Pennsylvanian.—As shown in figure 3, Pennsylvanian rocks are found bordering the Front Range on the eastern side from one end to the other. On the western side they are lacking in the region from Dillon to Walden, but are well developed to the south and north. The Pennsylvanian beds contain some marine fossils, the trails of amphibians, and some land plants such as grew in swamps. In general, the formations are made up chiefly of coarse clastic material, strongly cross-bedded, and much of it has a decided reddish hue. Coarse conglomerates are common and the various beds are usually lenticular. The freshness of the feldspars and the abundance of coarse mica in the sediments suggests that they were derived from a nearby source. The coarseness of the material and its reddish color suggest the rapid transportation of material under semi-arid conditions, and testify to active erosion in a bordering land mass. The formation varies greatly in thickness along the eastern side of the range and these variations, when studied in detail, suggest alluvial fans and delta deposits. The fossils found in the formation show that some of it was formed in a shallow sea and that part of it must have formed as a continental deposit.

On the western side of the range the black marine "Weber shale" conformably overlies the Mississippian rocks. In some places the "Weber shale" is sharply separated from the overlying "Weber grits" and in other localities the two formations grade into each other. The "Weber grits" consist of interbedded micaceous gray grits and conglomerates and gray and black shales. The overlying Maroon formation is separated from the "Weber grits" on the basis of the dark red color which predominates in the middle part of the Pennsylvanian-Permian section. No sharp division is possible, as a few beds having the typical maroon color are found far below the so-called "base" of the Maroon formation and gray beds of "Weber" aspect are found far above it. The color of the Maroon formation gradually changes to a brilliant

brick red in the upper part and coincides with a decrease in the amount of coarse clastic material. The upper red micaceous shales and grits, in earlier reports called the "Wyoming formation," on the mistaken assumption that they were Triassic red beds, are typically developed a few miles west of the margin of the Carboniferous sediments. The sediments in the overlap belt exhibit all the features supposed to be distinctive of the "Weber," Maroon and "Wyoming" formations. Black carbonaceous shales alternate with brick red micaceous shales; gray grits and maroon-colored grits are interlayered with the shales; coarse boulder conglomerates are common. It seems probable that such lithology characterizes the shore facies of the Carboniferous sediments.

The black shales at the base of the section and in the shore facies suggest that organic material was locally abundant; the gray grits indicate rapid erosion of granitic highlands; the red coloration shows the presence of areas in which rock decay was well advanced. The absence of black carbonaceous shales in most of the upper rocks suggests an arid or semi-arid climate at the time the Maroon and "Wyoming" formations were deposited. The red micaceous shales of the "Wyoming" were probably supplied from a region in which rock decay under arid conditions was an important factor. Alternations of red and gray grits in the Maroon formation suggest that the sediments were supplied from different sources, possibly an area of slight relief favoring the production of red clastic material while a more rugged surface furnished the coarse gray grits and conglomerates, although variations in the velocity of transportation from one area might have a similar effect.

On the eastern side of the range there are many places where one can observe successively higher beds in the Fountain formation overlapping the pre-Cambrian rocks as the formation is followed to its western limits. Followed eastward, the coarse clastic beds become decidedly shaly a short distance from the mountains. These facts indicate that the country to the west was a source of the sediments and that

there was a decided slope from this highland toward the east.

On the western side of the range in the region near Breckenridge the Pennsylvanian rocks are overlapped by Dakota sandstone between Boreas and Georgia Passes in a distance of about four miles. The Pennsylvanian beds rapidly thicken to the west, increasing from a mere film near Georgia Pass to 10,000 feet on Mount Silverheels, eight miles away. There is no evidence of an angular unconformity between this formation and the overlying Morrison in this region, and it is clear that its rapid disappearance represents the original thinning towards the Front Range highland to the east, from which it was derived. We also find that the line marking the overlap of the overlying Morrison formation is parallel to the earlier shorelines and a few miles farther east.

The western border of the Front Range highland in early Mesozoic time can thus be rather definitely established, but the rarity of post-Carboniferous overlaps makes it more difficult to place the boundary on much of the eastern side. The presence of Lower Cretaceous (?) sediments lying on the granite a few miles west of Canon City suggests that the Pennsylvanian beds did not extend far to the west in this region. From here to Wyoming, however, there is but little direct evidence bearing on the question. Ball found a few residual boulders of sandstone south of Georgetown which he believed to be erosion remnants of Pennsylvanian sediments, but they strongly resemble the Dakota sandstone. A few miles northeast of Central City I have found remnants of the Dakota sandstone, but careful search failed to show any rocks resembling the Pennsylvanian sediments.

