Geology of Glacier National Park And the Flathead Region Northwestern Montana

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By CLYDE P. ROSS

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A report on fieldwork and available data on the geologic, structural, and geomorphic studies of the rocks, ranging from Precambrian to Recent in age, in two adjacent mountainous regions of Montana

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GEOLOGY OF GLACIER NATIONAL PARK AND THE FLATHEAD REGION NORTHWESTERN MONTANA

By Clyde P. Ross

ABSTRACT

This report summarizes available data on two adjacent and partly overlapping regions in northwestern Montana. The first of these is Glacier National Park plus small areas east and west of the park. The second is here called, for convenience, the Flathead region; it embraces the mountains from the southern tip of Glacier Park to latitude 48° north and between the Great Plains on the east and Flathead Valley on the west. The fieldwork under the direction of the writer was done in 1948, 1949, 1950, and 1951, with some work in 1952 and 1953.

The two regions together include parts of the Swan, Flathead, Livingstone, and Lewis Ranges. They are drained largely by branches of the Flathead River. On the east and north, however, they are penetrated by tributaries of the Missouri River and in addition by streams that flow into Canada. Roads and highways reach the borders of the regions; but there are few roads in the regions and only two highways cross them. The principal economic value of the assemblage of mountains described in the present report is as a collecting ground for snow to furnish the water used in the surrounding lowlands and as a scenic and wildlife recreation area. A few metallic deposits and lignitic coal beds are known, but these have not proved to be important and cannot, as far as can now be judged, be expected to become so. No oil except minor seeps has yet been found, and most parts of the two regions covered do not appear geologically favorable to the presence of oil in commercial quantities. The high, Hungry Horse Dam on which construction was in progress during the fieldwork now floods part of the Flathead region and will greatly influence the future of that region.

The rocks range in age from Precambrian to Recent. The thickest units belong to the Belt series of Precambrian age, and special attention was paid to them. As a result, it is clear that at least the upper part of the series shows marked lateral changes within short distances. This fact introduces complexities into stratigraphic correlation and should be remembered wherever the series is studied. The stromatolites, or fossil algae, in the Belt series, although still imperfectly understood, give clues with respect to problems of ecology and stratigraphy.

The subdivisions of the Belt series within the areas covered by the present report are, in ascending order, Altyn limestone, Appekunny argillite, Grinnell argillite, Siyeh limestone, and Missoula group. Local subdivisions of the Missoula group are possible in certain areas, and all the units just named are expected to be subdivided when detailed studies are undertaken.

In the Glacier National Park and Flathead regions together, it is probable that between 25,000 and 30,000 feet of beds belonging to the Belt series, possibly more, are present. These consist largely of quartzitic argillite, quartzite, and carbonate rocks, mostly dolomitic. Small gabbroic and diabasic intrusive bodies and, at one horizon, basaltic lava are associated with the Belt series. Above the Belt series is a thick sequence of Cambrian, Devonian, and Carboniferous strata, in which limestone is dominant, followed by strata of Jurassic and Cretaceous age, largely limestone and shale and partly of terrestrial origin. Slightly consolidated gravel, sand, and silt of Tertiary age are preserved in some valleys and as erosional remnants on the plains close to the mountain border. Pleistocene and Recent glacial and fluviatile deposits are plentiful in mountain valleys and on the plains east of the moutains.

Sufficient crustal movements took place during the latter part of Belt time to produce tension cracks that permitted some intrusion and related extrusion to occur. Broad crustal warping probably took place at intervals during the Paleozoic era, but these successive movements left little record other than the absence of sedimentary rock units that might otherwise have been deposited. The same can be said of much of the Mesozoic era, but the uplift that was to give rise to the mountains may have begun during the Cretaceous period.

In or shortly after the late Paleocene, conditions changed drastically. Thrust and normal faults of major magnitude, preceded and accompanied by folds and minor fractures, resulted from a series of violent crustal movements that have not yet entirely ceased. The master structural feature produced during this deformation is known as the Lewis overthrust. Much remains obscure, but the concepts resulting from the present study are that the Lewis thrust originated fairly deep in the earth's crust and that the overthrust block moved many miles in a direction somewhat north of east over a mass of relatively incompetent rocks that were intricately folded, overturned, and overthrust to depths thousands of feet below present sea level before and during the advance of the main thrust. If, as seems quite possible, the thrust plane ever emerged at the surface, it was at some place so far to the east that erosion has since removed the evidence. The concept of a sole with which the exposed thrusts merge at depth and which is underlain by undisturbed rocks is not supported by evidence at hand.

The block above the Lewis overthrust was itself deformed but, in the part now remaining, much less intensively than the rocks below. Adjustments that may have begun during the overthrusting and continued to the present have fractured the overlying block.

A series of geomorphic events not clearly recorded in the present topography reached a culmination in a mature surface (the Blackfoot surface) near the end of the Tertiary period. Several stages of glaciation with an intermediate stage in which rejuvenated stream erosion cut deep gorges have modified and, over large areas, obliterated the Blackfoot surface. Nevertheless, the present topography still reflects the structure of the underlying rocks. Since the close of the Pleistocene epoch, renewed erosion has caused the streams to cut small inner gorges in the valley floors. Also small glaciers reappeared in the uplands carved by the far larger Pleistocene ice streams, and some of these minor glaciers persist to the present day.

INTRODUCTION

LOCATION

The present report is a composite one in that it presents data on two adjacent and slightly overlapping regions in northwestern Montana. The more northerly and better known of these comprises Glacier National Park plus small areas on either side of the park. This region, shown in plate 1, is an irregular mountain mass bounded on the north by the international boundary, on the east by the Great Plains, and on the west by the valley of that part of the Flathead River locally called the North Fork. Plate 1 extends eastward to longitude 113°10′ and thus includes some of the plains. The southern boundary of the park corresponds essentially to parts of the channels of the Middle Fork of the Flathead and of its tributary, Bear Creek, but rather than stop at this irregular line the map extends southward almost to latitude 48°10′.

The second region here described is the one in which the present project was begun because of the extreme lack of available geologic information in regard to it. For convenience this latter is here termed the "Flathead region." Much of it is in the drainage basin of the Flathead River, and a large part of the Flathead Range is included. The Flathead region, shown in plate 2, comprises parts of the Heart Butte, Marias Pass, and Nyack 30-minute quadrangles (pl. 3). It is north of latitude 48° N. west of longitude 112°30′ E., east of longitude 114°00′, and south of Glacier National Park except that the southern tip of the park has been included.

The position of the Glacier National Park and Flathead regions with respect to the rest of northwestern Montana is shown in plate 3. Together these regions embrace the northwestern corner of Teton County, the western end of Pondera County, the western part of Glacier County, the northern tip of Lake County, and much of the mountainous part of Flathead County. They include parts of the Lewis and Clark and Flathead National Forests.

SCOPE

The data on the Flathead region presented in the present report were gathered mainly during a 54-day geologic reconnaissance in the summer of 1948 and a 60-day reconnaissance in the summer of 1949. During this time a little more than 1,300 square miles within the area shown on plate 2 was covered. The information obtained has been supplemented on the peripheral parts of plate 2 by the results of previous mapping by Stebinger, Alden, Campbell, Erdmann, and others, as noted in more detail below. Much of the data on Glacier National Park assembled below and shown on plate 1 came from unpublished material gathered in and near Glacier National Park by Geological Survey parties under the direction of M. R. Campbell and east of the park boundary by Stebinger, Alden, and others. These data are supplemented, coordinated, modified, and, in places, corrected on the basis of 64 days of fieldwork in the summer of 1950 plus a little of the field time in 1948 and 1949. Some fieldwork was done in the park in the summers of 1951, 1952, and 1953 mostly in connection with the study of stromatolites. Plate 1 represents an area of about 2,375 square miles, but only about 1,000 square miles of this was studied in any detail during the 1949 and 1950 seasons. Most of the park not thus studied was visited by the writer or his assistants, which has aided in the interpretation of the field notes and maps of the previous workers. Plates 1 and 2 include index maps that show the areas mapped during each of the three field seasons; they also show areas mapped by previous workers and not remapped. These index maps are referred to in the rock descriptions as convenient means of indicating the particular areas described.

The investigation was started for several reasons: the need for information on this region of complex geology for use in the compilation of a new geologic map of Montana, then well advanced and later completed (Ross, Andrews, and Witkind, 1955); and the opportunity presented by the western part of the Flathead region for the study of the Belt series.

To prepare an adequate geologic map of western Montana, it was essential to decide on major stratigraphic subdivisions of the Belt series that could be mapped throughout western Montana. However, the geologic and economic interest in the Belt series extends far beyond problems related directly to the State map. Fieldwork in Glacier National Park in 1950 and 1951 coupled with the unpublished data on the geology of the park in the files of the U. S. Geological Survey yielded much information on the Belt series and modified some of the ideas previously held in regard to these rocks. The Belt series is better exposed in and just south of Glacier National Park than in many of the other areas in which it has been studied. Such data on the series as apply directly to the areas mapped are summarized below, but study of these rocks is still in progress, and there are certain lines of evidence and methods of attack that were opened during the fieldwork of 1948–51 that are too incomplete to be discussed adequately as yet. The problems of nomenclature and subdivision of the Belt series throughout Montana and adjacent regions are beyond the scope of the present paper.

Fossil names used to describe the zones in the present paper are those used by Richard Rezak in his work on algae in the Belt series (Rezak, 1957). Detailed descriptions of these fossils appear in his report. Rezak has also checked the stromatolite zones that appear on the map and mapped a new zone in the Missoula group over a small area in the southwest part of plate 1 and the corresponding part of plate 2.

Another objective was the study of the structure of a region that contains a segment of one of the greatest and earliest recognized overthrusts in the Western United States (the Lewis overthrust). In earlier geologic works, the Lewis overthrust was regarded as an erosion thrust that emerged at and moved over the surface of the ground close to the present mountain border. The results of the present investigation do not support this concept. If the Lewis overthrust did reach the surface, it was probably far to the east. Similarly little support is found for the idea of a sole with undeformed strata below, which was based on comparison with structural features in the Scottish Highlands rather than on evidence available in northern Montana. Steeply inclined faults in the western part of the region here described have hitherto been supposed to be in accord with the wedge theory of diastrophism. The evidence now at hand is inconclusive but favors the idea that the faults result from relatively minor adjustments and are probably normal instead of the thrusts required by the wedge theory. Deformation appears to have recurred at least as recently as the Pleistocene.

The field mapping was carried out, rather rapidly, on a scale of 1: 125,000. This was necessitated in part because of the lack of modern, large-scale topographic base maps suitable for detailed studies. All studies of the Belt series have contained generalizations not adequately supported by geologic maps. Even now large parts of the broad regions in which the series occurs are covered only by geologic maps of exploratory type, and the present project has been planned as a contribution toward more adequate mapping. The components of the series are so thick and contain so few recognized horizon markers that subdivisions can be established and lateral facies changes recognized only on the basis of regional mapping.

Certain of the other geologic problems in this part of Montana, such as the geomorphologic history, can be adequately attacked only on a regional basis. It is hoped that the generalized data assembled in the present, primarily descriptive, report will be tested, modified, and refined by future detailed work. Detailed studies will yield their richest rewards only if made after a general setting, such as is provided by this report, is available. For much of the remaining parts of northwestern Montana, too little is yet known to give such a setting. General studies should be undertaken initially for the mountains between the Flathead region and the general vicinity of Missoula and Helena and later extended westward to connect with the detailed studies being carried on in mining districts in Idaho. The initial objective, correlation of widely separated units of the Belt series, would be aided greatly by publication of maps by various geologists for which much of the fieldwork has already been done.

While the facts and concepts regarding such things as the stratigraphy of the Belt series and the character of the Lewis overthrust should be of interest in connection with economic studies throughout western Montana and adjacent regions, the two regions here reported on contain so little in the way of known mineral deposits of apparent economic value that little time was devoted to this aspect of the investigation. A little lignitic coal appears in the master stream valleys of the two regions, and years ago prospecting for copper and other metals was undertaken in the mountains, with such slight success that it has almost entirely ceased. Drilling for oil is being actively carried on in areas east of the mountains, but very little has been undertaken as yet within the areas represented on plates 1 and 2. The mountainous parts of the country covered by the report seem geologically unfavorable to the presence of oil pools of commercial interest, even though small oil seeps have been found there.

Part of the Flathead region has been flooded by the reservoir created by the Hungry Horse Dam, for which concrete began to be poured in 1949. The present report has no direct bearing on this project, and fieldwork was begun after the site of the dam had been selected. Such economic advantages as may result from the construction of the Hungry Horse Dam will be felt mainly in the Flathead Valley and more distant areas.

ACKNOWLEDGMENTS

Throughout the investigation progress was greatly facilitated by the cooperation of National Park Service and U. S. Forest Service officers. Aid in various ways was furnished by people living in the vicinity of the regions mapped. The spirit of helpfulness manifested by most of those with whom contact was made contributed greatly to the speed with which the fieldwork was carried out.

In 1948 Harold Masursky was the geologic assistant, and his careful work contributed substantially to the results. He became especially familiar with the lower Paleozoic formations, and most parts of plate 2 in which these units are shown reflect his efforts. In 1949 the geologic assistant was John Hensley, who also contributed materially to the success of the undertaking. In the fieldwork of 1950, highly efficient assistance was rendered by Edward C. Stoever, Jr., who contributed much to the geologic mapping, especially in the southern part of Glacier National Park. During the same season Stephan Nordeng devoted his attention mainly to a study of the stromatolitic remains in the Belt rocks of the park. In 1951 Richard Rezak, working alone, took up this phase of the investigation and continued it through 1953 with the assistance of Robert N. Oldale. Rezak has added materially to knowledge of the stromatolites and is continuing his investigations of them. The data relative to stromatolites in the present report were provided by Rezak, and a more detailed treatment of the subject by him has been published (Rezak, 1957).

During the early part of the 1948 season the pack train was furnished and managed and camp work done by David W. Stonehouse. During the latter part of that season, Herbert Moore performed these functions. In 1949 the pack and camp work was done by Mr. and Mrs. Harland Knowlton. In 1950 this work was done by Athylone J. French. All these packers proved to be skillful and experienced, and it is a pleasure to acknowledge the indispensible assistance they furnished.

Little could have been accomplished in regard to the geology of Glacier National Park in the short time devoted thereto if it had not been for the large amount of pertinent but unpublished material already available. In 1911 through 1914 field parties of the Geological Survey made extensive geologic studies and mapped the greater part of the park. The geologic personnel involved in that work included M. R. Campbell (in charge), W. C. Alden, T. W. Stanton, Eugene Stebinger, J. R. Hoats, J. E. Thomas, C. S. Corbett, E. M. Parks, C. R. Williams, and H. R. Bennett. Much of the material they gathered was available for use in the present investigation. Data credited to any of these men in the present report came from their field notes. The geologic map of Glacier National Park (pl. 1) is largely the result of their efforts, although it covers a wider area and is modified in various respects. A map embodying their work was compiled some years ago by W. C. Alden, and copies of it were furnished to the National Park Service for their use. Plate 1 of the present report incorporates much the same material as Alden's compilation but was taken, so far as possible, directly from the original field notes and maps of M. R. Campbell and the men who worked with him plus the results of the fieldwork of 1949 and 1950 with minor corrections in 1951. Much of the data obtained by Campbell's parties was available for the compilation of plate 1, but some items are missing. Similarly the current work in the Flathead region was supplemented in the plains in the eastern part by data assembled by Eugene Stebinger and others, parts of which were not published.

PREVIOUS PUBLICATIONS

Several valuable papers dealing with features of the geology of Glacier National Park are available, but they are not accompanied by geologic maps. Very little information on the geology of the Flathead region has been published. The presence of great faults along the eastern border of the mountains, glaciation within the mountains, and some of the other major geologic features of the two regions were appreciated more than 60 years ago. Some of the scenic features of the Glacier Park region were noted by explorers even earlier (Culver, 1892; Davis, 1886, p. 712; Pumpelly, 1918, p. 641–646; Stevens, 1860). Pumpelly's trips were made in 1882 and 1883 and this may have been the earliest visit of a geologist to the area of Glacier National Park. Near the beginning of the 20th century, data on the character and origin of the topographic features began to appear. One of the earliest summaries was by Elrod (1903), who, however, was concerned mainly with the vicinity of Flathead Lake. Matthes (1904) published a nontechnical description of the topography of Glacier National Park but barely touched on the origin of the features he described. His paper is based on observations he made as one of the topographers who surveyed and prepared maps of the area of the park for the U. S. Geological Survey. These maps, made in 1900–1904 and 1907–12, are still in use, with minor revisions, mainly with respect to cultural features. The three quadrangle maps of the area immediately to the south, used as base maps for the present work on the Flathead region, are of similar date, having been surveyed during 1907–14, with minor subsequent revisions. Detailed and comparatively recent maps of the principal forks of the Flathead River are available, (U. S. Geol. Survey 1937, 1939, 1947, 1950) and various maps of the U. S. Forest Service, as well as one by that Service in cooperation with the National Park Service, issued in 1938, have been of great assistance, particularly with respect to roads and trails. Data from these have been incorporated in plates 1 and 2.

Chapman (1900), a topographer of the U. S. Geological Survey who did exploratory work in the eastern part of the mountains from latitude 47° N. to the southern border of Glacier National Park, contributed valuable information and ideas in regard to this region, which includes the eastern part of the Flathead region of the present report.

Willis (1902) made the first contribution to the geology of the area of Glacier National Park by a valuable and fundamental paper to which is added an appendix on the igneous rocks by his associate, G. I. Finlay (1902). Willis discovered the Lewis overthrust, discussed it in some detail, and recognized the Precambrian age of the rocks now called the Belt series. He thought the Lewis was an erosion thrust and referred to the valley of the Flathead River west of the park as a graben. In those earlier reports on northern Montana in which an age assignment was hazarded, the Belt strata were thought to be Cambrian, although in the original definition of the series in the vicinity of Three Forks (Peale, 1893) in southern Montana the age was tentatively given as Algonkian.

Calhoun (1906) on the basis of work done in 1901, 1902, and 1903 presented comprehensive data on the glacial history of the eastern side of the mountains and of the plains east of them. Many of his generalizations are still accepted, and his clear descriptions are of much value in gaining a perspective as to the geomorphic features of the region. At about this time Walcott (1906, p. 18) made a reconnaissance across the Mission and Swan Ranges and the mountains east of them and published the first correlation table of the Belt series in northwestern Montana.

Alden, in part in cooperation with Stebinger, has written several papers dealing with glaciation in and near Glacier National Park (Alden, 1912, Alden and Stebinger, 1913, Alden, 1914 a and b, Alden, 1932). Campbell (1914, 1921) has prepared two papers intended to aid visitors to understand the geology of the park.

Powers and Shimer (1914) made the suggestion that the large overthrust described by Willis in the paper cited above divides into several smaller thrusts before reaching Sun River. They also listed fossils of Cretaceous, Jurassic, Mississippian, and Devonian age collected near the Sun River by W. O. Crosby.

Davis (1916, 1921) contributed interesting data on areas just west of that here described. He laid stress on the work done by large valley glaciers and thought that although the straight, steep fronts of the Mission and Swan Ranges had probably resulted from faulting the evidence is obscured by the effects of later glaciation to which the existing scarps are largely due. This conclusion is in accord with such general observations as were made during the present investigation.

Stebinger and his associates (Stebinger, 1916, 1917, 1918, Stebinger and Goldman, 1917) did much work in the plains east of Glacier National Park and plains east of the mountains south of the park. This work, which has been extensively drawn upon in the present report, established the presence of thrusts and tight folds in a zone that extends for some miles east of the mountain front. He also worked around Flathead Lake, and his field notes on that area have been utilized in the present report.

A highly condensed but very valuable paper by Clapp (1932) gives a summary of information on an area that extends from the Canadian boundary to latitude 46°30′ and from longitude 114°30′ eastward to the mountain front, based largely on fieldwork carried on by him or under his supervision during the 12 years preceding publication of the memoir. Those working with Clapp at various times included G. S. Lambert, Arthur Bevan, R. A. Wilson, C. F. Deiss, and others. While the map in the memoir includes almost the entire area described in the present report, it was necessarily based on scanty information for the greater part of that area. Clapp made reconnaissance trips in parts of Glacier Park and the Flathead region and had access to an unpublished thesis by C. M. Langton based on more detailed mapping in the vicinity of Schafer Ranger Station on the Middle Fork of the Flathead River. Bevan (1929), who worked in several places along and east of the front of the Rocky Mountains, has summarized data on that area gained from his own observations and other sources.

Several reports dealing with geologic features in Glacier National Park have been published in comparatively recent years. C. L. Fenton and M. A. Fenton (1931, 1933, 1937) have written papers, of which the principal ones are here cited. Their papers deal mainly with organic remains in the Belt series and the stratigraphy of that series, and constitute some of the most noteworthy contributions yet made to these subjects. They include discussion of details of sedimentary structures and paleontology, many of which are not repeated here. In addition to the comparatively technical papers just cited, C. L. Fenton (1939) has published an interesting popular account of some features of the geology of Glacier National Park. Billings (1938) has presented evidence to show that the Lewis overthrust is not an erosion thrust as Willis had supposed it to be. Two recent papers by Dyson (1949a, b), prepared for the use of visitors to Glacier National Park, are useful brief summaries. Two other papers by officers of the Park Service include road and trail logs in which attention is called to geologic features (Ruhle 1949, Beatty 1947).

Dam-site investigations carried out some years ago by Erdmann (1944, 1947) yielded facts and concepts of interest to all concerned with geologic matters in the drainage basin of the Flathead River. One of the dam-site studies he made, near the western border of the Nyack quadrangle, yielded data that have been incorporated in the maps accompanying plate 2 of the present report.

South of the eastern 2 of the 3 quadrangles included in plate 2 much work has been done by C. F. Deiss. This work was begun in 1933 in association with Clapp under the auspices of the State of Montana and continued at intervals until 1941. The last part of the investigation was carried out as a member of the U. S. Geological Survey but was interrupted when wartime needs diverted Deiss' activities. The investigation extended over large parts of the Saypo, Silvertip, Ovando, and Coopers Lake quadrangles, which together constitute a block immediately south of the Flathead region (pl. 3), covered in the present report. Deiss (1933, 1935, 1938, 1939, 1941, 1943a, b) has published reports based in whole or in part on his investigations in these quadrangles. While the published reports do not include geologic maps, Deiss has very kindly made his field maps available for examination in connection with the present report. His reports and maps furnish an invaluable basis for the study of the stratigraphy and structure in the regions here described. His contributions to knowledge of Paleozoic stratigraphy in northwestern Montana are especially outstanding. Sloss and Laird (1945), whose work included traverses across parts of the region mapped by Deiss, have supplemented his work with additional observations, but differ from him in regard to certain details of stratigraphic subdivision that have only slight bearing on the present study.

Recent papers (Imlay, 1945, p. 1019–1027; Cobban, 1945, p. 1262–1303; Imlay and others, 1948; Imlay, 1948, p. 13–33) give details in regard to the Jurassic strata in and near the regions here considered. Some of the observations reported on in these papers were made in the Heart Butte and Marias Pass quadrangles, others in the Saypo quadrangle. The subdivisions of the Jurassic rocks set up in these reports have been found to be present within the regions here reported on, although the scale of the work makes it quite impractical to show them on the map.

Reports dealing with areas in Canada north of Glacier National Park and with the Rocky Mountain Trench and related features in Montana west of the park have been consulted mainly in connection with the interpretation of structure. Daly's report (1912) on the geology along the international boundary provided the basis for subsequent work in the vicinity of that line. Among other things, he emphasized the striking character of the Rocky Mountain Trench and defined that feature. His work was necessarily reconnaissance but much of it has stood the test of time. Even where further work has modified some of his conclusions, his discussion of the problems involved continues to be a stimulus to those who follow him. Among those Canadians who have made notable contributions in the present connection are Schofield (1914), (1915), (1920), Mac-

Kenzie (1916; 1922, p. 97–132), Hume (1932, p. 1–20), and Link (1932, p. 786–798; 1935, p. 1464–1466; 1949, p. 1475–1501). Incidental mention of others will be found in the body of the present report. Among those who have dealt particularly with the structure of the Rocky Mountain Trench and related features are Evans (1933), Shepard (1922), (1926), Flint (1924), and Chamberlain (1925, 1945).

GEOGRAPHY

NOMENCLATURE OF THE RANGES

Geographic nomenclature, especially with respect to the mountain ranges, is in a state of confusion in the part of Montana with which this report is concerned. Few official decisions as to these names are available. The following summary cites the various names that have been applied to the mountain units, the history and authorities for use of these, and the limits within which each name appears to have been intended to be applicable. No new names are proposed.

The different mountain ranges described in the present report (pls. 1, 2, 3) collectively constitute a segment of the eastern part of the physiographic province termed "the Northern Rocky Mountains" (Fenneman, 1930). Within the United States his definition has received acceptance in official and general usage except for such modifications in detail as those of Freeman and his coworkers (Freeman and others, 1945, p. 56; Caldwell, 1954, p. 79–87). A different definition was proposed earlier by Daly (1906, p. 17-43), who used "North American Cordillera" as a broad term for the mountains west of the Great Plains and restricted the term "Rocky Mountains" to the ranges east of what he termed "the Rocky Mountain Trench," although he appreciated that other names had been applied to this same assemblage. Daly's Rocky Mountain Trench forms part of the western boundary of the Flathead region of the present report (pl. 3), although it extends north and south (Calkins, 1909, p. 11) far beyond the limits of that region. Daly's restricted use of "Rocky Mountains" as a topographic term is in accord with long-established usage in Canada (Dawson, 1886, p. 5B, 15B, 18B). It is accepted there and has some support in present local usage in the part of Montana south of Glacier National Park. However, it has not received official sanction or general usage in the United States (Fenneman, 1930, 1931, p. 200-203).

Within Glacier National Park the mountains are divided, by official and popular usage into the Lewis Range on the east and the Livingstone Range on the west. Willis (1902, p. 310-11) defined the Lewis Range as rising from the Great Plains in Canada about latitude 49°10′ and extending southward to about latitude 46°45′. He named it for Captain Meriwether Lewis, who, he said, was in 1806 the first white man to cross the range. According to Willis (1902, p. 312-313) the southernmost peak of the Livingston Range (as he spelled it) is Mount Heavens (now termed "Heavens Peak"), and the range extends northwestward "to its limit, probably in Mount Head, in British Columbia, about latitude 50°25′." The name "Livingstone Range" was first applied to a mountain mass in Canada by a Captain Blackiston, in 1858, and later defined by Dawson (1886, p. 11B, 22B, 80B). According to Daly (1912, p. 27-30) the southern end of the Livingstone Range of Dawson is a few miles north of North Kootenay Pass, which is about 27 miles north of the international boundary (Canadian Surveyor General's Office, 1916). Daly proposed the name Clarke Range as an approximate equivalent of Willis' Livingstone Range. Although he secured approval from Willis for this change, it has not secured recognition in the United States. The United States Board on Geographic Names (1933, p. 456-468) has rendered decisions which correspond in general to those of Willis within Glacier Natural Park but terminate both ranges close to the international boundary. The Board's decision puts the south end of the Livingstone (not Livingston) Range at McDonald Creek; but as Heavens Peak is the major summit next north from that creek, this agrees with Willis' statement. The Board, however, puts the south boundary of the Lewis Range at the south boundary of Glacier National Park, which would be near latitude 47°15′ and far north of the southern terminus proposed by Willis (46°45′). The Board's decisions pertain primarily to the crests of the ranges and say nothing as to boundaries between the two adjacent ranges. In Glacier National Park the line of demarcation between the Lewis and Livingstone Ranges is commonly taken to pass through Waterton Lake, up the Waterton Valley, over or around Flattop Mountain, thence down McDonald Creek and through McDonald Lake to the Middle Fork of the Flathead River.

The decision of the United States Board on Geographic Names (1933, p. 456) to place the southern border of the Lewis Range at the southern boundary of Glacier National Park leaves the great mass of mountains south of that boundary and east of the Flathead Range without satisfactory designation. Willis' original definition (1902, p. 310-311) would have included this mass in the Lewis Range. Bevan (1929 p. 430, fig. 1) included these mountains in his proposed Lewis and Clark Range, and his suggestion was adopted by Fenton and Fenton in their index map (1937, fig. 1). It has been employed in other geologic publications but has not become familiar to residents of the region. It has the disadvantage that the name Lewis Range is well established, as just noted, for mountains in Glacier National Park, and there is a Clarke or (Clark) Range west of the Lewis Range in southern Alberta, corresponding to the Livingstone Range in the United States. Geographic features in Canada are not shown on any of the maps accompanying the present report.

Another, but less satisfactory, proceeding would be to use Sawtooth Range for the unnamed mountains south of Glacier National Park. This name was originally loosely used by Chapman (1900, p. 154) and has been applied by Deiss (1943a, fig. 2, p. 207; 1943b, fig. 2, p. 1125-1127) to the mountains immediately along the border of the plains from the North Fork of Dearborn River to the South Fork of Two Medicine Creek. As thus defined, the Sawtooth Range of Deiss constitutes a material restriction of the Lewis and Clark Range of Bevan and leaves unnamed the mountains north of the South Fork of Two Medicine Creek and south of Glacier National Park. The name Sawtooth Range, however defined, has received little support from local usage. It has the disadvantage that there are so many Sawtooth Ranges or Mountains in the west with which it might be confused—there is a Sawtooth Ridge in the southern part of the Saypo quadrangle.

In the western part of the Flathead region, the nomenclature of the mountain ranges is comparatively well established. The westernmost of the ranges here, which is bounded on the west by Flathead Valley and Swan River (U. S. Board Geog. Names, p. 732) has long been known as the Swan Range. This range is bounded on the north by the depression occupied by the Flathead River (U. S. Board Geog. Names, p. 732) near Columbia Falls. Its southern end is far beyond the limits of the territory described in the present report. The next range to the east lies between the Middle and South Forks of the Flathead River and is called the Flathead Range on the U. S. Geological Survey's topographic map of the Nyack quadrangle and on other maps. This name, which appears to have support in local usage, is used in the present report. Fenton and Fenton (1937, fig. 1) use the names Swan Range and Flathead Range on their index map, cited above. The term "Flathead Range" as here used should not be confused with the Flathead Mountains, west of Flathead Valley, as used by Daly and others (Daly, pl. 3, 1912; Calkins, 1909, pl. 1. U. S. Board Geog. Names, 1933, p. 303-304). This source of confusion has been removed by a later decision of the Board on Geographic Names (U. S. Dept. Interior, Board on Geographic Names, decisions rendered between July 1, 1941 and June 30, 1943, p. 45) to substitute the name "Salish Mountains" for the mountain mass previously called Flathead Mountains (pl. 3).

DRAINAGE

Most of the Flathead region and the part of Glacier National Park west of the Continental Divide is in the drainage basin of the Flathead River, which in turn is tributary to the Clark Fork of the Columbia River. Most of Glacier National Park east of the Continental Divide drains into Canada through the Waterton, Belly, St. Mary, and Milk Rivers, but an area in its southern part is tributary to Two Medicine Creek. The water of Waterton, Belly, and St. Mary Rivers finally finds its way to Hudson Bay, but both Milk River and Two Medicine Creek are in the drainage basin of the Missouri River. Most of the Flathead region east of the divide drains into the Marias River (east of area shown on pl. 3), although a small area in the southeastern part drains to the Teton River. Both the Marias and the Teton Rivers join the Missouri River northeast of Great Falls in west-central Montana. Thus, while most of the water in the two regions here described is carried toward the Pacific Ocean, a part reaches Hudson Bay, and the rest flows toward the Gulf of Mexico.

Along the western border of Glacier National Park, the part of the Flathead River locally known as the North Fork of the Flathead flows southeast out of Canada until it reaches the Apgar Mountains, it leaves its broad valley, and crosses the mountains, finally entering Flathead Lake. The Middle and South Forks of the Flathead flow northwest until they reach points near the northern ends of the Flathead and Swan Ranges, respectively, and join the main Flathead. To accomplish the juncture, the Middle Fork has to swing west and then southwest, reaching the main stream a few miles from West Glacier, formerly Belton. The Swan River, in the southwest corner of the Flathead region, flows northwest; but, a short distance after entering the area of plate 2, it swings abruptly west and enters Flathead Lake.

