the Oreodont beds, and, according to R. W. Chaney[17], "have an important bearing on the physical conditions under which the sediments were laid down. A living member of the genus *celtis reticulata,* which grows in the southwest, is common along dry or intermittent water courses in the Colorado desert. . . . There seems to be little doubt as to the significance of certain members of this genus." Either an alternation of mild semi-arid and semi-humid climates characterized these stages of the Oligocene, or there were moist zones and semi-arid zones existing side by side. It seems probable that the moist river lowlands were bordered by drier uplands which, in places, had a semi-arid aspect. The sedimentary record also suggests recurrent periods of aridity.

In the upper Oligocene there is nothing definitely determinative of the climate. The entire fauna was richer and more diversified, indicating abundant food for both the herbivores and the carnivores. This stage is represented by an erosion interval near the mountains and was probably characterized by a moister climate than the lower and middle Oligocene. Apparently the Front Range was again rejuvenated during this epoch and the streams began cutting into the pre-Cambrian rocks with greater force.

Miocene.—The Miocene beds consist of coarse gravel and sand, largely made of pre-Cambrian rock fragments, interstratified with beds of clay and volcanic ash. Near the mountains where I have studied them they suggest alluvial fans bordering the Front Range and indicate semi-arid conditions of deposition. According to R. W. Chaney[18], the presence of Hackberry fruits and the absence of fossil leaves of Hackberry or other plants suggests an arid climate. With the exception of those forms which would find specialized local habitats along streams, the remaining mammalian fauna indicates a drier, more upland specialization than in the Oligocene, and horses and camels, especially, had grown

[17]Chaney, R. W., Notes on Two Fossil Hackberries from the Tertiary of the Western United States. Carnegie Inst. Wash.. Pub. 349, p. 54.

[18]Quoted by Wanless, H. R., The Stratigraphy of the White River Beds of South Dakota. Proc. Amer. Phil. Soc. Vol. 62, p. 236, 1923.

greatly in size, with marked elongation of the feet and legs, and had developed their nipping teeth and grinders to a degree far more suited to a grassy upland habitat.

The lithology of the Miocene indicates the alternation of semi-arid and humid conditions; the numerous intraformational unconformities and the flood plain deposits both testify to this fact. Apparently the lower Miocene inaugurated a series of climatic cycles which were comparatively short, geologically speaking. These cycles of moderately dry and wet periods increased in number and frequency through the Miocene and reached their climax in the middle Pliocene. They then apparently ceased and were followed by a period of aridity which lasted through the upper Pliocene.

The fauna of the middle Miocene indicates a climate similar to that of the lower Miocene. In Middle Park, Mr. L. B. Graff found the bones of a lower Miocene horse, a camel, a deer, and a Chalcothere. These bones were in a conglomerate consisting largely of basalt and granite pebbles, apparently interstratified with basalt flows. This indicates that in the Middle Park region, volcanic activity was again present early in the Miocene and continued for some time. The Florissant lake beds of the Pikes Peak quadrangle, with their abundant plant and insect remains, show that the climate in this locality was mild and moist in the early Miocene. The age of the Cripple Creek volcano is later than the Florissant lake beds and has been tentatively assigned by Cross to the Miocene. If this age is correct, the volcanic activity of Middle Park would correspond in general with that of the Pikes Peak region. The rich gold telluride ores of the Cripple Creek district are directly related to the formation of the volcano and are therefore probably of Miocene age. The Miocene volcanic activity corresponds to the beginning of an uplift which caused the rejuvenation of the streams and the start of the erosion cycle which developed the Rocky Mountain peneplain. According to Dr. H. J. Cook, there is evidence of marked erosion in the late Miocene near the eastern border of the state, where he has found deposits of coarse granitic sand belonging to this stage on extensive flood plains, two hundred miles from the mountains.

