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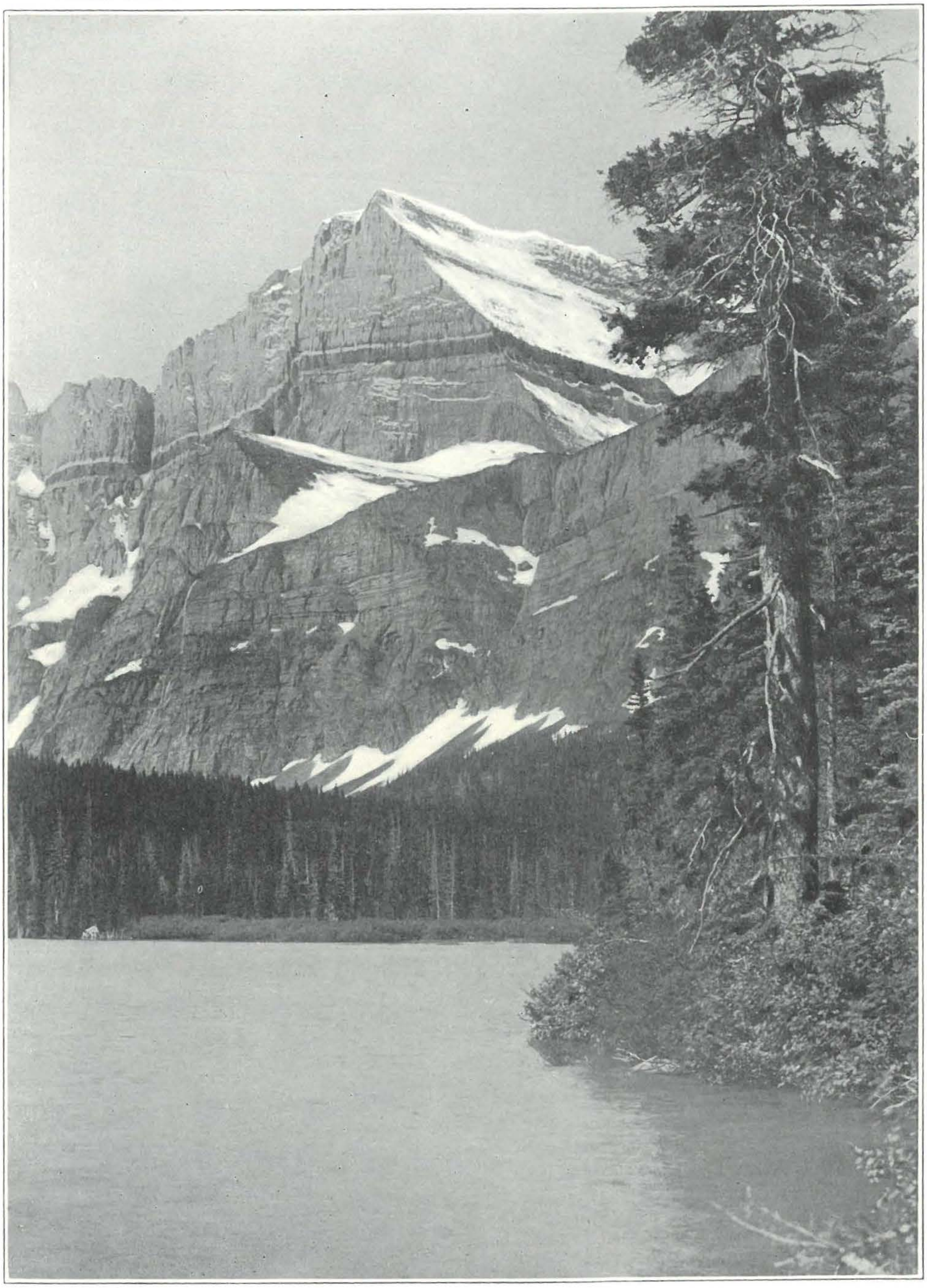

MOUNT GOULD, LEWIS RANGE

From South Fork of Swift Current, looking southwest. A characteristic cliff of Siyeh limestone overlying Grinnell Argillite; dark band of intrusive diorite. The valley is a glacial amphitheater typically developed on joint plains. From lake to summit, 4,670 feet.

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BY BAILEY WILLIS

(Presented before the Society January 1, 1902)

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Synopsis

The facts stated in the following article relate to the Front ranges of the Rocky mountains in Montana and adjacent Alberta, between the Great plains and the valley of North Fork of Flathead river. The Front ranges are two—Lewis range, which, rising from the Plains across northern Montana, extends into southern Alberta and ends, and Livingston range, which, lying 8 to 15 miles west of the Lewis, becomes in Alberta the easternmost height of the Rockies. The features of adjacent districts are described so far as they bear on the main subject, the stratigraphy and structure of the Front ranges.

Lewis and Livingston ranges consist of stratified rocks of Algonkian age, as determined on fossils which were found by Weller in the lowest limestone of the series and identified by Walcott as probably being *Beltina danai*, the species of crustacean discovered in the Grayson shales of the Belt mountains. The Algonkian series consists of limestone, argillite, and quartzite, classified in five formations. There is a certain degree of repetition in the general phases of sedimentation; limestone is succeeded by argillaceous and quartzitic beds, which are surmounted by a considerable thickness of highly ferruginous red sediments, and a second great limestone also is followed by quartzite and argillite, the last named being again of a deep red color and carrying casts of salt crystals. There is apparent conformity throughout. The series is so situated with reference to other rocks that no lower or upper stratigraphic limit could be determined. Dr G. M. Dawson classified the strata as Cambrian, Carboniferous, and Triassic, but it is believed that he mistook certain local overthrust faults for unconformities and was misled by lithologic resemblances.

Igneous rocks occur sparingly in the Algonkian series. An intrusive sheet of diorite is extensive in the upper limestone formation and an extrusive flow of diabase caps it.

Carboniferous limestone, with an abundant fauna of the Saint Louis horizon, was found west of the Front ranges. Cretaceous strata underlie the Great Plains, and fossils of Dakota, Benton, and Laramie age were collected from them. Early Tertiary conditions are represented by erosion surfaces on the Great Plains, probably also in the Galton range, and possibly in the Front ranges. Later Tertiary lake and marsh deposits occur in the valley of North Fork of the Flathead. Preglacial gravel beds were distinguished at a high level above existing drainage channels. The drift is not discussed.

The Algonkian strata form a syncline whose axis trends west of north. Southwestern dips vary from 5 to 30 degrees. Northeastern dips are generally 30 to 40 degrees and locally approach or pass verticality. Minor flexures within the syncline are very broad and low. The northeastern limit of the fold is an eroded margin; the southwestern is an anticlinal axis whose western limb is in part eroded, in part thrown down by a normal fault along North Fork valley. Syncline and anticlines are closely related to valley and ridge respectively, and this relation extends to heights of peaks.

Along its eastern margin the oldest Algonkian formation rests upon Cretaceous rocks. The outcrop of this abnormal contact is deeply sinuous throughout the stretch from Saint Mary lake to Waterton lake. The structure is described as an overthrust fault, on which the Algonkian series has moved northeastward relatively over the Cretaceous rocks. The displacement on the thrust surface is 7 miles or more, and the vertical throw is estimated at 3,400 feet or more. The thrust surface dips from no degrees to ten southwestward and strikes variously from north to North 60° West. Thus it is warped, and this warping is found to determine the general outline of the eastern face of the Rocky mountains, particularly the prominence of Chief mountain, and the relative position of the Lewis range, *en echelon* to the Livingston.

Under the subject of structural antecedents the writer discusses hypothetical conditions from which the overthrust fault may have resulted. The physical history of the region is traced from the Dakota epoch to Miocene time. Observed facts are arranged in sequence, interpreted, and supplemented by inferences. Deposition, deformation, erosion to a peneplain, and later deformation are considered as successive stages in development of the present geologic and physiographic relations. It is concluded that the Lewis range owes its present elevation above the Great Plains largely to upward movement on the overthrust; that this uplift was preceded by a peneplain stage which came to a close in early or mid Tertiary, and that the elevation of the Front ranges dates from that time. Subsequently they were isolated along their western margin by normal faulting, which determined new drainage lines.

Introduction

During the summer of 1901 the writer visited that portion of northwest Montana lying west of longitude 113 degrees 30 minutes and north of latitude 48 degrees 30 minutes, and examined especially the stratigraphy and structure of that part of the Rocky mountains between the Great plains on the northeast and Flathead valley on the southwest. The district lies in Teton and Flathead counties, Montana, and in the adjoining divisions of British America. It comprises the Front ranges, which consist of two heights, the Lewis and Livingston crests. Streams flowing from it enter the Saskatchewan, the Missouri, and the Columbia, and it thus contains the main continental divide between the Atlantic and Pacific oceans, as well as that between Hudsons bay and the gulf of Mexico.

The purposes of the expedition were those of general reconnaissance. The work laid out for the season extended to an investigation of a strip 180 miles long, south of the international boundary, as far west as longitude 116 degrees 30 minutes, and therefore detailed work in any specific district was impracticable. Nevertheless, two months were passed in actual fieldwork in the Front ranges of the Rocky mountains, and sufficient data were gathered to add materially to our knowledge of them.

In this trip the writer was associated with Mr Stuart Weller, paleontologist, and Mr George I. Finlay, assistant geologist, and he is indebted

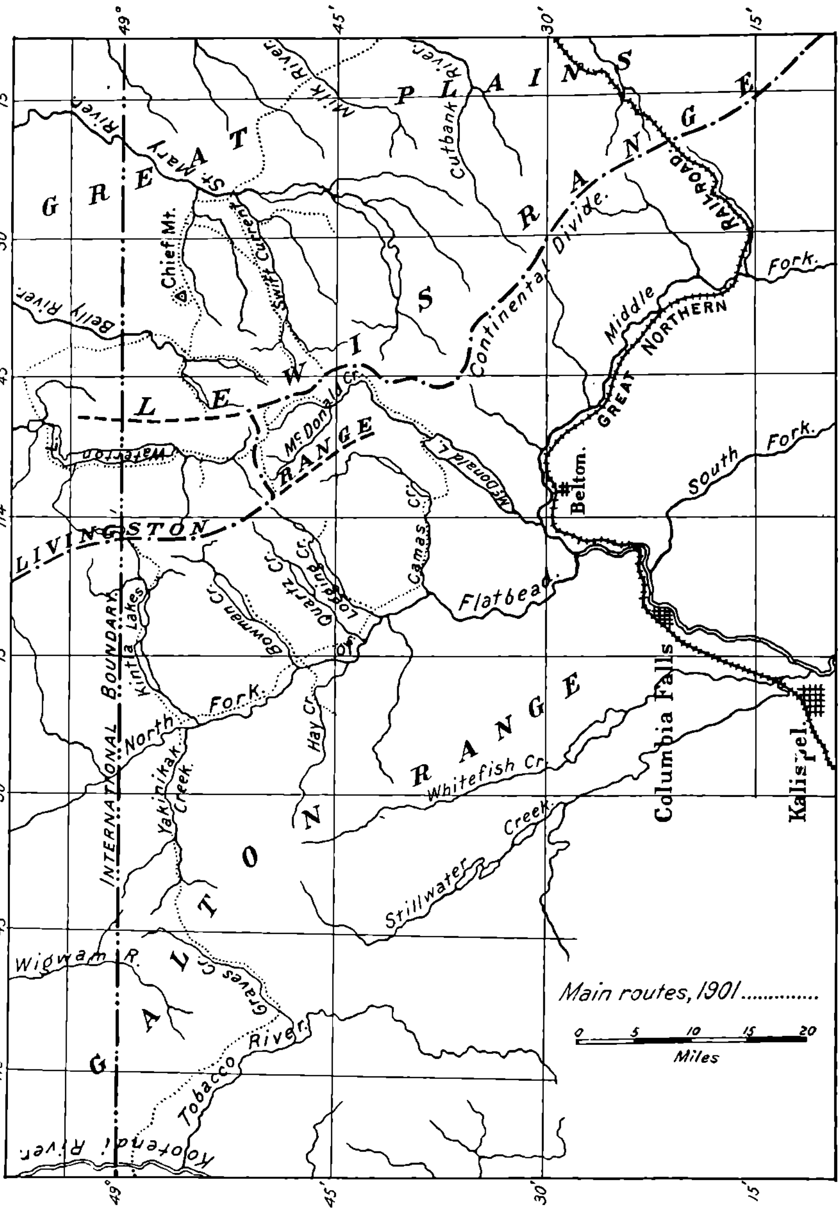


FIGURE 1.—*Map of Northwest Montana.*

Showing Lewis and Livingston ranges and their relations to the Great Plains.

to both gentlemen for their cordial assistance. Mr Weller especially, through his persevering search for fossils, contributed to the definite results of the work. Mr Finlay's notes on igneous rocks are appended to this article.

Physical Features

GREAT PLAINS

The eastern portion of the area examined lies adjacent to the Rocky mountains, in the Great plains, which were traversed from Blackfoot, a station on the Great Northern railway, to the 49th parallel. Although properly described as part of the plains which stretch eastward for a thousand miles, the surface here has marked relief, there being differences of elevation which amount to 500 feet between summits and valleys. About Blackfoot and Browning the relief is partly built up by moraine of the great continental glacier, and along the eastern base of the mountains there are generally morainic accumulations from the local glaciers which descended along the valleys.* The greater part of the inequality of altitude is due, however, to the down cutting of the streams. These are consequent on the general slope descending northeasterly. The valleys, as a rule, are broad and defined by one, two, or more terraces, of which the lower ones were built up and cut down by the stream in recent times, but the higher ones are plains of erosion across marine strata.

The highest surfaces of the plains are limited in extent, constituting according to field estimate not more than one-fiftieth of the total area. Nevertheless, their profiles fall into a uniform line that represents an ancient plain, due to erosion across Cretaceous shales and sandstones of unequal hardness. The extent and uniformity of this plain are very marked, and it is the initial physiographic fact of the region. It is herewith designated the Blackfoot plain, after the Indian tribe whose name is associated with the region. On this ancient surface there is a widely distributed thin layer of gravel which is supposed to antedate the Pleistocene deposits.

FRONT RANGES

Lewis range.—The Front ranges of the northern Rockies between latitudes 48 degrees 40 minutes and 49 degrees 10 minutes present two parallel crests about 8 miles apart. The eastern one rises from the Plains in Canada about latitude 49 degrees 10 minutes between Saint Marys

*See summary of observations of F. H. H. Calhoun, by R. D. Salisbury. Journal of Geology, University of Chicago, January, 1902.

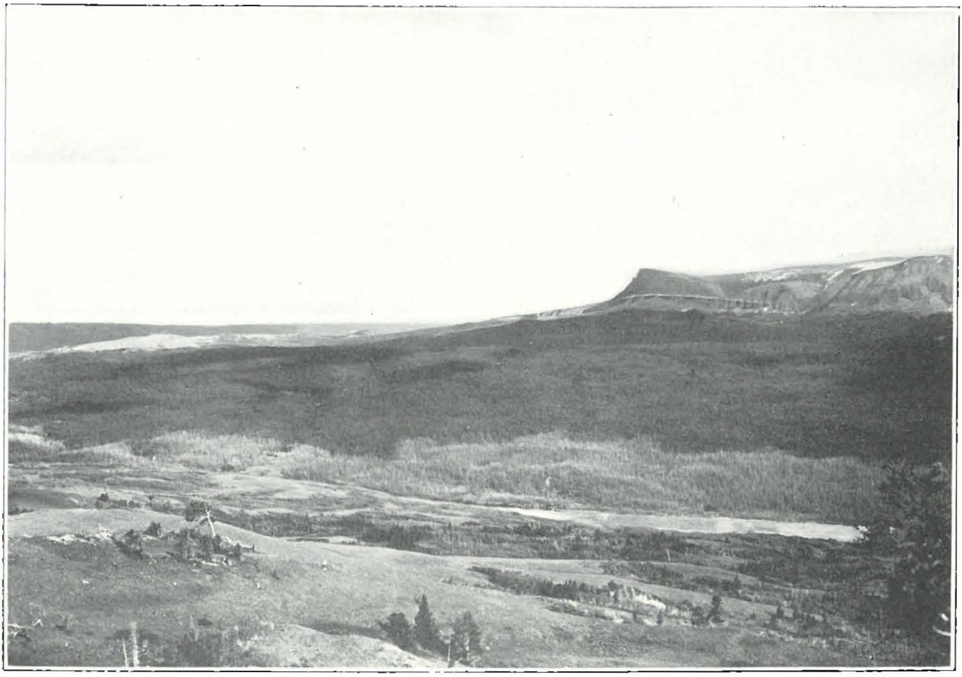


FIGURE 1.—MARGIN OF GREAT PLAINS AT FOOT OF LEWIS RANGE
Looking south across Swift Current valley to Saint Mary ridge and East Flattop

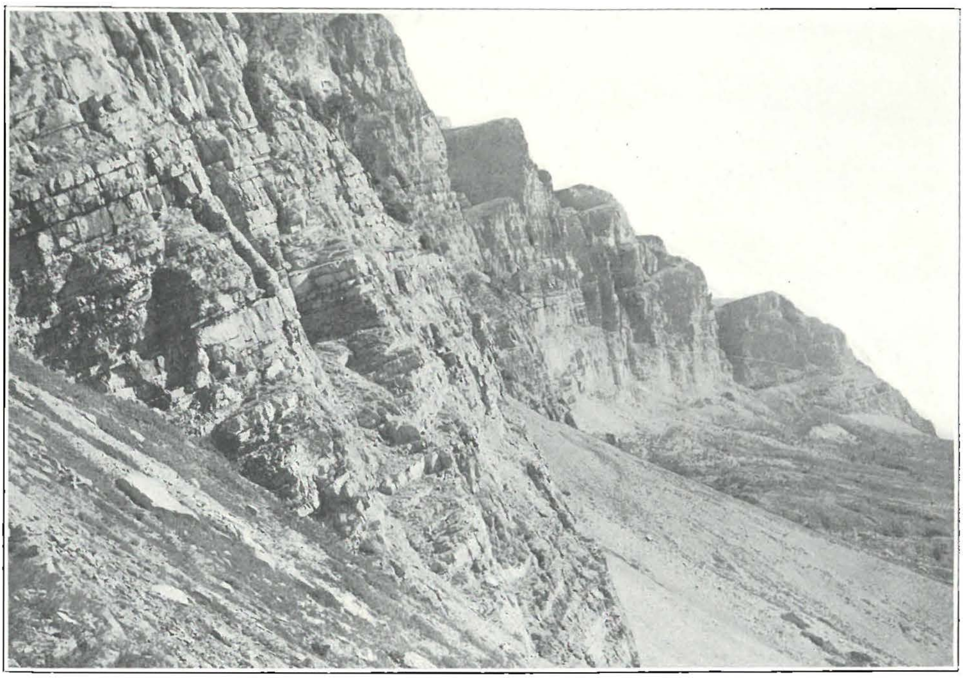


FIGURE 2.—NORTH SIDE OF SWIFT CURRENT VALLEY NEAR ALTYN
Looking east. Typical Altyn limestone cliff, lower member, overlying Benton shale. Locality of Algonkian fossils

MARGIN OF GREAT PLAINS AND NORTH SIDE SWIFT CURRENT VALLEY and Waterton rivers, and extends southeastward to about latitude 46 degrees 45 minutes. It will be designated the Lewis range after Captain Meriwether Lewis, who in 1806 was the first white man to cross it. As the Lewis range does not extend far north of the 49th parallel, the western crest becomes in Canada the easternmost heights of the Rocky mountains, and it has there been called the Livingston range. This name is herein adopted and applied to the mountains as far south as mount Heavens near McDonald lake. Here the Livingston range appears to fall away and lose its identity. Between the Lewis and Livingston ranges is an elevated valley in which Waterton river and the tributaries of McDonald lake have their sources, the former flowing northerly, the latter southwesterly from a flat-topped mountain in the heart of the range.

