The Rocks and Fossils of Glacier National Park: The Story of Their Origin and History

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A simple, nontechnical explanation of the geological processes that created the magnificent scenery

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THE ROCKS AND FOSSILS OF GLACIER NATIONAL PARK: THE STORY OF THEIR ORIGIN AND HISTORY

By C. P. Ross and Richard Rezak

ABSTRACT

The story of Glacier National Park begins about 500 million years ago, at a time when there were no mountains in the region—only a vast, exceedingly shallow sea, bordered by desolate plains. The sand, clay, and mud, in part very limy, that were laid down in this sea eventually hardened into the rocks that are now known as the Belt series. These are the principal rocks in the park. Scattered through these rocks are crinkled, limy masses of many forms, the remains of deposits made by colonies of algae. After the Belt series was laid down, successive seas slowly advanced and retreated through long ages across what is now Glacier National Park, burying the Belt rocks under younger ones. After another very long time, a gentle uplift, the forerunner of later events, brought this part of the continent above the reach of sea water for the last time. Much later, some 50 million years ago, the disturbance became far more intense. To climax this upheaval, a mass of rock thousands of feet thick and hundreds of miles long was shoved eastward for 35 miles or more. This tremendous dislocation, well exposed along the eastern boundary of the park, is known as the Lewis overthrust.

When the rocks of the region emerged from the sea they began to be attacked by erosion. As successive periods of crustal movement and erosion continued, the younger rocks were slowly stripped off the Belt series and sculpture of the latter by weather and water shaped the early Rocky Mountains.

The final episode in the park's geologic past was the ice age, beginning about a million years ago. Repeated advances and retreats of the great glaciers in the high valleys accentuated the mountain terrain and developed the scenic grandeur that is now Glacier National Park. One may say that the park is still in the ice age, for some glaciers still exist.

The present report, companion to two more technical reports on the region, informally presents the story of the park's development through past eras for readers without geologic training. Many places worth visiting are cited in the text, and a shaded relief map is provided to help find them.

INTRODUCTION

Mountain scenery of exceptional grandeur gives Glacier National Park its unique appeal. Here are found splendid alpine peaks with sharply chiseled faces, canyons separated from each other by narrow, intricately carved ridges, waterfalls, lakes, and glaciers tucked away in the higher valleys. Across the international boundary—an arbitrary, manmade line—lies Waterton Lakes Park. The two national parks are scenically and geologically a unit.

The many modern glaciers give the park its name, but the rugged landscapes that impress the visitor were carved by glaciers that have long since melted. Glaciers that exist today have shrunk markedly in recent years—some have disappeared entirely. The few glaciers visible from vantage points along the roads are difficult to distinguish at a distance from the many glistening snowfields which persist through the summer. All who possibly can should leave the roads and travel by foot, horse, or boat into the less accessible parts of the region. By such means one can easily obtain close views of glaciers or even reach them. For example, Sperry Glacier can be easily visited by foot or on horse. Figure 122 shows some of the striking views to be seen on this trip. Guided trips are available from the Many Glacier Hotel to Grinnell Glacier.

The farther one gets from the roads and other evidences of civilization, the greater will be the reward. Most of these trips are well within the capacity of a person in normal health. Opportunities to study glaciers and glacial effects, past and present, are fascinating, but to many visitors they are not the greatest of the recompenses of trips into the back country. The traveler may relax and get true rest even while unschooled muscles strain and tire and panting breath testifies to the rarity of the atmosphere. Snowfields disappear in midsummer from the immediate vicinity of the roads but they persist near the peaks, where they enliven the scenery. Visitors of all ages from the parched lowlands to the east or from crowded seacoast cities especially enjoy the opportunity to frolic with snowballs beneath a benign summer sun.

If observant and patient, one can watch wild animals, large and small. Some species found in the mountains of the park are becoming rare throughout the continent. To be sure, almost everyone has opportunity to see the scraggly bears that beg along the highways and raid garbage cans at the camps; and fortunate motorists may observe moose and other animals even from

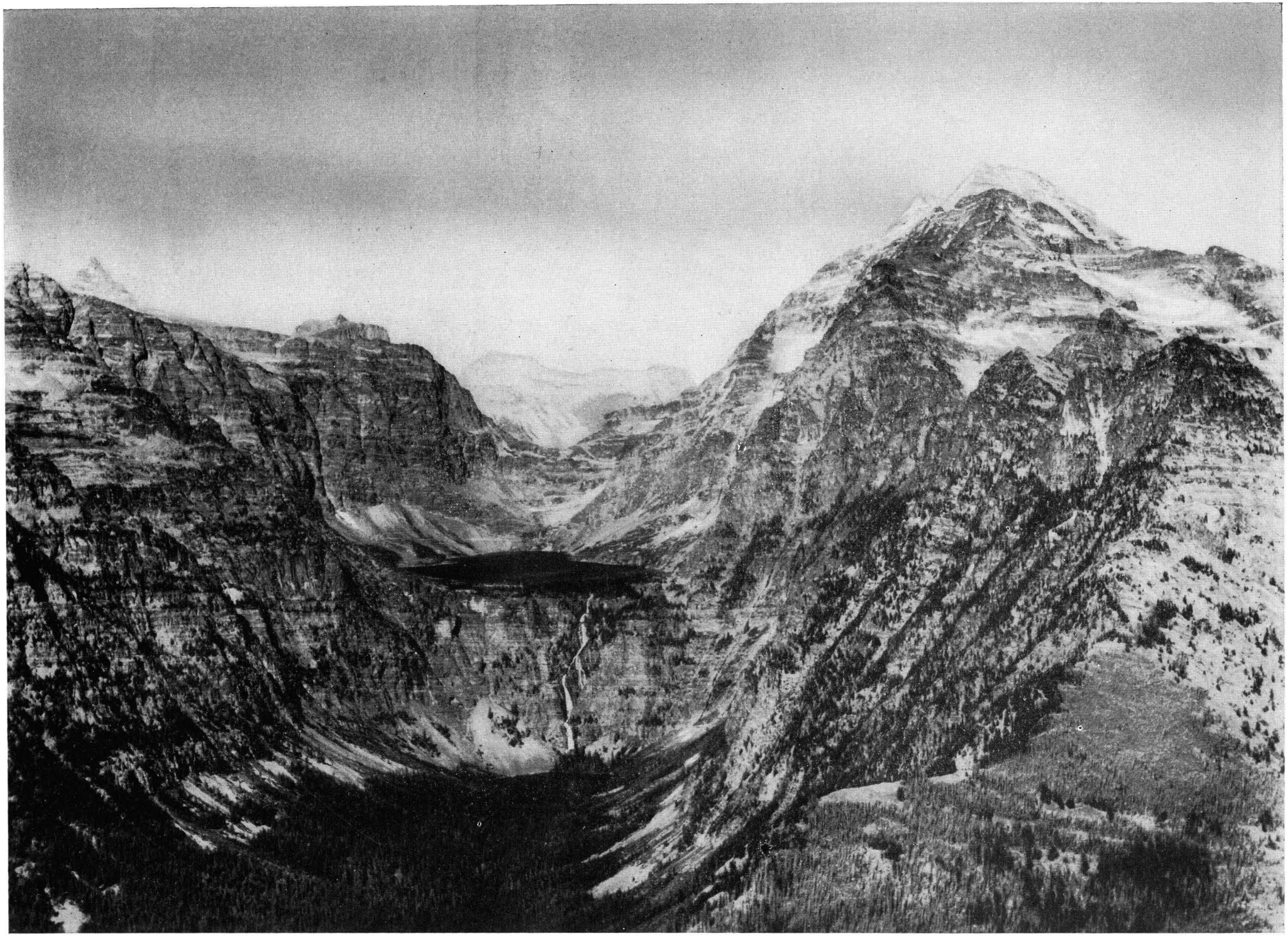

FIGURE 122.—Gunsight Pass and Mount Jackson. Lake Ellen Wilson, in the middle distance, is connected by the thin ribbon of Lincoln Falls with Lincoln Lake, 1,400 feet below. The saddle-horse trail from Sperry Chalet and Lake McDonald Hotel crosses Gunsight Pass above Lake Ellen Wilson. Small glaciers are visible in the upper right. (Photograph by permission of the U. S. Army Air Corps.)

their car windows. Far more thrilling are the glimpses of big game obtained away from the roads, where the animals are in their natural setting: the playful deer, the dignified elk and moose, and elusive goats that are thoroughly at home among the bleak crags.

For obvious reasons hunting is forbidden within the park, but fishing is permitted. Devotees of the latter sport will find that hiking over the trails can bring ample rewards.

The mountains will be enjoyed and appreciated most fully by those who have some knowledge of their geologic background. This is true even if one is limited to hurried views from the roads; it is even more true if one is privileged to make leisurely and intimate acquaintance with the park through travel over the trails. The purpose of this publication is to give visitors such an understanding. It presents, briefly and simply, the events in the geologic history of the park.

Scientific investigation of the area began in 1882 when the noted explorer and geologist, Raphael Pumpelly traversed it. However, systematic geologic explorations were not begun until 1901, when Bailey Willis, who later joined the faculty of Stanford University, assisted by G. I. Finlay and Stuart Weller, made studies which led to important conclusions concerning the nature and origin of the mountains. The outstanding result of their investigation was the recognition of the tremendous, gently inclined fracture or fault that they named the Lewis overthrust. This fault is the dominant structural feature of the region. It underlies the mountains and is exposed along the eastern front of the Lewis Range.

It is not strange that geologic exploration should have been long postponed in view of the fact that until the turn of the century white men had very scant knowledge about this part of Montana. A few fur trappers and traders had entered it early in the 19th century, but they built no settlements in or near the mountains. In 1853, Pitamakan Pass was visited by A. W. Tinkham in an unsuccessful search for a route for a railroad across the mountains. Late in the century, reports of the presence of copper and gold deposits aroused enough interest to prompt the Federal Government to purchase most of the area of the present Glacier National Park from the Blackfeet Indians. Though the area was thrown open to prospecting, results of the ensuing search for ore deposits were meager; a few caved tunnels and pits in the park remind visitors of the activity of this period, which ended about 1903.

In 1892 the Great Northern Railway built its line along what is now the southern border of the park. About 1895 a log hotel was built on the shore of Lake McDonald, and a steamboat was put in operation there, testifying to an early realization of the value of the region for recreation. Shortly afterward, on the strength of ill-founded rumors of oil, a road was built northward from the foot of Lake McDonald. These gains in transportation facilities were followed by homesteading in nearby valleys.

In 1900 to 1902, Francois E. Matthes and R. H. Sargent made a topographic survey of the Chief Mountain quadrangle, the first of a series of quadrangles mapped by the United States Geological Survey in the region. This map was published in 1904 and thus was available to show the striking character of the topography when creation of a national park was advocated. Congress enacted legislation in 1910 establishing Glacier National Park. Mapping of the entire area containing the park was completed in 1912, on a scale of 1:125,000 (approximately 2 miles to the inch). Copies of this map, valuable for reference and as a guide in the field, may be purchased from the U. S. Geological Survey, Denver Federal Center, Denver, Colo., and at various stations in the park itself. Plate 51 is a copy of this map, reduced in size so as to be more easily handled and with shading added to bring out the main topographic features.

From 1911 through 1914, parties of geologists of the Geological Survey, under the direction of M. R. Campbell, undertook a comprehensive investigation of the geology of the park. The topographic map served as a base for the field work. Associated with Campbell were W. C. Alden, Eugene Stebinger, T. W. Stanton, and others. This work was never completed, and the only publications that resulted were short, nontechnical papers. However, at intervals Alden continued studies of glacial phenomena in and near the park. Stebinger cooperated with Alden and also worked extensively on the coal and oil resources of the adjacent plains. Some of the publications of these two men are listed in the bibliography at the end of the present paper, together with other pertinent publications.

From time to time other geologists have studied various aspects of the geology of the region. For example, C. L. Fenton and M. A. Fenton, between 1931 and 1937, published several papers on the ancient sedimentary rocks (the Belt series), which make up most of the mountains of the park, and their fossils. In 1938 Marland Billings, of Harvard University, made a notable contribution concerning the Lewis overthrust. Many geologists have studied the Belt series and also younger formations preserved in parts of Montana, British Columbia, Alberta, and elsewhere, mostly in localities distant from Glacier National Park.

The work of all visiting geologists has been facilitated by officers of the National Park Service. Naturalists of the park staff have added to the body of geologic information. Their systematic yearly observations and measurements of the glaciers constitute important contributions to knowledge of glaciers in general. Two publications of the Glacier Natural History Association, both of which were written by James L. Dyson, of Lafayette College, long a ranger-naturalist of the park, provide convenient summaries of geologic and glacial data. Road and trail logs, in pamphlets, by former Park Naturalists G. C. Ruhle and M. E. Beatty, are valuable in directing visitors to specific features of geologic interest, as well as to many other things. These publications may be purchased in the park.

The present publication is an outgrowth of a project by the Geological Survey to prepare a new geologic map of Montana. Field work on this project was begun by C. P. Ross in 1946, and it soon became evident that so little was known about the region just south of Glacier National Park that the geology could not be represented adequately even on the small scale of the proposed State map (1:500,000, or about 8 miles to the inch) without new field work. Consequently, the geologic mapping south of the park that began in 1948 was soon extended to include the park, and it continued through 1950. As a part of the investigation, study of the fossils (mainly algal) in the Belt series was begun by Stephan Nordeng in 1950 and was continued through 1953 by Richard Rezak.

This account of the geology of Glacier National Park is based on reports on the field work of 1948 to 1953. The one that deals with the general geology is by C. P. Ross and will be published by the Geological Survey. The one that concerns the algae, by Richard Rezak, was published by the Geological Survey in 1957. These reports and the geologic maps accompanying them incorporate data collected by Campbell and his coworkers many years ago. If it were not for these earlier studies the reports and maps would be far less comprehensive than they are. However, more information must be gathered before the geology of the region may be satisfactorily understood in all its details. Readers desiring more technical and detailed information than the present paper affords may wish to consult the reports listed in the selected bibliography.

In the preparation of the present paper, invaluable advice and assistance have been given by Ruth C. Ross, Fritiof M. Fryxell, G. D. Robinson, and others. In particular, Fryxell's experience in writing papers of this type contributed materially to the arrangement and phrasing of this paper.

The character, relative ages, and interrelations of the rock units successively deposited, ranging from the oldest exposed (the Belt series) to the deposits being laid down today, constitute the principal evidence from which the geologic history of the region can be deduced. Therefore, a table outlining the facts is offered as appendix A. The table contains some of the technical names used in the text to indicate the different geologic ages and rock units, including subdivisions of the Belt series. It is customary to name individual rock units after geographic features where the units were first studied and, generally, where they are well exposed. Thus the Belt series takes its name from the Big Belt Mountains and the Little Belt Mountains in central Montana. Another table that shows the approximate span in years of the major geologic time units is presented as appendix B.

