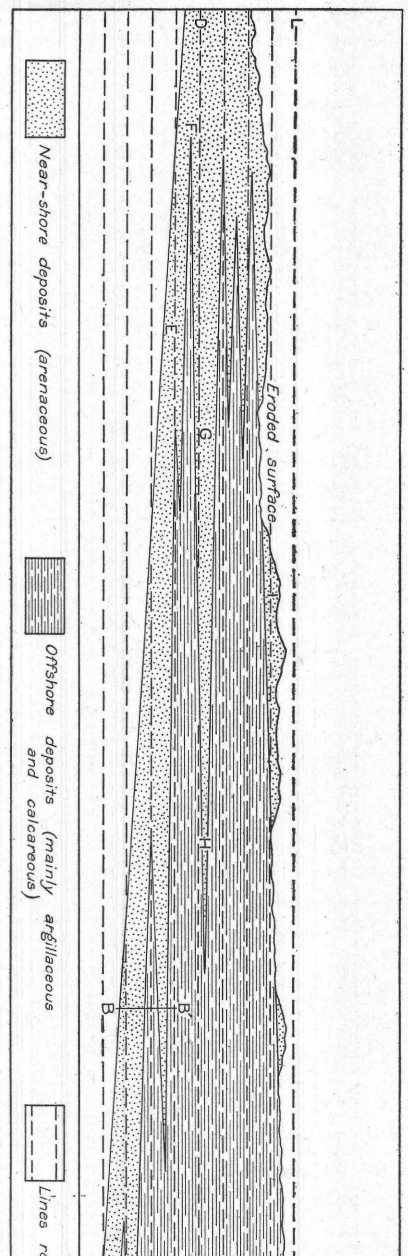

FIGURE 12.—Sketch section to illustrate the distinction between homogenetic equivalency and time equivalency.

If the diagram is taken to represent the Cretaceous rocks of the southern Rocky Mountain region, the line D-D the separation in time between the Colorado and Montana groups, and the line L-L′ the beginning of Laramie time, then the sandstone A-B may represent the Dakota; the sandstone at A′, the coal-bearing rocks at Engle, N. Mex.; the sandstone at B′, the coal-bearing rocks at Carthage and Zuni, N. Mex.; the sandstone at E, the coal-bearing rocks at Pinedale and elsewhere in Arizona; the sandstone at F, the coal measures of Colob Plateau, in Utah; the sandstone extending from G to H, the Mancos and Mesaverde from the Datil Mountains, N. Mex., to Durango, Colo.; the sandstone at I, the coal-bearing "Laramie" formation of the San Juan Basin; and the sandstone at J (projected across the spaces where it has been removed by erosion), the youngest coal-bearing rocks of Cretaceous age in northern Colorado and southern Wyoming—that is, the Laramie formation of the Denver Basin and the formations of corresponding age in northwestern Colorado and southern Wyoming.

It is quite impossible to make a diagram that will illustrate a general principle and at the same time adequately represent local details. Three qualifications seem desirable in the application just made. First, as the diagram stands, it might be interpreted to mean that the offshore and near-shore deposits accumulated at the same rate. If rate of sedimentation alone were to be illustrated the lines representing equivalency in age should bend downward toward the right, for, as is well known, the great bulk of sediments accumulate near shore, and a thick near-shore deposit is likely to be the time equivalent of a much thinner offshore deposit. Second, the representation of formation boundaries in the diagram by straight lines drawn at an angle with the lines representing equivalency in age is generalized and should not be interpreted as indicating abrupt changes in conditions of sedimentation. There is more likely to be an irregular transitional zone in which the offshore and near-shore deposits meet and interfinger. In this process of interfingering marine conditions will sometimes extend well up toward the source of the sediments and at other times brackish or fresh-water conditions will extend far out into the basin. Third, inasmuch as the basin fills most rapidly near shore a bed of given thickness, character, and stratigraphic position near the periphery of the basin is likely to be older than a bed of the same thickness, character, and stratigraphic position near its center. As portions of the basin near its periphery are built up to the limit of deposition the fresh sediments are transported toward the center over those previously deposited. This process, of course, is further complicated by oscillations both of the land and of the sea level.

PHYSIOGRAPHIC BASIS OF CORRELATION.

In view of some of the foregoing considerations it would seem wise to emphasize the physiographic conditions, in so far as they can be ascertained, that existed during the formation of beds whose correlation is attempted. A large volume of exact information is necessary in order to use such data to the best advantage, but it is my belief that enough is known about the Cretaceous and older Tertiary formations of the Rocky Mountain region to use the physiographic data in connection with structure, lithology, and paleontology to a greater extent than they have been used heretofore in making correlations.

ATTITUDE OF THE CRETACEOUS FORMATIONS TOWARD THE ROCKY MOUNTAINS.

Some of the most significant facts bearing on the use of physiography in correlating the Upper Cretaceous formations of the southern Rocky Mountain region are found in the relation of these formations to the mountains. It was the belief of early observers that highlands of considerable extent existed in the Rocky Mountain region throughout Upper Cretaceous time. Although for years there has been a growing tendency on the part of some investigators to regard this belief as unfounded, no one has taken the trouble heretofore to combat it, and it has persisted with characteristic tenacity. Whatever may have been its influence on the establishment of the time scale for the Upper Cretaceous formations of the Rocky Mountain region, the fact remains that a stratigraphic column has been established for areas east of the mountains which differs radically from that established for areas west of the mountains. If, however, there were in the mountain region during Upper Cretaceous time no highlands capable of contributing any considerable amount of sediment or of forming a barrier to the distribution of sediments derived from the continental land masses on either side of the interior sea, the two columns should not be so discordant as they seem to be, and it may be well to reexamine the principles on which they were established.

One of the principal objects of this paper is to point out some of the reasons for believing that no highlands of any considerable extent existed in the Rocky Mountain region of Colorado

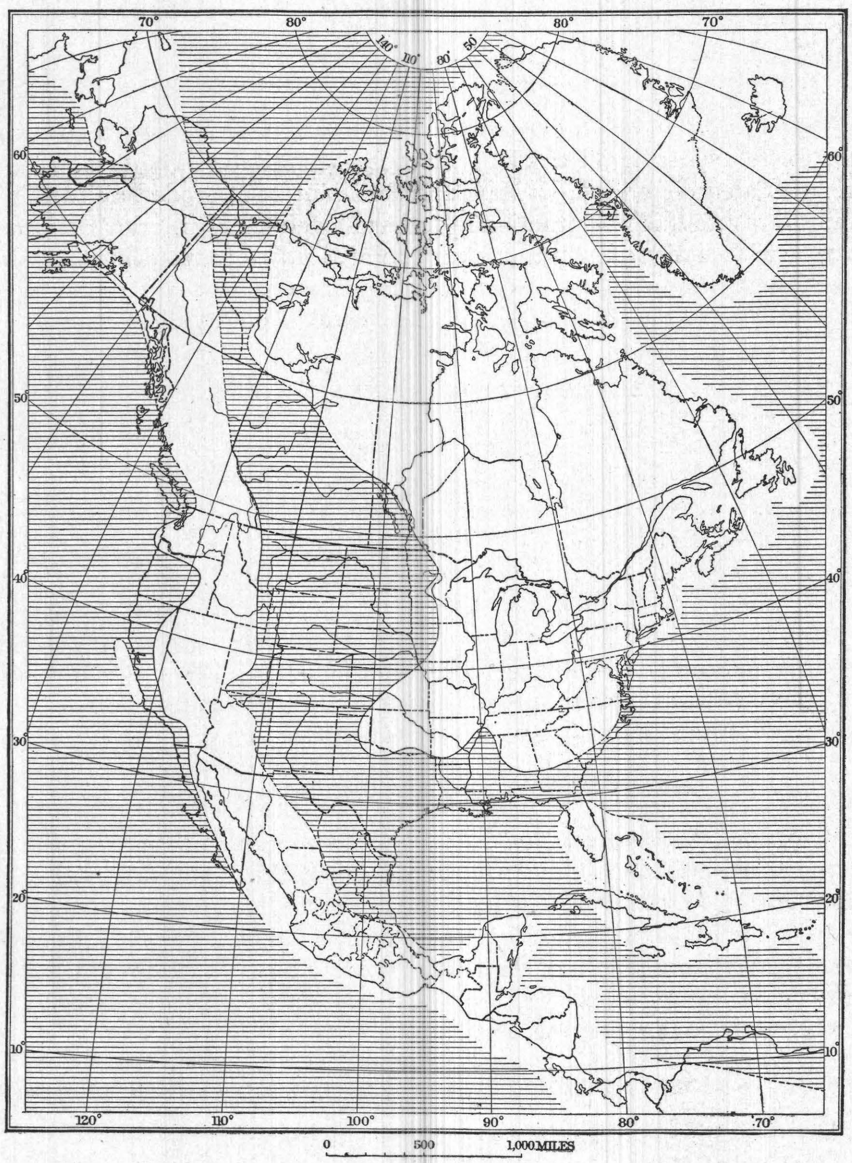

FIGURE 13.—Paleogeographic map of North America showing by shading the part of the continent submerged during the Benton epoch. (After Charles Schuchert.)

and New Mexico during the Upper Cretaceous epoch and that the sedimentary formations of this region were once essentially continuous across the areas now occupied by the mountains, with only such variations in thickness and character as are to be expected in different parts of a single basin. Schuchert[1] anticipated this conclusion in some measure when, in his maps, one of which is reproduced as figure 13, he extended the Cretaceous sea completely over the Rocky Mountain area. However, on page 586 of his text he states that the sea connected the Gulf of

[1] Schuchert, Charles, Paleogeography of North America: Geol. Soc. America Bull., vol. 20, pp. 427-606, 1910.

Mexico and the Arctic Ocean *east* of the Rocky Mountains and that throughout Cretaceous time "the Laramie Range seems to have been in slight upward movement with decided elevation toward the close of the period." This statement recalls Eldridge's description [1] of certain arches near Golden, Colo., which he supposed to have existed during the Cretaceous period, but whose existence Richardson [2] seems to doubt. If this arching were as important as Eldridge and others have maintained, indications of similar mid-Cretaceous movements should be present elsewhere, but they have not been found in the Rocky Mountain region, although evidences of the proximity of land occur all along the border of the continental mass west of the Cretaceous sea, as Stanton has frequently pointed out.

GEOGRAPHIC CONDITIONS PRIOR TO DAKOTA TIME.

There is little evidence of notable crustal movement in the Rocky Mountain region for a long time prior to the beginning of the Upper Cretaceous epoch. The highlands that occupied this region in late Paleozoic and early Mesozoic time had been eroded and the region brought to a condition of low relief, if not practically to base-level. The interior Cretaceous sea seems to have advanced with little interruption over the area now occupied by the southern part of the Rocky Mountains. Without entering into a long discussion of the pre-Cretaceous physiography, I may be permitted to call attention briefly to some of the principal arguments for this postulate of low relief.

JURASSIC EPICONTINENTAL SEA.

In late Jurassic time a shallow epicontinental sea covered the northern and western parts of the Rocky Mountain region.[3] The distribution, thickness, and character of the sediments laid down in this sea are not such as to indicate that the area now occupied by the Rocky Mountains furnished any considerable quantity of coarse material. Moreover, the presence of marine Jurassic fossils in western Texas,[4] although they constitute a later fauna than that of Wyoming, suggests that the southern part of the Rocky Mountain region may not have been much farther above sea level than the northern part.

PHYSIOGRAPHIC CONDITIONS INDICATED BY THE MORRISON FORMATION.

The Morrison formation lies with apparent conformity on the marine Jurassic beds in southern Wyoming. It overlaps the marine Jurassic both east and west of the Rocky Mountains and extends southward into New Mexico with remarkable uniformity in thickness, character, and fossil contents. Certain beds in North Park, South Park, and elsewhere in Colorado, in the midst of the mountainous area, indicate that the areal distribution of the Morrison was essentially the same as that shown later in this paper for the Dakota sandstone.

There are, however, a few places where the Morrison is known to terminate against older rocks, allowing the Dakota sandstone to overlap it. One such locality near Colorado Springs, Colo., is described by Cross,[5] and according to Hayden's atlas of Colorado the Dakota rests in several places on older rocks, the Morrison apparently being absent. However, this atlas has proved to be inaccurate in this respect in several places, and the Morrison has been found to be even more continuous than was formerly supposed. These discoveries led Cross and Larsen [6] to believe that the Morrison and its western equivalent in the Gunnison formation may have been connected across the mountain region.

THE COMANCHE SEA.

The Comanche sea appears to have found little obstruction to its passage as far west as the present Rocky Mountains. The Comanche sediments of eastern Colorado and New Mexico indicate that the sea advanced over a graded plain. It is not known to have invaded western

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[1] Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, pp. 82-104, 1896.

[2] Richardson, G. B., Structure of the foothills of the front range, central Colorado: Washington Acad. Sci. Jour., vol. 2, p. 429, 1912.

[3] Logan, W. N., A North American epicontinental sea of Jurassic age: Jour. Geology, vol. 8, pp. 242-273, 1900.

[4] Cragin, F. W., Paleontology of the Malone Jurassic formation of Texas: U. S. Geol. Survey Bull. 266, 1905.

[5] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

[6] Cross, Whitman, and Larsen, E. S., The stratigraphic break below the Jurassic sandstone in southwestern Colorado: Washington Acad. Sci. Jour., vol. 4, p. 238, 1914; Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90-E (Prof. Paper 90, pp. 39-50), 1914.

Colorado, but, on the other hand, there is no known evidence that the areas immediately west of the present mountains were far above sea level during Comanche time.