The evidence presented above indicates that the Front Range highland rose several thousand feet above the bottom of the early Pennsylvanian sea which bordered it to the east and west. It probably covered about the same area as the present Front Range and presented a steep western front and a moderately sloping eastern flank to the surrounding sea. The great thickness of sediments west of the range suggests that the sea bottom was subsiding slowly while the highland

maintained sufficient elevation to supply large quantities of coarse detrital material. Nearly all of the clastic material consists of pre-Cambrian rock, but some reworked fragments of the Paleozoic formations are locally abundant and indicate uplift and erosion at the beginning of Pennsylvanian time, even though no angular unconformity has been found.

Permian and Triassic.—The conditions existing in the Pennsylvanian lasted into the Permian and it is difficult to separate these two series. The sediments in the upper part of the Permian series are very red, micaceous shales, and may grade into Triassic beds at the top, although no definite Triassic fossils have been found in them. According to Lee[10], if any Triassic is present it is confined to a thin non-marine sandstone of Upper Triassic age. Locally, below this sandstone, beds of gypsum are interbedded with the red shales. On both sides of the range the sediments indicate a lessening in the intensity of erosion on the Front Range highland during Permian and Triassic(?) time, and the existence of an arid climate.

The conditions during the Triassic must be inferred chiefly from negative evidence. Sedimentation was practically halted, an arid climate prevailed in Wyoming and probably in Colorado. No diastrophism is recorded. In general the region under consideration had been reduced to a maturely eroded surface, which was highest in New Mexico and descended gradually northward through Colorado.

Jurassic.—No beds of definite Jurassic age are known on the western flank of the Front Range, but Jurassic beds of the Sundance formation are several hundred feet thick along the northeastern border of the range and carry a marine fauna. These sediments are predominantly sandstone and rest unconformably on the underlying red beds. The upper members of the Jurassic system vanish to the south and only basal sandstone is present along most of the eastern side of the Front Range. The successive disappearance of the upper

[10]Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming and southern Montana. U. S. Geol. Survey, Prof. Paper 149, p. 23, 1927.

beds indicates their removal by erosion and suggests an uplift which raised the southern part of the Front Range highland well above its northern end. As the Jurassic beds are overlain by the Lower Cretaceous(?) Morrison formation, this uplift probably occurred near the end of Jurassic time.

Lower Cretaceous(?) Morrison formation.—Lower Cretaceous(?) continental deposits surround the Front Range as a thin series of sandstones and variegated shales. The Morrison formation contains fossils of swamp-loving reptiles, sub-tropical vegetation, and lacustrine or fluviatile shells. It shows an erosional unconformity with the underlying beds and is separated from the overlying Dakota and associated formations by a distinct stratigraphic break, usually marked by a thin basal conglomerate.

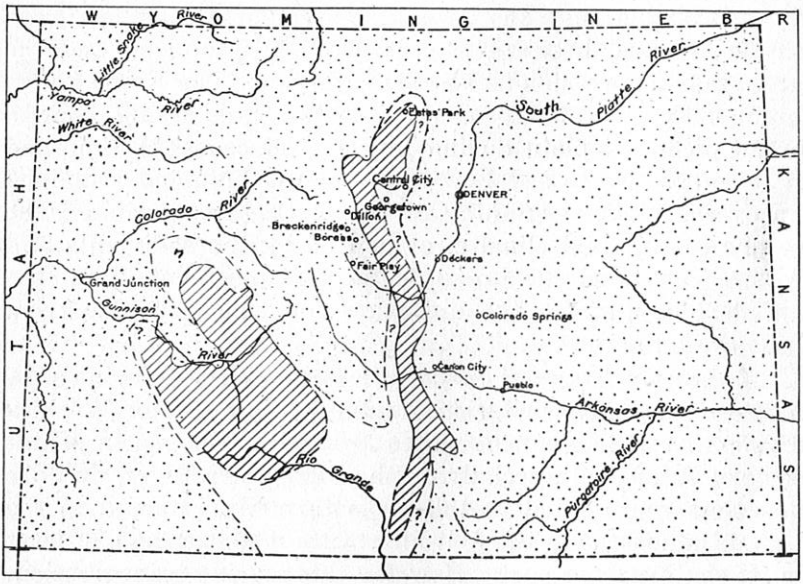

Fig. 4—Paleogeographic map of the Triassic and Jurassic rocks of Colorado.
Ruled area=highland at beginning of the Cretaceous.
Dotted areas, Triassic and Jurassic rocks at beginning of the Cretaceous.

