THE GEOLOGY OF
ROCKY MOUNTAIN NATIONAL PARK

By William L. Effinger

U. S. Department of the Interior
NATIONAL PARK SERVICE
FIELD DIVISION OF EDUCATION
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A REPORT ON

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FOREWORD

This paper, the Geology of Rocky Mountain National Park is one of several prepared by a special research group employed under the Civil Works Program of 1933-34, by the Field Division of Education, National Park Service, Berkeley, California. Its purpose is to satisfy specialized needs existing in the National Park Service and it must not, therefore, be judged or regarded as a complete statement of the subject with which it deals.

The objective of this paper is the compilation of much pertinent information as will be helpful in the preparation of geological museum exhibits at Rocky Mountain National Park, and more specifically to outline the story to be interpreted by such exhibits. It is thus designed to aid museum preparators and Park Naturalists. For this reason the author has stressed what he considers the major geological features connected with the park and the generalized geology of the area surrounding it. Consequently, some readers may be disappointed in the paper, because of the limited scope; or may discover the omission of certain features which were not considered significant in the interpretation of the landscape. Nevertheless, such interest has been manifested in the group of research papers, of which this is a part, that it seems worth while to make some of them available in mimeographed form. Not the least valuable feature of the paper should be its bibliography.

The format of the paper has been slightly modified from customary scholarly standards in order to save time and expense in mimeographing. Footnotes have been virtually eliminated and citations and comments are included in parentheses in the body of the text.

A REPORT ON

THE GEOLOGY OF ROCKY MOUNTAIN NATIONAL PARK

(By William L. Effinger)

INTRODUCTION

Purpose and Scope:

The purpose of this report is to present a statement of the salient facts of the geology of Rocky Mountain National Park. Emphasis has been placed upon certain phases of the subject which might serve as a basis for museum exhibits and exposition purposes. The material contained in this report has been derived from a critical review of the more important literature dealing with the Rocky Mountains of Northern Colorado. A bibliography of these papers accompanies the report and original sources are often quoted in the text.

The work has been carried on under the direction of the National Park Service, Field Division of Education as part of CWA project SLF-4.

Location and General Character:

Rocky Mountain National Park includes an area of approximately 398 square miles situated in the high mountains of the Front Range in north-central Colorado. The region extends on either side of the continental divide, lying between Larimar, Grand, and Boulder Counties. Estes Park, the eastern gateway, lies approximately 50 miles north-west of Denver by direct line, and is easily accessable by modern means of transportation. Grand Lake is the western entrance. Several roads and many fine trails run through the park, opening up a vast scenic wonderland of giant peaks, rugged ridges, and sparkling mountain lakes. These lakes are fed by living glaciers and snow fields in sheltered, steep walled gorges and cirques. Animal life is varied and abundant and the vegetation ranges in character from that of the middle altitudes to the extreme alpine. The lower valleys are often carpeted with meadows surrounded by great forests, in marked contrast to the barren and rugged peaks and rock strewn ridges of the higher elevations above timber line.

The great snow-capped range extending through the center of the park has a north-south trend, its southern portion forming a

part of the continental divide. This ridge with its peaks, many of which are over 13,000 feet elevation, forms the most prominent topographic feature of the park. The culminating point of the higher elevations is Longs Peak, named in honor of Col. S. H. Long who conducted one of the earliest explorations in this region. It rises 14,255 feet above sea level. This peak is situated on an eastern spur extending a few miles east from the main ridge. The eastern descent from the snow capped range is precipitous, while the western descent is more gradual. The main range is flanked by less commanding summits, arranged in order of prominence, down to the rank of foothills. Although somewhat dwarfed by the more majestic monarchs, the flanking ranges are exceedingly rugged, the massive ridges often being separated by gorges whose walls rise almost vertically, hundreds, and in some cases, thousands of feet. At the higher altitudes are many rock-bound lakes, some occupying basins at the bottom of the gorges, others perched high in the craggy sides of precipices in the most unexpected places. The changing color in these high altitude lakes has well led to their being called "gems of the mountains."

In the gorges and in many of the broader valleys are found conspicuous evidences of ancient glaciation. Great moraines have been formed by glaciers carrying boulders and smaller fragments of rock down the valleys and heaping them in great ridges at the sides and end of the ice. In many places the rocks are polished by the ice passing over them. For easily read records left by ancient glaciers, the Rocky Mountain National Park is almost unique.

The lower slopes of the mountains are wooded wherever they are not too precipitous for trees to take root. At an altitude of about 11,500 feet, known as timberline, the struggle between trees and elements is severe. Here may be found many interesting and curiously formed shrubs with gnarled and twisted trunks and branches, either growing close to the ground, or taking refuge behind protecting boulders and ridges. These are commonly known as timberline trees. On the slopes above timberline may be found a flora consisting mainly of descendants of arctic plants driven southward during the Great Ice Age.

It was because this region displayed so many of the grander features representative of the Rocky Mountains that it was set aside as a national park on January 26, 1915.

STRATIGRAPHY AND HISTORICAL GEOLOGY.

Some may revel alone in the wonders of the present scenery of the park; for others, however, this pleasure and inspiration may be greatly increased by the ability to perceive in each rocky ridge and profile, records of events which took place here millions of years ago when these rocks and profiles were in their formative stages. To repicture this story of the past and the agents which have operated to bring about the present state of things is to really understand and appreciate the meaning of scenery. The geological features of this region have long been under the careful scrutiny of many geologists and from their studies a great deal is known of its history, a history full of interesting events and shifting scenes. The characters of the present landscape are foreign to this drama of the past; they represent only a very recent shifting of the scenery. Recent in the geologist's language, for, although these features have been in existence for many hundreds of thousands of years, it is but a very brief interval as recorded by the geologist's clock. His only means of measuring time is by the rate of deposition of sediments, by the evolution of organisms or, more recently, by the use of the disintegration of radioactive minerals. The time concerned is of such length, and the yardstick always subject to so much correction, that time cannot be indicated in intervals less than millions of years. It is only in the latest of the geological epochs that events can be more accurately dated, using here as a yardstick, thousands of years. It is believed that the age of the earth is somewhere in the neighborhood of two billions of years old. The immensity of geologic time may be better grasped in the simile used by Jeans- "Let the height of the Woolworth building represent geologic time. We may then lay a nickel on its tower to represent the time of human existence. A thin sheet of paper on this will represent all historic time."

Just as human history is divided into various subdivisions on the basis of important events, so geological history has been subdivided into eras, periods, and epochs in accordance with the important events in the history of the earth. A chart showing the various divisions of geologic time and the names applied to them is presented.