The general character of the Comanche sediments is worthy of note in this connection. At their base is a sandstone that is generally conglomeratic in the Rocky Mountain region and consists of coarse sand in other regions. It differs from many sandstones in being singularly free from partings of clay or other fine-grained material. Because of its open texture, due to the absence of fine material, it is one of the most important water-bearing sandstones in the Rocky Mountain region. The pebbles in the conglomeratic parts consist almost wholly of resistant rock, such as chert, quartzite, and argillite. Observations made at many localities throughout the Rocky Mountain region give the general impression that the sandstone is due to a washing and reworking of residual silica distributed over a base-leveled surface. It is conceivable that owing to the shallowness of the sea for considerable distances from shore broad lagoons were formed that prevented free access of marine waters and that in these lagoons the weathered surface material was agitated by the waves sufficiently long to be thoroughly washed and evenly distributed, so that the coarser material was deposited relatively near shore and the finer material eventually came to rest beneath the deeper and quieter water at some distance out. This sandstone is the lower part of the Dakota in the Rocky Mountain region as formerly described. It has only recently been recognized as distinct in age from the true Dakota [1] and mapped as the Purgatoire formation. The reference of the Purgatoire to the Washita epoch of the Lower Cretaceous is in accordance with the classification used by the United States Geological Survey. If, however, the Washita is Upper Cretaceous, as Berry [2] asserts and as Haug [3] and other European geologists believe, then the Purgatoire is also Upper Cretaceous and the Dakota sandstone therefore holds a position somewhat above the base of this series.

Above this basal sandstone occurs a thin layer of clay, carbonaceous in some places, that constitutes the so-called "Dakota fire clay." That it is of Lower Cretaceous age is proved by the presence in it of certain marine invertebrates. If this thin layer of clay and the underlying sandstone are all that in the Rocky Mountain region can represent the great thicknesses of Lower Cretaceous rocks in Texas and Mexico, it is evident either that they represent a long period of time or that they represent only a part of the Lower Cretaceous. It is regarded as a well-established fact, based on both paleontologic and stratigraphic continuity, that the Lower Cretaceous of the Rocky Mountain region represents only the upper part of the Lower Cretaceous series. If, therefore, the Morrison is not Lower Cretaceous in age the greater part of Lower Cretaceous time must be represented by a hiatus at the base of the Purgatoire. Little evidence of such a hiatus has ever been found. If, however, it is granted that the Comanche sea advanced over a graded plain and that there was little warping of this plain prior to the beginning of Upper Cretaceous time, there might be no recognizable unconformity at the base of the Purgatoire formation, although the time break might be great.

From what has been written it is perhaps sufficiently evident that such highlands as may have existed in the Rocky Mountain region had been subjected to degradation through all of Jurassic and all of Lower Cretaceous time; and, furthermore, that so far as is now known these lands supplied very little sediment during these periods. It is quite otherwise in western Colorado and eastern Utah, where the thick sediments of Jurassic age, including in some places probable equivalents of the Morrison, indicate nearness to the continental land mass farther west. In other words, the Rocky Mountain region seems to have been reduced to a condition closely approximating base-level by the close of Lower Cretaceous time. Such areas as had escaped inundation by the Lower Cretaceous sea and had been exposed to the weather through long ages must have contained considerable quantities of siliceous material concentrated at the surface by the removal of the more easily decomposed minerals. This residual silica was available for the formation of the Dakota sandstone.

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[1] Stanton, T. W., The Morrison formation and its relation with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 657-669, 1905. Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (No. 186), 1912.

[2] Berry, E. W., Correlation of the Potomac formation: Maryland Geol. Survey, Lower Cretaceous, pp. 136-137, 1911.

[3] Haug, Emil, Traité de géologie, pp. 1169, 1293, Paris, 1907.

GEOGRAPHIC CONDITIONS INDICATED BY THE DAKOTA SANDSTONE.

EARLY CRETACEOUS PENEPLAIN.

Probably the best indication of the physiographic conditions prevailing in the Rocky Mountain region at the close of the Lower Cretaceous is given by the Dakota sandstone. This sandstone is essentially continuous both east and west of the Rocky Mountains and is present in many places between the mountain ranges—as, for example, in North, Middle, and South parks, Colo. It is upturned on all sides against the mountains in such a manner as to strengthen the belief that it once extended continuously over the areas now occupied by them.

The distribution of the Dakota sandstone, taken from Hayden's atlas of Colorado and from later maps of certain areas, is shown on figure 14. East of the mountains its altitude ranges from 6,000 to 10,000 feet. West of the mountains it is somewhat higher, attaining such altitudes as 12,600 feet in southwestern Colorado, 11,500 to 13,200 feet in central-western Colorado, and 13,400 feet near Breckenridge, between Middle and South parks. Inasmuch as the highest peaks of the Rocky Mountains are little more than 14,000 feet in altitude, it is reasonable to suppose that the Dakota sandstone may once have extended continuously over this region and that it would now be found on the highest peaks had it not been removed by erosion. This suggestion becomes especially pertinent when it is considered, for example, that in a district like Breckenridge the Dakota, together with the overlying marine Cretaceous, is found at altitudes of more than 13,000 feet, although 45 miles to the east it passes beneath the surface of the Great Plains, and if the thicknesses of the strata overlying the Dakota are correctly reported, it reaches depths below the present sea level, as shown in the sketch section, figure 15. Moreover, this suggestion gains added force from the fact that near Breckenridge, according to Ransome, the Dakota is overlain by remnants of Cretaceous sedimentary rocks estimated as 5,500 feet thick, a thickness comparable with that of the Cretaceous on either side of the mountains. Inasmuch as the highest peaks rise less than 1,000 feet above these remnants, there seems to be little room for doubt that the Cretaceous sedimentary formations, in this part of the range at least, once extended continuously over the area now occupied by the mountains. Also, the Dakota occurs at short intervals from Breckenridge northward and westward to the large areas west of the mountains in which the continuity of this sandstone is unbroken.

In this connection it may be in place to mention the somewhat remarkable uniformity in the altitudes of many of the highest peaks of the Rocky Mountains, a large number of which are close to 14,000 feet above the sea. This uniformity has been noted by many observers,[1] and the suggestion has been made by some that the tops of these peaks mark the approximate position of an ancient peneplain. Others regard this suggestion as visionary. It is conceivable that the flat top of Longs Peak, about 250 feet wide and 600 feet long, may be a remnant of the old peneplain, and the domelike summits of other mountains may possibly be similar remnants in a more advanced state of erosion. The few facts available can not be taken as a basis for definitely postulating an ancient peneplain, but the uniformity in altitude of the high peaks, together with the geologic evidence, seems to indicate that they are best explained as the least degraded portions of the base-leveled surface on which the Dakota sandstone was laid down.

Cross [2] has shown that the post-Cretaceous uplift of the Rocky Mountains was accompanied by the outpouring of large quantities of andesite and that although the andesitic débris forms a large part of the early Tertiary beds, such as the Denver and equivalent formations, no remnant of the flows has survived. This is somewhat remarkable if the andesite rested on the equally resistant crystalline rocks of the present mountains, but if it was outpoured on weak Cretaceous sedimentary beds that once covered the older crystalline rocks, its total removal is more readily understood, for these weak beds would erode easily, undermining the igneous material and thus facilitating its removal.

There are few places where the Dakota sandstone abuts against older rocks in such a manner as to indicate that it terminates against land masses that existed in Dakota time and few places

[1] Davis, W. M., The Colorado Front Range: Assoc. Am. Geog. Annals, vol. 1, pp. 21–87, 1911.

[2] Cross, Whitman, Geology of the Denver Basin, in Colorado: U. S. Geol. Survey Mon. 27, pp. 201–206, 1896.

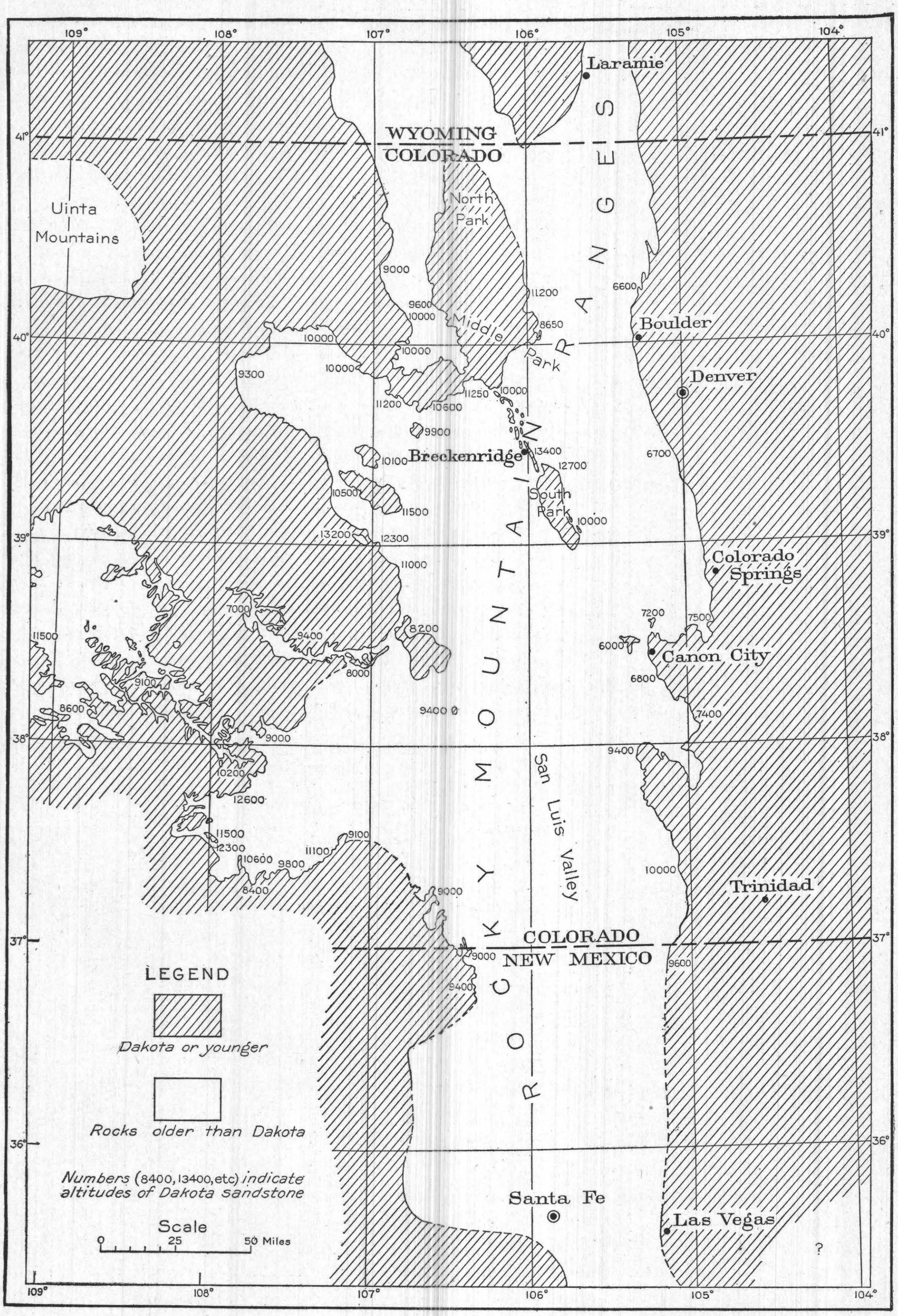

FIGURE 14.—Map of the southern part of the Rocky Mountain region showing altitudes of the Dakota sandstone and the relations of the Dakota to the Rocky Mountain ranges. (Adapted mainly from Hayden's atlas of Colorado.)

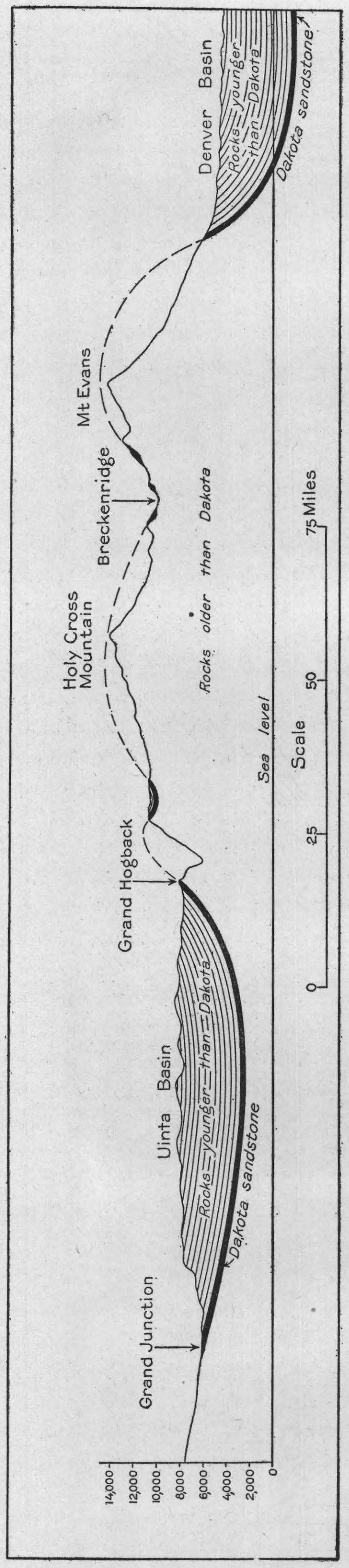

FIGURE 15.—Profile from western Colorado across the Rocky Mountains to the Denver Basin, showing the warped peneplain on which the Dakota sandstone is supposed to have been laid down.

where the succeeding Benton shale overlaps the Dakota and rests on older rocks. Cross [1] has described an apparent overlap of this kind near Pikes Peak, and several are indicated in Hayden's atlas of Colorado. But these supposed overlaps have been proved to be not overlaps in several places mentioned by the early observers, and the query arises whether the observed phenomena were correctly interpreted in other places.

The mapping of the Dakota sandstone in the vicinity of the Rocky Mountains in Hayden's atlas is approximately correct so far as it goes, but more recent observations have proved the presence of the Dakota in many places not shown on Hayden's map. The Dakota and the overlying Mancos, with McElmo beds below them, have been traced by Cross and Larsen [2] up Tomichi Creek, the eastern branch of Gunnison River, to a zone east of Sargent, where all these formations are abruptly upturned. A remnant of the McElmo and Dakota beds resting on granite was found by these same observers near Saguache Creek, 16 miles west of Saguache, a town on the western border of the San Luis Valley. R. D. George, on his map of Colorado, has recently added a number of details, such as the occurrence of the Dakota near Canon City, west of the mountain range through which the Royal Gorge is cut, and also at the crest of the Park Range, in northern Colorado. In brief, recent observations are strengthening the belief that the Dakota was originally continuous over the area occupied by the present mountains.

CHARACTER AND POSSIBLE ORIGIN OF THE DAKOTA SANDSTONE.