In summary, information gathered by many geologists in the course of more than half a century, coordinated and amplified as a result of recent field work by the writers and their associates, has made it possible to decipher the geologic history of the Glacier National Park region. That history may now be sketched with confidence in regard to the correctness of its broader features. Some questions remain unanswered or only partly answered; some details are only hazily appreciated; some may still be unsuspected. Not only will additional facts be learned, but interpretations of those now known will be modified as the science of geology itself grows.

GEOGRAPHIC SETTING

The mountains of Glacier National Park present an imposing front to the traveler from either east or west. On the east they rise with startling abruptness at the edge of the rolling, partly dissected lowlands of the western Great Plains. Monotonous plains topography gives way almost without warning to the diversified scenery of the Northern Rocky Mountains. The western boundary of the park is within that mountain unit, but it is marked by the relatively open valleys of branches of the Flathead River. The river flows into Flathead Lake in a great, nearly level trough known as Flathead Valley, which is thickly strewn with ranches, towns, and summer residences. From the Flathead Valley, the traveler approaches the mountains through the valley and over rounded, forested hills so that the cliffed mountains of the park burst into view suddenly.

The park contains parts of two of the ranges that constitute the Northern Rocky Mountains, a great assemblage that stretches from the eastern border of the park westward into the State of Washington. To avoid misunderstandings, one should remember that most Canadians and some geographers in this country give a less sweeping significance to the term "Rocky Mountains." Canadians commonly think of the western border of the Rockies as the series of major northwest-trending valleys, of which Flathead Valley in this country is a noble representative. These valleys are spoken of together as the Rocky Mountain Trench.

Plate 52 shows the names of the principal topographic features in northwestern Montana and adjacent parts of Canada. The mountain mass within Glacier National Park is made up of parts of the Lewis Range on the east and the Livingstone Range on the west. Although both names have been in use for a long time, the masses to which they should be applied remain in some doubt. Canadians call the part of the Livingstone Range that extends into Canada the Clarke (or Clark) Range and reserve the name "Livingstone" for mountains still farther north. In Glacier National Park the dividing line between the Livingstone and Lewis Ranges passes through Waterton Lake, up the valley south of that lake, over or around Flattop Mountain, down McDonald Creek, and through McDonald Lake to the Middle Fork of the Flathead. In present local usage, the Lewis Range constitutes the mountains within the park east of this line and stops at the southern boundary of the park. As originally defined over 50 years ago, the name was applied to the easternmost part of the Rocky Mountains almost as far south as Helena, the State capital. This usage still has much to commend it, even though part of the front range of the Rocky Mountains has since been called the Sawtooth Range by some people.

As plate 51 shows, the Continental Divide swings from the Livingstone Range to the Lewis Range at the north end of Flattop Mountain. The part of the park west of that divide is tributary to the Flathead River, whose water finally flows into the Pacific Ocean. Most of the park east of the divide drains into Canada through the Waterton, Belly, St. Mary, and Milk Rivers. All these rivers except the Milk River are tributary to Hudson Bay, at the northern border of the North American Continent. The Milk River and, farther south, Two Medicine Creek are tributaries of the Missouri River, whose water empties into the Mississippi and thence into the Gulf of Mexico. The fact that water that drains from the mountains of the park ends in such widely separated marine basins is marked by the name of Triple Divide Peak, which is about 6 miles south of St. Mary Lake.

THE BELT SEA AND ITS INHABITANTS

The predominant rocks of Glacier National Park, the Belt series, of almost inconceivable antiquity, were formed from sediments laid down more than half a billion years ago. Even then, the earth had been in existence about two billion years, long enough so that it had acquired, in a general way, its present pattern of continents and ocean basins. Thus, in that remote period at which the geologic history of the region begins, North America was already in existence, although its appearance then was very different from its appearance today. Then, as now, the earth was subject, somewhat intermittently, to great strains that significantly changed its crustal features. The surface features, the topography, of the earth have undergone practically continuous modifications.

During the long history of the continent, shallow seas repeatedly encroached upon it, submerging great areas and at times forming long seaways through the present interior. At times more of the continent might have been above sea level than at present, but there certainly were many periods in which vast expanses of what is now dry land were covered by water and received deposits from that water. Now advancing, now retreating, changing ceaselessly in position and configuration but so slowly that scarcely any differences could have been discerned within the three score years and ten of a man's lifetime, many of the seas persisted for millions of years—periods long even in terms of geologic time—only to become restricted or to disappear at last.

Changing sea basins were among other results of the strains from which the earth suffered. At intervals the rocks along certain stretches of the surface of North America were subjected to such great pressures that they were warped and flexed over rather wide expanses, or folded, crumpled, and fractured in narrower zones of more intense movement. Effects of these kinds influenced the rocks for miles beneath the surface of the ground. Naturally, deformation tended to be concentrated in relatively weak zones. Many of these were in places where depressions in the surface had been filled with exceptional thicknesses of sedimentary rocks.

These deposits had been laid down in the temporary seas, in some places in a succession of such seas. Originally the deposits included mud, sand, lime, and other materials, mostly derived from the adjacent lands. Even when hardened into sedimentary rocks, such as shale, sandstone, and limestone, these materials yield more readily when force is applied to them than do the great bodies of massive crystalline rocks that make up so much of the earth's crust.

Just how and why the forces originate and are applied and how the depressions or basins were localized where they were are matters that are still open to debate. We are learning some things about these mat-

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ters, but much remains unknown or uncertain. Theories are plentiful but proof is being gathered slowly. Notwithstanding these uncertainties as to causes, it is clear that such forces, acting parallel to the earth's surface, have from time to time been able to overcome the resistance of rocks, particularly in sediment-filled depressions.

The Belt series and the younger beds that, as indicated in appendix A, originally overlay them constituted a thick accumulation of comparatively weak rocks, ready to yield when adequate pressures were applied. The younger rocks are thick and weak but the Belt series is even thicker. At the present time the beds composing the Belt series are hardened into argillite, quartzite, and crystalline limestone, but they were originally soft muds and sands. The surprising thing is not that the rocks of the region yielded in spectacular fashion when suitable pressures were applied, but that events of this kind were so long delayed.

In the mountains of Glacier National Park the sedimentary rocks that are younger than the Belt series, and even parts of the latter, have long been eroded away. To study the younger rocks, one must journey beyond the park into areas where they are still preserved.

Belt sediments were laid down in a basin, or perhaps at times a group of basins, that extended from the Arctic Ocean, in the region of Hudson Bay, southward through Canada and into western Montana and Idaho. The southern margin might have been in southern Idaho, at about the latitude of the Snake River Plain. Rocks that somewhat resemble the Belt series are exposed at intervals far to the south of the Snake River Plain, but little is known in regard to their relationships to that series.

The western and eastern margins of the depressions cannot be accurately determined. Rocks belonging to the Belt series extend far to the west of the park and are buried under the extensive lava flows of eastern Washington. East of the park some rocks correlated with the Belt series extend well into eastern Montana, but most of these probably belong to the younger parts of the series. Early in its history the eastern edge of the Belt sea might have been between the park and the Sweetgrass Hills, a hundred miles to the east.

Clearly the Belt series, like many other widespread sedimentary deposits, was laid down in a great depression. The floor of this depression was of such extremely low relief that for all practical purposes it might be considered to have been a vast, almost featureless plain. The Belt sea, which by no means occupied the entire depresson, was much shallower than later seas that invaded Montana and other parts of North America. The evidence for the shallow nature of the Belt sea led some earlier geologists to believe that the sediments were deposited in lakes rather than a sea. Recent studies of the sediments, however, indicate that they were laid down in water bodies that were so salty and so extensive that they are better thought of as seas than lakes. All the seas that spread over continental areas at intervals during geologic time were shallower than the present oceans. Their maximum depths might have been hundreds rather than thousands of feet. Perhaps parts of the Belt sea attained depths of a few hundred feet, but during much of its existence the average depth was probably less than a hundred feet. Such things as ripple marks, mud cracks, clay spalls, raindrop impressions, certain kinds of fossil algae, and a few casts of salt crystals—all point to very shallow conditions and even exposure, at times, in mud flats from which the water had retreated.

Shallow though the Belt sea must have been, its deposits now have an aggregate thickness of more than four miles and in regions south of the park the thickness is even greater. How is it possible to reconcile the concept of deposition in a shallow sea with the fact that strata more than 20,000 feet thick accumulated in that sea? At first glance such a situation seems impossible, yet a reasonable solution is reached if one assumes that the marine strata were deposited on a subsiding sea floor—one that sank, as the sediments accumulated on it, slowly enough so that the shallow depths of water were maintained.

Why did the basin sink? Geologists study the earth's crust and its properties, as revealed not only by the rocks but also by precise surveying and interpretation of earthquake, gravity, and magnetic data. As a result of such studies, it is now generally believed that beneath an outer skin of rather rigid rock lies a thin layer that behaves like a stiff liquid. Parts of the crust that are overloaded sink in this liquid, and parts that are lighter rise proportionately.

Although this mechanism may operate in a broad way, it might not have been the only factor in the deposition of the Belt series. For the process to work perfectly every time that a layer of mud or similar sediment is spread over the sea bottom the increase in the load that results must cause subsidence. At the same time, the land from which that mud was removed must be lightened correspondingly and therefore must rise. Considering the wide areas of the earth's crust involved and the small weight of any individual layer of mud deposited, it does seem to be asking a good deal of the process of adjustment to regard it as the sole factor involved. Granting that it is a factor, and probably a very important one, other factors might have contributed also. Conceivably, lateral pressures, possibly in continuation of those that produced the basin in the first place, had a significant effect. Tidal measurements in the Gulf of Bothnia, the northern arm of the Baltic Sea, indicate, even today, the dynamic character of the earth's crust. In that region that crust is rising at a rate of about three feet per century—while deposition is also going on. If this uplift continues, the floor of the Gulf of Bothnia will become dry land. The fact remains that throughout the earth's history regions of the crust have repeatedly risen and subsided.

Earlier in this discussion we mentioned that large areas of the Belt sea were at times exposed as mud flats. The exposure of these large areas must have resulted from a combination of circumstances. The influence of tides might have been an important factor, although we have no idea of their magnitude during Belt time. The small vertical movement of the vast, almost reliefless plain that contained the Belt sea was probably not uniform over the entire area, and some tilting of the surface must have occurred. In such a shallow sea, a very small amount of tilting would cause radical changes in the position of the shorelines. To complicate matters, as the basin was subsiding, sediments were being carried to the sea by streams. The volume of the material furnished to the sea by the streams probably varied from season to season. During rainy periods when stream levels were higher a greater volume of sediment would be transported to the sea than during the dry periods. Thus, at times deposition would exceed the rate of subsidence and mud flats would develop close to the mouths of rivers and along the shorelines. When the volume of sediment decreased, during the dry periods, sinking could catch up with and pass the rate of upbuilding of the sea bottom, causing the mud flats to become submerged again. The great thicknesses of mud-cracked rock in the Belt series can be satisfactorily explained in this manner.

The occasional presence of salt-crystal casts also seems to indicate changes from warm moist seasons to warm dry seasons. The salt-crystal casts are not common and seem to be restricted to the more inaccessible areas of the park. Sparse occurrence of these casts seems to indicate that at no time during its history was the Belt sea extremely saline. It is believed that the beds containing these salt crystals were deposited in lagoons, completely separated from the sea by land-surface irregularities along the borders of the sea during the early parts of the dry cycles. At that time the mud flats were still exposed, and here and there behind the shoreline such lagoons might have existed. Evaporation of these small bodies of water would cause an increase in the salinity of the water and eventually salt crystals would have formed.

The foregoing discussion has given us a general idea of the environment in which the Belt rocks were deposited. In brief, the Belt rocks were deposited in a shallow, shifting sea that lay on a vast, almost featureless plain, in a climate that was generally warm and alternately humid and semiarid.

The Belt series is older than the rocks in which fossil remains are generally known to be plentiful. However, the presence in it of traces of organisms has long been known. The most abundant and most definitely recognizable are records of the former presence of certain primitive plants known as algae. Fossils of this kind are especially well displayed in Glacier National Park and have received much study there. They are visible at a number of places along Going-to-the-Sun Highway (fig. 124).

Algae are of many kinds and grow under many different environments. Everyone, whether he realizes it or not, comes into contact with certain kinds of algae almost daily. Webster's New Collegiate Dictionary defines the word "alga" as, "Any plant of a group (Algae) comprising practically all seaweeds, as rockweed, sea lettuce, etc., and allied fresh-water or nonaquatic forms, as pond scums, stoneworts, etc."

There is a great range in size and complexity among algae. Some are microscopic unicellular plants; others are large masses, colonies consisting of millions of cells and reaching lengths of several hundred feet. Some of the unicellular algae impart a characteristic color, ordinarily green, to the water in which they live. The pond scums and allied forms are of this type. Most algae are water dwellers, although some grow on soils, others on the stems of trees, and one species of red algae may be seen growing on the snowfields of Glacier National Park. Algae constitute most of the vegetation of the ocean. These marine algae serve as one of the most important sources of food for other life in the sea.

Most modern algae lack characteristics which make possible their preservation as fossils. Only algae that cause the precipitation of lime from the surrounding sea water and those that actually secrete lime or silica in their cell walls can be preserved after burial in the form of fossils. Algae of these types are responsible for the fossil records in the Belt series.

Appendix C gives the classification of fossil algae which is based on that of modern algae. The fossil algae of the Belt series belong to the group called Spongiostroma. As indicated in the table, microscopic plant structure is rarely recognized in these fossils. As a consequence of this apparent absence of microscopic structures, the algae of the Belt series have been classified on the basis of the external form and growth habit of the colonies.

The ancient algae of the Belt sea probably lived under environmental conditions not greatly different from those of the marshy flats around the Bahama Islands or parts of some of the coral islands of the southwest Pacific. True, some of the latter are commonly regarded as coral reefs, but actually they have been built up of limy materials, including skeletal parts, contributed by many kinds of sea-living organisms, and lime precipitated by algae is among the most abundant of these.

If this comparison is valid, what a contrast the present scene offers to the scene which imagination conjures out of the geologic past! Where the snow-clad peaks of the Rocky Mountains now stand, then stretched the monotonous reaches of the Belt sea. In its clear waters grew brightly colored algae, their varied colors made even brighter by sunlight—for algae can grow only in water sufficiently shallow and free of sediment to permit the penetration of sunlight. Under favorable conditions much of the sea bottom was covered with closely packed algal colonies. At other times there were isolated reefs and patches of algal growths. Around and above the colonies, each with its core of hard, precipitated lime, delicate tendrils floated. The drab gray and buff hues of present outcrops give no hint of the vivid colors that the soft tissues of the living plants must have displayed: shades of green and, perhaps, red and brown.