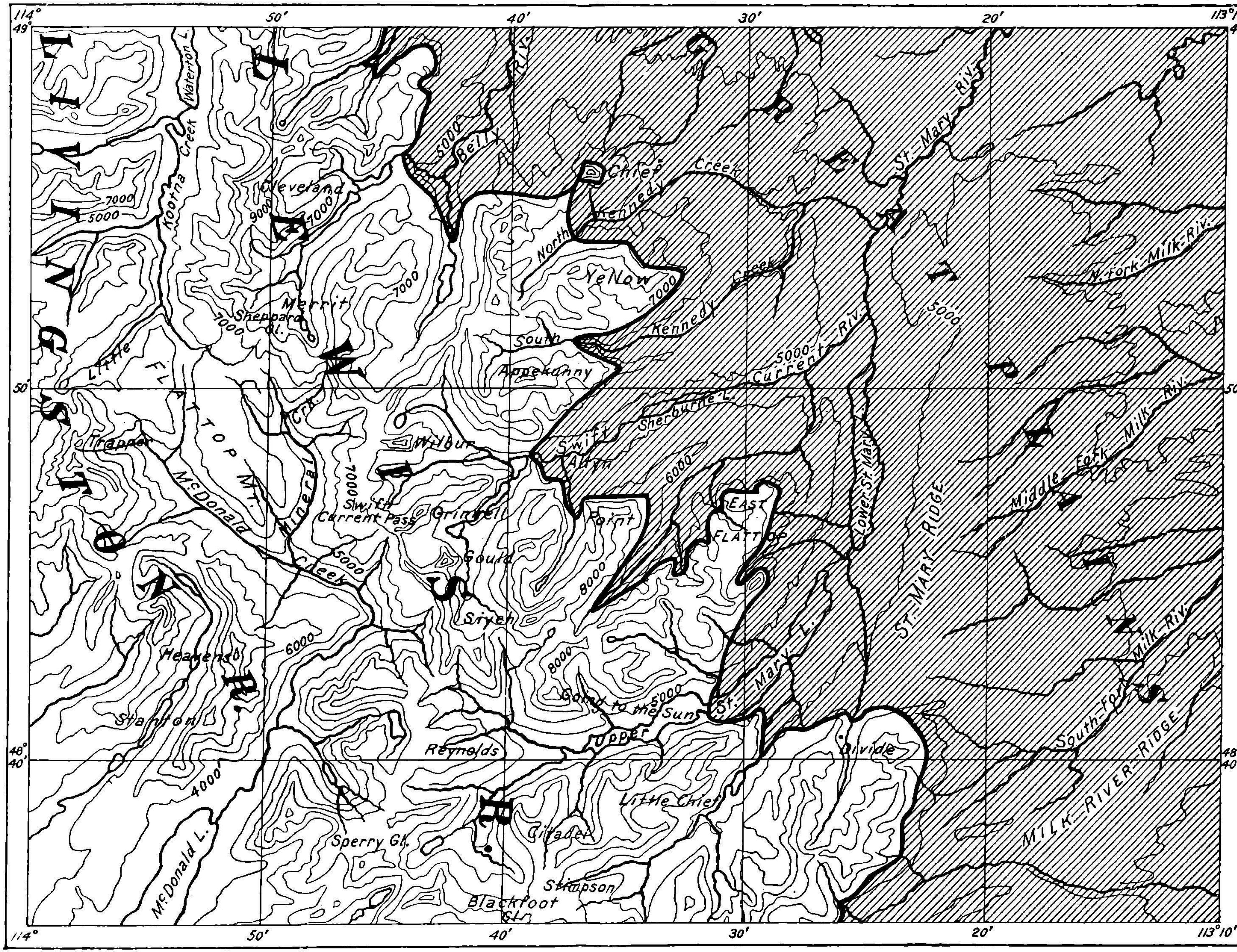
From the Great plains prominent spurs of Lewis range rise very boldly in the mountains known as Divide, Red Eagle, East Flattop, Yellow, and Chief, and in the heights west of Belly river. Looking at one of these promontories in profile it may be seen to present towards the northeast a bold and even precipitous scarp (figure 1, plate 47), from the foot of which the line of slope of the Great plains descends gently eastward. These mountain promontories carry the contours between 8,000 and 9,000 feet elevation as much as ten miles out to the northeastward from the main crest of the Lewis range. Between them are valleys excavated at elevations between 4,500 and 5,000 feet above the sea, which extend at moderate level very nearly to the crest of the range, and end in radiating canyons, under cliffs that rise boldly about their heads (see plate 46). They are also bounded along their sides by cliffs which outline the promontories (figure 2, plate 47). Thus the eastern margin of the Lewis range is deeply sinuous, and the heights above the general altitude of the Plains are marked off by cliffs from the lower slopes. The promontories are commonly sharp ridges of mature form, but are sometimes broad. That which lies between Boulder creek and Saint Mary lakes, and which is called East Flattop, carries a broad plateau-like summit at 7,000 to 8,000 feet above sea. This summit is unsympathetic to its environment and represents an older phase of topography. The slopes of the valleys exhibit soft and rounded forms, due either to erosion of incoherent clay shales, to deposition of glacial drift, or to numerous landslides.

The crest of the Lewis range is everywhere narrow, and in many places is a knife edge of jagged rocks. The precipices by which it is defined are frequently more than a thousand feet in height, and in some instances attain an altitude of 4,500 feet with a slope that is nowhere below 50 degrees. These cliffs are the walls of profound amphitheaters, usually occupied by lakes. The sculpture is that which is characteristic of the activity of valley glaciers in strongly jointed flat-bedded rocks. None of the high summits were ever submerged beneath a general ice-sheet, although glaciers accumulated to great depth in the valleys. The spurs which extend from the crest northeasterly have summit characters resembling those of the crest in its immediate vicinity and sometimes to a distance of several miles away from it.

Differences of elevation along the crest of the Lewis range are scarcely less pronounced than they are across it. Its rugged backbone is accentuated by high peaks between which are deep U-shaped wind gaps. The elevations of the highest summits range from 8,500 to 10,400, and those of the wind gaps from 5,500 to 6,500. Many small glaciers still linger in the shadows of the high peaks, and the Harrison and Blackfoot glaciers are nearly continuous for 5½ miles along the summit between Harrison creek and Saint Mary river.

Waterton-McDonald valley.—West of the Lewis crest and between it and the Livingston crest lies the central valley of the Front range. It has the trend common to all the major features, north 10 to 20 degrees west, and is drained by two streams, one of which, Waterton river and its head tributaries, flows north, the other, the McDonald lake drainage, flowing south and southwesterly. The divide between these streams is known as Flattop mountain, but should not be confused with the Flattop mountain east of the Lewis range. It has an elevation of about 6,800 feet, and is a broad expanse of slight relief, which was in fact the floor of an older valley under a previous condition of drainage lines. The head of Waterton river, Little Kootna creek, lies in a canyon 3,000 feet deep, across the northern end of Flattop mountain, and Mineral and McDonald creeks, which unite to flow to McDonald lake, lie respectively on the northeast and southwest sides of the mountain, also in deep, steep-sided canyons (see figures 1 and 1, plates 50 and 51, in panorama). These canyons represent the latest work of the streams in engraving their channels on the old valley floor. Remnants of the higher and earlier valley extend as broad benches along the western slope of the Lewis crest and the eastern slope of the Livingston crest. Northwestward beyond Little Kootna creek and southeastward beyond the canyon of Mineral creek are high mountain masses which attain very nearly the extreme altitudes of the eastern and western crests. The exact relations of these several physiographic features, the date of the ancient valley of Flattop mountain, and its relation to one or more episodes of glacial occupation, are not yet fully made out.

Livingston range.—North of McDonald lake and surrounded at its eastern and southern base by McDonald creek is a conspicuous height known as mount Heavens. During much of the summer season it is



MAP OF GREAT PLAINS AND FRONT RANGES, NORTHWEST MONTANA

Reduced from Browning and Chief Mountain atlas sheets, U. S. Geological Survey. Shaded area, Cretaceous rocks; white area, Algonkian rocks; heavy black line, outcrop of Lewis thrust. For section from Chief mountain to North Fork valley see plate 53.

extensively mantled with snow and carries a small glacier on its northeastern slope. This is the southernmost peak of the Livingston range, from which the crest is extended northwestward to its limit, probably in mount Head, in British Columbia, about in latitude 50 degrees 25 min, utes. Like the Lewis crest, that of the Livingston range is often narrow- but of the two it is the wider, and it presents massive mountain groups, with pyramidal forms instead of knife-edge arêttes. Between these groups are deep U-shaped wind gaps, very similar to those which mark the Lewis range, and from them the descents are steep to the headwaters of streams flowing southwesterly.

The main continental divide from a point in British Columbia follows the Livingston range to latitude 48 degrees 50 minutes, not quite as far south as mount Heavens, then descends on to Flattop mountain between Little Kootna and McDonald creeks, and ascends to the Lewis range, which it follows about to latitude 46 degrees 45 minutes.

The western slope of the Livingston range is deeply sculptured by valleys which, descending from the wind gaps, contain long, narrow lake basins. Each one of the streams south of the 49th parallel—Kintla, Bowman, Quartz, Logging, Camas, and McDonald—spreads out into one or more lakes, which vary in length from 2 to 10 miles. Unlike the rock-bound pools which lie in the amphitheaters of Lewis range, these waters are margined chiefly by slopes of gravel or talus, and only about their upper ends do the mountains rise with anything approaching a precipitous character. The shores and slopes are forest-clad, giving them an aspect very different from that of the valleys on the northeastern side of the mountains.

Although the mass of the Livingston range is thus deeply sculptured, the limit of the mountains on the west is definite, and, unlike the sinuous margin of the Lewis range toward the Great plains, it has the character of a bold face rising from foothills.

FLATHEAD VALLEY

West of the Livingston range in the United States and southern British Columbia extends the valley of the North fork of Flathead river. It is a broad depression with a general altitude along the river course from 3,100 feet near the forks of the Flathead to 3,500 feet about the 49th parallel. The river is a swift, clear stream, sometimes 50 yards wide, with many gravelly bars and deep pools. It winds in numerous oxbows, now between low gravel banks of its flood plain, again past higher terraces of drift, and occasionally under bluffs of stratified clays, with which sandstones and lignites are interbedded. The wide valley opens back from the channel of the stream to a distance of from 2 to 5 miles with an ascent by terraces and irregular slopes to foothills of the Livingston range on the east. The drift deposits extend above an elevation of 5,000 feet, and about that level present east and west profiles of a flat character, suggesting that the deeper part of the valley was once occupied by ice or gravel, and the space between it and the mountains was filled to a comparatively smooth surface.

The presence of the drift at so great an elevation carries the profile from the valley to the rocky heights of the Livingston range with a much gentler grade than would be the fact were the drift removed. It appeared from a brief examination of Camas, Logging, Bowman, and Kintla lakes that the face against which the drift is piled was limited along a line extending across the several valleys from southeast to northwest after the fashion of a definite scarp, and upon this apparent fact in part is based an inference as to the structural relation of the Flathead valley and the Livingston range.

Stratigraphy

General Statement

The strata encountered in that part of the Front range of the northern Rockies to which this article refers belong to five great periods of geologic history, separated by immense gaps. The oldest are sediments of pre-Cambrian age, in large part at least, with possibly some early Cambrian strata. They have an aggregate thickness of more than 12,500 feet. Carboniferous limestone was observed in a small area in the Galton range west of Flathead valley, on Yakinikak creek, and although it is absent from the Front range near the 49th parallel, it occurs to the northwest and southeast as well as west, and probably extended over the entire range. Strata of Cretaceous age occur extensively in the Great plains and in the valleys which penetrate so deeply into the eastern slope of the Lewis range. Lake beds of Tertiary age, either of Miocene or Pliocene date, are exposed in the bluffs along the North fork of Flathead river. East of the Front range on the foothills of the great promontories overlooking the Plains, and on the highest levels of the Great plains themselves, there are coarse gravel deposits of stream-worn material, which apparently antedate any glacial formations of the region, and may be Pliocene or early Pleistocene. Finally, the latest episodes of development are recorded in glacial drift, partly brought down from the valleys and partly deposited by the great continental glacier which spread from the northeast over the Plains toward the base of the Rockies. Closely related to all of that portion of the history which is of post-

Cretaceous age is the physiography of the range, a record that must be read in connection with the deposits from lakes and glaciers and should be interpreted in the light also of the structural geology.

The following is a tabular statement of these rocks and of the formations into which they are classified for the purposes of this report:

Geologic Formations represented

Pleistocene.	Eastern continental drift.	Characterized by boulders of granitic, gneissoid, and other Laurentide rocks; forms a moraine across Saint Mary and Belly valleys and beyond.
	Valley glacier drift.	Distinguished by absence of Laurentide rocks; composed of Algonkian sedimentary and igneous rocks in heterogeneous association as till and stratified drift.
Pleistocene or Pliocene.	Kennedy high level gravels.	Type locality—a gravel mesa, elevation 5,800 feet, 5 miles east of Chief mountain, north of Kennedy creek, and 900 feet above it; characterized by waterworn material of local origin, Algonkian rocks up to 2 feet in diameter; average coarse stuff under 1 foot, much of it 2 to 6 inches; distinguished by absence of glacial striæ, by stratification, and by altitude above present stream channels (figure 2, plate 51).
Later Tertiary.	Lake beds and marsh deposits of North Fork valley.	Clay, stratified, light gray; fine, very homogeneous; interbedded with very friable, light greenish sands and brown lignite.
Earlier Tertiary.	Blackfoot peneplain.	Highest and oldest peneplain of the Great plains in this district, cut across upturned Laramie and older strata.
Cretaceous.	Laramie sandstone.	Sandstone, hard, gray, cross-bedded, and soft shaly interbedded, carrying layers of oyster shells and containing plant remains.
	Benton shale.	Shale, dark, bluish gray, very fissile, fossiliferous, with occasional beds of sandstone, medium grained, brown, and thin limestone layers.
	Dakota sandstone.	Sandstone, yellow and brownish, and shale, arenaceous, with plant remains and freshwater shells.