Dakota is a name that has been used in the past for several different formations. In some of the older reports the Dakota is described as several hundred feet thick, including much more than is assigned to this formation at the present time. The Dakota of the reports published a few years ago includes a sandstone and a shale now known to be of Lower Cretaceous age. Where these can be definitely identified the Dakota sandstone proper has a maximum thickness of little more than 100 feet, and in many places its thickness is 50 feet or less. It is a coarse-grained sandstone, in some places conglomeratic and usually hard and quartzose. There are few places in the Rocky Mountain region where recognizable fossils have been found in it, and there is no certainty that the Dakota of one locality is the exact time equivalent of the Dakota of another locality. It seems to be the custom to assign a sandstone to the Dakota if it occurs immediately below shale known from fossil evidence to be of Benton age. In other words, the Dakota (the term being used now in its restricted sense as meaning the

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.
[2] Personal communication.

sandstone resting on the Purgatoire formation,[1] which was formerly regarded as the lower part of the Dakota) seems to be the basal sandstone of the Upper Cretaceous series—that is, the sandstone formed near shore in the advancing Upper Cretaceous sea.

Doubtless objection will be raised to this restriction of the term on the ground that the Dakota is a sandstone of fresh-water origin. It has been so regarded mainly because of its lack of marine invertebrates in most places where it has been observed, and the presence in it of fossil plants. Apparently because of this assumption that the Dakota is of fresh-water origin, sandstones near the base of the Cretaceous lithologically like the Dakota and once regarded as Dakota have, when marine invertebrates were found in them, been assigned to younger formations. The objection loses some of its force when the gradual slope over which the Cretaceous sea advanced is considered. It seems entirely possible that a basal sandstone formed on such a slope might be essentially of fresh-water character and be followed immediately by beds of marine origin. Thus, as the sea advanced the sandstone deposited one day might the next day be buried underneath marine shale.

According to this hypothesis, it follows that the Dakota of one locality may be the exact equivalent in age of some of the Benton shale of another locality. Paleontology has thus far thrown little light on this question, possibly because the fossils may not have been examined with this point in view, and possibly because fossils may not be adequate to show recognizable stages in so regular a transgression of the sea. It is especially difficult to make close paleontologic correlations between fresh-water beds and marine beds. The Cretaceous sea may have advanced rapidly, because the area that it submerged was nearly level, but there are some facts that cast doubt on this possibility. For example, in southwestern Wyoming the Bear River formation, which, according to report,[2] ranges from 500 to 5,000 feet in thickness, has been supposed to represent the Dakota, inasmuch as it is the oldest Upper Cretaceous formation of that locality and lies beneath shale of lower Colorado age.[3] If the Colorado of the Cretaceous section of southwestern Wyoming is equivalent in age to the Colorado of other localities, as the fossils tend to prove, the sediments of the Bear River must have accumulated in about the same time that it took the 50 to 100 feet of Dakota sandstone of other localities to form. Even though it is granted that the Bear River is a delta deposit, and that its formation was measurably rapid, the accumulation of its thick beds of sediment must have taken a long time. On the other hand, if certain marine fossils found near the base of the Bear River formation indicate Colorado age, as Stanton [4] states, most if not all of that formation must be younger than Dakota.

All things considered, it seems probable that the interior Cretaceous sea advanced from the Gulf of Mexico, and perhaps also from the Arctic Ocean, and completely covered the region now occupied by the Rocky Mountains. (See fig. 13, p. 31.) It is possible that areas which were never submerged by the Cretaceous sea may be found in the Rocky Mountains, as some geologists believe they will, but no such Cretaceous island is known at the present time. West of this region the sea seems to have encountered steeper slopes on the flanks of the old continent, where for some reason as yet unknown the basal sandstone differs considerably from the Dakota sandstone of localities farther east, and in many places at least is recognized as being of Benton age.

EVIDENCE OF COAL-BEARING FORMATIONS.

Throughout this paper the term "near-shore deposits" is used for rocks made up of material more or less coarse, some deposits containing coal beds and land plants, others containing brackish-water or littoral marine faunas. Inasmuch as the coal-bearing rocks prove nearness of land at the time when they were formed, they demand consideration, for they occur at one place or another in the Rocky Mountain region at almost every horizon within the Cretaceous system and at localities far from the rim of the Cretaceous basin. White [5] has pointed out that

1 Stose, G. W., U. S Geol. Survey Geol. Atlas, Apishapa folio (No. 186), 1912.
2 Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 50, 1907.
3 Stanton, T. W., The Colorado formation and its invertebrate fauna: U. S. Geol Survey Bull. 106, p. 45, 1893.
4 Veatch, A. C., op. cit., p. 63.
5 White, David, Physiographic conditions attending the formation of coal: U. S. Bur. Mines Bull. 38, pp. 52–84, 1913.

in large measure coal beds indicate accumulation of vegetal matter in coastal swamps. Although these swamps may have been modified in various ways by barriers, fluctuations of land and water level, etc., the accumulation as a rule took place not far from sea level. It is quite true that the presence of sand, littoral faunas, and coal beds [1] indicates deposition near shore, but these features do not indicate the character of the shore, nor do they prove that the sediments were derived from land near by rather than from land at a distance.

The formation of the interior Cretaceous basin falls in the class of great epirogenic movements where uniformity of action is to be expected. On the whole this basin seems to have been due to the downward warping of a base-leveled surface. While variations in the rate of warping probably occurred, it does not seem likely that upward warping of a magnitude sufficient to form land masses of any considerable extent occurred in the middle of the downward-warped area during the time when the general subsidence was going on.

The significance of the coal beds in my reconstruction of the physiography of Upper Cretaceous time may be stated as follows: The Rocky Mountain region reduced to base-level at the close of Lower Cretaceous time was included in the area whose subsidence caused the formation of the interior basin of Upper Cretaceous time. The basin did not attain at once its maximum depth, nor did the sea occupying it attain at once its maximum extent. Sedimentation proceeded contemporaneously with the advance of the sea, which doubtless was intermittent and perhaps even oscillatory. It thus happened that coastal swamps favorable for the accumulation of peat developed sometimes near the periphery of the basin and sometimes far out toward its center. Thus near the ancient western continent the near-shore deposits with their coal beds and other evidences of fresh-water conditions alternating with rocks containing brackish-water and littoral marine faunas are found throughout the Upper Cretaceous series, while farther from this old land mass the near-shore deposits wedge out and merge with offshore or purely marine deposits. Without carrying the discussion to unwarranted lengths I may say that it seems obvious that the occurrence of all the coal-bearing rocks of Upper Cretaceous age in the Rocky Mountain region may readily and rationally be explained without assuming that diastrophism reversed its normal processes and produced upward warping in the middle of an area that on the whole was being warped downward.

DISTRIBUTION OF UPPER CRETACEOUS FORMATIONS.

GENERAL FEATURES.

The general distribution of the Colorado formations in the Rocky Mountain region is too well known to require more than a passing remark in this connection. In most places where the Dakota sandstone occurs the Colorado overlies it with obvious conformity. In a few places, as, for example, near Pikes Peak,[2] the Benton seems to overlap the Dakota and to lie on older rocks.

East of the Rocky Mountains the rocks of Colorado age are lithologically separable from those of Montana age in some places but not in others and are so uniform in thickness that it seems necessary to postulate relatively uniform conditions of sedimentation over extensive areas during Colorado time. Certain supposed unconformities near Golden, Colo., described by Eldridge,[3] do not support this hypothesis. He explained the thinning out of some of the Cretaceous formations as due to the presence of highlands over which these formations did not at any time extend. Doubt has recently been thrown on the existence of these unconformities at Golden by Richardson,[4] who thinks that the observed relations may be due to strike faults. Others who have examined the region with this conception in mind do not accept Richardson's suggestion. It would seem that if these supposed highlands really existed they were of local occurrence. Several years ago I advocated Eldridge's hypothesis in explanation of similar

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1 Stanton, T. W., Boundary between Cretaceous and Tertiary in North America, as indicated by stratigraphy and invertebrate faunas: Geol. Soc. America Bull., vol 25, p. 345, 1914.

2 Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), 1894.

3 Eldridge, G. H., Geology of the Denver Basin, in Colorado: U. S. Geol. Survey Mon. 27, pp. 82–104, 1896.

4 Richardson, G. B., Structure of the foothills of the front range, central Colorado: Washington Acad. Sci. Jour., vol. 2, p. 429, 1912.

phenomena near Perry Park, Colo., but I have since come to believe that this explanation is doubtful.

West of the mountains, and also within them where isolated remnants of Cretaceous rocks occur, there is no definite line of separation between the Colorado and Montana groups, although the lower part of the shale overlying the Dakota is known to be of Colorado age and the upper part to be of Montana age. However, the discovery of the same fossils on both sides of the mountains indicates that the sea was continuous either across or around the present mountainous area, and the available data seem to indicate that it was continuous across. This conclusion is reiterated because of certain correlations that will be suggested later.

Where the rocks consist of limestone there could not have been large accessions of sediment such as would be expected from near-by highlands. Arenaceous shales occur in the Colorado group east of the mountains, but the content of sand seems to be no greater near the mountains than far from them, and there is no indication that this sand was derived from lands in the region of the present mountains rather than from lands on either side of the interior sea. In brief, the general lithologic character of the formations of the Colorado group argues against rather than for the presence of land in the mountain region during Colorado time.

The presence of sedimentary rocks of Colorado age in many places within the mountains indicates that at least some parts of the mountainous area were submerged by the sea in Colorado time, but S. F. Emmons and other geologists following him have maintained that islands persisted in that area throughout the Cretaceous period. This contention is not in accord with the evidence that the Dakota was laid down on a practically level floor nor with the fact that in North Park, South Park, and other intermontane localities the marine Cretaceous rocks have essentially the same character and thickness that they have on either side of the mountains.

West of the Rocky Mountains the rocks of Colorado age are, on the whole, more arenaceous and less calcareous than the corresponding rocks east of the mountains. Beds of limestone are thin and few in number, but in some places, especially near the western margin of the Cretaceous area, the sandstones are massive. In this connection it is a significant fact that west and south of the Rocky Mountains the Cretaceous sedimentary rocks are prevailingly argillaceous near the mountains and become progressively more arenaceous away from them, until near the margin of the old continent in New Mexico and Utah they consist mainly of sandstone, some of which is conglomeratic. This lithologic evidence is in harmony with the postulate of an early Cretaceous peneplain covering the Rocky Mountain region and extending far to the west, on which the Dakota sandstone was laid down as the Cretaceous sea advanced over it. If this advance was due to subsidence of the land, the subsidence must have been very regular, for the Colorado formations vary but little in thickness over wide areas. A rise in sea level allowing the water to spread over the surface of a relatively stable land during Colorado time might equally well explain the observed relations.

The sea seems to have transgressed the Rocky Mountain peneplain with relative rapidity, the thin Dakota sandstone being formed along its advancing front. Against the western land mass in central New Mexico, Arizona, and Utah the advance seems to have been halted and an unstable condition of sedimentation established, owing possibly to oscillations of the land but more likely to oscillations of sea level, the accumulations of sediments being built out from shore farther at some stages than at others. The shorter stages are best indicated by the occurrence of alternating layers of sediments of fresh-water, brackish-water, and marine origin. The longer stages are indicated in the sections given in the several figures accompanying this paper.

The formations referred to the Montana group seem to be more irregular in character and thickness than those of the Colorado group. Whether this irregularity is due to oscillations and surface warping in late Upper Cretaceous time or to some other cause has not been satisfactorily determined. It is a fact worthy of consideration in this connection that some of the greatest variations in thickness, as reported, occur in the soft Pierre shale close to the mountains, where duplication by faulting and thickening by lateral thrust would naturally be expected. Where measurements have been obtained from drill records, vertical sections, etc., at sufficient distances from the mountains to make it reasonably sure that original thicknesses were obtained, the rocks of the Montana group have been found fairly uniform in thickness and character. This uniformity is one of the things that I wish to show by the accompanying sections. Another is the probable source of the sediments and the direction in which the formations gradually change in thickness and in character.