West of the Continental Divide most of the tributary streams descend the mountain slopes roughly at right angles to the range crests and the master streams mentioned in the preceding paragraph. Among those that depart from this normal pattern is McDonald Creek, which flows southeast for 10 miles then swings abruptly southwest to join the Middle Fork of the Flathead. Several of the other streams have nearly right-angle bends, mostly in their upper reaches. For example, Nyack Creek in its upper reaches flows northwest and is almost in line with the upper part of McDonald Creek, whereas most of Nyack Creek flows southwest, joining the Middle Fork of the Flathead about 10 miles (air line) above the mouth of McDonald Creek. The headwaters of Nyack Creek are separated from those of Coal and Park Creeks by narrow, locally gently sloping passes. Presumably Surprise Pass at the head of Nyack Creek is so named because its slopes are so gentle that close observation is required to enable the traveler to judge when he has passed from the drainage basin of Nyack Creek into that of Coal Creek, or vice versa.

East of the Continental Divide the drainage pattern is somewhat more irregular, in keeping with the fact that the master streams are smaller and themselves have irregular courses. This is particularly true in Glacier National Park, although even here many of the streams flow at right angles to the range trends. In the part of the Lewis Range southeast of the park boundary, several streams and parts of streams almost parallel the trend of the range. These streams include the upper reaches of the South Fork of Two Medicine Creek, several of the tributaries of South Badger Creek, Muskrat Creek, and others. On the other hand, many of the streams flow northeast, transverse to the trend of the mountains, and some of these cut through major ridges without apparent regard for their presence. North Badger Creek and the North Fork of Birch Creek are among those in this category.

Some idea of the size of the streams west of the Continental Divide can be gained from the following data. At the gaging station at West Glacier (formerly Belton) (NE¼ sec. 34, T. 32 N., R. 19 W.), the Middle Fork of the Flathead has a drainage area of 1,140 square miles and an average discharge of 2,492 second-feet and in the water-year 1948–49 had a runoff of 2,695,000 acre-feet. In the calendar year 1948 at the gaging station in the NE¼ sec. 17, T. 30 N., R. 19 W., the South Fork of the Flathead had a drainage area of 1,640 square miles, an average discharge of 3,110 second-feet and a runoff of 2,779,000 acre-feet (U. S. Geol. Survey, 1952, p. 274). The main Flathead River at Columbia Falls has a drainage area of 4,464 square miles and, before Hungry Horse reservoir was in operation, had an average discharge of 8,687 second-feet. In calendar year 1947, a wet year, it had a runoff of 8,512,000 acre-feet (U. S. Geol. Survey, 1951, p. 255), whereas in calendar year 1948 the runoff was 7,501,000 acre-feet (U. S. Geol. Survey, 1952, p. 266-274). In calendar year 1954 the adjusted runoff was 9,421,000 acre-feet (U. S. Geol. Survey, 1955, p. 213).

The valley of the Middle Fork is much narrower than that of the South Fork. From the gaging stations mentioned above to the points where the upper reaches of these two streams enter the region, the channel of the South Fork has an average rise of about 12 feet to the mile, while that of the Middle Fork has a rise of about 33 feet to the mile.

East of the Continental Divide available data on stream flow are incomplete. St. Mary River near Kimball, Alberta, 4 miles north of the international boundary, has a drainage area of 497 square miles and in calendar year 1954 had a runoff of 776,300 acre-feet, which represents most of the runoff from the eastern side of Glacier National Park (U. S. Geol. Survey, 1957, p. 32). Data for the rest of the eastern part of the park and for the streams in the eastern part of the Flathead region are not at hand. Lakes and ponds are numerous in the dissected high plains east of the mountains. In the part of these plains represented on plates 1 and 2, well over 700 of these are mapped, most of which are south of latitude 48°30′ N. and fairly close to the mountains. Some of the ponds have been enlarged by dams to provide water for ranches in the vicinity. Most of these reservoirs are very small, but a few are moderately large. Lower Two Medicine Lake, damming of which was completed in 1913, has a usable capacity of 14,000 acre-feet; and Swift Reservoir, also known as the Birch Creek Reservoir, was completed in 1915 and has a usable capacity of 30,000 acre-feet (U. S. Geol. Survey, 1949, p. 44, 67-68). Neither of these reservoirs is actually filled to capacity.

RELIEF

Plates 1 and 2 represent parts of the Lewis, Livingstone, Flathead, and Swan Ranges, plus such minor ridges as Firefighter Mountain, Desert Mountain, and Apgar Mountains. East of the Lewis Range proper there are a few isolated peaks such as Chief Mountain and Divide Mountain. The Flathead and Swan Ranges are clearly defined mountain masses whose slopes descend from fairly straight and continuous range crests to major stream valleys on either side. Both are steeper on the southwest than on the northeast flank. Summits in the mapped part of the Swan Range culminate in Mount Aeneas, 7,630 feet, and Big Hawk Mountain, 7,540 feet, with several others nearly as high. Mud Lake, west of the Swan Range, has an altitude of 3,004 feet, the lowest point in the territory described in the present report. Thus, the maximum relief in the mapped part of the range is a little over 4,600 feet. The highest point in the Flathead Range is Great Northern Mountain, 8,700 feet; and Halfmoon Lake, at the northern end of the range, is a little less than 3,200 feet above sea level. Thus, the maximum relief in the Flathead Range is about 5,500 feet.

The other ranges are not quite such conveniently recognizable units, which has contributed to the confusion in the nomenclature of the geographical features commented upon above. In Glacier National Park the division between the Lewis and Livingstone Ranges might well escape a casual observer, who could easily suppose the great mass of mountains to be a single unit. The impressive cliffs arranged with little discernible pattern add to the unity in topographic character. Cliffs comparable to them are not present on a similar scale in the mountains nearby, as can be seen by comparing figs. 1, 22, 23, and 24 with figs. 2, 3, 27, and 28. The broad, relatively low tops of Flattop (pl. 1) and West Flattop Mountains (about 6,800 feet above sea level) and the wide Waterton Valley north of them together do constitute a break between the ranges that is fairly conspicuous to an observer from suitable vantage points, but relatively few park visitors reach such points. The northeast side of the mountains drops off steeply, in part precipitously (fig. 3), to the edge of the Great Plains, which are diversified by several prominent ridges. Farther west a jumbled mass of mountains extends to the series of gentle ridges on the east side of the valley of the Flathead River.

Within this mountain mass the Continental Divide winds southeastward, passing from the Livingstone Range around the north end of Flattop Mountain to the Lewis Range. Altitudes above sea level range from about 3,100 feet near West Glacier to 10,438 feet at the summit of Mount Cleveland. About a dozen peaks in the park attain altitudes in excess of 10,000 feet, and scores are over 8,000 feet high. On the Great Plains nearby, flat ridge tops are over 5,000 feet high, while the mountain buttresses on the east side of the Flathead River have broad, gently inclined crests that rise to similar altitudes. Thus, the relief within the main mountain mass is about 5,000 feet, and the maximum relief in the park is nearly 7,400 feet. As Waterton Lake (altitude 4,186 feet) is not far from Mount Cleveland, the local relief in the northern part of the park is about 6,300 feet. Most of the highest mountains are east of the Continental Divide. A few, notably in the vicinity of Kintla and Agassiz Glaciers, are west of it.

The southern extension of the Lewis Range differs from the part within Glacier National Park in that it is composed of subparallel ridges, many of which are cliffed along their northeastern flanks. As a whole, as figures 1 and 22 and 23 show, these mountains constitute a rather heterogeneous assemblage. However, some of the ridges, such as Slippery Bill Mountain, the elevations north and south of it, and the ridge surmounted by Half Dome Crag, are sufficiently large and distinct that they might be thought of as separate ranges or subranges. All these are bordered by large valleys that, as the principal mountain ranges of the region, trend northwest. The mountain front as seen from the plains to the east is straighter than the corresponding front in Glacier National Park, and fully as impressive. For example, Half Dome Crag rises 8,095 feet above the sea and is only 3 miles from the border of the plains at an altitude of 5,000 feet. This mountain front is far straighter than the Continental Divide, which winds from ridge to ridge some 8-15 miles within the mountain mass. As is the case farther north, many of the higher peaks are east of the divide. These include Mount Patrick Gass, 8,625 feet; Old Man of the Hills (Dupuyer Mountain), 8,237 feet; Family Peak, 8,095 feet; and others. A few high peaks, such as Bighorn Mountain, 8,199 feet, and Mount Fields, 8,595 feet, are on the Continental Divide, but most of the summits farther west are well under 8,000 feet in altitude.

FIGURE 1.—View northwest from Bennie Hill Lookout in the Heart Butte quadrangle, Flathead region, showing the unsystematic topography characteristic of this part of the southern extension of the Lewis Range. The rocks belong largely to the Hannan limestone.

FIGURE 2.—Altyn limestone in the lower slopes of Appekunny Mountain, northeast of Many Glacier Hotel, Glacier National Park. The view is at the type locality of the formation, close to the site of the former settlement of Altyn. The Lewis overthrust is at the base of the cliffs, and the smooth slopes below are underlain by shale of Cretaceous age, which yields few outcrops. Photograph by Baily Willis (1902, fig. 2, pl. 47).

CLIMATE

Climatological data are not available for the mountains of Glacier Park and the Flathead region, but a general idea can be obtained from U. S. Weather Bureau records for nearby towns and from conversation with those familiar with the region. Records of temperature and precipitation for the five stations nearest to the mountains are summarized in the table below.

Climatological data for the vicinity of Glacier National Park

[Adapted from U. S. Weather Bureau publication (1954, p. 208-218)]

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Departure from normal
Average temperature in ° F in 1953														
Near Babb	24.6	28.1	30.9	31.8	[1] 45.0	50.3	[1] 58.5	59.3	[1] 51.4	[1] 47.4	38.6	28.6	41.2	1.9
1 mile north of West Glacier (Belton)	32.1	30.1	34.9	38.8	48.9	55.1	63.9	62.4	54.9	45.4	35.3	29.5	44.3	2.0
Hungry Horse Dam	34.1	30.8	35.2	38.8	48.3	55.1	[1] 63.8	62.9	56.0	45.6	36.5	31.4	44.9	----
Polebridge	30.4	26.5	32.1	36.6	47.2	[1] 52.8	60.4	59.9	[1] 52.4	43.8	[1] 34.0	25.1	41.7	----
Precipitation in inches in 1953														
Near Babb	2.24	1.53	1.52	3.56	4.08	7.15	0.59	0.60	1.61	0.33	0.44	1.62	25.27	5.87
1 mile north of West Glacier (Belton)	7.07	3.24	1.62	3.19	2.99	3.95	1.09	1.17	.60	.89	2.73	4.78	32.36	6.60
Blackleaf	1.11	1.11	.70	1.64	6.71	6.86	.50	1.12	1.10	.20	.16	.21	18.50	----
Hungry Horse Dam	5.27	2.07	2.23	2.17	2.68	2.50	.10	1.52	.97	.56	2.46	4.50	27.03	----
Heart Butte	(2)	(2)	.60	.84	4.16	5.04	6.22	.28	1.45	.11	.11	.10	----	----
Polebridge	6.32	1.00	.66	2.47	1.72	3.12	.08	1.14	.96	.43	2.32	4.13	29.37	----
Summit	14.00	4.50	3.20	5.78	6.29	5.10	.21	1.03	2.38	2.58	3.91	6.58	55.57	24.08

[1] Record incomplete. [2] No record.

The weather in the mountains is moderately cool, but not excessively so. As in other parts of the Northern Rocky Mountains, there are wide daily fluctuations in temperature. In the hottest parts of the summer, the nights are cool, and fair days during the winter are likely to warm up enough to be comfortable. In winter, below zero temperatures occur rather frequently, but extreme cold is uncommon. The mean annual temperature at the stations listed above is over 40°F. In the summer the thermometer rarely rises close to 100°F, and then for short periods only. Night temperatures of less than 40°F are common throughout the year. In the higher mountains even the summer storms are likely to include some snow and sleet. The annual precipitation in the mountains is probably in excess of 40 inches while that in the bordering lowlands is in the neighborhood of 20-30 inches. Much of the precipitation is winter snowfall, but June commonly has more precipitation than any other month in the year. Showers are frequent in the summers. During occasional periods in that season, the skies are overcast for several successive days, accompanied by many showers of rain, snow, sleet, and hail; but the total precipitation resulting is not large. The precipitation in the mountains west of the divide is somewhat greater than that to the east. This is attested by the appearance of the vegetation and the experience of residents.

TRANSPORTATION

The part of Montana here described is served by the Great Northern Railway and several highways and can be reached from nearby airfields. The railroad passes around the southern part of Glacier National Park. The nearest airfield that has been used by scheduled flights of commercial airlines is between Columbia Falls and Kalispell. Another is at Cut Bank, east of the park. Airfields usable by smaller planes are maintained by the Forest and Park Services in and near the Flathead region and on the borders of Glacier National Park.

U. S. Highway No. 2 skirts the southern border of Glacier National Park close to the railroad. Other national highways serve the country on both sides of the park and provide connections with Canadian highways. The Going-to-the-Sun Highway provides a scenic route across the park from U. S. Highway No. 89 at St. Mary on the east to U. S. Highway No. 2 at West Glacier. Another paved branch road from U. S. Highway No. 89 serves Many Glacier Hotel in the northeastern part of the park. An unpaved road extends northwest from Apgar along the western border of the park, with short branches up some of the principal valleys, and connects with roads leading to Columbia Falls.

Many roads, mostly unimproved, reach the borders of the mountains of the Flathead region on both the east and the west, but none of these penetrate far within the mountains. A graded road extends up the South Fork of the Flathead as far as Spotted Bear Ranger Station (south of the area covered by pl. 2). A branch of this road ascends Desert Mountain east of Coram, and another encircles Firefighter Mountain, returning to the main road up the South Fork in sec. 13, T. 29 N., R. 18 W. Near Elk Park Ranger Station a branch road crosses to the southwest side of the South Fork, rejoining the main road a short distance south of the boundary of the Flathead region. The construction of the Hungry Horse Dam (pl. 3) has required changes in the road system above the dam site. A road that was under construction in 1949 and 1950 leaves the old one near the north end of Abbott Ridge, passes around the eastern sides of Hungry Horse and Firefighter Mountains, and rejoins the old one near Trout Lake. Farther up the South Fork, other changes are to be made so that the road will be above reservoir level throughout.

The rest of the mountainous areas are served only by trails intended for travel on horseback or foot. The principal trails are shown on plates 1 and 2 but are accurate only in a general way as existing maps are not precise and some changes in trails have been made since the mapping was done. In Glacier National Park, trails are numerous, those in common use, and such of the others as circumstances permit, are maintained by the U. S. Park Service.

Most of the trails in the national forests can be used by pack trains during the summer months. However, only those sections that are used frequently in servicing the forests are adequately maintained. Users of the other trails should expect to cut fallen trees out of their path and occasionally to do other maintenance work in order to get pack animals through safely.

RESOURCES

The land within the confines of Glacier National Park is not subject to commercial development except to the extent necessary to care for park visitors. The park presents magnificent scenery and affords protection to wildlife. As almost the whole of the Flathead region, south of the park, is within parts of two national forests, it is to a large extent in a natural state. Until recently, its principal resources of direct utility have been those related to its scenery and wildlife. Just as in the adjacent park, any attempt to appraise the value of the Flathead region to the Nation must take these factors into consideration. Fish and game are still abundant and varied, especially in those parts of the national forests remote from roads. Parts of Glacier National Park and of the Flathead and Lewis and Clark National Forests retain their wilderness character, but roads and airplane landing fields are encroaching on these.

The mountains of both Glacier National Park and the Flathead and Lewis and Clark National Forests serve as gathering grounds for precipitation, largely in the form of snow, which has been an essential source of supply of surface and ground water for the ranches and farms in these lowlands for over 60 years. The conservation work carried out by the Park and Forest Services in the mountains has contributed materially to maintenance of the water supply and, in the national forests especially, has helped to preserve the timber until such time as it may be used. Some grazing of domestic livestock and a little lumbering have been carried out in the forests, but neither has developed into an important industry as yet. The lumbering during 1950 and 1951 along the South Fork of the Flathead was necessitated by the construction of the Hungry Horse Dam. It has resulted in salvaging some valuable timber from the area that is now flooded by the dam. The water stored in Hungry Horse Reservoir is to be used for power and other purposes, and its flow is regulated in such fashion as to control floods, and to be effectively distributed as needed to the surrounding country.

From time to time some interest has been aroused in the possibility of finding oil, coal, copper, and gold. None of these possibilities were studied in any detail during the present investigation, but such data as are at hand are here summarized. So far as can be judged on the basis of existing information, it appears improbable that any of these commodities will be found in quantities of any great significance within the mountainous part of the regions described in the present report.

No new data on oil in the plains were obtained during the present investigation. A well was sunk in 1948 near the mouth of Blackleaf Canyon in sec. 14, T. 27 N., R. 9 W., to a depth of 7,571 feet without penetrating below disturbed and thrust-faulted rocks and without finding oil in significant quantities. The concepts in regard to structure that are outlined later in the present report suggest that similar negative results would be obtained by drilling anywhere within the mountains seen during the present investigation. The band of Cretaceous strata that extends northwestward from the southeast corner of the Marias Pass quadrangle might be more suitable for oil prospecting than other parts of the mountains, but even here deformation has been so intense that it seems unlikely that oil pools of commercial significance have survived, if they ever existed.

The studies here reported on contribute nothing to the problem of possible oil-bearing beds deep in the valley of the Flathead near the Canadian boundary. Erdmann (1947, p. 210–213) has summarized available data on oil and bituminous shale in and near that valley. He mentions reported oil seepages in British Columbia and also near Kintla and Bowman Lakes in Glacier National Park and west of the Flathead River near the mouth of Kishenehn Creek. Test wells in the NW¼NW¼NW¼, sec. 18, T. 37 N., R. 20 W., and in the center of sec. 12, T. 36 N., R. 22 W., were driven in 1902–4, without success. Wells in a nearby area in British Columbia found, according to Erdmann, a little high-gravity oil, but the results were disappointing. Erdmann's summary says that the oil seeps are probably all related to faults regarding which little is known. He says: "Unquestionably oil is present in sufficient amounts to make prospecting intriguing." Some renewal of interest in the British Columbia area has been reported recently.

Erdmann also mentions "cobbles of so-called oil shale" in the gravel along the Flathead River and rumors that deposits have been found in place. He quotes McKenzie's (1916, p. 34–35) description of oil shale in British Columbia and concludes that it is improbable that the reported oil shale along the Flathead in Montana will ever constitute a commercial source of oil.

Coal has long been known to occur in the valleys of the Flathead River and its major forks. The coal is lignitic and occurs in thin beds, and much of it is impure. The best known locality and the one at which most underground work has been done is The Coal Banks in T. 34 N., R. 20 W., on the west side of the Flathead River opposite the ranger station in the same township (pl. 1). Available data on this locality are summarized by Erdmann (1947, p. 207–210). He gives the total production for 1933 at the North Fork mine there (not shown on pl. 1), the only one then producing, as about 600 tons and says that when he visited the mine in September 1934 the daily output was about 10 tons. Kalispell was the principal market although small amounts were sold also in other towns. The road to the mine was usually closed by snow from January to April. More recent data on the operation of this mine are not at hand. The following table, taken from Erdmann's report, will give an idea of the character of the coal. Presumably the sample is fairly representative of the better material in the beds that floor the valleys of the forks of the Flathead. None of the coal beds, individually, appear to be more than a foot or two thick. The beds are separated by bone and clay beds.

Analysis of coal sample from North Fork mine, sec. 33, T. 34 N., R. 20 W. (Erdmann, 1947)

[Sample cut from face of first entry north, 250 feet from main adit. Laboratory sample 99161. Analyzed by U. S. Bur. Mines]

	Proximate analysis				Ultimate analysis					Heating value (Btu per lb)
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
Air dried	15.4	31.0	37.2	16.4	5.4	49.3	1.3	24.5	3.1	8,670
As received	20.8	29.0	34.8	15.4	5.8	46.2	1.2	28.5	2.9	8,120
Moisture free	--------	36.6	44.0	19.4	4.4	58.3	1.5	12.8	3.6	10,250
Moisture and ash free	--------	45.5	54.5	--------	5.4	72.4	1.9	15.8	4.5	12,720

Lignitic coal beds broadly similar in character to those of the North Fork mine are present along the Middle and South Forks of the Flathead. So far as is known those so far found along the Middle Fork are too thin and impure to have attracted much attention. A little mining has been done along the South Fork, but the deposits are even more remote from good transportation facilities than those along the main river. The abundant timber has furnished the most convenient source of fuel for the few people living along the South Fork, so that there has been little incentive to explore the coal. The known deposits are within the area flooded by the Hungry Horse Reservoir. Erdmann (1944, p. 111–114) says that beds of lignitic coal crop out along the South Fork at several localities. He thinks the coal-bearing zone may be 200–300 feet thick and there may be many thin lenticular seams. The largest seams he saw were 3–6 feet thick. He gives detailed sections of coal-bearing material along the South Fork in the NW¼ sec. 2, T. 27 N., R. 17 W., and in the southwest corner of sec. 12, T. 27 N., R. 17 W., and says good coal is reported along Wheeler Creek in sec. 14, 15, and 22, T. 27 N., R. 17 W. (In the published report the location was printed as T. 29 N.)

Some prospecting for metalliferous deposits has been carried on both within the present limits of Glacier National Park and south of the park. The work started at a time when the part of the present park east of the Continental Divide was in the Blackfeet Indian Reservation and therefore closed to prospecting by white men (Campbell, 1914, p. 5, 6, 26, 31, 43, 50). About 1890, copper ore was found near the heads of Quartz and Mineral Creeks, both of which are west of the divide. This increased the interest in the region to such an extent that the mountains east of the divide were purchased by the Government for $1.5 million under a treaty approved by the United States Senate on June 10, 1896. The land thus acquired from the Indians was thrown open to mineral entry only about 1898.

Byrne (1901, p. 48–49, 1903, p. 81–82) says that about 100 claims were staked at this time, mostly on two parallel veins associated with the intrusive dikes spoken of as metagabbro in the present report. He says these veins extended from Divide Mountain to Mount Grinnell. This is evidently an error as the metagabbro is confined to the area occupied by the Belt series and the distance between the mountains is much greater than the 10 miles mentioned by Byrne. It would appear that the exploration was concentrated in the area from St. Mary Lake northwest to the vicinity of Mount Grinnell and Ahern Pass, with some work in the valley of Mineral Creek, west of the divide. Metagabbro, both in dikes and in sills, is plentiful in this area. Campbell says the copper deposits are in veins and fracture zones, many of which are on the borders of metagabbro dikes. Byrne, in the two reports just cited, says that most of the claims soon came under the control of two companies and that most of the exploration was by tunnels. A few of the tunnels were several hundred feet long. Byrne speaks optimistically of the showings obtained in 1900 through 1903, but later reports do not mention the district. Campbell also mentions a brief and unsuccessful attempt to mine placer gold near St. Mary. Prospect cuts on fractures containing copper sulfides are visible near the southern tip of Glacier National Park along the lower slopes of Running Rabbit Mountain. The principal result of the mining within the park appears to have been to attract attention to the region, thereby aiding the creation of the national park in 1910.

Some prospecting for metalliferous deposits was carried on in the Flathead region in the past, but as far as known little was found, and there has been almost no activity for some years. According to local report, some gold was found in placer deposits, and possibly also in lodes, but the amounts recovered must have been small. Pits, trenches, and short tunnels were dug on cupriferous lodes in several localities but evidently without sufficient success to encourage continuation of the work.

The excavations of this sort in the Flathead region seen during the present investigation are along Felix Creek near the eastern border of unsurveyed T. 28 N., R. 17 W., and in and near Silver Basin at the head of the South Fork of Logan Creek in the northwestern part of unsurveyed T. 27 N., R. 16 W. The deposits are in irregular and discontinuous fracture and breccia zones in rock of the Belt series. The metallic minerals include pyrite, some chalcopyrite, a little bornite, and abundant chalcocite. The principal gangue mineral is quartz, which appears to have formed in part by replacement and in part by filling of open spaces. Somewhat ferruginous dolomite is also present. So far as can be judged from inspection of material on the dumps, the metal content of the lodes is low.

There are reports that lead ore was mined and packed out some years ago from a prospect in the vicinity of Muskrat Pass in and near the southwestern part of unsurveyed T. 28 N., R. 11 W. This prospect was not found during the present investigation, and no further information is available.

GENERAL GEOLOGY

STRATIGRAPHY

OUTLINE OF MAJOR POINTS

The rocks of the two regions range in age from Precambrian to Recent. Most were deposited in shallow seas. In addition, there are extensive deposits of continental origin of several different kinds. The thickest units belong to the Belt series of Precambrian age. Study of these has contributed to revision of concepts as to the character and stratigraphy of the rocks of the series. The principal contribution, obtained through areal geologic mapping over a broad region, is the evidence of marked lateral changes within short distances. In the regions represented in plates 1 and 2 the exposed part of the Belt series is now regarded as consisting, in ascending order, of the Ravalli group, Piegan group, and Missoula group. Each of the groups comprises subordinate units but subdivision is incomplete at present.

Sufficient new information in regard to the stromatolite content of the rocks has been obtained to produce new concepts as to the conditions during deposition of the Belt strata and to justify the hope that intensive study would yield additional valuable data applicable to problems in ecology and stratigraphy. Rezak (1957) has developed new names for the stromatolites, which make many of the names previously in use obsolete.

Paleozoic rocks are exposed only in areas where intense deformation has taken place, so that many of the details of their stratigraphy were not worked out and the rocks are mapped in systemic rather than formational units. The formations are broadly similar to those known to be present farther south but minor differences exist. The Cambrian system is represented only by scattered exposures, in most of which several of its formational units are not exposed. All the Ordovician and Silurian, part of the Devonian, and all the Permian systems are believed to be unrepresented.

No Triassic rocks were recognized. The Ellis group (Jurassic) is present but in most places is represented by narrow fault slivers. Slightly consolidated sedimentary rocks of Tertiary age line the sides of the major valleys and form erosional remnants in the plains close to the mountain border. They are extensively masked with Quaternary deposits, from which they could be discriminated satisfactorily only by detailed work. Pleistocene and Recent glacial and fluviatile deposits floor most of the mountain valleys and cover broad expanses on the plains.

The only intrusive igneous rocks are sills, dikes, and irregular masses, most of which were originally gabbro or diabase, now much altered. These have been found only in rocks of the Belt series, principally in the Siyeh limestone. They are themselves of Precambrian age and are thought to be genetically related to the Purcell basalt, flows of which are intercalated in the upper part of the Belt series.

BELT SERIES (PRECAMBRIAN)

CLASSIFICATION

All of the sedimentary rocks of supposed Precambrian age in northwestern Montana belong by definition (Wilmarth, 1925, p. 108–112) to the Belt series. The series comprises a very thick sequence of beds, largely argillaceous and quartzitic but containing also much carbonate. Shallow-water features, such as ripple marks and mud cracks, are abundant. The rocks are thoroughly consolidated and partly recrystallized but retain many of their original larger features. The units within the series are commonly thousands of feet thick, with few distinctive horizon markers and many points of similarity. Much of the broad region underlain by the Belt series in the Northwestern United States has been studied only in preliminary reconnaissance as yet. In consequence, much diversity in nomenclature and correlation of units in different areas persists. The definitions of stratigraphic units adopted in the present report differ only in details from those of previous workers in the general vicinity of Glacier National Park. This fact, however, would not be clear from reading published reports. Hence, a statement, as precise as available data permit, as to the stratigraphic nomenclature employed is essential before the rocks can be described. Some units are designated by lithologic terms as assignment of formal names would be premature.

In a tentative classification of the Belt series in general (Ross, 1949), the representatives of the series in the region that includes Glacier National Park are divided into the Ravalli group at the base, the Piegan group in the middle, and the Missoula group at the top. These groups are broadly equivalent to the Ravalli, Siyeh, or Wallace, and Missoula groups of Clapp (1932, p. 22) and the Ravalli, Piegan, and Missoula groups of Fenton and Fenton (1937, p. 1875–1903). They do not differ fundamentally from the classification adopted by Campbell and his associates in their field notes or from the summary by Dyson (1949a, p. 4–10) except that these geologists do not use formal group designations. Similarly, in the paper by Clapp and Deiss (1931, p. 673–696) that deals specifically with problems of Belt stratigraphy, the Ravalli and Piegan groups are not mentioned, although no essential difference in interpretation of the stratigraphy is involved. An idea of the relations between the subdivisions of the Belt series in the vicinity of Glacier National Park and in other regions can be had from the correlation table (p. 17).

For convenience in following the discussions below, two additional tables are included. The first of these (p. 18) summarizes the ideas of Fenton and Fenton (1937) in regard to subdivisions of the Belt series in the parts of Glacier National Park that they studied. Fenton and Fenton have done the most detailed stratigraphic work so far accomplished

Correlation chart for the Belt series in northwestern Montana

[Thicknesses are maxima for the different localities. Formation names whose authors are not given are in general use in the senses here employed]

Group	Formations in—			
	Vicinity of Libby, near the western border of Montana	Glacier National Park	Missoula and vicinity including the Philipsburg quadrangle	Helena and vicinity including Belt and Little Belt Mountains
Missoula group of Clapp and Deiss.	Top not exposed. Libby formation, 6,000 ft. Striped Peak formation, 2,000 ft.	Main body plus several subdivisions, including the Shepard formation. Purcell basalt near base. Total thickness not measured but may be 10,000–20,000 ft. The lower part of the group is the Miller Peak of Clapp which includes the Kintla, Roosville, Mount Rowe of the Fentons, and the Shepard formation.	Sheep Mountain quartzite, Garnet Range quartzite and argillite, McNamara, argillite and quartzite, Hellgate quartzite, Miller Peak argillite of Clapp and Deiss. Include Spokane of Calkins. Total thickness is 18,000 ft.	Hellgate quartzite, Miller Peak argillite of Clapp and Deiss (including Marsh of Walcott), 3,500 ft. Helena limestone, 4,000 ft. Empire shale, Spokane shale. Greyson shale, 7,400 ft.
Piegan group of the Fentons revised.	Wallace formation 17,000 ft.	Siyeh limestone of Fenton and Fenton, which has been defined and subdivided on different bases by other geologists 5,000± ft.	Newland or Wallace formation 7,800 ft. Base not exposed.	Newland limestone 4,500+ ft.
Ravalli group of Calkins, revised.	St. Regis formation, 1,200+ ft. Revett quarzite, 1,200+ ft. Burke formation, 1,500+ ft. Maximum for the group 10,000 ft.	Grinnell argillite 4,000± ft. Appekunny argillite 5,000+ ft. Altyn limestone, 2,000+ ft.	Grinnell argillite of Langton, 7,000 ft. Appekunny argillite, 6,000+ ft. } Ravalli formation of Calkins	Chamberlain shale, 1,500 ft. Relations of this unit to rest of group not known.
	Prichard formation, 9,700 ft. Bottom not exposed.		Prichard formation, 5,000 ft.	
			Neihart quartzite of Calkins; correlation with Neihart of type locality not established 1,000+ ft.	Neihart quartzite, 700 ft.
Total thickness.	44,700 ft.	26,000–36,000 ft.	45,800 ft.	21,600 ft.

and as a result propose to divide the formations of the Belt series into many members. At present, no basis exists for tracing most of their members on the geologic map of Glacier National Park; hence, the members are not adopted here. They are presumably significant in the particular localities where they were described, and some may prove to be widespread when further mapping is done. The second table (p. 19) gives the map units in the Belt series that are employed in the present report. In a broad way, the grouping here adopted corresponds to that of the Fentons and other recent investigators. Changes in the position of the boundary between the Piegan and Missoula groups are suggested with the aim of keeping lithologically similar beds together so far as possible. No basis other than similarity in lithologic characteristics is as yet available for the grouping of strata of the Belt series, although work done during the present investigation leads to the hope that the stromatolites and the trace element content of the different rocks will aid in this respect when further information has been accumulated.

Comparison of the two tables (p. 18, 19) shows that the differences are in details and that the principal ones are in the upper part of the series. In the table giving the Fentons' classification, their names for the algae are used, whereas in the second table Rezak's are used. The differences in the thicknesses given result in part from differences in the limits placed on the units and in part from actual variations in thicknesses in different localities. Differences in methods of measurements may also enter. The three formations in the Ravalli group (as that term is here used) are sufficiently distinctive, so that they can be recognized and mapped with confidence. All who have worked in the region are in essential agreement as to the limits of these three. One might query whether the Appekunny and Grinnell argillites would not better be term "formations" because both, and particularly the Appekunny, contain much quartzite.