Carboniferous	Yakinikak limestone.	Limestone, light gray to dark gray blue, crystalline, specked with black cleavage faces, or amorphous; sometimes oölitic; weathers rough; highly fossiliferous, Saint Louis horizon; type on Yakinikak creek, 4 miles west of North fork of Flathead river.
	Quartzite.	Quartzite, massive, coarse, white, or iron-stained; weathers into rounded bosses; 25 feet thick between conformable limestone above and unconformable argillite below.
Algonkian.	Kintla argillite.	Argillite and quartzite, thin-bedded, maroon red, ripple-marked, and sun-cracked, containing casts of salt crystals; also occasional beds of white quartzite and some calcareous; thickness, 800 feet; no upper limit seen; type locality, pyramidal peaks on 49th parallel, at head of Kintla drainage, foreground of figure 2, plate 50.
	Sheppard quartzite.	Quartzite, yellow, ferruginous; thickness, 700 feet ±; overlies extrusive diabase flow; type locality, cliffs between head of Belly river and central Flattop mountain.
	Siyeh limestone.	Limestone chiefly, but with argillite interbedded, usually massive, of mural aspect (plate 49), dark blue or grayish, weathering buff; often characterized by peculiar internal structures and by large concentric growths; indistinctly fossiliferous, associated with an intrusive diorite sheet and dikes and with an extrusive diabase flow at its upper surface; thickness, 4,000 feet; type locality, mount Siyeh, at head of Canyon creek, Swift Current drainage, but equally well exposed in other high peaks (plate 46), mount Gould.
	Grinnell argillite.	Argillite, dark red, shaly, sometimes arenaceous, ripple-marked, and sun-cracked; thickness, 1,000 to 1,800 feet; type locality, mount Grinnell, at head of Swift Current valley; also well exposed in Appekunny and Robertson mountains.
	Appekunny argillite.	Argillite, prevailingly gray, black, and greenish; thin-bedded, ripple-marked, interbedded with white quartzite; carries flattened concretions resembling fossils; thickness, 2,000 feet ±; type locality, Appekunny mountain, north of Swift Current valley; also generally well exposed in Lewis and Livingston ranges.

Algonkian.	Altyn limestone.	Limestone, of which two members are distinguished; an upper member of argillaceous, ferruginous limestone, yellow, terra-cotta, brown, and garnet red, very thin-bedded; thickness, about 600 feet; well exposed in summit of Chief mountain (figure 1, plate 52); and a lower member of massive limestone, grayish blue, heavy-bedded, somewhat silicious, with many flattened concretions, rarely but definitely fossiliferous; thickness, about 800 feet; type locality, basal cliffs of Appekunny mountains, north of Altyn, Swift Current valley (figure 2, plate 47).

ALGONKIAN

Correlation.—The oldest rocks found in this district are those which constitute the Lewis and Livingston ranges. The oldest formation of the series, the Altyn limestone, is assigned to the Algonkian period on the basis of fossils discovered by Weller in its characteristic occurrence at the foot of Appekunny mountain near Altyn, Montana. These fossils are fragments of very thin shells of crustaceans. They have been examined by Walcott, who states:

"The fragments of crustaceans collected by Professor Stuart Weller, in Montana, may be referred provisionally to *Beltina danai*, as described in volume X, page 338, of the Bulletin of the Geological Society of America.

"The mode of occurrence of the material is similar to that found in the Grayson shales of the Algonkian in the Belt mountains, Montana. Hundreds of broken fragments of the carapace of the crustaceans are distributed unevenly through the rock. Occasionally a segment or fragment of what appears to be one of the appendages is sufficiently well preserved to identify it."

The fossiliferous strata of the Belt formation in the Belt range are separated from the Cambrian by 7,700 feet of sediments and an extensive unconformity. In the Front range of the Rockies 10,700 feet of apparently conformable strata overlie the fossiliferous bed, and it is possible that the plane of division between Algonkian and Cambrian as determined by paleontologic evidence will be found in this great series. In the upper part of the Siyeh limestone near the head of Mineral creek, Weller found some indistinct forms which he considers possibly to be parts of crustaceans. Walcott expresses a similar view, saying:

"Mr Weller's suggestion that the fragments possibly represent crustacean remains appears to be the most plausible. If from a Devonian horizon they would suggest the genus *Licas*, or some of its subgenera. It is a case where more material is needed in order to arrive at any definite conclusion."

In the upper part of the Siyeh limestone there are also large concretionary masses which are irregularly cylindrical in form, with major axes at right angles to the bedding of the rocks, and which attain the dimensions of a keg, and even of a small barrel. Walcott states that these forms are similar to those found in the pre-Cambrian rocks north of Helena, Montana, but as yet they have yielded no evidence of organic origin. "Sir William Dawson considered that they represented a very simple form allied to Stromatopera."

In the British Boundary Commission report* Dr George M. Dawson describes these ancient rocks under the caption "Review of the Section," as follows: †

"The total thickness of the beds seen in this part of the Rocky mountains must be about 4,500 feet, though this can only be regarded as an approximation, as, owing to the short time at my disposal, few of the beds were actually measured. The entire series, arranged as a continuous section in descending order, is as follows:

H. Fawn-colored flaggy beds, seen only at a distance, but probably composed of magnesian sandstones and limestones. 100 feet.

G (Kintla formation). Beds characterized by a predominant red color and chiefly red sandstone, but including some thin, grayish beds, and magnesian sandstones, the whole generally thin-bedded, though sometimes rather massive. Ripple marks, &c. Weathers to a steep rocky talus where exposed in the mountain sides, and passes gradually down into the next series. 300 feet.

F (Sheppard quartzite). Fawn-colored flaggy beds of magnesian sandstone and limestone. Some red sandstones occur throughout, but are especially abundant toward the top. Apparently a continuation upward of the limestone D, and only separated from it by the trap overflow. 200 feet.

E Amygdaloidal trap; dark colored and hard. 50 to 100 feet.

D (Siyeh limestone). Compact bluish limestone, somewhat magnesian, and weathering brownish. This forms some of the boldest crags and peaks of the mountains, and apparently rests unconformably on Series C. 1,000 feet.

C (Grinnell and Appekunny formations). Sandstones, quartzites, and slaty rocks, of various tints, but chiefly reddish and greenish gray; the individual beds seldom of great thickness, and the color and texture of approximate beds rapidly alternating. In this series occurs a band of bright red rocks, of inconstant thickness; also two or more zones of coarse magnesian grit. 2,000 feet or more.

B (Uppermost bed of Altyn limestone). Limestone, pale gray, cherty, and highly magnesian; hard, much altered, and weathering white. It includes at least one band of coarse magnesian grit like that found in the last series, which weathers brown. 200 feet.

A (Altyn limestone, upper part). Impure dolomite and fine dolomitic quartzites; dark purplish and gray, but weathering bright brown of various shades. 700 feet or more."

* George M. Dawson: British Boundary Commission Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, 1875, pp. 67, 68, and Canada Geological Survey Report, 1885, p. 39 B et seq.

† The names used in this report are inserted in brackets after the letter by which Dawson designated the corresponding beds.

As regards thickness of the above described section, Dawson's figures sum up 4,500 feet. Elsewhere* he says:

"Between the eastern summit of the South Kootanie pass and the Flathead river, the minimum estimated thickness of the outcropping Cambrian beds is 11,000 feet, but the section includes neither the summit nor the base of the series. Other sections show a probable thickness of over 5,000 feet for a part of the series, but none were found in which its whole volume could be ascertained."

The writer's measure of the series which Dawson called Cambrian, namely, the Altyn, Appekunny, and Grinnell formations, is 6,700 feet, but, adding the Siyeh, Sheppard, and Kintla formations, is 10,700 feet, which is an approximation to his estimate of 11,000. The latter three formations occur in the section to which Dawson refers, and though he elsewhere classed them as Carboniferous and Triassic, they are part of the thickness which, in the quoted paragraph, he includes under Cambrian.

Dawson notes an apparent unconformity between D (the Siyeh limestone) and C (the Grinnell red beds) He says: †

"In the almost vertical side of Sheep mountain the total exposed thickness of beds of series C must be about 2,000 feet. These rest directly on the limestone B, and are overlain by the limestone series D, the latter resting with evident unconformity on them. This unconformity is shown very clearly by the existence of a thick belt of bright red rocks, forming part of series C, which is observed to run out altogether beneath the upper formation at one end of the mountain."

The writer also observed this relation, but he interprets it as due to a minor thrust rising from the Lewis major thrust which underlies Sheep mountain. The structure was identical in appearance and position with others seen traversing the Altyn formation in Yellow mountain (figure 6, page 335). It is also exceptional in the relations of division C to D, which were observed throughout many miles as the conformable contact of the Siyeh limestone on the Grinnell argillite.

About the outlet of Waterton lake, the Cretaceous rocks are deeply buried by drift and the outcrop of the Lewis thrust is obscured. The unusual superposition of the ancient argillites and limestones on the Cretaceous might well escape even so keen an observer as Dawson. He did not visit Chief mountain or any other locality where the evidence is clear.

In 1875 Dawson assigned no definite age to the rocks in question. In 1885, after more extended experience in the Canadian Rockies, he provisionally classified them as follows:

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* Canada Geological Survey, Report 1885, p. 158 B.

† Canada Geological Survey, Report 1885, p. 41 B.

Probably Triassic or Permo-Triassic............	Divisions F, G, and H.
Carboniferous and Devonian.................	Division D.
Cambrian....................................	Divisions A, B, and C.

The correlation appears to have been made on lithologic resemblances and the existence of the supposed unconformity between the red argillite C and the limestone D. A, B, and C are now known to be Algonkian, on fossil evidence. Mention is made by Dawson of the absence of fossils from C, but nothing is said about their occurrence or non-occurrence in D. Weller's careful search in the Siyeh limestone (D) showed the presence of indistinct remains, as already noted, but it also proved that fossils are rare and obscure in the formation. If the rock is of Carboniferous age, it is remarkable that it should not contain some of the larger characteristic forms, as the Carboniferous limestone on Yakinikak creek, but 26 miles distant, carries an abundant fauna. There is no metamorphic or structural condition affecting the one rather than the other in a degree sufficient to explain the difference in faunal content. Moreover, the Carboniferous limestone on Yakinikak creek rests unconformably on beds of the series of which the Siyeh limestone (D) is apparently a conformable formation.

The writer concludes that the Siyeh limestone is not of Carboniferous age, and that there is no evidence to justify its being separated from the underlying Algonkian, to which it is conformable and with which it is related in the obscure character of its fossils. This conclusion applies also to the Sheppard and Kintla formations, which Dawson placed in the Permo-Triassic. He could not otherwise refer them, conceiving them to overlie the Carboniferous, as they have strong Triassic characters; but with the assignment of the Siyeh limestone to the Algonkian, they also take a related place in that system. Nevertheless, to give full expression to Dawson's views, the following paragraphs are quoted from his report: *

"South of the line of the Crow Nest pass, the limestone series (Carboniferous) is conformably overlain by rocks which are referred to the Triassic or Permo-Triassic. In the vicinity of the South Kootanie pass, an interbedded, amygdaloidal diabase everywhere occurs at the base of the Triassic rocks. This, though classified under a separate letter (E) in the general section of that region (p. 39 B), is now known from the occurrence of a similar bed (if not the extension of the same one) among the distinctively Triassic rocks of the summit of the North Kootanie pass (p. 60 B) to be more properly ranked as a member of that series. The trap flow has a thickness of fifty to one hundred feet, and is overlain near the South Kootanie pass by red beds and fawn-colored magnesian sandstones 600 feet in thickness. Near the North Kootanie summit it forms part of a similar series

* Canada Geological Survey, Report 1885, p. 161.

of alternating, flaggy, magnesian sandstones and red sandstones and shales 2,000 feet in thickness (p. 60 B). In connection with the red beds, ripple-marked surfaces, mud cracks, and impressions of salt crystals occur, the whole indicating, as the conditions of deposition of the rocks, those of a basin cut off from the main ocean.

"With the single doubtful exception of certain red beds, seen from a distance, near the summit of the White Man's pass (p. 115 B), these Triassic rocks are entirely confined to the district south of the Crow Nest pass, and, as elsewhere more fully shown, we find here probably the northern limit of a great Triassic mediterranean sea, which extended far to the southward in the western part of the present continental area."

Altyn limestone.—The lowest member seen of the Algonkian strata is a limestone. Its unweathered surfaces are dark grayish blue, and in lithologic aspect it closely resembles Cambro-Silurian dolomites of the Appalachian region and the massive limestone of the Eo-Carboniferous. It is silicious, but there are no visible quartz grains or other evidences of marked mechanical sedimentation. Its stratification is often obscure, partly on account of its massive character and even more because of very decided deformation, which has resulted in faulting and crushing. Its thickness is undeterminable, but probably not less than 800 feet. Succeeding this basal member and included with it in the Altyn formation are limestones which differ chiefly in that they contain more earthy sediment and are very thinly bedded. In consequence of the ferruginous clay contained, they are decidedly yellow, brown, and terra-cotta in color. They are sometimes separated from the underlying massive limestone by a plane, above which they lie flat, while the mass below is greatly disturbed (see figure 5, page 334). The effect strongly suggests an unconformable relation between the two, but this is not believed to have been the original condition of deposition as they were seen in conformity, where not traversed by thrust faults. The thickness of the thin-bedded upper member of the Altyn limestone is approximately 600 feet.

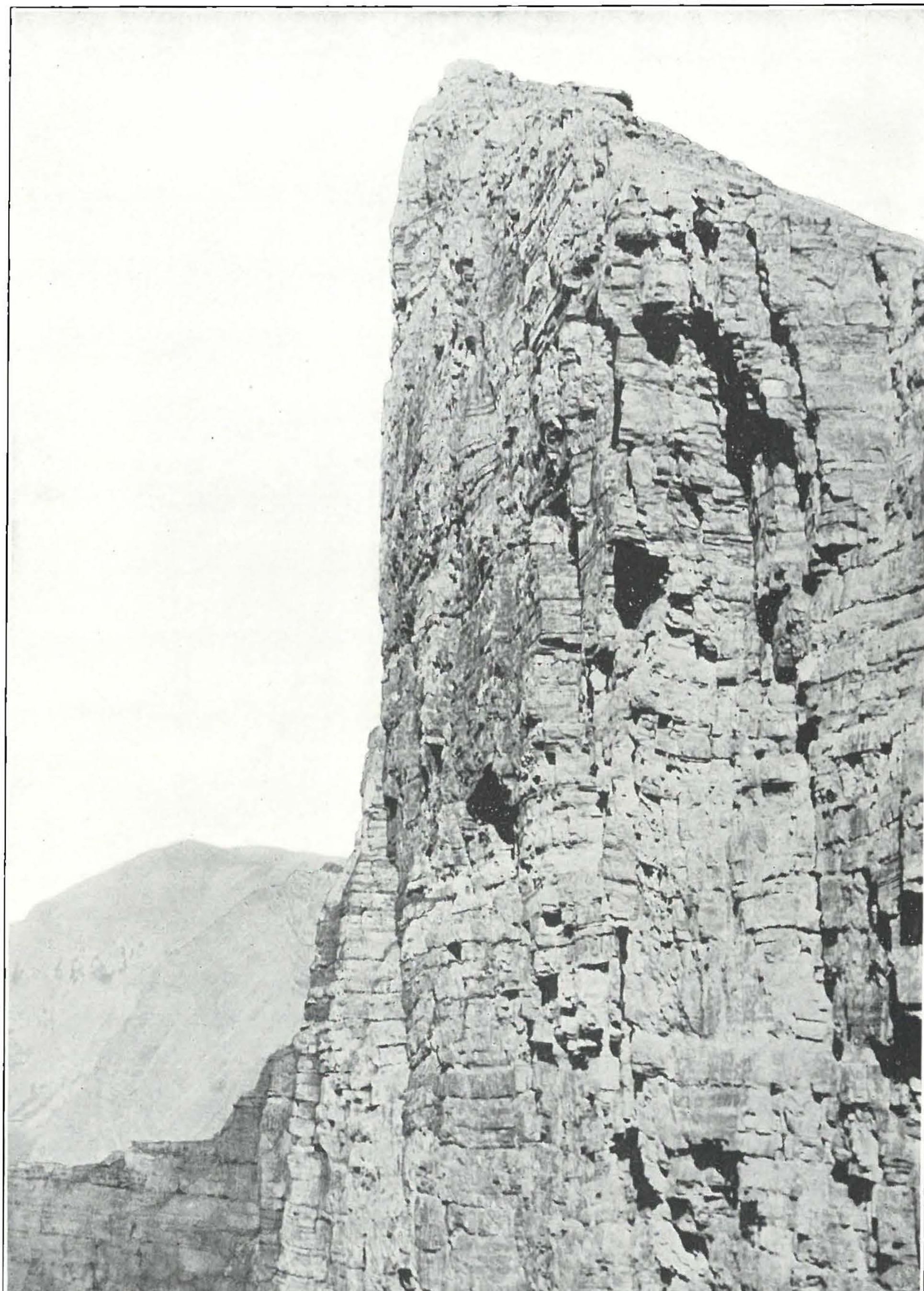
The Altyn limestone occurs typically in the cliffs of Appekunny mountain, between 6,000 and 7,400 feet above sea, due north of Altyn, in Swift Current valley (figure 2, plate 47). The westward dip carries the base down to about 4,800 feet west of Altyn, where it forms the ledge over which Swift Current falls at the outlet of McDermott lake. Northward and eastward from this locality the limestone forms the cliffs that surround Appekunny, constitutes the mass of Yellow mountain, the northern slopes of mount Robertson, and the ridge between Kennedy creek and Belly river, ending in the tower-like peak of Chief mountain. Beyond the forks of Belly river it was traced northwest into Canada and to the narrows of Waterton lake, whence the outcrop trends northward in the base of the Livingston range. Southeastward from Altyn the limestone was traced around Point and eastern Flattop mountains to the Narrows of upper Saint Mary lake. Thence it forms the base of the mountains southward to an unknown distance, but it may be replaced by any of the overlying formations, among which it is closely resembled by the Siyeh and Carboniferous limestones.