The Morrison formation, of Lower Cretaceous(?) age, overlaps the older formations extensively on the northwestern side of the Front Range (figure 4). On the southwestern slopes the overlap is narrow, probably less than two miles near Georgia Pass, and on the eastern side the only area where evidence of the overlap is still preserved is at the southern end of the range, near Canon City.

The widespread deposition of Morrison sediments on pre-Cambrian rocks in the northwest indicates that this region was almost base-leveled by Morrison time, and the narrowness of the overlap in the Breckenridge region suggests that here the Front Range highland was more elevated than farther north.

The relation between the Morrison and the overlying formations does not suggest important uplift and erosion. It is probable that any crustal movements which occurred in the interval between the close of the Morrison and the great marine invasion had little magnitude. The Front Range highland was probably a series of low hills rising from a broad piedmont plain during Lower Cretaceous(?) time and it is impossible to say how much of the highland remained uncovered at the beginning of Upper Cretaceous time. The return of a humid climate, evidenced by the sediments and fossils, converted the broad featureless piedmont plain into an ideal habitat for the dinosaurs for which the Morrison beds are famous.

Lower Cretaceous (*Purgatoire formation*).—Marine sediments with the characteristic fauna of the upper or Washita division of the Comanche series are well developed in southeastern Colorado, especially on the Purgatoire River, and are doubtless represented in the rocks formerly referred to the Dakota sandstone in the foot-hills of the Front Range, at least in its southeastern part. How far this marine transgression, which preceded the Dakota, extended to the north and northwest has not been definitely determined, but apparently it did not reach the western side of the Front Range highland. In the following discussion of the Dakota sandstone no at-

tempt is made to discriminate sharply between it and the late Comanche rocks which are probably present in at least a part of the area.

Upper Cretaceous and the Laramie Problem

Dakota sandstone.—The Morrison sediments are overlapped by the Dakota sandstone and associated formations west and northwest of Canon City, east of Breckenridge and along the southeastern border of South Park. These overlaps are found only in the southern half of the Front Range and suggest that while hills remained in this region, the northern half of the highland had been base-leveled. However, the distance across the Front Range is much greater in the north than in the south and, as a similar spread between outcrops in the southern part would destroy the evidence of the overlap, it is possible that some hilly areas existed in the northern part as well. Since Cretaceous sedimentation indicates that the Front Range highland was continuous with a higher land mass in New Mexico, it is probable that a general slope to the north existed. The distribution of Jurassic and Lower Cretaceous(?) sediments also suggests that the northern half of the highland was base-leveled before the southern half.

The Dakota sandstone and associated rocks consist chiefly of well washed sand and sandy shales and usually have a thin layer of conglomerate at their base. Locally seams of coal and fire clay occur. Fossils include warm-temperature plants, the trails of marsh-loving reptiles, and marine shells. The well washed sand covering the thin conglomerate suggests the beach of the slowly transgressing Cretaceous sea, and the alternations of shales containing marine fossils with sands containing land plants indicates that the slow subsidence of the land was marked by a series of oscillations. Since the sea was spreading over a very gently sloping surface on the old piedmont plain, these movements favored the development of widespread swamps and probably account for the carbonaceous seams in the formation. The basal conglomerate commonly consists entirely of chert pebbles, but

locally pebbles of pre-Cambrian rocks and fragments of limestone are found. A detailed study of such occurrences might throw light on the problem of the hilly areas of the Front Range highland. As pointed out by Lee[11] there are very few regions where the Dakota sandstone is overlapped by Benton shales in Colorado, but contrary to his opinion there are a few places in the Front Range where the evidence strongly suggests that Dakota sandstone was never deposited. In Twelve Mile Park, a short distance north of Canon City, Cross has described the apparent overlap of Benton upon pre-Cambrian rocks[12]. No such overlap is certainly known on the western side of the range, but at Georgia Pass, a few