The Siyeh limestone is a distinctive and easily recognized unit, but different geologists place somewhat different limits on the formation. The Campbell party, Dyson (1949a), and, so far as can be inferred, also Willis (1902, p. 316, 323) included beds of argillaceous and arenaceous composition at the top of the Siyeh. Fenton and Fenton, on the other hand, separate the upper clastic beds and include in the Siyeh only the rocks that are essentially carbonate-bearing—a practice which was followed in the present investigation because the clastic beds are lithologically much like the main body of the Missoula group. Recognition of the kinship of the clastic beds just above the limestone with the main body of the Missoula group has necessitated dropping the group boundary low enough, so that, in the

The Belt series in Glacier National Park according to Fenton and Fenton (1937)

Group	Formation	Member or zone	Character	Thickness (feet)
Missoula	Undifferentiated		Argillite and sandstone	4,800.
	Miller Peak	Mount Rowe member	Mainly red argillite	1,500.
		Roosville member	Argillite and argillaceous sandstone; largely greenish	550–1,000.
		Kintla member	Argillite and argillaceous sandstone; dominantly bright red	860–900.
Piegan	Sheppard		Dolomite, argillaceous and siliceous, and magnesian limestone; dark gray, green gray and brown.	585–1,500.
	Spokane		Strata, argillaceous and arenaceous dominantly red and green, though brown, buff, and gray are also seen. Purcell basalt is interbedded with this unit.	180–800.
	Siyeh	Granite Park member	Magnesian limestone, oolite, argillite, and quartzite; gray, greenish-gray, brown. Colonies of *Collenia willisii* abundant.	280–900.
		Collenia frequens zone	Limestone, dark-gray, in biostromes consisting mainly of *Collenia frequens* and *Collenia versiformis*, with thin beds of limestone and dolomite.	100–156.
		Goathaunt member	Limestone, dolomite, and subordinate oolite, dolomitic sandstone, and argillite; prevailing dark gray. *Collenia willisii* abundant.	2,000–3,200.
		Collenia symmetrica zone.	Quartzite, argillite, and argillitic dolomite; weathers green, brownish, or buff; purplish-red argillite in the lower 75 ft. *Collenia symmetrica* throughout.	500–900.
Ravalli	Grinnell	Rising Bull	Argillite, quartzite, and mud breccia; similar physically to Rising Wolf member	600–1,100.
		Red Gap member	Argillite; dominantly red but incidentally brownish or green; interbedded with pink, white, or greenish-white quartzite; brown sandstone, and sandy argillite.	Up to 2,800.
		Rising Wolf member	Quartzite, white and pink, interbedded with red argillite	200–700.
	Appekunny	Scenic Point member	Argillite, sandstone, conglomerate, mud breccia; green, purplish, buff, brown, gray, brownish red.	200–700.
		Appistoki member	Argillite gray, green, olive-brown, and rusty-gray interbedded with greenish, white, and pink quartzite.	2,000–2,200.
		Singleshot member	Argillite and quartzite interbedded with buff to greenish siliceous dolomite and dolomitic sandstone.	300–400.
	Altyn	Carthew member	Magnesian limestone, dolomite, quartzite and intermediate rocks; blue gray, buff, brown, and dark brownish red.	700–800.
		Hell Roaring member	Dolomite and dolomitic limestone; variably siliceous; blue gray and greenish gray; weathers buff. Contains *Collenia albertensis*.	1,200–1,300.
		Waterton member	Dolomite, dark-gray and reddish, weathers gray, reddish brown, and buff	280 with base not visible.

park, the Piegan group becomes so restricted as to include only the Siyeh limestone, as that term is here used. Further discussion of these names and their significance is given in the following description of the Piegan group.

For the purposes of this report, all of the Belt series above the Siyeh limestone as defined above belongs to the Missoula group. This procedure is the only one that permits the setting up of satisfactory map units, but the shift in the position of the boundary between the Piegan and Missoula groups proposed above departs from the ideas expressed by this writer earlier (Ross, 1949). The change is required by the fact that the clastic beds below the Shepard formation and above the characteristic limestone of the Siyeh are lithologically indistinguishable from the main body of the Missoula group.

RAVALLI GROUP

ALTYN LIMESTONE

In Glacier National Park the Ravalli group consists, in ascending order, of the Altyn limestone, Appekunny argillite, and Grinnell argillite. The Altyn is not exposed in the Flathead region, and its base has nowhere been recognized. This formation does not appear to be exposed in any other part of Montana. It is commonly regarded as part of the Ravalli group—a convenient procedure which is here adopted provisionally. However, one should bear in mind that no evidence exists as to the stratigraphic relations of the Altyn limestone of Glacier National Park to the basal components of the Ravalli group in other parts of Montana or to the underlying Prichard formation (Calkins, 1909, p. 33–42). This is one of many unsolved problems in the regional correlation of the Belt series.

The Altyn limestone forms a narrow band immediately above the Lewis overthrust along the front of the Lewis Range extending about as far south as latitude 48°20′ and northward past the Canadian border. Here it immediately overlies the Lewis overthrust and much of it has been cut out by that fault. The formation is also exposed in outlying blocks such as those in Divide and Chief

Subdivisions of the Belt series (upper Precambrian) in Glacier National Park and the Flathead region as used in the present report

Group	Formation or similar subdivision	Notes	Thickness
Missoula	Grayish-green argillite	Top unit in several localities, but mapped only on Chair Mountain. Commonly absent.	Several hundred ft.
	Main body	The principal map unit of the Missoula group. Includes all beds throughout the group not otherwise designated. Within the body subordinate units have been distinguished locally and others will be when further work is done. Consists mainly of red-purple and green argillite, in part calcareous. Includes limestone of varying purity, subordinate quartzite, and some conglomerate. Includes the Kintla argillite and parts of the Shepard formation of previous workers, also the "Spokane" of the Fentons. Contains stromatolite zones, one of which has been mapped as the *Conophyton* zone 2.	Over 5,000 ft. where not deeply eroded. In Flathead region may be as much as 20,000 ft.
	Pale-pink quartzite	Mapped only near Union Peak, but small masses of similar relatively pure quartzite are present in several places in upper part of group.	Few hundred ft.
	Limestone lenses	Intercalated in the main body. Only the larger and more definite masses are mapped. Similar to the Siyeh limestone lithologically but include a larger proportion of argillaceous beds. Stromatolites present.	From a few hundred to over 2,000 ft.
	Shepard formation	Quartzite, calcareous quartzite, and dolomite with subordinate argillite. Includes the yellow-weathering beds rich in carbonate that overlie the Purcell basalt. One or more stromatolite zones.	400+ ft.
	Purcell basalt	Dark-greenish and purplish lava, much altered but originally basaltic. In the park the principal flows are at or somewhat above the top of the Siyeh limestone and below the Shepard formation.	Up to 200+ ft.
	Greenish calcareous argillite	Discontinuous basal unit grading into Siyeh limestone. Not mapped separately in northern part of the park, partly because basal beds there are more diversified lithologically.	Up to several hundred ft.
Piegan	Siyeh limestone (Will be broken down into several units of formational rank eventually).	Limestone, partly magnesian and locally argillaceous, locally oolitic. "Molar tooth" markings are common. Dark bluish gray on fresh fracture and yellowish brown on weathered surfaces. Contains several stromatolite zones, one of which, the *Conophyton* zone 1, is mapped wherever recognized. Argillaceous beds at the top are here excluded and regarded as part of Missoula group.	1,800–5,000 ft. May be greater locally.
Ravalli	Grinnell argillite with a member consisting of grayish-blue-green calcareous argillite locally distinguished.	The grayish-blue-green calcareous argillite is a discontinuous gradational zone at the top of the unit, mapped only in the Flathead region. The main part of the formation contains red-purple, red, and green siliceous argillite, locally calcareous, with some light-colored quartzite.	1,000–4,000+ ft. Probably near 3,000 ft. in most places.
	Appekunny argillite	Dark-gray and greenish siliceous argillite, locally calcareous with quartzite prominent locally. Subordinate reddish beds in places.	2,000–5,000+ ft.
	Altyn limestone (Assigned to the Ravelli group provisionally. May prove to be pre-Ravalli.)	Dark, somewhat impure magnesian limestone and dolomite that weathers a distinctive grayish orange. Contains stromatolite zones.	2,000± ft with the base not exposed.

Mountains and on either side of Waterton Lake. The Altyn should occur near the western base of the Swan Range but has not been found there. It is either slightly below the depths so far reached by erosion or is masked by detrital material. Figure 2 shows the general character of the formation in Appekunny Mountain near the former settlement of Altyn, the type locality.

In general, this formation consists of a very light-gray[1] magnesian limestone that weathers grayish orange, rendering it conspicuous on distant cliffs. The Fentons (1937, p. 1881–1885) say the thickness is 2,180–2,480 feet, and Dyson (1949, p. 7) gives the average as about 2,300 feet. Willis (1902) reported an upper member of argillaceous ferrugeneous limestone, 600± feet thick, and a lower member of massive somewhat siliceous limestone with concretions, 800± feet thick. His figures appear to apply only to the middle one of three members described by the Fentons.

The Fentons divide their Altyn formation into three members called, in ascending order, the Waterton, Hell Roaring, and Carthew. The Waterton member of the Fentons corresponds essentially to the Waterton formation of Daly (1912, p. 50–56), which he described as underlying the Altyn formation. This unit, to which the Fentons assign an estimated thickness of 280 feet, with the base not visible, is exposed in Waterton Lakes Park in Canada but is not known to crop out in the United States. Whether the Waterton is to be regarded as a member of the Altyn or as an underlying formation, its absence in Glacier National Park reduces the exposed thickness of the Altyn there to about 2,000 feet.

The Fentons describe the Hell Roaring member as "dolomite and dolomitic limestone, variably siliceous; blue-gray to greenish-gray, weathering to gray, buff or cream; beds 2–24 inches thick. Many beds show laminae of limestone and dolomite and apparently primary dolomite nodules, associated with biostromes of *Collenia albertensis* Fenton and Fenton (= *C. frequens* of Rezak). Thickness estimated at 1,200 to 1,300 feet." They remark that, where it can be found, *Collenia albertensis* (= *C. frequens* of Rezak) is an index

[1] Rock-color chart (Goddard and others, 1948) used as a guide to color names throughout the present report, except where data on color are taken from the records of other geologists.

fossil. At Appekunny Mountain they found edgewise mud breccia and lenses of dolomitic sandstone or conglomerate in the upper part of the Hell Roaring member. They also report a zone consisting of beds crowded with *Collenia columnaris* Fenton and Fenton (= *C. frequens* of Rezak) at this locality and speak of carbonaceous films described as *Beltina* and *Morania antiqua* above their *Collenia columnaris* zone (= *C. frequens* zone of Rezak). They say that near Roes Creek, north of St. Mary Lake, the uppermost part of the Altyn that is exposed consists of buff-weathering sandy dolomite containing semirounded and angular pebbles, 2–15 millimeters in diameter. Probably the beds at this locality are in much the same stratigraphic position as those near Swiftcurrent Falls and Appekunny Mountain.

The Fentons describe their Carthew member as "magnesian limestones, dolomites, quartzites, and intermediate rocks which grade upward into the basal Appekunny. Colors range from blue gray through buff to brown and dark brownish red; bedding is thin to thick. Red beds, especially, show thin laminae. Thicknesses estimated at 700 to 900 feet." They have recognized this member only in Canada, where its type locality is, and in the northern part of Glacier National Park. They remark that near Many Glacier Hotel the basal beds of the Appekunny argillite rest on the Hell Roaring member of the Altyn. Farther south they think their Carthew member has been cut out by faulting.

During the present investigation the Altyn was studied east of Many Glacier Hotel and on the lower slopes of Appekunny Mountain nearby. The beds in these localities apparently belong to the Hell Roaring member of the Fentons. The specimen of Altyn limestone whose analysis is listed on page 55 came from near the hotel. The analysis shows the rock to be an impure dolomite. Three analyses listed by Daly (1912, p. 58–61), while differing in details, agree in showing the rock to be dolomitic, which appears to be true of most of the formation. Hence, Altyn dolomite probably would be a more precise name than Altyn limestone, but the latter is so well known that a change at this time would have little value. The analysed specimen and one from close to Swiftcurrent Falls are similar under the microscope. The main body of the rock consists of a mosaic of carbonate grains ranging in diameter from a few hundredths of a millimeter up to about 0.2 millimeter (fig. 6, *A* and *B*). A few thin layers of fine-grained carbonate parallel the bedding of the rock. So many of the grains have crystal faces that it is probable the whole aggregate has been recrystallized.

Scattered through the carbonate ground mass, and locally concentrated in layers up to about 10 millimeters thick, are larger pieces of several different kinds. Among the more abundant of these are rounded bodies that themselves consist of carbonate aggregates, mostly 0.5–2.0 millimeters in maximum dimension. Some of the more irregular of the aggregates may be pebbles, but some are undoubtedly oolites. One, illustrated in figure 6*A* is a cross section of an apparently cylinderical body, 0.8 millimeter in diameter, that is so clean cut as to appear very different from anything else in the section. In a personal letter dated April 2, 1952, J. Harlan Johnson states that in his opinion this body is organic although he is not sure just what it represents. He adds: "It appears to be a piece of spine and, if found in lower Paleozoic limestone, I would not hesitate to say it belonged to a trilobite or a chitonous brachiopod."

In addition to the carbonate aggregates, there are rounded to subangular clastic grains up to several millimeters in maximum dimension. These consist largely of quartz but include much feldspar, mostly alkali plagioclase with some microcline. Much of the feldspar is strikingly fresh, but some is sericitized. A few of the grains have rims of clear added material. Some grains contain both quartz and feldspar, and these seem to be bits of a rather coarse-grained granite. Other grains are very fine aggregates of quartz, some of which include rounded masses that look like silicified oolites.

The presence of witherite in small bodies formed by replacement along bedding planes in the Altyn limestone below Swiftcurrent Falls has been reported (Fuller, 1924). This must be an exceptional occurrence as the mineral has not been reported by other observers, and analyses of the rock show no especial abundance of barium.

Both Nordeng and Rezak visited the locality on the slopes of Appekunny Mountain where the Fentons found their *C. columnaris* zone. Numerous specimens of stromatolites are present. Nordeng in his field notes commented on the diversity of shapes present, which he interpreted as resulting from variation in conditions during growth. Rezak, with benefit of longer study of the stromatolites, including Nordeng's work, regards the apparent diversity in form as resulting mainly from differences in the angles at which joint surfaces cut the algal heads. Both Nordeng and Rezak report that the *Collenia columnaris* zone of the Fentons is not a persistent zone. Rezak has searched for the zone in exposures of the Altyn limestone other than those on Appekunny Mountain, and reports the zone to be well developed on Divide Mountain although at other localities it is either poorly developed or absent. In this connection it mav be significant that neither of the two sections measured by Stebinger and Bennett and tabulated below contain any beds in which stromatolites are reported.

Two sections of parts of the Altyn limestone were measured by Stebinger and Bennett in 1914 and are taken from their field notes. The first of these is in the lower part of the slope at the east end of Red Eagle Mountain, south of St. Mary Lake. The other is in the mountain north of Crossley Lake near the confluence of Mokowanis and Belly Rivers. There may be some duplication in the lower part of this section because of minor overthrusts and thicknesses of units exposed in cliffs are estimated. The descriptions, including color designations, are adapted from those in Stebinger's notebook. Presumably all the the rocks described as limestone in the field notes are magnesian.

Altyn limestone on Red Eagle Mountain

[After field notes of Eugene Stebinger and H. R. Bennett]

	Feet
Appekunny argillite.	
Altyn limestone:	
Limestone, light-gray to whitish-gray, with a slight bluish tinge, weathers to a buff drusy surface; very compact; interbedded with green argillite in beds 2-3 ft thick	8
Limestone, as above, in beds 2-3 ft thick with 6 beds of green argillite 1-8 in. thick appearing as dark bands on the buff surface of the limestone	16
Limestone, light-gray to whitish-gray, massive; similar to that above. Very compact but with rude bedding planes visible at intervals of 3-4 ft	30
Limestone, as above, with 2 beds, 1½ ft thick, of green calcareous argillite	6
Limestone, thin-bedded, with alternate beds 6 in. to 3 ft thick of compact buff-weathering limestone like that above and soft limestone that weathers chalky white. Near the middle is a 3-ft bed of limestone grit with siliceous pebbles one-fourth in. in diameter	84
Limestone, light-gray to whitish-gray, siliceous, massive, with slight bluish tinge; weathers to a buff, drusy surface. Very compact but rude bedding planes are visible at intervals of 3-4 ft	39

Altyn limestone on Red Eagle Mountain—Continued

	Feet
Altyn limestone—Continued	
Limestone, light-grayish-green, shaly, in beds 1/16-½ in. thick	2½
Limestone similar to the 39-ft. unit described above except that near the middle is a massive unit of 20 ft. thick without visible bedding	107
Limestone, thin-bedded, chalky	3
Limestone, cliff-forming; similar to 39-ft. unit above but with some beds only 2 ft thick and others up to 15 ft thick	81
Limestone, thin-bedded in layers ⅛-½ in. thick, mostly soft and weathering chalky white, but some beds are compact and weather buff	3½
Limestone, massive, light-gray to whitish-gray, siliceous, with slight bluish tinge; weathers to a buff drusy surface. Very compact but rude bedding planes are visible at intervals of 3-4 ft	107
Total	487

Altyn limestone near Crossley Lake

[After field notes of Eugene Stebinger and H. R. Bennett]

	Feet
Appekunny argillite.	
Altyn limestone:	
Dolomite, bluish-gray to light-gray; weathers to a delicate creamy-gray tint. Beds are ½-3 ft thick. Some beds appear sandy on weathered surfaces. In the upper 50 ft green argillite beds, ½-1 ft thick, are interbedded with the dolomite, forming a transition zone with the Appekunny argillite above	190
Limestone (or dolomite), bluish-gray, siliceous, massive; weathers cream. Forms a single cliff face	110
Dolomite similar to that below but in beds ½-1 ft thick	60
Dolomite, bluish-gray to light-gray, fine-grained; weathers to delicate creamy-gray tint. Beds are ½-3 ft thick. Thinner beds commonly have a fine hackly, fractured appearance. A few of them look sandy on weathered surfaces[1]	690
Dolomite similar to above unit but not exposed along line of section. Seen in nearby cliff	350±
Limestone (or dolomite), red; weathers deep brownish buff	125
Total	1,525

APPEKUNNY ARGILLITE

The Altyn limestone is overlain by the Appekunny argillite, which, like the Altyn, was originally defined by Willis (1902, p. 316–322). The Appekunny

[1] Note says that 150 ft of dolomite like that in the 690-ft unit above underlies the red limestone in Chief Mountain, constituting the lowest unit of the Altyn limestone seen by Stebinger up to the middle of September, 1914, and making the total exposed thickness in this part of the park 1,675 ft, an estimate 275 ft greater than that of Willis.

argillite is widely distributed and well exposed in Glacier National Park. It forms an irregular band in the northeastern part of the park just west of the exposures of Altyn limestone that are associated with the Lewis overthrust. Another band extends from the Canadian border southeastward in the western part of the park until it joins the band in the northeastern part of the park. There are also exposures near Waterton Lake.

Small exposures correlated with the Appekunny were noted along the road in unsurveyed T. 30 N., R. 18 W., on the west flank of the northern part of the Flathead Range, and more extensive outcrops might be found if further geologic work were done in that vicinity. Appekunny argillite is present low on the southwestern slopes of the Swan Range, mostly in unsurveyed parts of Tps. 26 and 27 N., R. 18 W., but here satisfactory outcrops are rare, and much of the formation is masked by dense vegetation, soil, and hillwash. The southern tip of the main body of Appekunny argillite shown on plate 1 (Glacier National Park) also appears on plate 2 (Flathead region).

The formation as a whole consists of dark fine-grained sedimentary rock sufficiently uniform in character, so that Willis (1902) gave it the name Appekunny argillite. Sufficient lithologic variations exist, however, both in the Appekunny and in the overlying Grinnell to give support to the Fentons (1937) and Dyson (1949a) in speaking of these units as formations rather than as argillites. This reflects the fact that both in the park and in more distant parts of northwestern Montana the two units possess greater diversity in lithologic character than could have been appreciated during Willis's pioneer studies. The distinction is subtle, and final decision should be based on consideration of a larger region than that covered by the present report. The Appekunny in the region here described originally consisted of beds containing varying proportions of argillaceous and siliceous material with distinctly subordinate quantities of carbonate. No limestone was present, and pure quartz sandstone was rare. All the components are thoroughly consolidated and sufficiently recrystallized, so that names that imply some metamorphism are required for the rocks in their present condition.

The somber, commonly rather massive rocks of the Appekunny argillite can be recognized and delimited throughout northwestern Montana more readily than some of the other units of the Belt series. It is only here and there that local development of schistosity or abnormal colors in some beds introduce some uncertainty. It does not necessarily follow that the top and bottom as mapped are everywhere at the same horizon. That is, beds lithologically akin to the Appekunny may persist over a greater stratigraphic range in one locality than another. Willis (1902, p. 322) recognized this in his remark that 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 diagonal to the stratification. To a degree, such a suggestion may be applicable to many contacts throughout the Belt series. The data summarized below are contributions toward testing such suggestions, but more information over even wider areas is needed.

The Appekunny argillite is rarely well exposed in the Flathead region. It was mapped on plate 2 on the basis that scattered outcrops and the soil between outcrops attested to the presence beneath the Grinnell argillite of argillaceous rock in which purple or red beds were essentially absent. In the few outcrops seen on the southwestern slopes of the Flathead and Swan Ranges, hard, in part somewhat calcareous, dark-greenish-gray or greenish-black argillite predominates. Some beds are bluish. No distinctly reddish beds were noted; but under the microscope, material from the Swan Range is seen to contain enough hematite to have a faintly reddish tint. Argillite from Wolf Creek on the west side of the Swan Range, although of uniform appearance in the hand specimen, has a microscopic texture suggestive of movement before the rock became firmly consolidated. Most of the original sediment consisted of a quartzose and calcareous mud in which the quartz grains probably ranged up to about 0.07 millimeters in maximum dimension and were poorly rounded. Micaceous flakes, in part muscovite, in part chlorite, are now abundant and are interpreted as recrystallized clay and other constituents of the mud. Originally laminae of finer grained material, up to about 1.5 millimeters in width, were present. These laminae are now broken into short slabs scattered irregularly through the rock. Apparently after the fine-grained laminae had acquired some cohesion but before the rock consolidated, sufficient movement took place to break up the laminae. A little pyrite is present.

In Glacier National Park the character of the formation is broadly similar. A few reddish beds were noted, but they are widely separated, and most of them are much less brightly colored than those typical of the overlying Grinnell argillite. The field notes of Campbell's men speak of red beds in a few places, but it appears that everywhere these are decidedly subordinate in amount. The restriction of the Appekunny to dark largely argillaceous rocks seemingly corresponds also to Dyson's usage (1949a, p. 7, 11).

In the southern tip of Glacier National Park, most exposures of the Appekunny argillite consist of greenish-gray massive argillite, almost as green as the greenish parts of the overlying Grinnell argillite. This rock consists of a uniform quartz mosaic with a mesh of micaceous flakes, largely chlorite. The quartz grains range up to 0.02 millimeter in diameter, and all have strain shadows and fuzzy borders. A little carbonate and possibly some feldspar are present. Some dark-gray to almost black beds and a few light-colored quartzite beds are present. Throughout the formation, ripple marks are fairly common.

In the localities seen in 1950 (see index map, pl. 1), exposures are more continuous than they are in the Flathead region. Here medium-dark-gray relatively massive beds predominate in the lower part, and the upper part of the formation consists mostly of greenish-gray comparatively thin-bedded material. Both here and to the south, the amount of slaty cleavage varies in proportion to the local deformation. For example, some of the dark-gray argillite in outcrops on the slopes southwest of Mount Thompson might be described as slate. In both the upper and the lower parts of the formation in the park, some beds are so calcareous that their nature is obvious at a glance. The three analyses of samples of Appekunny argillite from Glacier National Park in the table on page 55 all record the presence of small quantities of carbonate. Samples could be selected that would show much larger amounts, but none of the beds in the formation could be termed "limestone."

The thin-bedded parts of the formation are represented by the greenish distinctly layered rock from near Many Glacier Hotel, specimen ID–13950 in the table on page 55. In this rock the laminae are 0.5–1.0 millimeter wide. Some individual grains exceed 0.5 millimeter in maximum dimension, but most are 0.015 millimeter or less in diameter. Most are subangular, but a few grains are rounded, and some have grown together, so that the contacts between them are obliterated. Quartz makes up roughly 60 percent of the rock, feldspar (mostly alkali plagioclase) constitutes about 10 percent and the rest of the rock consists mainly of micaceous minerals, mostly chlorite.

The exposures of Appekunny argillite along the Going-to-the-Sun Highway above Lake McDonald include green and dark-gray argillite. The green argillite here, represented by analysed specimen ID–21550, has graded laminae 0.1–1 millimeter wide (fig. 6*c*). The largest grains are about 0.1 millimeter wide and are in an intricate mat of micaceous shreds, mostly chlorite. A little plagioclase is present. The dark-gray argillite from the same locality, represented by analysed specimen ID–21650, is more irregularly and indistinctly layered than the green rock. Most of it resembles the coarser parts of specimen ID–13950. The rock contains quite a little feldspar and enough carbonate to be readily seen, and pyrite is conspicuous. The three analyses show an average content of about 67 percent of silica, rather high for an argillite. The formation includes a few beds of relatively pure quartzite.

The Fentons saw the Appekunny argillite in the area from near Two Medicine Lake northward into Waterton Lakes Park. They propose to divide it into three members. They call the lowest of these the Singleshot and describe it as containing argillite and quartzite interbedded with buff to greenish siliceous dolomite and dolomitic sandstone. The fine-grained clastic rocks are gray, gray green, reddish, and black; quartzites are greenish, pink, or white. Mud cracks, ripple marks, and mud breccias are abundant. Locally, a basal coarse-grained pinkish sandstone is reported to rest on the Altyn limestone with slight angular unconformity. The thickness of the member is said to be 300–400 feet. As the Appekunny was nowhere found resting on the Altyn in localities mapped in 1949 and 1950 (pl. 1), it may be that the Singleshot member is absent or poorly exposed in the places where relatively detailed study of the Appekunny argillite was made during the present investigation.

The second and much the thickest member of the Appekunny is termed "the Appistoki member" by the Fentons. They say it contains "gray, green, olive-brown, and rusty-gray argillite in thin minor but thick major beds, interbedded with thickly stratified, greenish, white, or pink quartzite." Flat-pebble breccias, mud cracks, and ripple marks are abundant; rain and sleet prints are present in some layers. The thickness in the Lewis Range is given as 2,000–2,200 feet, which corresponds to the total thickness of the entire formation as originally estimated by Willis.

The uppermost member is called the Scenic Point member by the Fentons and is described as containing argillite, sandstone, and "gravelly conglomerate" and as being green, purplish, buff, brown, and dull brownish red at the type locality. North and west from Scenic Point, which overlooks Two Medicine Lake, the member is reported to grade into thickly bedded coarsely mud-cracked argillite, which gives way to thick quartzite and subordinate gray and iron-stained argillite beds. Mud breccias, mud cracks, and ripple marks are abundant. The thickness of the member is given as 200–700 feet.

Consideration of the various descriptions summarized above leads to the tentative conclusion that the rocks mapped during the present investigation as belonging to the Appekunny argillite correspond essentially to the Appistoki member of the Fentons. On this basis, most of their Scenic Point member may have been mapped with the Grinnell, and their Singleshot member probably is not exposed in the localities shown on the index maps on plates 1 and 2 as having been mapped in 1949 and 1950. Further, it seems probable that this member was included in the upper part of the Altyn limestone by the geologists under Campbell. As it has a large content of carbonate rocks, such an assignment would be in harmony with the work done in the present investigation.

Willis (1902) credits the Appekunny with a thickness of about 2,000 feet. The Fentons say that in the eastern part of the mountains the thickness is 2,500–5,300 feet, and they cite Clapp (1932, p. 22) as estimating thicknesses as great as 10,000 feet farther west, presumably beyond the limits of Glacier National Park. Clapp gives a minimum thickness in the park of 3,500 feet. Dyson (1949a, p. 7) says the thickness is 3,000 feet or more. In the Flathead region south of the park, the thickness is surely as much as 2,000 feet, and on the southwestern slopes of the Swan Range, it may exceed 5,000 feet. The wide variation in the thickness of the formation suggested by these figures may result from lateral variations in the lithologic character of the rocks, a feature that, in varying degree, is found in all the units in the Belt series. Erdmann (1947, p. 129-130) says that fieldwork incident to his examination of the Bad Rock Canyon dam site on the Flathead River "has demonstrated interfingering of the gray-green Appekunny lithology with the dull purplish-red Grinnell lithology in the 2,400 feet of strata occupying the Grinnell horizon in Bad Rock Canyon," as the Grinnell is mapped by Clapp (1932, pl. 1). Erdmann's conclusion reflects the difficulty in distinguishing the Appekunny argillite from the Grinnell argillite. It is inherent in any attempt at establishing stratigraphic subdivisions in a thick sequence of broadly similar argillaceous rocks such as those that compose these two formations. A similar difficulty led Stebinger to remark in his field notes of August 13, 1914, that the Grinnell-Appekunny contact on the spur between Snyder and Sprague Creeks and Lincoln Creek is "hard to locate or cannot be so located because of the large amount of green argillite in the base of the Grinnell." On the other hand, such subdivisions are needed, if the character of the Belt series is to be understood, and can generally be made with reasonable precision when systematic areal mapping over a sufficiently extensive territory is undertaken. Bad Rock Canyon at the north end of the Swan Range (pl. 3) is outside of the area mapped during the present investigation but has been visited by the writer. The green and purplish rocks so well exposed there are essentially similar to those of the Grinnell argillite in the part of the Swan Range mapped in plate 2.

Alden in his summary of data obtained by Campbell's parties says that the Appekunny argillite near Swiftcurrent Falls is composed mostly of greenish argillite, with some interbedded reddish argillite and lighter-colored quartzite. At the base he reports a transition upwards from buff Altyn limestone to greenish-buff Appekunny argillite. At the top of the formation he notes that there is a transition zone in which beds of maroon argillite are interbedded with green argillite, increasing upwards until the maroon beds characteristic of the Grinnell argillite predominate. In the fieldwork of 1949 and 1950, this transition zone would have been included in the Grinnell.

Nordeng reports in his field notes that the *Collenia columnaris* zone of the Fentons (=*C. frequens* zone of Rezak) in the upper part of the Altyn limestone is 50–75 feet below the base of the Appistoki member of the Appekunny argillite near Appekunny Falls. No fossils have been reported from the Appekunny anywhere; so it would appear that the Fentons' Singleshot member is very thin or absent at this locality.

The following is a complete section of the Appekunny argillite measured by Stebinger and Bennett in 1914 at the eastern end of Red Eagle Mountain above the Altyn limestone. (See p. 21.)

Appekunny argillite

[From field notes of Eugene Stebinger and H. R. Bennett, 1914]

	Feet
Grinnell argillite.	
Appekunny argillite:	
Argillite, green, thin-bedded, remarkably uniform; a few gray beds; surfaces weather rusty brown	1,412
Quartzite, gray to whitish-gray, coarse	35
Argillite, green, thin-bedded; a few quartzitic layers ½-3 in. thick; weathers rusty brown on bedding planes	200
Quartzite, white, coarse	7
Argillite, green; in beds ¼-6 in. thick; some layers of gray quartzite ½-1 in. thick	351
Argillite, light-red; and gray to greenish-gray coarse-grained quartzite in close alternation. Beds are ½-4 in. thick, and argillite and quartzite are about equal in quantity	59
Quartzite, white to gray and greenish-gray, coarse-grained	86
Argillite, green, dense	70
Covered; presumably green argillite	155
Argillite, green; in beds ¼-½ in. thick	160
Quartzite, light-gray to greenish-gray, coarse-grained	15
Argillite, green; ½-6 in. thick. Interbedded with light-red beds ½-2 ft thick in lower 20 ft	296
Argillite, light-red; a few green argillite beds 4-6 in. thick	33
Argillite, light-red; resembles the Grinnell; in beds ½-4 in. thick; has white mica on bedding planes	69
Argillite, green; which occasionally has light-purple tint; in beds ½-2 ft thick	139
Argillite, gray; interbedded with white to greenish white quartzite in beds 2-3 ft thick	20
Argillite, green; in beds ¼ in to 2 ft thick, mostly 1-4 in; occasional beds of banded green argillite with light-purple to reddish tinges	214
Quartzite, light- to dark-green	13
Argillite, green, dense; mostly in beds ½-2 in. thick, but some in massive beds 2-3 ft thick	47
Altyn limestone.	
Total	3,381

Corbett and Williams, also in 1914, measured a section of the Appekunny argillite on the mountain north of Crossley Lake which, while supposedly complete, is much thinner than the section just given. Corbett's field notes state that the measurement started at the highest limestone bed in the transition zone between the Altyn and Appekunny. This transition zone, although excluded from the section as given by Corbett, includes much quartzite and some argillite, so that it might well have been included in the Fentons' Singleshot member of the Appekunny. The section below stops at the horizon designated the base of the Grinnel argillite in Corbett's notes.