Appekunny argillite.—The Appekunny argillite is a mass of highly silicious argillaceous sediment approximately 2,000 feet in thickness. Being in general of a dark-gray color, it is very distinct between the yellow limestones below and the red argillites above. The mass is very thin bedded, the layers varying from a quarter of an inch to two feet in thickness. Variation is frequent from greenish-black argillaceous beds to those which are reddish and whitish. There are several definite horizons of whitish quartzite from 15 to 20 feet thick. The strata are frequently ripple-marked, and occasionally coarse-grained, but nowhere conglomeratic. An excellent section of these gray beds is exposed in the northeastern spur of Appekunny mountain, from which the name is taken, but the strata are so generally bared in the cliffs throughout the Lewis and Livingston ranges that they may be examined with equal advantage almost anywhere in the mountains.

The Appekunny argellite occurs everywhere above the Altyn limestone along the eastern front of the Lewis range from Saint Mary lakes to Waterton lake and beyond both northward and southward. It also appears at the western base of the Livingston range above Flathead valley and is there the lowest member of the series seen from Kintla lakes southward to McDonald lake.

Grinnell argillite.—A mass of red rocks of predominantly shaly argillaceous character is termed the Grinnell argillite from its characteristic occurrence with a thickness of about 1,800 feet in mount Grinnell. These beds are generally ripple-marked, exhibit mud cracks and the irregular surfaces of shallow water deposits. They appear to vary considerably in thickness, the maximum measurement having been obtained in the typical locality, while elsewhere to the north and northwest not more than 1,000 feet were found. It is possible that more detailed stratigraphic study may develop the fact that the Grinnell and Appekunny argillites are really phases of one great formation, and that the line of distinction between them is one diagonal to the stratification. The physical characters of the rocks closely resemble those of the Chemung and Catskill of New York, and it is desirable initially to recognize the possibility of their having similar interrelations.

The Grinnell argillite outcrops continuously along the eastern side of Lewis range and its spurs, occurring above the Appekunny argillite and



GOATHAUNT, LEWIS RANGE

A spur of mount Cleveland. View is looking northwest and is a typical exposure of Siyeh limestone; portion of cliff in view about 1,200 feet high; base below view descends nearly vertically as far again. Goat trails extend across cliff face.

dipping under the crest of the range at the heads of the great amphitheaters tributary to Swift Current valley. About the sources of the Kennedy creeks it forms the ridge which divides them from Belly river. Mount Robertson is a characteristic pyramidal summit composed of these red argillites. The formation occurs in its proper stratigraphic position between the forks of Belly river and west of that stream in the Mount Wilson range of the Canadian geologists, the northernmost extremity of the Lewis range; and it dips westward under the valley of Little Kootna creek and Waterton lake. On the western side of Livingston range the Grinnell argillite was recognized as a more silicious, less conspicuously red or shaly division of the system, occurring about upper Kintla lake.

Siyeh limestone.—Next above the Grinnell argillite is a conspicuous formation, the Siyeh limestone, which rests upon the red shales with a sharp plane of distinction, but apparently conformably. The Siyeh is in general an exceedingly massive limestone, heavily bedded in courses 2 to 6 feet thick like masonry (see plate 49). Occasionally it assumes slabby forms and contains argillaceous layers. It is dark blue or grayish, weathering buff, and is so jointed as to develop large rectangular blocks and cliffs of extraordinary height and steepness. Its thickness, as determined in the nearly vertical cliff of mount Siyeh, is about 4,000 feet.

This limestone offers certain phases of internal structure which may be interpreted as results of conditions of sedimentation or as effects of much later deformation. Some layers exhibit calcareous parts separated by thin argillaceous bands, which wind up and down across the general bedding and along it in a manner suggestive of the architectural ornament known as a fret. It is conceived that the effect might be due to concretionary growths in the limestone, either during or after deposition, or to horizontal compression of the stratum in which the forms occur. Other strata consist of fragments of calcareous rock from minute bits up to a few inches in diameter, but always thin, constituting a breccia in a crystalline limy cement. Again, other strata consist of alternating flattish masses of calcareous and ferruginous composition, which rest one upon another like cards inclined at angles of 30 to 45 degrees to the major bedding. At times the lamination is so minute as to yield a kind of limestone schist. These internal structures suggest much compression, but the apparent effects are limited by undisturbed bedding planes, and it is possible that the peculiarities are due to development of concretions and to breaking up of a superficial hard layer on the limestone ooze during deposition of the beds. Walcott has described similar structures as intraformational conglomerates.

The Siyeh limestone forms the mass of mount Siyeh, at the head of Canyon creek, a tributary which enters Swift Current at Altyn from the south. It constitutes the upper part of all the principal summits of Lewis range north of mount Siyeh, including mounts Gould, Wilbur, Merritt, and Cleveland. It extends beyond Waterton lake westward into the Livington range and forms the massive peaks between Waterton and North Fork drainage lines. Above upper Kintla lake it is sculptured in the splendid heights of Kintla peak and the Boundary mountains.

An exceedingly characteristic and general feature of the Siyeh limestone is the occurrence of an intrusive sheet of diorite, which is found throughout the area examined, with an approximately uniform thickness of 60 to 100 feet. The dikes by which this sheet was fed traversed the formation, following the vertical joint planes with offsets. The conditions of intrusion appear to have been extraordinarily uniform. The rock is described in more detail in the accompanying note by Mr Finlay:

The top of the Siyeh limestone, considered as a lithologic formation over that part of the area where it was observed, coincides with an extrusive igneous sheet, which was clearly erupted prior to the deposition of the succeeding strata, and exhibits the ropy flow structures incident to flow and cooling at the surface. The rock is of a rhyolitic nature.

Sheppard quartzite.—A distinctly sandy phase of deposition succeeding the extrusive rhyolitic eruption has resulted in a quartzite which is very roughly estimated to have a thickness of 700 feet. It forms the crest of Lewis range in the vicinity of mount Cleveland and Sheppard glacier between Belly river and Flattop mountain. It has not been studied in detail, but is recognized as a distinct division of the series.

Kintla argillite.—The highest beds of the ancient sequence of strata found in this part of the range are deep red argillaceous quartzites and silicious shales, with marked white quartzites and occasional calcareous beds. They are named the Kintla formation from their occurrence in mountains on the 49th parallel, northeast of Upper Kintla lake. They also form conspicuous peaks west of Little Kootna creek. The Kintla formation closely resembles the Grinnell, and represents a recurrence of conditions favorable to deposition of extremely muddy, ferruginous sediment. The presence of casts of salt crystals is apparently significant of aridity, as the red character is of subaerial oxidation. The formation has an observed thickness of 800 feet, but no overlying rocks were found. Its total thickness is not known, and the series remains incomplete.

CARBONIFEROUS—YAKINIKAK LIMESTONE

It having been determined by the work of McConnell and Dawson to the north and by that of Weed and Walcott to the south that the main range of the Rockies carries a great thickness of Carboniferous limestone, it was assumed that strata of that age would be found in the section near the 49th parallel, but in the Lewis and Livingston ranges nothing which could be referred to the Carboniferous system was observed. Dawson's correlation of the Siyeh limestone as Carboniferous has already been discussed. On crossing the Flathead valley, however, to the Galton range, which lies between North fork of the Flathead and Kootenai rivers, a small area of limestone was encountered in Yakinikak valley. The rock is a light gray and dark blue limestone about 100 feet thick, distinctly bedded, commonly crystalline, occasionally oolitic. Some fractures have a black, speckled appearance due to dark cleavage faces on calcite crystals. It is without upper stratigraphic limit, but rests conformably on a quartzite, which is unconformable on Algonkian strata. The quartzite is about 25 feet thick, and it and the limestone lie in a nearly horizontal position. The name Yakinikak is here applied to the limestone, exclusive of the quartzite, which may elsewhere develop independent importance.

The Yakinikak limestone contains numerous fossils of the Saint Louis horizon of the Mississippian series, and was fully identified by Weller as identical in lithologic character and faunal content with that formation in the Mississippi valley. Its occurrence on Yakinikak creek is apparently due to down-faulting, as it lies at a comparatively low level among mountains composed of the Algonkian argillites. Its presence in this locality, taken in connection with other occurrences north and south, may be considered evidence of the former extension of the upper Mississippian limestone over the entire region. The absence of the earlier Mississippian strata is significant of an unusual overlap.

In the course of a report of explorations in 1901 * for coal on Wigwam river Mr W. W. Leach, of the Canadian Survey, refers to the "Devono-Carboniferous limestones of the MacDonald range, a high and extremely rugged group of mountains which forms the divide between Wigwam and Flathead rivers." The Yakinikak limestone lies at the southern extremity of the MacDonald range, which may be said to die out at the 49th parallel, and it is probable that its fossiliferous strata make up the heights farther north. It is also possible that it rests on Siyeh limestone, in which case the break between the two would not be readily recognized, as the rocks are very similar and the angular difference of dip is slight.

TRIASSIC

Dawson's report for 1885 and the accompanying map represent certain rocks of the Livingston range near the South Kootanie pass as Tri-

* Summary Report, Geological Survey Department of Canada, 1901, p. 72.

assic. The validity of the correlation has been discussed. The evidence indicates that the strata are probably Algonkian.

CRETACEOUS

General note.—Cretaceous strata are but poorly exposed along the eastern base of Lewis range, although they form the subterrane beneath hundreds of square miles of the plains. The mantle of drift is widespread and often thick, and outcrops of rock in place are limited to occasional freshly scoured gullies or ledges of sandstone along hilltops. Such outcrops were noted, however, in traversing the plains from Cutbank river to Saint Mary lake, and others were found about the mountain slopes west of Saint Mary lakes, up Swift Current valley, on Kennedy creek, about Chief mountain, and on Belly river. Weller collected fossils sufficient to determine three horizons, namely, Dakota, Benton, and Laramie, and through the light thrown by fossils on their relations these occasional Cretaceous outcrops become interesting as elements of a structure which they do not suffice to make clear. Their distribution is such that the Dakota and Benton, while occupying normal relations one to another, are apparently above the Laramie. The significance of this from the point of view of structure is discussed under that head.

No occurrences of rocks of Cretaceous age were observed west of the Front range of the Rockies, and it is probable that there are none south of the Crow Nest coalfields.

Dakota.—Arenaceous and argillaceous shales and sandstones of Dakota age occur on North fork of Kennedy creek near its junction with South fork, 5½ miles east by south from Chief mountain, at an elevation of 4,800 feet. The exposures constitute a bluff 30 feet high, near the top of which are layers bearing fossil plants and freshwater shells. A collection of leaves, though badly broken up in transit, was examined by Mr Knowlton, who reports *Ficus proteoides ?* Lesq., *Magnolia boulayana* Lesq., *Liquidamba integrifolius* Lesq., *Liquidamba obtusilobatum* Lesq. *Diospyro rotundifolia* Lesq., *Phyllites rhomboideus* Lesq. "The above species, says Knowlton, "are all characteristic Dakota Group forms, and the beds at this locality are referred without hesitation to this age." The strike of these Dakota strata is nearly north and south and they dip at a low angle, 0–10 degrees, westward.

Benton.—Dark bluish black to leaden gray shales constitute the mass of Cretaceous rocks west of Saint Mary lakes. With them are associated thin beds of limestone and ferruginous sandstone. Weller's collections from outcrops north of lower Sherburne lake in Swift Current valley, and from southern slopes of Chief mountain, were submitted to Mr Stanton, who identifies *Inoceramus labiatus* Schlotheim, *Prionotropis* sp., *Ostrea con-*

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gesta Conrad?, *Camptonectes* sp. *Scaphites ventricosus* Meek and Hayden, *Anomia* sp., *Tellina* sp. Among these the *Inoceramus*, *Prionotropis*, and *Scaphites* are classed as characteristic Benton forms.

The topographic relations of the Dakota outcrop on Kennedy creek and the highest Benton outcrops under Chief mountain are such that if the beds were strictly horizontal the thickness of Cretaceous rocks would be 2,700 feet. As there is a slight dip from the former beneath the latter, this may be increased to 3,500 feet or more. It is, however, possible that the overthrusts which traverse the Algonkian are paralleled by others in the apparently undisturbed Cretaceous beds, and, if so, no estimate of thickness can be based on the meager data now available.

Just northeast of the northern end of Lower Saint Mary lake Weller collected from a gray sandstone and according to Stanton's determination obtained *Inoceramus* sp., possibly young of *I. labiatus*, *Mactra emmonsi* Meek? *Tellina modesta* Meek, *Donax cuneata* Stanton, *Corbula* sp., *Turritella* sp., and *Lunatia* sp. Of these Stanton says:

"Although the evidence of these fossils is not absolutely conclusive as to the horizon, it is probable that they are from the Benton or at least from some horizon within the Colorado group."

Laramie.—Ten miles east of Lower Saint Mary lake, on the Middle fork of Milk river, occur outcrops of thin-bedded and cross-bedded gray sandstone and arenaceous shale. Some of the layers contain scattered and fragmentary plant remains. Others are barren of fossils. Certain ones are composed of oyster shells. In a section measuring 70 feet Weller found five oyster beds, from which he collected *Ostrea glabra* Meek and Hayden, *Corbicula occidentalis* Meek and Hayden, and small specimens of an undetermined *Melania*, which may be the young of *M. wyomingensis* Meek. The *Ostrea* of the highest stratum is said by Stanton to approach more nearly to *O. subtrigonalis* Evans and Shumard. These are all classed as belonging to the Laramie fauna.

TERTIARY LAKE BEDS OF NORTH FORK

On the North fork of the Flathead there are, as already stated, bluffs of clay with interbedded sandstones and lignites, in which no fossils were found. Details of constitution are summarized in the tabular statement of formations. The materials, degree of induration, and the lignitic condition of the carbonaceous deposits serve to indicate that they may be of Miocene or Pliocene age, as are beds near Missoula, which they resemble. These deposits are called lake beds because they are very distinctly and evenly stratified. They consist of fine sediment, such as would settle from quiet water only, and they occur in a valley of such moderate width between mountains of such height that no simple condition of alluvial accumulation seems appropriate. It is possible that the lake was at times shallow like a flooded river. It is probable that it was some time reduced to the proportions of a river. It is certain that during considerable intervals some areas were marshes; but, admitting that a lake may pass through various phases of depth and extent, the term lake beds best describes these deposits.

PLEISTOCENE (?)—KENNEDY GRAVELS

The typical occurrence of Kennedy gravels is illustrated in figure 2, plate 51. There one may note the size and form of the constituent boulders and pebbles, the incoherent water-washed nature of the gravel shown by the slopes, the level top which falls into the horizon line of the Plains, and the elevated position of the gravel mass. This gravel mesa lies just 5 miles east of the top of Chief mountain, north of and 900 feet above North Fork of Kennedy creek. It is isolated, and equaled in height among the outlying hills only by a ridge of Cretaceous sandstone about 100 feet higher and two miles west of it. The gravel rests on Benton shales, which give rise to many landslides. The Kennedy deposit at this point is something more than 100 feet thick, but its base cannot be accurately placed.

Mr Finlay examined this gravel with care, and the following data are compiled from his notes. The gravel composing the mesa is well rounded or subangular. No striated stones were observed. Boulders two feet across occur, but are rare. Others from 6 to 12 inches in diameter are common. Finer gravel and gravelly soil make up the mass. Of the constituent rocks, limestone and quartzite are most abundant; green argillite forms about 10 per cent; red shale is rarer; Cretaceous sandstone more common. The intrusive diorite of the Siyeh formation is not represented. The gravel deposit is obscurely stratified.

Comparing these notes with Mr Finlay's observations on glacial drift, which covers the slopes 300 to 400 feet below the mesa summit and thence to the creek, it appears that the Kennedy gravels and the drift are alike in being composed of local Algonkian and Cretaceous materials, but differ in that the drift includes many striated stones, and also boulders of diorite from the intrusive sheet in the Siyeh formation. The latter rock does not extend in place into the watershed of North Fork of Kennedy. Boulders of diorite presumably entered the drift in the lower part of that valley by a course on or in the ice when it was confluent with that from Swift Current valley. That the Kennedy formation does not contain diorite boulders is a point in favor of its purely local origin.

The constituent materials, the forms of the boulders and pebbles, the obscure stratification, the topographic form, and the position of the mesa, all characterize this occurrence as a remnant of an alluvial cone of Kennedy creek. No earlier record has been detected in the history of that stream. Since that date, however, the valley has been cut down 900 feet, a glacial epoch has intervened, and the channel has recently been reëxcavated and sunk deeper in the subterrane.

Certain tabular drift surfaces between Swift Current and South Kennedy creeks and on the northern slope of Yellow mountain are probably not of the Kennedy formation, but are outwash plains beyond moraines. Gravel mesas, that are correlative with the Kennedy and may be included under the formation name, occur in Canada, one lying 6 to 8 miles north by west from Chief mountain and east of Belly river; another, a group of three hills, occurring east of lower Waterton lake, a few miles north of the boundary (figure 2). The basis of correlation in these two cases is general form, altitude, and constitution of the masses, which were not, however, examined in detail.

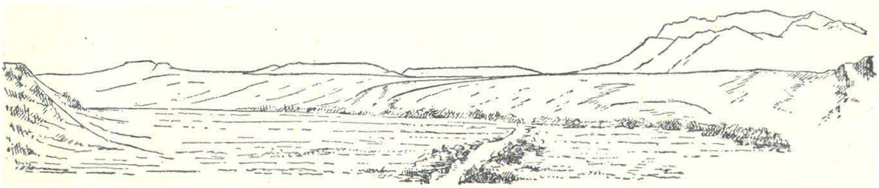


FIGURE 2.—*Sketch of northern End of Lewis Range.*

Showing flat topped foothills of the Kennedy formation standing above terraces of valley drift. Looking east near the outlet of Waterton lake, Alberta, down Pass creek.