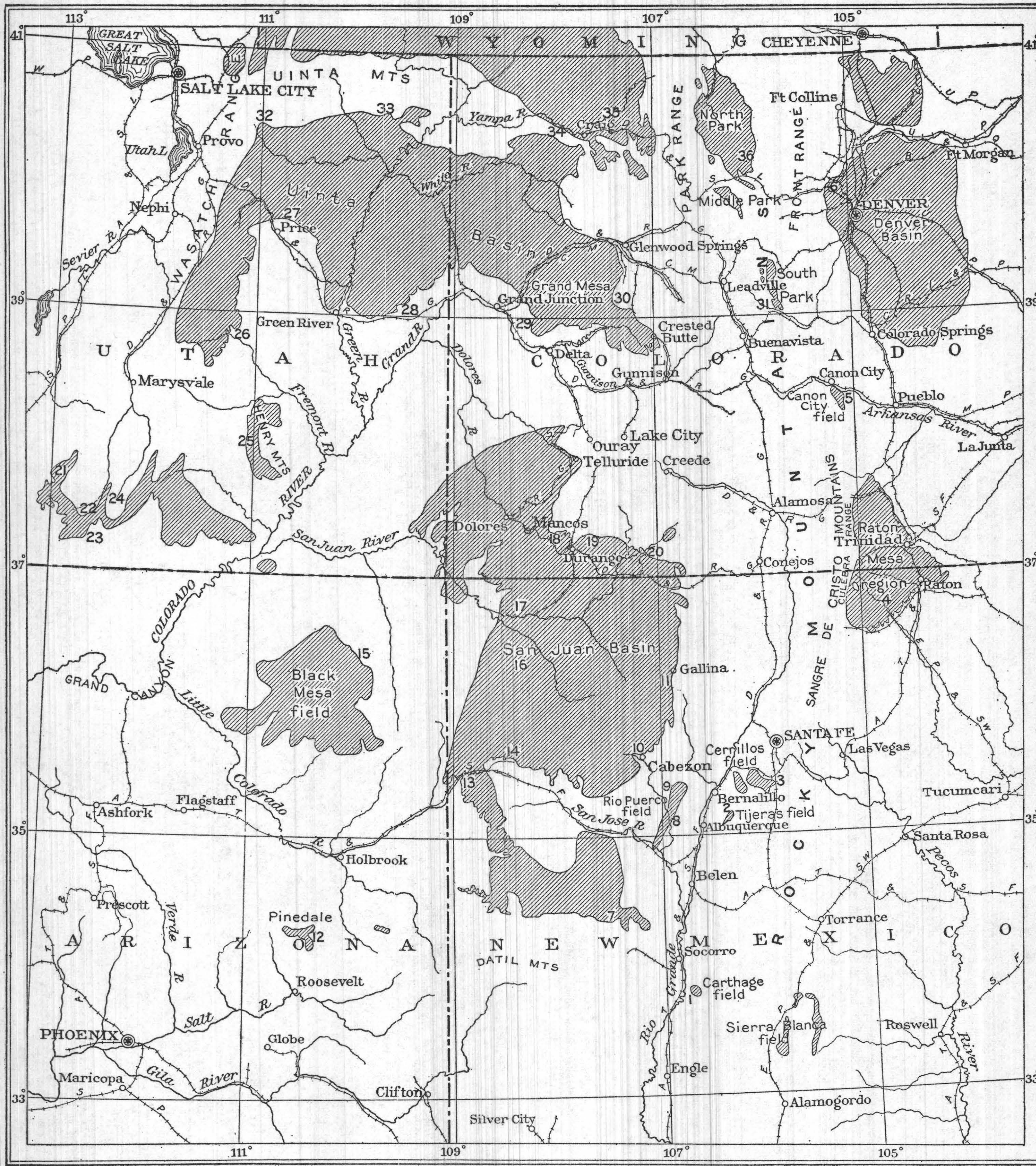
Inasmuch as the following descriptions of sections are somewhat lengthy, it may be appropriate to state here that I desire to emphasize my belief that the Cretaceous sediments came mainly from the continental land mass west of the interior sea, and that they spread eastward over the present site of the Rocky Mountains—in other words, that no mountains or even islands of any considerable size existed there in Cretaceous time. I have already stated that the advance of the sea in Colorado time was halted against the western continent. Whether or not this continent suffered differential uplift at the close of the Colorado epoch, as certain conglomerates and possible unconformities in Utah and elsewhere seem to indicate, there is little question that this or whatever land furnished the sedimentary material must have been relatively high or of great lateral extent in order to supply the enormous masses of sediment that accumulated in the interior Cretaceous sea. On the other hand, sedimentation seems to have been continuous in many places throughout Upper Cretaceous time, and it is not possible to distinguish stratigraphically between the Montana and the Colorado.

Among the conclusions that may be drawn from a study of the sections described below, two stand out rather prominently. First, the area of maximum depth in that part of the basin here described, as indicated by the maximum filling shown in the published sections, is in northern Colorado and southern Wyoming. It is a fair assumption, borne out in a measure by the character of the sediments, that the filling of the basin progressed from the periphery toward this center, and that as time went on the center finally contained the youngest rocks. It may be noted in this connection that the youngest coal-bearing rocks of Cretaceous age—that is, the Laramie of the Denver Basin and formations of corresponding position—occur over a relatively small area in southern Wyoming and northern Colorado, on both sides of the mountains. If these mountains were above sea level during Upper Cretaceous time they must have stood near the center of the basin. Inasmuch as the mid-Cretaceous marine formations occur in full thickness in North Park, Colo., in the center of the area in which these youngest Cretaceous coal-bearing rocks occur, it seems reasonable to assume that there were no mountains there at the time and that the marine formations and perhaps also the overlying coal measures once covered the region.

The second conclusion that may be drawn from the sections is that the sandstone formations near the ancient western continent thin eastward, toward the present Rocky Mountains, and the shale formations are thin to the west but thicken toward the present mountains; also that the shales have about the same thickness and character on either side of the mountains and in the intermontane areas. If, as is postulated in this paper, the main mass of sediments came from the west, the sandstones should thin eastward and finally be replaced by shale, and it is quite natural that the massive mid-Cretaceous sandstones on the west should be replaced farther east by thin, inconspicuous sandy layers and that sands in great quantity should have reached the center of the basin only in late Cretaceous (Fox Hills and Laramie) time, after its peripheral parts had been filled.

THE SECTIONS ILLUSTRATED.

The sections on figures 16 to 22 have been selected with a view to showing comprehensively the distribution of the Cretaceous formations. They have been generalized in order that the features having a bearing on the present study may not be obscured by nonessential details. References are given to published descriptions, but in some of the sections modifications have been made in accordance with information obtained since the time of publication. Two groups of sedimentary rocks are especially emphasized—near-shore deposits, including those of fresh-water and brackish-water origin together with sandstones of marine origin; and offshore deposits, consisting principally of marine shale with some limestone.



MAP OF THE COAL FIELDS IN THE SOUTHERN ROCKY MOUNTAIN REGION, SHOWING THE LOCATION OF THE SECTIONS DESCRIBED.

Adapted from map of the coal fields of North America, by M. R. Campbell.

The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents. For example, the Vermejo formation of the Canon City field seems to be the homogenetic equivalent of the Laramie of the Denver Basin (section 6), inasmuch as it consists principally of coal-bearing rocks of fresh-water origin, but it seems to be the time equivalent of the Fox Hills sandstone of this basin.

The several sections will be considered in groups with special reference to their relation to the Rocky Mountains. The approximate location of the sections is indicated on Plate V by numbers corresponding to those given in parentheses in the section headings in the text.

CARTHAGE, N. MEX., TO BOULDER, COLO.

The sections of figure 16 are so chosen that a line connecting the localities at which they were measured will pass east of the Rocky Mountains to a point well south of the end of the main range and near the border of the southwestern continental land mass of Upper Cretaceous time. (See fig. 13, p. 31.)

CARTHAGE (1).[1]

Although Carthage is the southernmost locality at which a satisfactory section is available, the sedimentary rocks of Upper Cretaceous age extended at least 70 miles farther south, to the vicinity of Engle, N. Mex., where coal beds of Benton age have been found. The rocks of the Carthage field are badly faulted, but the succession, as shown in the section, seems to be well established.

A sandstone at the base of the section is referred with a query to the Dakota because, like the Dakota (?) of the other sections, it lies below rocks of Benton age. No fossils were found in it, and it may represent the Tres Hermanos sandstone member of the Mancos shale of the Tijeras section, described below. The Dakota (?) is overlain by marine shale with thin layers of sandstone of Colorado age, and these in turn by coal-bearing rocks that contain brackish-water invertebrates which range in age from lower Colorado to Laramie. Because of lithologic similarity Gardner correlated these rocks with the Mesaverde of the San Juan Basin and referred them with a query to the Montana. Later investigations indicate that they are older than Montana. The coal measures are overlain unconformably by Tertiary red beds containing Palæosyops near the base.

The area between Carthage and Tijeras, a distance of about 80 miles, has not been examined in detail, but no rocks of Cretaceous age have been found there.

TIJERAS (2).[2]

At the base of the Tijeras section lies a sandstone that is called Dakota on the evidence of lithology and stratigraphic position. No fossils have been found in it. The overlying shale, the Mancos, consists of a thick shale of marine origin with a sandstone, the Tres Hermanos member, near the base. The principal part of the coal measures is of Montana age and is correlated by lithology and invertebrate fossils with the Mesaverde of the San Juan Basin. Some of the upper part may be younger than Montana, but the few fossils found in it were not sufficient to determine the age.

The Cretaceous rocks of the Tijeras field obviously were connected at one time with those of the Hagan and Cerrillos fields, to the north, and for the purposes of this paper the formations represented in these fields, now separated because of erosion, may be regarded as essentially continuous.

CERRILLOS (3).[3]

At Cerrillos the Galisteo sandstone lies unconformably on the Mesaverde formation and is lithologically similar to the beds of Tertiary age in the San Juan Basin. For these reasons it is regarded as Tertiary, but evidence is not at hand for closer correlation. The coal-bearing

[1] Gardner, J. H., The Carthage coal field, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 452-460, 1910.

[2] Lee, W. T., Stratigraphy of the coal fields of northern central New Mexico: Geol. Soc. America Bull., vol. 23, pp. 629-633, 1912.

[1] Idem, pp. 633-659.

Mesaverde formation has yielded a large number of marine and brackish-water invertebrates and land plants, all of which indicate Montana age. The Mancos consists of a thick shale with marine fossils of Montana age at the top and of Benton age near the base. It contains the

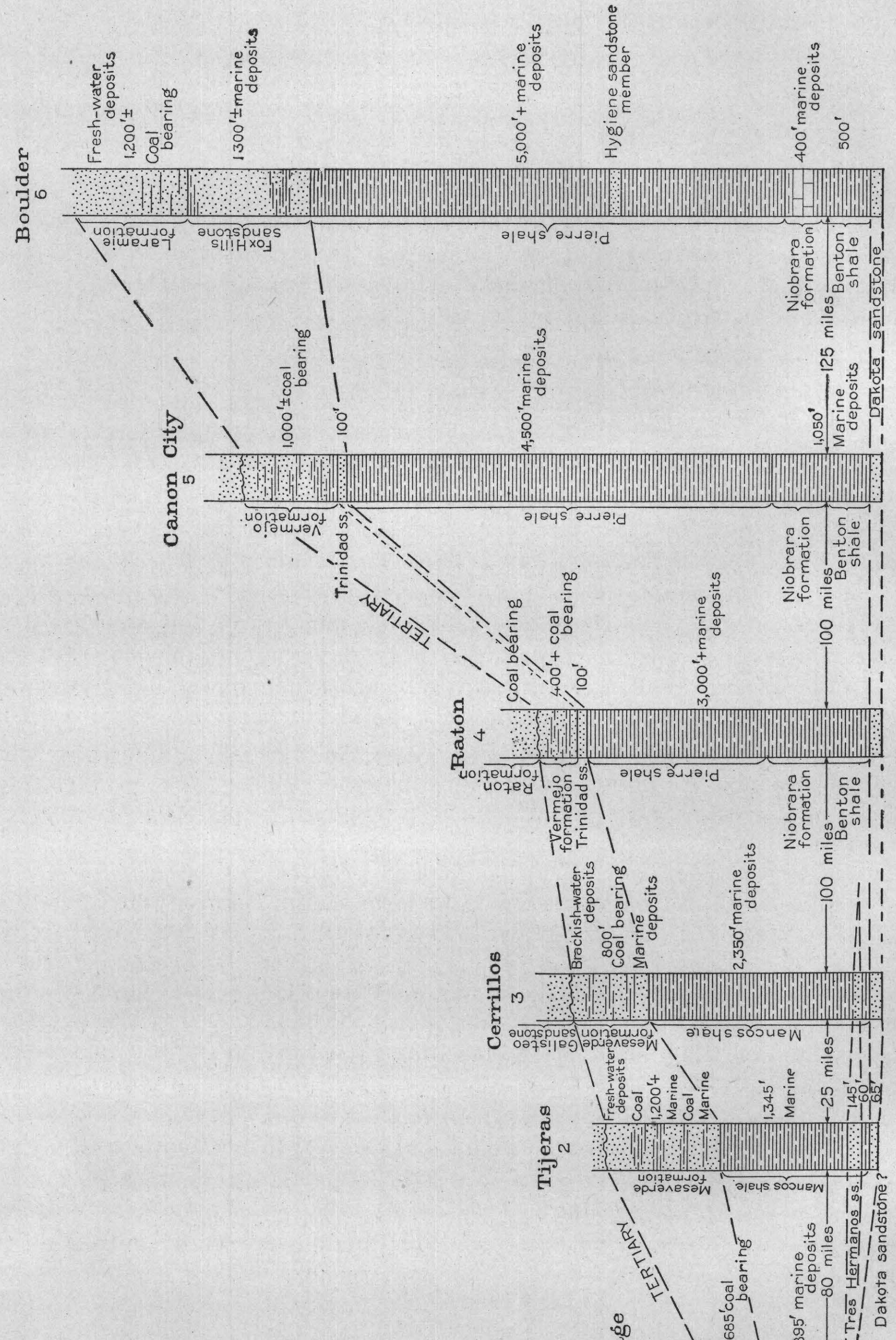


FIGURE 16.—Group of sections from Carthage, N. Mex., to Boulder, Colo. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

Tres Hermanos sandstone, here a single layer only a few feet thick. The sandstone below the Mancos is referred to the Dakota because of its conglomeratic character and its position between the Mancos shale and the Morrison formation.

No coal-bearing rocks are known to occur between the Cerrillos and Raton fields, but except for about 35 miles east of Cerrillos, where all rocks younger than the "red beds" have been eroded away, the older Cretaceous rocks are continuous. The Mancos of the Cerrillos section is so similar in thickness and character to the Pierre of the Raton section as to suggest that the Mancos was originally continuous with the Pierre across the intervening area.

RATON (4).[1]

The coal measures of the Raton Mesa region consist of the Raton formation, which is Tertiary in age, and the Vermejo formation, which is of Montana age. The Vermejo flora tends to correlate this formation with the Mesaverde of the Cerrillos field and of the San Juan Basin, but the marine invertebrates from the top of the underlying shale suggest that the Vermejo is younger than the Mesaverde. In brief, the Vermejo is recognized as a Montana formation, but it seems to occupy a place in the time scale higher than the Mesaverde. The total thickness of the marine Cretaceous of this section is not known, but a well bored near Raton indicates that it is more than 3,000 feet. The drill did not reach the base of the shale.

Although Raton is about 100 miles from Canon City, as shown on the plate of sections, the coal-bearing formations of the two regions are separated by only about 30 miles and the older Cretaceous rocks are continuous between these coal fields.

CANON CITY (5).[1]

The coal measures of the Canon City field lie unconformably beneath rocks supposed to be of Tertiary age because of their lithologic character and structural relations. The coal measures are correlated by fossil plants with the Vermejo formation of the Raton Mesa region and contain invertebrates that tend to correlate them with the Fox Hills sandstone to the north. The thickness of the Pierre shale in this field is estimated as 4,500 feet. This thickness was obtained from well borings in the trough of a syncline, where it seems probable that, because of crushing, the shale is now thicker than it was when originally deposited. The thickness of the Colorado portion of this section is taken from the Pueblo folio.

Canon City and Boulder are about 125 miles apart, but the coal measures represented in the two sections are separated only by the 40 miles between Canon City and Colorado Springs. From Colorado Springs to northern Colorado the coal measures are nearly continuous.