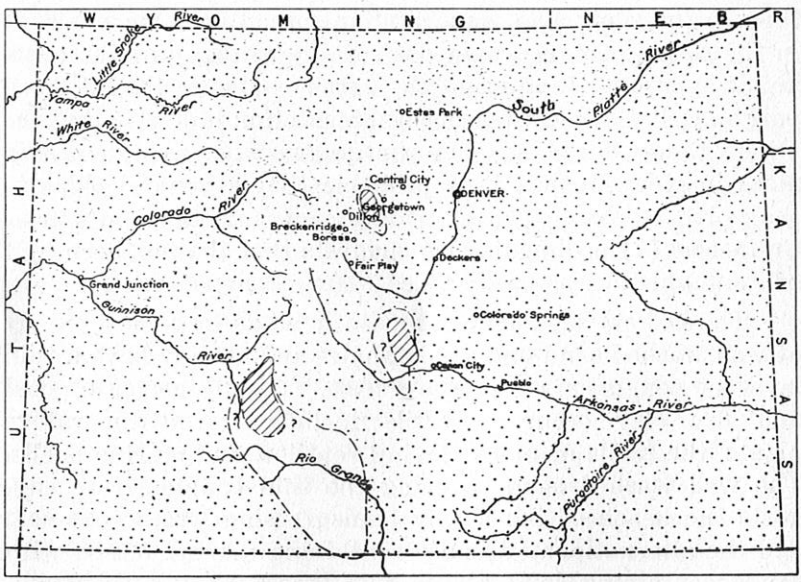

Fig. 5—Paleogeographic map of the Cretaceous Dakota Sandstone in Colorado.
Ruled area=highland at beginning of the Benton.
Dotted areas, Dakota sandstone and associated formations at the beginning of the Benton.

[11]Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico, U. S. Geol. Survey, Prof. Paper 95, p. 36, 1915.
[12]Cross, Whitman, U. S. Geol. Survey Atlas, Pikes Peak Folio, (No. 7), p. 4.

miles southeast of Breckenridge, the basal sandstone and conglomerate underlying the Benton shale is only twenty feet thick. If this is the Dakota sandstone, it has decreased from 175 feet to 20 feet in five miles. This rapid thinning toward the east can be found at several places near Breckenridge, but as yet no one has found a definite overlap. However, these facts indicate that some areas of the Front Range highland were above water at the close of Dakota time. The gradual flooding of the region probably left a series of islands extending north from the New Mexico land mass, islands which diminished in size to the north and probably disappeared in the region near Estes Park. (See Fig. 5.)

Benton shale.—Because of the Laramie problem, the thick series of Upper Cretaceous marine sediments which followed the Dakota will be considered in more detail than has been accorded to the sediments of previous periods. The Benton shale everywhere overlies the Dakota, although in Twelve Mile Park it is said by Cross to be only a very few feet thick. Similarly, in South Park it appears to be much thinner on the eastern border of the park than on the western side. These relations suggest the conditions noted during the deposition of the Pennsylvanian beds on the western slope, when the Front Range highland maintained its elevation while the land to the west of it was downwarped into a great basin. It seems probable that such conditions recurred on both sides of the Front Range highland during the deposition of the Upper Cretaceous formations.

Niobrara formation and Pierre shale.—The Niobrara formation also thins greatly from Colorado Springs west to Twelve Mile Park. However, I have found no evidence that this region remained above water after Niobrara time and the sedimentation of the lower half of the Pierre indicates a gradual deepening of the sea. The Pierre formation, which averaged about 5,000 feet in thickness in the troughs bordering the Front Range, thinned out decidedly over the central part of the Front Range highland, if the lateral downwarping

of the basins on either side was at all similar to that of Pennsylvanian time. Sandstones occur with increasing frequency above the middle of the Pierre and suggest the slow shoaling of the sea from this time on. It is extremely significant that the Pierre sandstones are best developed close to the present Front Range and grade into shale farther away. These sands are calcareous and contain no feldspars.

Fox Hills and Laramie formations.—The Fox Hills sandstone is the last definitely marine sandstone in the Cretaceous of the eastern side of the range. It is overlain by the Laramie formation, which contains brackish, freshwater and land fossils and consists of interbedded sandstones, shales, fire clays, and coal beds. The fossils indicate that the mild, humid climate of the Cretaceous period was unchanged.

In reconstructing the Front Range region of that time, it has been customary to picture the entire thickness of the Pierre, Niobrara, and Dakota formations as above the pre-Cambrian rocks throughout the entire area. Two facts, however, seem incompatible with this interpretation. (1) The gradation from shale to sand in the Pierre shale as the Front Range is approached indicates a marked shoaling of the sea over the ancient highland and suggests uplift in that region. (2) Many of the Laramie sands consist of arkose, some of them containing as much as 85 per cent of fresh feldspar. The humid climate of the Laramie would not favor the preservation of fresh feldspar while it was being broken up and carried a long distance. The source of such material must have been near at hand. The entire lack of feldspathic sediments in the underlying Cretaceous beds is well known. The Pennsylvanian formations are decidedly arkosic, but it is very unlikely that they would stand reworking without a great decrease in the percentage of feldspar which they contained. No volcanic rocks are known as possible sources of this material, and the andesitic sediment of the overlying Denver formation is very different in character from the arkosic sands of the Laramie. It is there-

fore concluded that pre-Cambrian rocks were the source of these sediments and that they were exposed a short distance away, in the center of the slowly rising Front Range highland. This would indicate that the shale deposited over the highland during early Pierre time was eroded and reworked in upper Pierre time and incorporated in the sediments of this part of the epoch. It is probable that the sandstones in the Fox Hills formation are the result of the reworking of the Dakota and the Morrison formations.