Gravels are widely spread on the highest tables of the Plains north of Cutbank river and between the forks of Milk river. Their position suggests a correlation with the Kennedy formation. On the other hand, the gravels of the Plains are composed chiefly of quartzite and presumably have lost the more soluble constituents, which still occur in the Kennedy formation. From this distinction, greater antiquity may be argued for the high level gravels of the Plains. Salisbury, in summarizing the results of Calhoun's observations in 1901 in this region, says: *

"The high-level quartzite gravels on the plains east of the mountains are believed to be deposits made by streams at the close of the first epoch of baseleveling recorded in the present topography."

If this belief be confirmed, the high-level gravels of the Plains and the Kennedy formation are alike in genesis and derivation from the Lewis range. They may, nevertheless, belong to widely different stages

* Journal of Geology, University of Chicago, January, 1902.

of uplift and erosion. The characteristics of the gravels and the physiographic record of the mountains may decide the relation on closer study.

Structure

GENERAL STATEMENT

The structural geology of the region comprises three dominant facts, to which all other phenomena are incidental. These facts are, first, the synclinal structure of the Front ranges; second, the superposition of Algonkian strata on Cretaceous in consequence of an overthrust fault, and, third, a normal fault which probably separates the mass of the Livingston range from the equivalent rocks beneath the Flathead valley.

SYNCLINE OF THE FRONT RANGES

General features.—The strata herein described as Algonkian, from the Altyn limestone at the base to the Kintla argillite at the top, are flexed in a shallow basin. Throughout the eastern, the Lewis range, the strata dip gently southwestward. The amount of dip varies from 5 degrees or less to 30 degrees. Throughout the western, the Livingston range, the strata dip northeastward, usually at angles between 30 and 40 degrees. Thus each crest is a limit of the syncline, and the intervening valley follows the synclinal axis with a trend of north 25 degrees west. The structure is of large proportions. The beds involved in the flexure are at least 10,000 feet thick. The width of the syncline is 8 miles near the top of the Siyeh formation, which forms the conspicuous elevated rims, and in the Appekunny argillite, the lowest bed which appears on both sides, it may be measured at 20 miles. The structure is exceedingly simple (figures 1, plates 50 and 51, in panorama, and section 5, plate 53). In broad views irregularities of dip are scarcely noticeable.

FIGURE 3.—*Mounts Heavens and Stanton, looking south from Trapper Peak.*
Showing the steepest northeastern dip observed.

Details of local folds.—The Grinnell red beds locally exhibit internal folds a few yards in dimensions, representing movements within the soft mass of argillites. In a peak known as mount Stanton, southwest of mount Heavens, on the western margin of the syncline, gray argillites of the Appekunny formation stand vertically, and are even overturned. (See figure 3.) Again, east of the head of lower Logging Creek lake and about 2,000 feet above it, cliffs of this argillite exhibit marked cleavage, which traverses the bedding at an angle of 20 degrees. The local strike of bedding is north 55 degrees west; dip, 20 degrees south-

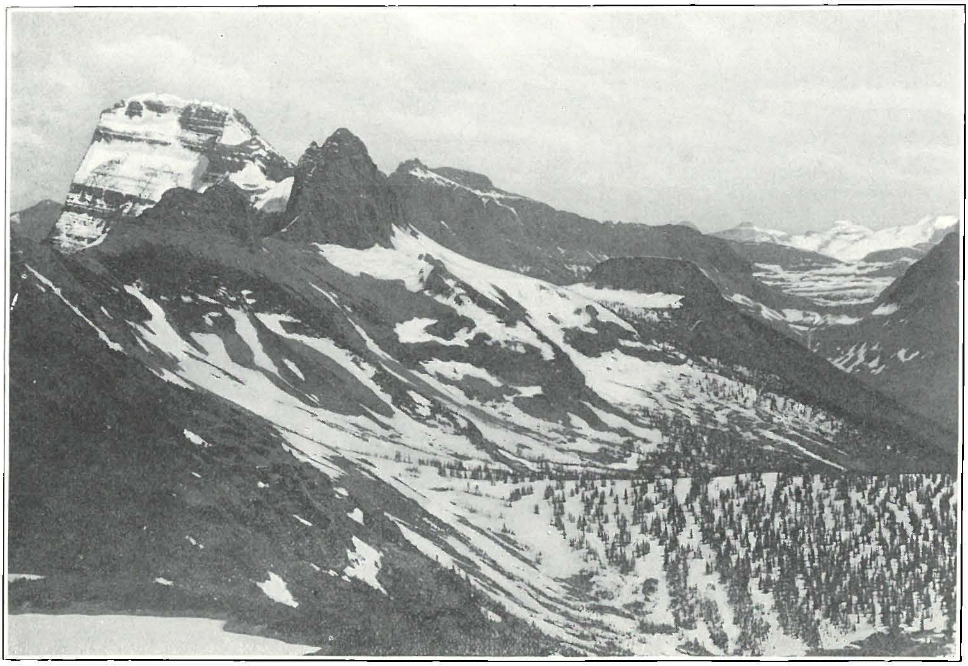


Figure 1.—Panorama from Swift Current Pass, Lewis Range

Looking south by east. East half from Gould on left to Stimpson and Blackfoot far off on right. Foreground of old valley floor continued in plate 51

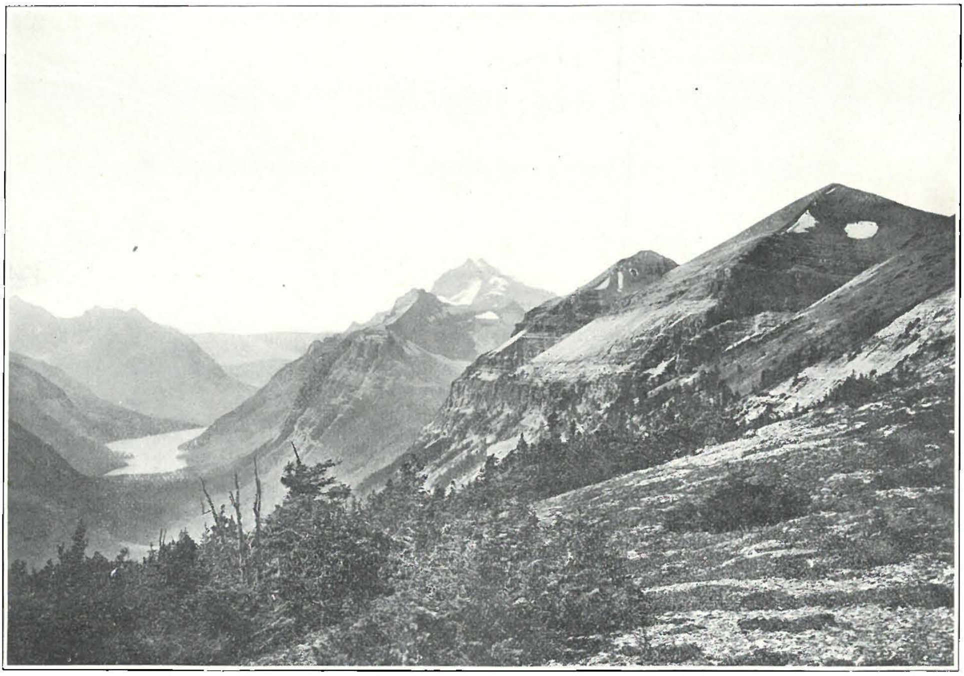


Figure 2.—Upper Knitla Lake and Boundary Mountains, Livingston Range

Looking due west from International summit on Continental divide. Foreground on extrusive diabase underlying Knitla argillite; distant peak, Siyeh limestone; remote hills, Galton range.

PANORAMA FROM SWIFT CURRENT PASS AND VIEW IN LIVINGSTON RANGE

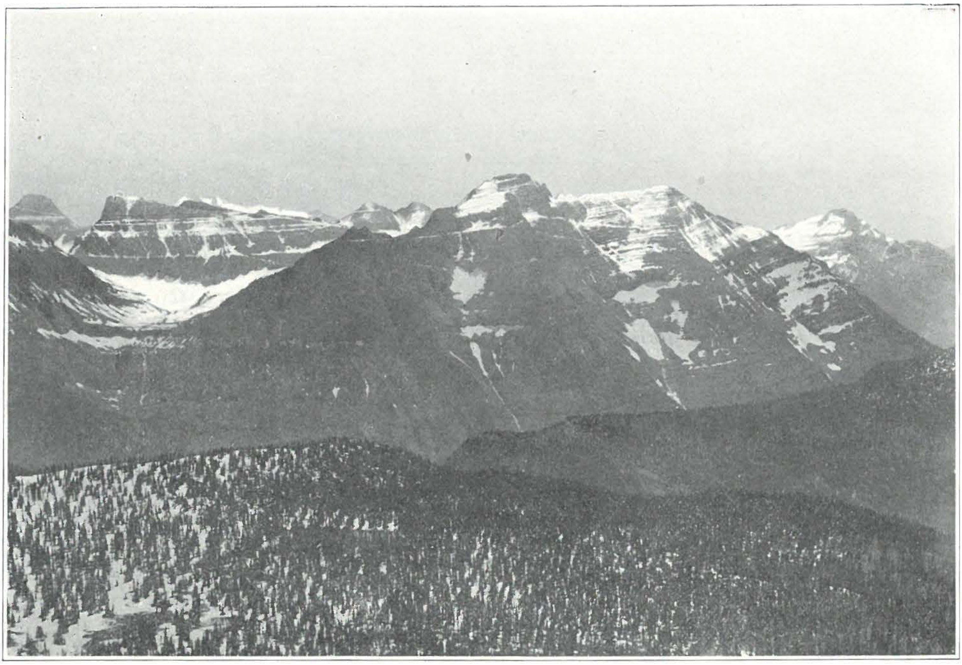


FIGURE 1.—PANORAMA FROM SWIFT CURRENT PASS, LEWIS RANGE

Looking south by east. West half from Reynolds on left to McDonald valley on right. Oblique joint plains are noticeable. Foreground shows canyon of Mineral creek in old valley floor. Continued in plate 50

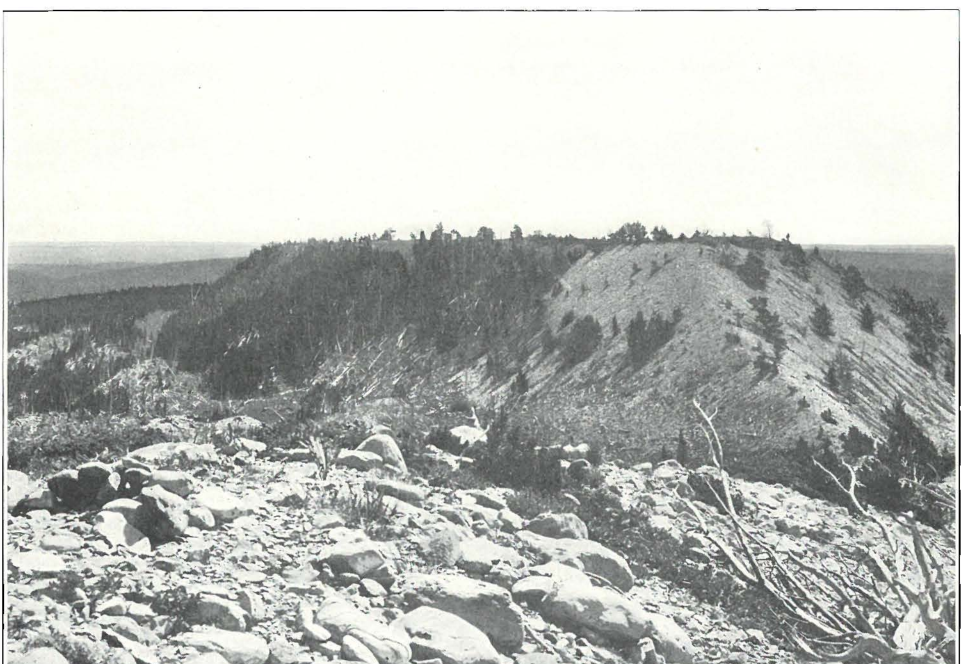


FIGURE 2.—EASTERN FOOTHILLS OF CHIEF MOUNTAIN

Looking east to Great Plains. Typical occurrence of Kennedy high level gravels, 900 feet above Kennedy creek

PANORAMA FROM SWIFT CURRENT PASS AND FOOTHILLS OF CHIEF MOUNTAIN

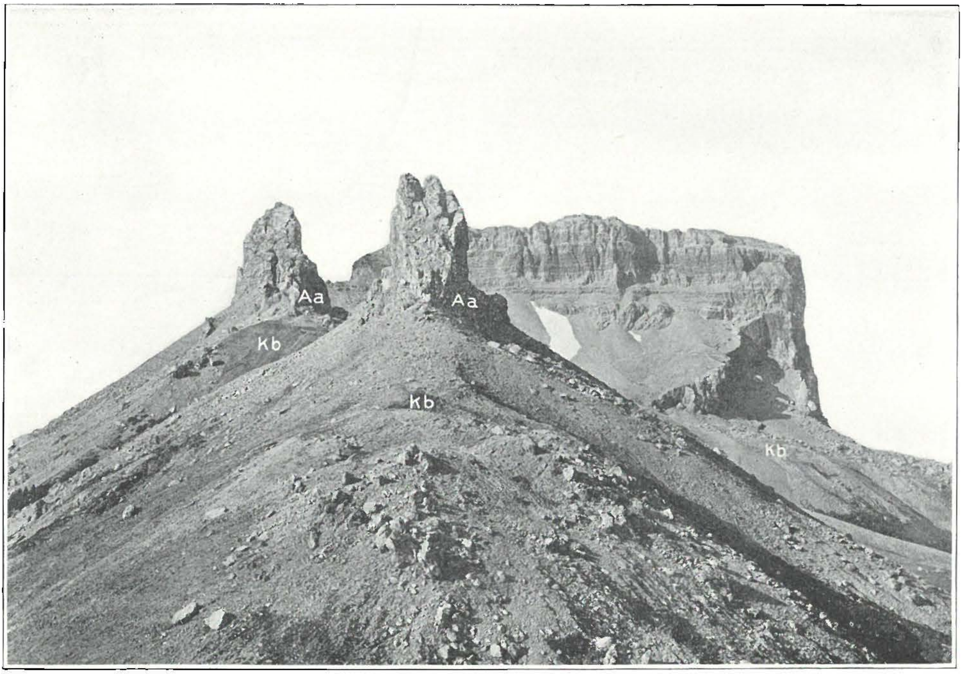


FIGURE 1.—CHIEF MOUNTAIN, LEWIS RANGE

Looking east along Chief Mountain ridge. *Aa* = Algonkian—Altyn limestone; *Kb* = Cretaceous—Benton shale. Upper part Chief Mountain shows upper member Altyn formation

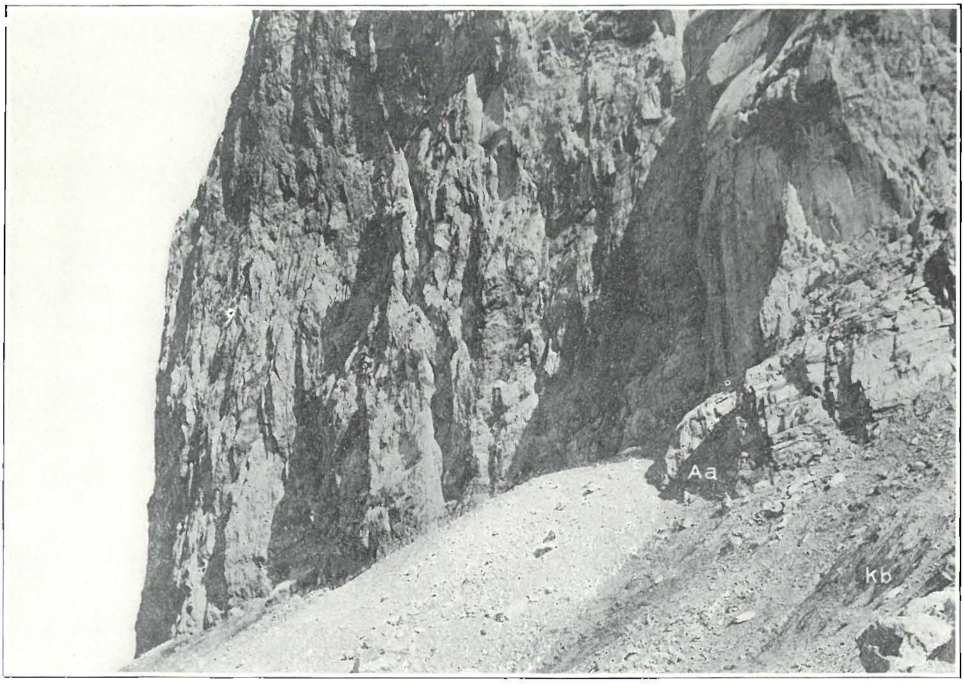


FIGURE 2.—CLIFFS AT NORTHERN BASE OF CHIEF MOUNTAIN

Looking southeast. *Aa* = Algonkian—Altyn limestone; *Kb* = Cretaceous—Benton shale. Limestone exhibits vertical slickenfaces with horizontal motion and in general chaotic fracture

CHIEF MOUNTAIN, LEWIS RANGE

west, and that of cleavage north 45 degrees west; dip, 40 degrees southwest. The structures in mount Stanton and above Logging Creek lake are exceptional. Of a different type is a broad flexure, an anticlinal swell within the syncline. The axis passes through mount Cleveland (elevation, 10,438, the highest in the Lewis range), and thence south 30 degrees east through mount Merritt and mount Wilbur, where the fold dies out. It is noteworthy that the axis carries the major heights of the range. It is a very gentle rise of the strata, usually marked by opposing dips of 5 degrees or less; but in mount Cleveland the northeasterly dip becomes as much as 10 degrees. Between mount Cleveland and Belly river the westerly opposing dip is 20 to 35 degrees.