GEOLOGICAL TIME SCALE

PSYCHOZOIC or RECENT ERA		Mental Dominance
	Pleistocene or Glacial Epoch-	Periodic glaciation and appearance of man.
	Pliocene-	Cooling of climates.
CENOZOIC ERA	Miocene-	Culmination of mammals and land floras.
3% of Geol. Time.	Oligocene-	Rise of anthropoids.
60,000,000 years.	Eocene-	Spread of modernized mammals.
	Paleocene-	Expansion of archaic mammals.
	Cretaceous-	Last of ammonites and dinosaurs.
MESOZOIC ERA 7% 140,000,000 years.	Jurassic-	Rise of toothed birds, great expansion of reptiles.
	Triassic-	Rise of dinosaurs, pterodactyls etc.
PALEOZOIC ERA 17% 340,000,000 years.	Permian-Periodic glaciation in s. hemisphere, extinction of trilobites, spread of primitive insects.	
	Pennsylvanian-Warm, humid, climate with extensive coal making. Dominance of spore floras. Spread of reptiles.	
	Mississippian-Spread of ancient sharks and culmination of crinoids.	
	Devonian-Rise of amphibians, marine fishes, and primitive ammonites. First spread of forests.	
	Silurian-Rise of air-breathing invertebrates. Spread of Paleozoic reef-corals. First known occurrence of land plants.	
	Ordovician-Rise of fresh-water fishes and corals. Spread of molluscs. Culmination of trilobites.	
	Cambrian-Rise of shell-bearing molluscs. Dominance of trilobites. First appearance of well-known marine faunas.	
PROTEROZOIC ERA-Primitive Marine Life. An early and late glacial period.		

ARCHEOZOIC ERA- The oldest known life. Geologic history very obscure. Archeozoic and Proterozoic include approximately 75% of geologic time, or have a duration of 1,500,000,000 years.

GEOLOGIC FORMATIONS OF NORTHEASTERN COLORADO

Recent-	Aluvium, river gravels, soils, etc.
Pleistocene-	Glacial deposits
	Nussbaum in part
	Nussbaum in part
Pliocene	Ogalalla
Miocene	Arikaree
Oligocene	White River
	Denver, Dawson
Eocene	Arapaho, Raton (?)
	Middle Park
	Laramie
	Fox Hills
Upper	Pierre
Cretaceous	Niobrara
	Benton
	Dakota
L. Cret.	Purgatoire
	Morrison
Jurassic	Sundance
Triassic	Lykins
Permian	Lyons
Pennsylv.	Fountain
Mississip.	not represented
Devonian	not represented
Silurian	not represented
Ordovician	Fremont, Harding, Manitou
Canbrian	Sawatch ss. and dolomite
Pre-Cambrian	Big Thompson schist and granites.

One region such as that within the borders of the Rocky Mountain National Park, contains a complete succession of the rocks formed during the entire geological time. Deposition during geological time seems to have predominated in certain areas of the earth at the expense of others. These areas of greater deposition seem to have been the lower portions of the continent, basin, or trough-like structures; and in them, sediments generally were accumulating. In order to accomodate the deposition of many thousands of feet of sediments which are known to have accumulated, the floor of the basin must have been sinking in relation to the surrounding areas which furnished the source of the detrital materials. These predominantly subsiding areas have been termed geosynclines. One of these, known as the Cordilleran geosyncline, is known to have occupied the site of the present Rocky Mountains extending from Mexico across parts of Arizona, New Mexico, Colorado, Utah, Wyoming, Idaho, Montana, Alberta and British Columbia, and northward across Eastern Alaska. When the continents were depressed in relation to sea level, the ocean waters entered these troughs, and if the continent was extensively depressed the waters spread beyond the margins of the geosynclines flooding the adjoining areas. At other times the continents were raised in relation to sea level and the ocean waters drained from them completely, usually lingering longest, however, in the geosynclines. During these times the surface of the newly formed deposits would be subject to erosion, and portions of the newly-formed sediments removed. Those sediments either were carried by the rivers beyond the margins of the continent, or some of the detrital material might be caught in the lower basins and valleys as aluvium, and stream and lake deposits. These subareal deposits, forming as they do above sea level, are known as continental deposits, in contrast to marine deposits, those formed in sea water.

Rocky Mountain National Park is located almost on the eastern border of the Cordilleran geosyncline; consequently marine waters spread over it repeatedly and thick sedmimentary beds were deposited. Within the boundaries of the park almost nothing remains of the greater part of these formations with the exception of the very oldest. This region has been subject to great denudation during the later part of its history and the record has been largely destroyed. However, in the surrounding region, especially the foothill region immediately east of the park, most of the formations which formerly covered the rocks now seen in the park, are excellently represented. We may now take up briefly the more important events taking place in this region in past

geologic time.

Pre-Cambrian Time.

The formation of the earth was followed by long eras, the history of which is veiled in the darkness of antiquity. Enormous groups of ancient rocks, lying in tangled confusion below the Paleozoic, form an impressive record of these early times. When these rocks lie in their normal order of superposition, the local history is not difficult to interpret. However, as is very often the case, these rocks have suffered intense deformation during the great length of time since their formation, and have been intruded by igneous masses. They are like a manuscript that has been scattered and torn, leaving us only "internal evidence" as a clue to the order in which the recovered portions should be fitted together. Moreover, the almost general absence of fossils leaves us with no secure means of correlating portions of the record now widely separated by erosion or by intervening areas of younger rocks. We might easily compare the early records of geologic history, so beset with difficulties, to the bare inklings of early human history. Written documents tell clearly the story of the last two thousand years of man's development, but back but back of the last five thousand years stretch the millennia of forgotten civilizations known to us only through the ruins they have left. The scattered implements of Paleolithic man record chapters in the history of civilization no less real because they are not yet fully understood. They are too disconnected to permit a full synthesis of pre-history; however, by means of constant research in every part of the world, the veil of time is being pushed back more and more into antiquity.

Pre-Cambrian time was very long, being estimated at 1500 million years, or three quarters of all known geologic time. It is not certain how many eras of time are represented; however, two have been generally recognized: the Archeozoic and the Proterozoic.

The entire region of Rocky Mountain National Park is underlain by Pre-Cambrian rocks; and all the main peaks, with the exception of Specimen Mountain, consist of various phases of this complex. These rocks are covered over in many of the valleys and lower basins by glacial debris, recent stream deposits, and soil; however, numerous outcrops exist in the bare rocks of the steep walled valleys and gorges. Three important phases have

been recognized, the oldest being a schistose complex known as the Big Thompson Schist. This has been intruded by at least two granitic intrusions, an older Longs Peak Granite, and a younger Mt. Olympus Granite. The Big Thompson Schist has been described by Fuller (Fuller, M. B., 1926) as a remnant of a former extensive blanket of highly metamorphosed sedimentary rocks that stretched from an unknown shoreline at the east of the present foothills, westward across the site of the front range to beyond Middle Park. This formation is believed to have been originally a fine grained, highly silicious sandstone with little conglomerate and limestone at the east. These graded westward into fine grained shale.