For some years the official classification of the United States Geological Survey has treated the Laramie as the latest Cretaceous formation of this region and has assigned the Arapahoe, Denver and Middle Park formations to the Eocene. In my opinion the facts presented in this paper strongly support the view that the boundary between the Cretaceous and the Eocene is at the top of the Denver formation, and I have therefore departed from the accepted classification to that extent.

Arapahoe, Denver, and Middle Park formations.—Above the Laramie is the Arapahoe formation which is so closely associated with the Denver formation that it might be considered its basal member. The basal conglomerate of the Arapahoe contains pebbles of all the older formations, including the pre-Cambrian, and shows a small erosional unconformity with the Laramie, but I know of no place in the Front Range region where it shows the slightest indication of an angular unconformity with the underlying beds. The conglomerate is local and is confined to the region near Denver. Where I have examined it, stream channels were clearly shown, and the character of the deposit suggests a fanglomerate. Dinosaur bones have been found in it. They suggest a mild climate much like that of the Laramie. The coarseness of the detrital formation evidences a decided stream gradient and explains the rarity of coal-forming swamps which were common in the underlying formation. Probably the uplift of the Front Range highland was becoming more rapid and the clastic material derived from it reflected this in its increased coarseness.

From the facts just presented it seems clear that the Laramide revolution did not occur at the end of the Laramie epoch, and that the interpretation of the pre-Cambrian pebbles in the Arapahoe [13] as representing the removal of 14,000 feet of sediments after the deposition of the Laramie is without basis. There is no evidence of a greater time interval between these two formations than that between the Fox Hills and the Laramie.

The Denver formation, which followed the Laramie on the east side of the range, and the Middle Park formation, which is equivalent to the Denver on the west side, enable us to trace the gradual development of the orogenic forces that culminated in the Laramide revolution. The basal sediments of the Denver contain large amounts of pre-Cambrian debris mingled with andesitic material. The latter is the first indication of volcanic activity in the Front Range highland since pre-Cambrian and is a fitting accompaniment to the increasing intensity of diastrophism. The pre-Cambrian waste becomes less and less important in successively higher beds of the formation and the material more than 900 feet above the base is said by Cross to be entirely andesitic in character, excepting in the uppermost beds where pre-Cambrian pebbles again appear. Cross[14] concluded that "The Archean and sedimentary rocks in the mountainous area drained by the tributaries of the Denver sea must have been covered by andesitic lava flows, so that no material other than the eruptive debris could appear in the Denver sediments, from this the prominent source until erosion had laid bare, here and there, small areas of granite, of gneiss or of sandstone." This conclusion as to erosion and derivation of material is well supported by the evidence given, but the interpretation of the Denver sediments as sea deposits was generally rejected long ago in favor of alluvial deposits. There may be some material which was deposited in shallow

[13] Emmons, S. F., Cross, Whitman, and Eldredge, G. H., Geology of the Denver Basin, Colorado, U. S. Geol. Survey, Mon. 27, p. 209, 1896.
[14] Idem, p. 202.

lakes, but a large amount of the interstratified coarse gravel and conglomerate represents gravel wash deposited where swiftly flowing mountain streams were checked by the lower gradient of the plains.

The fossils include dinosaurs, archaic mammals, and sub-tropical plants adapted to the mild climate of the preceding Laramie epoch.

The Middle Park formation bears the same general relation to the underlying Cretaceous beds as the Denver does. However, there is no sandstone beneath it with a fauna which corresponds to that of the Laramie. The sandy beds beneath the Middle Park formation contain a fauna that is indistinguishable from that of the Pierre. Alternating with the marine beds are some sandy shales containing fragmentary plant remains indicating shallow water near-shore conditions. It is significant that the Benton, Niobrara, and Pierre faunas are identical on both sides of the Front Range, but that the Fox Hills and Laramie faunas of the eastern slope are not represented on the western slope.