LIVINGSTON ANTICLINE

The western limit of the Front Ranges syncline is an anticlinal axis, which may be traced just west of the summit of Livingston range in spurs jutting out between Camas and Logging creeks. It is indicated by southwest dips of 5 to 20 degrees, and thus appears to maintain the comparatively gentle inclination of strata observed in the Lewis range in the same direction. Between the high spurs the axis is buried beneath drift which fills the valleys, and northwest from Logging creek no instance of southwesterly dip was observed. Conditions of normal faulting and erosion appear to have resulted in removal of the western limb above drainage lines throughout much of the range.

LEWIS OVERTHRUST

Character and extent.—The simple structure of the Algonkian series overlies a great dislocation. Along the eastern front of the Lewis range Altyn limestone rests upon Cretaceous rocks. This inverted relation was noted from Saint Mary lakes to Waterton lake, a distance of 28 miles in a straight line northwest, and across the general trend the contact was observed to have a width of 5 to 7 miles. The outcrop of Altyn limestone over Cretaceous was observed in a sinuous course, as shown on the map (plate 48 and also figure 4), from Single Shot around the valleys of Swift Current and Kennedy creeks, around the promontories of Appekunny, Yellow, and Chief mountains, past the forks of Belly river and into Canada. The surface of contact was actually seen only beneath Chief mountain, but its position was determined within 20 feet or less at several points. Each series near the contact has yielded fossils, which afford conclusive evidence that in age they are separated by all of Paleozoic and most of Mesozoic time, and that the older is on top. This relation is interpreted as an overthrust (figures 1 and 2, plate 52). A similar structure has been described by McConnell for the same range in latitude 51 degrees.*

Warped thrust surface.—The strike and dip of the thrust plane can not be measured directly, but by graphic construction they may be determined for any triangular area provided the relative heights and horizontal positions of its three corners are known. The topographic map gives these facts within fairly satisfactory limits, and the results are given in figure 4 for five areas between Flattop and Chief mountains. They show that the strike varies from north 15 degrees 30 minutes west to north, and then to north 59 degrees west, and the dip ranges from 3 degrees to 7 degrees 45 minutes.† In these solutions any such area, as that of the triangle Flattop, Swift Current, Appekunny, is considered a plane, which is assumed to coincide with the fault surface. It was observed in the field that the fault surface was curved in cross-sections in the direction of the dip, the dips being exceedingly low, if not truly zero, under East Flattop, Yellow mountain, and Chief, but being also as steep as 10 degrees or more where the overthrust approaches the falls of Swift Current, South Kennedy and North Kennedy creeks. The differences of strike in different segments also show that it is a warped surface. Thus the mathematical determinations of dip and strike are averages, true only of planes which subtend curved surfaces. They nevertheless give valuable indications of the form of the warped surface.

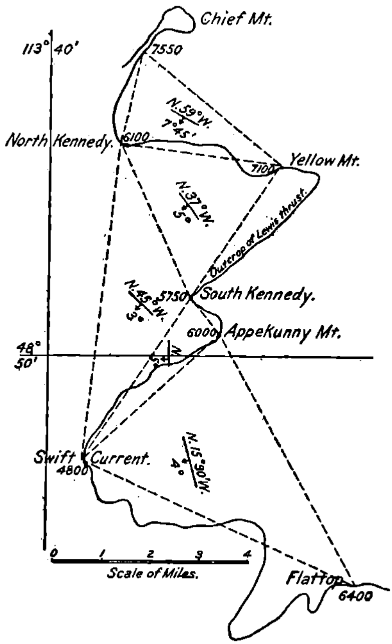


FIGURE 4.—*Diagram of Strikes and Dips of Planes Subtending Areas of the Lewis Thrust.*

So far as the figures go, they show that the strike of the fault surface makes northerly and westerly in a step-like manner, which corresponds to the offset of the mountains about Chief. The prominence and isolation of Chief mountain is in large measure due to the fact that its mass forms the northeastern corner of this offset. West of Chief the strike

* Canada Geol. and Nat. History Survey, Report 1886, Part II.

† The method of reaching these results is by solution of the simple problem of descriptive geometry: Given the horizontal and vertical projections of three points, to find the horizontal trace and the inclination of their plane.

trends more strongly westward, according to field observations of its position at the forks of Belly, and again more northerly along the western slope of Belly valley. About the northern end of the Lewis range, in Canada (the Wilson range of Dawson), the strike is thought to be to the westward again. From Waterton lake the outcrop of the fault surface follows the base of the mountains northwestward, and the strike approximately coincides with this direction. According to these observations, the relation of the Lewis and Livingston ranges, en echelon at the 49th parallel, is an effect of step-like though very gentle flexure in the fault surface of the Lewis thrust.

As to the origin of the flexures in the Lewis thrust surface, several hypotheses suggest themselves. They may be original—that is, the surface may never have been plane. They may have been developed during or after the episode of thrusting movement. They may or may not coincide with flexures of the Algonkian strata ; and if coincident as to axes they may not equal the structure of the Algonkian in degree of flexure. Only close studies of the relations with the aid of the complete topographic map will answer the questions thus raised.

Structure beneath the thrust surface.—The structure of Cretaceous strata beneath the Lewis thrust was not connectedly observed. The rocks are commonly covered with drift of talus, and they are much disturbed superficially by landslides, to which the Benton shales give rise. Out of perhaps twenty reliable observations of dip, distributed over the entire area of Cretaceous subterrane, nine-tenths are to the southwest and vary from a degree to 25 degrees. In the field the monoclinal southwestern dip was taken to be a simple structure. From the determinations of Stanton and Knowlton, however, it follows that in this supposed monocline the younger, Laramie, strata underlie the older Benton and Dakota. Such an apparent relation might result (*a*) from the existence of eastward dips along Saint Mary valley, west of Maine, or (*b*) from an overthrust of Dakota and Benton on Laramie, parallel to and beneath the Lewis thrust. Two and a half miles southwest of Maine ridges of Cretaceous sandstone, probably Dakota, exhibit an anticlinal attitude, which may represent an important axis or a local incident. The thickness of the strata and more precise dips must be observed before either of the above possible suggestions can be confirmed or excluded.

Structure above the thrust surface.—The detailed structure of the Algonkian mass above the Lewis overthrust is sometimes chaotic when considered in the small, yet simple when observed in the large. The chaotic structure is best exhibited in Chief mountain, where the lower massive member of the Altyn limestone is crushed (see figure 2, plate 52, and figure 5). The fractures divide the masses irregularly into blocks of all angular shapes varying from a few inches to 25 feet on a side. The surfaces are slickened over wide areas, and where they preserve their orientation in the cliffs the slickens demonstrate much relative horizontal displacement of adjacent fragments. Certain fracture planes are in fact steep fault surfaces along which displacement has occurred in the direction of the strike rather than in that of the dip. Such faults are, however, without apparent system. In other places, as north of Altyn, the cliffs present mural faces traversed by remarkably regular lines of bedding which are crossed by nearly vertical joints (see figure 2, plate 47).

Viewed in the large, the structure of the Altyn limestone sometimes is that of major and minor thrust faults. Yellow mountain, as seen from

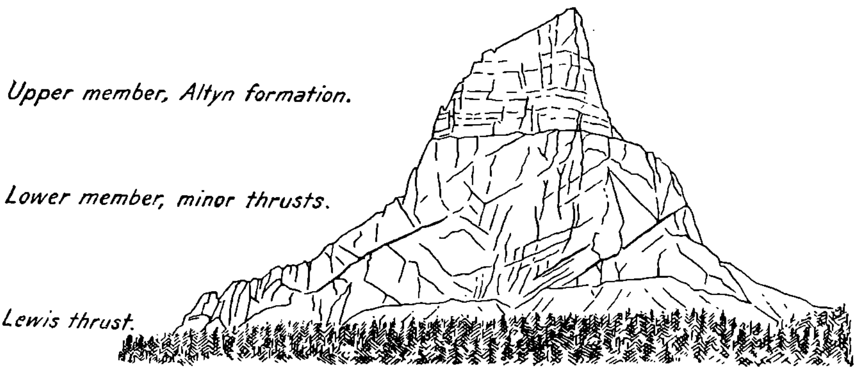


FIGURE 5.—*Chief Mountain, looking north.*

Showing the zone of minor thrusts in massive limestone between the Lewis thrust at the base and the undisturbed upper member of the Altyn formation.

Chief Mountain ridge, exhibits these relations very clearly (see figure 6). The basal major thrust lies at the foot of the cliffs, somewhat obscured by talus, but sloping about 8 degrees in a curve which on the left is less inclined and descends more rapidly to the right. Springing from it are several minor thrusts, which dip more steeply and which upward pass out either into the air or into an upper major thrust. The upper major thrust is at the base of argillites which dip gently and without appreciable disturbance to the southwest. It simulates an unconformity.

In Chief mountain a similar structure is more strikingly exhibited (see figure 5). The base of massive Altyn limestone is traversed by minor thrusts which are often subparallel to the bedding, so far as it can be made out. These thrusts dip 30 degrees and occupy a zone about 1,000 feet thick above the Lewis major thrust. They are limited above by an upper major thrust which is at the base of nearly horizontal thin-bedded limestones, constituting the upper member of the Altyn formation.

The thickness of strata within which major and minor thrusts are developed is by no means constant. As stated, near Altyn the lowest beds of Altyn limestone present mural regularity of structure, whereas in Yellow mountain probably not more than 500 feet of strata are so repeated as to pile up 2,400 feet high. West of Waterton lake, in the section seen by Dawson, the effects of minor thrusting are still greater; but, though the resulting pile of overthrust segments be great, the maximum thickness of strata involved is probably less than 1,000 feet.

Above the zone of minor thrusting as limited by the upper major thrust the strata are not notably dislocated, if at all, on planes of over-

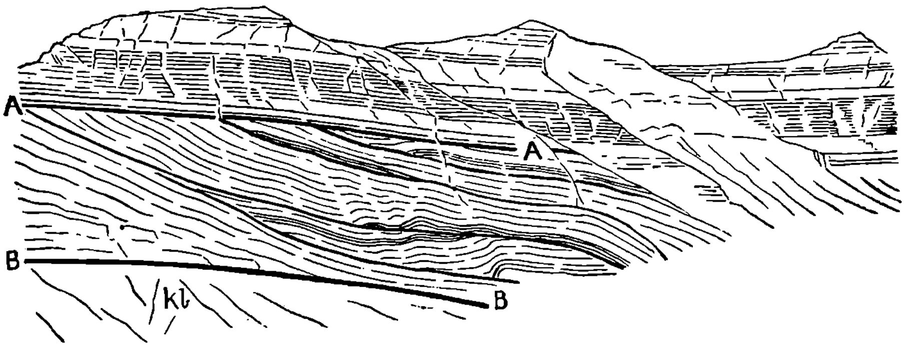


FIGURE 6.—*Structure of Yellow Mountain, drawn from photograph from Chief Mountain, looking southeast.*

AA, upper major thrust under Appekunny argillite. *AB*, minor thrusts traversing and repeating Altyn limestone, minor folding and faulting omitted. *BB*, Lewis thrust. *Kb*, Cretaceous-Benton, much covered by talus.

thrusting. Nevertheless, it is important to state, as bearing on the distribution of that stress which produced the thrusts, the fact that dividing planes which are parallel to the Lewis overthrust traverse the higher Algonkian strata in the heart of the syncline. The appearance of these planes, which may be called X planes, is given in photographs from near Swift Current pass looking southwest (figures 1, plates 50 and 51). They were also sketched from Trapper peak looking south. In both cases they appeared as elements of the profile or as snow-covered benches on the faces of the cliffs. They cross the stratification, indifferent to the direction of dip. With the field glass no displacement along them could be made out. Nevertheless, whether the strain exceeded the limit of rupture or not, it follows from the parallelism of the X planes and the Lewis overthrust that the stress which produced the system was effective throughout the mass. Between the highest X planes in mount Reynolds, in the upper part of the Siyeh limestone, and the Altyn limestone at the Lewis thrust the thickness of strata is something more than 8,000 feet.

STRUCTURAL ANTECEDENTS OF LEWIS THRUST

Explanation.—By structural antecedent the writer means those earlier relations of rock masses from which an existing structure has developed. Thus an overturned anticline is one usual antecedent of an Appalachian thrust fault. The Lewis overthrust is a result of conditions which can now be stated hypothetically only, but which so stated may aid future investigation to a truer understanding. To this end the following hypothesis of its antecedent phases is presented:

Assumptions.—Certain general assumptions may first be stated. The surface of the overthrust is essentially parallel to the bedding of the Algonkian series, and in this particular district to the Altyn formation, where the latter has not been dislocated by minor thrusts. This apparently is true not only of the segments of thrust surface beneath eastern Flattop, Yellow, and Chief mountains, but also of the more deeply buried portion which appears to dip down with the Algonkian strata into the syncline. While observation is not complete, it may be assumed on a basis of fact that thrust surface and bedding are nearly parallel over extensive areas.

As regards structure of the Cretaceous rocks, it is not found that the thrust surface coincides with their bedding or any other internal feature of their mass. But, with reference to physiographic features, it was observed that the thrust plane was apparently continuous with the highest peneplain of the Plains—that is, with the Blackfoot plain, the peneplain which is cut on the upturned edges of the Cretaceous strata. As illustrating this relation, figure 1, plate 47, may be described. On the right is East Flattop mountain, as it appears when one is looking south across Swift Current valley. It is composed of Algonkian strata, in which a white quartzite shows the nearly horizontal attitude. At the base of the cliff, just above the tree-covered slope, is the position of the Lewis overthrust. The wooded slope consists of Benton shales, extensively covered by drift. On the left is Saint Mary ridge, the even crest of which is somewhat built up as a lateral moraine of Saint Mary glacier, but which from this point of view corresponds closely with the profile of the old peneplain. That plain is strongly represented in Milk River ridge, 12 miles east of the brow of Flattop mountain. Its gentle rise westward, about 100 feet to the mile, carries it into the thrust surface beneath Flattop.

This relation of the thrust surface to the peneplain is one of critical importance as a means of determining the antecedents of the Lewis thrust, and it is important to verify or disprove it by more extended observations. So far as detailed topographic data are available south of the 49th parallel, they show that the peneplain must rise materially toward the mountains to cross Saint Mary valley at a height sufficient to meet the thrust surface, and this being so, the eastward slope of the plain and the westward dip of the thrust would occupy anticlinal attitudes, one to the other. It would follow also that the peneplain must be warped, as is the thrust surface, since the elevations possibly common to both are unlike in Flattop, Yellow, and Chief mountains. In general, however, it is true from Divide mountain to Waterton lake that the peneplain may be seen constantly to run into the foot of the cliffs which mark the base of the known Algonkian. Before the overthrust was worked out, the writer observed this peculiar position of the peneplain as one bearing on the physiographic history and presenting difficulties. These difficulties lay in the problem of the relative ages of the topographic features of the plains and those of the mountains. Flattop presents some interesting facts in this connection.

The summit of Flattop is broad, gently sloping, long past maturity in topographic phase. It bears no erratics, striæ, or other signs of glaciation. The rocks of the summit are quartzitic argillites, which are exceedingly resistant to erosion as compared with any rocks on the Plains. The topography of the summit is unsympathetic to its environment and it lies 1,200 to 1,800 feet above the position of the peneplain if the latter be extended to the base of the cliffs. It follows that this past mature topography on hard rocks could not have developed in its present altitude above the plains. Either the surface of the Plains was higher and has been lowered by erosion, or the summit of Flattop was lower and has been elevated by thrust.

If they formerly presented a topographic surface near the level of Flattop's summit hills, the Plains have been degraded 1,200 feet, while Flattop survived as a residual height. The Blackfoot plain on the Cretaceous rocks is so extensive and so completely planed as to indicate a long epoch of erosion, and it seems improbable that Flattop could have retained any part of its ancient summit hills, were they indeed relatively so old.

On the other hand, the summit of Flattop is of that topographic form which would be reached by the harder rocks during the development of the Blackfoot plain on the softer ones. The mass of Flattop rests upon the inclined thrust plane, on which it has been pushed forward at least 7 miles. These relations strongly suggest that the summit of Flattop, once nearly as low as the peneplain, has been pushed upward as well as forward on the incline.

On the evidence presented in the preceding paragraphs it is assumed that the Lewis thrust plane and the Blackfoot peneplain are one, at least as far as the former is now traceable beneath the eastern spurs of the Lewis range.