The second important phase of the Pre-Cambrian rocks of Northern Colorado, the Longs Peak Granite, was pushed up as extensive, intrusive masses into the sedimentary beds. It formed huge stocks and batholiths which fingered into the strata as dikes and sills. The third phase, the Mt. Olympus Granite, was intruded before the Longs Peak Granite was entirely crystalized at all points, and some time before the metamorphic processes induced by the Longs Peak Granite were complete. The Mt. Olympus granite intruded mostly into the region immediately to the east of the Longs Peak Granite.

From this fragmentary and greatly distorted record of Pre-Cambrian time it is difficult to interpret much of the oldest history. We would perhaps be safe in assuming that in this very long time the seas spread over this region many times depositing muds, sands and limestones to extensive thicknesses. These were subsequently folded and distorted by mountain-making movements and intruded by masses of molten magma which solidified into granite. Toward the close of the Pre-Cambrian and during the early and middle part of the following Cambrian, the granites and metamorphosed sediments deeply eroded.

Practically nothing has been found in the way of fossils from the metamorphosed sediments of this region. Luckily, however, not all Pre-Cambrian rocks are as barren of fossils, and although life was probably not as abundant at this time as during later times, numerous indications of it have been found. These consist of simple forms of plant life such as algae and the lower groups of animals such as the protozoans, sponges, perhaps some of the limey corals, and the worm-like creatures which represent the highest type of life represented at this time. This

is not a very impressive array of creatures but it is significant in indicating that organic life had not evolved very far in these early times. The ancestors of numerous other groups of animals must have been in existence at this time; however, it is believed that they may have been lacking sufficient hard parts to become preserved in the rocks, the soft tissues being easily destroyed.

Paleozoic Era.

Cambrian Period:

Early in Cambrian time the seas invaded the continental borders and advanced slowly toward the interior. They did not reach Colorado until nearly the close of the period, and as a consequence, no lower, middle, or early upper Cambrian rocks are found in the state. In later Cambrian time the seas invaded northern and central Colorado, the waters coming in from the northwest. The waters of the sea found the surface of decayed rock much as one finds the surface of the lower granitic areas of today, strewn with broken rock, sand, and clay, grading downward into the unweathered bedrock. The rivers which formerly carried the sediments beyond the region into the oceans bordering the continent, now dropped them in the shore waters of the invading sea. The waves worked over the residual surface material, and the sediments brought in by the streams, sorting them and spreading them over the sea floor in layers or strata of conglomerate, sandstone and shale. In some parts of the sea the shore waters were clear and made a favorable habitat for animals and plants. The animals took lime from the waters, made it into their shells and other parts, and as the animals died, these limy parts accumulated on the bottom. Century after century these accumulations grew, and the waves broke and ground many of them into a mud-like mass and spread a mixture of limestone mud, shells, and shell fragments over the sea floor in layers which afterward consolidated into limestone strata of the upper part of the Cambrian formation.

Cambrian rocks have not been recognized in the boundaries of the park, but they are known to occur at numerous points along the eastern slope of the Front Range in southern Colorado. There they consist principally of sandstone with some shale and a little limestone. They also occur bordering the Pre-Cambrian masses in the San Juan Mountains, along the White River Plateau,

and in the Uinta Mountains. The formation is generally thin, but in the Uinta region it reaches a thickness of 1,200 feet.

Lands during Cambrian time must have been scenes of barren desolation, for rocks of this age bear no direct evidence of terrestrial life of any sort. Moist lowlands may have been clothed in feeble vegetation more like sea weeds than any of the plants which we know growing on the land today. Animals had not yet learned to breathe air, and there is not a trace of land animals or of inhabitants of rivers and lakes. The seas, however, swarmed with a great variety of invertebrate animals; the dominant types were trilobites, animals somewhat resembling the modern horse-shoe crab.

Ordovician Period:

For some time after the opening of the Ordovician period the land areas continued to decrease and the seas to advance. Much of the land surface had evidently been worn down to such an extent that the slope to the sea was gentle and the rivers were able to carry but little coarse material. Some sand and clay was deposited but limestone seems to be the predominant type of deposit. Early in Ordovician time the seas occupied the Cordilleran trough and extended into Colorado from the northwest, much as in the Cambrian. Consequently the Ordovician sediments are represented in some places along the Front Range of Colorado and have been divided into several distinct formations, the oldest being the Manitou limestone, followed by the Harding sandstone and the Fremont limestone. The Harding sandstone is a very important formation, since in it have been found the remains of very primitive fish. For a long time these were the oldest known evidence of this group, but recently somewhat similar forms have been reported from the Cambrian.

The shallow seas still remained the principal arena of life during this period. The Ordovician deposits of this region or any other, have yielded no proven record of either land animals or plants. The invertebrates continued to dominate the marine waters, the most common groups being the brachiopods, the now extinct graptolites, bryozoa, true corals, crinoids and the cephalopod, Endoceras. The most notable advance in the life of this period is seen in the occurrence of very primitive fishes. These remains were first discovered in the Harding Sandstone near Canyon City, Colorado and were announced by Charles D. Walcott in 1891. The remains consist of bony plates which show

close affinities to well known forms occuring in Silurian and Devonian rocks, and clearly belong to the order of fishes known as the Ostracodermi. Strange as these fish look, they are yet related to the living hagfishes (Cyclostomes).

Silurian Period:

It is believed that the seas retreated from what is now the mountain region of Colorado in late Ordovician time, and there is no evidence of a return to this area until late in the Devonian. Colorado and much of the surrounding territory was land area during late Ordovician, all of Silurian and the greater part of Devonian times. It is known from a study of Silurian rocks elsewhere that the climate was mild and equable over North America even far north in the Arctic circle, for coral reefs built up by organisms very sensitive to cold flourished there. Invertebrates continued to dominate the marine life. It is in Silurian rocks that the earliest remains of supposed land plants have been discovered. These consist of a few fragmentary stems, some of which bear small bract-like leaves. It is possible that the land surface existing in Colorado at this time was clothed by these primitive land plants occupying perhaps the lowlands along the rivers and shores but probably far from being profusely distributed. Fishes undoubtedly lived in the streams; and scorpions and thousand-legged worms (millipeds) are known from the upper Silurian rocks and may have been the first animals to inhabit the lands.