The base of the Middle Park formation is a bed of volcanic breccia which is overlain by a thick series of andesitic sandstones and shales. As the sandstones are followed northwest they become shaly and coal seams appear in them. Changes in character of the sediments suggest that coarse alluvial deposits at the base of the arching highland graded out into swampy stretches on the level plains a few miles away. The only fossils from this formation are plant remains which occur in great profusion. The flora indicates a mild, though not sub-tropical, climate, and is similar to the flora of the Denver formation. Evidently the plains and mountains were covered by dense forests.

Pre-Cambrian fragments are found in the lower 1,000 feet of the formation and then nothing but andesitic debris appears until, at horizons about 4,000 feet above the base, pre-Cambrian fragments recur, though not abundantly, in small lenses of conglomerates.

Laramide revolution.—The Denver and Middle Park

formations record the rapid arching of the ancient Front Range highland and an intense volcanic activity which covered the pre-Cambrian core with a thick series of andesitic lavas. The rejuvenation of the streams caused by this uplift enabled some of them to cut trenches through the lava cap before the end of Denver time, but there is little doubt that the greater part of the highland was still covered with andesitic lavas at the close of the Denver epoch. The increasing speed of the uplift culminated in the sharp monoclinal folding and thrust faulting which outlined the Front Range area as we find it today. Extensive thrust faulting took place on the western side and to a less extent on the eastern side of the range. Although the interpretation of an ancestral Front Range covered with 14,000 feet of sediments, rising more than 15,000 feet above the surrounding plains, is not supported by the facts here presented, the great faulting and the sharp folding must have created a mountain range higher than the present one. The folding and faulting is post-Denver and, in the Montezuma quadrangle, was followed by the intrusion of a large stock of quartz monzonite which cuts the Williams Range thrust fault. If the folding and thrust faulting mark the close of the Cretaceous, this stock implies the continuation of igneous activity into the Eocene. The ore deposits in the mineral belt of the Front Range, which extends northeast from Breckenridge to Boulder, were deposited from solutions emanating from the magma that gave rise to the late stocks and dikes in this region. The general relation of the pre-Tertiary rocks are shown diagrammatically in figure 6.

TERTIARY

Introduction and Summary.—In the deciphering of the Tertiary history, fossils, abundant at certain horizons, give us the most valuable information as a whole, but the sediments themselves are very helpful in the interpretation of intervening horizons. I am indebted to Dr. H. J. Cook, of the Colorado Museum of Natural History, for most of the in-

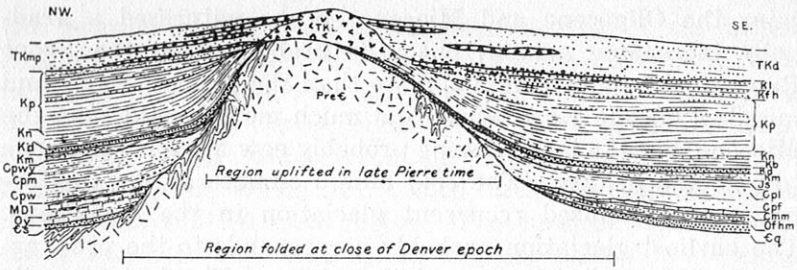

Fig. 6—Diagramatic section showing general relations of the pre-Tertiary formations of the Front Range in Denver time. Vertical scale greatly exaggerated and true thicknesses of sediments not shown.

Lowest Tertiary or Uppermost Cretaceous	TKmp, Middle Park fm. TKL, Andesitic lavas	Lowest Tertiary or Uppermost Cretaceous	TKd, Denver fm
Upper Cretaceous	Kp, Pierre shale Kn, Niobrara ls. Kd, Dakota ss.	Upper Cretaceous	Kl, Laramie fm. Kfh, Fox Hills sh. Kp, Pierre sh. Kn, Niobrara ls. Kb, Benton sh. Kd, Dakota ss.
Lower Cretaceous	Km, Morrison fm.	Lower Cretaceous	Km, Morrison fm
		Jurassic	Js, Sundance fm.
Permian and Pennsylvanian	Cpwy, "Wyoming" fm. Cpm, Maroon fm. Cpw, 'Weber grits'	Permian and Pennsylvanian	Cpl, Lykins fm. Cpf, Fountain fm.
Mississippian and Devonian	MDl, Leadville ls.	Mississippian	Cmm, Millsap fm.
Ordovician	Oy, Yule ls.	Ordovician	Ofhm, Fremont ls.
Cambrian	Cs, Sawatch quartzite	Cambrian	Cq, quartzite

formation on the Tertiary fauna in the section above.