To these assumptions may be added another based on broad observations of stratigraphy and structure, namely, that a structural effect of the first magnitude in sedimentary rocks was originally conditioned by circumstances of deposition. This thesis was considered at some length in Mechanics of Appalachian Structure* and in an article by Hayes and the writer.†

The three fundamental assumptions thus are: (*a*) The thrust surface coincides essentially with the bedding of the Algonkian series. (*b*) It coincides essentially with the highest peneplain on the Cretaceous rocks. (*c*) The antecedent structures of the Lewis thrust were determined by conditions of deposition.

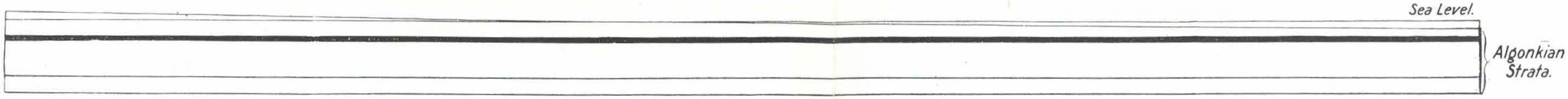
These assumptions being premised, the development of the several stages may most readily be stated in proper order, from ancient to modern, and in simple assertive style. It may be understood that the writer is conscious of the unproved character of some of the points.

Antecedents by deposition.—The first stage considered is that of Cretaceous deposition (see section 1, plate 53). The Dakota epoch of the Cretaceous period was one of wide invasion of the sea westward and northwestward. The deposits in this region contain freshwater shells, and may be considered as having formed in estuaries or lagoons. They are succeeded by marine deposits (Benton), which may be followed by other formations of the Cretaceous system, but of these only the Laramie is identified. Dawson ‡ gives a section of 8,290 feet of Cretaceous in the foothills of the Rocky mountains. We have reason to think there are more than 3,500 feet of Dakota and Benton under Chief mountain. The surface beneath the Dakota formation was a plane; primarily a peneplain; subsequently a surface of marine planation. It sloped gently eastward, and was practically flat in its early history. As it subsided and was buried under marine deposits, it was no longer flat, but curved in gentle flexures, according to any inequalities of subsidence (see section 2, plate 53). Variations in thickness of strata are among the evidences of unequal subsidence, and had we good measures of the Cretaceous strata, we might demonstrate a point of first importance in the hypothesis. As it is, we must rely on the special case of a shore. As Cretaceons rocks do not occur west of the Lewis range in the region

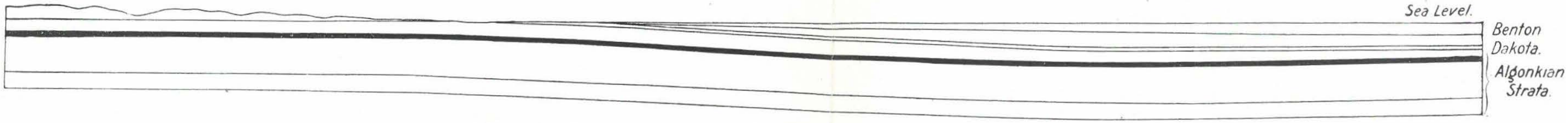
* Thirteenth Annual Report U. S. Geol. Survey, p. 253 et seq.

† American Journal of Science, Third Series, vol. xlvi, pp. 257–268, Conditions of Appalachian Faulting.

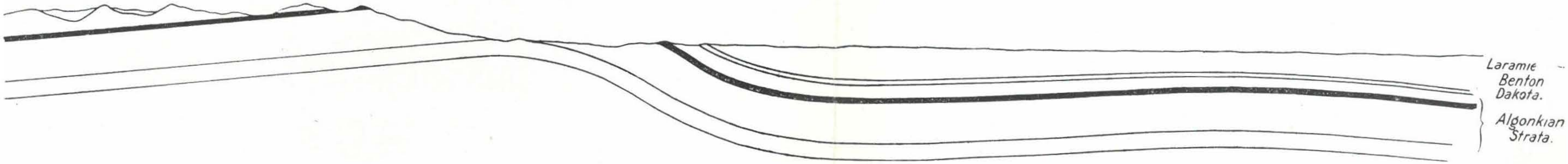
‡ Canada Geol. Survey, Report 1885, p. 166 B.



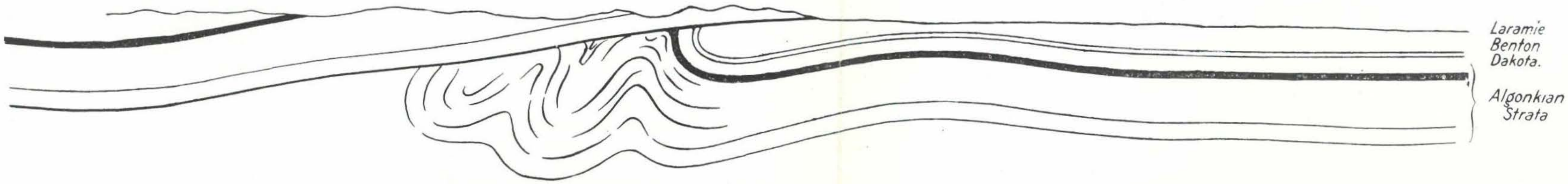
SECTION 1.—HYPOTHETICAL STRUCTURE AND SUBAERIAL AND SUBMARINE PROFILE OF NORTHWEST MONTANA IN DAKOTA TIME



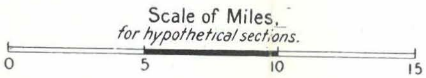
SECTION 2.—HYPOTHETICAL STRUCTURE AND DEPOSITS DEVELOPED DURING BENTON TIME

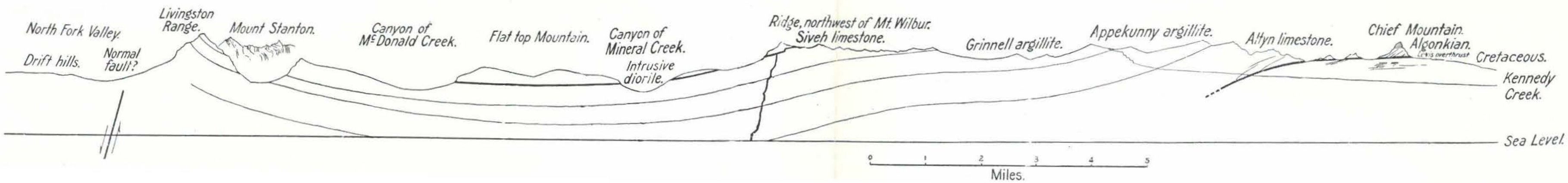


SECTION 3.—HYPOTHETICAL STRUCTURE AND SUBAERIAL PROFILE RESULTING FROM EARLIER EPISODE OF POST-LARAMIE DEFORMATION



SECTION 4.—HYPOTHETICAL STRUCTURE RESULTING FROM LATER (POST-BLACKFOOT CYCLE) EPISODE OF DEFORMATION





SECTION 5.—OBSERVED SECTION OF THE FRONT RANGES FROM CHIEF MOUNTAIN TO NORTH FORK VALLEY
Topographic profile based on contour map, Chief Mountain quadrangle, U. S. Geological Survey

GEOLOGICAL SECTIONS

under discussion, it is probable that the Dakota-Benton sea did not extend many miles west of the present limit of the Plains in this latitude. A shore established on a flat surface and remaining nearly fixed during an episode of deposition in an adjacent zone is a line between an area of subsidence and one of uplift. The case is one of markedly unequal subsidence, the movement being on the one side plus, on the other minus. The sequence of changes is shown in sections 1 and 2, plate 53. Section 1 represents the condition during the Dakota invasion. Section 2 shows the effects of subsidence and uplift incident to deposition of 4,000 feet of Dakota and Benton sediments. The drawings are to natural scale.

The surface on which Dakota sediments gathered probably consisted of Carboniferous and Algonkian rocks. The observed angular unconformity beneath the Carboniferous is slight. The present deformation of the Algonkian is apparently attributable altogether to post-Cretaceous movements. It is assumed that the Algonkian strata were essentially flat in Dakota time and were bent in consequence of the subsidence which occurred during Benton time. These assumptions also are shown in sections 1 and 2, plate 53.

Whatever later stages of deposition followed may have been accompanied by further subsidence and curvature, but that which is attributed to the Benton epoch is sufficient to occasion the development of an anticline (section 3, plate 53) whenever compression should occur.

The preceding statement is made to show reason why an anticline should have developed near the present site of the Front range. Its essential principle is that of initial dips, as a condition which determines the loci of anticlines and synclines,* and the special case is based on the probable position of the Dakota-Benton shore. In what follows the episodes of deformation and erosion leading to the present relations are discussed.

Antecedents by folding and erosion.—Along the eastern base of the Rocky mountains in general the facts of structure express the action of a compressive stress, the Cretaceous and older strata being folded. The post-Cretaceous effects are commonly attributed to a single episode of compression; in what follows they are assigned to two episodes, at least for the particular district under discussion.

The first episode of compression began at some date not closely determinable, but which may be placed not earlier than Laramie time, nor later than early Tertiary. It is possible that flexure went on during Laramie deposition. It is also possible that it did not begin till after that deposition was completed. The distinction is not important to the

*Mechanics of Appalachian structure, op. cit., plates showing models A to E 1.

present thesis. Flexure in its early stages was an effect involving relatively great stress, as the nearly flat Algonkian strata were exceedingly inflexible. It is probable that folds developed slowly. As the Laramie sea was shallow and was succeeded by emergence of the area, the anticlines were subject to erosion, whether they developed earlier or later, and the synclines received their waste either as sediments beneath marine waters or in estuaries or in lakes or as valley deposits.

The effect which for a time satisfied the compressive stress was one of moderate folding (see section 3, plate 53). The succeeding condition was one of quiescence and it endured long enough for the planation of Cretaceous rocks to the Blackfoot peneplain. The name Blackfoot may be extended to the topographic cycle ending in the development of the plain. The Blackfoot cycle can not be accurately dated by any evidence now available. It was post-Laramie and probably earlier than the orogenic movements which, in Montana, gave rise to ranges and lake basins. The latter having yielded Miocene vertebrates, the movement may be placed in mid-Tertiary. That it was preceded by the Blackfoot cycle is an inference based on general observations of an extensive peneplain over the summits of the Rockies of western Montana and Idaho, observations which leave no doubt in the writer's mind of the existence of such a peneplain, but which do not suffice positively to identify it as the Blackfoot plain. On the probability of that identification the Blackfoot cycle may be placed in early Tertiary time.

At the close of the Blackfoot cycle the topographic features of the region under discussion were the peneplain on Cretaceous rocks and low hilly, past-mature relief on Algonkian rocks, such as is now presented by the summit hills of eastern Flattop. To illustrate them would require a profile differing from that of section 3, plate 53, only in degree of relief.

Conditions of overthrusting.—Among the effects of folding and erosion, at the close of the Blackfoot cycle was the exposure of the edges of some Algonkian strata as outcrops; being gently inclined westward, these beds had probably wide extent underground. They were relatively stiff and lay with one edge free. Under these conditions, supposing that a compressive stress again became effective, a part at least of the Algonkian beds were so placed that they met but slight resistance in their tendency to yield by moving forward. So far as they were unopposed, or not sufficiently opposed to check and fold them, they did ride forward (see section 4, plate 53). That part which was thus overthrust separated from that which was not in general along bedding planes near the base of a particularly rigid stratum, such as the Altyn limestone.

The Siyeh limestone, the Carboniferous limestone, or other stiff formation may elsewhere be found to have determined the thrust surface within the old rocks.

Associated structures of the Lewis thrust.—At the margin and beneath the advancing overthrust mass, the effect should be to disturb a superficial layer of greater or less depth. Strata might be overturned; or, if rigid, they might be pushed forward on a thrust plane parallel to the initial thrust; or in soft shales like the Benton, confused crushing might ensue. The weight of the overriding Algonkian might be that of a few hundred or of several thousand feet of rock. In Flattop the thickness is 1,800 feet or less; in Chief it is 1,600 feet. Along the advancing margin it would not in any case be that of the series of Algonkian strata observed in the syncline of the Front ranges. The weight would not be sufficient to restrain rocks from breaking, and the local effects of deformation would be fracture, accompanied by irregular but extensive displacement. These deductions in part correspond with the observed conditions of the overthrust and underthrust masses.

The surface on which the overthrust mass would ride forward would practically coincide with the Blackfoot plain, with which the thrust surface would thus become identified, but it is probable that in the process the peneplain would be deformed. In underlying strata not taking part in the displacement, the stress from which the overthrust resulted should have been exerted to accentuate any previously existing flexures. The Lewis anticline, if the structural antecedent of the Lewis thrust may be so called, was probably paralleled by a gentler fold somewhat further east, as a result of the earlier stage of compression. Any rise of that fold during the later stage of compression would be expressed in arching of the Blackfoot plain; such arching as exists, in fact, if the peneplain and the thrust surface coincide along the eastern base of Lewis range. An experimental illustration of an overthrust, a parallel fold, and the coincidence of thrust surface and subaerial plane may be seen in the sections of model E1, Mechanics of Appalachian Structure.

The displacement observed on the Lewis thrust is 7 miles; the actual displacement is probably greater. The superficial movement requires accommodation of subterranean masses to an equivalent amount in some manner. This adjustment does not affect the preceding discussion of the development of the thrust, but it is a phase of the subject which is naturally suggested in sequel. In section 4, plate 53, close folding of strata is indicated in a position corresponding to a place beneath the Lewis range, but both the manner of folding and the locus assigned it is suggestive only. Applying the general rule that the nature of deformation is determined by the character of rocks and the superincumbent load, the adjustment may consist in fracture, in flow and fracture, or in flow, and at successive depths deformation related to the Lewis thrust no doubt takes on the corresponding forms of crushing, folding, and viscous flow. The meridional sector in which such shortening may take place is indeterminate. It may correspond with the meridian of the Lewis range or extend eastward or westward. General relations suggest that a western sector moved relatively toward an eastern, which was stationary; but the mechanical effects would be similar if an eastern had moved against and under a western mass, or if they had both been in motion each toward the other. The facts thus afford no certain basis of conclusion as to the locus of deeper-seated shortening, corresponding to the Lewis thrust.

The relation of the Lewis thrust to the syncline of the Front ranges presents interesting questions. Did they develop successively or simultaneously? If successively, the broad mechanical effects may have been produced in either order, namely, the thrust first and the syncline later, or *vice versa*. If simultaneously—that is, as effects of a single episode of compressive stress—the manner in which the force was distributed, partly in thrusting and partly in folding, may be definitely analyzed. Let it be assumed that as a result of the earlier compression the Algonkian strata were bent in a synclinal flexure of less pronounced character than the present one. Then, in the later compression, the stress transmitted through the series was resolved into two components—the one tangential, the other radial to the bedding. The former was adequate to cause thrusting; the other was competent to increase the curvature of the beds. For a given stress the ratio of these two components changed with the increase of curvature, the tangential component losing as the radial gained. Thus thrust would cease when the tangential became inadequate to overcome the resistance opposed to it, and curvature would increase till the stress was taken up in the growing anticline west of the syncline. One effect would be to concentrate folding along the western margin of the syncline and to produce steeper dips toward the northeast than those toward the southwest. Such is the fact, but it might have arisen in other ways also. Another result would be to give to the thrust surface a synclinal form, but one which would be less pronounced than that of the overlying strata; and, again, the topographic surface developed on Algonkian rocks during the Blackfoot cycle should be depressed along the synclinal axis to an amount corresponding to the degree of flexure suffered by the strata during the later compression. This point is again referred to under physiographic problems.

Date of the Lewis thrust.—On the hypothesis of a single episode of compression, from which resulted all the phenomena of folding and thrusting in Cretaceous and Algonkian rocks in the district, the Lewis thrust and the associated structures must be assigned to a date closely following the Laramie deposition. The growth of the Front ranges and the development of the Blackfoot plain must be placed later, and the expression of the Lewis thrust must be considered subordinate at the surface to these later effects of orogeny and erosion.

On the other hand, on the hypothesis of two episodes of compression, separated by the Blackfoot cycle, the Lewis thrust must result from the second episode, and falls probably in mid-Tertiary. Its orogenic effects are then dominant in the Front ranges, and the physiographic history is to be read in terms of structure as well as of erosion.

It is concluded that the data of the Lewis thrust may be placed in either late Cretaceous or mid-Tertiary time, and the principal criteria for determining which date is correct are to be found in the relations of structure to physiography.

NORTH FORK NORMAL FAULT

Topographic relations.—The valley of North fork of Flathead river is apparently a structural valley of much greater length than the watershed which coincides with its southern portion. The form of the valley is long as compared with its width. The North fork has no extended tributaries, but streams from the western side have more extensive basins than those from the eastern, which are notably short. There is marked contrast in the aspect of the mountains, west and east. Those on the west, the Galton range, are broad and massive (distance of figure 2, plate 50); they attain heights of 7,000 to 7,500 feet above sea, and they are traversed by open, V-shaped valleys. Those on the east, the Livingston range, are abruptly precipitous, vary in altitude from 8,000 to 10,000 feet, and present acute peaks rising from U-shaped valleys. Over the summits of the Galton range the lowland topography of an earlier cycle is easily traced; in the Livingston range that cycle has not been recognized. A long slope extends from the heights of Galton to the valley; abrupt rise from hills of drift characterizes the western spurs of Livingston.