Pliocene.—It is difficult to separate the upper Miocene and lower Pliocene faunas. Evidence of world-wide movements at the close of the Miocene is expressed in the appearance of numerous Asiatic forms of mammals at this time. Sub-tropical plants, trees, birds, alligators, and crocodiles, and an extremely rich and varied mammalian fauna indicate a very mild climate. These conditions persisted through the close of the Miocene and the first half of the Pliocene.

There are no beds certainly ascribable to the upper Pliocene, but a few beds of sand thought to be later than middle Pliocene may represent arid deposits of this stage. There is no doubt that a profound change took place in the latter part of the Pliocene epoch, and that the change was in the direction of severe aridity. The rich and varied fauna of the early and middle Pliocene was greatly restricted by early Pleistocene time. The camels were rapidly becoming adapted to desert conditions in early Pleistocene and it is unlikely that this marked specialization would have taken place without great stress of climatic conditions. Intense aridity favors the deep oxidation of ore deposits and it is probable that much of the secondary enrichment present in the Leadville, Breckenridge and Central City mining districts occurred in upper Pliocene time.

The rejuvenation of the Front Range at the close of the Miocene and the subsequent humid climate caused active erosion. By the end of the humid cycle in middle Pliocene a broad belt on the eastern side of the range had been reduced to a gently rolling upland plain, and the higher parts of the mountains near the divide were carved into broad deep valleys. This period of degradation is not well developed on the western side of the range and probably reflects a difference in the amount of precipitation, suggesting that the prevailing moisture-laden winds were from the east and were robbed of their burden before crossing the divide.

QUATERNARY

Pleistecene.—At the close of the Pliocene or early in the Pleistocene, there was a marked uplift in the Front Range, and soon afterward the climate became cold and humid. Glaciers formed in the high mountains, and in places came down to altitudes of about 8,000 feet. This glaciation was followed by an interglacial stage of long duration during which the high terrace gravels of the Front Range were formed. The close of the Pleistocene was marked by wide-spread glaciation, though it was probably less severe than the earlier one, as the glaciers in general did not descend below an altitude of 8,500 feet. There is indirect evidence of more than these two glacial stages in the Front Range, although only the two glacial tills have been recognized. Three well developed terraces occur near Idaho Springs, and the highest one, 160 feet above Clear Creek, can be definitely correlated with the interglacial stage which followed the formation of the early glacial till. The lowest terrace is 5 feet thick, and its bed-rock floor is 20 feet above Clear Creek. It is contemporaneous with the early outwash gravels of the last glacial stage. The intermediate terrace is 20 feet thick, and its floor is 35 feet above Clear Creek. Evidently the first interglacial stage was followed by a more humid period in which Clear Creek deepened its valley 125 feet before the return of a drier climate arrested erosion and caused the formation of the intermediate terrace gravels. These gravels suggest an interglacial stage following a glaciation not recorded by tills. Twenty feet of gravel and 15 feet of bed-rock were excavated by the stream in the early part of the last glacial stage before the lowest terrace was formed. It is thin and probably does not record a distinct interglacial stage but only a brief interval when the climate was much less humid. The bed-rock floor of the valley is about 35 feet below the lowest terrace, but has been partly filled with gravels deposited during the close of the last glacial stage.

