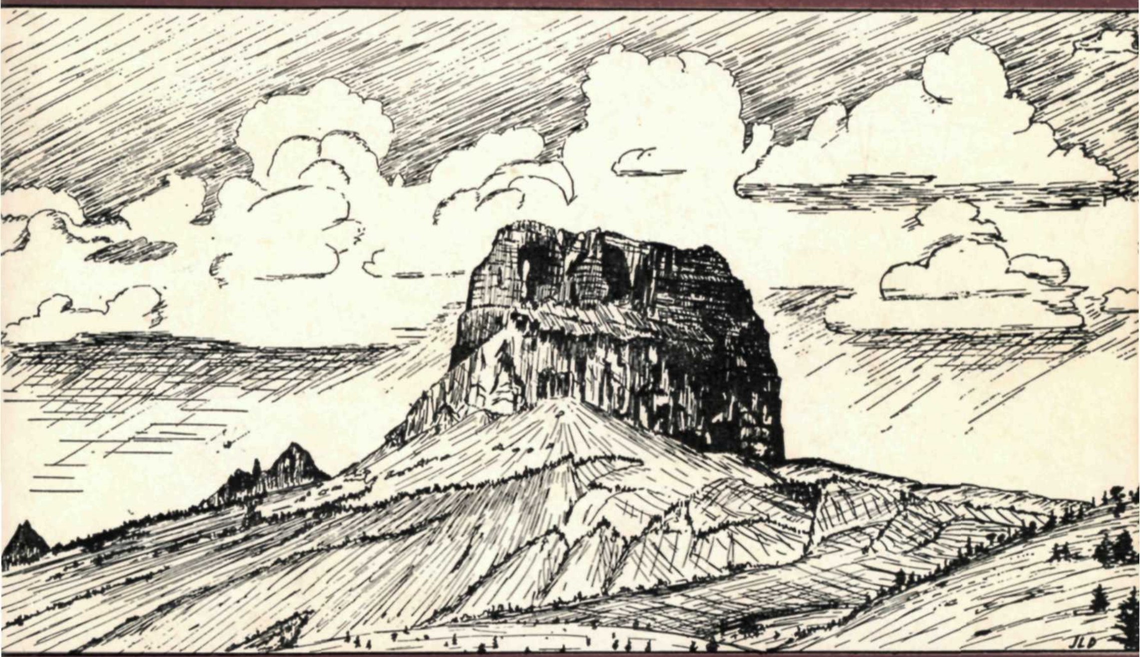
The Geologic Story of Glacier National Park



CHIEF MOUNTAIN

Special Bulletin No. 3

GLACIER NATURAL HISTORY ASSOCIATION

Price 25 Cents

THE GEOLOGIC STORY

o f

GLACIER NATIONAL PARK

By JAMES L. DYSON

Head, Department of Geology and Geography
Lafayette College*

Until recently a geologist was visualized by most people as a queer sort of fellow who went around the countryside breaking rocks with a little hammer. Fortunately, the general public today has a much clearer picture of the geologist and his science, but there are still many among us who mistakenly feel that geology is something too remote for practical application.

Geology is the science of the Earth. It includes a history of our planet starting with its origin, and a history of the life which has lived upon it. From it we can determine the reason for every feature of the landscape and every rock structure underneath the surface, and we can further learn what processes gave rise to them.

Practically everything to be seen on the face of the Earth owes its origin directly or indirectly to geological processes. These may be grouped into two great categories: Internal forces or agents which raise, lower, bend, and break the Earth's crust; and external, more familiar agents such as water, wind, and ice, which wear away the surface and carry the materials to another place — ultimately to the sea. Let us consider a few of the products of these geologic agents: (1) The soil covering most of the landscape and furnishing the plant products which serve as our food; (2) the solid rock, so conspicuous in all mountain ranges; (3) the hills, the valleys, and the mountains; (4) all the streams, ponds, lakes — even the sea. If you live in a place where man has covered up the rock and the soil, evidence of geological processes is yielded by the buildings themselves, whether they be of stone quarried from the Earth's crust, or of brick made from clay. The stone and brick are supported by a framework of steel originally taken from a mine in the form of iron ore. The concrete and asphalt of the roads came from rocks within the Earth, as did every drop of gasoline which plays so vital a part in world affairs today. Even those commonplaces of Ameri-

* Dr. Dyson worked as a ranger-naturalist in Glacier National Park for eight summers starting in 1935.

can life, the bottle and the "tin" can, are products of geology. As you read this you need look only at your watch or perhaps an item of jewelry which you wear to see something — gold, silver, platinum, a diamond or other gem stone — which is a part of geology.

Thus, from here it is a short step to the realization that a number of *geologic processes and agents working over long periods of time* have given rise to innumerable features and structures ranging from the loftiest mountains down to the smallest hills and valleys; from the soil which grows our food to the gasoline and coal which feed our industries; from our huge iron ore deposits down to the much smaller, but now no less significant, deposits of uranium.

How is all this related to a national park? Nowhere within our land can the accomplishments of the great geological processes, or their present-day operation, be seen to better advantage than in many of our national parks and monuments. In fact, it is for this reason principally that many of them were established. Notable is Grand Canyon National Park, containing the most spectacular part of the Colorado's mile-deep canyon cut during the past million or so years through a series of rocks which themselves record a billion or more years of Earth history. Mount Rainier is the largest volcano in the United States. On it glaciers are now wearing away materials formerly extruded and piled up to spectacular height by volcanic forces. Crater Lake lies in the sunken throat of a volcano which at one time probably rivaled Rainier in size. In Carlsbad Caverns and Mammoth Cave National Parks are two of the world's largest caverns which clearly demonstrate the tremendous effectiveness of subsurface water in dissolving limestone. Bryce Canyon and Zion National Parks and the Badlands National Monument illustrated on a much smaller but no less spectacular scale than the Grand Canyon the wonderful erosive power of running water. In Grand Teton one can see a huge block of the crust which has been raised thousands of feet along a high-angle fault, and at Lassen Peak in California and Craters of the Moon in Idaho there are exhibited some of the most recent volcanic features north of the Rio Grande. Despite Yellowstone's wildlife and fishing it is best known perhaps for its geysers. This brief list is by no means complete, for something of prime geologic interest can be found in almost every national park and monument.

Now we come to Glacier National Park. Within its boundaries there perhaps is exhibited a greater variety of geologic features than in any of the others. Much of the park lies above timberline so that the rocks which comprise its mountains are exposed to view. Held within these superb mountains is an entertaining geologic story which they are anxious and willing to tell us. All we need to do is unlock the door with

Chart of Geologic Time

(FOR A CHRONOLOGICAL ORDER OF EVENTS, THE CHART SHOULD BE READ FROM BOTTOM TO TOP)

ERAS	PERIODS	DATES	EVENTS IN GLACIER PARK AREA
CENOZOIC		The Present	Erosion of the mountains; formation of alluvial fans and talus cones.
	Post Glacial	15,000 B. C.	Birth of modern glaciers.
	Pleistocene		Appearance of present forests.
		1,000,000 B. C.	Extensive glaciation. Formation of lakes, waterfalls, horn peaks, cirques, Valleys scoured deeply by glaciers.
	Pliocene		
	Miocene		Disappearance of forests. Mountains worn down, raised, eroded again.
	Oligocene		
	Eocene		Lewis overthrust probably occurred early in Eocene.
		58,000,000 B. C.	
MESOZOIC	Cretaceous		Great mountain building (Rocky Mountain revolution) by forces which eventually formed Lewis overthrust. Sea withdrew and never again returned. Thick accumulation of marine sediments. Invertebrates abundant in sea. Expansion of the sea.
		127,000,000 B. C.	
	Jurassic		
	Triassic		Dinosaurs probably inhabited park and nearby area.
		182,000,000 B. C.	
PALEOZOIC	Permian		
	Carboniferous	255,000,000 B. C.	
	Devonian		Seas covered region during much of era.
	Silurian		
	Ordovician		
	Cambrian		
		510,000,00, B. C.	
PROTERO-ZOIC			Sea withdrew and region was eroded at end of era. Area covered by sea in which Belt sediments were deposited. Algae lived in sea. Intrusions (diorite sill and dikes) from flows (Purcell) of igneous material.
ARCHEO-ZOIC		2,110,000,000 B. C.	?