Devonian Period:

No early Devonian rocks have been found in Colorado, and therefore there is no direct evidence than any part of the state was covered by the sea during early Devonian time. In middle and late Devonian time the seas spread eastward from the deeper portion of the Cordilleran geosyncline, an embayment entering western Colorado. Formations which were deposited as sediments in this Colorado embayment are now known in the San Juan, at Salida, at Glenwood Springs, along the White River plateau, and elsewhere. Although the Devonian sea extended eastward at least to the Front Range in the southern part of the state, it is doubtful whether they ever extended over the region now occupied by Rocky Mountain National Park. Since deposits of this age are lacking in the foothill region east of the park it is very likely that this region remained a rather low land during all of Silurian and Devonian time.

The abundance, size and variety of fishes during this time has led to the Devonian being known as the "Age of Fishes." Over 100 species and more than 40 genera of fresh water fishes are known. It was from a slab of Uppermost Devonian strata from Warren, Penn., that Professor Beecher many years ago found what appears to be a crude footprint. If this be such, it heralds the most momentous step in the whole advance of organisms from the lowly amoeba to man, namely the emergence of our ancestors from the water to the land. This footprint is believed to have been made by an amphibian and is the first evidence of the existence of this group. The transitional stages between this form and the lower organism from which it was developed are not known but it has been suggested that the amphibians were developed from one of the groups of fishes (Crossopterygii) which are known to have had organs which might readily serve as a primitive lung, and fins containing skeletal elements quite readily homologized with those of the amphibian limb. Those "lungfishes" which were abundant throughout the Devonian period, lived in regions subject to seasonal rainfall alternating with periods of droughts. During the latter the shrinking water-holes brought death and destruction to great numbers but there were always some holes which did not go dry. Here the stagnation and crowding put a high premium on the ability to gulp air into the swim-bladder, where the supply of oxygen led to the spread of minute bloodvessels and the gradual perfection of lungs, through countless generations. The Crossopterygii with their stout fins could forsake their pools, perhaps in the cool of the night, and flounder about on the banks on short forays in search of food. Once the lungs had reached a certain stage of efficiency and the fins had been modified into stubby limbs, the metamorphosis was complete and air-breathing land vertebrates had arrived.

During the Devonian a varied, rich, and luxuriant vegetation existed, and fossils of all the higher cryptograms are found. Many of them were represented by large tree-like forms, and the first forests appear. Ferns, clubmosses and horsetails were represented by very large species which reached tree proportions. Fossil logs of primitive evergreens are also found in late Devonian strata, but these plants were more like seed-bearing ferns than like the conifers of today.

Mississippian Period:

It is believed that for a very short time at the close of

the Devonian the sea withdrew from the Colorado region only to be shortly followed by another invasion even more marked than the preceding. It is probable that most of the state of Colorado was covered by the early Mississippian sea, this being the most complete submergence of the Colorado region since Pre-Cambrian time. The Mississippian series is represented in the Castle Rock quadrangle by 85 feet of strata referred to as the Millsap limestone; however, no rocks of this age are known farther north in the foothills of Eastern Colorado so that it is difficult to say whether this sea spread over the region now occupied by the park. If it did, the material deposited was eroded away before the subsequent Pennsylvanian period. Mississippian deposits are found in many places in Wyoming and are known as the Madison limestone.

Although the life of the Mississippian was clearly evolved from that of the Devonian, the Mississippian faunas were given a distinctive character by the decline of such groups as the corals and trilobites and the great expansion of others like the echinoderms, the lacy bryozoa and spiny brachiopods. Fishes were locally abundant, though less varied than during the Devonian. Land animals left an indisputable record in the form of numerous footprints, though actual bones are still unknown in America. Doubtless many of these record the tragic search for water as the vanishing mudholes gave way to barren flats during the summer droughts.

Pennsylvanian Period:

Long before the end of Mississippian time a general rise of the Colorado area began resulting in a general withdrawal of the seas from the Colorado region. Disturbances of the earth's crust became active at the close of the Mississippian and during the Pennsylvanian causing large areas in Colorado, Wyoming, Utah, Arizona and New Mexico to be extensively uplifted to form low mountain ridges. These mountains have commonly been referred to in the past as the Ancestral Rocky Mountains, but since these mountains are not a part of the present Rocky Mountains it seems less confusing to call them, as suggested by Schuchert, the Colorado Mountains. Early in the Pennsylvanian there began another period of subsidence allowing the seas to slowly creep over the land, the waves assorting the materials they found on the surface, carrying the finer sands and clays into deep water to make sandstone and shale, and leaving the coarse material as a conglomerate. The transgression of the sea was so extensive, as

is shown by the present distribution of Pennsylvanian rocks, that the recently uplifted Colorado Mountains stood as island masses surrounded at times by the sea. These land areas were undergoing vigorous erosion and the streams were carrying great quantities of waste material into the surrounding lowlands and out into the sea. The shoreline in the Colorado area was probably very uneven; in some regions there were extensive bays which were being rapidly filled with coarse deposits laid down as deltas at the mouths of streams. Some of these delta deposits are very extensive and were evidently laid down in continental basins wholly cut off from the sea; other deposits seem more likely to have been formed along river courses and flood plains, and in fresh water basins.

The Fountain formation, so well represented in the foothills along the Front Range, was formed during this time. It consists chiefly of arkose, red sandstone, grit and conglomerate, being coarse grained, crumbling, and mottled with gray and various light shades of red. The material is irregularly bedded and varies greatly from place to place, having many of the characters of fluviatile material. The formation is 5000 feet thick near Colorado Springs but thins toward the north extending into Wyoming. It is believed that this formation represents a great aluvial cone with its apex in the mountains in Central Colorado and its base toward the north.

At the top of the Fountain formation is a persistent sandstone member laid down in shore waters. It is cross-bedded, thinly laminated and decidedly quartizitic. It varies slightly in color but is generally pink. This is the Lyons formation.

From a study of the present distribution of the Pennsylvanian deposits in this region and the character of the deposits, the relative extent of the seas and the position of the important land areas are fairly well known. These are shown by Heaton. (Heaton, R. L. 1933).

Invertebrate life of the Pennsylvanian seas was not only prolific but varied. Spiny brachiopods and one type of foraminifera, the fusulines, were extremely important, in some cases forming large bodies of limestone. Corals were simple cup forms but not very abundant. During this time, land insects were numerous and reached their largest size. Many are known which exceeded 4 inches in length, and one form found in the Coal

Measures of Belgium had a wing spread of 29 inches. Cockroaches, scorpions, spiders, and centipedes were common. The amphibia were sprawling creatures, mostly, only a few inches long. However, some forms are known which exceed ten or more feet. A few reptiles of small size appeared during part of the later period, but their remains are very rare.