DENVER BASIN—BOULDER (6).[2]

The Laramie formation of the Denver Basin consists of coal-bearing rocks. Beneath it lie sandstone and sandy shale of Fox Hills age, which are described as 600 feet thick near Colorado Springs[3] and 1,300 feet thick near Boulder. Fenneman states, without explaining how or where the measurement was made, that the Pierre shale near Boulder is more than 5,000 feet thick. For the same shale near Colorado Springs Finlay gives a thickness of 2,500 feet, although Eldridge[4] states that its thickness between these two localities is 7,700 to 7,900 feet. It is partly because of these great variations in reported thickness that I am disposed to question the meaning of the figures and to believe that the maximum thicknesses as measured represent something more than the original or depositional thickness of the shale. For this reason I have used the section giving an intermediate thickness. A relatively thin sandy member known as the Hygiene sandstone occurs 1,000 to 2,700 feet above the base of the Pierre. It has not been definitely recognized outside of the Boulder region, and little is known of its relation to formations of other fields.

SUMMARY.

On considering this series of sections together, it seems obvious that shore conditions favorable to the accumulation of coal and of the sediments normally associated with coal existed in central New Mexico early in Upper Cretaceous time and progressively later toward the north.

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[1] Lee, W. T., unpublished manuscript.

[2] Fenneman, N. M., Geology of the Boulder district, Colo.: U. S. Geol. Survey Bull. 265, pp. 28–34, 1905.

[3] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs, folio (in preparation).

[4] Eldridge, G. H., Geology of the Denver Basin, in Colorado: U. S. Geol. Survey Mon. 27, p. 69, 1896.

In other words, as the sea filled with sediments derived from the land mass to the southwest, the shore along this particular line of sections was pushed gradually farther north. This suggests that had not the Cretaceous rocks connecting the several fields been eroded away there might now be a coal-bearing formation extending from Carthage, N. Mex., northward through Colorado and beyond, that would be of Benton age at one extremity and of Laramie age at the other.

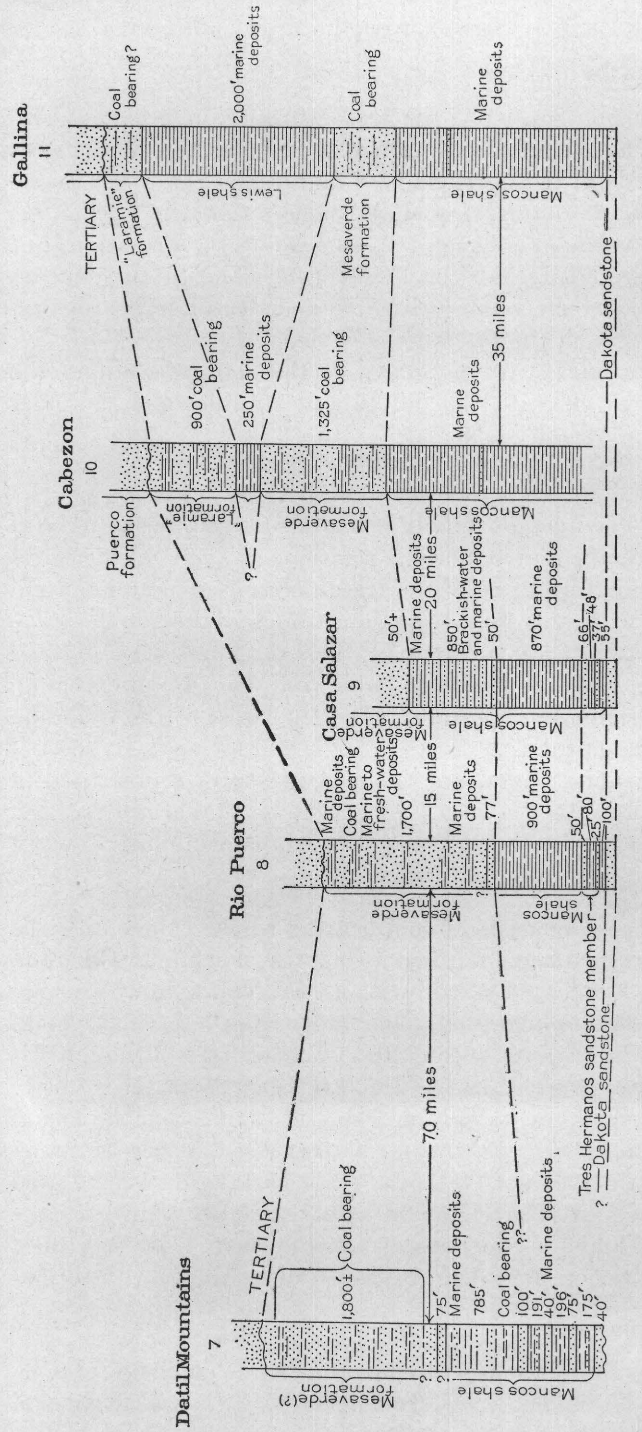

FIGURE 17.—Group of sections from Datil Mountains to Gallina, N. Mex. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

DATIL MOUNTAINS TO GALLINA, N. MEX.

The series of sections given in figure 17 has been chosen for the purpose of showing the change in character of the Cretaceous formations in a north-northeasterly direction from a point in the Datil Mountains near the western Cretaceous land to the present Rocky Mountains—the Gallina locality.

DATIL MOUNTAINS (7).[1]

The coal-bearing formations west of the Rio Grande are separated by erosion from those to the east, just described, but there are good reasons for believing that they are parts of formations that once extended continuously over western New Mexico. In the Datil Mountains a thin conglomeratic sandstone of irregular occurrence is regarded as the Dakota, and above it are sandstone and shale about 3,700 feet thick. The lower half of these rocks is referred on fossil evidence to the Mancos and the upper half to the Mesaverde. The Mancos, which elsewhere is almost exclusively a marine shale, here consists of sandstone and shale in nearly equal proportion and contains several beds of coal in the upper part. The Mesaverde of this section is similar to the typical Mesaverde, which is essentially a coal-bearing sandstone.

The Cretaceous formations are practically continuous from the Datil Mountains to the Rio Puerco field, but little is known of them in the intervening areas.

RIO PUERCO FIELD (8).[2]

In the Rio Puerco field the Mesaverde formation lies unconformably beneath rocks that are lithologically similar to some of the Tertiary beds of the San Juan Basin. It consists of

[1] Winchester, D. E., unpublished manuscript.
[2] Lee, W. T., Stratigraphy of the coal fields of northern central New Mexico: Geol. Soc. America Bull., vol. 23, pp. 622–629, 1912.

arenaceous rocks of marine, brackish-water, and fresh-water origin alternating with beds of coal. Arenaceous rocks not notably different from those of the coal measures extend nearly 700 feet below the lowest known coal and terminate with the Punta de la Mesa sandstone, a member that can be recognized as far north as Gallina, about 75 miles from Rio Puerco. This sandstone was formerly included in the Mesaverde because of its obvious relation to the sandy beds above it, but is now regarded as a member of the Mancos shale. The name Mancos shale is somewhat misleading for this field. Only the lower part of the formation is shale, and fossils indicative of Benton age occur practically to the top of this part. Near the base of the Mancos occurs the Tres Hermanos sandstone member, which is recognizable from the Datil Mountains to Casa Salazar but which was not found farther north, near Gallina. This sandstone is coal bearing in the Datil Mountains, but in the Rio Puerco field only a single layer of carbonaceous shale was found in it. The sandstone below the Tres Hermanos is called Dakota (?) because it is at the base of such Upper Cretaceous rocks as occur here. No fossils have been found in it.

CASA SALAZAR (9).[1]

The section near Casa Salazar differs from the Rio Puerco section mainly in the character of the rocks above the Punta de la Mesa sandstone member. They consist of shaly sandstone that seems to be transitional between the shale of the upper part of the Mancos at Cabezon and the lower part of the arenaceous beds of the Rio Puerco field. Only the base of the Mesaverde formation is exposed here.

The Mancos shale is exposed continuously between Casa Salazar and Cabezon and the continuity of the Mesaverde is only slightly interrupted.

CABEZON (10).[2]

At Cabezon the Puerco formation lies unconformably on the "Laramie," and the Lewis seems to be the attenuated edge of a shale formation that is very much thicker farther north. The Mesaverde seems to thicken as the Lewis thins and vice versa.

From Cabezon to Gallina the Cretaceous formations are continuous, but for a few miles they are not exposed at the surface because of the Tertiary overlap.

GALLINA (11).[3]

Near Gallina the Tertiary rocks lie unconformably on the "Laramie" formation, which is much thinner than it is near Cabezon. This formation, though regarded by some as of Laramie age, contains fossil plants which indicate that it is Montana. The Mesaverde also is much thinner, but the Lewis has greatly increased in thickness. The Mancos shale is reported as 500 to 1,000 feet thick and has a sandy bed (the Punta de la Mesa (?) sandstone) 275 feet from the top. The Dakota underlies the Mancos, but the Tres Hermanos sandstone, if represented at all, is inconspicuous.

SUMMARY.

The Datil Mountain locality is nearest the western continental land mass of Cretaceous time and the Gallina locality farthest from it. As in the sections farther east, the sandstones shown at the base of the several sections are homogenetically equivalent but may not represent equivalency in time. Near-shore deposits, including coal, began to accumulate in the Datil Mountain region early in Colorado time while marine shale was accumulating farther north. The coal measures of the Datil Mountains, being principally if not wholly of Colorado age, were in process of formation while marine shale was accumulating near Cabezon and Gallina.

During Mesaverde time the strand line seems to have moved northward along this line of sections because of the filling of the sea and perhaps in part because of change of sea level. However, the open sea could not have been far away, for marine invertebrates occur at several horizons in the Mesaverde of the Rio Puerco field. A second notable advance of the sea occurred in Montana time, resulting in the formation of the Lewis shale. Inasmuch as this shale is notably lenticular, according to the reported measurements, there must either have been

[1] Lee, W. T., unpublished manuscript.

[2] Gardner, J. H., The coal field between San Mateo and Cuba, N. Mex.: U. S. Geol. Survey Bull. 381, pp. 461-473, 1908.

[3] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, pp. 335-351, 1907.

a local downward warping of the basin in which it was deposited or else the advance of the sea was so slow that near-shore sediments now included in the upper part of the Mesaverde and perhaps also in the lower part of the "Laramie" were accumulating near Cabezon while offshore or marine clays were accumulating near Gallina.

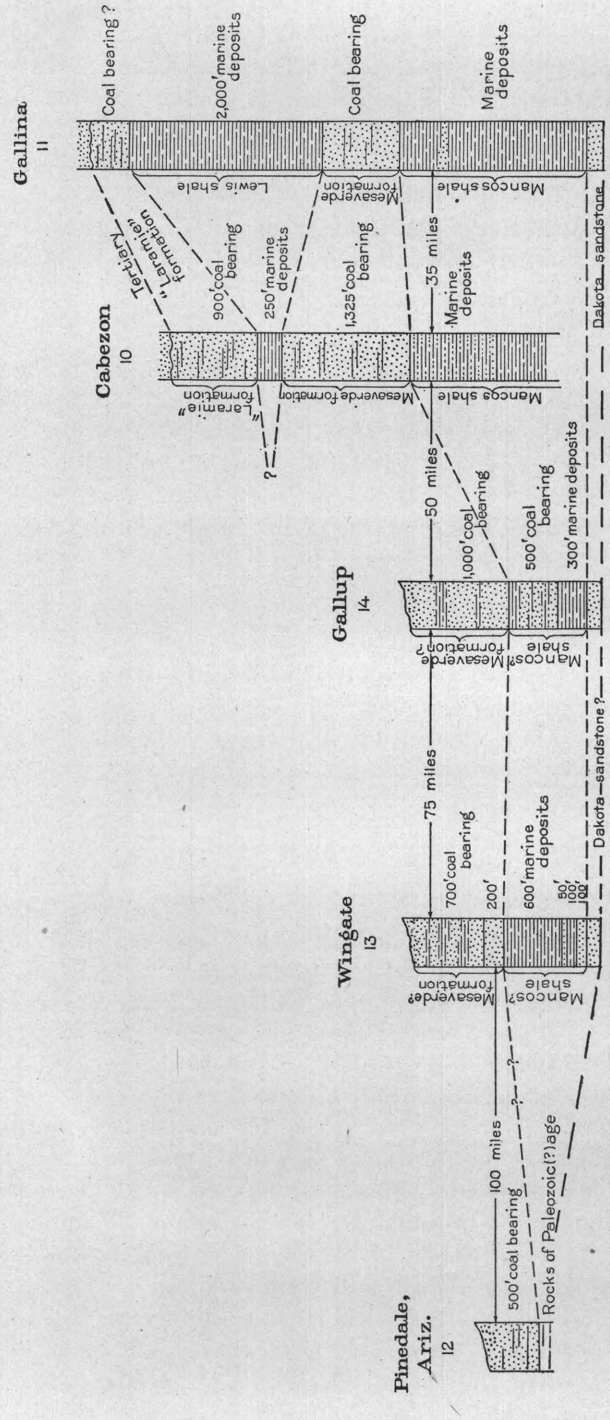

FIGURE 18.—Group of sections from Pinedale, Ariz., to Gallina, N. Mex. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

Of the five localities included in this series Gallina is nearest to the present highlands of the Rocky Mountains and the Datil Mountain locality is farthest from them. An inspection of the sections of figure 17 shows that the offshore deposits (the Mancos and Lewis shales) increase and the near-shore deposits decrease in thickness toward the Rocky Mountain area. Had this area furnished the sediments this relation would have been reversed.

PINEDALE, ARIZ., TO GALLINA, N. MEX.

The sections shown in figure 18 are chosen to illustrate the change in character of the formations along a line crossing the San Juan Basin from a point in Arizona near the border of the western continental land of Cretaceous time northeastward to the present Rocky Mountains. Because of the absence of other published sections for the eastern part of this basin the Cabezon and Gallina sections are here repeated.