Once established on the sea bottom, the algal colonies were strong enough to resist attack by waves and currents. They tended to maintain themselves and grow upwards, making the water even shallower than when their growth began. At times of low water, algal heads would have been exposed. The reefs served, furthermore, as gathering grounds for sediment, and their volume was also increased where evaporation of sea water or other factors caused the chemical precipitation of dissolved lime. Under modern conditions palms or other plants would have taken root, but this aid to island growth was absent in Belt time. The lands bordering the sea likewise could not have had a vegetable cover like that of the present day. They must have presented a bleak and desolate appearance for no fossils of land life have been found in rocks older than Silurian. (See app. B.) Conceivably some of the hardier plants had begun their struggle for existence on the land during Precambrian time, but these could be found only along the shores of the sea where there was an abundance of the moisture so necessary for their survival.

Floating, swimming, and crawling among the algal growths were probably extremely primitive forms of animal life. The presence of such life during Belt time, however, is known only by indirect evidence. In many places the Belt rocks contain burrows that are very similar to those made by modern worms and trails that resemble very closely trails made by modern mollusks. During the following Cambrian period, when the first deposits containing an abundance of animal fossils were laid down, animal life was already diverse and complex.

The plants grew as thin mats of fine threadlike filaments. Each filament was made up of a row of closely packed cells and was covered with a sheath of sticky matter. In the process of photosynthesis, plants absorb carbon dioxide and give off oxygen. The solubility of lime in sea water is proportional to the amount of carbon dioxide present in the water. We may recall, here, a simple experiment that is usually included in children's chemistry sets. A milky solution of lime is cleared by the bubbling of carbon dioxide from one's breath. What has happened is that the increase of carbon dioxide in the solution has increased the solubility of the lime, causing the disappearance of the lime precipitate that produced the milky appearance of the solution. When the algae remove carbon dioxide from the water around a colony, that water becomes saturated with lime, and a very fine precipitate is formed. This fine precipitate of lime adheres to the sheath of the algae and forms a thin coating over the colony. After the coating of lime is formed, the old algal mat dies and a new one begins to grow on the new surface of the colony. In this way the colonies continue to grow and expand until a change in environment occurs. Perhaps an influx of very fine clayey material may cause the water to become murky and decrease the penetrating power of the sunlight. With a lack of sunlight, the algae die and the growth of the colony is brought to an end. Changes in environment such as this occurred several times during the deposition of the Belt sediments and account for the many beds of algal colonies separated by various thicknesses of barren rock.

Fossil algae occur in eight distinct layers or zones in the Belt series of the park area. (See app. D.) Each zone is characterized by the dominance of one or two kinds of algae. The zones bear the names of the species that occur in greatest abundance. Thus, the *Conophyton* zone 1 consists primarily of *Conophyton inclinatum* Rezak, but this is not the only species that may exist in the zone. In addition, we find *Collenia frequens* Walcott, *Collenia multiflabella* Rezak, and *Cryptozoon occidentale* Dawson, all of which are less common.

The individual masses of algae, ordinarily called heads, may assume any one of a number of shapes. The heads may be dome-shaped, columnar, fan-shaped, or conical. They are composed of layers of limestone, separated by layers which contain more silt. On weathered surfaces the impure layers tend to stand out in relief, because they yield to weathering processes more slowly than the layers of pure limestone. Thus the structure of the heads is clearly revealed on the rock surfaces.

Scientific names have been used for the heads for lack of other names. Insofar as possible, the descriptions of species have been written in nonscientific language so that anyone interested in visiting fossil localities can recognize the various species. A few of the technical terms are defined in the glossary, appendix E. A key to the identification of the fossils is included as appendix D.

Nowhere in or near Glacier National Park has erosion laid bare the rocks that underlie the Belt series and constitute the floor upon which the Belt sediments were laid down. This floor probably consists of rocks like those that crop out near the southern border of Montana, far to the southeast of the park. These are the oldest rocks known in Montana, and many of them are of granitic character. Layers of sandstone and conglomerate (consolidated gravel) interbedded in the Altyn limestone, the lowest exposed unit in the park, show from their composition that they must have been eroded from granitic rocks. Hence, rocks of that kind must have been exposed on the land areas that bordered the Belt sea. Much the greater part of the Altyn limestone consists of crystalline magnesium-rich limestone.

The lowest fossil zone in the Belt series of Glacier National Park lies in the upper part of the Altyn limestone. This is the *Collenia frequens* zone (fig. 123). The zone consists of closely crowded columnar colonies which stand at angles of 35° to nearly 90° to the bedding surfaces. Columns are from 2 to 15 inches in diameter and from 6 inches to nearly 6 feet in height. The laminae are smooth and moderately to strongly convex upward. The zone may be observed along the lower slopes of Altyn Peak near Appekunny Falls, near the Rising Sun campground close to St. Mary Lake, and near the fire tower on Divide Mountain.

The Appekunny and Grinnell argillites, the two formations next above the Altyn limestone, consist mainly of beds that originated as fine sand and silt mixed with clay and a little limy matter. The original sediments hardened into shale and sandstone and, as time went on, were converted into argillite and quartzite. Most parts of the Appekunny and Grinnell argillites contain no known fossils, but a few have been found recently in

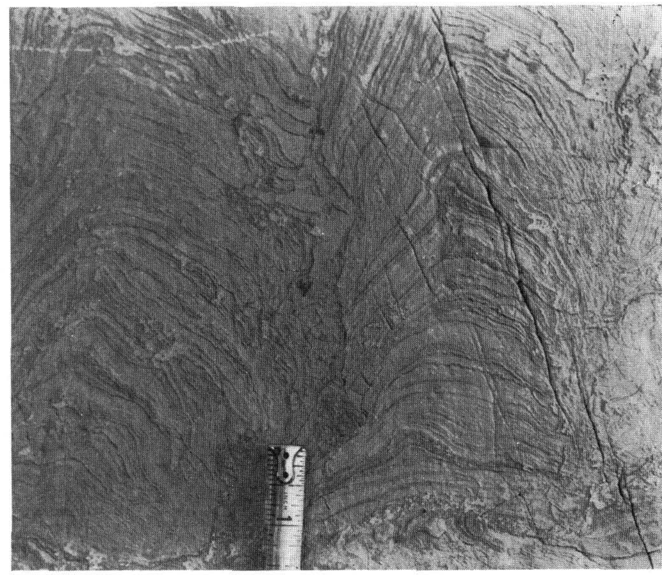

FIGURE 123.—*Collenia frequens* Walcott in the *Collenia frequens* zone in the Altyn limestone, near Appekunny Falls.

the Grinnell. The sediments from which the two formations were derived must have been carried into the Belt sea by streams that had flowed long distances across lands underlain largely by rocks like granite. The sediments must have been brought long distances because they consist largely of mineral grains that are resistant to destruction by chemical and mechanical means. Minerals that yielded readily to weathering had not survived the trip.

It is remarkable that rocks as nearly homogeneous as those making up the Appekunny and Grinnell argillites could have accumulated to as great thicknesses as they did. They are not, as the names may suggest, derived exclusively from mudstone or shale, but material of that kind is plentiful in both units. For such an accumulation to have occurred, both the sources of the sediments and the conditions of deposition must have remained essentially unchanged for tremendously long intervals of time. The strata contain ripple marks, crossbedding, and other features that indicate deposition in water ranging in depth from a few inches to as much, perhaps, as a few hundred feet. The volume of sedimentary material may be accounted for in a measure by imagining that silt-laden streams deposited their loads in broad deltas. Some stream mouths might have been close enough together so that their spreading deltas merged with each other. Currents moving along the seashore might have aided in spreading the deposits. The extreme shallowness of the water helped to permit deposition of nearly uniform material over expanses many times greater than the area of Glacier National Park. Both formations are visible along the highway northeast of Lake McDonald.

The three lowest units of the Belt series, which together belong to the Ravalli group, have now been mentioned. Passing upward, we find that the next younger subdivision, the Siyeh limestone of the Piegan group, consists mostly of impure crystalline limestone and some sandy and argillaceous beds. The visitor to the park will have no difficulty in making firsthand acquaintance with the Siyeh limestone, for most of the higher stretches of the Going-to-the-Sun Highway (the only road that crosses the park) have been blasted from this formation, which is widespread throughout the mountains of the park.

Siyeh limestone records recurrence of conditions of deposition similar to those of Altyn time and strikingly different from the conditions under which the Appekunny and Grinnell argillites were laid down. The water continued to be shallow, but instead of being silt laden it was clear and contained abundant carbonates in chemical solution. Possibly the courses of some of the rivers that brought sediment to the Belt sea had changed or new currents had arisen in the sea that diverted much of the sediment to other localities. The relatively pure limestone masses are smaller in area than other units of the Belt series in Montana.

When the great masses of limestone in Glacier National Park were first studied, many years ago, it was commonly supposed that they were so old that no living things could have existed at the time they were laid down. Even those willing to entertain the idea that life of some sort did exist and traces of it might have been preserved would not have supposed that the limestone itself could have been formed from carbonate of organic derivation. Other theories were advanced, involving, for example, speculation that the composition of the atmosphere in Belt time was so greatly different from that of the present time that locally great volumes of limestone could easily be precipitated chemically. None of the theories received general acceptance. Probably the limestone of the Belt series originated in much the same way as later limestones, in all of which carbonate derived directly and indirectly from organic sources is abundant.

Fossil algae occur from the top to the bottom of the Siyeh limestone in three zones.

The lowermost and by far the thickest zone in the Siyeh limestone is the *Collenia symmetrica* zone 1. This zone comprises the lower two-thirds of the formation. It consists almost entirely of *Collenia symmetrica* Fenton and Fenton. The colonies are from 1 foot to 6 feet in diameter and from 8 inches to 2 feet in height. They have a dome-shaped or flattened dome-shaped cross section and are subcircular in plan. The laminae are rather smooth and are ordinarily flattened centrally but are sharply downfolded at the margins of the colonies. The basal part generally shows an absence of laminae, which presumably was caused by growth on a mud-cracked surface. This zone is well exposed on The Garden Wall near Logan Pass, along Going-to-the-Sun Highway east of Logan Pass, near the south end of Lake McDonald, and on U. S. Highway 2 about 2.2 miles east of West Glacier.

The second zone in the Siyeh limestone is the *Conophyton* zone 1. This is the most conspicuous zone in the park. It generally forms massive, grayish limestone ledges that can be seen from several miles away. (See fig. 124.) The zone is made up of three parts, each containing a characteristic species. The lowest one-third of the zone contains colonies of *Collenia frequens* Walcott. (See p. 9.) The middle one-third of the zone contains large masses of *Conophyton inclinatum* Rezak. Colonies of *Conophyton* are conical and inclined at low angles to the bedding surfaces. They range from 2 to 48 inches in diameter, although the average is about 8 inches, and up to 3 feet in length. The laminae are smooth, concentric, and conical. The unique form of this species makes it very easy to recognize. (See fig. 125.)

The upper part of the *Conophyton* zone 1 contains *Collenia multiflabella* Rezak and *Cryptozoon occidentale* Dawson. Colonies of *Collenia multiflabella* Rezak are generally quite large, reaching diameters of 5 feet and heights of 3 feet. They are roughly circular in plan and flattened or discoid in cross section. The lower part consists of columnar heads that expand upward and are capped by later laminae that are continuous over the columns. The laminae are crenulate, flattened at their crest, and slightly downfolded at the margins of the colonies. (See fig. 127.) Colonies of *Cryptozoon occidentale* Dawson may also be seen in the upper part of the *Conophyton* zone 1, but they are less common than *Collenia multiflabella* Rezak. Colonies of *Cryptozoon occidentale* Dawson are roughly circular in plan and fan shaped in cross section. They range in height from a few inches to 6 feet, and the maximum width is about equal to the height. Laminae are smooth, flattened at the crest, and downfolded at the margins of the colonies. (See fig. 126.)

Conophyton zone 1 may be seen along Going-to-the-Sun Highway just east of Logan Pass, just west of Logan Pass, and just east of the tunnel below the big switchback on the Garden Wall. The trail from Logan Pass to Granite Park crosses the zone near Logan Pass and also just west of Haystack Butte.

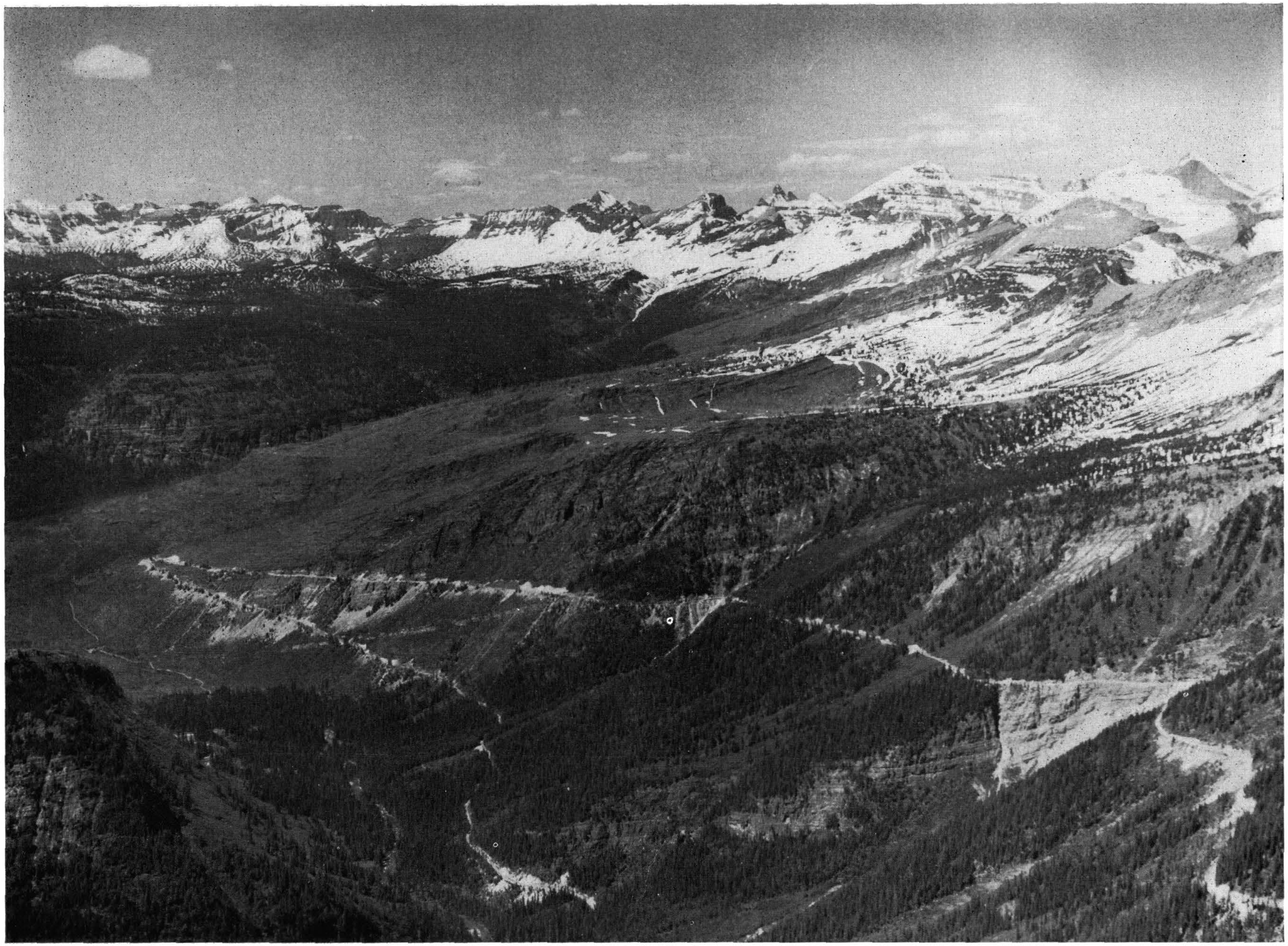

FIGURE 124.—The Garden Wall as seen from the top of Mount Oberlin. The *Conophyton* zone 1 may be seen crossing Going-to-the-Sun Highway at two points. This 100-foot zone appears as a narrow light-colored band crossing diagonally just below the center of the photograph.