ERAS, PERIODS, AND DATES IN THIS CHART ARE IN ACCORDANCE WITH THOSE WHICH HAVE BEEN ADOPTED AS OFFICIAL BY THE NATIONAL PARK SERVICE.

the key the geologist gives us and then go see for ourselves. Why do the mountains rise so precipitously above the plains? What is that conspicuous black band across the faces of so many of the peaks, and how did it get there? Why are some of the rocks so red? The answers to these and other questions come out as the geologic story unfolds. The American people are interested in this story for they realize that to understand what they see is to increase their enjoyment thousandfold.

The Story Begins

The most striking feature of the mountains — certainly the one which comes first to a visitor's attention — is the color banding. No matter where one looks this feature greets his view. If he enters the park at the St. Mary Entrance, there ahead on the sides of Singleshot and East Flattop Mountains are white and purple bands. Should he enter first the Swiftcurrent Valley, he would soon note the banding in the mountains lying to his right and left, and finally culminating in the precipitous Garden Wall at the head of the valley. The visitor soon realizes that every mountain within the park is composed of rock layers of various colors. With very few exceptions these strata are of sedimentary origin; that is, they accumulated by depositions of muds and sands in a body of water and are now mainly limestones, shales, and sandstones. These sedimentary rocks all belong to a single large unit known as the Belt series, so named because of exposures in the Little Belt and Big Belt Mountains farther south in Montana. In Glacier National Park these rocks, which have a maximum thickness of more than 20,000 feet, are in the form of a large syncline (downfold), the east and west edges of which form the crests of the Lewis and Livingstone Ranges (Figure 3D). Throughout the large area of western Montana, northern Idaho, and southern British Columbia where Belt rocks occur, they are important mountain-makers. In addition to the ranges already mentioned they are the principal rocks in many others, including the Mission, Swan, and Flathead in the region south of Glacier Park; the Bitterroot and Coeur d'Alene between Idaho and Montana; and the Purcell in British Columbia. Further, rocks of similar age form the core of the Uinta Range in Utah and the lower section of the Grand Canyon in Arizona.

During the Proterozoic Era of Earth history a long, narrow section of North America extending from the Arctic Ocean southward, probably as far as Arizona and southern California, slowly sank to form a large, shallow, sea-filled trough known as a geosyncline (Figure 1). Streams from adjacent lands carried muds and sands into the sea, at times almost completely filling it. Inasmuch as thousands of feet of sediments were deposited, the geosyncline must have continued to sink throughout the period of sedimentation. Eventually the muds were compacted into shales, or limestones if they contained a lot of lime, and the sands into sandstones. These are the rocks we now know as the Belt series. The surfaces of many of the sandstone layers are covered with ripple marks which could have been made only by wave and current action in shallow water. Mudcracks on many of the shale beds prove that at times the sediments, probably near the mouths of rivers were exposed to the air long enough to dry out. Great thicknesses of limestone and numerous fossils of calcareous algae, primitive marine plants, are evidences that the body of water was a sea.

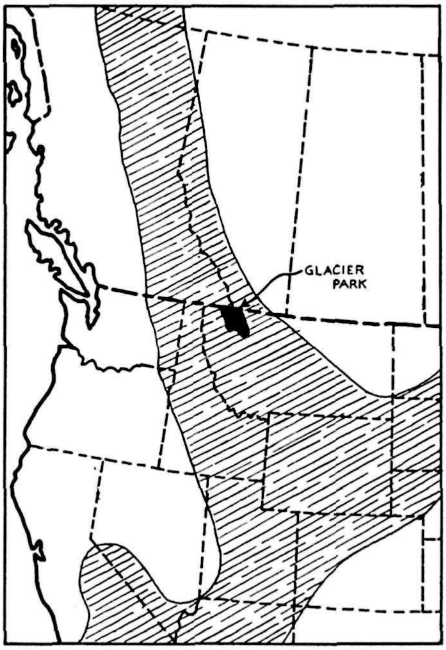
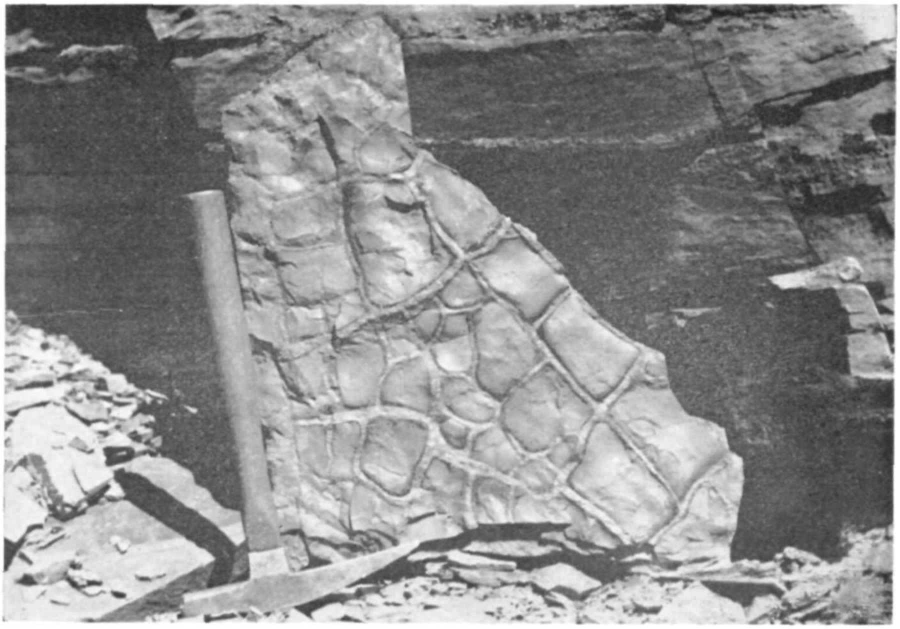


FIGURE I. BELT GEOSYNCLINE

Throughout the geologic past the appearance and disappearance of seas on the continents have been frequent events. In fact such changes are slowly taking place even today. Hudson Bay and the Baltic and North Seas are examples of shallow seas situated on the continents. The area around Hudson Bay is rising; as attested by the fact that some of the fish weirs constructed in water along the shore during the past several hundred years are now a considerable distance inland. We know also that our Atlantic coast has been subsiding for a number of years at an annual rate of about 0.02 foot. To be sure, these movements are slow, but if continued over a long period they might conceivably make some rather profound changes, even as the birth and death of the Belt sea.

Within Glacier National Park the Belt series is divided on the basis of lithologic differences into six distinct formations. Because each has a characteristic color, these formations can easily be identified, often from distances of several miles. Usually two, sometimes three or four, of them comprise a single mountain, the oldest always at the mountain base and the youngest on the summit, this being the relative position in which they were deposited in the form of sediment.