PINEDALE (12).[1]

The coal measures of the Pinedale region occupy a small area south of Holbrook, Ariz., and seem to have been continuous at one time with those of the San Juan Basin, although they are now separated by erosion. They are about 500 feet thick and contain coal near the base. No sandstone referable to the Dakota was found. Just above the beds of coal were found fossils of Benton age that correlate these rocks with the coal measures of southern Utah. The Cretaceous rocks lie unconformably on shaly sandstone of probable Paleozoic age. Two other small areas have been described by Gilbert.[2]

FORT WINGATE (13).[3]

The section at Stinking Spring, 12 miles west of Fort Wingate, N. Mex., was measured long before the present formational nomenclature of this region was adopted. The coal-bearing

[1] Veatch, A. C., Coal deposits near Pinedale, Navajo County, Ariz.: U. S. Geol. Survey Bull. 431, pp. 239-242, 1911.

[2] Gilbert, G. K., Report on the geology of portions of New Mexico and Arizona examined in 1873: U. S. Geog. and Geol. Expl. W. 100th Mer., vol. 3, p. 544, 1875.

[3] Idem, pp. 503-567.

rocks seem to be what are now called Mesaverde by some authors and are referred to the upper part of the Mancos shale by others. They are underlain by a marine shale that is doubtless the Mancos, and certain sandstones near the base of this shale hold a position similar to that of the Tres Hermanos sandstone. The lowest sandstone is called Dakota, but there is nothing aside from stratigraphic position to indicate that it is equivalent in age to the Dakota of other localities.

GALLUP (14).[1]

The coal measures near Gallup are supposed to be approximately equivalent in age to the original Mesaverde and hence of Montana age, but the coal of this region may extend downward into the Colorado, as it is known to farther south and east, and its lower beds are supposed to be Mancos. Below the coal-bearing rocks occurs typical Mancos shale, but it is described as only 300 feet thick. A lower sandstone 200 feet thick is called Dakota. This thickness seems to be too great for the Dakota, and some of the sandstone may be equivalent to the sandstone of the Fort Wingate section near the base of the Cretaceous, which contains marine invertebrates and is therefore regarded as younger than Dakota. It is probable that here, as in many other places in western New Mexico and Colorado, where the lowest sandstone of the Upper Cretaceous is called Dakota, the name has little time significance beyond the fact that the sandstone lies below shale referable to some part of the Benton. It seems probable that this sandstone may, in some places at least, be of Benton age.

The coal measures of the Gallup section are homogenetically equivalent to the Mesaverde formation of the Cabezon section, but obviously they are not equivalent in age if the reference of their lower part to the Mancos is correct.

SUMMARY.

In this series of sections, as in those already described, purely marine conditions persisted longest near the present mountains. If the time correlations are correct, near-shore deposits were accumulating in the Wingate-Gallup region while offshore deposits were being formed in the Cabezon-Gallina region.

NORTHERN ARIZONA TO RATON, N. MEX.

Although the coal-bearing rocks of Black Mesa, in northeastern Arizona, are not now connected with those of the San Juan Basin, the two areas were probably connected at one time and are now separated only because of erosion. Hence, the sections of figure 19 show the variations in character of the several formations in the northern part of this basin, from its most westerly exposure eastward to the Rocky Mountains. At one time these formations probably extended across the space now occupied by the mountains and were continuous with those of the Raton section, which is included here for comparison.

NORTHEASTERN ARIZONA (15).[2]

The first section of this series was measured in the northeastern part of the Black Mesa coal field, near Chilchivito Spring, and shows the general relations of the formations throughout the field, although their thicknesses vary from place to place. From the unpublished notes of members of Gregory's party another measurement near this spring shows Mancos 565 feet thick and Mesaverde 865 feet. About 20 miles farther southeast the Mancos is reported as 470 feet thick and the Mesaverde formation as 820 feet. Near Oraibi, about 70 miles southwest of Chilchivito, the Mancos was found to be about 225 feet thick and is overlain by an unknown thickness of Mesaverde. In the western part of the field, 6 miles east of Blue Canyon store, the Mancos is 490 feet and the Mesaverde more than 221 feet thick.

The coal measures of the Black Mesa field are referred with doubt to the Mesaverde, the underlying shale to the Mancos, and the lowest sandstone of the Cretaceous to the Dakota. This correlation is doubtless homogenetically correct, as is indicated by the connecting lines in

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[1] Gardner, J. H., The coal field between Gallup and San Mateo, N. Mex.: U. S. Geol. Survey Bull. 341, pp. 364-378, 1909.
[2] Campbell, M. R., and Gregory, H. E., The Black Mesa coal field, Ariz.: U. S. Geol. Survey Bull. 431, pp. 229-238, 1911.

figure 19, but few data for determining the age relations of these formations have been obtained. The lowest sandstone seems to have been called Dakota only because of its position. It is possible that the coal measures above the Mancos shale are the western continuation of the Mesaverde in the San Juan Basin, but the authors cited regard them as equivalent in age to the coal measures of the Mancos near Gallup.

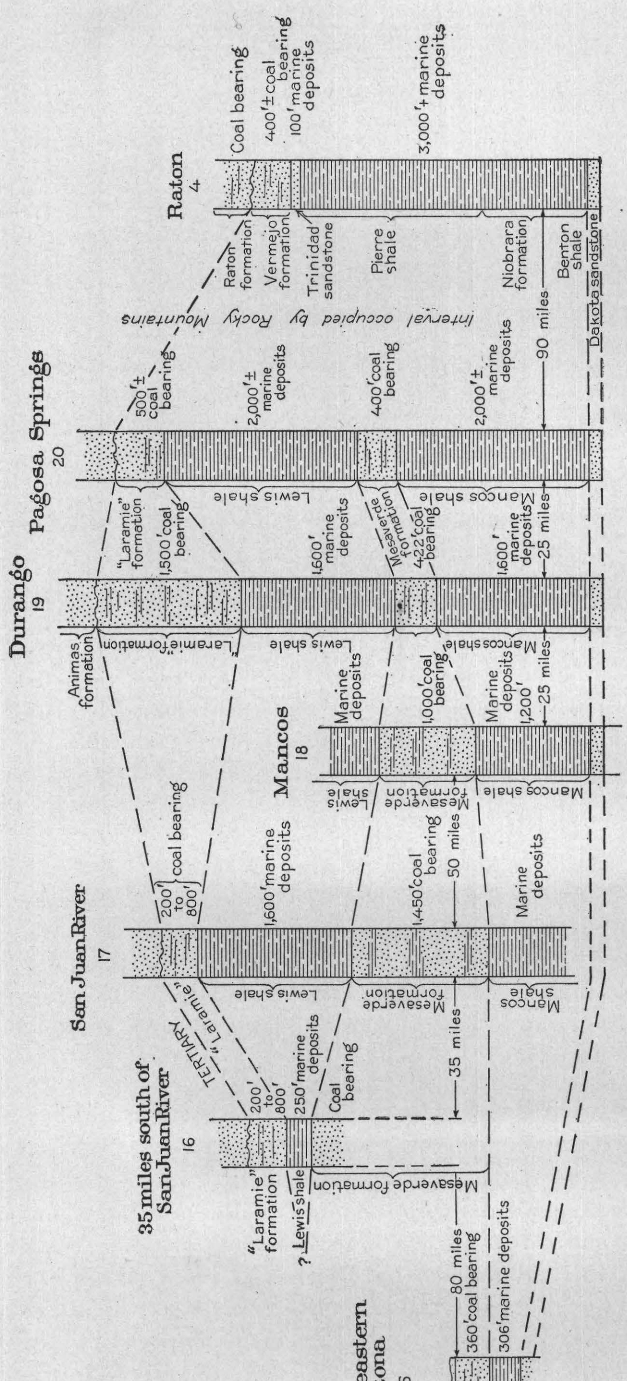

FIGURE 19.—Group of sections from Black Mesa, northern Arizona, to Raton, N. Mex. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

SAN JUAN BASIN (16 to 20).

The coal measures on San Juan River consist of two formations, the "Laramie" above and the Mesaverde below, separated by a marine shale. This shale, the Lewis, has a thickness of 1,600 feet or more at locality 17 (see Pl. V) and farther east but thins to 250 feet 35 miles to the southeast, at locality 16.[1] These formations are exposed continuously eastward around the San Juan Basin. The original descriptions of the Mancos shale, the Mesaverde formation, and the Lewis shale were based on their occurrence near Mancos, Colo.[2] (section 18).

The Durango section[3] (No. 19) was prepared by J. H. Gardner, who examined the sedimentary rocks of the Ignacio quadrangle for folio publication. Although the name "Laramie" is retained for the upper coal measures they contain fossil plants regarded by Knowlton as of Montana age.

From Durango eastward to Pagosa Springs[4] (locality 20) and beyond the several Cretaceous formations have been traced continuously, and near Pagosa Springs the "Laramie" formation contains plants indicative of Montana age.

SUMMARY.

The Lewis shale seems to have its maximum thickness and the Mesaverde its minimum thickness in the northeastern part of the San Juan Basin. In this group of sections, as in those previously described, the marine shales are thickest near the Rocky Mountains and the coal-bearing sandstone formations become progressively thicker away from the mountains. It is obvious

[1] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376-426, 1907.

[2] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

[3] Lee, W. T., Stratigraphy of the coal fields of northern central New Mexico: Geol. Soc. America Bull., vol. 23, p. 584, 1912.

[4] Idem, pp. 615-619. Lee, W. T., and Knowlton, F. H., unpublished manuscript.

that the Mesaverde of the Pagosa Springs section is to be correlated with the Mesaverde of the San Juan River section, but it seems equally obvious that the 400 feet of the former does not represent the same interval of time as the 1,450 feet of the latter. It also seems obvious that the 250 feet of Lewis shale south of San Juan River does not represent the same time interval as the 2,000±feet of Lewis shale in the Pagosa Springs section.

The Lewis contains invertebrates that tend to correlate it with the upper part of the Pierre of the Raton field, east of the mountains (section 4). On the other hand, plants similar to those from the Vermejo formation if not identical with them occur in both the Mesaverde and the "Laramie" formations of this basin. It has been shown on page 42 that the Vermejo formation is probably the homogenetic equivalent of the Mesaverde formation of central New Mexico. The evidence of the fossils seems to indicate that the Vermejo of the Raton field is intermediate in age between the Mesaverde and the "Laramie" of the San Juan Basin. If we assume that the Cretaceous formations once extended across the area now occupied by the mountains, it seems probable that the Trinidad sandstone and the Vermejo formation are the homogenetic equivalents of the Mesaverde. It is possible, however, that could the formations be restored it would be seen that the Mesaverde thins out to the east before reaching Raton and that the Trinidad and Vermejo formations are the homogenetic equivalents of the "Laramie" of the San Juan Basin. The absence of marine deposits above the Vermejo renders it difficult to determine which alternative is more likely to be correct.

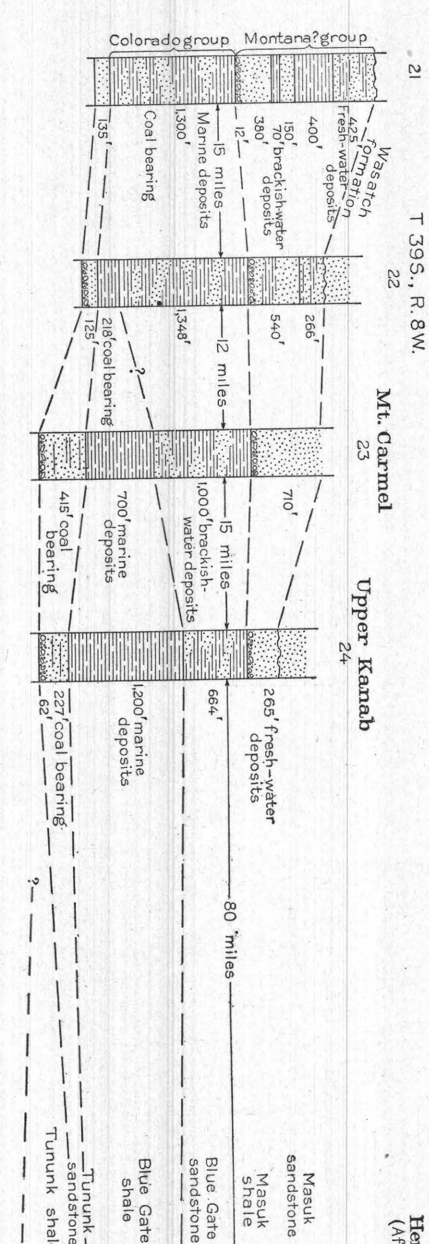

FIGURE 20.—Group of sections in Colob Plateau and Henry Mountains, Utah. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

COLOB PLATEAU TO HENRY MOUNTAINS, UTAH.

The group shown in figure 20 contains the most westerly sections obtainable of the Cretaceous coal-bearing rocks of the southern Rocky Mountain region. However, the Henry Mountain section shows the probable connection of some, if not all, of the Cretaceous rocks of the Colob Plateau with the Mancos shale, the Mesaverde formation, etc., farther east.

COLOB PLATEAU (21 to 24).[1]

The lower part of the coal-bearing and associated rocks of Colob Plateau is of Colorado age. The top of the Colorado is drawn at a conglomerate that seems to be persistent throughout the Colob Plateau region, but its significance has not been determined. The rocks above it contain fossil leaves, but unfortunately their affinities are not sufficiently well known to determine the

[1] Richardson, G. B., unpublished manuscript.

age of the rocks. Richardson has suggested that the sedimentary rocks above this conglomerate may be either Montana or Tertiary. At the westernmost locality for which a section is given (No. 21) the rocks consist of alternating layers of sandstone and shale with little evidence of differentiation into separate formations. Farther east the coal-bearing rocks occur in an upper and a lower group, separated by a marine shale, which seems to be the Mancos of localities still farther east. The coal measures above the shale seem to be homogenetically equivalent to Gilbert's Blue Gate sandstone of the Henry Mountains and to the Mesaverde of localities farther east.

The coal-bearing rocks of the Colob Plateau seem to have been connected at one time with those in northeastern Arizona but have been separated from them by erosion.

HENRY MOUNTAINS (25).[1]

The Henry Mountain section seems to be comparable in some ways to the section farther north, at locality 26, and in other ways to the sections in the San Juan Basin. Gilbert's Tununk sandstone is comparable to the Ferron sandstone member of the Mancos shale, his Tununk shale to the shale underlying the Ferron as described by Lupton, his Blue Gate shale to the main body of the Mancos shale, and his Blue Gate sandstone to the Mesaverde formation. The Masuk shale of Gilbert holds a position suggestive of the Lewis and his Masuk sandstone a position suggestive of the "Laramie" as developed farther south, but no satisfactory evidence of age has yet been found in these upper formations.