It is generally agreed that there were probably five distinct advances of the continental ice sheets in the Central States east of Colorado, but few of the interglacial stages are known to have been long. The Yarmouth interglacial stage, which followed the earliest or Kansas glaciation, is estimated to have lasted about 200,000 years[19], and is probably the most important. The Peorian deglaciation preceded the last (Wisconsin) glaciation, and was correlated by Wright[20] with the Toronto deglaciation which has been estimated by Coleman[21] as lasting more than 62,000 years. Coleman[22] has recently suggested, however, that the Toronto interglacial beds belong far back in the Pleistocene, as they are overlain by four different sheets of till, and he correlates the Toronto with the Yarmouth interglacial stage. The Yarmouth interglacial stage probably corresponds to the interglacial stage represented by the high terrace gravels of the Breckenridge district and the 160 foot terrace gravels of Clear Creek at Idaho Springs; the intermediate terrace on Clear Creek probably corresponds to the Peorian interglacial stage of the plains. The early till found at many places in the Front Range can thus be correlated with Kansan glaciation, and the late till with Wisconsin glaciation. No tills corresponding to the Illinoian or Iowan glacial stages are known. Wisconsin glaciation was probably more extensive in the mountains than Illinoian glaciation and probably has obliterated all traces of this intermediate till, just as it has destroyed the evidence of Kansas till in all except the few places where Kansan glaciers pushed well beyond the limits of the last glaciation.

The stages of glaciation were marked by a cool, moist climate, and the interglacial stages, by mild and less humid intervals. In the high mountains of the Front Range, where a few glaciers still exist, it is not likely that records of all the advances and retreats equivalent to those of the con-

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[19]Brooks, C. E. P., The Evolution of Climate; Ernest Benn, Ltd., London, p. 90, 1925.
[20]Wright, W. B., The Quaternary Ice Age. London, 1914.
[21]Coleman, A. P., An Estimate of Post-Glacial and Interglacial Time in North America. Internat. Cong. Geol., Report 12, p. 435, 1913.
[22]Coleman, A. P., Ice Ages, Recent and Ancient, The Macmillan Co., New York, p. 26, 1926.

tinental ice sheets at much lower altitudes would be preserved, and it is possible that only the Yarmouth interglacial stage was long enough and mild enough to cause the complete disappearance of glaciers from the Front Range..

Recent.—Ever since the uplift of the range in the early Pleistocene, the rejuvenated streams have been cutting down the mountains and destroying the older erosion surfaces. Since the pre-Yarmouth glacial stage the valleys have been deepened by streams as much as 175 feet in some places, and presumably most of this cutting was caused by the increased precipitation attending the return of glaciation. Only minor changes in stream adjustment have occurred since the Wisconsin glaciation, but there is evidence of recent uplift in the present canyon cutting of some of the streams.

Summary of Paleozoic to Recent History of the Front Range

Since pre-Cambrian time the Front Range region has been a positive topographic area, supplying sediments to the surrounding region throughout much of the Paleozoic, Mesozoic, and Cenozoic eras.

Cambrian, Ordovician, Devonian, and Mississippian marine sediments were deposited on the western side of the range and, with the exception of Devonian, on the eastern side near its southern end.

It is improbable that any of the Paleozoic seas covered the Front Range highland, but if they did the erosion interval between succeeding periods was marked by the uplift of the same region, and in each of these intervals erosion uniformly removed the formation just deposited to a line within a short distance of the edge of the underlying formation.

Minor warping of the Front Range highland occurred between successive periods, but apparently none of magnitude took place until the late Mississippian or early Pennsylvanian. At this time the Front Range highland was elevated while the adjoining areas were depressed and thick continental and interstratified marine delta deposits were formed during Pennsylvanian and Permian time.

Little erosion or diastrophism is recorded for the Triassic period. In the Jurassic period thin marine beds were laid down, and then largely removed by erosion before Lower Cretaceous (?) continental sediments were spread over wide, featureless piedmont plains on both sides of the series of low hills that then constituted the only exposed parts of the Front Range highland. Late in Lower Cretaceous time the sea advanced from Texas across Oklahoma, eastern New Mexico, and southeastern Colorado to the southeastern border of the Front Range upland, but its marginal deposits are not easily separable from the overlying Upper Cretaceous.