Appekunny argillite near Crossley Lake

[After field notes of C. S. Corbett and C. R. Williams, 1914]

	Feet
Argillite, green, lower 2 ft rather sandy, thin-bedded	12
Argillite, red, thin-bedded	37
Argillite, green and gray, thin-bedded; contains beds up to 4 in. thick. In part covered	305
Sandstone, gray; with argillaceous layers	4
Argillite and quartzite; interbedded in beds up to 6 in. thick	12
Quartzite, light-gray, massive	4
Argillite, gray, thin-bedded; a few massive beds up to 5 in. thick and a few thin sandy layers	95
Quartzite, dark-gray, massive	3
Sandstone, gray, thin-bedded	4
Argillite, gray, thin-bedded	20
Argillite, green, thin-bedded	49
Sandstone, green, thin-bedded	3
Argillite, green, thin-bedded	3
Sandstone, green, thin-bedded	2
Argillite, green; becomes sandy toward top	3
Sandstone, green	4
Argillite, green, thin-bedded	111
Argillite, green, massive; in beds up to 3 ft. thick with some thin-bedded green argillite	168
Argillite, light-green, massive	15
Quartzite, light-green, massive	12
Argillite, light-greenish-gray, quartzitic, thin-bedded; some massive beds up to 2 ft thick	45
Quartzite, light-greenish-gray, massive; weathers buff	18
Argillite, green, thin-bedded	12
Argillite, green, massive	2
Quartzite, white, massive	14
Argillite, gray, sandy, thin-bedded	5
Quartzite, gray, massive	1
Argillite, gray, sandy, thin-bedded	11
Quartzite, white, massive	1
Argillite, gray, thin-bedded	4
Quartzite, gray, thin-bedded	1
Argillite, gray, thin-bedded	12
Quartzite, light-gray, crossbedded	8
Argillite, gray, sandy, thin-bedded; some beds of fine-grained argillite and 1 bed of white quartzite 8 in. thick	36
Quartzite, white, massive	11
Argillite, gray, thin-bedded	17
Argillite, green, thin-bedded	115
Quartzite, white, massive	13
Argillite, green, thin-bedded	5
Quartzite, light-gray, massive	13
Argillite, gray, thin-bedded	2
Argillite, green, thin-bedded	6
Argillite, green, massive	6
Argillite, green, thin-bedded, occasional massive beds up to 2 ft thick	2
Argillite, red; some green beds	32

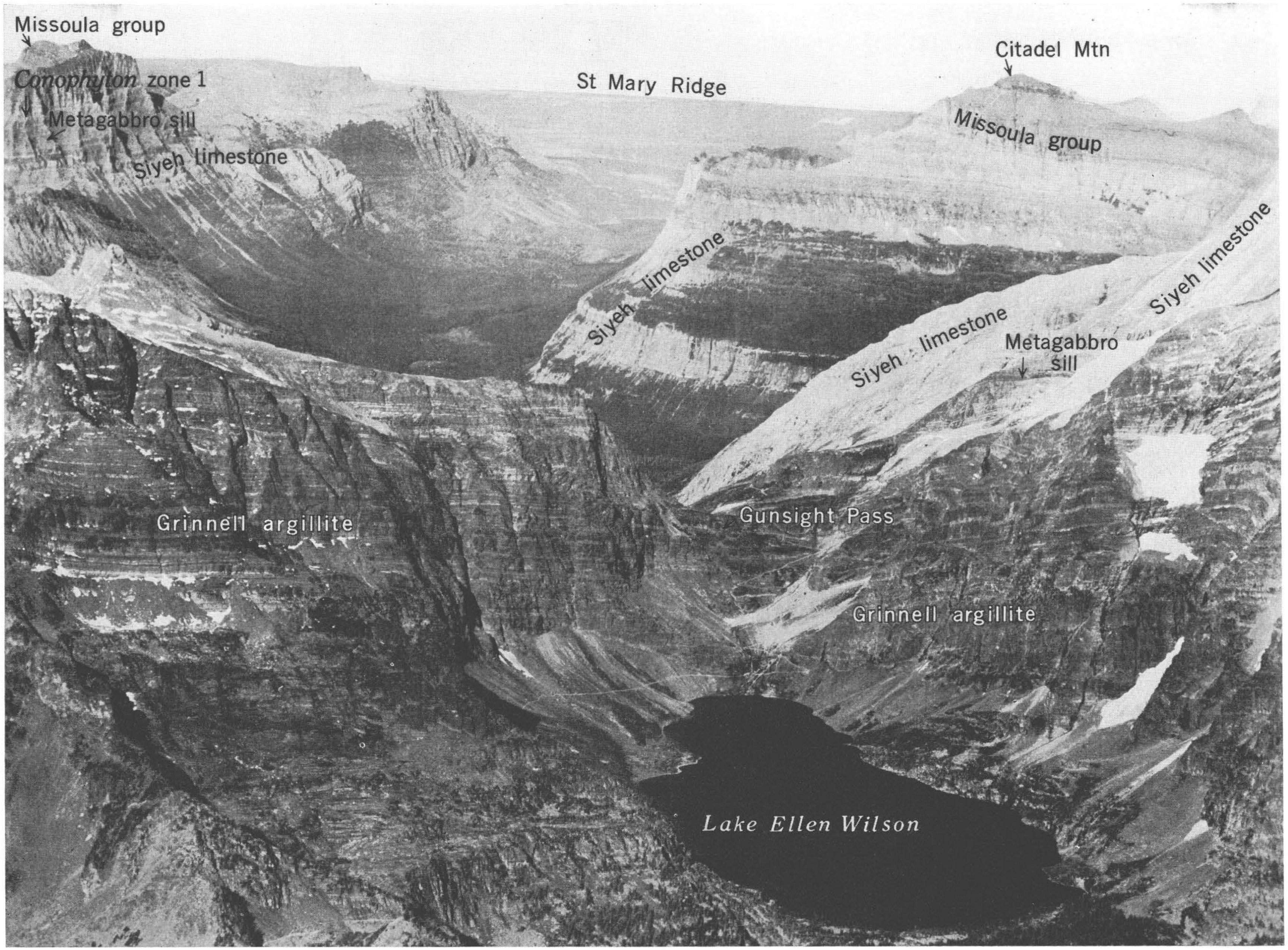


FIGURE 3.—Air view northeast from above Gunsight Pass toward the valley of St. Mary River, with Lake Ellen Wilson in the foreground. Shows the general character and topographic expression of the Grinnell argillite, Siyeh limestone and, in the distance, the Missoula group. Metagabbro sills and the *Conophyton* zone 1 are visible. One of the ridges on the Great Plains that is capped by early glacial deposits can also be seen. Photograph by U. S. Army Air Corps.

Appekunny argillite near Crossley Lake—Continued

	Feet
Argillite, green; beds up to 5 in. thick	72
Argillite, greenish-gray, massive	18
Argillite, gray, thin-bedded	11
Quartzite, gray, massive; beds 1-3 ft thick, with few thin argillaceous beds	21
Argillite, green and gray, thin-bedded	16
Argillite, gray, massive	4
Argillite, green and gray, thin-bedded	122
Argillite, green, massive; 2 beds each 5 ft thick	10
Quartzite, buff, massive; beds 2-5 ft thick	31
Total	1,563

GRINNELL ARGILLITE

The Grinnell argillite is the uppermost unit of the Ravalli group and the one that is best exposed in the Flathead region. It underlies broad areas in the southwestern parts of the Flathead and Swan Ranges. In these mountains the Grinnell, like the Appekunny, is largely obscured by the extensive cover of vegetation and soil. However, the Grinnell extends high enough to reach the parts of the mountains that have been extensively denuded by glacial action. In these places parts of the formation are well exposed. In Glacier National Park the Grinnell argillite, like the Appekunny which underlies it, is exposed along the southwestern flank of the mountain mass from the Canadian border nearly to latitude 48°30′ and thence northward along the eastern mountain flank back to the Canadian border. There are also exposures on both sides of Waterton Valley.

The most distinctive feature of the Grinnell argillite is the purplish and reddish color of many of the beds. Some beds are green and some are white, but most display in varying degree the characteristic color of the formation, which is due to iron in the Grinnell. Like the Appekunny, the Grinnell argillite contains many argillaceous beds. Both formations are fine grained, but the Grinnell is somewhat the coarser. It is also more siliceous and contains less carbonate and more recognizable feldspar than the Appekunny argillite does. Two of the three samples analysed (see p. 55) contain about 70 percent of silica, and none of them contain more than a small fraction of a percent of carbon dioxide. The samples selected for analysis represent the average rock, and the differences in the composition of the two formations would be emphasized if analyses of the more strikingly siliceous and calcareous beds in each were available.

The Grinnell argillite, as can be seen from figure 3, is a fairly uniform even-bedded unit. In some exposures it has a massive appearance but, wherever it is sharply deformed, as in the outcrops pictured in figures 25 and 28, the bedding is emphasized, and individual beds are seen to be thin. The argillaceous beds that compose much of the formation are resistant to weathering, which is indicated by the presence of unweathered joint blocks far from present outcrops. On the slopes northeast of Harrison Lake, for example, such blocks are so abundantly scattered over surfaces underlain by Appekunny argillite that in reconnaissance work it would be easy to imagine that the Grinnell contacts are lower on the slopes than is actually the case. Ripple-marked and mud-cracked beds and intraformational conglomerate or breccia are common throughout the Grinnell argillite (figs. 4, 5) but are particularly abundant in the middle part of the formation. Figure 4 shows broken bits of thin dark argillaceous layers enclosed in white quartzite. Figure 5, in addition to ripple marks, shows bulbous forms whose origin is not clear. They are somewhat like the forms that the Fentons (1937, p. 1912–1913) regard as channel fillings.

Stromatolites have been recorded from the Grinnell argillite only in 2 localities: 1 along the Going-to-the-Sun highway and 1 in Bad Rock Canyon. (Rezak, 1957, p. 136–137) This fact may aid in distinguishing its outcrops from otherwise similar exposures of the Missoula group in which stromatolites are far more abundant and easily recognized.

The Grinnell argillite is mostly in shades of red purple which, where of characteristic color, are distinctive enough to be recognized with confidence by anyone familiar with the formation. While the Missoula group also contains many red-purple beds, colors in that group approach reddish brown in hue. Typical beds in the Grinnell argillite are definitely more purplish than those typical of the Missoula, but the distinction is sufficiently delicate and the range in color is wide enough so that, as noted below, reliance on this feature alone is dangerous.

Even with the aid of color charts, precise designation of color in rocks presents difficulties. The opportunity for confusion is increased when descriptions by different authors are compared. Willis (1902, p. 316, 322), who defined the Grinnell argillite, spoke of it as dark-red shaley argillite. Both the Fentons (1937, p. 1887–1890) and Dyson (1949a, p. 7–8) speak of the red as a conspicuous feature. Probably all these authors used the term "red" in a general sense and ignored the purplish hues. The

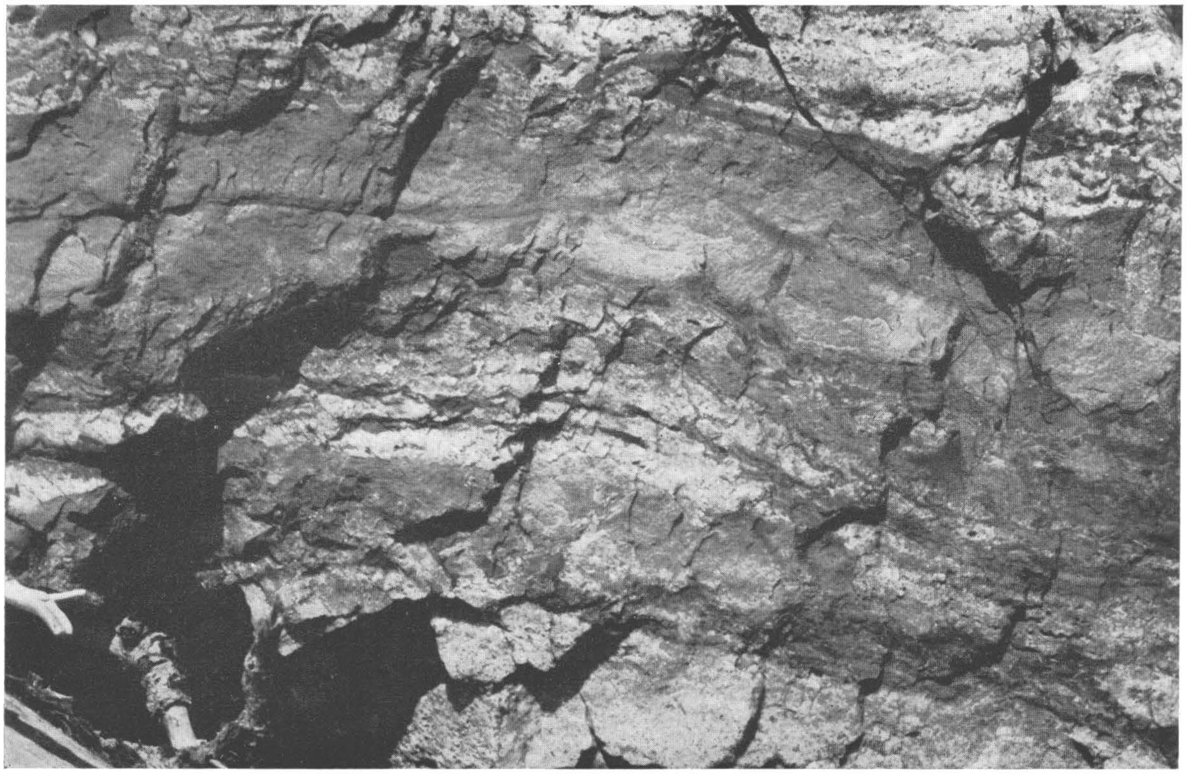


FIGURE 4.—Grinnell argillite on Broken Leg Mountain, Nyack quadrangle, Flathead region. Somewhat more distinctly laminated than is common because of the presence of white quartzitic layers containing included fragments of argillite.

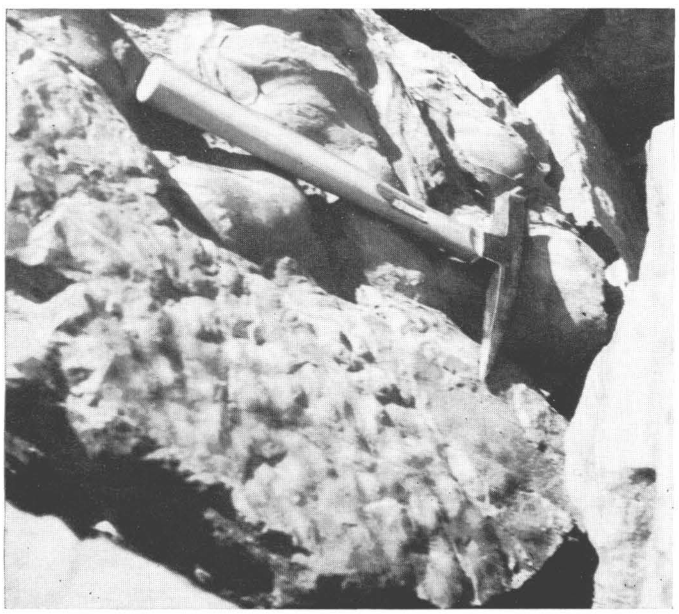
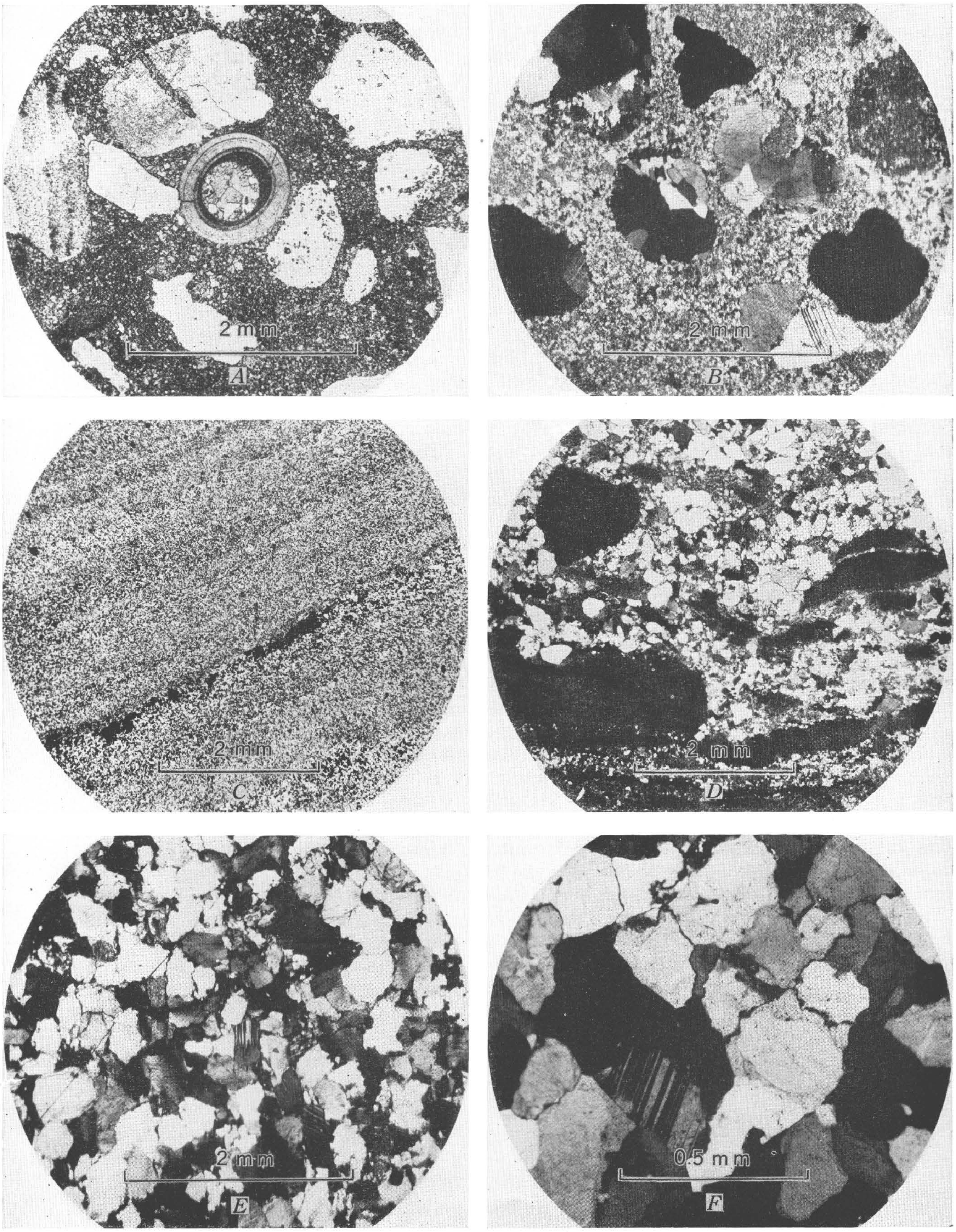


FIGURE 5.—Grinnell argillite on Broken Leg Mountain, Nyack quadrangle, Flathead region. Shows ripple marks and bulbous masses.

Fentons at the beginning of their description do say "red or purplish." Even the most distinctly red beds in both the Grinnell and the Missoula have a purplish cast.

The Grinnell argillite shows under the microscope rather less variation than might be expected from the variations in its megascopic appearance. From the appearance in thin section, it is clear that the original rock ranged from a siliceous mudstone or siltstone to a somewhat arkosic sandstone, a conclusion that is in agreement with the analyses on page 55. In the more argillaceous beds individual grains are only a few hundredths of a millimeter in diameter, but in the coarser layers the grain diameter ranges from 0.4 to more than 1 millimeter. Locally, coarse grains are irregularly scattered through a fine-grained matrix. In some argillaceous rocks the bedding is so irregular (fig. 6*d*) as to suggest that the original mud layers were disturbed while still unconsolidated. The argillaceous rocks

FIGURE 6.—Photomicrographs of rocks of the Belt series.
A. (Plane light) Supposed fossil in Altyn limestone near Swiftcurrent Falls, Glacier National Park. Fine-grained groundmass is carbonate, and large clastic grains are quartz and feldspar.
B. (Crossed nicols) Another view of the specimen shown in A, showing grains of quartz and one of striated plagioclase feldspar.
C. (Crossed nicols) Appekunny argillite from east of Lake McDonald, Glacier National Park. Shows rhythmic bedding.
D. (Plane light) Edgewise conglomerate in Grinnell argillite, Tom Tom Lookout, Swan Range, Nyack quadrangle, Flathead region. Note disturbed flakes of fine-grained argillite in quartzitic rock.
E. (Crossed nicols) Coarse-grained Grinnell argillite containing striated plagioclase feldspar, from the upper part of the formation, Wheeler Creek, Swan Range, Nyack quadrangle, Flathead region.
F. (Crossed nicols) Coarse-grained white quartzite in Grinnell argillite, Park Creek, Nyack quadrangle, Flathead region. Some of the grains show rims of added quartz.



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now consist largely of quartz and fine flakes of mica, with some feldspar and, locally carbonate. The coarser grained rocks are similar except that micaceous minerals are less abundant and in some beds are nearly absent. Feldspar, largely alkalic plagioclase, is more conspicuous (fig. 6*e*) in the coarse-grained layers, but this difference may be more apparent than real. The minerals would be difficult to recognize in fine-grained rocks. Some of the grains in the coarser grained rocks are themselves fragments of fine-grained sedimentary rocks, and some of the quartz grains had been subjected to marked pressure before they were incorporated in the present rock. Many of the grains in these rocks are well rounded. Some are rimmed with material added late in the process of consolidation. This feature, shown somewhat indistinctly in figure 6E, is not as well developed as it is in many quartzites, suggesting that the process of recrystallization is far from complete. Carbonate is less widespread than it is in the Appekunny argillite. It is too scanty to be detected under the microscope in many of the rocks and is abundant in very few outside of the transition zone at the top. It is plentiful in some beds in Felix Basin, but those have been hydrothermally altered, and at least part of the carbonate may have been introduced in solution.

In the Flathead and Swan Ranges the Grinnell argillite crops out extensively with the Appekunny argillite below and the Siyeh limestone above, evidently in normal stratigraphic relations uncomplicated by deformation. The formation consists largely of pale- and grayish-blue-green, grayish-purple, and grayish-red-purple siliceous argillite, in part slightly calcareous, and some quartzite. In the Swan Range the lowest and thickest part of the Grinnell is dominantly pale- and grayish-red-purple argillite, nowhere well exposed. Above this is the middle member in which the proportion of red-purple beds decreases upwards, and much of the rock is quartzitic argillite and argillaceous quartzite, with thin argillite partings, generally rather dark red purple. Some of these partings more nearly resemble parts of the argillite of the Missoula group and of the red argillite in the Grinnell formation farther north than do any of the thicker beds in the Swan Range. The outcrops pictured in figures 4 and 5 belong to this middle member. The uppermost member of the Grinnell argillite commonly consists of grayish-blue-green calcareous argillite and argillaceous limestone, constituting a transition zone below the Siyeh limestone of the Piegan group. This member contains a few red-purple beds, and the unit below it contains some green beds. Nevertheless, the distinction is sufficiently definite so that the transition zone at the top of the Grinnell has been shown on plate 2. Conceivably this transition zone, or some part of it, corresponds to the "*Collenia symmetrica* zone," which the Fentons (1937, p. 1894) define as the "upper phase of the transition between the argillitic and arenaceous Grinnell to the dolomitic and limy Siyeh" and place at the base of the Siyeh limestone as defined by them. On that basis the uppermost member of the Grinnell as mapped on plate 2 would become the basal unit of the Siyeh limestone. This unit is more argillaceous than any part of the Siyeh limestone of the present report. No stromatolites were found in this unit in the Flathead region. If they should be found, the probability that the transition zone belongs in the Siyeh would be greatly increased.

The Grinnell argillite in the Flathead Range has features closely akin to those in the Swan Range but is even less satisfactorily exposed. Here also, the transition zone at the top is mapped, but the two subdivisions of the formation beneath this zone were not recognized, possibly because the exposures are so incomplete.

Along the northeastern side of that part of the Middle Fork of the Flathead River below its confluence with Bear Creek, Clapp (1932, pl. 1) mapped a rather large area as being underlain by the Grinnell formation, with the Missoula group on the opposite side of the river. This interpretation, which appears to have been accepted by Erdmann (1944, p. 45), would require that a large fault lies approximately along the channel of the Middle Fork. As indicated on plates 1 and 2 of the present report, the rocks on both sides of the Middle Fork below Bear Creek belong to the Missoula group and are in the normal stratigraphic position for that unit. This eliminates the necessity for a fault in the valley of the Middle Fork. No evidence of faulting here was found during the present study, and Clapp's error presumably arose from inferences in regard to color.

In most parts of the park the Grinnell argillite consists largely of reddish-purple argillaceous rocks, which in many localities are interbedded with otherwise similar green rocks. Exceptionally, especially near the top of the formation, the green beds predominate. In some places, notably low in the sequence white and pink to reddish quartzite is conspicuous. Among the localities where the color is exceptionally reddish rather than purplish may be mentioned outcrops along the Going-to-the-Sun Highway west of St. Mary Lake. Here the beds might well be mistaken for components of the Missoula group if their stratigraphic position were not known.

During the present investigation the Grinnell argillite was studied more closely in the southern part of Glacier National Park than in the area north of latitude 48°40′. Where examined, the 3 subdivisions noted in the Swan Range are probably present, but the distinctions between the lower 2 are inconspicuous. The transition zone at the top is certainly present in most localities but, where seen, is less conspicuous than in the Swan Range. This may be due to absence of prominent exposures of the unit along the lines of traverse rather than to any fundamental stratigraphic difference. Nevertheless, present data make it impracticable to map the transition zone throughout the park, and it is not shown on plate 1. Some of the men who worked under Campbell distinguished the zone in the field; others did not. Allowance has been made for this so far as possible in the compilation of plate 1, but it may have resulted in places in some inconsistency in the placing of the upper boundary of the Grinnell. Insofar as information permits, that boundary is placed at the top of the rocks that are dominantly argillaceous and below those that are dominantly carbonate rocks.

The Fentons (1937, p. 1887–1890) studied the Grinnell argillite mainly in and north of the northern part of Glacier National Park in localities not examined closely during the present investigation. The three members they propose are, as judged from their descriptions, different from those in the Swan Range. Their lowest subdivision, which they call the Rising Wolf member, contains variable white and pink quartzite beds interbedded with red argillite in layers that range from mere laminae to beds 5 feet in thickness. Ripple marks and mud cracks are common. The thickness is given as 200–700 feet. The Fentons note that this member is not everywhere clearly distinguishable. The colors of both argillaceous and quartzitic beds in it differ from one locality to another. In some places, such as the vicinity of Ptarmigan Lake, green beds are conspicuous.

The thick middle unit is called the Red Gap member by the Fentons, (1937, p. 1889) and their descriptions show it to be of varied character. It is reported to consist of argillite "in thin minor and thick major beds, dominantly red but incidentally brownish or green, interbedded with pink, white, or greenish-white quartzite, brown sandstone, and sandy argillite." A characteristic feature is the thick beds of red argillite with flat mud-crack polygons. The maximum thickness is reported as 2,800 feet, but in places it thins to as little as 650 feet.

The upper part of the formation is called the Rising Bull member by the Fentons and is described by them as containing argillite, quartzite and mud breccias, forming the initial transition between the Grinnell and the Siyeh. The mud breccias of the Fentons (1937, p. 1905–1909) correspond to intraformational conglomerate. The rocks include beds of gray, red, green, pink and white. The thickness is reported to range from 600–1,100 feet. In and west of Waterton Lakes Park, a thin flow of amygdaloidal lava is intercalated in the upper part of the member, but no lava has been found in the Grinnell argillite anywhere south of the international boundary.

The wide variations in thickness estimates and in descriptions of the character of the rocks in different localities must reflect much lateral variation in the Grinnell argillite. In the Swan Range the two lower members together, as judged from plate 2, may have a thickness of 4,000–5,000 feet, and the upper member or transition zone is about 500 feet thick in the Flathead region, probably thinning northward. The unsatisfactory exposures in that region introduce a large element of uncertainty into any estimates of thickness. Nevertheless, the formation in the Flathead region must be exceptionally thick. The thickness of the whole formation in the southern part of Glacier National Park, as judged from plate 1, is close to 2,000 feet. Willis (1902, p. 322–323) speaks of the Grinnell in and near the northeastern part of the park as 1,000–1,800 feet thick. The Fentons (1937, p. 1887) give a range in thickness of 1,500–3,500 feet. Dyson (1949a, p. 7) says the thickness "varies" considerably but is greater than 3,000 feet in several localities.

In 1914 the Grinnell argillite was measured and described at the same two localities as the observations on the Appekunny argillite recorded above. Most of the Grinnell on Red Eagle Mountain was studied by Eugene Stebinger, but the transition zone at the top was studied by Corbett and Williams in connection with their examination of the Siyeh limestone. A thickness of 739 feet at the base of the section measured by Corbett and Williams contains so little limestone that it is here included in the Grinnell. Presumably agreement was reached in the field between Stebinger and Corbett, so that their sections do not overlap. Corbett and Williams did all of the work near Crossley Lake, but their observations were made on 2 different days and may not represent the whole of the Grinnell argillite in the vicinity. On the second day they measured 184 feet of beds which are here placed at the top of the Grinnell. (See following table.) Possibly some beds are missing between these and the section of the Grinnell they had measured earlier.