MUD CRACKS ON A LAYER OF THE APPEKUNNY FORMATION
(PHOTO BY C. L. FENTON. OUR AMAZING EARTH, DOUBLEDAY & CO.)

RIPPLE MARKS ON A LAYER OF THE SHEPARD FORMATION NEAR LOGAN PASS. THEIR ASSYMMETRICAL FORM INDICATES FORMATION BY CURRENTS IN SHALLOW WATER. (DYSON PHOTO)

The Belt Formations

ALTYN FORMATION. This is the oldest of the several formations and thus occupies a stratigraphic position at the base of the entire series. It is composed mainly of sandy dolomites (magnesian limestones) and limestones which weather to a light buff color. It outcrops all along the base of the eastern front of the Lewis Range and comprises the entire block of Chief Mountain. Because of its comparatively great resistance to weathering and erosion it usually forms a conspicuous ridge or terrace wherever it crosses a valley. In the Swiftcurrent Valley it forms the dam which holds in Swiftcurrent Lake and creates Swiftcurrent Falls. In Two Medicine Valley the highway crosses a similar terrace which gives rise also to Trick Falls. In the St. Mary Valley it creates the Narrows and forms the imposing wall in lee of which East Glacier Campground is located. The rock of this formation can best be examined on the ridge immediately east of Many Glacier Hotel (between hotel and parking lot) and above Swiftcurrent Falls. Its average thickness is about 2,300 feet.

APPEKUNNY FORMATION. Lying on top of the Altyn are 3,000 or more feet of prevailing greenish shales and argillites* comprising the Appekunny formation. Slabs of these rocks, because of their great hardness, have been used as flagstones in the walks at the Many Glacier Ranger Station and adjacent Park Service residential area. Mud cracks and ripple marks are common. The formation is prominent on the side of Singleshot Mountain near the St. Mary entrance to the park, and everywhere immediately overlying the lighter-hued Altyn along the east edge of the Lewis Range where, especially when seen from a distance, it appears to have a purplish color. It also outcrops along the western base of the Livingstone Range (Figure 3D), but such exposures are as a rule obscured by a cover of dense forest. Accessible outcrops can readily be examined along Going-to-the-Sun Highway for several miles east of Sun Point and near McDonald Falls, and also along the lower part of the Grinnell Glacier trail.

GRINNELL FORMATION. Because of their dominantly red color, the shaly argillites which comprise the bulk of this formation are the most conspicuous rocks in the park. They lie immediately on top of the Appekunny and although their thickness varies considerably it is greater than 3,000 feet in several localities. Interbedded with the red argillites are thin white layers of quartzite, a former sandstone which has been converted by pressure into an extraordinarily hard, dense rock. Mud cracks, ripple and current marks, raindrop impressions, and other

* Argillite is the term used by geologists for a rock, originally a shale, which has been recrystalized or made harder by greater pressure. In external appearance it looks like shale.

features made while the sediments were accumulating are common. The red color is due to abundant iron oxide occurring mainly as a cement between the sand and mud grains. All the rocks of Glacier Park contain some iron, or rather contain iron-bearing minerals. These minerals have various colors unless they have been oxidized, in which case the color is red or brown. Oxidation of the Grinnell formation probably took place while the mud was accumulating and during those periods when it was exposed to the atmosphere. At such times also the mud dried and cracked, the marks of which are so prominent on the surfaces of the layers today.

The Grinnell formation seems to be everywhere. In the Many Glacier region it comprises the bulk of Grinnell Point, Altyn Peak, and Mount Allen, and is no less striking in the bases of Mount Wilbur and the Garden Wall. Ptarmigan Tunnel is drilled through it, and the trails to Grinnell Glacier, Cracker and Iceberg Lakes cross it. Redrock Falls, on the trail to Swiftcurrent Pass, and Ptarmigan Falls on the Iceberg Lake trail drop over several of its highly colored layers.

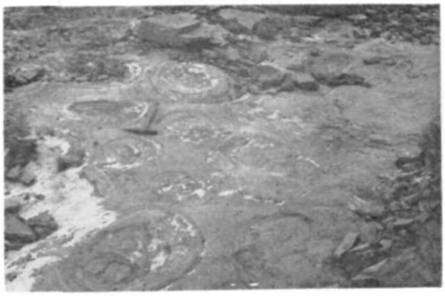
From the Blackfeet Highway on top of Two Medicine Ridge one can see the dark red rocks of this formation capping the summits of Rising Wolf and Red Mountains. Even from the valley floor it is just as noticeable. Sinopah Mountain standing alone and impressive across the lake from Two Medicine Chalets carries the red banner of the Grinnell formation.

These red rocks constitute an important scenic feature for many miles along Going-to-the-Sun Highway. If one begins his trip on this highway at its east entrance he soon finds himself in the midst of a group of imposing red peaks—Goat and Going-to-the-Sun on the right, Red Eagle and Mahtotopa on the left. The road crosses the formation along a mile and a half stretch just west of Baring Creek bridge. Innumerable loose slabs of red rock along the side of the road contain excellent mud cracks and ripple marks. Near Avalanche Creek on the west side of Logan Pass the highway crosses the Grinnell where it comes to the surface on the western limb of the big syncline.

The formation is well exposed in the vicinity of Sperry Chalet and Glacier. It forms all the mountains surrounding the basin in which the chalet is located, and the trail from chalet to glacier lies wholly on it. At the glacier intensely folded white quartzite layers and red argillites are very conspicuous.

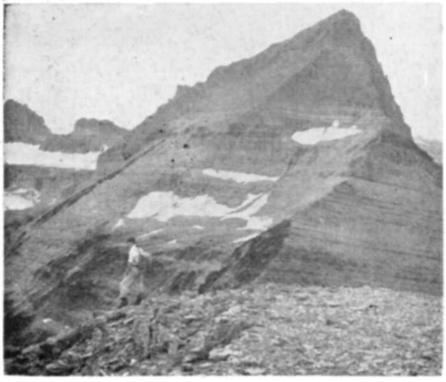
The visitor can readily trace the Grinnell from place to place throughout the entire park area, and can thus easily visualize that it as well as all other formations at one time filled the intervening spaces between the mountains. (See color of cover pages.)

SIYEH FORMATION. Next above the Grinnell is a thick limestone formation which, because of its weathered buff color, stands out in sharp contrast to the red beds upon which it rests. It is the greatest cliff-maker in the park and in several places its entire thickness of 4,000 feet may be exposed in a single nearly vertical cliff. Since it is younger than the three preceding formations, it is confined mainly to the higher elevations, capping many of the loftiest peaks within the Lewis and Livingstone Ranges. In the Many Glacier area such peaks are Mount Gould and the Garden Wall, Mounts Siyeh, Grinnell, Allen, Wilbur, and Henkel. A number of others including Little Chief, Jackson, Gunsight, Fusillade, Going-to-the-Sun, Piegan, Pollock, Cannon, and Heavens Peak, are visible from Going-to-the-Sun Highway. The huge peaks — Kinnerly, Kintla, Carter, and Rainbow — which stand guard at the heads of Kintla and Bowman Lakes are composed of the Siyeh. The list also includes Cleveland, highest and largest of all.