FIGURE 125.—Mass of *Conophyton inclinatum* Rezak in *Conophyton* zone 1 in Siyeh limestone, on Going-to-the-Sun Highway, 6.4 miles west of Logan Pass.

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FIGURE 126.—*Cryptozoon occidentale* **Dawson in Missoula** group in railroad cut about 3 miles southeast of Nyack, Mont.

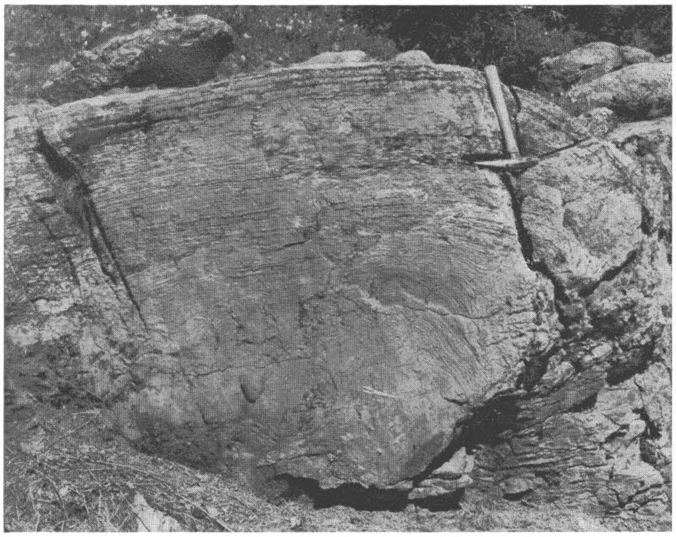

FIGURE 127.—*Collenia multiflabella* Rezak in *Collenia multiflabella* zone in Siyeh limestone, on east side of Logan Pass just above the point where Reynolds Creek plunges into St. Mary valley.

The uppermost zone in the Siyeh limestone lies between the *Conophyton* zone 1 and the red and green argillites of the Missoula group. This zone contains large beds of *Collenia multiflabella* Rezak, for which it is named, and minor quantities of *Cryptozoon occidentale* Dawson. (See p. 10 and fig. 127.)

The *Collenia multiflabella* zone is well exposed at Logan Pass, where the comfort station stands on one of the beds in the zone. Short walks from the comfort station on the Hidden Lake trail and toward St. Mary valley will reveal exceptionally well preserved heads of *Collenia multiflabella* Rezak. Here, because of the resistance of the fossil beds to weathering, many ledges containing the fossils may be seen. The zone is also well exposed just northwest of the tunnel below the big switchback on The Garden Wall.

In addition to the masses known to be fossils, the limestone contains many intricate structures such as those shown on figure 128, whose origin is not understood.

Weathered surfaces of most limestone outcrops show such structures as fantastically irregular patterns etched in stone. Certain of them have a fancied resemblance to the grinding surfaces of molar teeth of elephants or similar beasts and are called "molar tooth structures." Figure 129 illustrates structures of this kind.

Some or all of the structures may be of organic origin, presumably mostly algal. If some or all of the forms now preserved seem difficult to account for as algal, perhaps they are traces of some other sort of plants or even of primitive animals. The differences between very primitive plants and animals are slight—so slight that the distinction is not easily made. As one thinks over these various ideas, the most logical assumption seems to be that the Siyeh limestone is dominantly of organic origin. The other limestone masses in the Belt series do not contain equally large proportions of recognized fossils, but they too may be largely organic in origin.

A very marked, although not abrupt, change in the sedimentary environment ended deposition of the Siyeh limestone, and the rocks of the Missoula group, the last of the major subdivisions of the Belt series, came into being. The striking change in the character of the marine sediments is probably related to crustal disturbances that are recorded by the eruptions of igneous rocks at this time. Low in the Missoula group, lava flows are interbedded with the sedimentary rocks. These dark-colored lavas were originally somewhat like the basalt that is so abundant in eastern Washington and Oregon, except that they were extruded on the sea floor instead of on dry land. This is inferred, in part, from the fact that the lava in Glacier National Park is characterized by curious ellipsoidal structures that give the name "pillow lavas" to flows like these. Such structures are known to originate when lava erupts under water and are only locally present in the basalt of Washington and Oregon. One of the best places to see lava is Granite Park, the flat on which Granite Park Chalet is built. Granite Park supposedly owes its name to the lava once erroneously thought to be granite.

The lava, of course, came from deeper within the earth's crust, and some that did not reach the surface

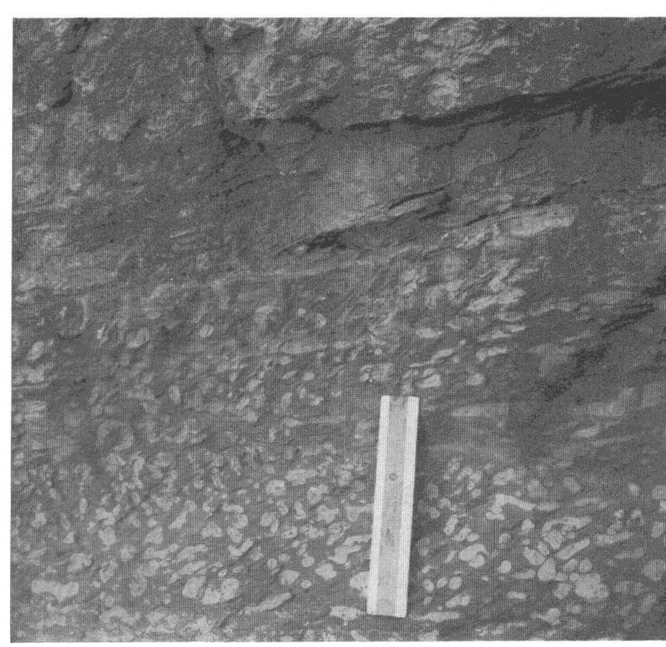

FIGURE 128.—Inclusionlike patterns etched in Siyeh limestone, exposed in road cuts northwest of Logan Pass.

in Belt time is preserved as the nearly black bodies that are conspicuous in many exposures of the Siyeh. Within the park most of these are steep fissure fillings, called dikes, or nearly flat-lying masses called sills, which approximately parallel the bedding in the limestone. Most of the dikes are 10 to 200 feet wide. Among other places, cliffs from St. Mary Lake northwestward past Lake Sherburne reveal conspicuous dikes. Prospectors of the early days found ore minerals close to some of these dikes. The sills are a few score feet to more than 100 feet thick and are even more conspicuous than the dikes, in part because their black rock is bordered on both sides by white zones of limestone bleached by the heat of the intrusion. In most localities only a single sill is exposed and, as it happens, this is commonly a short distance below the massive bed that marks the most widespread of the zones of algal fossils. Sills are well exposed on Clements Mountain and other peaks near Logan Pass. Figure 130 shows a sill and its border of bleached and recrystallized limestone. Other sills are shown in figure 131.

Sills and dikes doubtless were introduced as a result of crustal disturbances. At the levels now open to observation, these disturbances were not violent. They made steep cracks and strained the limestone beds, then

FIGURE 129.—"Molar tooth" structures, exposed in road cuts northwest of Logan Pass.

newly deposited and relatively soft, so that in a few places the molten material could penetrate along bedding surfaces. The rocks were not compressed enough to be folded or broken, for the beds of the Missoula group lie practically parallel to the limestone beds on which they rest. If violent disturbances had occurred,

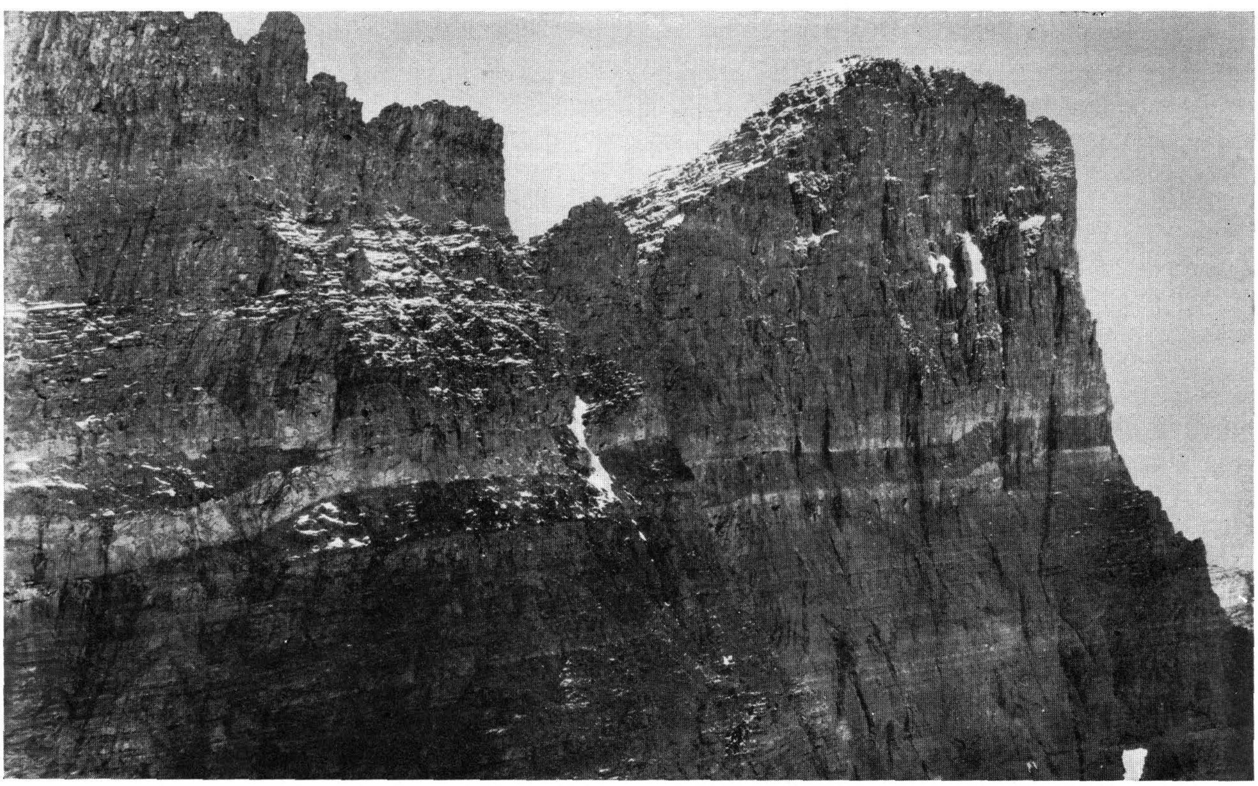

FIGURE 130.—Sill in Siyeh limestone on the east face of Mount Gould, as seen from Cataract Mountain. The dark band across the center of the picture is rock that was intruded while in a molten condition. The bleached and baked zones above and below the sill attest to the heat of the sill while it was being emplaced. (Photograph by Eugene Stebinger.)

FIGURE 131.—Two sills in Siyeh limestone. The view is of Pollock Mountain and the headwaters of Cataract Creek as seen from the southwest flank of Allen Mountain opposite Morning Eagle Falls. (Photograph by H. E. Malde.)

the limestone, already deposited, would have been tilted and perhaps also broken, so that later sediments, deposited on a flat sea bottom, could not have been parallel to the limestone beds.

The Missoula group consists, for the most part, of argillite beds of purplish red color and some green beds. Much of the rock is sandy and most is somewhat limy. Here and there, throughout the group, are limestone beds and limestone masses, some over 1,000 feet thick. The limestone contains algal fossils. Most of the limestone interbedded with the argillite is so similar to the Siyeh limestone just below that, where relationships to other rocks are not apparent, one might easily be mistaken for the other. The argillite beds show abundant ripple marks, mud cracks, bits of dried mud that had been tumbled about by rills of water while still soft, and other indications that the mud layers, from which the argillite formed, were exposed frequently to the air during the time they were accumulating. The Missoula group is much the thickest subdivision of the Belt series in Montana, but in the part of the park that visitors generally see it is not conspicuous because most of it has been removed by erosion. In many places it is represented only by red summits and pinnacles on some of the higher mountains.

Three fossil zones have been recognized in the Missoula group. The lower few hundred feet of the group consists chiefly of red and green argillite and thin beds of pink limestone. This is the *Collenia undosa* zone. The limestone beds are about 1 foot thick, and although none has great lateral extent together they are numerous enough to be recognized over a large area. The limestone beds are crowded with *Collenia undosa* Walcott, *Collenia symmetrica* Fenton and Fenton (p. 10, 11), and *Cryptozoon occidentale* Dawson (p. 10). Colonies are composed of alternating layers of pink limestone and green argillite. On the fresh rock surfaces they present a spectacular appearance, with the structure of the laminae made especially conspicuous by the alternating colors. On weathered surfaces the laminae develop strong relief, owing to the more rapid decay of the pure limestone layers.

Colonies of *Collenia undosa* Walcott generally expand upward to form fan-shaped cross sections. Sizes range from 1 inch high and 2 inches wide to 18 inches high and 20 inches wide. The laminae are coarsely crenulate and dome shaped. They expand upward with growth and unite laterally with adjoining heads to form compound colonies. (See figure 132.)

This zone is well exposed between the comfort station at Logan Pass and the saddle between Mount Oberlin and Clements Mountain, 0.2 mile east of the big switchback on The Garden Wall, 0.6 mile north of the south end of Lake McDonald on Going-to-the-

Sun Highway, and 1.2 miles south of Walton on U. S. Highway 2.

The upper half of the Missoula group is exposed only in the southwest part of the park and in the Flathead region to the south of the park. Elsewhere it has been removed by erosion.

The second zone of *Collenia symmetrica* Fenton and Fenton occurs about 6,000 feet above the base of the Missoula group. This zone, about 50 feet thick, is made up of 3 distinct layers of *Collenia symmetrica* Fenton and Fenton (p. 10, 11) separated by various thicknesses of barren limestone. The zone differs from its counterpart in the Siyeh limestone in thickness and lateral persistence of the fossil layers. Zone 2 is much more compact vertically than zone 1, and the individual fossil beds cover larger areas than the fossil beds of zone 1. (See fig. 133.) The zone may be seen on the southwest spur of Running Rabbit Mountain about 400 feet below the top of the mountain and also just west of the tunnel at Singleshot, on the Great Northern Railway tracks along Bear Creek.