Grinnell argillite on Red Eagle Mountain

[After Eugene Stebinger, C. S. Corbett and C. R. Williams, field notes, 1914]

	Feet
Beds here assigned to the Siyeh limestone.	
Grinnell argillite:	
Argillite, gray, calcareous	189
Quartzite, gray and green, interbedded	145
Argillite, green	138
Argillite, green and gray with numerous thin beds of coarse-grained sandstone and light-gray limestone	125
Argillite, deep-red, shaly, intercalated with a somewhat larger amount of gray to reddish-gray coarse-grained crossbedded quartzite in beds 1–2 ft thick	440
Argillite, alternate red and green; in beds 1–12 in. thick	10
Argillite, deep-red, shaly; alternating with gray to reddish crossbedded quartzite in the proportion of about 60 percent of argillite to 40 percent of quartzite	73
Quartzite, reddish-gray to white; interfingered with an irregular layer, 1–3 in. thick, of red argillite	6
Argillite, deep-red, shaly; alternating with gray to reddish crossbedded quartzite in the proportion of about 70 percent of argillite to 30 percent of quartzite	753
Argillite, deep-red, shaly	44
Argillite, red to maroon, shaly; intercalated with 20 percent of gray to white quartzite in beds ½–2 ft thick; mostly crossbedded	315
Argillite alternate green and red, with a few thin beds of white quartzite	46
Argillite, green; alternating with red coarse-grained crossbedded sandstone in beds 4 in. thick	8
Quartzite, white	42
Argillite, green, with beds of white quartzite up to 4 in. thick	
Quartzite, white, massive	23
Quartzite, white, and argillite, green	22
Quartzite, white, massive	20
Argillite, green	19
Quartzite, white, in beds up to 6 in. thick	16
Argillite, deep-red, shaly, intercalated with about 60 percent of gray to reddish-gray coarse-grained crossbedded quartzite in beds 1–2 ft thick	257

Grinnell argillite on Red Eagle Mountatin—Continued

	Feet
Grinnell argillite—Continued	
Quartzite, pink, and deep-red argillite, in about equal, quantities, in beds 1–3 ft thick	27
Argillite, deep-red, shaly; intercalated with a somewhat larger quantity of gray to reddish-gray coarse crossbedded quartzite in beds 1-2 ft thick	47
Quartzite, pink, coarse-grained	5
Quartzite, alternating pink and gray, alternating with maroon and gray argillite in layers from 2 in to 3 ft thick	8
Quartzite, reddish-gray to pink, with several thin red argillite layers	20
Argillite, red, with a thin layer of green argillite	4
Argillite, green and red, interbedded with white quartzite	3
Quartzite, white, coarse-grained; crossbedded with a shaly layer	2
Argillite, red, thin-bedded, with a layer of green argillite	39
Argillite, red and green, in equal proportions, in beds ½–4 in. thick, with several thin quartzite beds	50
Argillite, maroon, with several green bands	14
Argillite, red, shaly, with scattered green layers and a bed 1½ ft thick, of greenish-gray coarse-grained crossbedded argillite at the top	59
Argillite, red and green, thin-bedded, with a little coarse-grained grayish-white quartzite	86
Total	3,055

Grinnell argillite north of Crossley Lake

[After field notes of C. S. Corbett and C. R. Williams, 1914]

	Feet
Argillite, green, gray, calcareous, thin-bedded (weathering buff) in units up to 3 ft thick, with a few thin beds of quartzite	103
Argillite, gray, shaly, with a few beds of quartzite up to a foot thick	44
Argillite, gray, shaly, and quartzite, gray; in units up to 3 ft thick	24
Sandstone, gray, thin-bedded, argillite, gray, and quartzite, light-gray	13
(Section interrupted here and some may be missing. Beds above this horizon were grouped with the Siyeh limestone by Corbett and Williams.)	
Quartzite, gray, with red pebblelike pieces of argillite and 2 beds of red argillite, 6 and 8 in. thick, respectively	5
Argillite, red	2
Quartzite, red and grayish-white, thin-bedded, crossbedded. The latter color bed contains numerous pebblelike pieces of red argillite	50
Argillite, red and green, in units up to 6 in. thick	40
Argillite, green	5
Argillite, red, with thin green argillite seams and a gray sandstone bed 2 ft thick	4

Grinnell argillite north of Crossley Lake—Continued

	Feet
Argillite, red, with thin green argillite layers and a bed of gray sandstone 2 in. thick	4
Argillite, green	3
Quartzite, white	5
Argillite, red, and quartzite, white; in beds up to a foot thick	17
Quartzite, white, thin-bedded	5
Argillite, red, with numerous beds of white quartzite up to 6 in. thick	66
Quartzite, reddish-gray, thin-bedded	35
Argillite, red, in beds up to 3 ft thick and with thin layers of green argillite, interbedded with gray quartzite in beds up to 1½ ft thick	80
Quartzite, light-green, with some green argillite	13
Argillite, red, with numerous layers of buff argillite, 2 in. thick	23
Quartzite, red, thin-bedded; interbedded with much red argillite	35
Argillite, green, with numerous beds of white quartzite, 1–3 in. thick in the upper 25 ft	73
Argillite, red	3
Argillite, green	3
Argillite, red, with occasional beds of white quartzite up to 6 in. thick	26
Argillite, green and red, intercalated, the former predominating	13
Argillite, red, with small seams of green argillite and white quartzite	7
Argillite, green	3
Argillite, red	5
Argillite, green	5
Argillite, vivid-red	4
Argillite, green	1
Argillite, vivid-red, interbedded with much green argillite and white quartzite up to 8 in. thick	374
Quartzite, red, massive	2
Argillite, vivid-red, shaly, with numerous beds at irregular intervals of buff argillite and white quartzite, ½–3 in. thick	63
(Break in measurements here which Corbett says may introduce an error of about 10 ft.)	
Quartzite, red-tinted, in beds 2 or 3 in. thick; interbedded with some red argillite	62
Argillite, light-green, thin-bedded	3
Quartzite, red, argillitic, crossbedded in beds up to 6 in. thick	18
Argillite, green, quartzitic in places, with some red argillite in units up to a foot thick	40
Argillite, green	8
Sandstone, gray, crossbedded	1
Quartzite, greenish-white	5
Argillite, green	9
Argillite, red	3
Argillite, green	3
Argillite, red, with a few very thin seams of green argillite	18
Argillite, green	1
Argillite, red	2
Argillite, green	2
Argillite, red	10

Grinnell argillite north of Crossley Lake—Continued

	Feet
Argillite, green, intermixed, and white quartzite	1
Argillite, red, with a 3-in. layer of white quartzite	9
Argillite, green, thin-bedded	2
Argillite, red, thin-bedded	6
Total	1,361

PIEGAN GROUP

The terms "Piegan group" and "Siyeh limestone" have been used in different ways by different authors. These terms are here redefined in such a way as to make the units convenient to map. In a general way, both the Fentons (1937, p. 1890–1900) and Clapp (1932, p. 22, pl. 1) recognize 3 major subdivisions within the middle group of the 3 into which the greater part of the Belt series is divided. This group is the Piegan group as the Fentons defined it (1937, p. 1890–1892). Their name has been retained, but as already indicated its application has been restricted. The 2 upper subdivisions formerly included in the Piegan group or its equivalents are here excluded from it. The lower unit of the original Piegan group is the Siyeh limestone of the Fentons and of the present report. It is the only 1 of the 3 that constitutes a homogeneous, readily mappable unit throughout Glacier National Park and the Flathead region. Argillaceous beds that have been included by some at the base and top of the Siyeh have been separated therefrom in the present report. As pointed out in the description of the Missoula group, doubt exists as to the proper correlation of the 2 upper units of the Piegan group as originally defined by the Fentons, but these 2 units seem best regarded as parts of the Missoula group.

As far as Glacier National Park and neighboring areas are concerned, the name "Piegan group," as restricted in the preceding paragraph, might well be dropped altogether. However, in a preliminary attempt at broad correlation of the subdivisions of the Belt series (Ross, 1949), Piegan group was adopted as a convenient name for the thick sequence of beds in Montana and adjacent areas that differ in details from place to place but are characterized everywhere by a high carbonate content and the group lies between the Missoula group above and the Ravalli group below. In the present report the designation Piegan group is retained because of its usefulness in correlation throughout Montana and because the thick Siyeh limestone is expected to be divided into several units of formational rank when more detailed mapping is done. When this is accomplished, the name "Siyeh limestone" is expected to be restricted in its application or abandoned altogether.

SIYEH LIMESTONE

The Siyeh limestone underlies broad areas in the median parts of the Flathead and Swan Ranges. These areas extend almost the entire length of the parts of both ranges that are within the Flathead region and that in the Flathead Range persists to the foot of Lake McDonald.

According to Clapp's map (1932, pl. 1) and Deiss's unpublished geologic map of the Ovando quadrangle, the Siyeh limestone is continuously exposed as far south as T. 18 N., R. 15 W., and at intervals beyond this. Study of these exposures and the relations of the limestone in them to overlying beds in the light of data in the present report should yield significant information as to the interrelations of the Piegan and Missoula groups and their components. Such a study should do much to settle the problem of the upper limit of the Piegan group in the Glacier Park region. Additional mapping will be required to determine what relation the so-called Spokane formation in Glacier National Park may bear to the Spokane argillite of the Spokane Hills, east of Helena. Part of the work needed is understood to have been already accomplished (Knopf, 1950), although the maps have not yet been published.

In Glacier National Park the Siyeh limestone forms the core of the mountain mass, although capped in places by later units. It extends from near the intersection of longitude 113°30′ with latitude 48°30′ northwestward past the Canadian border, widening northward. Its general character can be seen in figures 3, 6, 17, 27, and 28.

The Siyeh limestone is a crystalline carbonate rock that contains varying amount of magnesia, silica, and other impurities. The analyses listed in the table on page 55 show that it contains from 20 to nearly 50 percent of silica and significant quantities of alumina, so that it is a distinctly impure carbonate rock. Some beds are more argillaceous than those selected for analysis, but no aggregates of argillite or of distinctly argillaceous limestone of mappable dimensions are known to be present.

Nearly all of the Siyeh limestone is thick-bedded or massive as viewed from a distance, but much of it shows thin, wavey laminations on fresh fracture surfaces. Close inspection commonly reveals a fine lamination. Some of the limestone is oolitic. The color of the Siyeh limestone on fresh fracture surfaces is dusky blue or, more rarely, greenish gray, varying in value and hue (Goddard and others, 1948) apparently with variations in composition. The rock weathers in orange and brownish tones and commonly shows irregular etched markings on weathered surfaces (figs. 7, 8). These features are distinctive and easily recognizable, but they are quite as characteristic of the limestone here regarded as within the Missoula group as they are of the Siyeh limestone. They correspond to differences in the calcium carbonate content of the rock, but the origin of these small-scale differences is not understood. They include the forms termed "molar tooth" structures by Daly (1912, p. 72–76). His term is derived from resemblance to the markings on a molar tooth of an elephant and is vividly descriptive of some of the structures. However, there is infinite variety in the details of form assumed by the structures, and many have no resemblance to molar-tooth markings. The Fentons (1937, p. 1927–1929) speak of them as segregation structures and, in accord with Daly, think that segregation occurred long after induration. Such an explanation is probably correct for some of the structural features, but the characters displayed and the relation, or lack thereof, to bedding and parting planes of all sorts are so different in different exposures that it seems evident that no single explanation will fit all of these features. Perhaps some have direct or indirect relation to the life processes of primitive organisms in the original lime muds from which the present limestone is derived. Figures 7 and 8 show two examples, but the variations are too numerous to be adequately pictured or described here.

Textural variations in the limestone on a microscopic scale are quite as diverse as would be expected from the descriptions already given. Two examples are shown in figure 9. Where special features are absent the rock is laminated, and in many laminae the grains average only a few thousandths or a few hundredths of a millimeter in diameter. Beds from one to a few millimeters thick composed largely of subrounded quartz grains are widely distributed but commonly are not abundant. A little sericite is present in these beds and in some of the limestone beds. Most thin sections exhibit irregularities in the texture of the carbonate, related to the "molar tooth" and other structures that are so conspicuous in the outcrop (fig. 9*A*). Most of the rock does not contain well-defined oolites, but in many

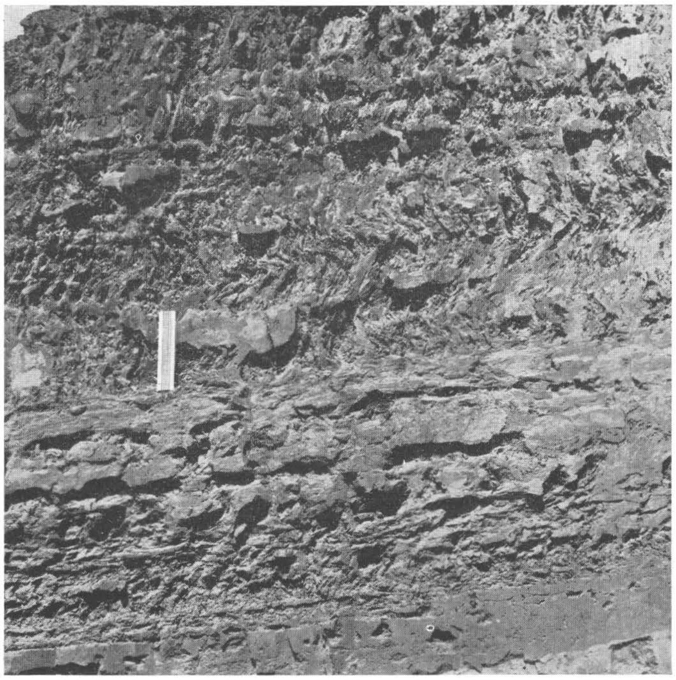

FIGURE 7.—Molar-tooth structure in Siyeh limestone in roadcut along Going-to-the-Sun Highway, Glacier National Park.

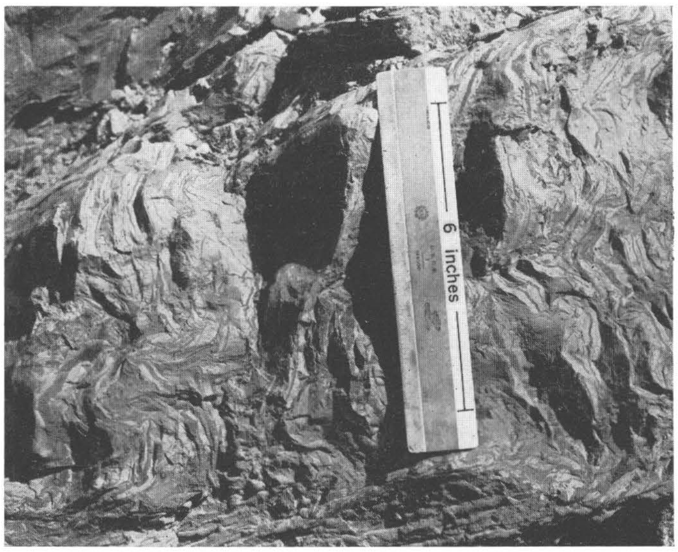

FIGURE 8.—Irregular banding in Siyeh limestone in roadcut along Going-to-the-Sun Highway, Glacier National Park. These irregularities may correspond to movement in the limestone before consolidation, but they are in essentially undeformed beds.

there are irregularities in grain that may be derived from oolites now thoroughly recrystallized. Where oolites are preserved, some are roughly elliptical in section and 1 or 2 millimeters long (fig. 9*B*). These are fine-grained and preserve no internal features characteristic of oolites. The same rock may contain oolites that are circular in section and have well-preserved concentric structure. Some of these are broken, and others are invaded in the outer layers by grains of clastic quartz. Most such oolites seen under the microscope are less than a millimeter in diameter and are themselves components of pebble-like masses embedded in the fine-grained limestone.

The stromatolite zones at several horizons in the Siyeh limestone locally provide means of subdividing that thick formation, but none of these has yet been mapped throughout plates 1 and 2. In the following descriptions the zones are designated by the names of the principal stromatolites found in each, and the nomenclature proposed by Rezak is used. This fact should be borne in mind when comparing the descriptions with those of previous writers, who used different names for the stromatolites, and consequently for the zones. For discuscussion of the differences in nomenclature, see Rezak's (1957) paper entitled, "Stromatolites of the Belt Series in Glacier National Park and vicinity, Montana."

No mappable subdivisions of the Siyeh limestone have been recognized in the Swan or Flathead Ranges; however, some stromatolite zones are known. These and other features are expected to permit subdivision when thoroughly detailed mapping is undertaken. By far the most conspicuous masses of stromatolites found are in the vicinity of Clayton Lake. The ridge crest surmounted by Tongue Mountain, west of the lake has almost continuous exposures of these fossils for a distance of more than a mile along the trail (fig. 10). Rezak visited this ridge in 1952 and concluded that the most abundant forms belong to *Collenia symetrica* Fenton and Fenton, although *C. frequens* Walcott is also present. On Graves Creek, southeast of Clayton Lake, outcrops of stromatolites are present near the trail but are less abundant and much more imperfectly exposed than on Tongue Mountain. These probably are *C. symmetrica.* An outcrop of stromatolites on the ridge above the head of Forrest Creek surely represents some form of the genus *Collenia,* possibly *Collenia symmetrica.* The Siyeh limestone in several other localities in the Swan Range has wavy laminae that may represent stromatolites, but these are much too small and indefinite to be named on the basis of present information. Most of the scattered outcrops of *Collenia* noted in the Swan Range are at or near the same stratigraphic horizon. Together they may mark a zone corresponding more or less to the *Conophyton* zone 1 of the park (the *Collenia frequens* zone of the Fentons).

Most of the mapping in the Swan and Flathead Ranges was done in 1949 before the significance

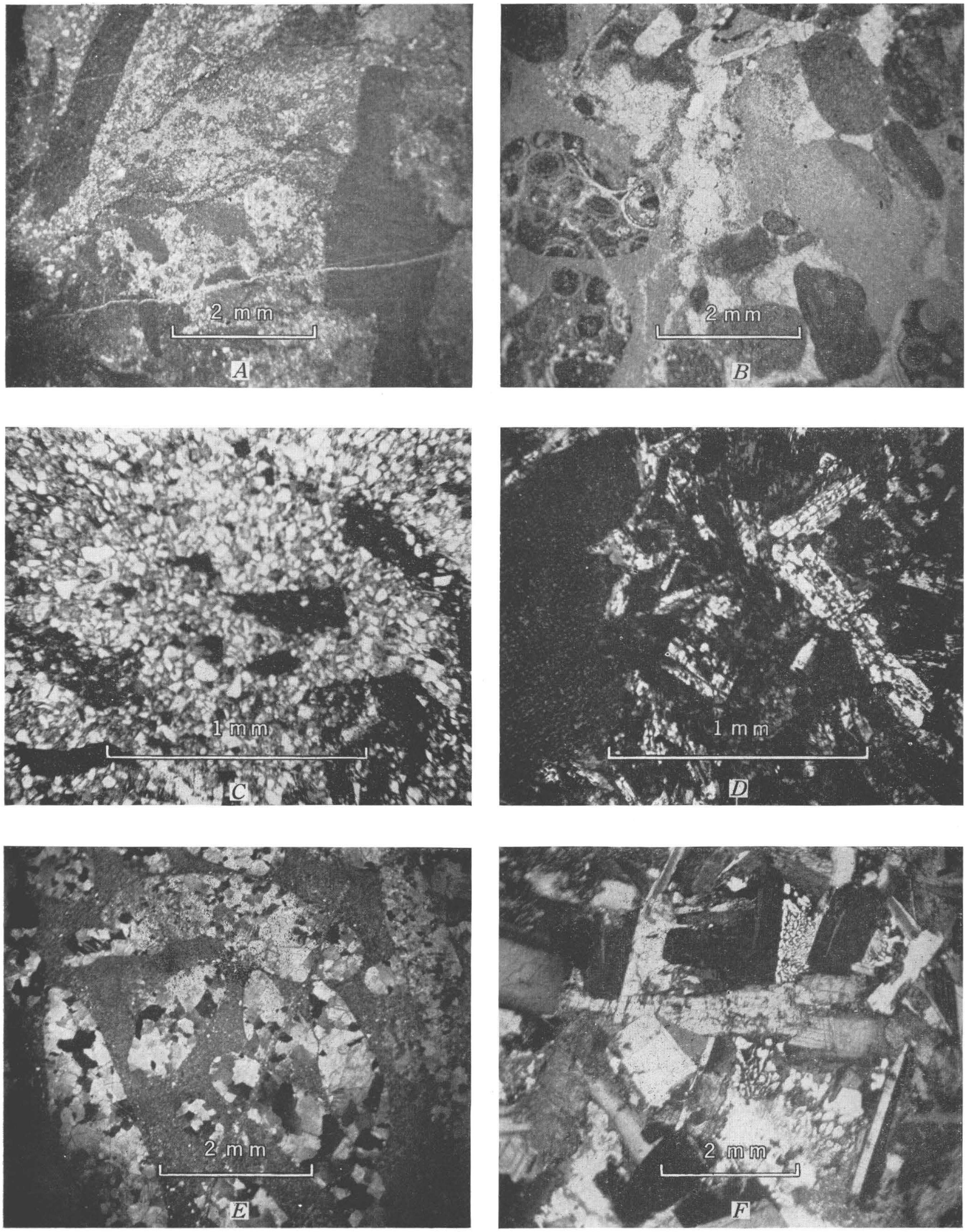

Figure 9.

FIGURE 10.—*Conophyton inclinatum* in Siyeh limestone, roadcut above the big switchback on Going-to-the-Sun Highway, Glacier National Park.

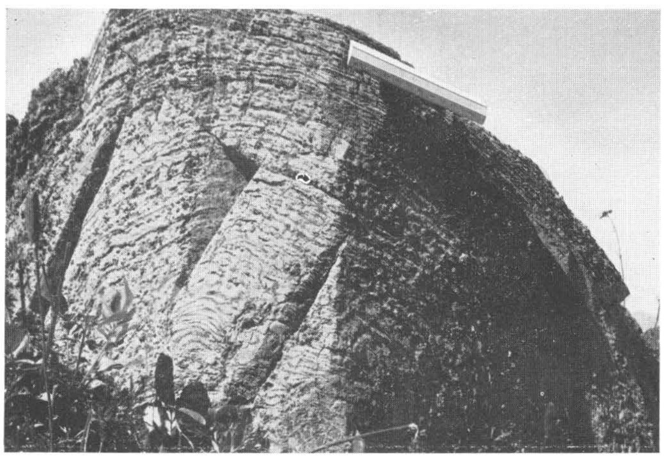

FIGURE 11.—Stromatolite on Tongue Mountain, Nyack quadrangle, Flathead region. Presumably *Collenia symmetrica* or a similar species.

of the stromatolites was appreciated and before special studies of them had been initiated. In the course of this mapping no stromatolites were recorded from the Flathead Range although some are probably present there. Nordeng in 1950 found some in highway and railroad cuts at the north end of the range. Rezak regards these as dominantly *Collenia symmetrica.*

In Glacier National Park the *Conophyton* zone 1, named by Rezak (the *Collenia frequens* zone of the Fentons), is so persistent and easily recognized even at a distance (fig. 3) that it has been shown on plate 1 throughout the area of the Siyeh limestone. On this basis the Siyeh limestone in Glacier National Park might be thought of as having three mapped components: this zone and the beds above and below it. However, formal division of the formation is not here attempted, partly because of the difficulty with present incomplete data in carrying it throughout the region covered by plates 1 and 2. Detailed mapping will result in discrimination of map units other than the three indicated above, at least in parts of the park. Because of lateral variations it seems probable that some of these units will not be found persistent enough to be mapped throughout the park, and it may be that few of them can be carried far beyond the limits of Glacier National Park. That is, it is anticipated that future work will result in establishing local units, some of which will be valid only over a few scores or hundreds of square miles, rather than throughout the broad region underlain by the Siyeh limestone.

The Fentons (1937, p. 1892–1897) have set up four subdivisions of the formation within the park. In ascending order these, with Rezak's revisions in nomenclature shown in parentheses, are the *Collenia symmetrica* zone and Goathaunt member (= *C. symmetrica* zone 1) *Collenia frequens* zone (*Conophyton* zone 1) and Granite Park member. They describe their *Collenia symmetrica* zone as the "upper phase of the transition between the argillitic and arenaceous Grinnell to the dolomitic and limy Siyeh" and add that it includes quartzite, argillite, and argillaceous dolomite that weather green, brownish, or buff, with subordinate purplish-red argillite limited to the lower 75 feet of the unit. The member is reported to have a thickness of 500–900 feet and to grade upward into the Goathaunt member. It must grade downward into the upper part of the Grinnell argillite. The part that contains the "purplish red argillite" of the Fentons and any part above this in which argillite and quartzite predominate over carbonate rocks belongs with the transition zone at the top of the Grinnell as mapped in plate 2. This matter has been commented on in the description of the Grinnell argillite.

Clearly the *Collenia symmetrica* zone 1 does not, as the name might imply, consist mainly of a

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FIGURE 9.—Photomicrographs of rocks of the Belt series and associated igneous rocks.
A. (Plane light) Irregularly textured Siyeh limestone near head of Hidden Creek, Glacier National Park.
B. (Plane light) Oolitic Siyeh limestone south of Red Eagle Pass, Glacier National Park.
C. (Plane light) Red argillite of the Missoula group on Argosy Mountain, Nyack quadrangle, Flathead region. A quartzitic argillite, with fragments of fine-grained argillite in it. Grains are subangular and do not appear to have been recrystallized.
D. (Crossed nicols) Purcell basalt, Flattop Mountain, Glacier National Park.
E. (Crossed nicols) Limestone in the Shepard formation, Flattop Mountain, Glacier National Park. Shows oval masses of coarse-grained carbonate in a fine-grained carbonate matrix. Oval bodies may be recrystallized oolites.
F. (Crossed nicols) Metagabbro from an irregular intrusive mass near the Spotted Bear airfield, Flathead region. Note interstitial micropegmatite.

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definite biostrome in which *C. symmetrica* is dominant. Nordeng comments that, on the contrary, it is a zone in which *C. symmetrica* occurs with varying frequency, with occasional colonies of *Collenia clappi* Fenton and Fenton. Later studies by Rezak have led him to regard *C. symmetrica* and *C. clappii* as synonymous and to drop the latter term. Probably the zone has much lateral variation and would not be recognizable throughout Glacier National Park on the basis of its stromatolite content. Thus, if an equivalent unit is mapped in the future, it is likely to receive some name other than a paleontological one. Rezak reports that *C. symmetrica* may be found anywhere in the Siyeh limestone below the *Conophyton* zone 1, mostly in isolated bioherms in dense black and tan laminated argillaceous limestone. Isolated heads of *Collenia multiflabella Rezak* are present in the bioherms of *C. symmetrica.* Most such bioherms noted by Rezak are stratigraphically higher than the *C. symmetrica* zone of the Fentons; that is, these bioherms are within the Goathaunt member of the Fentons.

The Goathaunt member of the Fentons consists of the greater part of the limestone typical of the Siyeh. They say it contains limestone, dolomite, and subordinate quantities of oolite, dolomitic sandstone, and argillite and add that mud breccias, commonly containing coarse sand and pebbles, are abundant in northern exposures. They estimate the thickness as 2,000–3,200 feet, whereas they give the thickness of the entire Siyeh limestone in Glacier Park as 2,900–4,000 feet.

The Fentons speak of their *Collenia frequens* zone (= *Conophyton* zone 1 of Rezak) as composed of dark-gray crystalline to amorphous limestone in one or more massive biostromes with thinly bedded calcareous or dolomitic intercalations. They say that the biostromes consist of little except *Collenia frequens* (= *Conophyton inclinatum* Rezak) and *Collenia versiformis* Fenton and Fenton (= *Cryptozoon occidentale* Dawson) and assign a thickness of 100–156 feet to the zone. It is clear that the zone is a mappable unit, although very thin in comparison to most of the other map units in the Belt series, and it would appear that the paleontological designation given by Rezak is appropriate. Consequently, this designation is employed in the present report. The zone within the Siyeh limestone is designated the *Conophyton* zone 1 to distinguish it from the similar zone recently found within the Missoula group and designated the *Conophyton* zone 2.

The *Collenia frequens* zone (= *Conophyton* zone 1) was studied by Nordeng in 1950 and by Rezak in 1951. Their descriptions differ in many respects from each other and from that given by the Fentons. This arises partly from differences in the character of the zone from place to place, but perhaps even more from the fact that classification of the different species of *Collenia* has not been standardized in the past. Nordeng reports that *Collenia willisii* Fenton and Fenton (= *Collenia multiflabella*) is the principal form in the lower part of the zone. As the Fentons note that *Collenia willisii* (= *Collenia multiflabella*) is common in their Goathaunt member, which underlies the *Collenia frequens* zone (= *Conophyton* zone 1), it may be that Nordeng extended the *Conophyton* zone 1 somewhat lower stratigraphically than they did. He says that the beds containing *C. willisii* (= *C. multiflabella*) are followed upward by a biostrome of *Collenia versiformis* (= *Cryptozoon occidentale*), overlain by bioherms and biostromes of *Collenia frequens* (= *Conophyton*). Above these he found in most places a biostrome 2–3 feet thick "of what is usually identified as *Collenia versiformis* but has a stronger resemblance to *Collenia columnaris* (= *Collenia frequens*)." Nordeng noted much variation in the thick ness and abundance of the components of the *Collenia frequens* zone but regarded the biostrome composed of *Collenia versiformis* as the most persistent and the masses of *Collenia frequens* as the most conspicuous.

Rezak thinks of the *Conophyton* zone 1 as made up essentially of three parts. At the base he reports a biostrome of *Collenia frequens* which is relatively thin near and east of Logan Pass but thickens westward. Directly above this biostrome he found podlike bioherms of *Conophyton,* 5–22 feet wide and up to 6 feet high. The closely packed heads of *Conophyton* in these range from a few inches to 4 feet in diameter (fig. 10). Each of the bioherms has associated with it undistorted finely laminated black and tan limestone. The laminae are continuous from the colonies on the margin of each reef and are interpreted by Rezak as off-reef deposits. Each dips west and is overlain by other bioherms. The subzone containing *Conophyton* with the associated off-reef deposits is about 50 feet thick near Logan Pass but only a few feet thick at Heavens Peak Lookout. If, as both Nordeng and Rezak think, the exposure of stromatolites near the lower end of Lake McDonald is the stratigraphic equivalent of the *Conophyton* zone 1, this particular part of that zone in absent or obscure there. (See the stratigraphic section measured at that locality by Nordeng and given on p. 40). Rezak notes that the uppermost part of the *Conophyton* zone 1 consists of a layer 1–12 feet thick in which *Cryptozoon occidentale* predominates but which also contains *Collenia multiflabella.*

The Fentons report that their Granite Park member, the top unit of their Siyeh formation, contains magnesian limestone, oolite, argillite and quartzite, with colors that range through gray, greenish gray and brown. The thickness is given as 280–900 feet. This is one of the transitional zones between formations of the Belt series in which consistency and uniformity of definition and mapping are difficult to attain. In at least some places, the argillite and quartzite grouped with this member by the Fentons are probably included in the calcareous argillite at the base of the Missoula group as mapped on plate 2 and the southern part of plate 1.

The Fentons say that their Granite Park member contains many algal bioherms. These include large colonies of *Collenia willisii* (= *Collenia mulitflabella*) and also masses of *Collenia frequens* (=*Conophyton*) and of *Collenia versiformis* (= *Cryptozoon occidentale*). Some of these stromatolitic masses may be low enough in stratigraphic position so that they merge with the *Conophyton* zone 1 as shown on plate 1. This statement applies particularly to the large biostrome described by the Fentons as 6.4 miles along the highway westward from Logan Pass and 1.4 miles east of the loop, or big switchback, which was included in the *Conophyton* zone 1 in the mapping done in 1950 (pl. 1). Nordeng notes that a zone at the top of the Siyeh limestone is composed entirely of *Collenia willisii* (= *Collenia multiflabella*) and is present over much the same area as the *Conophyton* zone 1 that has been mapped. He adds that this *Collenia willisii* zone (= *Collenia multiflabella* zone) is distinguished by the presence of alternating gray dolomite and brown argillite layers. Rezak also found biostromes up to 6 feet thick and isolated bioherms consisting dominantly of *Collenia multiflabella* at Logan Pass and along the Garden Wall in the uppermost part of the Siyeh limestone. In addition, *Cryptozoon occidentale* is present here.

In the Swan and Flathead Ranges the Siyeh limestone has not been measured but has an apparent thickness of at least 5,000 feet, as judged from plate 2. Erdman (1944, p. 48–55, 88–95) supplies details in regard to the Siyeh limestone in the northern part of the Swan Range, including partial sections and chemical analyses. He estimates that the Siyeh limestone on the southeast slope of Teakettle Mountain in T. 31 N., R. 20 W., is 4,550 feet thick (accurate within 5 percent).

The Fentons, as already noted, estimate the thickness in Glacier Park as 2,900–4,000 feet, but these estimates include clastic rocks not here included in the Siyeh limestone and would, therefore, be high by several hundred feet. Comparatively detailed stratigraphic sections of the Siyeh limestone in the park, adopted from the field notes of geologists under M. R. Campbell, followed by a partial section made by Nordeng in 1950 and one measured by Rezak in 1951 follow. The most reliable and detailed section appears to be that pieced together from measurements made by Corbett and Williams in three different localities near Red Eagle Creek. (See p. 41.) As the separate measurements are each tied to recognizable horizon markers, they have been compiled below with confidence that they represent a fairly accurate picture of the entire formation in the part of the park close to Red Eagle Creek. In accord with present concepts, the red and green argillite beds measured on the upper part of Almost-a-Dog Mountain and originally listed by Corbett and Williams as the upper part of the Siyeh are not included. It seems more appropriate to regard them as part of the Missoula group. Similarly, it may be that a small part of the lowest unit that is listed below should be regarded as belonging to the transition zone at the top of the Grinnell argillite and, consequently, eliminated here. Similar modifications have been introduced in copying the two other sections listed below from the field notes of geologists in Campbell's parties. Thus, the three sections as here given represent with a fair degree of accuracy the complete thickness of the Siyeh limestone, as the term is used in the present report, in the northeastern part of Glacier National Park. It will be noted that the average thickness on this basis is close to 2,000 feet. Equally complete measurements in the western part of the park are not at hand, but would probably show a greater average thickness. In comparing the sections listed below with generalized statements as to character of the Siyeh limestone given above and in other publications, it should be borne in mind that nomenclature of color, texture, and other features is so far from standarized that descriptions of the same rock by different geologists may differ markedly.