The Upper Cretaceous sea advanced over a slowly sinking region, but the central part of the highland did not subside as rapidly as the margins and, as in Pennsylvanian time, a much thicker series of sediments formed along the edge of the ancient land mass than over its center. The middle of Pierre time saw the end of subsidence and the initiation of uplift which soon pushed the central part of the Front Range highland above the sea and exposed the recently deposited shales to erosion. These were reworked into the upper part of the marine Cretaceous, and the pre-Cambrian core of the highland was re-exposed as a source of sediments when the Laramie sands were forming. More rapid uplift, accompanied by marked volcanic activity, ushered in Denver time. Thick flows of andesitic lava accumulated on the highland and effectually covered the older rocks. Thrust faulting and strong monoclinal folding marked the end of Denver time and the close of the Cretaceous period. Intrusive and extrusive activity continued into the Eocene and it was at this time that the ore deposits of the Front Range were largely formed.

The mild, humid climate which the Cretaceous period enjoyed continued through the Eocene and the newly formed mountains were covered by a dense growth of vegetation. Late in the Eocene, after most of the ores of the mineral belt had been deposited, the Flattop peneplain was formed

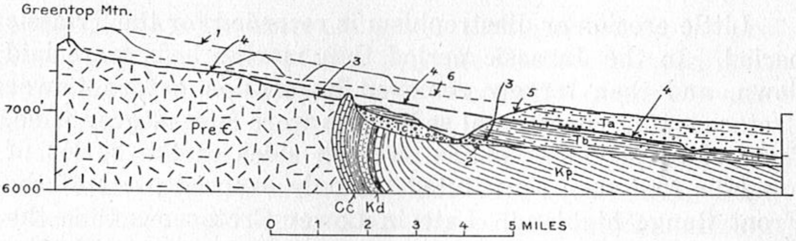

Figure 7—Section at Horse Creek, Wyo., showing present and restored ancient surfaces of Tertiary beds, from Greentop Mountain at the left to northeast corner Sec. 1, T. 16 N., R. 69 W. Monadnocks near line of section are projected on section.

1. Eocene (Flattop) peneplain.
2. Early Oligocene erosion surface.
3. Oligocene (Brule) partial peneplain.
4. Miocene (Rocky Mountain) peneplain.
5. Present surface, largely developed in Pleistocene time.
6. Former extent of Arikaree formation.

Ta, Miocene Arikaree fm.
Tb, Oligocene Brule clay.
Tc, Oligocene Chadron ss.
Kp, Cretaceous Pierre sh.
Kd, Cretaceous Dakota ss.
Cc, Pennsylvanian Casper fm.
Pre-Є, pre-Cambrian rocks.

in the northern and southern parts of the range, largely by re-exposure of the old land surface on which the Cretaceous sediments were deposited. In the region west of the mountain front between Golden and Boulder, however, where the maximum uplift had taken place, the topography was probably that of a mountainous upland rather than a nearly level plain.

Uplift and renewed erosion occurred at the end of the Eocene, but the period of erosion was too brief to impose a new peneplain far back from the mountain front. A mild but less humid climate characterized the Oligocene. Volcanic activity and renewed uplift marked the Miocene epoch and continued ore deposition, as at Cripple Creek. The rejuvenated streams slowly carved a new erosion surface, known as the Rocky Mountain peneplain, on the flanks of the mountains. During lower and middle Pliocene the mild, humid climate facilitated the formation of a wide piedmont plain well below the level of the Flattop peneplain and assisted in the dissection of the higher parts of the range (see figure 7). The marked aridity of late Pliocene and early Pleistocene probably had little effect on the sculpturing of the mountains, but was economically important in the enrichment of ores.

Marked uplift occurred early in Pleistocene, and was accompanied by severe glaciation. A period of deglaciation followed, probably corresponding to the Yarmouth interglacial stage of the plains. No tills are known in the Front Range which can be correlated with the Illinoian tills of the plains, but well developed terraces older than Wisconsin time and younger than Yarmouth suggest a less humid interval corresponding to the Peorian deglaciation of the plains. It was followed by a stage of severe glaciation, of Wisconsin age, which has only recently closed.

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