Conophyton zone 2 lies about 400 feet above the *Collenia symmetrica* zone 2. It resembles its counterpart in the Siyeh limestone when viewed from a distance; however, it differs considerably in its fossil content. *Conophyton inclinatum* Rezak and *Collenia frequens* Walcott are the only species that are recognized in the zone. They occur in 4 alternating layers, each layer containing only 1 species. The lowermost layer consists of *Collenia frequens* Walcott, and the uppermost layer consists of *Conophyton inclinatum* Rezak. The second and third layers are separated by about 10 feet of barren, black limestone. This zone may be seen at the top of Running Rabbit Mountain, at the pass between Giefer Creek and Twenty-five Mile Creek on the west side of Baldhead Mountain, and along the Great Northern Railway tracks opposite the point where Devil Creek flows into Bear Creek. The zone on the western slopes of Scalplock, Rampage, and Riverview Mountains may be viewed from U.S. Highway 2, between Essex and Pinnacle. (See figs. 134, 135, and 136.

Deposition of the Missoula group probably marked the final filling of the Belt basin. During this filling, which might have lasted more than half of all Belt time, conditions fluctuated markedly. In some depressions within the basin, the water was clear enough so that much algal limestone could be deposited. On the whole, however, mud flats must have been common features of the region. Possibly the Belt basin was finally obliterated by earth stresses that reversed crustal movement so that downwarping actually gave way to uplift. If so, the movement must have been gentle indeed, for no direct evidence in support of it has been found in nearby parts of Montana. Possibly the movement was so gentle that, locally, deposition was scarcely interrupted at all. In distant areas, such as parts of Idaho and Canada, the evidence of crustal disturbance at about this time is a little more convincing. In some of these areas an interruption in the deposition of sediments, which can be best accounted for by uplift, did take place. Even in these places, however, the rocks were broadly arched or upwarped—not strongly folded or broken.

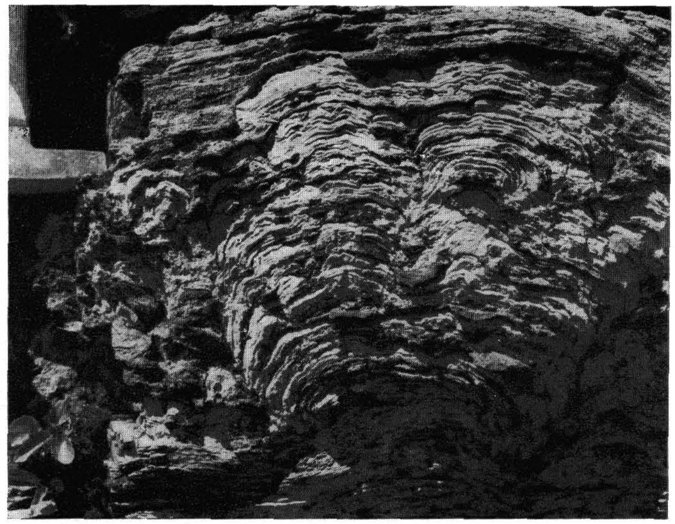

FIGURE 132.—*Collenia undosa* Walcott in *Collenia undosa* zone in Missoula group, in cirque facing Logan Pass between Mount Oberlin and Clements Mountain.

Let us review briefly the important environmental conditions that existed during the time when the Belt sea spread over much of western North America. Presumably, warm weather prevailed. The abundant algae remind one of the marine algae that in modern seas are most luxuriant in the tropics. Red rocks are plentiful in the Belt series, and red sediments and soils are more commonly formed today under warm than under cold conditions. Very large quantities of sediment were dumped into the Belt basin from land that had such slight relief that the streams carried almost no gravel. This suggests that rain was at times abundant and also that weathering penetrated deeply into the ground, so that the rock was disintegrated and yielded readily to erosion. The fact that at times parts of the floor of the Belt sea were exposed to the air may be accounted for, in part, by long severe dry spells.

PRELUDE TO MOUNTAIN BUILDING

The deposition of the Belt series fulfilled one of the requirements for the crustal deformation that is related to mountain building: the accumulation of a large thickness of sedimentary rocks mechanically weaker than the

FIGURE 133.—*Collenia symmetrica* Fenton and Fenton *in Collenia symmetrica* zone 2 in Missoula group, just east of snowshed 7 on the Great Northern Railway tracks along Bear Creek. Note size of colonies in upper right corner of photograph compared with man in lower left corner.

parts of the earth's crust that are composed of massive crystalline rock. Obviously other requirements were lacking. A vast interval of time, spanning more than 450 million years, was to elapse before the changes set in that gave rise to mountains. During this interval, the deposition of sedimentary rocks continued, so that eventually the ancient Belt series came to be buried beneath younger strata throughout the broad region that included the site of Glacier National Park. As these younger rocks have been stripped from the surface in the park by erosion it is now necessary to go outside the park to study them.

Processes which made possible the accumulation of sediment to form the Belt rocks continued for the later deposits; that is, space for the later deposits was made available in part by the sinking of the basin floor as the load of sediments increased and possibly in part by broad downward flexure of the earth's crust under lateral pressures. As these adjustments took place, the originally soft sediments were packed under the weight of successively younger deposits and gradually hardened and changed into the rocks we find today. They remained relatively nonresistant, however, so that they would yield when adequate pressures were built up. Eventually, as will be shown below, deformation did take place.

Between the pause at the end of Belt sedimentation and the beginning of the Tertiary period, at least six interruptions in the deposition of sedimentary rocks took place in the region. Facts of this kind are learned mainly from studying the fossiles in the rocks. Evolution brings about changes in the character of plants and animals as the years go by. In consequence, the fossils in old rocks may be radically different from those in younger ones. Gaps in the record of progressive changes of this kind in any particular locality demonstrate that during the corresponding part of geologic time no sediments were deposited there.

FIGURE 134.—*Conophyton inclinatum* Rezak in *Conophyton* zone 2 in Missoula group, along Great Northern Railway tracks opposite point where Devil Creek flows into Bear Creek. This joint surface shows nearly circular sections of the cones.

FIGURE 135.—*Conophyton inclinatum* Rezak in *Conophyton* zone 2, in same locality as figure 134. Bedding surface shows conical nature of laminae.

None of the interruptions to sedimentation before the beginning of the Tertiary period was accompanied by mountain building. If enough deformation to lead to the development of mountains had taken place, clear evidence of it would be visible in the rocks. On the contrary, those of one age rest on those beneath them in nearly perfect parallelism, even where the fossils prove that major interruptions in sedimentation have occurred. Mountain-building deformation would have disturbed the rocks so that parallelism would have been impossible.

It is probable that half of the long time interval between the end of Belt sedimentation and the beginning of the upheavals related to the Lewis overthrust is not represented by sediments in the general vicinity of the park. Whereas the older formations deposited during this interval were laid down in seas that had greater average depths than the Belt sea, some of the younger formations are nonmarine, having been laid down in lakes, swamps, or on river flood plains. Those among the younger sedimentary units that are of marine origin are thinner and probably less widespread than the older marine deposits. Seemingly as time went on the region was encroached upon by the sea to a decreasing degree.

The long period of accumulation of sedimentary strata was drawing to a close, and the forces of uplift

FIGURE 136.—*Collenia frequens* Walcott in *Conophyton* zone 2 in Missoula group, at top of Running Rabbit Mountain.

were gaining ascendency over those of depression. Plate 53*A* shows diagrammatically conditions as they are believed to have been at this time. Slow oscillation of the earth's crust continued, and for some 30 million years before violent deformation took place the region remained dry land much of the time. Near the close of the Mesozoic era preliminary folding might have taken place. The preparations had been long, but finally the stage was set for those dramatic events that may now be recounted.

THE LEWIS OVERTHRUST

The broad uplift, possibly with some folding, that had begun earlier continued during the first few million years of the Tertiary period, presumably at an increasing rate. Stream flow was accelerated. As a result, large valleys were cut and the sedimentary rocks that covered the region began to be swept away. The younger, upper beds must have been so soft that they yielded readily to erosion. Large parts of them were removed, exposing older rocks to attack by water and wind, heat and cold.

Some geologists have supposed that erosion by stream flow and associated processes reduced the whole country to a nearly level surface before violent deformation took place. More likely the crustal disturbances were marked enough so that active erosion continued. At the time the major upheaval began, the site of the present Rocky Mountains in this region might well have been hilly, or mountainous, although the topography was by no means as rugged as that of the present day.

The broad uplift and accompanying minor folding of very early Tertiary time gradually merged into more intensive folding. Pressures mounted until they could not be relieved merely by regional warping, and eventually the weaker rocks crumpled into folds. At a fairly early stage, at about the middle of the Paleocene epoch, conditions were like those shown in plate 53*B*. At this time, as the diagram shows, parts of the younger sedimentary rocks had been eroded away. The effects of the crustal deformation extended to the surface of the ground and were reflected in the topography.

Later the folds were still further compressed and came to resemble those shown beneath the Lewis overthrust in plate 53*B* and *C*. Most folds are cracked on or near their crests, and in many places the cracks have grown into overthrusts. Most of these thrusts are small. In the vicinity of Glacier National Park none appear to approach the Lewis itself in magnitude, but farther northwest and southeast some may do so. Much of the folding and part of the fracturing was well advanced before the major fracture that developed into the Lewis overthrust originated. As the Lewis overthrust grew, the folds and fractures continued to yield to mounting pressures. The intricate crumpling and crushing in the immediate vicinity of the main overthrust, visible in localities like that near Marias Pass, shown in figure 139, must have taken place when the heavy overthrust slab was forced over the soft rocks beneath.

Folds that originated at the time represented by plate 53*B* but that have been accentuated and locally broken by the effects of later pressures, are visible in ridges, cliffs, and canyon walls both in the mountains south of Glacier National Park and in the part of the Great Plains within some 20 miles of the mountain edge at the eastern border of the park. All the sedimentary rocks that were present were squeezed and folded, but the Belt series, being strong and buried under a blanket of other rocks, was deformed the least. Most visitors, especially those who stay on the roads, get the impression that the Belt strata are undisturbed and lie almost as flat today as they did when deposited in the sea that vanished so many million years ago. Actually they are folded, and in certain zones they are intensely so. From points on and near the trails in the park it is possible to observe places where the beds of the Belt series, as revealed in outcrops on ridges, cliffs, and canyon walls, are folded and crumpled almost as intricately as the soft younger strata in the mountains south of the park and in the Great Plains adjoining the park to the east.

One example of crumpled Belt rocks is shown in figure 137. The mountains in this view are not far north

FIGURE 137.—Folded rocks of the Belt series on McPartland Mountain, as seen from the trail to Sperry Glacier. This is one of several zones of relatively intense crumpling in the hard rocks of the park. The photograph has been retouched slightly to emphasize structure.

FIGURE 138.—Contorted quartzite in the Grinnell argillite, Two Medicine Pass. The light bands represent layers of tough quartzite that were bent and contorted during the disturbance that produced the Lewis overthrust.

of Lake McDonald and the highway, but steep trail climbing is necessary to bring one to points from which the folds are visible. Figure 138 shows a close view of an outcrop of crumpled Belt strata (Grinnell argillite) along the rarely used trail over Two Medicine Pass.

As a result of the folding, the strata were crowded laterally into less space than they had occupied before, which to some extent relieved the accumulated crustal stresses. Compression continued, however, and eventually the strata broke. The great fault known as the Lewis overthrust developed. The beginning of overthrusting initiated the climactic stage in mountain building.

The fracturing that gave rise to the Lewis overthrust began several miles below the surface and probably a long way west of the site of Glacier National Park, where the hard but brittle Belt rocks broke. A slab of tremendous dimensions began to move towards the plains region. As the process went on, this slab extended far northwestward into Canada in one direction and southeastward into southern Montana in the other, a distance of at least 350 miles. The fault surface beneath the displaced slab of rock sloped southwestward. Once the fracture had occurred the pressure that had caused it forced the displaced slab to travel eastward. In some places only a single fault surface formed, with crushed and crumpled soft rocks beneath it. Such a place appears in the cliffs north of Marias Pass, as shown in figure 139. More commonly, numerous faults formed, the larger of which were roughly parallel to each other.

Rocks between these faults were crumpled and crushed in a variety of ways. In some places the zone in which fracturing occurred was as much as 2,000 feet thick; generally it must have been at least several hundred feet thick. Plate 53*C* shows the situation believed to have existed after overthrusting reached the site of Glacier National Park.

Millions of years probably elapsed between the time when the overthrusting began and the time when it completely ceased. During this long interval, the overthrust slab must have moved very slowly and with frequent pauses. Though the total displacement eventually amounted to many miles, some of the individual movements might have gained only a few inches before

FIGURE 139.—Lewis overthrust on Summit Mountain, as seen from Marias Pass. The dark rock on the upper half of the mountain is of Precambrian age. The lower, lighter colored rock is of Cretaceous age. Note the extreme amount of folding in the Cretaceous rocks under the Lewis overthrust.

cumulative resistance forced a halt. The applications of pressure were intermittent, and tremendous friction had to be overcome in order to move the enormously heavy rock mass above the thrust zone. The magnitude of these physical factors—the pressures and the resistance those pressures had to overcome—is far too vast to comprehend or to express in terms of the ordinary units of measurement.

The fracture zone that constitutes the Lewis overthrust was inclined upward in an east and northeast direction toward the surface, as indicated in plate 53*C*. If it had reached the surface, the forward end of the moving slab of rock above the fracture zone would have been abruptly freed from the resistances that had retarded its progress underground. Motion for a time might have been rapid, comparable with the motion which takes place at the broken ends of a slab of concrete that fails in a testing machine. The eastern end of the overthrust block might have rushed forward tumultously. If such a thing had occurred, the rock at the eastern end of the moving mass, freed from the confinement from all sides that had formerly held it together, would have broken up; as it advanced over the surface of the ground the edge would have become a great pile of rubble. Masses of broken rock assigned such an origin have been found in front of overthrusts in other regions. The absence of rubble or breccia is among the compelling reasons that have forced the abandonment of the long-held idea that the Lewis overthrust emerged at the surface and moved over a plain near the front of the present mountains. Those who held that idea assumed that the ground surface was then level enough so that the overthrust slab could move over it readily. They also thought that the relatively flat surfaces that cap ridges east of the park are remnants of the nearly level topography over which the Lewis overthrust moved after it had reached the surface of the ground.

If the advancing slab of rock had been pushed out into the air, the confining pressures that held it together would have tended to be dissipated. Such a slab moving over ground as irregular as is now believed to have existed should have scarred and broken the hills and have itself been broken to a greater or less extent, depending on local conditions. No evidence of either of these things has been found. Further, the flat uplands are regarded now as remnants of a surface much younger than, and not directly related to, the overthrust. The development of this younger surface, called the Blackfoot surface, was guided, to some extent, by the differences in resistance in the rocks above and below the overthrust. The partial correspondence in position between the thrust surface and the remnants of an erosion surface that developed later results from this guidance.