ALGAE COLONIES IN SIYEH LIMESTONE NEAR GRINNELL GLACIER. (DYSON PHOTO)

Within the Siyeh there is a bed, averaging about 60 feet thick, composed almost entirely of fossil algae which apparently formed an extensive reef or biostrome on the floor of the shallow Belt Sea. The algae colonies are in the form of rounded masses up to several feet in diameter and bear a crude resemblance externally and internally to a head of lettuce or cabbage. Geologists know these algae by the genus name **Collenia.** Because of the rounded and smoothed surfaces on these colonies, mountain climbers frequently find the reef difficult to cross. It appears as a distinct light gray horizontal band on the east face of Mount Wilbur about midway between the base of the cliff and the peak's summit, where it can easily be seen from Many Glacier Hotel and Swiftcurrent Camp. It is also discernible on the Pinnacle Wall above Iceberg Lake and in Mount Grinnell. The Swiftcurrent Pass trail crosses it just east of the pass, and it is also exposed along Going-to-the-Sun Highway below the big switchback on the west side of



GENTLY TILTED STRATA OF THE SIYEH FORMATION IN GRINNELL MOUNTAIN (DYSON PHOTO)

Logan Pass where attention is directed to it by a sign. Unweathered portions of the reef rock are light blue. A similar but thinner reef outcrops at Logan Pass near the start of the Hidden Lake trail. Although most of the fossil algae occur in the Siyeh they are present in the younger formations and also in the Altyn. Other than algae the only undoubted fossils of the Belt series within Glacier National Park are burrows probably made by worms. They are rare and are restricted mainly to the Siyeh formation.

FOSSIL ALGAE IN SIYEH FORMATION, HOLE-IN-THE-WALL BASIN.
(THE ROCK BOOK BY C. L. FENTON AND M. A. FENTON, DOUBLEDAY AND CO.)

At the top of the Siyeh are several hundred feet of sandy and shaly beds, mostly reddish in color, grouped by some geologists into a distinct formation known as the **Spokane.** At Logan Pass it is about 700 feet thick and is well exposed in the lower parts of Clements and Reynolds Mountains, and at the site of the former "Clements" Glacier.

SHEPARD FORMATION. Several hundred feet of limy beds which weather yellow-brown lie on top of the Siyeh. Although named for outcrops on the cliff above Shepard Glacier (south of Stoney Indian Pass and near the site of the old Fifty-Mountain tent camp) the formation is exposed on the summit of Swiftcurrent Mountain at the head of Swiftcurrent Valley, on Reynolds and Clements Mountains near Loan Pass, and on Citadel and Almost-a-Dog, visible from Going-to-the-Sun Highway in St. Mary Valley. The formation is replete with mud cracks and ripple marks. Some rock surfaces exhibit two or three sets of the latter.

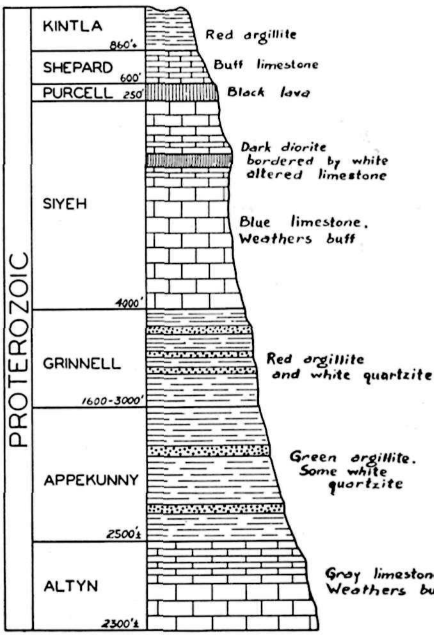
KINTLA FORMATION. These beds have the same bright red color as those of the Grinnell. However, because they are the youngest rocks of the Belt series they outcrop only on a few mountaintops, and inasmuch as these are mainly in the northwest part of the park, comparatively few people have noticed this formation. Visitors to Cameron Lake in Waterton Lakes National Park can see it in the red north wall of Mount Custer. The mountains around colorful Boulder Pass and Hole-in-the-Wall Basin are likewise composed of it.

Within the rocks of this formation there is a great abundance of small cubes believed to be casts of salt crystals which formed when the sediments were accumulating. Their presence indicates an arid climate and intensive evaporation of the sea, similar to the condition at Great Salt Lake today.

Igneous Rocks of the Belt Series

Not all of Glacier Park's rocks accumulated slowly and quietly as sediment in a body of water. At many places, interbedded with and cutting across the sediments, there are bodies of igneous rock which reached their present position in the form of hot molten material forced up from deep within the crust.

PURCELL LAVA. Soon after the youngest layers of Siyeh limestone had accumulated on the floor of the sea and while they were still under water, a mass of molten rock was squeezed up from far below and extruded in the form of a submarine lava flow over the recently accumulated sediments. Several times this lava poured out forming a total thickness varying between 50 and 275 feet. One of the best exposures is on the west side of Swiftcurrent Pass and in Granite Park just west and northwest of the chalet. In fact it is this lava flow which gives the name, albeit wrongly, to Granite Park. The material of the flow is very fine-grained and dark (basic), in contrast to the light color and coarse grain of granite. Nonetheless, many prospectors are wont to call every igneous rock, regardless of its composition, a granite. A number of ellipsoidal structures ("pillows") up to two feet in diameter within this lava indicate that it was extruded under water. The Purcell is thickest in the vicinity of Boulder Pass, where the trail traverses its ropy and stringy surface for a distance of several hundred yards.



COLUMNAR SECTION OF BELT ROCKS

Later, after the Shepard and part of the Kintla formation were laid down on top of the Purcell, another similar flow spread over the sea floor.

DIORITE SILL. Few persons visit the park without noticing the pronounced black layer, within the Siyeh formation, present on many of the high peaks. It is most in evidence on the face of the Garden Wall viewed from the vicinity of Many Glacier Hotel, although it is plainly visible also in Mount Wilbur and the wall above Iceberg Lake. Passengers on the Waterton Lake launch can see it cutting across the stupendous north face of Mount Cleveland. From Going-to-the-Sun Highway it can be seen on Mahtotopa, Little Chief, Citadel, Piegan, and Going-to-the-Sun Mountains, and on the west side of the Garden Wall, where it also forms the cap of Haystack Butte. It is everywhere about 100 feet thick, and thus can be used as a very accurate scale for determining the height of mountains on which it is discernible.

THE GARDEN WALL AND GRINNELL GLACIER. THE WALL IS COMPOSED OF SIYEH LIMESTONE ABOVE THE LEVEL OF THE GLACIER AND THE GRINNELL FORMATION BELOW IT. (DYSON PHOTO)

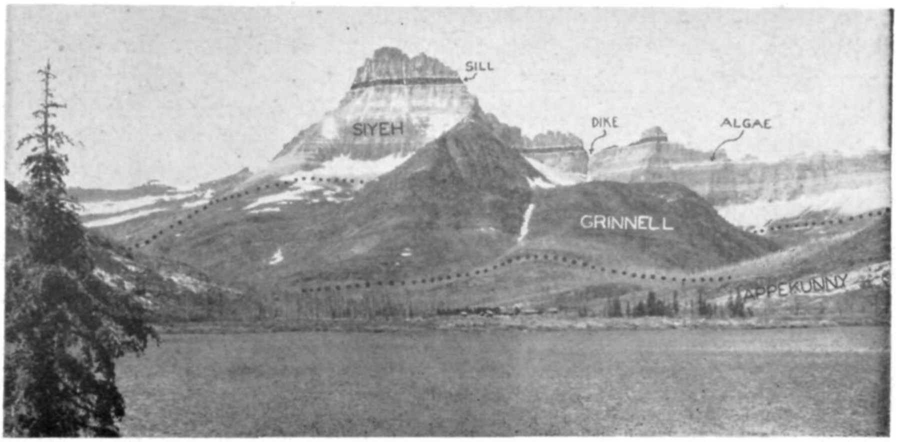
This imposing layer of rock, unlike the lava, never reached the surface in a molten state, but was intruded between beds of sedimentary rock and thus became a sill instead of a flow. We need only a glance to determine its intrusive nature. Wherever it occurs it is bordered at top and bottom by thinner gray layers. These are Siyeh limestone which was changed to marble by the tremendous heat of the diorite during its intrusion. This effect is termed **contact metamorphism** by geologists. Because this contact-metamorphosed zone is at both top and bottom of the sill we know the latter was intruded into the adjacent rocks. Lava flows, even though covered later by sediments, of course alter only the underlying rocks.