The erosion of the Front Range produced mature topography in the higher parts of the uplift before the end of Eocene time and the Flattop peneplain was developed over wide areas. In Oligocene time a second peneplain was partially developed along the mountain edges. Strong uplift, accompanied by volcanic activity in the Miocene, rejuvenated erosion and the Rocky Mountain peneplain was developed during late Miocene and Pliocene time. Marked uplift occurred in early Pleistocene time and deep valleys and gorges were cut in the mountains during this and the Recent epoch.

The mild climate of Denver time probably continued through the Eocene. In the plains surrounding the moun-

tains the Oligocene and Miocene epochs witnessed a gradually increasing aridity, but it is probable that the Front Range had a more humid climate than the plains. Early and middle Pliocene were warm and much more humid than the Miocene, but the late Pliocene probably saw an abrupt change to extreme aridity. The cold humid climate of the Quaternary period caused recurrent glaciation in the mountains. The earliest glaciation probably corresponds to the pre-Yarmouth (Kansan) glaciers of the plains. The last stage is correlated with the Wisconsin glaciation, and evidence is given for an intermediate glacial stage, probably of Illinoian age.

Eocene.—There is very little direct evidence of the Eocene history of the Front Range. From Eocene beds deposited elsewhere, we can learn the climatic characteristics of this epoch, but practically no Eocene beds are known which are directly related to the Front Range. The flora, fauna, and the sediments of the Eocene, everywhere bespeak a moist climate. In the Wasatch and Wind River formations of the lower Eocene, we find that a large percentage of mammals have feet indicating dry rather than swampy ground, but there was a moderate number of marshy land dwellers. The presence of streams of considerable size is certainly indicated. Lemuroid monkeys of sub-tropical habitat, requiring a moist climate, were present, as well as many other animals not adapted to arid conditions. There is little doubt that the assemblage of mammals indicates a moist, sub-tropical climate.

Dr. W. H. Bradley [15], of the U. S. Geological Survey, has recently made a critical study of the sedimentation of the Eocene in southwestern Wyoming, and has come to interesting conclusions as to the rainfall and temperature of that region in this epoch. Many parts of the Green River formation (middle Eocene) contain lacustrine varves. After a study of these varves, the hydrographic basin of the lake, and

[15]Bradley, W. H., The Varves and Climate of the Green River Epoch. U. S. Geol. Survey Prof. Pap. 158, pp. 87-110, 1929.

the relation of the flora of the lake to that of the basin, Bradley has estimated the temperature, mean annual rainfall, and duration of this stage of the Eocene. According to these estimates, the temperature of the Green River epoch fluctuated rather widely from an annual mean of 65° F., and the rainfall, which also varied with the seasons, had a mean average of 30 to 43 inches. The duration of the Green River epoch is estimated at six and one-half million years, with an uncertainty factor of 25 per cent. The climate was probably characterized by short, cool, moist winters and relatively long, warm summers. The total time indicated for the whole of the Eocene is roughly twenty-three million years, which agrees rather well with Barrell's figure of twenty to twenty-six million years, based on analyses of radioactive minerals.

In the fauna of the middle Eocene, the lemuroid monkeys were more abundant than in the lower Eocene and many mammals were adapted to low, marshy country. The teeth of Eocene horses were not adapted to eating grass. Apparently the fauna, flora, and sediments all indicate a moist, sub-tropical climate.

The sediments of the upper Eocene are in general fluviatile in character. Scott[16] states that "Among all the many hoofed mammals of the Uinta and Bridger, there was not a single one that had the high-crowned, persistently growing teeth of the grazers; all of them must have fed upon soft vegetable tissue which did not rapidly abrade the teeth." However, only one species of lemuroid monkey is known in the upper Eocene and this marked contrast with the middle Eocene may well be due to a chilling of the climate. Notable development of cursorial or running types of mammals appears here, indicating a higher and drier region than they had previously been adapted to. Oreodonts, tapirs and large lizards suggestive of a warm temperate climate are abundant at the close of the Eocene. The assemblage suggests the continuation of a mild climate, slightly

[16]Scott, W. B., A History of the Land Mammals of the Western Hemisphere, Macmillan Co., N. Y., p. 273, 1913.

less moist and slightly cooler than in the preceding epoch, but nevertheless decidedly genial and temperate.