Siyeh limestone along Garden Wall from Collenia undosa *zone in lower part of Missoula group down to* Conophyton *zone 1 in the Siyeh on Going-to-the-Sun Highway, about 7.7 miles west of Logan Pass*

[Measured by Richard Rezak, 1951]

	Feet
Collenia undosa Walcott, isolated heads. Laminae are pink; matrix is green argillite	1
Argillite, alternating green, tan, and purple; finely laminated	34
C. undosa, poorly developed heads, similar to those at top of section	2
Argillite, alternating green, tan, and purple, finely laminated	71
Argillite, alternating green, tan, and red, finely laminated. Contains irregular bands of calcareous, oolitic, white, pink, and green sandstone. Sandstone is commonly crossbedded and in lower 4 ft of unit contains pyrite cubes; averages 6 in. in thickness	73
Argillite, blue, calcareous; weathers tan. Contains two thin beds of *C. undosa*. Biostrome at base seems to be continuous	8
Sandstone, pink, calcareous, oolitic; crossbedded; contains large pyrite cubes	2
Argillite and limestone, alternating tan and blue-gray. Becomes more calcareous toward base. Has stringers of pink, calcareous, oolitic sandstone in lower part	21
Limestone, pink to gray oolitic with some green argillaceous bands	19
Top of Siyeh limestone. Dark-gray to black beds with limestone (dense, fine-grained) predominating	20
Collenia multiflabella Rezak, large (2–3 ft diameter) colonies, *C. multiflabella* zone?	2
Limestone, blue-gray to black, finely laminated. Contains small bioherms of *Cryptozoon occidentale* and *C. multiflabella* Dawson (emend. Rezak)	21
Sandstone, black, crossbedded, oolitic; calcareous. Contains poorly preserved, unidentifiable stromatolites	5
Limestone, dark-gray and tan, argillaceous. Has fine-grained tan laminae	174
Biostrome of *C. multiflabella*? Poorly preserved	6
Limestone, dark-gray, dense, fine-grained. Shows evidence of algal activity	55
Limestone, dark-gray, dense, fine-grained. Contains biostromes of *Conophyton*?	68
Covered	165
Limestone, black, massive, laminated with unidentifiable stromatolites	20
Limestone, black, thin-bedded. Contains *C. multiflabella* and *Cryptozoon occidentale* in upper part. Lower part contains abundant *Conophyton*. *Conophyton* zone 1	50

Siyeh limestone along Going-to-the-Sun Highway near southwestern end of Lake McDonald

[Measured by Stephan Nordeng, 1950, for the present study. Rezak's revised names of stromatolites given in parenthesis]

	Feet
Argillite, gray-green, grading into gray impure limestone, with lenses of yellow sandy quartzite. Nordeng suggests that this unit may be equivalent to part of the Shepard formation; so next unit below would be top of Siyeh limestone	11
Limestone, dense, thick-bedded, laminated with a biostrome a foot thick about 3 ft from top of unit, containing unidentified poorly developed stromatolites	7
Limestone, black, roughly crossbedded, sandy with calcite veinlets	4
Limestone, black, dense, fine-grained	2
Limestone, light-gray to black, laminated, sandy with layers of mud breccia and some zones of poorly developed stromatolites	3
Limestone, fine-grained, sandy, with breccia in lower part	15
Covered	40
Limestone, light-gray to green, fine-grained sandy	4
Limestone, black, dense with sandy lenses	3
Sandstone, light-gray to buff	5
Limestone, black	7
Sandstone, light-gray to buff	9
Covered or so changed as a result of a forest fire as to be indeterminate	293
Limestone, black, dense, wavy-bedded, nodular	135
Bioherm containing *Collenia versiformis* (=*Cryptozoon occidentale*) in heads ½–1 in. wide, up to 8 in. tall, digitate, showing very slight flexure of laminae. Most heads appear to expand upward although some are almost perfectly parallel. At top the stromatolites take the form of *Collenia willisii* (=*C. multiflabella*). Bioherm is overlain by a thin quartzite layer	3
Limestone, black, with thin wavy bedding	130
Stromatolites of *Collenia symmetrica* Fenton and Fenton type, with internal structure obscure	2
Limestone, black, dense	7
Stromatolite zone containing very poorly preserved *Collenia frequens*? and *Collenia symmetrica*?	1
Limestone, black, nodular	40
Covered	130
Limestone, black, dolomitic, with well-developed "molar tooth" structure	6
Sandstone and mud breccia	2
Zone of well-developed *Collenia versiformis* (=*Cryptozoon occidentale*)	3
Covered	40
Collenia frequens zone (=*Conophyton* zone 1). Black limestone with some "molar-tooth" structure. Contains good examples of *Collenia versiformis* (=*Cryptozoon occidentale*, possibly some *Collenia clappii* (=*C. symmetrica*) but more probably *Collenia willisii* (=*C. multiflabella*), also small heads of probable *Collenia frequens*	10
Covered	30
Limestone, black, thick-bedded	33
Limestone, black, massive, with numerous gray to greenish argillite beds	55
Covered	170
Biostrome within and covered by edgewise conglomerate. Apparently contains some *Collenia versiformis* (=*Cryptozoon occidentale* and an undetermined form; possibly *Collenia symmetrica*	2

Siyeh limestone along Going-to-the-Sun Highway near Southwestern end of Lake McDonald—Continued

	Feet
Limestone, black, thin-bedded	30
Biostrome, 2½ ft high, 1½–2 ft in diameter consisting of rather closely crowded colonies of *Collenia willisii* (=*C. multiflabella*). The enclosing limestone shows wavy laminae and some mud pebbles	2½
Biostrome containing *Collenia versiformis* (= *Cryptozoon occidentale* and an unknown form resembling a gymnosolen	4
Not exposed. Thickness of part of the formation measured. Beds below are not exposed along the highway and not susceptible of satisfactory measurement	--
Total	1,239

Siyeh limestone near Red Eagle Creek

[From field notes of C. S. Corbett and C. R. Williams, 1914]

	Feet
Limestone, thin-bedded; with numerous beds of sandy limestone and some of calcareous sandstone. The sandy beds are 1–8 in. thick and contain pyrite	102
Limestone, rather thin-bedded with argillaceous partings and a few beds of sandy limestone	466
Limestone, gray, massive in beds up to 2 ft thick	100
Limestone, shaly	1
Limestone, gray, massive with bedding planes at 1- to 2-ft intervals	11
(Above beds measured east of Red Eagle Glacier and stopped at top of unit called "massive member" in the field notes, almost certainly equivalent to the *Conophyton* zone 1 of the present report.)	
Massive member (Conophyton zone 1) with a 1-ft bed of thin-bedded limestone near the middle	78
Argillite, dark-gray, shaly and very fine-grained quartzite	8
Limestone, gray, massive with gnarly structure and a few beds of thin-bedded limestone	24
Argillite, dark-gray, probably calcareous	3
Limestone, massive with gnarly structure with numerous beds of thin-bedded limestone and, in the lower part, some of gray sandstone	371
Limestone, massive, sandy	1
Limestone, massive, with some thin-bedded limestone	103
Limestone, thin-bedded and massive; in alternating units up to 3 ft thick, with numerous beds of gray sandstone	140
Limestone, massive, containing a few beds of thin-bedded limestone	249
Limestone, thin-bedded, impure; with a few beds of dark-gray shale up to 6 in. thick of massive limestone up to a foot thick	171
Limestone, white, baked, thin-bedded	35
(Above beds measured between Red Eagle and Little Chief Mountains, and the baked limestone at the base overlies a sill 90 ft thick.)	
Limestone, white, baked; with pyrite crystals	22
Limestone, thin-bedded; becoming more massive upward	78
Argillite, greenish-gray, with numerous beds of gray sandstone, each in units up to 4 ft thick	35

Siyeh limestone near Red Eagle Creek—Continued

	Feet
Argillite, pink	3
Sandstone, argillitic	3
Argillite, pink	4
Sandstone, buff	3
Argillite, gray	2
Sandstone, gray	2
Argillite, green, with a few thin beds of limestone	16
Limestone, thin-bedded	11
Sandstone, buff	1
Limestone, thin-bedded	8
Argillite, greenish-gray	2
Shale, dark-gray	2
Limestone, thin-bedded	17
Argillite, green	6
Limestone, thin-bedded	19
Limestone, massive	1
Shale, gray	1
Limestone, argillitic	9
Sandstone, gray	2
Limestone, thin-bedded	2
Sandstone, gray	1
Limestone, gray, thin-bedded	2
Limestone, argillitic; with some thin beds of gray sandstone	19
Sandstone, gray	4
Limestone, argillitic	5
Argillite, gray and green	11
Limestone, massive	1
Argillite, green	2
Sandstone, gray	1
Limestone, massive	1
Argillite, gray	13
Limestone, massive	1
Limestone and sandstone, argillitic	11
Argillite, green; and sandstone in units up to 2 ft thick	19
Limestone, thin-bedded argillitic	10
Limestone	2
Argillite, gray	1
Argillite and sandstone, gray	12
Argillite, gray	5
Limestone, thin-bedded	1
Argillite, gray, calcareous	44
(Above beds measured on Red Eagle Mountain. The probability is that some or all of the gray and buff argillite and sandstone listed are calcareous, although not so designated in the field notes. The base of the section is at the top of beds interpreted as belonging to the transition zone at the top of the Grinnell argillite.)	
Thickness of beds above the *Conophyton* zone	680
Thickness of beds from top of sill through *Conophyton* zone	1,183
Thickness of beds below the sill	415
Total thickness of Siyeh limestone near Red Eagle Creek	2,278

An approximate idea of the Siyeh limestone on the west side of Mount Cleveland may be gained from the following section adapted from the field notes of E. M. Parks. Thicknesses given in this section are estimates based mainly on barometric readings.

Siyeh limestone on Mount Cleveland

[From field notes of E. M. Parks, 1914]

	Feet
Limestone with some argillite near base and a stromatolite zone, 30 ft thick, starting 20 ft above the sill	565
Sill	65
Limestone, bluish-gray to dark-blue rather thick-bedded	800
Upper part of transition zone, here so calcareous that it may be grouped with the limestone. Consists of thin beds of green argillite and impure limestone. The latter comprises 20 percent of the whole in the lower part and 50 percent in the upper part	325
Total, omitting sill	1,690

Another composite section of the Siyeh limestone is given below. Most of this was measured by Corbett and Williams on the ridge between the North Fork of Belly River and Mokawanis River but the upper part was measured by Stebinger and Bennett.

Siyeh limestone near Belly River

[From field notes of Eugene Stebinger and H. R. Bennett, 1914]

	Feet
Limestone, magnesian, baked in lower part	17
Sill	69
Limestone, baked	15
Limestone, thin-bedded, slabby; with siliceous markings, occasional beds of blue-gray shale up to a foot thick and some beds of magnesian limestone. Includes a zone up to 2 ft thick containing *Collenia*	183
Limestone containing *Collenia*	10
Limestone, buff thin-bedded, shaly	9
Limestone containing *Collenia*	2
Limestone, buff, thin-bedded; with siliceous markings and a few beds of gray shale up to a foot thick	148
Limestone, thin-bedded, shaly; and calcareous shale, mostly blue-gray, weathering buff with some beds of massive limestone, some of which contain *Collenia*	150
Limestone, bluish-gray, compact, with stromatolites throughout. Probably the *Collenia frequens* zone. (*Conophyton* zone 1 of Rezak)	67
(Above beds were measured by Stebinger and Bennett. Those listed below were measured by Corbett and Williams at a different place. They carried their section to the top of a peak where the rocks which in the present report are referred to as the *Conophyton* zone 1 are absent. By comparison with exposures in nearby peaks, Corbett infers that the top of his section is immediately below this zone.)	

Siyeh limestone near Belly River—Continued

	Feet
Limestone, massive; with some bedding planes visible. *Collenia* in upper 5 ft	35
Sill; probably same sill as listed above, but at a lower horizon	65
Limestone, predominantly massive; with some thin-bedded limestone. Several beds, especially in lower part, contain *Collenia*. Upper 10 ft is baked	198
Limestone, dark-gray, massive, sandy, crossbedded	3
Limestone, dark-gray, massive, with *Collenia*. Many of the *Collenia* are shallow; domed forms up to 6 ft in diameter	15
Limestone, thin-bedded	17
Limestone, dark-gray, rather thin-bedded, sandy	3
Limestone, light-gray, massive, sandy	2
Limestone, alternating thin-bedded and massive. The thin-bedded material predominates and is in part argillaceous. Some of the massive beds (commonly less than 3 ft thick) contain *Collenia*	646
Quartzite, dark-gray	1
Limestone, argillitic	9
Argillite, gray, calcareous	18
Quartzite, gray, crossbedded	1
Argillite, greenish-gray and gray calcareous with thin limestone and quartzite beds	33
Limestone, alternating massive and thin-bedded; the former containing *Collenia*	25
Argillite, greenish-gray	4
Limestone thin-bedded, argillaceous in upper part	29
Alternating beds of calcareous argillite and argillaceous limestone with numerous beds of comparatively pure limestone	29
Limestone, rather massive, sandy; with *Collenia*	15
Argillite, calcareous; with several thin quartzite beds and a little argillitic limestone	30
Quartzite, white and gray, massive	13
Limestone, argillitic	8
Limestone, gray, rather thin-bedded	2
Quartzite, gray, crossbedded; in beds a foot thick, in part separated by argillaceous layers	11
Limestone, argillitic; with a few thin quartzite beds	15
Quartzite, gray, massive	1
Limestone, gray, argillaceous; with numerous quartzite beds nearly a foot thick	31
Quartzite, gray, massive	1
Limestone, massive	1
Argillite, green, with thin quartzite beds	9
Argillite, calcareous, with thin quartzite beds	10
Limestone, massive	1
Quartzite, light-gray	1
Argillite, gray, calcareous	5
Limestone, massive; with domes of *Collenia* up to 2 ft in diameter	6
Argillite, gray, calcareous	8
Limestone, thin-bedded, argillaceous; with a few quartzite beds up to 6 in. thick	22
Thickness, exclusive of sills	1,859

MISSOULA GROUP

CORRELATIONS AND DIVISIONS

All the Belt series above the components already described belongs to the Missoula group. The assemblage, where not eroded, is very thick, and its mappable divisions differ markedly within short distances. In a broad way the Missoula group consists of red and green fine-grained clastic rocks with some intercalated limestone, mostly impure. Among the clastic beds all gradations between argillite and quartzite exist. Ripple marks, mud cracks, and other evidence of shallow-water deposition are plentiful. The limestone, especially the relatively pure beds, has close lithologic similarity to the Siyeh limestone described above.

Many names and descriptive terms have been applied to components of the Missoula group in Glacier National Park and other areas in northwestern Montana. It is not the purpose of the present report to attempt stratigraphic correlations throughout the broad region in which the group crops out; but as names from distant localities have been applied in previous work in Glacier National Park, some discussion is required. As already indicated, the top of the Piegan group and the base of the Missoula group are placed in the present report at the top of the definitely calcareous beds in the Siyeh limestone and at the base of beds so predominantly argillaceous that their resemblance to the dominant part of the Missoula group is obvious. This places the base of the Missoula group in and near Glacier National Park stratigraphically lower than has been done in any previous publication. The decision to do this arose from the relationships of the Missoula group in the southern part of the Flathead region to beds farther south, and, in turn, from the relationships of those beds to the Missoula group in its type locality near Missoula. So far as mapping within the park is concerned, the procedure provides convenient map units and avoids long-range correlations. It seems the only logical procedure so long as lithologic character remains the basic criterion for stratigraphic subdivision and areal mapping in the rocks of the Belt series. Some uncertainty is introduced in the interpretation of data recorded by geologists who used other limits for the divisions of the Piegan and Missoula groups. The principal difficulty is in the interpretation of the field notes of Campbell's men for areas not checked during the fieldwork of 1949 and 1950 (shown on index map of pl. 1). Any inconsistencies that may have resulted are small in terms of a map of the scale and detail of plate 1.

The argillaceous rocks above the Siyeh limestone of the present report correspond essentially to the Spokane formation of the Fentons (1937, p. 1897–1898) and to the red and green argillite band in the Siyeh of Clapp (1932, pl. 1). Clapp and Deiss (1931, p. 691–693) agree with the Fentons in correlating the argillite "band" with the Spokane formation although they do not apply it quite so specifically to rocks in Glacier National Park. The correlation of this unit in Glacier National Park with the Spokane formation of the Spokane Hills (Walcott, 1899, p. 199–215) and other localities in the general vicinity of Helena (Pardee and Schrader, 1933, p. 11, 125–126) must remain questionable, at least, until much further work is done in the broad region between Glacier National Park and Helena. No map now available brings the Spokane formation from the Helena region into the vicinity of the Flathead region, and further, neither the Spokane, of the Fentons, in the park nor units above it can be traced satisfactorily southward even as far as the Flathead region. Consequently, the name "Spokane" is not here employed, and the beds thus designated by the Fentons are regarded as an unnamed part of the Missoula group.

The argillaceous beds immediately above the Siyeh limestone in the northern part of the park are overlain by flows of the Purcell basalt, with some intercalated sedimentary rocks. Data summarized by the Fentons (1937, p. 1903) suggest that in Canada similar lava occurs at widely separated horizons in the Belt series, so that correlations in localities distant from Glacier National Park would have to be made with caution. In the park, flows belonging to the Purcell basalt are succeeded upward by the Sheppard formation of the Fentons (1937, p. 1899–1900), now spelled Shepard because of a decision of the U. S. Board on Geographic Names (Wilmarth, 1938, p. 1980). This unit can be safely mapped only where it is underlain by Purcell basalt, but it is there an easily recognized map unit and the only assembly of sedimentary beds constituting a formation within the Missoula group to which a formal stratigraphic name is attached in the present report. The Shepard formation is equivalent to the Sheppard quartzite of Willis (1902, p. 316, 324), but on the whole, it contains much less quartzite than he supposed. The Shepard formation, which is largely dolomitic, is the equivalent of the upper part of the Siyeh of Clapp (1932) as nearly as can be judged by comparing his small-scale map with plate 1 of the present report. If so, Clapp and Deiss (1932, p. 691) suggest correlation with the Helena limestone of the Helena region. The same objections apply to using Helena in Glacier National Park as those given above in regard to the Spokane formation. Willis (1902, p. 316, 324) proposed the name "Kintla argillite" for the part of the Belt series above the Shepard formation in the northern part of Glacier National Park. However, he observed a thickness of only 800 feet and, as he saw no beds above his Kintla argillite, assigned no upper limit. Daly's (1912, p. 81–82) use of the name is essentially the same as Willis'. It is now known that the Missoula group extends for thousands rather than hundreds of feet above the Purcell basalt. As there is no way of separating the Kintla argillite of Willis from similar beds at horizons above those he saw, the name is not useful at present.

In the southern part of the park and in the Flathead region, no subdivisions of the Missoula group have received formal stratigraphic names. Some names have been used by other workers in areas south of the Flathead region, but none can be used in the Flathead region with confidence because of the marked lateral changes in lithologic character that are a feature of the group. The most complete sets of names are those that have been proposed for the vicinity of Missoula, the type locality of the group, and for areas to the northeast and north. Near Missoula, division of the group into five formations was proposed by Clapp and Deiss (1931, p. 677–683). Clearly these cannot be recognized far from that area, for when Deiss carried his studies into the Saypo, Ovando, and Silvertip quadrangles (pl. 3) short distances away (Deiss, 1943, p. 211–218), he was able to recognize only the Miller Peak argillite, the lowest of the five divisions near Missoula, and proposed three new formations above this basal unit, the Cayuse limestone, Hoadley formation, and Ahorn quartzite in ascending order. While there are significant differences in character and thickness between the divisions of the group in the Silvertip and Missoula areas, Deiss (written communications, 1950) tentatively regards the part of the Miller Peak argillite (the basal formation of the group) present in the Saypo, Ovando, and Silvertip quadrangles as equivalent to the upper 1,000 feet of the Miller Peak argillite in its type locality, which is south of Missoula. He thinks that the Cayuse limestone (1,000 ft) is probably equivalent to the lower part of the Hellgate formation and that the Hoadley formation (4,100 ft) is probably equivalent to the upper half of the Hellgate formation and the whole of the McNamara formation. The Ahorn quartzite (2,100 ft) he regards as equivalent to the lower part of the Garnet Range formation which near Missoula is 7,600 feet thick. As one example of the lithologic changes implied by such correlations, it may be pointed out that Clapp and Deiss say the lower 1,600 feet of the Garnet Range formation is made up of brown and green-gray to gray thin-bedded siliceous micaceous coarse-grained quartzite, with argillitic and coarse-grained quartzitic sandstones near the base. Above this 1,600 foot unit is 600 feet of black-gray to dark-blue-gray sandy micaceous argillite. In contrast, the supposedly equivalent Ahorn quartzite is described as consisting of 1,700 feet of pink thick-bedded quartzite with occasional beds of red sandstone overlain by 400 feet of green and red-gray thin-bedded argillite with a few intercalated thin beds of fine-grained sandstone. Unfortunately no maps showing the distribution of these various divisions of the Missoula group have been published.

Comparison of the data summarized above with descriptions of the rocks in the Flathead and Glacier National Park regions given below shows that there are significant differences between beds in the southern part of the Flathead region and those reported farther south as well as differences from place to place within the two regions covered by the present report. Some of the differences in the character of the uppermost beds of the Missoula group in different localities are explained by Deiss (1935, p. 95–124) on the assumption of marked differences in the amount of removal of the upper part of the group by erosion before deposition of Paleozoic strata began.

Even if this assumption should prove to be correct, there are differences in the character of the beds within distances of a few miles that cannot be accounted for in this manner. It must be remembered that wherever the contact between Precambrian and Cambrian strata in this part of Montana has been observed, the beds are essentially flat and parallel to each other. Deiss (1935, p. 102) calls attention to two localities where angular discordances are reported, but both are far from the areas here considered. Hence, the explanation of differences in character as a result of differences in depth of erosion would have to account for differences in the amount of erosion amounting to thousands of too small to show at the scale of the map. Distinctly purplish rocks, so common in the Grinnell argillite, are almost entirely absent in the Missoula group, a feature which in most localities is sufficient as a basis for discriminating between rocks of the two formations with considerable confidence. However, as noted in the description of the Grinnell argillite, the rocks of that unit, especially where exceptionally reddish, may bear sufficient resemblance to some of those in the Missoula group that confusion is possible where stratigraphic relations are not evident. Although most of the main body is argillaceous, quartzite, of varying degrees of purity, is widely distributed. In places near the top of the group, it is the dominant rock.

One distinction between the beds of the Missoula group and those at lower horizons is that the older rocks seem slightly more metamorphosed than those of Missoula age. In the Missoula group the original shapes of most of the clastic grains are preserved to a greater extent than in the Grinnell argillite. Some are subangular and, locally, even sharply angular, but many are well rounded (fig. 9*c*). The components of the coarser beds are more perfectly rounded than those of most of the fine-grained layers. Some of the rounded grains are coated with thin films of sericite. Some recrystallization has taken place as some quartz grains are intimately interlocked and some plagioclase grains have clear, added rims. In some of the argillite, thin very fine-grained layers were broken and twisted around before consolidation. The composition of the clastic rocks of the Missoula group is so nearly identical with that of comparable beds in the Grinnell argillite that no distinction can be made on that basis.

Here and there within the dominantly argillaceous main body of the Missoula group, certain beds weather a rusty brown that is similar to parts of the Siyeh limestone and to limestone beds above the Siyeh. Some of these rusty beds are impure limestone in assemblages so intimately interbedded with argillite that they were not mapped separately. Most of them, however, do not contain enough calcium carbonate to be detected by field tests. In a few places argillaceous beds contain small calcareous bodies that appear to be in whole or in part made up of stromatolites (fig. 15). Some are irregular lenses several feet long; others are concretionlike bodies commonly a few inches in diameter but alined within a single bed or assemblage of narrow beds for distances of tens or scores of feet along the strike. Some of these bodies are obviously calcareous, but many appear to be partly or wholly siliceous. The first variety is well displayed on the trail leading to Spruce Lookout, while the latter are common on Patrol Ridge, where together the outcrops probably represent a stratigraphic thickness of some scores of feet at least.

Ripple marks are very common in the argillite of the Missoula group, and mud-cracked surfaces are fairly so (figs. 12–15). The ripple marks tend to be smaller, less accentuated, and somewhat more uniform than those in the Grinnell argillite. In the Grinnell argillite, cross ripples and certain bulbous forms of obscure origin are rather common (fig. 5). Intraformational conglomerate is fairly plentiful but is a less common and striking feature than in the Grinnell.

Wherever sufficiently detailed observations have been made, variations within short distances in the components of the main body of the Missoula group

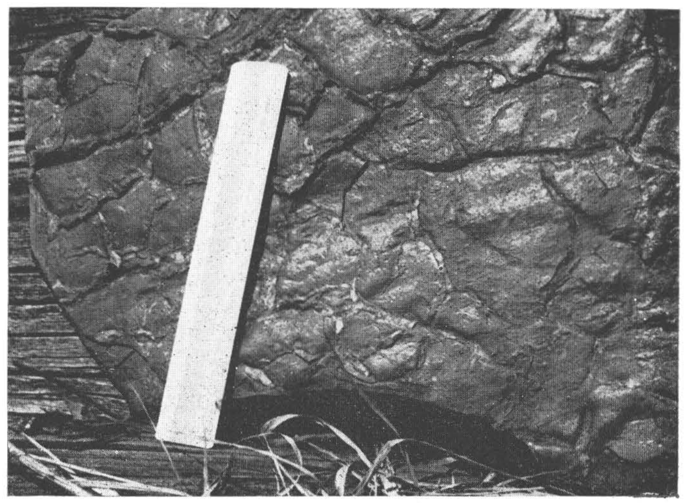

FIGURE 12.—Argillite of the Missoula group with sand-filled mud cracks, Upper Twin Creek, Marias Pass quadrangle, Flathead region.

FIGURE 13.—Cusped ripple marks in argillite of the Missoula group, head of Grouse Creek, Marias Pass quadrangle, Flathead region.

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Wherever sufficiently detailed observations have been made, variations within short distances in the components of the main body of the Missoula group

FIGURE 12.—Argillite of the Missoula group with sand-filled mud cracks, Upper Twin Creek, Marias Pass quadrangle, Flathead region.

FIGURE 13.—Cusped ripple marks in argillite of the Missoula group, head of Grouse Creek, Marias Pass quadrangle, Flathead region.

are manifest. The scattered data available are summarized below.

On the east side of Cruiser Mountain, Masursky in 1949 found somewhat less than 1,000 feet of ripple-marked and mud-cracked red-purple and yellow-green argillite with a few quartzite beds. Next above he noted two narrow sills, grouped as a single sill on the map because of limitations of scale. Above the sills quartzite beds become increasingly numerous and thicker until at the top the rock is almost exclusively quartzite, which is in part purplish red, in part almost white. The color differences are not diffuse, but occur in speckles, shreds, and bands. The thickness of beds of the Missoula group above the sills is roughly equal to that of the exposed beds below. Unfortunately, available data as to the lateral extent of the quartzitic rocks on Cruiser Mountain do not permit representing them on the map. Most of the Precambrian rocks above the sill that is mapped are quartzitic. Near the crest of Cruiser Mountain, the beds of the Missoula group are overlain by nearly white rather coarse-grained quartzite regarded as belonging to the Flathead quartzite of Cambrian age. The lithologic difference is sufficiently well marked so that Masursky felt that the top of the Precambrian rocks could be fixed with confidence, but he found no evidence of discordance or unconformity at the contact.

FIGURE 14.—Clay spalls in argillite of the Missoula group, below Mount Bradley, Marias Pass quadrangle, Flathead region.

FIGURE 15.—Laminated argillite of the Missoula group with a small stromatolite, in railroad cut nearly opposite the mouth of Coal Creek, Nyack quadrangle, Flathead region.

On Chair Mountain, about 5 miles northwest, the uppermost beds of the Belt series are distinctly different from those just described. At this locality, exposures on the lower slopes on the Dolly Varden Creek side are poor but consist mainly of purplish-red ripple-marked argillite. On the ridge crest, light-red to pink crossbedded quartzite is overlain by several hundred feet of green argillite, which, in turn, is overlain by Flathead quartzite. The green argillite is increasingly gritty upward. This green argillite is distinguished on plate 2 but was not found in any locality other than Chair Mountain. In most places the horizon at which it might be expected has been removed by recent erosion or has been faulted out.

On Argosy Mountain most of the beds of the Missoula group are quartzitic. Most are reddish, but some are pink to nearly white, and some purplish-red and green argillite is present. The beds on this mountain are so much deformed that it would be difficult to determine the proportions of the different kinds of rocks present. The lower slopes on and near Union Peak are underlain largely by red and green, locally gray, thin-bedded argillite. Near the ridge tops some light-red and nearly colorless quartzite is exposed. On and southwest of Union Peak, pinkish quartzite is so conspicuous that it is mapped on plate 2. There is much white, reddish, and greenish quartzite on Lodgepole Ridge, but like that on Argosy Mountain, it is so intermingled with argillite that it could be distinguished only on a large scale map.

Rather pale-reddish or pinkish coarse-grained quartzite crops out along the South Fork of the Flathead River close to the southern boundary of plate 2 and attracts attention in roadcuts and cliffs along the stream for some distance south of that boundary.

Presumably this quartzite is near the top of the Missoula group, but the base of the block of Cambrian rocks east of the river is not exposed; consequently, the character of the rocks at the contact is not determinable.

The localities described above are in the upper part of the Missoula group. Erdman (1944, p. 56–59) in connection with his study of the Hungry Horse dam site measured the lower part of the group near the dam site. The descriptions in the section below are somewhat abbreviated from those in his report. He also gives a very detailed section of the unit near the top of the generalized section in which carbonate rocks are abundant.

Generalized section of lower part of Missoula group in secs. 4, 5, 8, 9, T. 29 N., R. 18 W.

[Adapted from section by C. E. Erdman (1944, p. 56–57)]

	Feet
Top concealed.	
Argillite, dull, red and maroon, irregularly bedded, platy; some variegated dull green rock, and some thin beds of gray quartzite; thin red shaly films on some bedding surfaces	1,500±
Argillite, green, dull; irregular beds ¼–2 in. thick; some layers of gray-green sandstone	825
Dolomite (top concealed); mainly lentils and irregular masses of limestone and dolomite intermingled in such a way as to suggest "molar tooth" structure; some greenish argillite and occasional thin layers of pure gray limestone or sandy green limestone. Resembles Siyeh limestone	500
Argillite, green to gray-green; thin layers of quartzitic sandstone	290
Argillite, red to maroon, dull; few layers of dull green rock and some reddish quartzitic sandstone; has ripple marks and mud cracks	240
Argillite, gray-green; mud cracks and ripple marks; some layers of brown quartzitic sandstone	1,200
Argillite, red and maroon, dull, with ripple marks, mud cracks and mud lumps; few layers of green and buff sandy argillite	165
Argillite, green, dull, with a few limestone and sandstone beds; mud cracks, clay galls and blebs parallel to bedding	170
Argillite, red and maroon, dull; red beds appear to lens out to northwest	70
Argillite, gray-green, massive; some sandstone or quartzite and limestone layers	160
Transition zone, alternating beds about 1 in. thick of gray limestone, greenish-gray argillite, gray quartzite, and buff-weathering dolomite. The whole is sprinkled with sand in grains and lenses, some of which contain mud lumps. Proportion of carbonate rocks decreases upward, and near top of zone some layers are reddish	260
Top of Siyeh limestone.	
Total	5,380

In the part of Glacier National Park south of exposures of the Purcell basalt, the following section of the lower part of the Missoula group was measured in July 1914 by C. S. Corbett and E. S. Williams. The top of this section is at the base of a limestone body thought by Corbett and Williams to belong to the Shepard formation. In the absence of the lava, this cannot be regarded as a definite correlation.