A group of sandstones at the base of the Cretaceous, called the Henrys Fork group, is of Benton age at the top, according to the fossil evidence, but may be Dakota and older below. By the method of correlation suggested in this paper the Cretaceous portion of this group of rocks is regarded as homogenetically equivalent to the Dakota, but it may be very different in age from the Dakota of other localities.

SOUTHERN PART OF UINTA BASIN.

The coal-bearing rocks are exposed continuously from central Utah eastward through central-western Colorado to the mountains, where they are upturned in the Grand Hogback. They have been observed throughout this distance and examined in detail at several localities, as shown by the sections in figure 21.

EMERY (26).[2]

The southwestern extremity of the coal measures of the Uinta Basin is exposed near Emery, Utah, about 75 miles northwest of the Henry Mountains. The Cretaceous formations of the two localities seem to be comparable both in the order of succession and in lithologic character, as just suggested, although Lupton regards his Mesaverde as probably equivalent to Gilbert's Masuk sandstone and correlates his Ferron sandstone member of the Mancos shale with Gilbert's Blue Gate sandstone. This correlation, assuming that the formations were continuous, requires that the 500 feet of Gilbert's Masuk shale represent the 2,500 feet of shale above the Ferron sandstone, and by comparison with sections farther south it would seem to necessitate the correlation of the Ferron with the original Mesaverde. This correlation is rendered doubtful by the nature of the fossils.

WELLINGTON (27).[3]

The same formations are exposed in the Wellington and Sunnyside areas, Utah, that were found by Lupton 50 miles farther southwest. Here also few data regarding the age of the beds were found in the upper portions of the Mesaverde. It is significant that the base of the arenaceous rocks of this formation occurs progressively lower in the section toward the west. In tracing exact horizons Clark found that the base of the Mesaverde is stratigraphically about 150 feet lower in the western part of the area that he examined than in the eastern part. Here, then, is found, in an area examined in detail, the same transition laterally from shale to sandstone

[1] Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.
[2] Lupton, C. T., unpublished manuscript.
[3] Clark, F. R., unpublished manuscript.

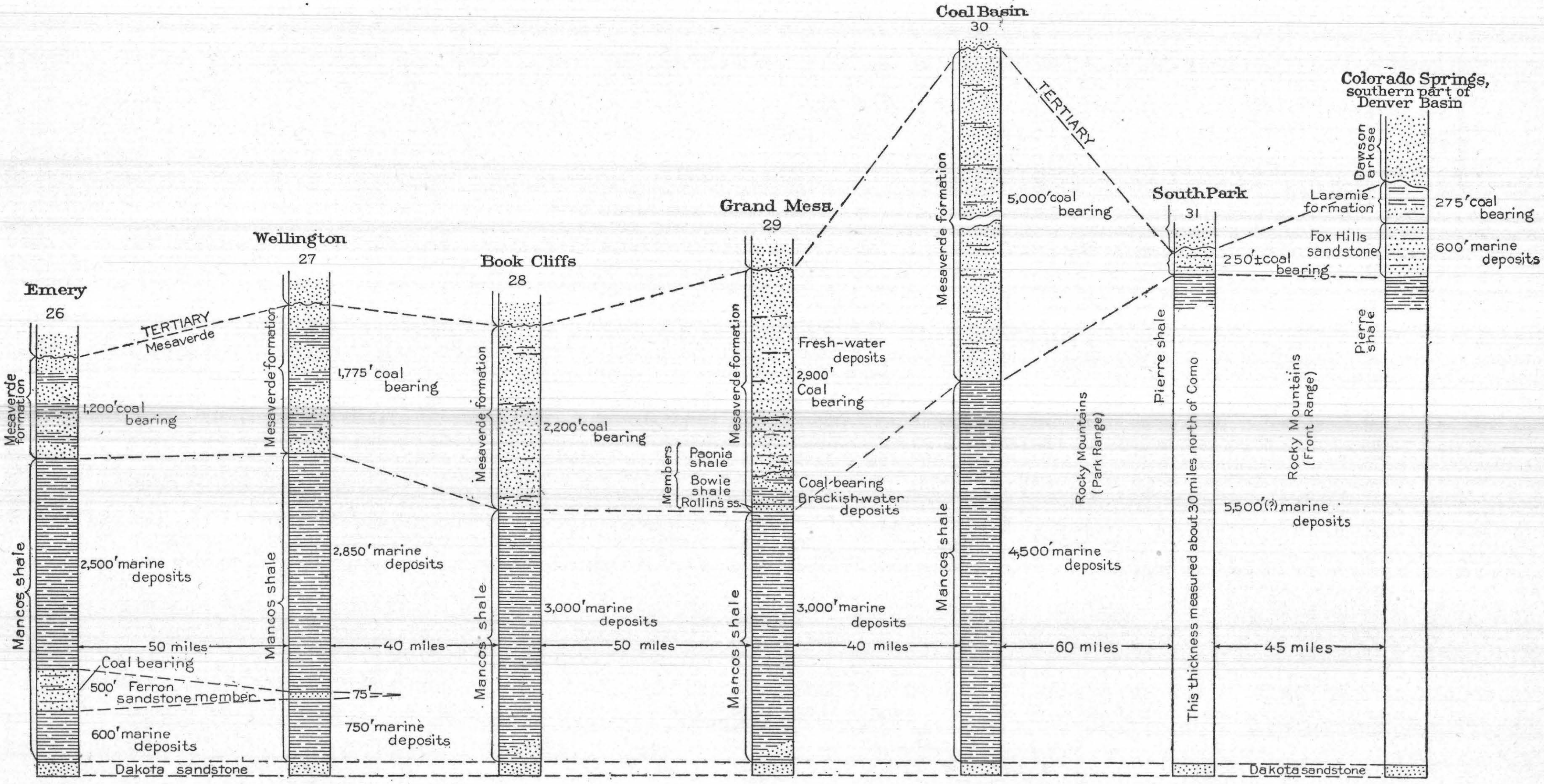

FIGURE 21.—Group of sections from Emery, Utah, along the southern border of the Uinta Basin eastward through South Park to the Denver Basin, Colo. (For location see Pl. V.) The names at the left of each section indicate correlations that have been made. The lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

that was described for the San Juan Basin, where points of observation were far apart. The Ferron sandstone member of Lupton's section occurs in the Wellington area, but is notably thinner and seems to disappear farther east.

BOOK CLIFFS (28).[1]

The generalized section given for the Book Cliffs of Utah and western Colorado does not differ essentially from the one just described, except that Richardson makes no mention of the sandstone later named Ferron by Lupton. A well drilled 10 miles northeast of Grand Junction, Colo., indicates that the Mancos is more than 2,800 feet thick. The drill did not reach the Dakota sandstone. The sedimentary rocks between the Mancos shale and the rocks of Eocene age are all referred to the Mesaverde, with some qualifying statements, and no attempt is made to divide them into members. Some fossil plants and invertebrates were found, and dinosaur bones were obtained east of Green River, about 500 feet above the top of the Mancos shale.

GRAND MESA (29).[2]

A basal conglomerate lying unconformably on the Gunnison formation in the Grand Mesa field is referred to the Dakota because of its stratigraphic position. Certain coal-bearing rocks above this conglomerate heretofore regarded as Dakota are referred on fossil evidence to the Mancos. Above these the Mancos through an estimated thickness of 3,000 feet is principally shale. All the rocks between the Mancos shale and the base of the Tertiary are referred to the Mesaverde, although an unconformity is described as separating them into a marine and brackish-water division below and a fresh-water division above. The Mesaverde comprises a small sandstone member, the Rollins, overlain by a coal-bearing sandstone and shale member, the Bowie, both containing marine and brackish-water invertebrates; and a higher coal-bearing member, the Paonia, containing fossil plants and fresh-water shells. The Paonia member lies unconformably on the Bowie in some places and on the Rollins sandstone in other places. These members have not been differentiated in neighboring fields.

COAL BASIN (30).[3]

Beekly examined the formations in the neighborhood of Coal Basin, Colo., south of Glenwood Springs. His work consisted mainly in obtaining data for the classification of the coal lands, but his measurements of the formations were made with care. The section was measured at the Grand Hogback and is therefore at the eastern margin of the Uinta Basin. The thickness of the sedimentary formations in the Grand Hogback renders it obvious that they once extended much farther east over the area now occupied by the mountains. It seems probable that they once connected with those near Como, in South Park,[4] about 60 miles east of the Grand Hogback, where coal-bearing rocks overlie marine shale of great though unknown thickness. It seems to be a debatable question whether the coal measures of South Park shall be correlated with the Laramie to the east or with the Mesaverde to the west. From the fact that at the north end of this park, near Breckenridge,[5] about 30 miles north of Como, these marine rocks are estimated as 5,500 feet thick, it is reasonable to suppose that near Como they are comparable in thickness to the Mancos shale on the west and to the marine Cretaceous about 45 miles to the east, where they are reported as about 5,500 feet thick at Canon City (section 5, fig. 16) and more than 7,000 feet thick at Boulder (section 6).

SOUTH PARK (31) AND COLORADO SPRINGS.

Although the coal measures of the Denver Basin east of the mountains are known as Laramie and those west of the mountains as Mesaverde, the suggestion seems pertinent that could the eroded portions of the formations be restored the Mesaverde would be found to extend east-

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[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, pp. 12–23, 1909.

[2] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, pp. 18–19, 1912.

[3] Beekly, A. L., unpublished manuscript.

[4] Washburne, C. W., The South Park coal field, Colo.: U. S. Geol. Survey Bull. 381, pp. 307–316, 1910.

[5] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, p. 39, 1911.

ward and include the coal measures of South Park and the Laramie of the Denver Basin. In other words, the coal measures east and west of the mountains may be homogenetically equivalent although differing in age, just as the coal measures of the San Juan Basin seem to differ in age, although continuous from place to place. It may be equally pertinent also to inquire, first, if the Mesaverde of the Grand Hogback is the time equivalent of the original Mesaverde of the San Juan Basin; and second, if there is as great a difference in age between the Mesaverde of the Grand Hogback and the Laramie of the Denver Basin as the time significance of the names indicates.

NORTHERN PART OF UINTA BASIN AND AREA TO THE EAST.

The group of sections shown in figure 22 represents the Cretaceous formations that now extend from the Wasatch Mountains, in Utah, eastward to the Rocky Mountains and probably at one time extended eastward across the site of the Rocky Mountains. They are obscured in many places west of Axial, Colo., by the overlapping Tertiary strata, but from that point eastward to the mountains they are continuously exposed. Most of them have been eroded from the mountainous area farther east, but remnants have been preserved in the center of this area that serve to show the possible connection between the Cretaceous formations of the Uinta Basin and those of the Denver Basin.

BLACKTAIL MOUNTAIN (32).[1]

The sandstone at the base of the Cretaceous is referred with some doubt to the Dakota. Above this sandstone is a shale that is correlated with the Mowry shale member of the Benton of Wyoming. Above the shale is a coal-bearing formation that seems to correspond to the Ferron sandstone member of the Mancos shale, and this in turn is overlain by the marine shale that constitutes the main body of the Mancos. The Mesaverde is described as 3,263 feet thick and contains coal throughout the upper half. Unlike the Mesaverde of other localities, it is not coal-bearing in the lower part. The coals are described as lignitic or subbituminous like those above the unconformity within the Mesaverde of the Grand Mesa field. This suggests the question whether all the rocks here called Mesaverde constitute a single formation.

DEEP CREEK (33).[2]

Deep Creek is about 15 miles northwest of Vernal, Utah, and 70 miles east of Blacktail Mountain, described above. A sandstone at the base of the Cretaceous in this district is referred doubtfully to the Dakota, and above this sandstone occur other sandstones and shales 390 feet thick, with coal near the top, which obviously represent the lower shale and coal measures of the Blacktail Mountain field, but are notably thinner. Above this coal lies the main mass of the Mancos shale, 2,100 feet thick. The younger Cretaceous rocks have been eroded away at Deep Creek and the Wasatch formation rests unconformably on the Mancos shale. Near Vernal, however, the Mesaverde is present in normal development. Gale[3] states that it is about 1,500 feet thick at Green River and increases in thickness toward the east.

AXIAL (34).[4]

Axial is in the Yampa coal field described by Gale[5] several years ago. More recently Hancock has mapped the part of this field near Axial for folio publication. His section measured near Axial differs only in detail from that given by Gale for the whole field. The coal measures that occur near the base of the Mancos in the sections farther west are represented here by an inconspicuous sandstone that contains no coal and that disappears toward the east. The Mancos shale has an enormous thickness, and the marine conditions indicated by its fossils

[1] Lupton, C. T., The Blacktail (Tabby) Mountain coal field, Wasatch County, Utah: U. S. Geol. Survey Bull. 471, pp. 595–655, 1912.
[2] Lupton, C. T., The Deep Creek district of the Vernal coal field, Uinta County, Utah: U. S. Geol. Survey Bull. 471, pp. 579–595, 1912.
[3] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 204–219, 1910.
[4] Hancock, E. T., unpublished manuscript.
[5] Gale, H. S., op. cit.