The sill can readily be examined in a number of places where trails cross it, notably at Swiftcurrent and Piegan Passes, and north of Granite Park near Ahern Pass. But nowhere is it as accessible as on Logan Pass. It lies beneath the parking lot at a depth of only a few feet, and is exposed on both sides of the pass. To inspect it one need walk only about 200 yards along the trail leading to Granite Park. In a distance of less than 100 feet the trail traverses from fresh Siyeh limestone across the entire altered (contact-metamorphosed) zone, here 12 to 20 feet wide, into the center of the sill. All parts of the sill and adjacent rocks can readily be examined and studied in detail at this site.

TOP OF THE DIORITE SILL OF BLACKFOOT GLACIER. THE MAN IS STANDING ON THE SILL. LIGHT ROCK OVERLYING SILL IS CONTACT-METAMORPHOSED SIYEH LIMESTONE. (DYSON PHOTO)

A number of **dikes*** of Belt age, some of which undoubtedly were feeders to the sill and flows, cut vertically up through the sedimentary formations. Some of the dikes are less resistant to weathering and erosion than the rocks surrounding them; consequently their more rapid removal results in the formation of narrow vertical chimneys or recesses which appear as snow-filled chutes on the mountainsides in spring and early summer. Such a feature almost invariably indicates the presence of a dike. From Many Glacier Hotel one of these can be seen on the red mountains in front of Mount Wilbur. Another, 1,500 feet high, transects the Pinnacle Wall at the outlet of Iceberg Lake. The dike which forms this impressive chute is less than thirty feet wide. Though not so conspicuous as the sills some of these dikes are of interest because they contain various ore minerals, principally copper, which today form small deposits along their borders. About the beginning of the century these were responsible for a short-lived mining boom, the best known vestige of which is the remains of the mill at Cracker Lake. The old Cracker Mine, with entrance now caved in, was driven along a dike which has a width of over 100 feet.

From the boat landing at the head of Josephine Lake the dump of another mine appears as a tiny gray-green mound on a narrow shelf high on the precipitous wall of Grinnell Point. Like the Cracker Mine this one was dug along the edge of a similar but smaller dike. All these deposits are insignificant in size and of no commercial value. Had they been important this great area might never have been set aside as a national park.



MOUNT WILBUR AND THE PINNACLE WALL VIEWED FROM MANY GLACIER HOTEL. THE UPPER PART OF APPEKUNNY AND ALL OF THE GRINNELL AND SIYEH FORMATIONS ARE VISIBLE. THE SNOW-FILLED CHUTE LEFT OF THE WORD "GRINNELL" IS FORMED BY THE SAME DIKE WHICH PASSES THROUGH THE PINNACLE WALL.
(HILEMAN PHOTO, COURTESY GLACIER PARK CO.)

* A dike is like a sill in all respects except that it cuts across adjacent layers instead of paralleling them.

The Story Continues

For the succeeding several hundred million years the geologic history of Glacier National Park is rather obscure, but additional Belt sediments apparently were deposited before uplift of the area caused the sea to withdraw. Following this event many feet of the younger Belt sediments were removed by erosion. The sea probably returned and received more sediments during much of the Paleozoic Era, although no trace of these rocks has been found inside the park boundaries.

CRETACEOUS ROCKS. Not until the Cretaceous period of Earth history, about 100 million years ago, did the geologic record again become clear. At that time a great thickness of mud and sand was deposited in the geosyncline burying deeply the ancient Belt and other rocks which had accumulated as sediment during the preceding several hundred million years. Life had made tremendous advances in this interval, and the abundance of fossils in Cretaceous rocks indicates that the sea swarmed with shelled creatures during that period.

THE LEWIS OVERTHRUST. Toward the end of Cretaceous time tremendous crustal forces, principally from the west, were directed against the geosyncline with the result that its rocks were compressed and uplifted, converting the site of the former sea into a mountainous region. Similar activity took place throughout the length and breadth of the entire geosyncline, which resulted in the formation of the Rocky Mountain system stretching between Mexico and Alaska. A number of mountains were formed on other continents during this period. So widespread and tremendous was the deformation, especially in the present day Rocky Mountain region, that it is known as the **Rocky Mountain,** or **Laramide** (after the Laramie Range in Wyoming), revolution. Mountain-building forces continued for several million years in the Glacier Park area, finally squeezing the rocks into a great fold (anticline). Continued pressure from the west overturned the fold and put additional strain on the rock layers, eventually causing them to break along a great low-angle fault. The western limb of the fold, now a great slice of the crust, was driven upward and eastward over the eastern limb ultimately reversing the order of rock layers by placing older on top of younger ones (Figure 3). These younger layers are Cretaceous shales and sandstones underlying the plains immediately east of the mountains. The mountains themselves have been carved by streams and glaciers from the Belt formations comprising the upper block of older rock, that slice of the crust which has been moved more than 15 miles toward the east. The surface over which it was pushed is the Lewis overthrust. At the time this great break occurred the part of it now exposed in Glacier National Park was deeply buried. It was long after that when removal by erosion of overlying Belt rocks, possibly several thousand feet of them, finally exposed the fault.

Movement along this fault was slow — so slow that had people been present at the time they probably would not have been aware that anything of an unusual nature was occurring. Occasionally along many large faults, however, there is sudden movement of small magnitude,