We know little about how major faults like the Lewis overthrust come to an end. Somewhere and somehow each must do so. In the vicinity of the park, the rocks above and below the thrust zone are so completely different from each other that an end to the discordance is difficult to visualize. One possibility is that at a distance of many miles to the east the fracturing gradually decreased and the thrust zone finally feathered out in a few minor cracks without reaching the surface at all. Another possibility is that the thrust zone did reach the surface but so far east of the present mountain front that all evidence of it has been eroded away long since. To the northwest and southeast the thrust zone extends far beyond the limits of Glacier National Park into regions whose geology is incompletely known. Probably in both these directions the thrust zone passes into groups of minor fractures and into folds.

The total amount of displacement on the Lewis overthrust—that is, the distance the rock slab was moved eastward—is a matter of great interest. It has been stated commonly that the displacement amounts to at least 15 miles. This figure is based on the fact that the most easterly exposure of the overthrust, along the mountain front, is about 15 miles east of the exposure in the vicinity of Marias Pass, measured at right angles to the general trend of the overthrust. Certainly the displacement is at least this great, but it could be much greater. East of the mountain front the Cretaceous strata underlying the Great Plains are conspicuously deformed throughout a belt extending 20 miles and more from the most easterly exposure of the overthrust. The deformation in these rocks resulted from the forces that culminated in the overthrust. It is reasonable to suppose that the overthrust slab once extended over most or all of the disturbed zone. Hence one should add 20 miles, locally more, to the figure of 15 miles previously mentioned, and 35 or 40 miles would then represent the minimum amount of displacement. As the Lewis overthrust disappears from view westward under the mountains and is not known to reappear anywhere, the total amount of displacement cannot be determined. It may be much greater than 35 miles. Plate 53*D* shows the situation today. This diagram, like the others in the sequence, corresponds only to the central part of Glacier National Park. If one inspects the diagram and visualizes the Lewis overthrust extended in both directions from the small segment of it shown, it is easy to see that the actual displacement may be very large.

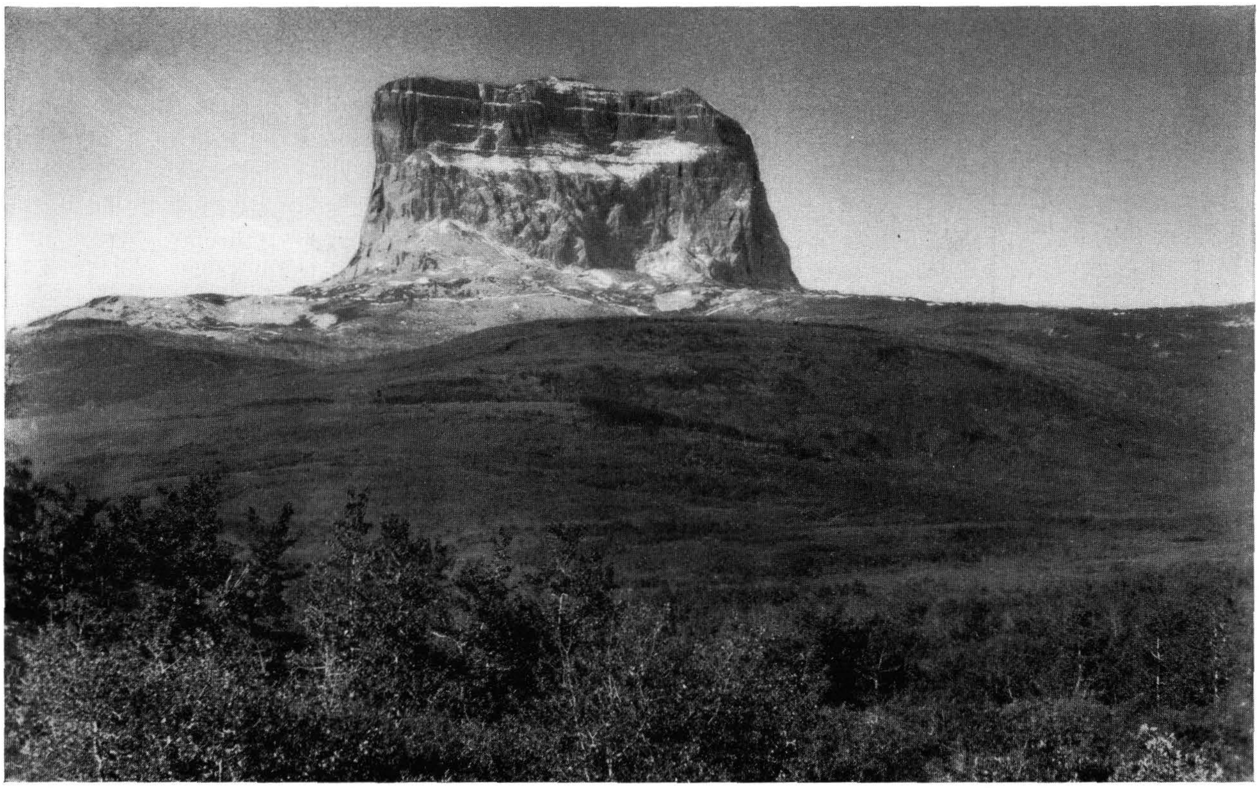

FIGURE 140.—Chief Mountain from the northeast, as seen from the East Fork of Lee Creek. (Photograph by Eugene Stebinger.)

The trace of the Lewis overthrust zigzags back and forth along the eastern border of the park. Exposures on the sides of the embayments and prominences of the mountain front enable one to observe some of the characteristics of the thrust zone. In most places near the eastern border the thrust is inclined at such low angles that it looks flat. The dip varies, but it averages less than 10°. However, both south of Marias Pass and north of the international boundary the thrust zone is much more steeply inclined, probably at 45° and more. One cannot be sure whether the variations in dip are original or the result of disturbances later than the thrusting. It seems likely that most of the irregularities were produced while the overthrusting was in progress. The thrust zone far north and south of the park displays other irregularities. The fault surfaces branch and are locally interrupted. Probably if one could follow the zone continuously north or south he would finally reach a point where the fractures either feather out or merge into folds. At such a point the amount of displacement would be small, even though at intermediate points it was large. Where the thrust zone is steeply inclined, it promptly attains such depths that all its influence on topographic forms is lost. Where, as near the eastern border of the park, the zone is comparatively flat, it exerts greater influence on the topography. This is one of the reasons for the scenic splendors for which Glacier National Park is famous.

Sharp contrasts in rock character that are so well displayed in the park gave rise to the term "rootless mountains," which is often applied to the mountains. The significance of this term is especially obvious with regard to the mountains along the eastern border and outlying summits, such as Chief Mountain (figs. 140 and 141), where the pedestal on which the mountain rests is composed of shale of Cretaceous age, but the mountain itself is carved from the more resistant beds of the Belt series. The fracture zone of the Lewis overthrust lies between the two and the result is a marked zone of weakness on the lower mountain slopes.

Erosion has sapped or undermined the Belt rocks, and this process has developed the exceptionally steep, bold mountain slopes facing the Great Plains. It has aided greatly in the relatively rapid retreat of the mountain front that has laid bare so much of the disturbed zone originally overlain by the slab above the overthrust. Where mountain streams have cut through the fracture zone into the soft rock (largely shale) below, the front of the Lewis Range has been embayed. If streams had been able to cut deep enough into the central part of the Lewis Range or into the Livingstone Range to the west, the mountains there would have been shown to be similarly "rootless"; that is, the rock encountered be-

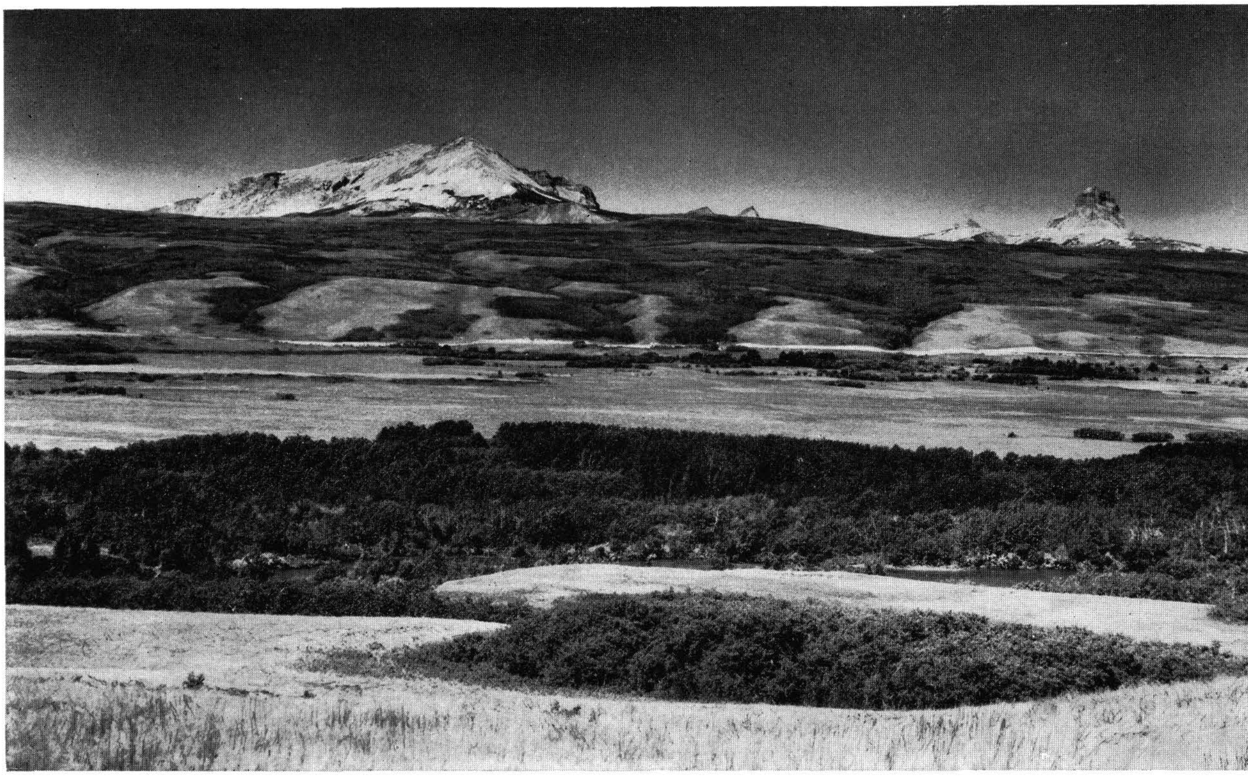

FIGURE 141.—View west across St. Mary River valley toward Yellow Mountain and Chief Mountain, showing the very irregular eastern margin of the Lewis Range. (Photograph by H. E. Malde.)

neath the overthrust would have been strikingly different from that from which the present mountains are carved. It would have been as different in different localities as the rock now exposed in the mountains south of the park. The diversity in character and age of the rocks in those mountains is shown in appendix A.

The process of overthrusting caused hard, massive Belt rocks to be pushed against and over soft ones, so that the latter were compressed anew and probably also shoved deeper into the earth. As a result, the height attained by the top of the overthrust slab might not have been spectacularly great. If all the rocks had been so resistant that they were essentially incompressible, the slab that was shoved forward during the thrusting would have moved some miles upward into the air. But there are reasons for believing that this did not happen. One reason is that the upper surface of the slab would have been attacked by erosion as soon as uplift started. As the overthrust movement was slow and erosion in the uplifted region was vigorous, much of the upper surface of the advancing slab was worn away before it had had a chance to attain really great heights. The fact that the rocks beneath the overthrust were shoved downward during the disturbance also had great influence in limiting the height attained by the surface of the ground.

Differences in the assumed position of sea level with relation to the ground surface in the block diagrams in plate 53 are intended merely to give an idea of the relief at different stages in the history of the region. The diagrams indicate that the mountain tops were higher above the sea after thrusting than they were before, but not tremendously so. The final diagram, which corresponds to the present day, shows that erosion has been vigorous enough so that the height above sea level is less now than it was at the close of the overthrusting. This is probable even though, on the whole, regional uplift might have been continuous.

Despite the strength of the Belt rocks, it would hardly seem likely that the overthrust slab itself could wholly escape deformation, in view of the great distance it was shoved, the magnitude of the stresses it transmitted, and the enormous frictional resistance it encountered. Attention has already been called to folds locally developed in the overthrust slab during the upheaval. The zone that includes the folds in McPartland Mountain, shown in figure 137, extends from near the Canadian border to the southern part of the park. It is more tightly folded than any other part of the overthrust slab within the park, but the entire slab is flexed into broader folds.

After the major thrusting the slab must have settled, and strains within it tended to be relieved by fracture and faults, accompanied by some folding. The largest of these faults extend northwestward and are in or on the borders of the master valleys in the drainage basin of the Flathead River. A few smaller faults have been detected along valleys roughly at right angles to these. Many of the fractures produced during the settling of the overthrust block produced little displacement in the rocks and many of these might have escaped detection.

Wherever the rocks were broken, streams were able to cut their valleys faster, a fact which has influenced the drainage pattern in the region. In addition, the larger faults of northwesterly trend appear to have allowed slices of the rocks to drop. The depressions thus formed were occupied and enlarged by rivers. In the course of this process the depressions became floored with sediments. That part of the valley of the Flathead River that lies along the western border of Glacier National Park is a conspicuous example. The valley of the Middle Fork of the Flathead is another. In both the principal fault is thought to be a few miles northeast of the present streamway. Movements along faults of this kind continued intermittently for a long time Perhaps the earthquakes that occasionally are felt in Montana are related to movements of this kind. However, no direct evidence is known of movement as recent as this in the Glacier National Park region.

The two valleys just mentioned and others like them, mostly outside the park, contain a variety of sediments, dumped mainly by active streams from the mountains on either side. In the course of the sedimentation, undrained or nearly undrained hollows were formed in the valley bottoms, giving rise to lakes, ponds, and swamps. Plant remains accumulated in some of these and were eventually converted into coal of varying quality. Some of this coal has been mined for fuel on a small scale, notably at the Coal Banks which is west of the Flathead River and nearly opposite the mouth of Logging Creek.

The oldest of these sediments, now converted into rock, are of Eocene or perhaps early Oligocene age. Sedimentation within the river valleys was intermittent and was interspersed with disturbances that tilted and broke the beds. The forces exerted were trivial in comparison with those related to the Lewis overthrust. Some of the movements may represent nothing more than settling of unstable blocks under the load of later sediments. Most of the tilted sedimentary rocks are of Tertiary age, but some contain fossils that seem to show that they were deposited early in Pleistocene time, less than a million years ago. Slight movements might have occurred even more recently.