Permian Period:

The Permian may be said to have brought to a climax conditions which began in Pennsylvanian time, not only in the Rocky Mountains area but throughout the continent. The shrinking seas gave way to widespread continental areas. The abundant rainfall of the early Pennsylvanian was succeeded by Permian aridity which greatly reduced land waters and caused scarcity of food. The seas which spread into the Southern Cordilleran geosyncline covered parts of western Colorado but in eastern Colorado semi-continental conditions initiated in the Pennsylvanian continued into the Permian. Here, deposits of red, brown, and chocolate sandstones, shales, and sandy shales with local thin calcareous or limy beds were deposited. Cross bedding and flow and plunge structure are very common as well as abrupt changes in the character of the material, the texture and color. These red beds in Colorado have been called the Lykins formation.

The life of the early Permian is so much like that of the Pennsylvanian that it is hard to fix the boundary line between the two. Permian time, however, is marked by rising lands and greater aridity which shut out the continental seas. These conditions were generally adverse to life and the struggle for existence was intense. All forms of life were greatly reduced in numbers and many forms disappeared entirely. Mountain-making movements of the earth's crust were very marked; for it was during this time that the principal movements occurred, producing the Appalachian mountains of eastern North America. The Urals of Europe, and the Variscan chains were completed across southern England, Germany, and Northern France. In the Orient there were also folding and thrusts along the arc of the Japanese Islands. The widespread aridity and other great changes wrought in climate by these major movements in the earth's crust had marked effect upon the vertebrate life. The amphibians which had dominated the land during the warm and humid Mississippian and Pennsylvanian, and which were dependent upon bodies of water for at least a portion of their life history, found that environment becoming very scarce. However, the relatively insignif-

icant reptiles of the late Paleozoic were increasing greatly in number during the Permian. Before the close of the period they had undoubtedly mastered all the land, and heralded in a time when they were to reign supreme.

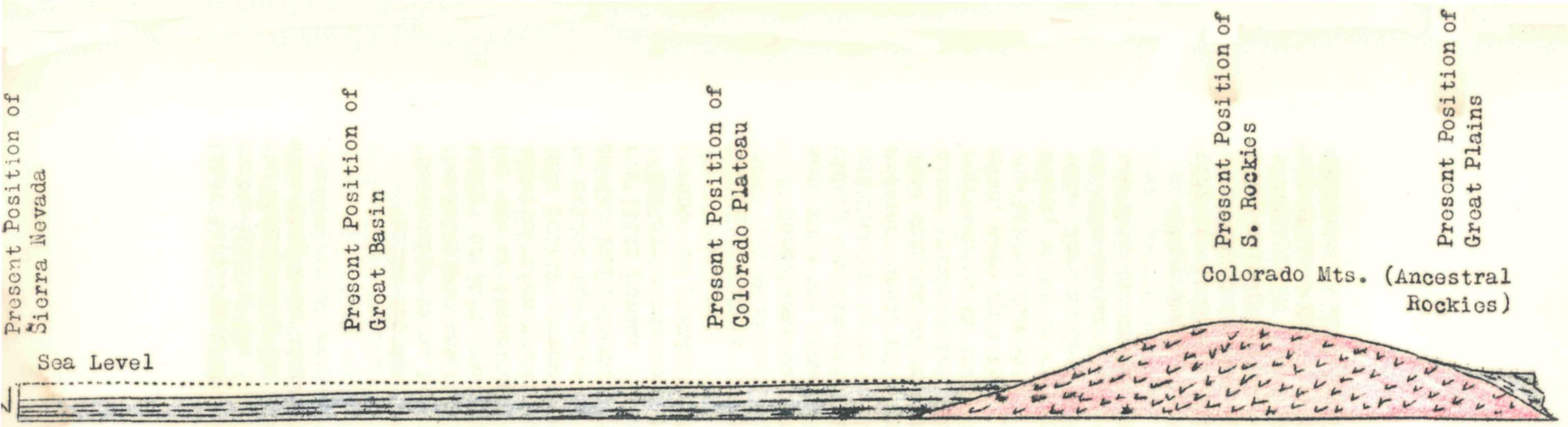
MESOZOIC ERA

To the founders of geology the Mesozoic was known as the "Secondary" time, coming after their "Primary" which included the Paleozoic and older eras and which was followed by the "Tertiary" or last era. Just as the Paleozoic may be referred to as the age of invertebrates because during its time many groups of invertebrates reached the peak of their development only to fall into decline; from the organic standpoint, the Mesozoic may fitly be called the Age of Reptiles, for in the seas, in the air, and on the land, it was dominated by a very diverse and monstrous reptilian horde. The mentality of these reptiles was always of a low order but better things were already indicated by the appearance of primitive mammals in the Early Jurassic.

TRIASSIC PERIOD:

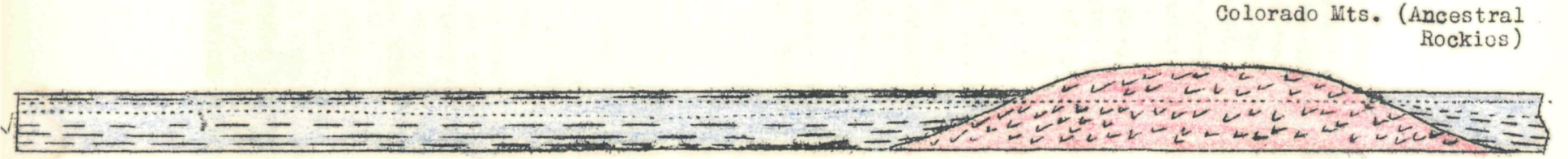
Conditions during the Triassic in the Rocky Mountain Region were much the same as during the Permian. Triassic rocks are widely distributed through the Rocky Mountain Region from Idaho and Wyoming to Arizona and New Mexico, constituting one of the greatest areas of continental Triassic deposits in North America. Here continental red beds predominate, though marine members of older Triassic interfinger from the west. These deposits are represented in the foothills east of the park, and, with the Permian, make up a thick series of red beds commonly referred to as the Lykins formation. The rocks consist chiefly of shaly sandstone, which in many places is accompanied by thick beds of gypsum. Just as in the Permian, the sea is believed to have entered this region for very short intervals of time resulting in the thin limestones intercalated with the red beds.