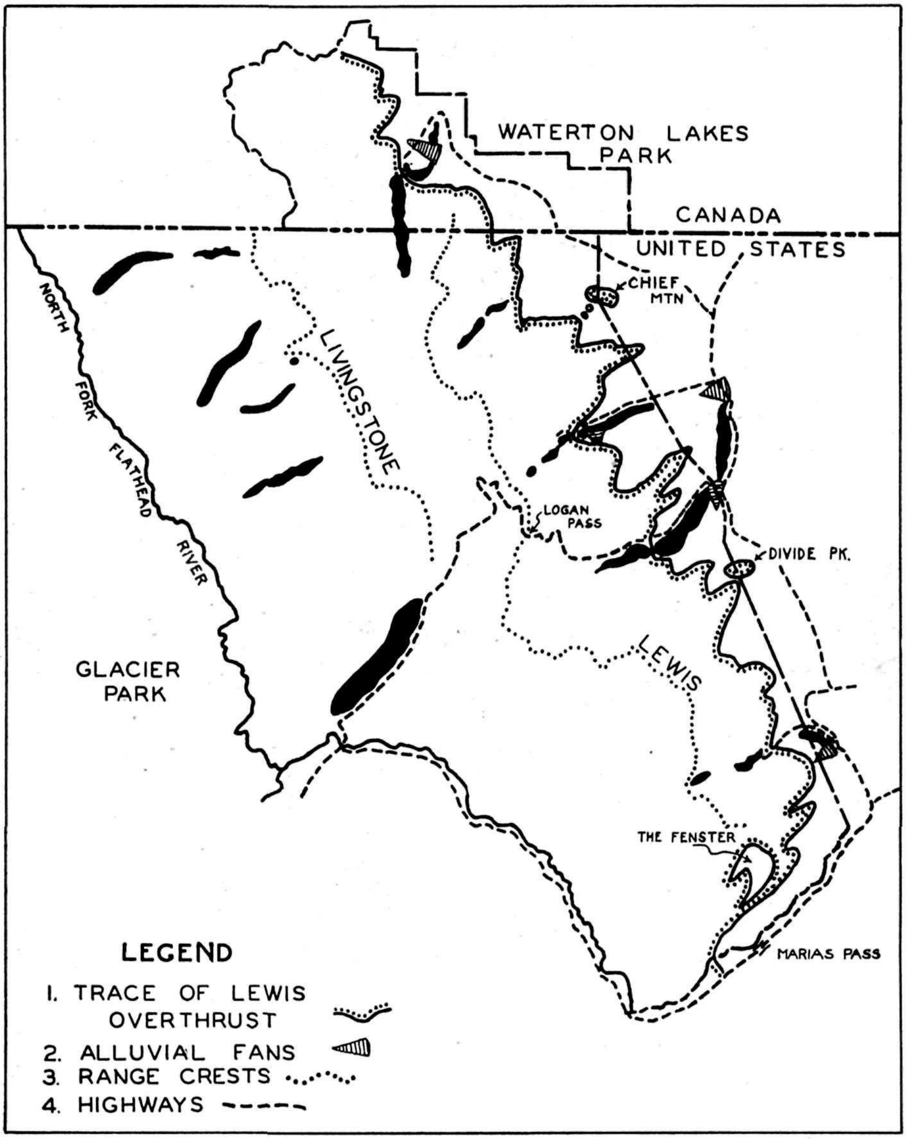


FIGURE 2. MAP OF WATERTON-GLACIER INTERNATIONAL PEACE PARK

usually not more than a few inches, but strong enough to vibrate the crust. These vibrations are earthquakes, and their frequent occurrence in California and elsewhere along the Pacific coast indicates the presence of numerous active faults. Their occurrence also in the northern Rockies, as at Helena, Montana in 1935 and 1936, attests to the fact that some of the faults here are still active.

The Lewis overthrust comes to the surface at the base of the Altyn formation along the entire precipitous east front of the Lewis Range and can be traced nearly 100 miles northward into Canada and for almost an equal distance south of the park. The section lying within the park is tilted very gently toward the southwest, the angle of dip seldom exceeding ten degrees. In some places it is practically horizontal. For this reason the lower courses of all the largest, and some of the small, valleys on the east side of the Lewis Range have been cut entirely through the upper block (overthrust) of Belt rocks down into the weak Cretaceous shales underneath. This causes the trace of the overthrust to be very sinuous and also accounts for the deep indentations in the mountain front formed by Swiftcurrent, St. Mary, Two Medicine, and other valleys. The floors in the lower courses of these valleys, because they lie below the level of the thrust surface, are composed of Cretaceous shales. In most places these rocks are covered by glacial moraine, but they are exposed along the highway from Babb into the Swiftcurrent Valley, especially along the shore of Sherburne Reservoir and near the entrance station. Because these shales readily disintegrate when exposed to the atmosphere they give rise to slumps and landslides which, although of small proportions, cause a great deal of damage to the highway, sections of which must be rebuilt annually. At most damaged spots along the route the shales appear as a dark mud or clay in the roadcuts. The bumpy topography of the whole slope lying north of the road has been formed by innumerable such small landslides.

A deep well located near Cameron Falls in Waterton Townsite (Waterton Lakes National Park) about one mile west of the edge of the mountains passes through 1,500 feet of Belt rocks and then penetrates the Lewis overthrust and the Cretaceous shales beneath.

In the southern part of Glacier National Park just north of Marias Pass, Debris Creek has cut a hole or ''window'' (known as a **fenster** by geologists) through the overthrust block (Figure 2). Thus a small area of Cretaceous rock completely surrounded by the Belt series lies within the mountains. This is the only such Cretaceous outcrop in the park, but like the well at Waterton, it serves as a reminder that the rocks of this period are everywhere present under the mountains, and their surface constitutes the ''sliding board'' over which the upper, more massive block of Belt rocks was pushed. And so we see that the mountains of Glacier National Park, unlike many of the world's great ranges, have no roots, for they rest on a base of greatly different and much less resistant material, the Cretaceous shales. Presumably the Lewis overthrust and Cretaceous rocks beneath it would be penetrated by a well

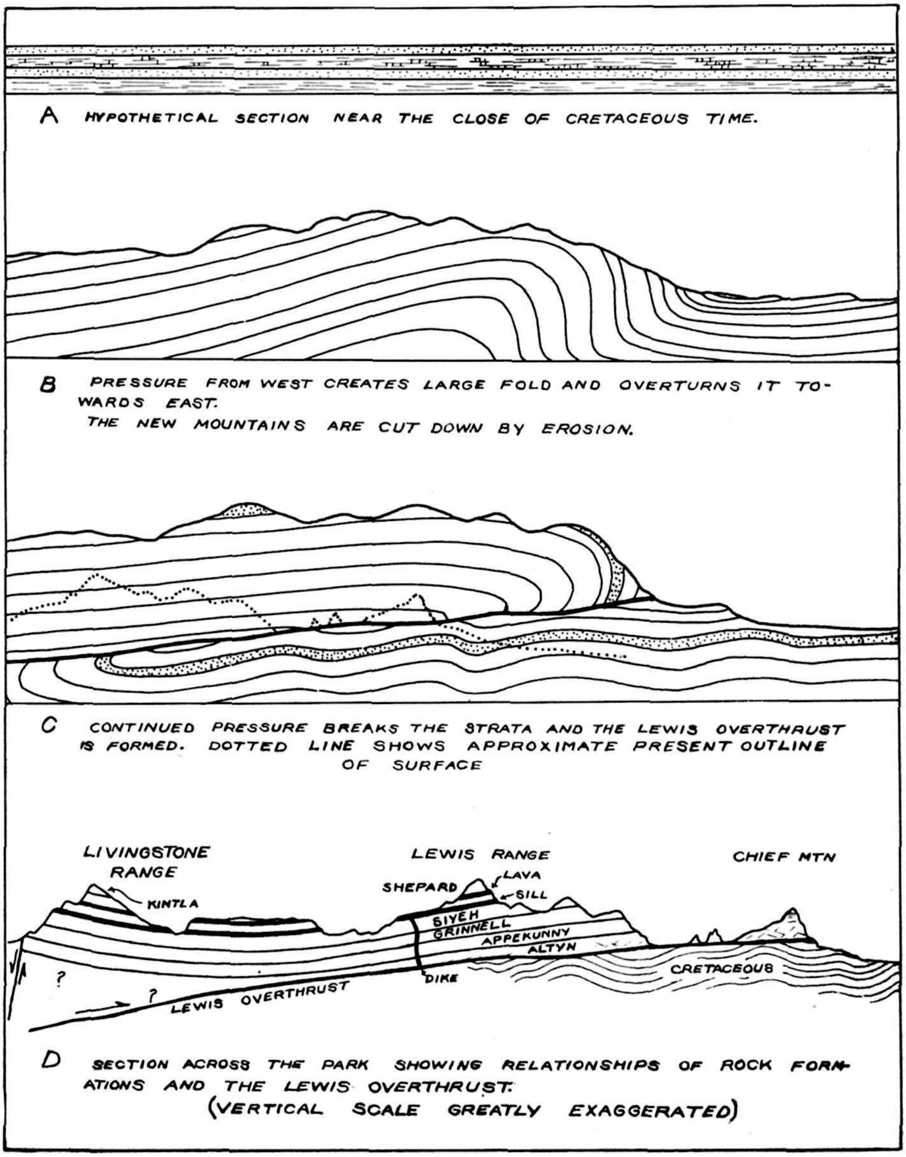


FIGURE 3. HISTORY OF LEWIS OVERTHRUST

drilled anywhere within the mountains, although in the Livingstone Range the depth of such a well would be very great (Figure 3D).