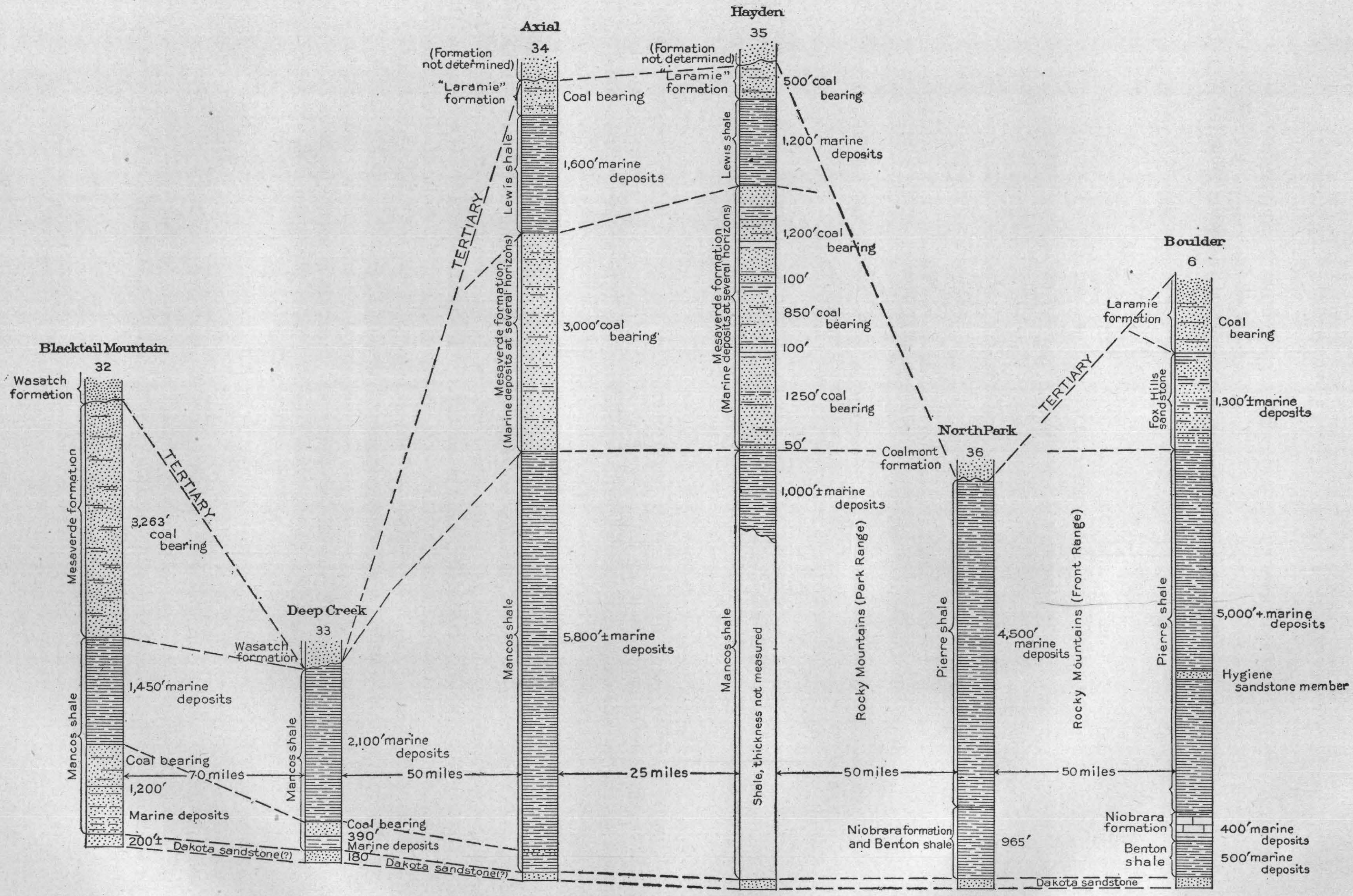

FIGURE 22.—Group of sections from the Blacktail Mountain coal field, Utah, along the northern border of the Uinta Basin eastward through North Park to Boulder, Colo. (For location, see Pl. V.) The names at the left of each section indicate correlations that have been made. Ths lines connecting the sections are intended to show homogenetic equivalents rather than time equivalents.

did not wholly cease with the beginning of the deposition of the overlying Mesaverde, which contains marine invertebrates at several horizons, the marine beds alternating with coal and its associated fresh or brackish water beds. The Mesaverde is separated from a younger coal-bearing formation by a thick marine shale which, because of its stratigraphic position, has been called the Lewis. This shale becomes sandy toward the west and in part at least merges into the "Laramie" above and into the Mesaverde below. This suggests that the enormous thickness of Mesaverde in other parts of the Yampa field—over 5,000 feet, according to Gale—may be due to the fact that the Lewis in these parts has not been distinguished because of its sandy character and that what has been called Mesaverde in that region may include equivalents of both Lewis and "Laramie."

HAYDEN (35).[1]

The section near Hayden, Colo., in T. 5 N., R. 89 W., was measured several years ago and the description was prepared for publication, but it has not yet appeared in print. The "Laramie" and Mesaverde formations were measured with considerable care because of their coal beds, which were being examined in detail, but the thickness assigned to the Lewis shale is believed to be less reliable, inasmuch as the shale occupies a broad valley and is not continuously exposed. In a reconnaissance trip through this field I received the impression that the Lewis shale thickens toward the east and that the Mesaverde becomes thinner and less sandy in the same direction, but while this impression accords with other observations in western Colorado no definite statement to that effect can now be made.

The Cretaceous formations extend eastward to Steamboat Springs, about 25 miles from Hayden, where they are upturned, the Dakota forming a prominent hogback. Thus, although the distance between the Hayden and North Park sections is about 50 miles, as shown on figure 22, the Cretaceous rocks are lacking over a mountainous area only about 25 miles wide.

NORTH PARK (36).[2]

The base of the Cretaceous in North Park consists of a sandstone that is presumably Dakota. Above this sandstone is 965 feet of shale referred on the evidence of the invertebrates to the Niobrara and Benton formations and 4,500 feet referred to the Pierre shale. The shales have the character and approximately the same thickness as the Mancos, to the west, and apparently differ but slightly from the Pierre and associated shales to the east. Unconformably overlying the Pierre shale are 4,000 to 6,000 feet of coal-bearing rocks of nonmarine origin consisting of shale, sandstone, and conglomerate, to which Beekly has given the name Coalmont formation. Although this formation is classed as "Cretaceous or Tertiary" it contains a flora said to be of Tertiary age and is correlated with the "Upper Laramie" of Veatch, which in turn is regarded by some as essentially equivalent in age to the Denver formation. These facts strengthen the assumption that the unconformity between the Pierre shale and the Coalmont formation is the same as the post-Laramie unconformity of the Denver Basin.

On the assumption that the upper part of the Mancos and the upper part of the Pierre occupy different positions in the time scale, according to current usage, there seems to be serious doubt as to whether the beds in North Park should be correlated with those east of the mountains, in which case the 4,500 feet of beds of Montana age would be Pierre, or whether they are more closely allied with those to the west, in which case all the marine Cretaceous beds of North Park would be referred to the Mancos. Whatever differences in age may be indicated by the invertebrates, it seems obvious that the Mancos is the homogenetic equivalent of the older marine Cretaceous rocks—in other words, that the Mancos of the Uinta Basin and the Pierre, Niobrara, and Benton of North Park and of the Denver Basin are parts of the same formation and were once continuous across the areas now occupied by the mountains.

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[1] Davis, J. A., unpublished manuscript.

[2] Beekly, A. L., Geology and coal resources of North Park, Colo.: U. S. Geol. Survey Bull. 596, p. 20, 1915.

SUMMARY.

The sandstones at the base of the several sections of figure 22 are doubtless homogenetic but not necessarily time equivalents. The sandstones associated with the lower coal to the west lose their coal-bearing character toward the east and finally thin out altogether. Although the horizon is recognizable near Axial it has not been distinguished farther east.

The principal shale of the Mancos is relatively thin in Utah and thickens toward the east. The resemblance of the shale in North Park to the Mancos on the west and the Pierre on the east strengthens the hypothesis that no barrier existed in the Rocky Mountain region during Cretaceous time and that the Mancos and the Pierre are parts of a once continuous formation.

An inspection of the sections also suggests that the base of the Mesaverde of the Blacktail Mountain locality is older than the base of this formation as developed farther east and that this formation may be the homogenetic equivalent of the Fox Hills of the Boulder region, although the latter has generally been regarded as much younger than the Mesaverde.

The Lewis shale is well defined in some places, but toward the west it seems to become arenaceous and coal bearing and to merge into the Mesaverde below and the "Laramie" above. This fact, considered in connection with the occurrence of marine invertebrates at several horizons in the Mesaverde of the Uinta Basin, suggests that the Lewis shale of this basin may not be as definitely separable from the Mesaverde as some have supposed and that the Mesaverde, Lewis, and "Laramie" together of this basin may be comparable with the Fox Hills and Laramie of the Denver Basin. At first glance it seems difficult to reconcile this hypothesis with the great differences in thickness of the formations in the Uinta Basin and in the Denver Basin. But if the sediments came mainly from the lands to the west arenaceous beds should be thick in the western fields and should thin eastward. This difference seems to be even more conspicuously shown in the Cretaceous beds of southern Wyoming, north of the areas discussed in this paper.

The youngest coal-bearing rocks of Cretaceous age in this region occur on either side of the mountains at localities less than 100 miles apart, and there is good reason for believing that they were originally deposited in North Park. Remnants of them occur farther north, so distributed as to indicate that they originally occupied a relatively small area which may represent, so far as the region here described is concerned, the last part of the Cretaceous basin to be filled.

GENERAL CONCLUSIONS.

No claim is made that the views expressed in this paper are final. Many of them will doubtless be modified when more detailed work is done in the several areas described, but it is believed that they are worthy of consideration as field work is continued. Little is known of some of the sections discussed, while others have been examined carefully, but all are believed to be sufficiently accurate to show the broad general relations of the Cretaceous formations. The points to which especial attention is directed are as follows:

1. It seems evident that no notable crustal movement affected the southern Rocky Mountain region for a long period prior to the beginning of Upper Cretaceous time, and there was ample time for the peneplanation of this region before the invasion of the Cretaceous sea.

2. The distribution of the Dakota sandstone about the present mountains, its attitude toward them, its presence upon them and within them at great altitudes, and its relation to the older formations all indicate that the Dakota originally extended continuously over the area now occupied by the Rocky Mountains.

3. There are good reasons for believing that the marine Cretaceous formations overlying the Dakota also extended uninterruptedly over the areas now occupied by the Rocky Mountains. If islands persisted there throughout the Cretaceous period, their location is now not known. Among these reasons may be mentioned (*a*) the absence of conglomeratic or arkosic material in these formations near the mountains, (*b*) the fact that the marine formations are comparable in thickness and character on either side of the mountains as well as within them but do not in the mountain region contain intercalated beds of fresh-water origin, as they do farther west,

and (*c*) the fact that the marine shales in western New Mexico and Colorado thicken toward the present mountains while the sandstones thin in the same direction.

4. The several so-called basins containing Cretaceous rocks all seem to be of post-Cretaceous origin. Little evidence has been brought forward to show that they were separate basins of deposition during Cretaceous time. The physical evidence thus far produced seems to favor the hypothesis that the interior Cretaceous sea occupied a single basin extending from Utah and Arizona eastward over the present site of the Rocky Mountains. Certain paleontologic evidence, however, seems to oppose this hypothesis.

5. When rocks at two or more localities are correlated and designated by the same name, there may be no intention of implying that they are exact time equivalents, but that is the impression usually conveyed to the reader. There seems to be need of some definite term to express the fact that rocks at two or more localities may be equivalent in lithology and appear to hold the same stratigraphic position and even to contain essentially the same fossils and yet differ in age. Until a better term is proposed this relation may be expressed as "homogenetic." For example, the Mesaverde, a sandy, coal-bearing formation, known to be of Montana age in its type locality, seems to thicken downward at the expense of the underlying shale and has been described as continuous with coal-bearing rocks near Gallup, N. Mex., that contain fossils indicative of Colorado age. These rocks near Gallup are homogenetically equivalent to the Mesaverde. To follow this conception still further and apply it to beds that can not be traced through intervening areas, this term still seems useful, inasmuch as there may be less uncertainty in homogenetic correlation than in paleontologic correlation, especially where there is conflict of opinion arising from different classes of fossils. For example, there seems to be little doubt that the Vermejo formation of the Raton coal field is the homogenetic equivalent of the Mesaverde of the Cerrillos field (section 3), to the south, and of the Vermejo of the Canon City field (section 5), to the north; and yet some of the paleontologic evidence indicates that the Vermejo at Canon City is of late Montana age, while the Mesaverde at Cerrillos is early Montana.

6. The conceptions herein presented have an intimate bearing on the problem of the Cretaceous-Tertiary boundary in the Rocky Mountain region. Certain conglomerates that rest unconformably on Cretaceous beds are regarded as basal Tertiary by some geologists and as Cretaceous by others. These conglomerates contain great numbers of pebbles of crystalline and metamorphic rocks such as are now found in the mountains, and they are so distributed as to prove that they were derived from the present mountainous areas. Inasmuch as the Cretaceous formations were originally continuous over the site of these mountains, it follows that there must have been uplift and erosion sufficient to remove them and to reach the pre-Cretaceous rocks before the materials for the conglomerates could be obtained. In the Rocky Mountain region of Colorado and New Mexico all deposits above these conglomerates are of the nonmarine type that characterizes the undisputed Tertiary formations of the same regions. Such a measure of this unconformity has been severely criticised. Whether or not the post-Cretaceous erosion removed 20,000 or 14,000 feet of sediments, less or more, the uplift was obviously sufficient to cause the streams to cut through whatever Cretaceous formations were deposited over the areas now occupied by the mountains and enough more of the formations that underlie the Cretaceous to obtain the large quantities of coarse material now found in the lower part of the Tertiary.

Briefly stated, it is conceived that the interior Cretaceous basin was formed by the slow and somewhat intermittent downward warping of a nearly base-leveled surface, probably accompanied by a rise of sea level. This subsiding area, reaching from the Gulf of Mexico to the Arctic Ocean and from Utah to the Mississippi, is so large that the subsidence may be better called an epeirogenic movement rather than a downward warping, a term usually applied to smaller areas. The rate of sedimentation in this basin was comparable with the rate of subsidence. The sediments and the fossils they contain are of such a nature as to render it improbable that the sea was at any time very deep. It was probably for the most part so shallow that the sediments were somewhat uniformly distributed over its floor by waves and currents. The long period of quiescence was terminated and a new period of very different character was begun by an orogenic movement that resuscitated the mountains which had been worn down and whose roots had been buried beneath the Cretaceous strata. This movement was followed at short intervals by other similar movements, which produced the present highlands of the Rocky Mountain region and which also introduced the long series of volcanic events that characterized the Tertiary period in western America. As nearly as can now be determined, this movement corresponds in time with movements in other parts of the world which are universally recognized as terminating the Cretaceous period and introducing the Tertiary. It naturally follows that the conglomerates and other sediments derived by erosion from the newly uplifted mountains—such as those of the Denver, Arapahoe, Dawson, Raton, and related formations—belong to the Tertiary system.