The principal sources of the sediments comprising the red beds are believed to have been the Colorado Mountains which had been formed in Pennsylvanian time but which were evidently still being slowly uplifted and eroded. The Triassic period closed with a widespread elevation of the land in the Rocky Mountain Region, and while sedimentation may have continued uninterruptedly from Triassic to Jurassic in limited areas, the general relations of



Illustrative Profile - Early Triassis Time.

Early Triassic time, when the "Ancestral Rockies" were high the sea occupied areas west of them.



Illustrative Profile - Late Triassic Time

Late Triassic Time, when the mountains were eroded, the basin filled, and products accumulating above sea level to form the non-marine Triassic deposits.

0 Scale in Miles 300

the Jurassic to the Triassic rocks are uncomformable.

Little is known of the land plants of the Triassic. This may be due either to the fact that the arid climates so general over the continents at that time were not conducive to extensive development of plant life; or it may, on the other hand, be due to the red bed being a poor environment for the preservation of plants. From what is known, the forests then were predominantly of conifers much like our modern evergreens, and of cycads. The undergrowth consisted of ferns, tree ferns, and scouring rushes. The chief groups of Paleozoic plants were extinct, or nearly so, for the seed ferns so characteristic of the Coal Measures had largely vanished and the great scale trees are known only by rare specimens. The vertebrates of the land were becoming varied, the reptiles already far surpassing the largest of the amphibians and showing themselves to be adaptive to all conditions on the lands and even reverting to a marine habitat to easily compete with the fishes. Long-snouted phytosaurs, resembling the modern gavials in appearance and habits, were common in the streams. The dinosaurs made their appearance in the Triassic and by the middle of the period outnumbered all other groups of reptiles and held complete sway over the lands. Unlike other reptiles, they were adapted to a running locomotion, since they carried their bodies up off the ground and had the legs under the body and not at the sides. The Triassic dinosaurs were much smaller than those living in the successive periods of the Mesozoic. They were mostly slender and few reached a length of more than 10 or 15 feet. True mammals appeared just before the close of the period but they were small, insignificant creatures and their remains are among the rarest of all fossils.

Jurassic Period:

Land conditions prevailed over the greater part of the continent in early Jurassic time, the Triassic beds being exposed to erosion. Following this interval of non-deposition, conditions changed and continental deposits once again began to accumulate over the northern Colorado region. These deposits are overlain by marine deposits which indicate an incursion of the sea over this region in Upper Jurassic time; however, their stay in the Rocky Mountain region was of short duration. These deposits are known as the Sundance formation which outcrops east of the Front Range in Colorado and consist of creamy white to buff sandstone and cherty limestone, also shales and shaly limestone. The marine

members of this formation contain numerous invertebrate fossils. After the retreat of the Jurassic seas, fresh-water basins occupied large areas in the Cordilleran zone, and in these were deposited vari-colored marly shales, fresh-water limestones, and sandstones with local conglomerates, all of which intergrade laterally as is the habit of continental deposits. The coarser sediments are commonly irregularly cross-bedded. In these beds no marine fossils have ever been found but more than 150 kinds of terrestrial animals and land plants are known. These include the greatest of all dinosaurs, primitive mammals, crocodiles, fresh-water clams and land snails, and land plants. During the Jurassic the Colorado region must have appeared somewhat similar to the present basins of the Amazon or Parana rivers, with low alluvial plains crossed by sluggish streams heading in the distant highlands to the west and carrying heavy loads of mud and sand, especially during flood seasons. Locally, lakes and swamps broke the monotonous topography of the plain. The climate had become more humid and vegetation spread over the landscape profusely.

Reptiles take first place in both sea and land faunas of the Jurassic and of these the dinosaurs were supreme. All of the dinosaurs of the American Jurassic have come from the Morrison formation of the Cordilleran region, which, although named from Morrison, Colorado, extends far to the north into Montana and west into Utah. These are represented by five major tribes. One of the best known American forms, Brontosaurus, reached a length of about 65 feet, while the more slender Diplodocus had a length of 80 feet. The plated dinosaur, Stegosaurus, must have weighed about 10 tons. In contrast to these large forms, others were small and very agile. Among the most bizarre animals of this time were the pterodactyls or winged reptile which possessed leathery wings and naked bodies, somewhat bat-like in appearance. These ranged from minute size with a wing spread equal to that of a sparrow up to species that spanned 3 or 4 feet from wing tip to wing tip.

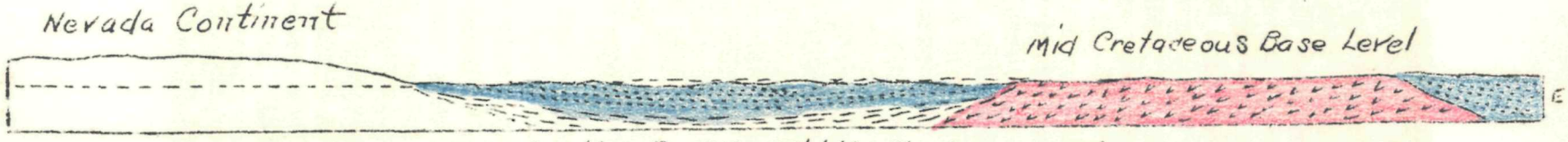
In the seas ichthyosaurs and plesiosaurs were both at the zenith of their development, the former with a streamline contour and powerful fluked tail.

Cretaceous Period:

The close of the Jurassic was a time of great land emergence and the continent was probably larger than it is now. In early

Illustrative Profile - Early Jurassic Time

Early Jurassic Time, after rise of Nevada Continent and the reduction of the "Ancestral Rockies" to a peneplained condition.



Illustrative Profile-Middle Cretaceous Time

The beginning of the Upper Cretaceous epoch, when the "Ancestral Rockies" were base leveled

0 Scale in Miles 300

lower Cretaceous time a sea covered part of eastern Mexico and from this area it invaded the United States; however, it did not reach Colorado until late in Lower Cretaceous time. This invading sea gradually extended north-ward over what is now the mountain zone until in early Upper Cretaceous time it joined a great southward advancing arm of the Arctic ocean and with it formed a continuous mediterranean sea the length of the continent. In Colorado, over the area of the present mountains were laid down in conformable succession the Dakota sandstone, Benton, Niobrara, Pierre, Fox Hills, and Laramie formations, making in places a total thickness of Cretaceous sediments, mainly shale, of 10,000 feet or more.

Soon after the maximum inundation of the sea (Benton Time) the northern end of the geosyncline emerged and the great eperic sea began a southward retreat that was hastened by the rapid filling of its basin with sediments pouring in from the rising highlands to the west. The sea lingered longest in an elongate embayment extending northward from the Gulf of Mexico across the western Great Plains states, known as the Lance sea. The final retreat of the sea transformed its old floor into a vast swampy lowland over which the streams spread thick non-marine sediments during the closing stages of the period. In the swamps of this lowland accumulated the vegetation that was to make the vast coal beds of the latest Cretaceous formations of the Rocky Mountain region from Alberta to Mexico.