These Tertiary and early Pleistocene rocks are for the most part hidden beneath recent stream and glacial deposits, and therefore they are to be observed only in those places where the beds have been freshly exposed, as in stream cuts and manmade excavations. With a little search, one can find good exposures that exhibit tilted and crumpled beds—for example near the North Fork Road between West Glacier (formerly Belton) and the Canadian border, along U.S. Highway 2 between Nyack and Walton, and the bank of the Middle Fork of Flathead River below Double Mountain—visible from U.S. Highway 2.

This chapter has sought to explain how the mountains of Glacier National Park acquired their geologic structure. It has emphasized the fact that mountain building proceeded by stages that were different in character and that unfolded majestically one after the other through millions of years. In terms of geologic chronology, the mountain-building movements began late in Cretaceous time, then gained in intensity, and culminated in the overthrusting during late Paleocene and early Eocene time. Thereafter the movements diminished, but they continued intermittently until relatively recent time.

LANDSCAPES AFTER THE OVERTHRUSTING

In the development of the topography of the Glacier National Park region, deformation of the earth's crust by titanic pressures and sculpture of the surface through the agencies of weathering and erosion went hand in hand. Streams, glaciers, and wind; heat, cold, and frost; rain and avalanches—various forces of this kind have affected the region at one time or another, and all have played a part in giving character to the landscape. But these forces would not have been able to bring into being the majestic scenery of the present if the earth's crust had remained quiescent since the dramatic disturbances associated with the Lewis overthrust died out. No comparably violent earth movements have taken place. On the contrary, the relatively recent crustal movements have been mainly intermittent, broad uplifts in which the mountainous area must have risen at a faster rate than the plains to the east. Nearly all the movements were so gentle that they left little discernible imprint on the rocks; their record is to be sought in complexities and apparently anomalous features of the topography.

Throughout the late Tertiary and probably somewhat beyond the close of that period the process of carving and modifying the topography continued steadily. Uplift persisted enough so that the streams remained vigorous. Erosion worked faster than crustal rise, as illustrated by the difference in relief above sea level between plate 53 *C* and *D*. The streams that existed when movement along the Lewis overthrust came to an end were guided to a large extent by structural features and by any irregularities that may have persisted from the time, long previous, when the land emerged from the sea. Many streams had sought out courses along faults and related features, including minor fracture zones. As the principal faults and folds trended toward the northwest, similar trends had become evident also in the orientation of major valleys and ridges. Many of the other mountain valleys trend roughly at right angles to these. A few, such as the valley of Ole Creek, follow known subsidiary faults that can be mapped with some degree of certainty. Others may follow undetected faults or fracture zones that have weakened the rocks without noticeably moving them. Many of the valleys began to be carved before the post-Belt rocks were eroded away and might have been controlled by features in those rocks not detectable in the resistant rocks that remain.

With continued modification of the landscape, the streams gradually deepened their channels and, in consequence, flowed more and more slowly. Meanwhile the principal valleys acquired gentle slopes and broad, flat floors, and the uplands between the valleys assumed rounded forms. If this had continued long enough the valleys would have been widened until the ridges between them were all but consumed, so that the region would have been essentially reduced to a plain, across which the streams would have meandered sluggishly. Actually, this did not happen. The principal mountain masses were not obliterated or even extensively subdued. Although the valleys were far broader and their sides gentler than they are at present, the streams remained vigorous enough to carry gravel from the mountains outward to mantle the plains to the east. The landscape forms more nearly resembled those near and west of the town of Kalispell (pl. 52) than the cliffs, canyons, and pinnacles of the present park. For convenience, the old surface to which those forms belonged has been called the Blackfoot surface. Figure 142 is an attempt to reconstruct the appearance of a part of that surface. At present the maximum relief within the park is nearly 7,400 feet. In contrast, the maximum relief there in Blackfoot time might have been between 2,500 and 3,000 feet.

Remnants of the Blackfoot surface are widely scattered over the park and the surrounding country. All of them, of course, have been modified by later events, many so much so that recognition is difficult or doubtful. The largest existing remnants of lowlands of Blackfoot time within the mountains are the broad, nearly level summits of Flattop Mountain and West Flattop Mountain. In fact, these mountains were so named because both are surmounted by remnants of what probably was once a very wide valley floor. The preservation of features such as these in the midst of a region as rugged as Glacier National Park seems extraordinary and anomalous, but several reasons for it can be offered. The lowland of which they are remnants was one of the largest in the mountain area because it was developed along one of the greatest of the downwarps in the region, a downwarp so broad that the rocks along its lowest part were scarcely flexed at all. The nearly flat strata that are exposed in the bottom of the downwarp in the locality of the two Flattops are hard enough to have resisted erosion. The canyons of McDonald Creek, Mineral Creek, and others have cut deeply, but substantial patches of the old surface, held up by resistant rock, are preserved. Smaller flat areas, such as Granite Park, The Hanging Gardens, and many others, originally merged with the plain on the summits of the two Flattops. Undoubtedly the plain or broad valley once extended northward over the present Waterton Valley, for the flat area south of Kootenai Peak, the nearly flat crest of Porcupine Ridge, and other similar features near the Canadian border closely correspond to it in altitude.

Beyond the mountain front, in the Great Plains to the east and southeast of the park, are hills with flat tops bearing gravel. These flat summits likewise represent erosion surfaces, a few small patches of which have survived here whereas elsewhere they have been worn away. The most prominent summit flats are probably remnants of the Blackfoot surface. St. Mary Ridge and Milk River Ridge are among the larger hills thus capped. The flat ridge tops correspond in position to portions of a nearly flat plain believed to have been present at the time that the broad valleys were forming within the mountain mass. Streams emerging from the mountain valleys deposited gravel on the plain at the eastern border.

Another broad valley lay along the west border of the park, where now is situated the southeastward-flowing part of the main Flathead River, locally called the North Fork. Here the long, smooth-topped spurs between the river and the southwest side of the Livingstone Range are so different from the rugged mountains of that range as to demand an explanation. Unlike the two Flattops, the spurs are composed of soft strata of Tertiary age and are mantled by still younger glacial debris. The spur crests are believed to be modified remnants of the floor of a valley of the Blackfoot surface, now cut by streams from the Livingstone Range.

The topography of Glacier National Park has been so greatly modified during the last million years that it is now difficult to reconstruct all the features of the

Blackfoot landscape. Nevertheless it is certain that that landscape differed from the present one in having lower local relief and more subdued contours and also in details of the drainage pattern. A striking instance of the latter difference is to be found along the western border of the park. When one views the present topography from the lookout above Hidden Lake near U. S. Highway 2, or from a similar vantage point, he is struck by the fact that the valley of the upper part of the Flathead River (the North Fork) lines up so perfectly with the valley of the Middle Fork of the Flathead that they look like a single valley. This is far from being true nowadays. The two branches of the Flathead now flow in opposite directions, and both swing sharply westward before they come together southwest of the Apgar Mountains. East of the Apgar Mountains lies a broad, high depression which is wholly streamless in that central part called McGees Meadow and which elsewhere is drained only by streams so tiny that they could have had little to do with the carving of the depression. One can hardly escape the conclusion that formerly a single river flowed northwest from near the mouth of Bear Creek down the valley of the Middle Fork, over McGees Meadow, and thence into Canada.

THE GLACIERS

The more striking features of the scenery of Glacier National Park result from glacial sculpture, but glacial sculpture there and in the adjacent Waterton Lakes Park could not have been so spectacular if the geologic history had been different. The effects of glaciation are outlined below, but the processes of glaciation which are described in other publications, are not given detailed treatment.

Glaciers formerly existed in all the mountains of the general region, but glacial sculpturing on a scale comparable with that in the two parks is absent. One reason is that the large and massive Lewis and Livingstone Ranges rise farther above the lowlands at their bases than the nearby ranges. Another is that the thick-bedded, relatively flat-lying but much-jointed rocks of the Belt series are ideally suited to yield cliffs, aretes and other awe-inspiring forms through the agency of glacial sculpture. The forms of the Lewis overthrust itself and of the great slab of rock moved forward by that thrust had much to do with localizing the cliffs and aretes within the area now covered by the two national parks. Further, the eastern front of the mountains of Glacier National Park would not be nearly so impressively precipitous today if the geologic structure had not been such as to facilitate rapid retreat of that front by undermining or sapping once erosion was in a position to attack. Details of the structure of the slab above the thrust zone are reflected in the modern topography. For example, the stream pattern corresponds largely to zones of structural weakness in the rocks. Many of the higher, more rugged mountains are carved from crumpled and upheaved rocks. The largest and broadest downwarp in the rocks is reflected by relatively low and flat-topped mountains, such as Flattop Mountain in the north-central part of the park. The contrasts that have resulted from features of this kind add to the interest of the scenery.

Not long after the close of the Tertiary period the climate of the Northern Hemisphere changed so that huge glaciers formed on the northerly parts of the land areas and smaller glaciers formed in mountain masses farther south. Vast sheets of ice—glaciers of continental proportions—originated in Canada and moved outward in all directions from the centers of ice accumulation. In the Mississippi Valley, and, to a less extent, farther east, the continental glaciers advanced hundreds of miles into the United States. In Montana they approached but never quite reached Glacier National Park. The edge of the continental glaciers barely entered the northeast corner of the region shown in plate 51. Smaller glaciers formed in the mountains, originating near range crests and flowing down valleys. Glaciers of this sort are termed mountain or alpine glaciers or, emphasizing the features that restrict them, they may be called valley glaciers. All such terms contrast the glaciers within mountains with the continental glaciers that spread with relatively little regard for local topographic forms.

In the Glacier National Park region the Blackfoot surface had been cut by reinvigorated streams before mountain glaciation began. When conditions made it possible, glacial ice gathered at the heads of the streams and started to flow down the valleys. Thus, about a million years ago, began the glaciation of the ice age (the Pleistocene epoch of the geologic time scale). The climatic factors responsible for the extensive glaciation probably were complicated, and as yet they are not well understood, but the fact that such glaciation did take place was long ago established. A wealth of detailed information about the vicissitudes of the ice age and the changes its glaciers wrought has been gathered as a result of studies made in many parts of the world, including the region of Glacier National Park.

As soon as mountain glaciers started they began to carve the rocks on which they lay. In upland valleys the ice plucked out joint blocks and started to produce the cliffs and supersharp ridge crests for which Glacier National Park is famous. The rocks attacked by the ice were broken down into rubble which, in turn, was embedded in the moving ice and served to scour off the surfaces over which the glaciers advanced. Many of the lakes throughout the park were formed by rubble-laden ice that bit into the rock, forming hollows that were later to be filled by water. Some of the lakes have been increased in size and some might have been created by dams of loose material thrown across valleys by the glaciers or by tributary streams after the glaciers had retreated.

Glacial erosion was accompanied by glacial deposition. In many places more rubble was formed than could be ground up into silt or carried away either by the glaciers themselves or by the streams of meltwater that issued from them. Piles of debris accumulated along the sides and at the ends of the glaciers. Within the mountains, debris masses (moraines) left by the glaciers of the ice age partially have since been swept away or modified beyond ready recognition. Where large mountain glaciers reached and spread on the plains or in broad valleys cut in the plains, the ground over wide areas was mantled by glacial debris, in places to depths of scores or even hundreds of feet. As a result, even now, bedrock in most areas east of the mountains can be seen only in the sides of valleys trenched through the glacial mantle by later streams.

Glaciation was by no means continuous. The glaciers grew and retreated in sensitive response to fluctuations in climate. Within the ice age proper there were two sharply separated glacial episodes, each of which might have had at least two subdivisions: During the first of the two major episodes the ice occupied and enlarged former stream valleys incised in the Blackfoot surface. The glaciers covered much of the mountainous tract and extended to the plains east of the mountains. An interruption might have occurred within this glacial episode at least long enough for the ice to have disappeared temporarily from the plains. At the close of the first major episode the ice might have melted almost entirely. Stream erosion appears to have been extremely active at this time, so that the valleys were deepened greatly and much of the glacial detritus in them was swept out. The great valleys of the region were cut almost to their present depths during this interglacial interval. Apparently some were deepened as much as 3,000 feet. Figure 143 is a view of a portion of the area as it might have appeared while the deepening by stream erosion was in progress.

Views showing stages in the development of the present topography in Glacier National Park are given in figures 142, 143, and 144.

When the glaciers returned after the interglacial interval, they moved down the greatly deepened valleys and nearly filled them with ice. All the mountains except the higher peaks and ridge crests were buried under the ice streams. Probably few peaks rose more than 1,000 feet above the ice. Some of the larger glaciers not only reached the plains to the east but pushed many miles across them, depositing detritus. A few trunk glaciers are thought to have reached to, or close to, the border of the continental glacier that entered the northeast corner of the region, as shown in plate 51.

West of the Continental Divide also, many large glaciers filled the mountain valleys. The largest passed westward through Bad Rock Canyon and possibly other openings in the mountains beyond the park limits into Flathead Valley, where they joined ice moving southward from Canada. The confluent ice lobe pushed southward to the site of the town of Polson, where it deposited the morainal dam which impounds Flathead Lake. At an earlier stage, a similar ice lobe reached 18 miles still farther south, leaving a moraine near Charlo, Mont.