Lower part of the Missoula group on the upper slopes of Almost-a-Dog Mountain

[Measured by C. S. Corbett and E. S. Williams, July 30, 1914]

	Feet
Argillite, green	29
Argillite, red, micaceous; some beds as much as 6 in. thick	17
Argillite, green and gray, interbedded; a few red beds. Beds range up to a foot in thickness	385
Argillite, pinkish-gray; in beds up to 5 in. thick with sandy layers up to 3 in. thick	18
Argillite, red micaceous	45
Argillite, greenish-gray, rather coarse-grained	14
Argillite, red; in beds up to 6 in. thick	32
Argillite greenish-gray; in beds up to a foot thick	52
Argillite, red	6
Argillite, gray; with numerous beds of green argillite in it. Beds range up to 8 in. thick but are finely laminated. A few beds of gray sandy limestone in the lower part	294
Argillite, red; in beds up to 6 in. in thickness	26
Argillite, green and gray, interbedded. Gray beds are a little coarser grained than the green ones and range up to 5 in. in thickness	25
Argillite, red; with a few thin gray layers	56
Argillite, pink, thin-bedded	4
Argillite pinkish-gray; weathers buff	3
Argillite, green, thin-bedded	25
Argillite, gray; with thin sandy layers; weathers pink	8
Argillite, red; with some gray beds	7
Argillite, gray, sandy, slightly calcareous	3
Argillite, red, thin-bedded; with some gray beds	15
Limestone, gray, sandy	1
Argillite, red; with thin green beds and a few sandy beds up to 4 in. thick	24
Argillite, gray and pink, calcareous; with calcareous red sandstone at base	12
Total	1,101

The Fentons (1937, p. 1897–1898) report the following section of the lowest part of the main body of the Missoula group in the basin above Hole-in-the-Wall Falls in the northern part of the park. The sedimentary beds in the section represent what they called the Spokane formation, and others have referred to as the "red band in the Siyeh" or similar. expressions. If the greenish calcareous argillite distinguished at the base of the group in the Flathead region had been mapped in the northern part of the park, the lower 75 feet of the section and possibly some of the beds above that would have been included in it.

Partial section of the Missoula group in Hole-in-the-Wall Basin

[After C. L. and M. A. Fenton, 1937, p. 1897–1898]

	Feet
Diabasic lava belonging to the Purcell basalt, dark-greenish, massive; flow structures pronounced; pipes, pillows, and inclusions of sedimentary material abundant basally	180–200
Argillite, green, finely banded, hard and much fractured. Upper part has been caught up and included in the lava flow above	3–5
Diabasic lava, dark-greenish; pillows and flow structures less pronounced than in the flow above. Thickness increases eastward	6–20
Argillite, dark-green, finely banded, with several sandy layers. Large ripple marks in upper beds. Near the top is a metamorphosed red layer 6–8 in. thick; near the bottom is a bed containing altered colonies of *Collenia undosa*	16
Argillite, with several beds of quartzite, both dark and red; some layers of brownish-red conglomerate. Crossbedding, ripple marks and mud cracks throughout	75
Argillite, red, buff, and buff-red in lower parts; grades upward into greenish, and terminates in red argillites interbedded with quartzite. Ripple marks, mud cracks, and crossbedding common in the quartzite	270
Argillite, greenish to buff; thick beds 2–3 ft thick; other, less abundant, beds are thinner	15
Limestone, magnesian, gray to buff, thinly bedded, shaly; grades upward into yellow to reddish and finely mud-cracked argillite	60
Total of sedimentary rocks	445–461
Top of Siyeh limestone.	

In August 1914 E. M. Parks noted that 700 feet of alternating reddish and greenish argillite beds underlies the Purcell basalt on the west side of Mount Cleveland. A more detailed section of the beds in the same locality, obtained by Eugene Stebinger and H. R. Bennett in September 1914 is given below. Stratigraphically, this coresponds to the section in Hole-in-the-Wall Basin just given, but there are many differences in detail. Similar differences would be found wherever comparable observations were made.

Lower part of the Missoula group on the ridge between the North Fork of Belly River and Mokowanis River

[From field notes by Eugene Stebinger and H. R. Bennett, Sept. 20, 1914]

	Feet
Purcell basalt.	
Hornfels, deep-greenish, siliceous. A baked mud with contorted structure faintly visible, suggesting that the mud was disturbed by the passage over it of the lava that overlies it, hence the eruption of the lava took place under water	10
Shale, green-gray to gray, calcareous	45
Shale, deep-maroon, somewhat calcareous ripple-marked, mud-cracked; with a few quartzite beds	132
Shale, gray to dark-green-gray, calcareous; weathers buff	147
Limestone, shaly, and shale, slabby gray to green-gray, thin-bedded; weathers buff; contains stromatolites	158
Shale, deep-red, ripple-marked, mud-cracked	59
Limestone, shaly, and shale, slabby gray to green-gray, thin-bedded; weathers buff; contains stromatolites	225
Shale, light- to deep-maroon; with many ripple marks and mud cracks; contains stromatolites	88
Total	864

In the lower part of the Missoula group near Logan Pass, Rezak found thin and individually nonpersistent biostromes characterized by *Collenia undosa* Walcott. They are especially well developed near the east base of Mount Oberlin where eight biostromes of *Collenia undosa* with occasional heads of *Cryptozoon occidentale* and *Collenia symmetrica* were noted. Each biostrome is associated with alternating layers of green argillite and pink limestone. Similar biostromes are exposed 0.2 mile east of the loop on the Garden Wall, 0.6 mile east of the lower end of Lake McDonald and along U. S. Highway No. 2 1.2 miles south of Walton. Biostromes that are probably to be correlated with these are present along the railroad west of the mouth of Coal Creek (fig. 15), along the Garden Wall near Granite Park, and on the northwestern slope of West Flattop Mountain. Similar forms are exposed in scattered outcrops along the ridge crest south of Baldhead Mountain. All these appear to be below the horizon of the Shepard formation although that unit is not mapped in their vicinity. Presumably they correspond to the stromatolites recorded by Stebinger and Bennett in the section given above.

The part of the main body of the Missoula group above the Shepard formation that remains uneroded in the northern part of Glacier National Park appears to be less than 1,000 feet thick and has been little studied. This is the unit which Willis (1902, p. 316, 324) called the Kintla argillite. The description below is adapted from one by Daly (1912, p. 81–83) and includes data from Willis' report. The name was originally taken from exposures north of the international boundary northeast of Upper Kintla Lake, Mont. The rocks are deep-red argillaceous quartzite and siliceous fissile shale or argillite with some white quartzite and occasional calcareous beds. Casts of salt crystals, ripple marks, and mud cracks are abundant. Some beds in the lower 60 feet at the head of Kintla Creek, in Canada, are lithologically identical with those characteristic of the Shepard formation. Above these is a 40-foot lava flow, which Daly says is lithologically like the Purcell lava and the flow in the Shepard formation but which is much less persistent than the Purcell lava itself. Evidently Daly used the name Purcell only for the thicker and more persistent masses of lava, but it has come to be applied to all flows of similar composition and of approximately similar stratigraphic position. The argillite contains angular grains of clear quartz, fresh microcline and microperthite, cloudy orthoclase, and a little plagioclase in an argillaceous cement containing much hematite. The section below represents, according to Daly, the Kintla formation at the type locality.

Columnar section of Kintla formation

[Quoted from R. A. Daly, 1912, p. 82]

	Feet
Top, erosion-surface.	
Argillite relatively homogenous, thin-bedded, bright-red, purplish- and brownish-red, and subordinate quartzitic sandstone	460
Argillite (dominant), heterogenous, thin-bedded, red, and sandstone, gray and brownish sandstone, magnesian oolitic limestone, and gray concretionary limestone	300
Amygdaloid	40
Argillite, thin-bedded, red, with thin intercalations of magnesian quartzite	60
	860

The Fentons (1937, p. 1901) give a somewhat similar composite section for the Kintla formation at and near the type locality, quoted as follows:

	Feet
Base, conformable top of Sheppard formation.	
Argillite, thin-bedded and homogenous, bright-red to purplish- or brownish-red; minor beds of quartzite and sandstone	440–460
Argillite, thin-bedded, bright-red to brownish, interbedded with red, brown, or brownish-gray sandstone, the latter increasing northward	175–200
Limestone, gray to pinkish-gray; weathers pink. Bears two algal bioherms composed of *Collenia clappii* n. sp	20– 30
Argillite, thin-bedded, bright-red, with layers of argillaceous red sandstone	95–100
Lava, amygdaloidal, green to purplish	40– 50
Argillite, thin-bedded, bright-red, with dull-red magnesian quartzites	60
	830–900

The descriptions given above taken in connection with plates 1 and 2 show that most of the main body of the Missoula group has been eroded from Glacier National Park. Even in the Flathead region there are few places where Palezoic beds remain resting on the Missoula. None of the sections measured represent more than a fraction of the original thickness of the group. Inspection of plate 2 indicates that the total thickness of the group is surely over 10,000 feet and may well be nearly twice that figure. Thus the aggregate thickness of the main body and of units mapped separately in the Flathead region is probably fully as great as the 18,000 estimated by Clapp and Deiss (1931, p. 677) for the type locality of the group.

GREENISH CALCAREOUS ARGILLITE

The foregoing descriptions apply to those parts of the thick Missoula group that have not been separated as yet into formations or other subdivisions. The components of the group differ from place to place. In the Flathead region a nearly continuous basal zone, transitional with the Siyeh limestone below, is termed "greenish calcareous argillite." Similar rocks are present locally in Glacier National Park but have not been mapped separately there. The lithologic designation chosen for the unit reflects the fact that much of it reacts readily to dilute acid. However, the carbonate-rich beds in it, as in other components of the Belt series, do contain significant quantities of magnesian carbonate. Those parts of the unit that are especially rich in carbonate resemble the Siyeh limestone in appearance. It is correlated with the Missoula rather than the Piegan group because it is dominantly argillaceous and many of its beds are lithologically identical with some of those high in the Missoula group. Nearly everywhere there is a sharper change in lithologic character at the base than at the top of the greenish calcareous argillite. In places, in fact, the upper boundary is necessarily somewhat arbitrary as green beds are interbedded with the reddish ones higher in the sequence.

The unit is exposed on both sides of Quintonkon and Wheeler Creeks and on and northwest of Pioneer Ridge. It is thus nearly continuous at the base of the Missoula group in the Swan Range. Even in the valley of Graves Creek, where it is not mapped, some beds may be present. In the Flathead Range it has been mapped only in the vicinity of Sheep Creek and opposite the mouth of Harrison Creek. Some green beds are present near the base of the Missoula between these localities, and more detailed study might result in mapping some of the basal unit here.

The basal green calcareous argillite is well displayed in the Belton Hills but has not been traced farther north in Glacier National Park. It was not recognized by members of Campbell's parties and was not sought in the northern part of the park during the fieldwork in 1950. Such data as are at hand indicate that in most places north of the latitude of the Belton Hills it is thin or absent. Calcareous green rocks that might be correlated with it are present near the base of the slopes at the south end of Flattop Mountain, but the three measured sections of the lower part of the Missoula group include relatively few beds that resemble it. Where well- displayed in the Flathead region, the greenish calcareous argillite is estimated to be 500–800 feet thick, but in many localities its thickness is much less. It seems probable that there are few places in the northern part of the park where its thickness exceeds 100 feet.

PURCELL BASALT

The name "Purcell lava" was originated by Daly (1912, p. 161–163, 207–220) for a large body of lava which he regarded as a persistent horizon marker. He says that the lava has been found in the vicinity of the international boundary from the border of the Great Plains to the eastern summits of the Purcell Range. He places the Purcell lava immediately above his Siyeh formation and units that he equated with that formation. As the composition appears to be that of an altered basalt, the unit is best termed "Purcell basalt" (Wilmarth, 1938, p. 1746).

Daly remarks that "magnesian strata characterized by the peculiar molar tooth structure" become prominent "at a horizon about a thousand feet or more below the Purcell Lava." Because the top of the Siyeh limestone, as here restricted, is in places almost as far as that below the base of the lava, the correspondence is reasonably close. As noted above, Daly apparently intended to exclude such minor flows as those in Glacier National Park from his Purcell lava, but common usage has extended the name to include the minor flows of similar composition and approximately similar stratigraphic position. Nevertheless, it should be noted that the presence of lava that looks like the Purcell basalt is not in itself sufficient for stratigraphic correlation of associated beds. In the park, most of the lava is immediately below the Shepard formation, but in the vicinity of Boulder Peak, some is well above that formation, and the small masses west of the Flathead River may be even higher stratigraphically. On the other hand, similar lava is reported (Fenton and Fenton, 1937, p. 1887–1888) to be intercalated in the Grinnell argillite in Waterton Lakes Park, Canada. This lava is not regarded by the Fentons as belonging to the Purcell basalt, and its exact character is not recorded. There appears, nevertheless, to be sufficient resemblance so that confusion would be possible in localities where stratigraphic relations are not otherwise clear.

Lava flows correlated with the Purcell basalt are exposed at Granite Park, around the periphery of Flattop Mountain, and thence at intervals northward to the Canadian border. They are present on Cathedral Peak, Mount Cleveland, Porcupine Ridge, near Kootenai Peak, near Brown Pass, Boulder Peak, and north of Upper Kintla Lake. On Boulder Peak the flows are at two horizons, separated by argillaceous and calcareous beds. Two small exposures of similar rock have been recorded on the west side of the Flathead River west of the Apgar Mountains.

In Glacier National Park the lava is an irregularly amygdaloidal rock most of which has conspicuous pillow structure. The color on fresh fracture is greenish gray to almost black, locally somewhat purplish. Weathered surfaces are stained brownish. According to the Fentons (1937, p. 1903–1904), in the vicinity of Granite Park the formation includes two major flows—

> "the first 30–42 feet in thickness, the second 18 feet thick. The basal 20–25 feet of the lower flow contains ellipsoidal pillows, 10–25 inches in diameter, separated by cherty inclusions; the lavas surround detached masses of modified argillite 2–12 feet thick, the base being irregular. The upper 10–17 feet is a massive, ropy lava. The second main flow is massive and amygdaloidal, containing mud inclusions, steam tubes, and irregular cavities—evidences of subaqueous extrusion."

Near Fifty Mountain Camp the pillows are especially conspicuous and range up to several feet in maximum diameter. The Fentons (1937, p. 1903–1904) speak of 150 feet of lava on Mount Kipp, 175 feet on Cathedral Peak, 200–220 feet in Hole-in-the-Wall Basin, and 275 feet of lava west of Boulder

Pass. Above Pocket Lake on Boulder Peak, they counted 8 flows in the upper 100 feet of the lava.

Daly (1912, p. 207–220) says that the lava is much altered but evidently a basalt. In the outcrops in Canada that he saw, much of the rock is a devitrified glass with numerous feldspar phenocrysts. It contains labradorite and much chlorite, leucoxene and an undetermined micaceous mineral. The analysis below is from the freshest of the specimens collected during Daly's investigation. It comes from a thick body of lava in the McGillivray Range about a mile south of the international boundary. This range is west of the Kootenai River and therefore much west of Glacier National Park. Analyses of basalt from Glacier National Park are not at hand, but they would probably be broadly similar to this one.

Purcell basalt

[From R. A. Daly, 1912, p. 209, analyst Prof. M. Dittrich]

Silica (SiO_2)	41.50
Titanium oxide (TiO_2)	3.33
Alumina (Al_2O_3)	17.09
Ferric oxide (Fe_2O_3)	3.31
Ferrous oxide (FeO)	10.08
Manganese oxide (MnO)	Trace
Magnesia (MgO)	12.74
Calcium oxide (CaO)	.97
Soda (Na_2O)	2.84
Potassium oxide (K_2O)	.22
Water at 110°C (H_2O)	.21
Water above 110°C (H_2O)	6.99
Carbon dioxide (CO_2)	None
Phosphoric oxide (P_2O_5)	1.08
	100.36

All the lava in the park appears to be too altered for precise determination. Finlay (1902, p. 350–351) says that the lava he saw had normal diabasic texture and was composed principally of augite with less abundant idiomorphic plagioclase with the habit of labradorite. He was unable to determine the feldspar accurately. The small amount of olivine originally present in the rock was altered to serpentine and chlorite.

At the south end of Flattop Mountain, the rock is even more thoroughly altered. Traces of diabasic texture remain, and there are remnants of phenocrysts that may have originally been augite and olivine. Some of the rock (exemplified by fig. 9*D*) contains feathery plagioclase laths with the habit of a calcic plagioclase but with indices of refraction close to that of canada balsam. These are crowded with specks of a secondary mineral of high index and low birefringence, presumably a chlorite. The main part of the laths now approximate oligoclase or albite-oligoclase in composition but may well have resulted by recrystallization from an originally more calcic plagioclase. Much of the rock consists of a fine-grained nearly opaque aggregate of secondary minerals that include chlorite, sulfides, calcite, quartz, and possibly serpentine. The writer's examination of this highly altered rock was kindly supplemented by Howard Powers.

L. D. Burling (1916) says the Purcell lava near Shepard Glacier is 150 feet thick and—

"composed of 6 or more flows, each of uneven and more or less ropy surface, separated by small and more or less local accumulations of shale. The lower 25 or 30 feet of the flow is composed of a conglomeration of dense, homogenous, spheroidal masses averaging 1 to 2 feet in diameter. They preserve their shape in the lower layers, being separated from each other by chert or drusy cavities, and many individuals have displaced considerable portions of the mud upon which they were rolled or shoved, even to the extent of complete burial. The bottom of the flow is therefore exceedingly irregular. Toward the top of this bed the individual spheroids yield more or less to the pressure of their fellows, and they unite to form an upper surface of moderate unevenness."

The upper part of the formation is composed of a bed about 20 feet thick which is massive but very porous. Vesicles are plentiful in the lower parts of several of the individual flows.

SHEPARD FORMATION

The Shepard formation in Glacier National Park is essentially coextensive with the Purcell basalt just described. That is, it is exposed at intervals from Granite Park northward past the international boundary. Originally Willis (1902, p. 316, 324) applied the name "Sheppard quartzite" to what he regarded as yellow ferruginous quartzite resting on the Purcell basalt along the crest of the Lewis Range in the vicinity of Mount Cleveland and Shepard Glacier between Belly River and Flattop Mountain. Because of a decision of the U. S. Board on Geographic Names (Wilmarth, 1938, p. 1980) and because much of the formation was found not to be quartzite, the name was changed to Shepard formation. The field notes of members of M. R. Campbell's parties, descriptions published by the Fentons, and observations during the present investigation are in agreement that both in the type locality and in other places in the park quartzite is subordinate to dolomitic rocks.

The formation is characterized by the fact that most of the beds in it weather to a distinctive color that ranges from pale yellowish brown to grayish orange. A typical specimen proved on analysis to be a fairly pure dolomite, as is shown in the table of analyses of Belt ricks on page 55, but many of the beds in the formation are more argillaceous or siliceous than the sample analyzed. West of Continental Creek, the Shepard contains beds of conglomerate containing lava pebbles.

As can be seen from figure 9*E*, the dolomite analysed is a peculiar rock. The matrix consists of dolomite grains about 0.01 millimeter in diameter, but embedded in it are numerous oval masses up to 4.0 millimeters long that consist of carbonate grains up to 0.2 millimeter in diameter. Perhaps these ovals are thoroughly recrystallized oolites.

Although in the Shepard formation as in most subdivisions of the Belt series variations in composition are plentiful, the color of weathered surfaces is so distinctive that, where coupled with the presence of lava below, the formation could be mapped with confidence. Attempts to extend the mapping of the Shepard far beyond the limits of the lava were unsuccessful. The characteristic color either disappears or is found in discontinuous beds at several horizons separated by beds that have none of the special features of the Shepard formation. The Shepard formation is reported to contain stromatolites. When these and other features have been studied in detail, it may prove possible to correlate carbonate-bearing units farther south with those now assigned to the formation.

Willis (1902, p. 316) gives the thickness of the Shepard at the type locality as about 700 feet. Parks, in his field notes, recorded 400 feet on Mount Cleveland, and Stebinger and Bennett, in their field notes, measured the following section of the formation on the slopes south of the North Fork of Belly River, where the top has been removed by erosion. The Shepard formation here overlies 115 feet of Purcell basalt, which in turn overlies the argillaceous beds of the lower part of the Missoula group measured by Willis and by Parks and listed above.

Shepard formation near Belly River

[According to the field notes of Eugene Stebinger and H. R. Bennett]

	Feet
Eroded.	
Limestone, bluish to green-gray, fine-grained, thin-bedded; with molar-tooth markings, and *Collenia*; weathers dull buff yellow	395
Limestone, blue-gray, pure; in laminated beds 2–5 ft thick interbedded with green-gray calcareous shale in 2- to 4-ft beds	115
Shale, red, micaceous	17
Shale, green-gray, calcareous, thin-bedded	64
Purcell basalt.	
Total	591

LIMESTONE

Unnamed more or less lenticular bodies of carbonate rocks of mappable proportions are present in the Missoula group at various horizons. The largest single mass extends along the northeast side of the Middle Fork of the Flathead River from near the head of Cy Creek to a point north of Harrison Creek where it disappears under deposits of Tertiary age. This mass may have a maximum thickness of nearly 3,000 feet, but it thins at both ends. It resembles the Siyeh limestone in general appearance to such an extent that Clapp (1932, pl. 1) mapped it as part of his Siyeh group and Clapp and Deiss (1931, p. 691, fig. 3) referred to it as the upper Siyeh limestone. It is not, as persistent a feature as might be inferred from their publication, based on reconnaissance. The thinner carbonate bodies around Mount Bradley, east of Spruce Park, near Hematite Peak, and in the vicinity of Grouse and Twin Creeks represent the feathering out of the large limestone mass into the main body of the Missoula group. Bodies at higher horizons are mapped in the vicinity of Baldhead and Square Mountains. There are, in addition, detached carbonate masses near the Continental Divide from Mount Cannon to Mount Logan. Some of these last-mentioned masses are so similar in character and stratigraphic position to the Shepard formation that they were correlated with that unit in the field notes of Campbell's men. Perhaps detailed studies may trace a connection between the Shepard as now mapped and carbonate rocks farther south, through argillaceous beds with some carbonate content in intervening areas. Clearly, however, the carbonate rock in the Missoula group extends through such a wide stratigraphic range that much of it cannot be correlated strictly with the Shepard formation.

The carbonate bodies near the Middle Fork of the Flathead are somewhat better known than the outlying masses. The parts of these that are relatively rich in carbonate are closely similar in appearance and composition to the Siyeh limestone. Like much of that rock, it is a limestone with some magnesian carbonate and some clastic impurities, whereas the characteristic rock of the Shepard formation is more nearly a dolomite. The thinner bodies mapped as limestone and parts of the larger ones, especially along their margins, are more impure than typical Siyeh limestone. These impure beds contain different proportions of argillaceous and siliceous material, and some of them react feebly or not at all to field tests with dilute acid.

They resemble the green calcareous argillite that in places has been mapped at the base of the Missoula group. All of the rock mapped as limestone in the Missoula group weathers with the colors characteristic of the Siyeh limestone. This is the feature that guided the sketching of parts of contacts in the field.

So-called segregation structures of one kind or another are conspicuous on weathered surfaces. Some of these are identical in appearance with the molar tooth structure for which the Siyeh limestone is noted. Others are so irregular and angular in outline that they bear no resemblance to the markings on teeth. Far more intensive study than could be given in the various reconnaissance examinations that the region has received will be required before these structural features will be understood.

Stromatolite zones are fairly plentiful in the limestone bodies of the Missoula group but have received less study than those in the Siyeh limestone. During the summer of 1952, Rezak discovered 2 hitherto unknown stromatolite zones in a large limestone lens approximately 6,000 feet above the base of the Missoula group. The larger and stratigraphically higher of the 2 zones is about 100 feet thick. It was mapped by Rezak in and near the southern part of Glacier National Park but has not been looked for farther south. Because it closely resembles the better known *Conophyton* zone 1 in the Siyeh limestone, it is mapped on plates 1 and 2 as the *Conophyton zone* 2. Only two species of stromatolites occur in the zone: *Conophyton inclinatum* and *Collenia frequens*. The zone is divided into five parts that persist over the entire area in which it was examined. At the base is 23 feet of well-developed *C. frequens*. The next unit is 35 feet thick and consists of large heads of *Conophyton inclinatum*. Overlying this is 12 feet of barren black shaly limestone. Above this is 6 feet of *C. frequens*, and at the top of the zone there is 24 feet of *Conophyton inclinatum*. The *Conophyton* in this zone does not occur in the podlike bioherms that are so characteristic in the Siyeh limestone.

The second zone lies about 500 feet below the one described above. It is only about 35 feet thick and contains extremely large heads of *Collenia symmetrica*. The colonies measure up to 5 feet in height and 6 feet in diameter. Subordinate species that occur in this zone are *Cryptozoon occidentale* and *Collenia frequens*.

Both zones are well exposed in the southwestern part of Glacier Park and the adjoining area east of the Middle Fork. They may be seen near the top of Running Rabbit Mountain and along the Great Northern Railroad tracks a few miles to the east of the mountains. The *Conophyton* zone 2 has a prominent outcrop west of Ole Creek. The other zone, characterized by *Collenia symmetrica*, is well displayed on and near Mount Furlong.

CHEMICAL COMPOSITION OF ROCKS OF THE BELT SERIES

The table below shows the chemical composition of 14 samples of rocks of the Belt series in and south of Glacier National Park. The table is arranged with the sample at the left representing the stratigraphically lowest formation. The analyses show that the rocks include impure dolomite and limestone, argillaceous quartzite, and siliceous argillite. Most of them are moderately high in silica. The most quartzose beds were not analyzed as the intention was to include material fairly representative of the different formations, rather than that representative of special features. All of the samples contain some carbonate, and only 5 show less than 1.0 percent. All of the carbonate-rich rocks contain both calcium and magnesium carbonates, and the amounts of other carbonates present must be small. When calculations are made based on the assumption that all of the calcium and magnesium occur as carbonate, it is found that 3 of the carbonate rocks show excess of carbon dioxide but 3 show deficiencies of somewhat less than 3 percent carbon dioxide. Obviously in the latter, part of the calcium and magnesium is in noncarbonate minerals. As most of the carbonate rocks have rusty colors on weathered surfaces and some are yellowish on fresh fracture, some iron carbonate is present, but the percentage of FeO recorded suggests that the amount must be small. Probably some of the calcium and magnesium in all of the rocks is in silicate minerals, which would leave a little carbon dioxide available for iron or other carbonates, even in those that seem deficient in that component under the assumption that all of the magnesia and lime are in carbonates. It is a fair guess that the carbonate rocks contain 1–4 percent ferrous carbonate.

Judged by the analyses, the Altyn limestone should be more properly called a dolomite, and the basal calcareous argillite of the Missoula group is likewise dolomitic. As many beds of the basal argillite effervesce with cold dilute acid, it is probable that much of the unit is less magnesian than the sample recorded in the table. The sample from the Shepard formation has a little more lime than the mineral dolomite, but it and most of the argillitic rocks analysed are dolomitic. The two samples from the Siyeh limestone and the one from a large body of similar rock within the Missoula group are limestones with less than 8 percent of magnesium carbonate in them. Analyses of four specimens from the Siyeh limestone quoted by Erdmann (1944, p. 54) agree in showing that calcium carbonate is much more abundant than magnesium carbonate. Obviously these limestones contain much clastic material.

A large part of the sodium and potassium present in all of the rocks analyzed probably is in feldspar grains or in minerals derived from the decomposition of alkali feldspars. Some of the argillaceous rock may contain nearly 10 percent of alkali feldspar.

All of the green argillaceous rocks contain more ferrous oxide than ferric oxide, and the reverse is true of those of purplish and reddish colors. In these rocks the coloring matter is presumably ferrous silicate, including chlorite, in the green rocks and hematite in the others. One specimen of purplish Grinnell argillite yielded 5.08 percent of ferric oxide and 2.16 percent of ferrous oxide, but in most the sum of the iron oxides is about 4 percent. One decidedly purplish-red argillite sample from the Missoula group yielded only 0.78 percent of Fe_2O_3 and 0.76 percent of FeO. Clearly very little ferric oxide, properly distributed, suffices to impart a strong color to a rock. As the ferrous oxide enters into the composition of complex silicates, a distinct green color may require much more of the coloring constituent. The amount of water in all of the samples is low; that given off below 100°C is less than 0.2 percent and in most samples well below 0.1 percent. Three samples of argillite yielded approximately 3.1 percent of water when heated above 100°C, but most of the other yielded less than 2 percent. This paucity of water is one of the indications that the rocks have begun to be metamorphosed. In most other respects they accord more nearly to typical sedimentary than to metamorphic rocks.

Analyses of rocks of the Belt series

[All analyses made in the laboratory of the U. S. Geological Survey. Samples ID–15150, 15250, 15350, 15450 were analysed by Robert N. Eccher. Samples ID–13550, 13650 13750, 13850, 13950, 14050, 21350, 21450, 21550, 21650 were analysed by Harry M. Hyman]

	ID–14050 [1]	ID–13950 [2]	ID–21650 [3]	ID–21550 [4]	ID–21350 [5]	ID–21450 [6]	ID–13650 [7]	ID–13550 [8]	ID–15450 [9]	ID–13850 [10]	ID–13750 [11]	ID–15350 [12]	ID–15150 [13]	ID–15250 [14]
Silica (SiO_2)	18.85	69.82	65.74	66.73	63.25	70.21	70.15	23.73	48.81	7.53	42.16	53.57	71.66	66.45
Alumina (Al_2O_3)	1.90	11.96	14.42	15.97	16.55	14.19	15.29	4.25	7.51	1.23	6.17	11.98	4.50	16.05
Ferric oxide (Fe_2O_3)	.12	.84	.71	.90	5.08	1.79	3.36	.45	.24	.25	.37	1.35	.78	1.02
Ferrous oxide (FeO)	.62	2.25	[15] 3.47	3.70	2.16	2.22	.63	.99	1.65	1.58	1.72	2.67	.76	2.54
Magnesia (MgO)	16.36	2.12	2.33	2.77	2.57	2.58	1.58	2.73	3.73	17.36	3.68	6.43	4.44	3.32
Calcium oxide (CaO)	23.79	3.22	2.32	.20	.26	.17	.12	36.31	17.55	28.85	22.81	6.47	5.73	.28
Soda (Na_2O)	.18	2.03	1.62	1.42	.78	1.04	1.69	.32	1.13	.08	.66	.61	.54	1.42
Potash (K_2O)	1.06	2.90	3.98	4.01	5.27	3.98	4.22	.94	1.91	.36	1.39	3.99	1.65	4.65
Water freed below 100° C (H_2O-)	.02	.09	.03	.07	.06	.05	.07	.14	.04	.05	.16	.10	.02	.17
Water freed above 100° C (H_2O+)	.01	1.61	2.36	3.09	3.10	2.69	2.00	1.19	1.49	.22	1.32	2.54	.67	3.15
Titanium oxide (TiO_2)	.06	.42	.54	.57	.63	.60	.61	.14	.33	.05	.22	.50	.08	.54
Carbon dioxide (CO_2)	36.65	2.39	1.77	.10	.02	.11	.03	28.61	15.42	41.97	18.94	9.37	8.63	.11
Phosphoric oxide (P_2O_5)	.12	.04	.15	.10	.19	.05	.08	.07	.07	.03	.05	.12	.09	.08
Manganese oxide (MnO)	.05	.10	.08	.04	.02	.02	.01	.07	.03	.27	.04	.04	.12	.01
Sulphur (S)			.52											
Total	99.91	99.79	100.04	99.67	99.94	99.70	99.84	99.90	99.91	99.83	99.69	99.74	99.67	99.79
Less O for S			.26											
Difference			99.78											
Bulk density			2.74	2.72	2.79	2.70								
Powder density			2.70	2.71	2.74	2.68								
Calcium carbonate [16] ($CaCO_3$)	42.46	3.27	2.00	.01	.00	.01	.00	60.47	28.91	51.50	37.06	10.68	11.29	.02
Magnesium carbonate [16] ($MgCO_3$)	34.21	1.82	1.70	.17	.03	.20	.05	3.83	5.18	36.31	5.10	8.96	7.02	.19

[1] Altyn limestone from near Many Glacier Hotel, Glacier National Park.
[2] Appekunny argillite from near Many Glacier Hotel, Glacier National Park.
[3] Dark Appekunny argillite from highway above Lake McDonald, Glacier National Park.
[4] Green beds in Appekunny argillite from highway above Lake McDonald, Glacier National Park.
[5] Purple beds in Grinnell argillite from highway above Lake McDonald, Glacier National Park.
[6] Green beds in Grinnel argillite from highway above Lake McDonald, Glacier National Park.
[7] Purple beds in Grinnell argillite, from Noisy Creek, Nyack quadrangle.
[8] Siyeh limestone, from Alpine trail, Nyack quadrangle.
[9] Siyeh limestone, from U. S. Highway 2.
[10] Shepard formation, from unsurveyed NW¼, sec. 22, T. 35 N., R. 17 W., Glacier National Park, collected by M. E. Beatty.
[11] Limestone in the Missoula group, from Emery Creek, Nyack quadrangle.
[12] Green calcareous argillite, near base of Missoula group, from Middle Fork of the Flathead River, Nyack quadrangle.
[13] Red-purple quartzite of Missoula group, from Middle Fork of the Flathead River, Nyack quadrangle.
[14] Green argillite of Missoula group, from Middle Fork of the Flathead River, Nyack quadrangle.
[15] Because of the presence of acid-soluble sulfides, results for ferrous iron are not reliable. Sample contains organic matter.
[16] Calculated content of calcium and magnesium carbonates on the assumption that the CaO and MgO combine proportionately with available CO_2 to form carbonates.