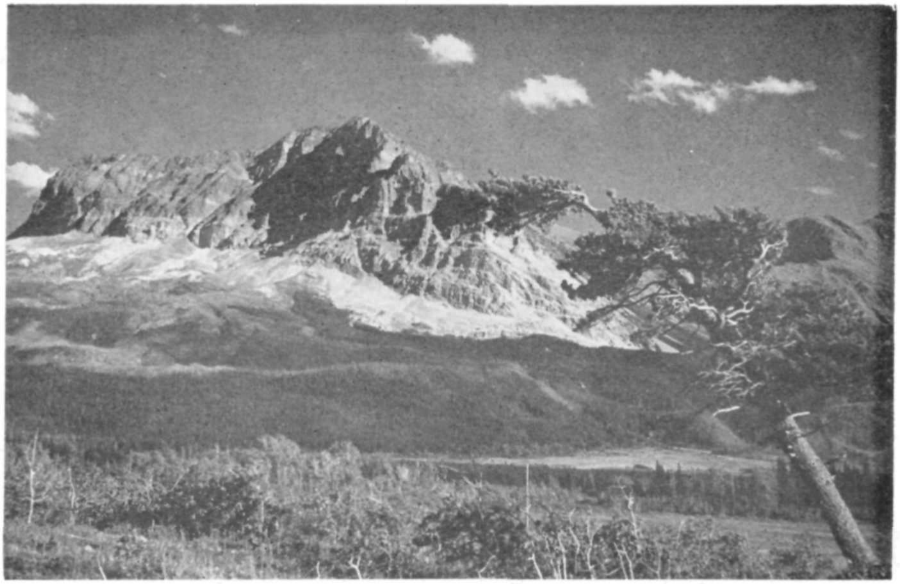
Erosion in the eastern part of the overthrust block, in addition to producing its crenulated edge, has left several isolated remnants (outliers) east of the main mass of the mountains. The best known of these is Chief Mountain situated near the northeast corner of the park several miles west of the Chief Mountain International Highway. It is a mass of Altyn limestone rising vertically on its east, south and north sides for a distance of 1,500 feet. The Lewis overthrust is well exposed all around its base. Two smaller pinnacles immediately to the west are similar outliers, and, like Chief Mountain, were once part of the main mass of the Lewis Range (Figure 3D and cover sketch). Divide Peak, at the west end of Hudson Bay Divide, is another outlier. It, too, is composed entirely of the Altyn formation.

Although the Lewis overthrust is exposed in a great number of places very few of these are easily accessible, and at only one does a trail provide a close approach to the actual contact between Belt and Cretaceous rocks. The latter site lies along Roes Creek only a few hundred yards from East Glacier Campground. Before reaching the fault at the base of a high cliff of Altyn limestone, the trail crosses several outcrops of Cretaceous sandstone replete with fossil pelecypods (clams) and gastropods (snails). The fault surface is covered by loose rock where the trail crosses it, but on the opposite side of the stream a zone of crushed Altyn limestone and Cretaceous shale is visible.

From U. S. Highway No. 2 just east of Marias Pass an excellent distant view of the thrust may be obtained. About three miles to the north it appears as a nearly horizontal line high on the side of Summit Mountain. Above it is a vertical cliff in which white Altyn and red Grinnell are prominent, and below is a gentler slope composed of gray-brown Cretaceous shale.

Cretaceous rocks with relatively low resistance to Earth stresses, were strongly crumpled and folded during the period of overthrusting. The folded zone extends several miles eastward from the mountains (Figure 3D), and may be seen to good advantage along Blackfeet Highway on the north side of Two Medicine Ridge, where a series of thin shales and sandstones has been squeezed into anticlines and synclines.

It is because of the Lewis overthrust that there are no significant foothills on the east side of the Lewis Range. The fault has brought into direct contact the massive and resistant Belt rocks which stand up as mountains, and the relatively weak shales of the plains which are carved into subdued landscape features by erosion.



LEWIS OVERTHRUST AT BASE OF MT. WYNN SEEN FROM HIGHWAY EAST OF MANY GLACIER HOTEL. OVERTHRUST LIES AT BASE OF CLIFF. CRETACEOUS ROCKS OUTCROP ON GENTLE SLOPE BELOW THRUST.
(DYSON PHOTO)

After the Lewis overthrust had taken place, and probably following a period of erosion, the western part of the block broke along a vertical fault and sank several thousand feet. For a short period of time a lake, in which clay was deposited, covered the floor of this depressed area. The present valley of the North Fork of the Flathead River lies on this downfaulted block (Figure 3D), and the western boundary of the Livingstone Range marks the trace of the fault. Because the fault is of the high-angle variety the front of this range is much straighter than that of the Lewis Range which is formed by the notched eastern edge of the relatively thin overthrust block. The Belton Hills and Apgar Mountains near the park's west entrance are isolated blocks separated from the Livingstone Range by normal faults probably dating from the time the North Fork Valley subsided.

The Effect of the Ice Age

In Miocene and Pliocene time the mountains were deeply eroded by streams. It was during this time that Chief Mountain, Divide Peak, and two smaller outliers, and the fenster along Debris Creek were formed. All of the existing mountain valleys were cut out of the overthrust block, although not to as a great a depth as they have today. The time required for their formation amounted to several millions of years. The result of all this erosion was a landscape very similar to the present day Blue

Ridge in Virginia and North Carolina, the type which geologists call mature.

Near the close of Pliocene time the climate cooled, timberline began to lower, and increasing amounts of permanent snow accumulated in the higher parts of the mountains. Finally glaciers formed from the snow and began to move down the stream-carved valleys. This marked the advent of Pleistocene time (The Glacial Age) nearly a million years ago. Glaciers eventually filled all valleys and covered all the park area except the summits of the highest peaks. Glaciers extended from valleys on the east side of the Lewis Range far out onto the plains, and from the Livingstone Range and the west side of the Lewis Range they moved into the wide Flathead Valley. The forests disappeared and it is probable that not a single tree remained in the area which is now the park. Available evidence indicates that climatic fluctuations during Pleistocene time caused the glaciers to disappear for a considerable period of time, or at least to shrink to insignificant size and then to return. At the end of Pleistocene time they began to shrink and about 9,000 years ago, during what is generally regarded as post-Pleistocene time, disappeared again.

The large Pleistocene glaciers greatly altered the pre-existing landscape of the park by gouging out valleys to much greater depth, and making their sides and heads much steeper than the streams had been able to cut them. Most of the lakes, vertical cliffs, sharp peaks, and waterfalls which constitute much of the park's magnificent scenery were created as a result of intensive glacier action.*

The Last Chapter

Although events of the last 9,000 or so years didn't create the large spectacular features of the landscape, this period is nonetheless interesting because it witnessed the birth of all existing park glaciers and the return of the trees composing the present-day forests. As soon as the glaciers began to shrink trees undoubtedly started to reclothe the newly exposed surfaces. New varieties came from areas which had not been glaciated. From the Pacific coast came grand fir, Douglas-fir, larch, hemlock, white pine and others. From the east came another group including aspen, paper birch, hawthorn and maple. The native trees driven out by the ice also returned to again become important elements of the flora. These are Engelmann spruce, alpine fir, and lodgepole pine. A few species, among which are the alpine willows, driven southward from the far north during the Pleistocene period still persist at high altitudes but they are always ready to move down into the valleys if the

* For a complete discussion of glaciers and their effects see Special Bulletin No. 2 (Glaciers and Glaciation in Glacier National Park) of the Glacier Natural History Association.

climate should again become cool. Of course, continued warming would cause them to disappear. After the large Pleistocene streams of ice disappeared there followed a period of about 5,000 years during which the climate was somewhat warmer and drier than at present, conditions under which even very small glaciers could not have survived. Then about 4,000 years ago the advent of the cooler climate brought about the origin of the present glaciers. During the period of their existence they have fluctuated in size, probably attaining maximum dimensions around the middle of the last century. Since then they have been steadily shrinking, a sure indication that the climate is becoming milder, as it has so many times in the past.