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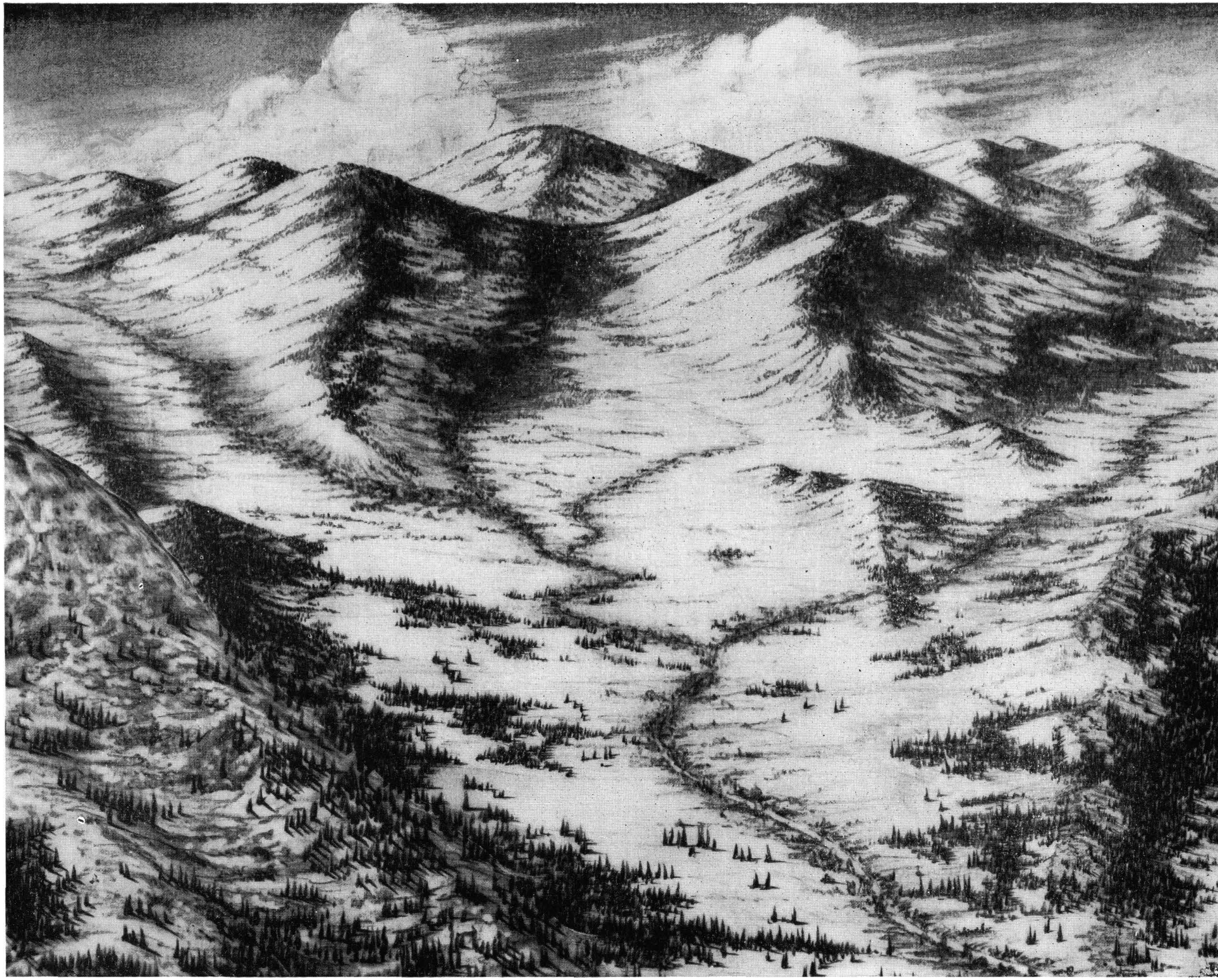

FIGURE 142.—A stage in the development of the present topography in Glacier National Park, based on an inclined aerial photograph of the head of Red Eagle Creek in the Lewis Range: Topography after the Blackfoot surface had formed.

FIGURE 143.—A stage in the development of the present topography in Glacier National Park, based on an inclined aerial photograph of the head of Red Eagle Creek in the Lewis Range: Topography at about the middle of Pleistocene time, early in the stage of accelerated erosion that preceded the main Wisconsin glacial advance.

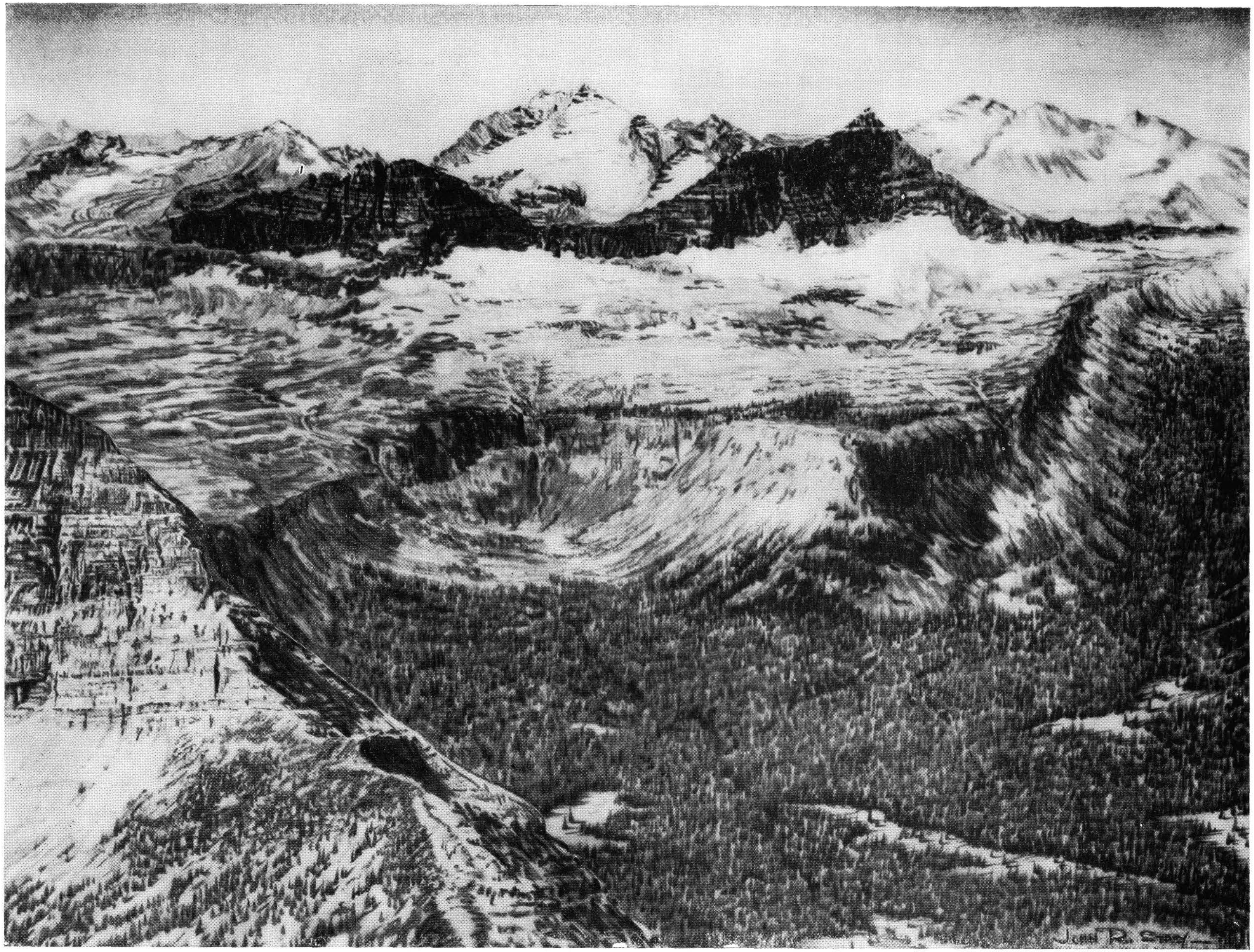

FIGURE 144.—A stage in the development of the present topography in Glacier National Park, based on an inclined aerial photograph of the head of Red Eagle Creek in the Lewis Range: Topography at the present time.

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APPENDIX

APPENDIX A.—*Age and character of the rock units of Glacier National Park and vicinity*

Geologic age	Group	Formation or rock unit	Character	Thickness (feet)
Recent.		Modern alluvium, etc.	Sand, silt, and gravel in stream bottoms, and hill wash and landslide debris on slopes.	Variable, generally thin.
Pleistocene.		Glacial deposits (deposits of several glacial stages present).	Gravel, poorly sorted and rounded, and sand and silt; in part in moraines and other features whose forms show their glacial origin.	Variable.
		Terrace alluvium (products of several erosion episodes).	Gravel, sand.	Variable.
Late Eocene and younger, probably includes Pleistocene.		Old alluvium and associated deposits.	Sand, clay, limy deposits, cemented gravel, lignite; all compacted and more or less cemented; commonly mantled with younger material; not distinguished on maps.	At least several hundred.
Cretaceous.	Montana.	St. Mary River formation.	Clay and sandstone, light-gray, fresh and brackish water types, and some red and varigated shale.	Somewhat less than 1,000.
		Horsethief sandstone Bearpaw shale and Two Medicine formation distinguished locally only. Eagle sandstone and Virgelle sandstone present in small areas.	Sandstone and shale, largely gray and green; marine.	3,000±.
		Colorado shale.	Shale, mostly dark-colored, and some sandy shale and sandstone.	Not measured; total may be 1,800+.
		Kootenai formation.	Sandstone, principally red-purple, red, gray, and green, and some sandy and carbonaceous shale and firmly cemented gravel; laid down on the continent rather than in seas.	Variable; maximum may be 1,500±.
Jurassic.	Ellis.	Two or more formations present but not separately mapped.	Shale, largely soft, black, and some sandy limestone and sandstone; marine.	400.
Carboniferous.		Hannan limestone.	Limestone, thick- and thin-bedded, in part dolomitic, and a little shale; marine.	1,500±.
Devonian.		Probably 2 or 3 formations present but not named or separately mapped.	Limestone, largely dark, in part fetid, marine, and some calcareous shale.	1,500±.
Cambrian.		Formations not distinguished in the region immediately south of Glacier National Park. Farther south, Switchback shale, Steamboat limestone, Pentagon shale, Pagoda limestone, Dearborn limestone, Damnation limestone, Gordon shale, and Flathead sandstone, in descending order, are distinguished.	Limestone, much of which contains blebs of clay, in part shaly; more or less micaceous shale, in part carbonaceous at several horizons; quartzite and a little conglomerate at base.	Variable—1,900±.

APPENDIX A.—*Age and character of the rock units of Glacier National Park and vicinity*—Continued

Geologic age	Group	Formation or rock unit	Character	Thickness (feet)
Precambrian (Belt series).	Missoula.	Probably more than 7 formations, but mostly not named and only in part distinguished on maps.	Argillite, red-purple and green, and calcareous and sandy argillite interspersed, a little conglomerate and some quartzite, lenses of limestone, some of which are thick, are present locally; Purcell basalt, lava flows up to 200 feet thick, near base of group; contains algal remains.	Possibly as much as 20,000 originally, only remnants now present within the park.
	Piegan.	Siyeh limestone.	Limestone, dark-bluish-gray, somewhat magnesian, locally oolitic and argillaceous; "molar tooth" markings are common; contains several zones of algal remains.	1,800–5,000; may exceed 5,000 locally.
	Ravalli.	Grinnel argillite.	At top: argillite, grayish-blue-green, calcareous. Main body: argillite, red-purple, red, and green, locally calcareous, and some light-colored quartzite.	1,000–4,000+; probably near 3,000 in most places.
		Appekunny argillite.	Argillite, dark-gray and greenish, siliceous, locally limy; quartzite prominent locally; subordinate reddish beds in places.	2,000–5,000+
		Altyn limestone.	Limestone, dark, impure magnesian, with sandy beds; contains algal remains.	2,000±, with the base not exposed.

APPENDIX B.—*Approximate geologic time scale*

[The ± figures express probable degree of accuracy of estimates]

Geologic age	Approximate number of million years ago [1]		Approximate length in millions of years [1]
Quaternary	0–1	±50,000 years	1
Tertiary:			
Pliocene	1–12	±1–2 million years	11
Miocene	12–28		16
Oligocene	28–40		12
Eocene, Paleocene	40–60		20
Cretaceous	60–130	±5 million years	70
Jurassic	130–155		25
Triassic	155–185		30
Permian	185–210	±10 million years	25
Carboniferous	[2] 210–265		55
Devonian	265–320		55
Silurian	320–360		40
Ordovician	360–440		80
Cambrian	440–520		80
Precambrian	550–2,100	±10–300 million years [3]	5, 100+

[1] From the report of the National Research Council, Committee on the Measurement of Geologic Time, 1949-50, with minor modifications.
[2] Estimate of J. P. Marble, chairman, Committee on the Measurement of Geologic Time, March 17, 1954.
[3] The figure depends on the age of the crust of the earth. For the age of the crust of the earth, the data are at present uncertain, but the order of magnitude is about 3,250 million years.

APPENDIX C.—*Classification of fossil algae*

[After Johnson, 1951]

Class	Family	Characteristic structures
Rhodophyta (red algae)	Corallinaceae	Rows of closely packed cells, rectangular in section. Spore cases or conceptacles.
	Solenoperaceae	Rows of closely packed cells with polygonal cross sections. Cross partitions present though frequently very thin.
Phaeophyta (brown algae)	Laminariales and others	Corded strands of parallel threads. Frond types.
Chlorophyta (grass-green algae)	Charophyta	Highly developed small bushy plants. Fossils usually consist of calcified, heavily ribbed, spherical reproductive organs and the whorled branches that bear them.
	Dasycladaceae	A central stalk, preserved as a tube or bulb, surrounded by tufts of leaves or leaf bases, preserved as knobs or brushlike protuberances.
	Codiaceae	Small tubes, loosely arranged so as to form segmented stems. Tubes round in cross section and branching.
Cyanophyta (possibly Chlorophyta)	Porostromata	Small tubes so loosely arranged as not to compress each other. No cross partitions visible.
Cyanophyta (blue-green algae)	Spongiostroma [1]	Cellular structure rarely preserved. The lime is deposited as crusts on the outside of the colony or cell, or between the tissues, not in the cell wall. Classified on the basis of growth habit and form of colony.
Pyrrophyta (yellow-green algae)	No known fossils	
Chrysophyta (golden-brown algae)	Bacillariophyceae	Diatoms.

[1] Fossil algae of the Belt series belong to this group.

APPENDIX D.—*Key to the identification of fossil algae in the Belt series of Glacier National Park*

I. Incrusting forms, growth upwards from a point on the substratum by the addition of convex upward laminae. Genus: *Cryptozoon*
  A. Gross form turbinate.
    1. Laminae conform to upper surface of colony in later stages of development.
      a. Laminae smooth ---------- *Cryptozoon occidentale*, figure 126

II. Incrusting forms, growth upwards from a surface on the substratum by the addition of convex upward laminae. Genus: *Collenia*
  A. Gross form hemispheroidal or depressed spheroidal.
    1. Laminae conform to upper surface of colony.
      a. Laminae coarsely crenulate ---------- *Collenia undosa*, figure 132
      b. Laminae smooth ---------- *Collenia symmetrica*, figure 133
    2. Laminae conform to upper surface of colony only during later stages of development.
      a. Laminae finely crenulate ---------- *Collenia multiflabella*, figure 127
  B. Gross form irregularly cylindroidal.
    1. Laminae flattened to strongly convex.
      a. Laminae smooth ---------- *Collenia frequens*, figure 136

III. Colonies of nested conical laminae with basal apex attached to the substratum ---------- Genus: *Conophyton*
  A. Gross form cylindroidal.
    1. Axes of cylindroids at a low angle to bedding.
      a. Laminae smooth ---------- *Conophyton inclinatum*, figures 134, 135

APPENDIX E.—*Glossary*

Bedding	The layers in sedimentary rocks.
Conceptacle	A cavity opening to the surface of an algal colony; contains reproductive organs.
Crenulate	The minutely wavy character of the laminae in an algal colony.
Environment	The total of all the conditions and influences affecting the life and development of an organism.
Fault	A fracture in rock along which displacement has occurred.
Filament	A threadlike series of algal cells.
Fossil	A remain or a trace of a plant or animal of past geological ages, or direct evidence of its presence preserved in the rocks.
Algal head	Term used to refer to a single algal structure.
Joint	A simple fracture that is at some angle to the bedding of a rock.
Laminae	Thin layers; in this report, the thin subparallel to concentric layers of rock that comprise a colony of fossil algae.
Reef	A ridge or mound of sand or rock lying at or near the surface of the water. In organic reefs the ridge or mound is composed of the skeletons of organisms.
Turbinate	Shaped like a spinning top.

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