Geologic relations.—The geologic relations in a cross-section of North Fork valley are simple. Proceeding from southwest to northeast in the vicinity of Hay and Bowman creeks, one encounters: In Galton range, calcareous argillite, probably of the Siyeh formation, lying with a dip of

30 degrees northeast; in Flathead valley, drift and lake beds; in Livingston range, Appekunny argillite, dipping 30 to 45 degrees northeast. The dip of the Siyeh formation in Galton range carries it under Flathead valley to a position several thousand feet below the Appekunny beds, which it properly overlies. The relations are those of a normal fault of great displacement, and downthrow on the west.

From the topographic relations the position of this normal fault is inferred to be along the base of Livingston range, the downthrown block underlying Flathead valley.

Date of normal faulting.—By reasonable inference the lake beds of North fork are connected with the normal faulting. The strata are tilted to a dip of 14 degrees northeastward toward the fault, as though they had shared in late movements. The date of faulting is thus tentatively fixed as Miocene or possibly Pliocene. Elsewhere in Montana similar faults are related to lake basins which have yielded Miocene vertebrates and, pending exact determinations, the North Fork fault is assigned to Miocene rather than Pliocene.

This conclusion has been anticipated in placing the latest probable date of Lewis thrust as mid-Tertiary; for the normal fault has resulted in a detachment of Livingston range, such that the strata could not in their present position receive the pressure which overthrust and flexed them. It follows that the thrusting must have preceded the normal faulting—that is, must have been accomplished by Miocene time.

STRUCTURE AND PHYSIOGRAPHY

Great plains and Front ranges.—Recognition of the tilted attitude of Cretaceous strata and of the even surface extended across their edges is sufficient to demonstrate the character of the Great plains, at least in the belt adjacent to the Front ranges. The surface is one of planation, independent of structure, and, marine planation being excluded on strong negative grounds, it may be considered a peneplain. Several stages of erosion may be noted in the relief of the Great plains, but the one here referred to is that which is represented by the highest levels and which is oldest. In the preceding discussion of antecedents of the Lewis thrust it was named Blackfoot peneplain and assigned to a pre-Miocene cycle of erosion. It is well represented in Milk River ridge between Cutbank creek and South fork of Milk river, west of the 113th meridian, where its elevation above sea is between 5,000 and 5,100 feet.*

The rise of the Lewis range above the Blackfoot plain is more than is

* See the Browning atlas sheet of the topographic map of the United States.

reasonably attributed to difference of hardness of rocks. Limestones and quartzites could not have maintained such relative altitude so near a lowland in which shale and sandstone were reduced to a plain. The later forms sculptured in the Blackfoot plain are apparently represented by equivalent features in the Front ranges. When their correlation has been worked out, remnants of a surface may be recognized as belonging to the Blackfoot cycle in old age. They may be traced among high shoulders of the peaks, which must then be considered monadnocks, or they may be the tops of peaks. In the latter case the surface may appear closely to conform to the highest summits of the crests and to lie above the structural valleys. The criteria which effect this alternative can better be discussed when the structural factors shall have been estimated.

The relatively great altitude of the Lewis range, considered as a result of mountain growth, might be attributed to a monoclinal flexure or a normal fault; but there is neither monoclinal flexure nor normal fault between the Lewis range and the Plains. There is, however, a great overthrust, and it is appropriate to consider the quantitative sufficiency of the thrust to produce the difference of elevation. Eastern Flattop mountain furnishes most satisfactorily the data for estimate. Its surface is topographically old. It may represent the Blackfoot peneplain as far as it developed on silicious argillite, or it may have suffered some erosion in initial uplift immediately preceding the thrust movement. In the latter case the surface which should be compared in altitude with the Blackfoot plain lies somewhat above existing features. The highest hill on Flattop, a low, rounded summit of bare rock, is 8,340 feet above sea. It is reasonable to place the ancient surface not above 8,500 feet, or not more than 3,500 feet above the Blackfoot plain, in Milk River ridge. By reference to figure 4 it will be seen that the dip of the thrust plane beneath Flattop is about 4 degrees, with a corresponding displacement of 4 miles. The vertical component, or vertical throw, of the thrust for this section is a little less than 1,500 feet. The observed displacement of Flattop is 7 miles, leaving 3 miles not reckoned in the above figures, and the dip is known to become materially steeper as the thrust descends. If the average dip for 3 miles below the outcrop at Swift Current falls be 7 degrees (or about that determined southwest of Chief), the vertical component of the thrust would be a little more than 1,900 feet. The two estimates should be added, and their sum is 3,400 feet. In these figures the only one not checked by observation is the dip of 7 degrees below the outcrop, but it is less than would be estimated on the basis of observations near Swift Current falls and on North fork of Kennedy.

The writer concludes that the altitude of the Lewis range above the Great plains is due to the vertical throw of the Lewis overthrust; and also conversely that the observed displacement on the Lewis thrust nearly approaches the actual, since much greater displacement on the probable dips would have resulted in greater elevation.

Heights and anticlines.—In northern Lewis range and in Livingston range greatest altitudes are in general related to anticlines. In Lewis range an anticlinal axis already described is definite in mount Cleveland (10,438 feet above sea), swings southeastward about the head of Belly river near mount Merritt (9,944 feet), trends again southward through mounts Wilbur (9,293) and Gould (9,541 feet), and is lost in an expanse of nearly level strata centering about Citadel (9,024 feet). In mount Cleveland, where the anticlinal is narrow and dips from the axis exceed 10 degrees, the altitude is the greatest of the range. In mount Merritt the fold is broader and dips are 5 degrees or less. Farther south the arch is merely a leveling of the southwesterly dip, with reference to which it occupies a lower monoclinal position, and the heights named above are also lower than others which lie farther east. Thus Siyeh (10,004), Going-to-the-sun (9,594), and Little Chief (9,542 feet) lie east of the anticlinal zone and are cut from elevated edges of hard strata dipping southwest. The many heights slightly above or below 9,000 feet, which are grouped between McDonald lake and the headwaters of Saint Mary river, appear to correspond with the widening area of level strata. The anticlinal axis winds from north-south to southeast and back to south, and Lewis range trends with it. Where the axis widens to a bench in the southwest-dipping monocline the range also widens and loses its distinctive crest. Thus there is a relation between altitude as expressed in peaks and elevation due to folding, and there is also a general relation of mountain belt to anticlinal zone.

In Livingston range an anticlinal axis may be noted west of mount Heavens (8994) and near the head of Logging lake, where a group of nameless peaks reaches 8,500 feet. The arch crosses spurs jutting southwestward from the crest, which is on the eastern anticlinal limb. Beyond Logging lake northwestward the mountains rise to heights between 9,000 and 10,000 feet, but the axis was not observed. It probably is cut off and thrown down by the North Fork normal fault. The position of the crest is an accident of erosion due to the work of streams and glaciers, which under favoring conditions of slope and exposure have forced the divide eastward till it is now from 1 to 4 miles east of the anticline. In general, however, the summit follows the trend of the fold, and the two may reasonably be considered as being related.

Valleys and synclines.—In the Front ranges valleys fall readily into two classes, namely, (1) valleys independent of structure and (2) valleys related to structure. Saint Mary, Swift Current, and Kennedy valleys belong to the first class; they are effects of streams of water and ice cutting retrogressively headward across the edges of strata which dip away from their direction of fall. Waterton and upper McDonald valleys belong to the second class, and to them alone need consideration be given here.

To an observer on central Flattop mountain the synclinal structure of the Front ranges is the obvious fact (figure 1, plate 50, and figure 1, plate 51, in panorama). Scarcely less apparent is the broad synclinal valley of which the summit of Flattop was formerly the floor. For a distance of 12 miles from northwest to southeast the relation is exceedingly direct. The summit of Flattop has a general elevation of 6,800 feet and the axis of the syncline is parallel to its trend, and northeastward and southwestward the mountain slopes and the strata rise to the crests of Lewis and Livingston ranges respectively. The syncline pitches northwestward, but is drained southeastward by McDonald and Mineral creeks, which, united, flow out southwest. This condition may be attributed to capture and inversion of a stream which was formerly consequent on the pitch. Southeast from and in line with this synclinal valley, shutting it off at that end, is the group of mountains of which Reynolds is a representative. Their relatively great height, 2,000 feet above Flattop, may be due to rise of resistant limestone and quartzite on the axial pitch. In the other direction Little Kootna creek and Waterton river lie over on the eastern limb of the syncline and crossing the dip on a long slant escape to the plains, while the synclinal axis coincides with peaks that rise to 9,000 feet. The divide, however, is farther west. The unsymmetrical position of Waterton river may be due to conditions preceding folding or to capture following on it; but its drainage basin is within the syncline, limited by the anticlines of Lewis and Livingston ranges.

Thus, as might be expected, there are details of stream arrangement which have resulted from adjustment. They have also been affected by glaciation, but the broad fact of a synclinal valley between anticlinal heights is dominant.

Distinctive character of Front ranges.—The Front ranges are distinguished from physiographic districts adjacent to them by the dominant influence of structure on altitude described in the preceding paragraphs.

In strong contrast, the Great Plains exhibit features of erosion entirely independent of structure. Galton range, though as a mass bounded by structural limits, is within itself apparently a simple uplifted block. Whatever minor flexures or faults may exist, near the 49th parallel they are not sufficiently pronounced to interrupt the unity of the mountain mass. While the general altitude of 7,500 feet is due to uplift, details of heights express effects of earlier or later erosion only. In this respect Galton range is like the Plains and unlike the Front ranges.

Over the Plains and over Galton range a peneplain was developed. On the soft rock of the Plains it was planed flat. On the harder rocks of the Galton mass it was probably not so completely smoothed. Observations of 1901 were neither so extensive nor so precise as to distinguish monadnocks from features of later carving, but the general relation of height to an old lowland is as distinct as it is on the Schooley plain, in the Highlands of the Hudson, New York. The peneplain on the Great plains, the Blackfoot plain, is neither incidental nor local. It is the result of a long cycle of erosion, which affected a wide territory, and its representative must occur in the nearby mountains among the oldest features, if not as the oldest, unless it has been obliterated by later activities. A tentative correlation of the Blackfoot plain with the peneplain over Galton range is a reasonable inference from these facts. Nevertheless, in the intervening Front ranges the observer seeks in vain for that general uniformity of altitudes or that breadth of contour which might represent the Blackfoot plain.

Recognition of peneplain in the Front ranges.—The peculiarly bold sculpture of the Front ranges is explicable, offhand, as an effect of great elevation, from which there resulted special conditions of glaciation and erosion. It resembles the sculpture of the Cascade range, Washington, as nearly as is consistent with diversity of rock types. But unlike the Cascades, whose summits inherit common altitudes from a broad peneplain, the Front ranges exhibit no general upper limit of heights common to many widely distributed peaks. Instead, they present an extreme case of localized deformation, accentuated by intense corrasion. Realizing this, one may still recognize the position of the oldest topographic surface of the province near the summits of the ranges. It is notable that each peak approaches in height those of its neighbors which stand in similar structural positions—that is, along the strike. A surface restored over the peaks, or over their wider shoulders, should represent that from which they are carved, plus or minus the effects of warping and minus the effects of later erosion. Detailed observations of structure will determine the former; studies of stratigraphy in relation to sculpture will evaluate the amount by which erosion has reduced altitudes relatively on the several rock types—argillite, limestone, quartzite, and diorite. The determinations may be checked on some surviving areas of ancient relief. When existing profiles have been raised or lowered in accordance with these values, there will result a surface, which, in the writer's judgment, will closely correspond with the peneplain over Galton range. The conclusion involves elements which the eye cannot rightly estimate in the field and for which precise data are not at hand. For this reason the writer is disinclined definitely to place the peneplain relatively to the heights of the Front ranges; but, recognizing the insignificant extent of summit areas, or of shoulders that might support modified monadnocks, he thinks it may be located on top of the highest peaks rather than below them.

On the same ground of inadequate data, the extremely intricate problems of sculpture must be left to the future. The student who may read the record will find it replete with facts of waterwork and icework, and he may discuss evidences of distinct episodes of uplift or of glaciation which the writer has not ventured to interpret.

Igneous Rocks of the Algonkian Series

By George I. Finlay

GENERAL COMMENT

Occurrences of igneous rocks in the Front ranges, so far as observed, are limited to the Siyeh formation and a dike in older rocks on Trail creek west of Waterton lake. The drift of the North Fork valley contains boulders which represent other rock types.

The igneous rocks of the Siyeh limestone are two—an intrusive diorite and an extrusive diabase. They are described below. The dike on Trail creek is a diabase.

DIORITE

On mount Gould and on mounts Grinnell, Wilbur, and Robertson there is found a band of diorite 60 to 100 feet thick. Near the upper and lower surfaces this intrusive sheet was chilled and is fine-grained. In the center the texture is medium or fine-grained. Several dikes which have acted as conduits for the molten rock are exposed in the region near Swift Current pass. One of these extends across the cirque occupied by the Siyeh glacier and runs vertically up the amphitheatral walls. It is 150 feet in width. A second dike, vertical and 30 feet wide, comes in beside the Sheppard glacier. Along the trail to the east of Swift Current pass the diorite sheet breaks across the Siyeh argillite and runs upward as a dike for 500 feet. It then resumes its horizontal position as an intercalated sheet between the beds of argillite. As a dike it skips for 600 feet across the strata on mount Cleveland.

Under the microscope the diorite is found to contain abundant plagioclase, with small amounts of another feldspar, much weathered, which does not show twinning. This mineral is closely intergrown with quartz. Brown hornblende is the principal dark silicate. The plagioclase has an extinction angle high enough for labradorite, but it gives no definite clue as to its exact basicity. No section of a fresh piece twinned on the albite and Carlsbad laws at the same time could be observed. The quartz is not present in sufficient amounts to make advisable the name quartz-diorite for the rock. The small patches of biotite originally present are entirely altered to chlorite. Pyrrhotite is occasionally met with, apatite occurs in crystals of unusual length, and magnetite in lath-shaped pieces is common.

DIABASE

In the field this rock is always much weathered, presenting a dull green color by reason of the secondary chlorite which it contains. It is a typical altered diabase. Exposures are found near the top of mount Grinnell, where the thickness of the sheet is 42 feet, and on Sheppard mountain opposite mount Flattop. Here the extrusive character of the flow is well shown, for its upper surface is ropy and vesicular, with amygdaloidal cavities containing calcite. Its place is at the top of the Siyeh formation, 600 feet above the sheet of diorite, with heavy bedded ferruginous sandstone and green argillite immediately below and above it respectively. The argillite has filled in the irregularities of the upper surface of the diabase. Five dikes of the same rock, genetically connected with it, were observed on Flattop. They contain inclusions of the argillite, and range from an inch to 6 feet in width. They are nearly vertical.

Under the microscope the rock is seen to be made up principally of augite and plagioclase, arranged in such a manner as to give the normal diabase structure. The plagioclase is idiomorphic in long, slender laths. It has the habit of labradorite, but no material was studied which offered data for its accurate determination. The extinction angle is high. The augite is much more abundant than the feldspar. It is an allotriomorphic mineral, red-brown when fresh, but frequently entirely gone over to chlorite. The small amount of olivine originally present in the rock is now altered to serpentine and chlorite. Besides the chlorite, which is the chief alteration product, resulting from the plagioclase as well as from the augite and olivine, much secondary calcite has been derived from the feldspar. Apatite is found and titaniferous magnetite, in grains and definite crystals, is abundant. The medium texture of the diabase is fairly uniform throughout the flow.

OTHER IGNEOUS ROCKS

Other igneous rocks of petrographic interest, besides the above, are boulders of augite-andesite, diabase, melanite, phonolite, and tinguaite, which occur east of Livingston range and in the river drift along the North Fork of the Flathead river. Of these only the diabase could be traced to its source. It is found as an intrusive sheet 50 feet in thickness along the bed of Trail creek, about 4 miles west of the Great plains in British Columbia, where it had been seen previously by Dawson. Notable amounts of greenish plagioclase, radiating in star-like or more complex aggregates from one or more common central points, are found in it.

DIABASE AND ANDESITE BOULDERS

This diabase and pieces of andesite make up a large part of the igneous rocks in the North Fork river drift. Much more rarely phonolite and tinguaite are found. The first of these carries the black titaniferous garnet melanite. The mineral is distinctly recognizable, with orthoclase feldspars, at times nearly three-fourths of an inch long, in the hand specimen. The microscope reveals a holocrystalline porphyritic structure. Nephelite, which amounts to perhaps 25 per cent of the rock, is seen to be responsible for the greasy appearance in the hand specimen. With it in the groundmass twinned orthoclase is found in a second generation. Of unusual interest as being abnormal are the phenocrysts of apple-green hornblende, recognizable by the cleavage pattern on basal sections, which make up about 10 per cent of the rock. Orthoclase occurs, with the abundant large crystals of garnet, and almost as commonly observed six-sided pieces of nosean.

TINGUAITE BOULDERS

The tinguaite has likewise a porphyritic texture. The orthoclase feldspars are so abundant as to make up 40 per cent of the rock. They attain a maximum size of 2 centimeters by 5 centimeters, and commonly give rectangular cross-sections. They are set in a dull green groundmass, with here and there inconspicuous darker spots, where ægirine appears in small phenocrysts. Seen by transmitted light, they are a bright emerald green. Under the microscope the groundmass resolves itself into a matted aggregate of ægirine needles and sanidine, with small amounts of nephelite. The tinguaite was found near the mouth of Coal creek, but no indications of the rock were met at a distance from the North fork of Flathead river.