Surrounding all these small glaciers are **recent moraines** composed of rock debris eroded from the basins in which glaciers lie. These

MOUNT JACKSON, VISIBLE FROM GOING-TO-THE-SUN HIGHWAY, IS COMPOSED OF STEEPLY TILTED STRATA OF THE SIYEH FORMATION. JACKSON GLACIER TO THE LEFT OF THE MOUNTAIN LIES ON THE SURFACES OF SEVERAL OF THESE STRATA. (DYSON PHOTO)

MORAINE NEAR GRINNELL GLACIER IS 120 FEET HIGH.
(DYSON PHOTO)

moraines thus represent the amount of material removed, and then deposited, within the last 4,000 years. They are particularly striking at Grinnell and Sperry Glaciers and at the site of the former Clements Glacier near Logan Pass.

Following disappearance of the large Pleistocene glaciers streams returned to the valleys and began to cut new valleys within the old. Because post-Pleistocene time has been of such short duration these new valleys are small youthful gorges. Interesting examples are Sunrift Gorge, where Baring Creek has cut a narrow channel into the upper part of the Appekunny formation; and the gorge at Hidden Falls on Hidden Creek in the Grinnell Valley. Sunrift Gorge lies only a few feet north of Going-to-the-Sun Highway at Baring Creek bridge, and Hidden Gorge is a stop on the guided trip which Ranger-Naturalists conduct from Many Glacier Hotel to Grinnell Lake. Both of these channels have very smooth, straight sides because they have been eroded along vertical fractures known as joints. The latter are common throughout the mountains and are responsible for the smooth surfaces on some of the highest cliffs. The gorge of Avalanche Creek near Avalanche Campground is another example of post-glacial stream erosion, only here the whirling action of sand and gravel-laden water has carved out a number of cylindrical **potholes** in the stream course. Some of them, though only 6 to 10 feet across, are 20 or more feet deep.

Since we know that the streams did not begin to cut these gorges until the large Pleistocene glaciers had disappeared from those sites, approximately 10,000 years have been required for their formation. Thus the average maximum rate of down-cutting has been of the magnitude of 0.002 to 0.003 inch per year. With these figures as a foundation it is not so difficult to comprehend that the much larger valleys of the park could not have been eroded in less than several millions of years.

Another common, though seldom noticed, post-glacial feature of the park is the **alluvial fan.** These are fan-shaped accumulations of gravel deposited by swift, tributary streams where they enter a main valley. Some of them have grown so large as to dam the stream in the major valley and cause a lake (Figure 2). St. Mary, Lower St. Mary, Lower

Two Medicine, and Waterton Lakes are held in by such dams. The alluvial fan of Divide Creek which holds in St. Mary Lake can easily be distinguished from Going-to-the-Sun Highway on the north side of the lake near its outlet. The St. Mary Entrance Station is located on this fan. The lower lake is dammed by a large fan built into the St. Mary Valley by Swiftcurrent Creek. The straight section of highway between the town of Babb and the St. Mary River bridge lies on the lower part of this fan. Inasmuch as the Pleistocene glaciers undoubtedly removed any such fans made previously, those which are present today must have been constructed since disappearance of the ice, and are then not more than 12,000 years old. Most of them are somewhat older, possibly by as much as two or three thousand years, than the gorges mentioned above because the latter are located nearer the source of the glaciers, and their sites were thus still covered by ice after the fans had already begun to form. After the Pleistocene glaciers began their final retreat several thousand years elapsed before they disappeared from the mountains.

FRONT OF LEWIS RANGE, NORTH SIDE OF SWIFTCURRENT VALLEY. THE LEWIS OVERTHRUST LIES AT THE BASE OF THE CLIFF. THREE LARGE TALUS CONES ARE VISIBLE BELOW MT. ALTYN ON THE LEFT.
(DYSON PHOTO)

One of the most conspicuous of all post-glacial features is the **talus cone,** an accumulation of angular rock fragments which fall from cliffs. It is only at the base of a crevice or chimney that this material takes the apparent form of a distinct cone. Elsewhere it is referred to as a **talus slope** or simply as **talus,** or, in the parlance of some mountaineers, as **scree.** Although several thousand years have been required for their formation most talus accumulations in the park are still actively growing, especially in spring and early summer when rocks are pried loose by the alternate freezing and thawing of moisture within fractures. The artillery-like crack made when a falling rock crashes to the base of a high cliff is a familiar sound to anyone who has spent much time in the mountains.

The Future

We know that the processes of erosion and weathering will continue, that alluvial fans and talus cones will grow larger, and gorges will be eroded deeper, and as a result the mountains will be cut down to lower elevations. But, as we have seen, this event will require much time. If the present climate continues for a few more years our remaining glaciers will disappear, but there is nothing in geologic history which says they won't return again, possibly even to the size of their heyday in the Pleistocene. And if history repeats itself, and all past geologic history has been a repitition, then the mountains will eventually be worn down to an uneventful plain and the sea will invade the land again.

But certain breeds of man are the only despoilers of mountains that we need fear, so if the good citizens of our land keep the human invader and his dams and earth-moving equipment out of our national parks these grand mountains will endure for many thousands, yes, even millions of years.

——::——

PRINTED IN U. S. A.

BY

GLACIER NATURAL HISTORY ASSOCIATION

IN COOPERATION WITH

NATIONAL PARK SERVICE DEPARTMENT OF THE INTERIOR

1957

O'NEIL PRINTERS—KALISPELL, MONTANA

GLACIER NATURAL HISTORY ASSOCIATION, Inc.

Glacier National Park

West Glacier, Montana

Organized for the purpose of cooperating with the National Park Service by assisting the Interpretive Division of Glacier National Park in the development of a broad public understanding of the geology, plant and animal life, history, Indians, and related subjects bearing on the park region. It aids in the development of the Glacier National Park library, museums, and wayside exhibits; offers books on natural history for sale to the public; assists in the acquisition of non-federally owned lands within the park in behalf of the United States Government; and cooperates with the Government in the interest of Glacier National Park.

Revenues obtained by the Association are devoted entirely to the purposes outlined. Any person interested in the furtherance of these purposes may become a member upon payment of the annual fee of one dollar. Gifts and donations are accepted for land acquisition or general use.

The following Special Bulletins published by the Association are for sale.

Bull. No. 1—Motorists Guide to the Going-to-the-Sun Highway 25¢

Bull. No. 2—Glaciers and Glaciation in Glacier National Park 25¢

Bull. No. 3—Geologic Story of Glacier National Park .... 25¢

Bull. No. 4—Trees and Forests of Glacier National Park .... 50¢

Bull. No. 5—101 Wildflowers of Glacier National Park .... 50¢

Bull. No. 6—Mammals of Glacier National Park $1.00