The closing stages of the Mesozoic are marked by one of the most extensive mountain making movements North America had experienced since the Pre-Cambrian. This orogeny involved a region fully 3000 miles wide, extending from eastern Colorado to eastern Nevada and central Idaho; and from western Alaska to Mexico. At this time the Cordilleran geocyncline which had been the site of so many marine transgressions during the Paleozoic and Mesozoic and which had only recently been covered by the Cretaceous sea, was folded and faulted on a grand scale. Great forces within the earth's crust brought about extensive compression from the west. In the northern portion of the Cordilleran region the effects of this compression were very complex, resulting in great folds and extensive thrust faults causing large portions of the rocky crust of the earth to over-ride other portions generally lying to the east. In the Southern Rockies, the region in which we are most interested, the dominant structures were great open arches such as are so well shown by the Front Range in Colorado,

or the Park and Sawatch ranges. Between these upfolded regions are major downfolds or synclinal areas which are still recognisable in the "Parks", namely North, Middle, and South Park, of Central Colorado. Farther northeast in the Plains, the dome-like arches of the Black Hills and the Big Horn arches were formed. To the west of the Colorado Rockies lay the Great Colorado Plateau which was bodily uplifted but without perceptable folding of the underlying rocks. Between the Colorado Plateau and the Rocky mountain region several thrust faults were developed. One of the best known of these is the one lying along the front of the Sawatch Range. These thrusts are even more extensively developed in the Middle and Northern Rocky Mountains. The Lewis over-thrust in Montana has been traced for some 50 miles north and south and has driven Pre-Cambrian strata over the Cretaceous rocks of the Plains. The Absoroka Range east of Yellowstone Park is defined by another such thrust traceable for 125 to 150 miles and having a displacement of at least 28 miles.

Accompanying these throws of mountain-making were great outbursts of attendant vulcanism. Volcanoes are known to have been active in this region throughout the later Cretaceous, and toward the end of the period they spread farther east over the rising areas. It is probable that during the building of the Rockies every state west of the Great Plains had its active volcanoes, for the Cretaceous formations of the Great Plains contain many layers of bentonite (rock made of altered volcanic ash) indicating great showers of volcanic dust. Another phase of igneous activity is represented in the great igneous batholiths of molten igneous rock which welled up from unknown depths, intruding the overlying rocks. The most notable of these were the great Idaho batholith and the Boulder batholith of Idaho and Montana.

The building of so vast a mountain system required a long period of time, even geologically speaking, and it must not be thought of as a great catyclism of nature happening in the course of a few hours, days, or years. The movements are known to have begun long before the close of the Cretaceous and probably took place in various parts of the range at slightly different times. Although the climax of the movements naturally determined the end of the Cretaceous period, this was hardly a point in time but rather a phase in a great diastrophic cycle, and it came long after the uplift had begun. The movements also did not close with the Cretaceous, but some of the dying-out phases were carried over into the Eocene and Oligocene. The drawn out nature of this orogeny has been

the source of much controversy as to where the boundary line between Mesozoic and Cenozoic rocks should be drawn in the Cordilleran region.

The boundary line between the Mesozoic and the Cenozoic has given rise to one of the most prolonged controversies in the history of American geology. This has been largely due to the Laramie group which includes several thousands of feet of non-marine deposits which formed over the floor of the Cordilleran geosyncline by aggrading streams after the sea had made a great retreat. The underlying deposits belong clearly to the Cretaceous period and the overlying Fort Union formation and the formations overlying it belong to the Cenozoic. The Laramie contains land plants which are remarkably modern in their aspect and were believed by the early paleobotanists to be of Cenozoic age. Many fine skeletons of dinosaurs are also represented in the Laramie formation, and these are clearly allied with Cretaceous types and are quite unknown anywhere in undoubted Cenozoic rocks. The discovery, in 1912, of the Cannonball marine beds of North Dakota practically settled the question, since these beds, with a fauna of about 80 species of marine invertebrates showing undoubted Cretaceous age, interfinger with the eastern part of the Laramie group. The Laramie with its great dinosaurs is therefore clearly of latest Cretaceous time, and the overlying Fort Union formation, in which no trace of dinosaur bones occur, contains distinct mammalian fossils which show a definite correlation with the oldest Cenozoic formations.

CENOZOIC ERA.

The closing of the Cretaceous period, with its great crustal changes and the formation of extensive mountain ranges, saw another great critical period in the history of the earth. Withdrawal of the seas from the continents resulted in a struggle of marine invertebrates and many of the older groups which had flourished during the Mesozoic died out completely. The same is true of land animals and plants; many of the old groups became extinct, and relatively insignificant groups began to show marked evolutionary trends, adaptive radiation taking the places in nature formerly occupied by the extinct forms. With the opening of the Cenozoic we have the introduction of the modern groups. So long as the dinosaurs held their own, and the grasses, cereals and fruits had not become generally distributed, the primitive mammals could only bide their time. However, with the opening of the Cenozoic these necessary environments were an actuality and the mammals quickly

took advantage of this opportunity and swept into dominance all over the earth, so that the Cenozoic may well be spoken of as the "Age of Mammals".

During the latter part of the Cretaceous there was a great subordination and extinction of the older groups of plants which had seen so prominent a development during the Mesozoic. The deciduous trees, belonging to the highest order of the plant kingdom, suddenly became very conspicuous and dominated the landscape just as they do today. The indirect effect of the coming of the angiosperms upon the advances of the higher animals can hardly be exaggerated, for they supply nearly all the plant food for the mammals which now dominate all other life upon the earth. Angiosperms provide the nuts and fruits of the forest, the grasses of the prairies, the cereals which furnish fodder and grain for man and his domestic animals, and all the vegetables and fruits that man has cultivated, to say nothing of the flowers that add so much pleasure and inspiration to human surroundings.

Just as the Cenozoic has seen the modernization of animals and plants, so this last short era of geologic time has witnessed the shaping of every feature of the present landscape. With the retreat of the Late Cretaceous seas and the folding of the Cordilleran region, North America assumed approximately its present size and outline. During the Cenozoic the continent has remained essentially emergent, the seas at times have extended over the coastal regions for short distances but these rarely exceeded 5 or 6% of the continent. The available geologic record, therefore, lies principally in the formations along the coastal areas and the continental formations spread over the land surface, and in features still evident in the modern landscape.