At the time when the Laramie formation and the lower part of the Denver formation were being deposited, the pre-Cambrian rocks of the range, as already stated, were exposed to erosion. Comparatively little of these ancient rocks was removed before they were flooded with lava which effectually prevented their further erosion for a long time. In other words, the base-leveled surface over which the Cretaceous sea advanced was not appreciably dissected before it was protected by extrusive rock. At the beginning of the Eocene the Front Range was a lofty mountain range along which many active volcanoes were still pouring out lava. Precipitation in the mountains must have been quite heavy. However, they were probably covered by a dense growth of vegetation which tended to prevent erosion. There is no indication of continued uplift during the Eocene and it is probable that the streams were not rejuvenated after the initial uplift. In the Pikes Peak quadrangle and in the region north of Estes Park there is abundant evidence that the ancient granite floor on which the pre-Tertiary sediments were deposited is still preserved. Remnants of Dakota and Morrison rocks are common on the nearly level upland south and west of Cripple Creek. This region has been greatly disturbed by faulting, but it is still possible to recognize the ancient uplifted land surface. Similarly one can trace the Pennsylvanian sediments south from Wyoming onto the old floor of Sherman granite and note the gradual rise of this ancient surface, persisting far south of the apron of Pennsylvanian rocks, until it is preserved only in the flat summits of the higher peaks in Estes Park. The fact that so much of this surface lasted through the Tertiary and Quaternary suggests that a much larger area of it was still in evidence at the close of the Eocene. The greatest uplift, judging from the sharpness of the folding and the intensity of the faulting, occurred in the region limited on the northeast by a line extending from Golden to Boulder and on the

southwest by a line reaching from Como to a point about 10 miles north of Dillon. In the area between these portions of the mountain flanks, erosion was probably much more active than in the regions to the north and south. It is probable that erosion carved this elevated tract into a mountainous upland by the end of the Eocene, and reduced the region to the north and south to a smooth plain which in great part represented a re-exposure of approximately the old floor over which the Cretaceous sea had advanced. Remnants of andesitic flows in Estes Park indicate that some of the lava cover has not yet been removed from the pre-Cambrian rock floor and thus it is easily understood that at the close of the Eocene, erosion had not deeply trenched the pre-Cambrian rocks. In the region from Breckenridge northeastward to Boulder, however, all of the lavas had been stripped off and the underlying crystalline rocks were undergoing erosion. A definite peneplain was established during the Eocene, the Flattop peneplain, but it was in large part the re-exposure of a much more ancient land surface. At the borders of the mountains the upturned strata were beveled and reduced to nearly the same level as the surrounding plains before the Oligocene. Before the lower Oligocene sediments were deposited, however, there was a gentle arching of the Front Range and decided erosion along the mountain front.

Oligocene.—The Oligocene beds near the Front Range consist chiefly of clays interstratified with thin gravels and sands, although the base is frequently a very coarse gravel or conglomerate. After the late Eocene or early Oligocene uplift, the borders of the Front Range were dissected much more rapidly than the middle. Only as the rapids or falls, forming at the edge of the uplift, worked their way upstream could the change in elevation affect the erosive powers of the streams. Thus we find that the lower Oligocene (Chadron) sandstone is deposited on the very uneven surface of the upturned sediments bordering the mountains, at an altitude well below that of the Flattop peneplain, but

that it also extended over a relatively smooth, sloping, granite surface which soon merged with the late Oligocene peneplain. These relations are not all shown in figure 6, which is a cross-section several miles south of the nearest place where Chadron sandstone overlaps the pre-Cambrian rocks.

Near mountains the sediments derived from them are spread out as fans. During an arid cycle the fans accumulate to a great thickness lapping far up the mountain slopes, the common condition of the Basin Ranges today. During the humid cycles these fans are rapidly eroded and carried away, and the sediments washed out of the mountains during a moist period may be transported long distances, leaving no record near their sources. The Oligocene gravels overlapping the granite on the east slope of the Front Range indicate a period of comparative aridity following one of humidity. Another humid cycle is indicated by the erosional unconformity between the Chadron and the overlying Brule clay, which in turn suggests the return of a drier climate.

The fauna of the Chadron includes an early form of the opossum which probably required a mild climate. Upland running forms of the rhinoceros were abundant and had teeth better adapted to woody, herbaceous food than had the earlier forms which evidently fed on lush vegetation. Some aquatic forms of the rhinoceros were present, and their teeth were changing rapidly to accommodate them better to a browsing habit. The horses were rapidly changing toward upland forms. Peccaries, indicative of a mild climate, were also common. Several varieties of small deer with dainty feet, indicative of hard ground, were abundant, as were small camels of a comparatively dry climate type. This assemblage suggests a mild but drier and slightly cooler climate than that of the Eocene.

The fauna of the Brule clay (middle Oligocene) does not suggest a climate differing in any way from that of the lower Oligocene. Adaptations for running and browsing continued to develop. Hackberry seeds occur in millions in