The opening of the Cenozoic era found the Central and Western Colorado region mountainous, due to the mountain making movements of the closing stages of the Cretaceous. The higher portions of the great open folds of the Southern Rocky Mountains were undergoing rapid erosion. During the Eocene epoch the synclinal basins of western Colorado, Utah, and Wyoming caught much of the erosional debris from the surrounding ranges and in them the thick Eocene formations are still preserved. Most of these mountain-rimmed basins had through-following streams and therefore persisted as

forested lowlands, in which Cenozoic mammals had their favorite haunts. The sediments of these basins consequently enclose a record of mammalian evolution scarcely equaled elsewhere in the world. During Eocene time most of the sediments from the erosion of the mountains were caught in these basins, for no Eocene sediments are known from the area immediately east of the Front Range. Sediments were undoubtedly being carried eastward by streams draining the Front Range, but the region immediately east of the range must have had an elevation sufficient to prevent the accumulation of deposits here. In all probability this region east of the foothills was undergoing slight erosion.

As the Eocene epoch closed, the intermountain basins became filled with deposits so that during the Oligocene Epoch the streams reached the foothills ladened with sediment. These were spread over the Great Plains as alluvial aprons and flood plain deposits. By the end of Oligocene time the mountains had been worn low, though monadnocks 2000 or 3000 feet high rose in places above the plains.

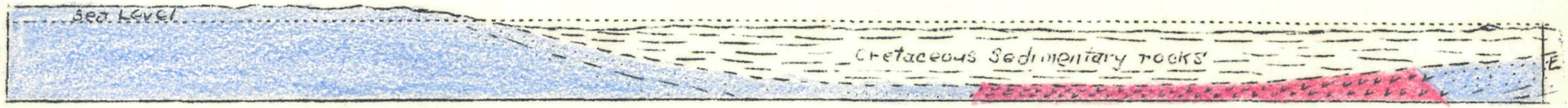
In Miocene time rejuvenation began with a broad, gentle regional upwarp along the axis of the Rockies. This was in general free of faulting or other marked diastrophism so far as the Rocky Mountain region is concerned, and the uplift was gradual, intermittent and long drawn out, reaching its culmination in Pleistocene time. As a result of this warping, there was little deposition of Miocene or Pliocene sediment within the mountains, though the vast area of stream deposits to the east of them was greatly extended until it stretched from the Dakotas to Texas and from the front of the mountains to eastern Kansas and Nebraska. This regional upwarp of late Cenozoic time gave the Rockies their present height. Erosion has been extremely active since this time and has resulted in the carving of the present features of this grand mountain region. So recent has the last uplift of this area been that the erosive agents have still much to accomplish and we may consider the present mountains as in a young stage of development. The work of the streams in carving out the rugged features of the present mountains has been greatly modified by the work of extensive glaciers which held sway in this region during the great Ice Age. This last great drama of geologic time has left so many of the familiar features of the present landscape of the Rocky Mountains that it is worthy of special consideration.

Pleistocene:

This is the latest and most recent of the geological epochs and because of the extensive glaciation which gripped the earth at this time it is commonly referred to as the Ice Age. Fully one-sixth of the existing lands were covered with great sheets of ice. So recent was this last episode that the ice sheets have not yet completely disappeared and the desolate continent of Antarctica, like the ice capped island of Greenland, stand as vivid reminders of the past. Aside from Antarctica, the great ice sheets of the Pleistocene were in the northern hemisphere, one centering over the Canadian region and the other over Scandinavia. The ice covered nearly half of North America, reaching from Alaska to Greenland and southward into the United States as far as the Ohio and Missouri rivers, covering an area of about 4 million square miles.

In addition to these continental ice caps, nearly all the lofty mountains of the world were extensively effected by valley glaciers, and it is this type that is so excellently recorded in Rocky Mountain National Park. Conspicuous evidence of these former glaciers may be found in the latoral, terminal, and ground moraines, the smoothly rounded rock surfaces, polished and striated boulders, steep-walled gorges, U-shaped valleys, and pocket lakes. There appears to be two stages of glaciation represented in the park, - an older one of which little is known and a younger one called the Wisconsin stage, because it coincides in time with the last stage of continental glaciation, which is typically developed in the state of Wisconsin. It is believed that some of the broad open valleys in the lower parts of the park, such as Estes Park and Tahosa Valley were shaped by ice belonging to the earlier of the two stages. They have the broad floors, the steep walls and the perched lakes which characterize glacial valleys, but they lie outside the area affected by the glaciers of the Wisconsin stage.

During the younger or Wisconsin stage of glaciation the ice accumulated in the valleys previously occupied by the streams - and to some extent perhaps by older glaciers - and pushed its way from the high mountains down these valleys to altitudes of about 8000 feet. The areas occupied by the ice are plainly marked and could be mapped accurately with little difficulty. This has not as yet been completely done,



Illustrative Profile - End of Cretaceous Time

The close of the Cretaceous period, after the Cretaceous Basin was filled with sedimentary rock.

Illustrative Profile - Present Time

The present time showing the Great Basin lower than the plateaus whose material was derived from it and the still higher Southern Rockies standing in the middle of the area formerly covered by the Cretaceous Sea

0 Scale in Miles 300

From W.T. Lee

however, an illustration showing the outlines of these glaciated areas together with a description of the features developed by these ancient glaciers, is presented in Willis T. Lee's pamphlet on the Geologic Story of Rocky Mountain National Park, Colorado, to which the reader is referred for greater completeness.

SUMMARY

Probably the most important phase of the geologic history of the Rocky Mountain National Park is the growth and history of the mountains themselves. Although this region has had an extremely interesting history and has been the scene of many important events, few except those of the very earliest and the very latest geologic time, are represented within the actual boundaries of the park. The formations which portray the Paleozoic and Mesozoic history are represented in southern Colorado and in the foothill region immediately east of the park. Many of these formations at one time extended over the now mountainous region subsequently removed by the extensive erosion this region has suffered. Considering the fact that this region has been set aside because it typifies the grander features of the Rocky Mountain region as a whole, and that the mountains themselves are the primary object of wonder to the average person visiting the park, it seems most fitting that this phase of the geology be given the greatest consideration. A very brief statement has already been given presenting the more important series of events which have resulted in the formation of so grand a feature of the earth's crust. With the hope of more concretely presenting this series of events the following diagrams are included. It must be remembered that such a far flung and complicated system of structure as the Rocky Mountains can only be a most sketchy generalization of the structure at one locality. The locality here chosen for such representation is naturally the southern Rocky Mountains.

Paleogeographic maps illustrating the distribution of land and sea in this region during the various geological periods may be found in Heaton's report. (Heaton, R. L., 1933).

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