PRECAMBRIAN INTRUSIVE ROCKS

The Belt series throughout the two regions here described is intruded by igneous rocks of peculiar, but on the whole gabbroic, composition. In Glacier National Park north of latitude 48°28′, they form narrow sills and dikes which are almost everywhere confined to the Siyeh limestone. The sills are a few score to over 100 feet thick, and most of the dikes are 10–200 feet wide. In most places only a single sill is exposed, and this is commonly a short distance below the *Conophyton* zone 1. However, the sill is not so strictly conformable with the bedding as to be a horizon marker of reliability closer than several hundred feet stratigraphically. In a few localities the sill departs sufficiently from conformity with the bedding to cut across the *Conophyton* zone 1 at a low angle. Here and there the igneous rock is not continuously exposed, and in other places a couple of sills close together are visible. The sills form black lines on cliff faces, rendered doubly conspicuous by white border zones of recrystallized limestone (figs. 3, 16). Long, thin, steep dikes in the Siyeh limestone are conspicuous from St. Mary Lake northwestward past Lake Sherburne. Shorter dikes are exposed in other localities, such as the west end of Porcupine Ridge.

In the Flathead region the intrusions are more irregularly scattered, more diverse in character, and mostly in the Missoula group. The most conspicuous sills, are near the top of that group on the eastern slopes of Cruiser and Ringer Mountains, but there are small ones in several other places, such as Scalplock Mountain. In addition there are several irregularly shaped intrusions, such as those on and near Lodgepole Mountain and on the ridge between the South Fork of the Flathead River and Sullivan Creek (Section *C–C′*, pl. 2).

The character of the rock in all of the intrusions is broadly similar although almost every outcrop has peculiarities in color and texture that reflect minor differences in composition. The petrographic notes that follow are based in part on data furnished by Ray E. Wilcox, who kindly examined three of the thin sections. The rocks are composed principally of titaniferous augite, largely altered to hornblende, and zoned plagioclase that ranges in composition from An_{75} at the core to An_{25} in some of the outermost zones. Some separate hornblende crystals may be of primary origin. Most of the plagioclase is decidedly calcic. In addition, some potash feldspar, micropegmatitic intergrowths of quartz and alkalic feldspar, minor amounts of quartz, apatite and opaque iron oxides, and such alteration products as sericite, chlorite and calcite are present. Exceptionally, potash feldspar is sufficiently plentiful to color the rock pink. The rock has diabasic texture, obscured, however, by alteration products and interstitial micropegmatite, which commonly constitutes 10–20 percent of the whole and which is locally more abundant. A photomicrograph of this rock is shown on figure 9*F*.

The best available description of the intrusive bodies in the Belt series close to Glacier National Park is that of Daly (1912, p. 212–255). Although most of his observations were made north of the international boundary, they agree in general with those made south of that line. He noted rather more hornblende as an original constituent than was found in specimens examined during the present investigation. Finlay (1902, p. 349), who examined the intrusive rocks in what is now Glacier National Park in connection with Willis' studies, called them diorite; but Daly, more accurately, spoke of them as "somewhat acidified, abnormal gabbro." Because many details are obscured by alteration products and the origin of such abnormal features as the micropegmatite is still open to debate, it will serve present purposes to speak of the rock as metagabbro. Much similarity exists between this rock and that called metadiorite by Gibson and Jenks (1938), but the abundance of calcic plagioclase and the presence of residual pyroxene in the rock of Glacier National Park indicate that the original rock had the composition of gabbro rather than diorite.

S. J. Schofield (1914, 1915) has given extensive information, including analyses, on sills in a part of Canada just north of the boundary and west of longitude 115° that are much thicker but otherwise somewhat similar to the sills in Glacier National Park. He thinks the sills in his area—

> "represent intrusions from a single intercrustal reservoir of a series of magmas—acid magmas—which gave rise to composite sills where rock types vary in the gabbro * * * . The simple sills solidified in the usual manner of such intrusives while the acid material differentiated under the influence of gravity giving rise to composite sills."

Differentiation by gravity would not hold for the thin, steep dikes in Glacier National Park, and the other intrusive masses in that region bear no visible evidence of being stratiform. R. A. Daly thought of the peculiar composition of these rocks as a

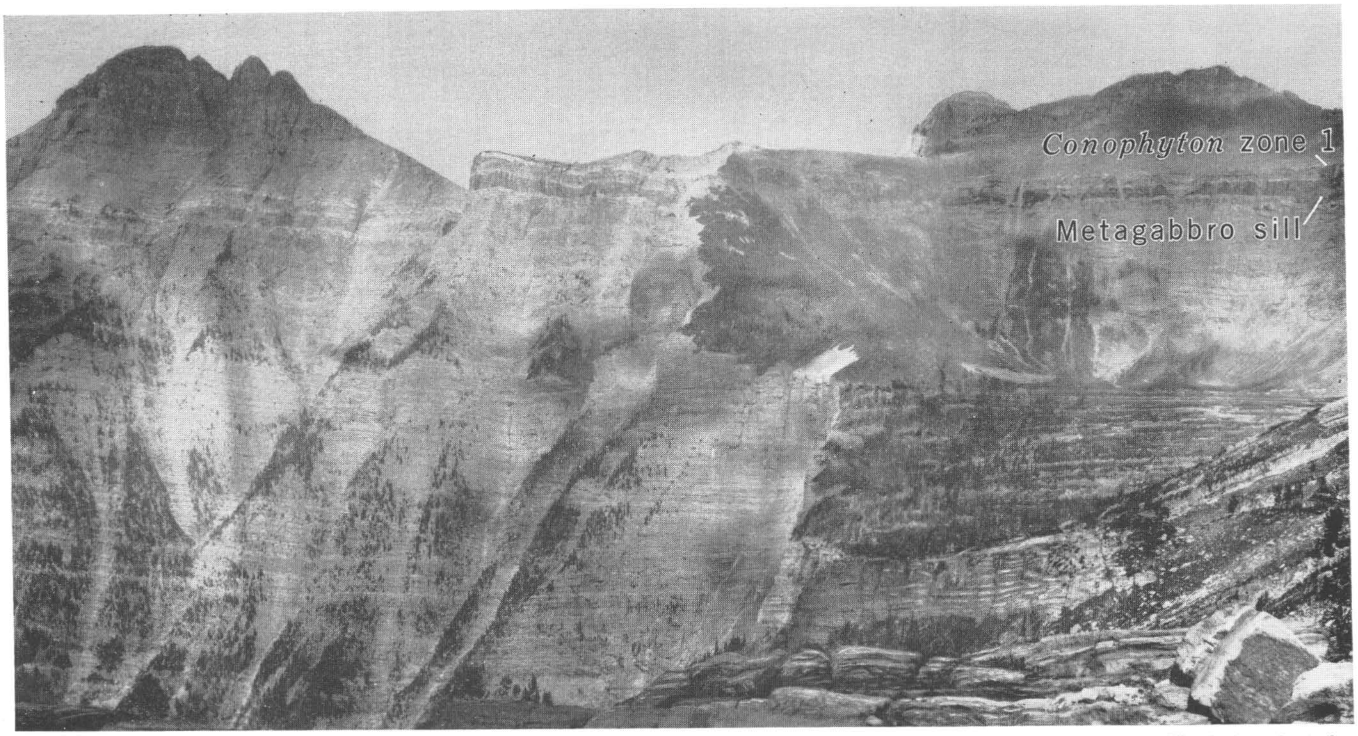

FIGURE 16.—View north from the head of Avalanche Basin, Glacier National Park. Most of the rock shown belongs to the Siyeh limestone. The dark peak at the left consists of beds belonging to the Missoula group. The *Conophyton* zone 1 and a sill of metagabbro are visible in the upper part of the cliffs. Note the pronounced discordance between the nearly flat basin floor at the right of the view and the cliffed gorge to the left. Photograph by Eugene Stebinger.

result of assimilation of quartzite wall rocks in one locality or "metargillite" wallrocks in another, but in Glacier National Park the wallrock for most of the intrusions is limestone, and no significant difference has been found between those and the intrusions in argillaceous rocks; so, his explanation, also, seems inapplicable. N. L. Bowen (1938, p. 71–74, 82–83) cites several examples of diabasic and gabbroic rocks that contain interstitial micropegmatite. He interprets the micropegmatite as one of the last constituents to crystallize in the course of the original consolidation of the rock. He regards olivine and quartz as complementary. It seems quite possible that his explanation may fit the rocks under discussion, although the data at hand are inadequate for a final decision.

R. A. Daly, S. J. Schofield, and the Fentons are agreed that the intrusive rocks and the Purcell basalt are genetically related and, hence, essentially of the same age. This opinion is based on the fact that the two are, in numerous localities, found at neighboring stratigraphic horizons and they have similar compositions. No place is recorded where a sill or other intrusive body of metagabbro has been traced into a lava flow. Even so, a genetic relation between the two is the most logical explanation now available.

PALEOZOIC STRATA

BASIS FOR DIVISIONS USED

Exposures of Paleozoic strata are confined almost entirely to areas in the eastern part of the mountains of the Flathead region. The rocks in these areas consist of marine deposits of Cambrian, Devonian, and Carboniferous age that are northward extensions of units described and named by C. F. Deiss (1933, 1943b, p. 1129–1136, 1943a, p. 216–231). His nomenclature for Paleozoic strata in and west of the Saypo quadrangle is applicable in a general way to those of the Flathead region. Lateral changes appear to exist, but more intensive paleontologic and stratigraphic work are required before these can be evaluated. In any case, they could not be adequately shown on small scale maps such as accompany the present report. Most of the names of Paleozoic formations used by Deiss are his own. The problems of correlation between these formations and those that have long been recognized farther south in Montana await further investigation.

Deiss recognized formations of Middle and Late Cambrian age in and near the Silvertip quadrangle and nine formations of similar age and character in the southern part of the Saypo quadrangle. Although the Cambrian rocks are shown undifferentiated on plate 2 of the present report, such data as were obtained as to the different formations are summarized below. It would be difficult to show the individual formations on a map of the scale of plate 2 even if sufficient data were obtained to permit their identification.

Deiss (1933) named several subdivisions of the Devonian rocks which he regarded as members of the Jefferson limestone, but in his later papers on the Saypo quadrangle, he spoke only of two units of Late Devonian age for which available data were insufficient on which to base formal names. L. L. Sloss and W. M. Laird (1945, 1946, 1947) speak of three Devonian units. Both their reports and those of Deiss that deal with Saypo quadrangle indicate that such names as Three Forks shale and Jefferson limestone, so familiar farther south, are not at present applicable in the part of Montana

Paleozoic strata south of the Flathead region

[Adapted from C. F. Deiss (1933-1943a, b)]

	Southwestern Saypo quadrangle	Central Saypo quadrangle	Pentagon Mountain in Silvertip quadrangle in unsurveyed Secs. 18, 13, 14, 23, 24, T. 25 N., Rs. 11 and 12 W.	Spotted Bear Mountain in Silvertip quadrangle Secs. 23, 25, T. 25 N., R. 15 W.
Mississippian	Hannan limestone: Basal limestone breccia overlain by gray limestone and alternating units of shaly-bedded argillaceous limestone which grades upward into hard tan-gray and pale-gray crystalline fossiliferous limestone: contains much pale-gray chert in nodules and beds as much as 7 in. thick. Upper 200 ft consists of white-gray finely crystalline thin- and thick-bedded dolomite. 1,370 ft thick.	Hannan limestone: Basal limestone breccia overlain by 400 ft of black and tan brittle limestone. Medial 600–700 ft light-gray fossiliferous cherty crystalline limestone. Upper 300 ft buff and light-gray dense thin- and thick-bedded finely crystalline dolomite which weathers white-gray. 1,400-1,500 ft thick.	Hannan limestone: Upper part of formation absent. Rooney member rather coarse-grained and thick-bedded gray limestone, 550 ft thick. Dean Lake member, blue-gray, gray, and black limestone with chert. 60 ft thick. Saypo member, chocolate and gray limestone, shaly at top and bottom. 141 ft thick. Silvertip member, breccia-conglomerate composed of gray argillaceous limestone 40 ft thick. Total exposed 791 ft.	Hannan limestone: Upper part of formation absent. Rooney member, chocolate and gray thin, bedded argillaceous limestone with coarse-grained white thick- and thin-bedded limestone at base. 177 ft thick. Saypo member, gray, white, and pink limestone interbedded with buff and red calcareous sandstone with chocolate limestone below. 220 ft thick. Silvertip member, gray-white breccia-conglomerate. 23 ft thick. Total exposed 420 ft.
—Disconformity—				
Devonian	Dolomitic limestone and shale overlain by tan-gray fine- to medium-grained fossiliferous limestone. Alternate units of drab-brown petroliferous arenaceous thick-bedded dolomite and light-gray hard finely crystalline thick- and thin-bedded limestone. All more or less petroliferous and argillaceous. 980 ft thick.	Dolomitic limestone and shale overlain by tan-gray fine- to medium-grained fossiliferous limestone. Alternate units of drab-brown, petroliferous, arenaceous thick-bedded dolomite and light-gray hard finely crystalline thick- and thin-bedded limestone. All more or less petroliferous and argillaceous. 1,000 ft thick.	Spotted Bear member, thin-bedded limestone at top and bottom. Massive tan and brown limestone in main part. A little shaly. 282 ft thick. Lone Butte member, drab-brown petroliferous limestone at top. Red-chocolate and brown petroliferous limestone, locally shaly. Thickness 220 ft. Coopers Lake member, thick- and thin-bedded chocolate, tan and gray limestone. 268 ft thick. Total thickness 844 ft.	Spotted Bear member, gray thin-bedded partly argillaceous limestone at top and bottom. Thicker bedded gray, tan, and pink limestone in middle part. Thickness 287 ft. Lone Butte member, massive chocolate and blue-gray limestone with clay bands and nodules. 185 ft thick. Coopers Lake member, gray and tan limestone partly siliceous. 298 ft thick. Glen Creek member, dull red shale. 40 ft thick. White Ridge member, tan-gray limestone flecked with pink. 50 ft thick. Total thickness 860 ft.
—Unconformity—				
Upper Cambrian	Devils Glen dolomite: White-gray to pale-buff-gray finely crystalline thick- and thin-bedded dolomite. Mottled salmon pink and coarse grained in upper part of formation. Weathers white gray and forms shear cliffs. 198–250 ft thick.	Devils Glen dolomite: White-gray to pale-buff-gray finely crystalline thick- and thin-bedded dolomite. Mottled salmon pink and coarse grained in upper part of formation. Weathers white gray, and forms shear cliffs. 200–250 ft thick.	Devils Glen dolomite: Thick-bedded buff siliceous dolomite with a bed of sandy dolomite below and one of red-pink calcareous argillaceous sandstone at base. 43 ft thick.	Devils Glen formation: Thick-bedded white and cream-gray massive dolomite. 400 ft thick.
Middle Cambrian	Switchback shale: Green and gray soft shale; locally calcareous and arenaceous; interbedded with flaggy-bedded magnesian limestone which weathers rusty tan. 75–125 ft thick.	Switchback shale: Green and gray soft shale; locally calcareous and arenaceous; interbedded with flaggy magnesian limestone which weathers rusty tan. Contains youngest known Middle Cambrian trilobites and others which belong to basal upper Cambrian (*Cedaris*) fauna. 125–175 ft (?) thick.	Switchback formation (type locality): Mostly thick- and thin-bedded cream-gray massive argillaceous limestone with green-gray shale and shaly limestone at base. 106 ft thick.	Switchback formation: Brown calcareous and shaly sandstone underlain by cream-gray limestone. 70 ft thick.
	Steamboat limestone: Pale-gray and tan fine-grained thick- and thin-bedded limestone overlain by interbedded tan-gray irregularly bedded fossiliferous limestone and green fissile shale. Shale in units 2–8 ft thick separated by much thicker units of limestone. 275 ft thick.	Steamboat limestone: Pale-gray and tan fine-grained thick- and thin-bedded limestone overlain by interbedded tan-gray irregularly bedded fossiliferous limestone and green fissile shale. Shale in units 2–8 ft thick separated by much thicker units of limestone. Base of formation not exposed. 275 ft thick.	Gordon Mountain formation (type locality): Chocolate, tan, and gray mostly thick-bedded limestone, argillaceous near top and with clay and shale at several horizons. 216 ft thick.	Gordon Mountain formation: Buff brown argillaceous limestone. 368 ft thick.
	Pentagon shale: Buff-gray platy calcareous thick-bedded fossiliferous shale, which grades upward into thin- and thick-bedded limestone. 0–290 ft thick.	Absent.	Pentagon formation (type locality): Gray, tan, and chocolate limestone; mostly platy and argillaceous. Some shale. 290 ft thick.	Pentagon formation and Pagoda formation: Mostly obscured by soil and glacial drift. Interval represents 296 ft of beds.
	Pagoda limestone: Green fissile shale interbedded with thin-bedded limestone; overlain by cream and chocolate-gray finely crystalline limestone; thin-bedded in lower and upper parts, and oolitic and thick-bedded in middle part. 200 ft thick.	Pagoda limestone: Green fissile shale interbedded with thin-bedded limestone; overlain by cream and chocolate-gray finely crystalline limestone; thin-bedded in lower and upper parts, and oolitic and thick-bedded in middle part. Exposed thickness not known.	Pagoda formation: Massive thin- and thick-bedded limestone at top with some black fissile shale, followed below by gray to black calcareous shale with thin limestone beds and, near base, limestone conglomerate with red, green, and gray pebbles. 290 ft thick.	

Paleozoic strata south of the Flathead region—Continued

	Southwestern Saypo quadrangle	Central Saypo quadrangle	Pentagon Mountain in Silvertip quadrangle in unsurveyed Secs. 18, 13, 14, 23, 24, T. 25 N., Rs. 11 and 12 W.	Spotted Bear Mountain in Silvertip quadrangle Secs. 23, 25, T. 25 N., R. 15 W.
Middle Cambrian—Continued	Dearborn limestone: Green fissile shale and intercalated limestone conglomerate; overlain by tan-gray thick- and thin-bedded limestone which contains varying amounts of buff and orange-tan clay as flakes, nodules, and partings. 300 ft thick.	Lower part of the Cambrian strata not exposed.	Steamboat formation: Gray and chocolate-gray platy limestone with buff clay. 74 ft thick.	Steamboat formation: Tan, gray, and chocolate limestone with flakes of buff siliceous limestone in some beds. 91 ft thick.
			Dearborn formation: Thick- and thin-bedded tan and gray limestone with clay bands and nodules. Green-gray fissile shale at base. 213 ft thick.	Dearborn formation: Mostly gray and buff argillaceous limestone. Locally has bands of calcareous clay. Near base has beds of lithographic limestone. 238 ft thick.
			Nannie Basin formation: Gray, tan-gray, and blue-gray limestone with flakes and nodules of buff clay. 170 ft thick.	Nannie Basin formation: Gray argillaceous limestone with bands of buff and gray clay; underlain by pink-gray limestone. 59 ft exposed.
	Damnation limestone: Blue and tan-gray thin-bedded fossiliferous limestone with much limonitic clay; overlain by chocolate-gray and tan fine-grained thick- and thin-bedded hard massive limestone, which also contains flakes and blebs of buff siliceous clay. 150 ft thick.		Damnation formation: Thin-bedded shaly tan limestone with flakes and nodules of buff clay; weathers bright buff. 21 ft thick.	Strata below are faulted out.
	Gordon shale: Drab-green-gray and maroon fissile to chunky micaceous shale interbedded in upper middle part with thin beds of sandstone and thicker beds of limestone. Upper beds very fossiliferous. 220 ft thick.		Wolsey formation: Sandy micaceous limestone with much green shale at top. Green-gray micaceous fissile shale, with thin sandstone and sandy limestone beds. Contains hematite oolites. 140 ft thick.	
	Flathead sandstone: Coarse- and fine-grained crossbedded sandstone interbedded with thin units of micaceous and arenaceous shale. Most diagnostic feature is presence of white quartz pebbles ⅛–3 in. in diameter. Basal beds commonly pebbly conglomerate. 50–100 ft thick.		Flathead formation: White to cream thin- and thick-bedded quartzite, with limonite grains; underlain by red crossbedded pebbly quartzite, with pebbles up to 1½ in. in diameter. 117 ft thick.	

under discussion. The present studies have added some facts as to exposures beyond those they covered, but the studies have otherwise contributed little to the data on the Paleozoic rocks assembled by Deiss and by Sloss and Laird.

Deiss grouped all of the Paleozoic rocks above the Devonian strata as the Hannan limestone of Mississipian age, a convenient designation which is adopted here. Both Deiss and Sloss and Laird in the papers just cited indicate that subdivision of the Hannan is possible. These authorities differ as to the details, and the matter has not yet been submitted to the test of areal mapping. For the kind of mapping embodied in plate 2, the formation is a convenient, easily recognized body without subdivision.

Deiss believes unconformities separate the Cambrian, Devonian, and Mississippian assemblages from each other and from the Precambrian and Mesozoic strata. As angular discordances are nowhere marked, proof of the stratigraphic breaks is furnished mainly by the fossil evidence. Within the Paleozoic sequence this evidence as presented by Deiss seems conclusive except that Sloss and Laird (1947, p. 1420–1421) raise a question as to whether there is an unconformity between the Devonian and Mississippian strata. The seemingly complete absence of Ordovician, Silurian, Permian, and Triassic rocks leaves no doubt that major breaks in the record exist. At the base of the Paleozoic succession, more uncertainty exists, in part because of the absence of diagnostic fossils. Deiss (1935, p. 95–124) has assembled much data favoring the concept of an unconformity below the Flathead quartzite. The few exposures of this horizon in the Flathead region do not give positive evidence on this point. For the purposes of the present report, this question may be left open.

Four stratigraphic sections of the Paleozoic rocks south of the Flathead region are given below, adapted from the publications by Deiss cited above. The correlations between the sections seem implied but were not made in the reports cited. A notable feature is that Deiss found it necessary to propose new names because he believes that few of the well-known formation names of southern Montana are applicable here. The members named in the sections from Pentagon and Spotted Bear Mountains are of local significance only. They have not been formally adopted by the Geological Survey.

CAMBRIAN ROCKS

The sedimentary rocks of Cambrian age are mapped as an undifferentiated unit. Wherever they are well exposed, it is obvious that formational divisions are present; but, in a country as intricately faulted as the eastern part of the Flathead region, mapping of formations would be time consuming and impracticable in many places on the scale of the present map. The following descriptions give such information as is available regarding the distribution of beds that seem to be correlatable with units farther south recognized by Deiss.

Large masses of Paleozoic rocks are exposed in the northern part of the Silvertip quadrangle (unpublished geologic map by C. F. Deiss). A small body of Cambrian strata extends from this mass across the southern border of the Flathead region into the area between the two Twin Creeks. The Flathead quartzite was not found within this body although boulders suggest that it is present a short distance to the south. The lowest beds that are present are on the lower slopes of the east side of lower Twin Creek below Tanner Creek. These beds are mainly dark-greenish micaceous shale, with some quartzite. The apparent thickness is over 500 feet, but this is undoubtedly exaggerated by crumpling and perhaps also by minor thrust faulting. Exposures are inadequate for determining structural details, but in nearby cliffs intricate deformation is well displayed. An undetermined thickness of dark-gray highly oolitic limestone with chert in its upper part overlies the shale and is succeeded upward by other limestone beds, mostly light gray but in part mottled. The blebs and flakes of clayey material that distinguish much of the Cambrian limestone of the region are nowhere conspicuous along lower Twin Creek.

The general character of the rocks just described and their relations to Paleozoic rocks in the Silvertip quadrangle and to Precambrian rocks north and east of them are all in accord with a Cambrian assignment. Presumably the shaly rocks on the lower slopes belong, at least in part, to the Wolsey formation (or shale) described by Deiss, even though the apparent thickness is great. The limestones above would then belong to formations higher in the Cambrian sequence, possibly ranging upward into the Pagoda formation. Deiss (1935, p. 37–38) describes his Pagoda formation as variable in thickness and character. In one locality the Pagoda formation, like the rocks here discussed, contains conspicuous oolitic beds.

Eastward, the next exposures of Cambrian rocks are on both flanks of the valley of Dolly Varden Creek. On the southwest slope, massive beds of limestone form steep cliffs and are overridden by beds of the Missoula group along a steep thrust fault. The upper cliffs expose white dolomite which presumably belongs to the Devil Glen dolomite. On the ridge from Gable Peaks to Cruiser Mountain, east of Dolly Varden Creek, the Cambrian beds are less disturbed, although parts of them are covered by landslide debris. The table below records observations made on and near Gable Peaks. The two lowest formations here are surely the Flathead quartzite and Wolsey shale. The Wolsey shale appears to be essentially equivalent to the formation which Deiss spoke of as the Gordon shale in the Saypo quadrangle. The Damnation limestone, which Deiss reported as only 21 feet thick a few miles to the south, was not recognized on Gable Peaks and may be absent there. It seems a reasonable assumption that the 130 feet of poorly exposed beds above the Wolsey belong to the Nannie Basin formation of Deiss, although, if so, they are more shaly than his description shows the formation to be farther south. However, shale appears to be more conspicuous throughout the Cambrian rocks on Gable Peaks than it is in the localities in which Deiss measured his sections. The other highly tentative correlations in the table below are based largely on the fact that the Pagoda formation is the only one in which Deiss reports that, locally, oolitic beds are conspicuous. No diagnostic fossils were found on or near Gable Peaks, except that Masursky found *Elrathiella* cf. *E. plana* Deiss in limestone on Cruiser Mountain some distance to the south. A. R. Palmer, who examined Harold Masursky's specimen, suggests that it may have come from a horizon high in the Pagoda or low in the Pentagon formation, which would be consistent with the tentative correlations in the table.

Both in the table below that summarizes data for Gable Peaks and in the correlation table for Cambrian rocks given above Deiss's name Nannie Basin formation (1933, p. 36) is retained for local use even though in his later papers Deiss dropped that name and included the rocks in his Dearborn limestone.

In addition to those on Cruiser Mountain, a patch of Cambrian rocks was recognized by Masursky in the fault complex north of Lodgepole Creek. The formations that are represented in that area were not identified.

Cambrian strata on and near Gable Peaks

Approximate thickness in feet	Character	Tentative correlation
230	Gray massive limestone with light-yellow streaks. Buff-weathering fossiliferous limestone with thin beds of hard chocolate limestone and nearly black shale.	Pentagon formation.
275	Gray oolitic limestone in beds 1-3 ft thick.	Pagoda formation.
40	Covered. Largely greenish-black micaceous shale.	Steamboat formation.
130	Light-chocolate limestone with yellow mottlings and partings.	Dearborn formation.
130	Poorly exposed greenish micaceous and sandy shale with thin beds of oolitic limestone.	Nannie Basin formation.
90	Covered. Largely shale.	Wolsey shale.
75	Poorly exposed red and green micaceous shale.	
25	Reddish and white quartzite with beds of grit and fine conglomerate (pebbles up to an inch in diameter) crossbedded.	Flathead quartzite.
Total 995		

Beds of Cambrian age crop out in the eastern part of the region mapped (fig. 24) in a band that extends from the North Fork of Dupuyer Creek to the vicinity of Heart Butte, a distance of roughly 14 miles. The most conspicuous and widespread unit is a limestone with numerous yellow, tan, and brown flakes of argillaceous material in it. The clayey flakes appear to be like those reported by Deiss from beds of Middle Cambrian age in several localities farther south, particularly in the Steamboat limestone. Only a few poorly preserved fossils were found, mostly by Masursky. The only collection of any diagnostic value is from the ridge north of Swift Reservoir. This collection was examined by G. Arthur Cooper and later by A. R. Palmer. It contains *Solenopleurella* sp. and *Elrathiella* cf. *E. plana* Diess. Although the *Solenpleurella* resembles *S. pagodensis* Deiss, it is not, according to Palmer, identical with that species. Palmer is inclined to think that the collection may have come from the lower part of the Pagoda limestone of Deiss. In this connection it may be remarked that Deiss (1933, p. 38) in his original description of the Pentagon shale says: "It is a significant fact that the Pentagon formation is shale and shaly limestones only in the immediate vicinity of Pentagon Mountain, but that its equivalent in all of the other sections is generally massive limestone." He adds that the limestone has a small amount of clay disseminated as flakes. The quotation is modified by the fact that later Deiss (1943a, p. 221–222) tentatively assigned some shale and limestone in the southern part of the Saypo quadrangle to the Pentagon shale. The rocks in the vicinity of Swift Reservoir are limestone, and many contain clay flakes. Shale was noted among the Cambrian rocks in only a few places in the eastern part of the Flathead region. The principal exposures recorded are green and maroon shale outcrops along Whitetail Creek west of Feather Woman Mountain and in the ridges east of Mount Richmond.

DEVONIAN ROCKS

Beds believed to be of Devonian age have been mapped in discontinuous bands from the southern border of the Heart Butte quadrangle east of the North Fork of Teton River north to Feather Woman Mountain and Heart Butte. There are smaller patches southeast of Half Dome Crag, on Spotted Eagle Mountain, Family Peak, Mount Dreyer, and in several other localities in and near the Heart Butte quadrangle, mostly near its southern boundary. Several of these scattered masses were mapped from distant vantage points on the basis of color and relations to the Hannan limestone, so that revisions are to be expected when detailed mapping is done, especially as few Devonian fossils have been found anywhere in the area. There are exposures of Devonian strata on and near Big Lodge and Tent Mountains in the Marias Pass quadrangle, but none are known farther west.

The Devonian rocks in this part of Montana have not been divided into named formations. Deiss (1943b, p. 1134–1135) reports that 1,000 feet of Upper Devonian strata are present in the central part of the Saypo quadrangle and that they can be mapped as one and locally two formations. Sloss and Laird (1945, 1946, 1947) have measured sections in and west of the Saypo quadrangle. They divide the Devonian rocks into three major subdivisions, termed "units A, B, and C," and indicate that the thickness in different localities ranges up to somewhat over 1,500 feet.

The Devonian rocks in the area described in the present paper must be broadly similar to those farther south described by Deiss and by Sloss and Laird. They are characterized by much dark limestone that weathers brownish and most of which is commonly distinctly fetid. Some beds contain blebs of different kinds, but few contain numerous yellow, tan, and brown argillaceous flakes and blebs similar to those that are so widespread and conspicuous in the Cambrian rocks. Few complete sections of Devonian rocks were seen during the present study. The data tabulated below result from two traverses made by Harold Masursky in which thickness estimates were based on aneroid barometer and Brunton clinometer readings.

Section of Devonian rocks with top about at benchmark 7540 between Phone Creek and Lucky Creek

[Calculated from Harold Masursky's notes]

	Approximate thickness in feet
Limestone, gray; resembles a coquina with crinoid stems and bryazoa	2
Shale, brown, calcareous; weathers pink and buff	2
Limestone, black; brecciated and cemented with calcite veinlets	230
Limestone, black, fine-grained, thick-bedded, with some calcite veinlets	34
Limestone, dark-gray; weathers cream and tan	17
Dolomite, gray; weathers to a lighter gray	48
Limestone, black, in beds 2–5 ft thick; weathers gray	17
Shale, brown, limy	68
Limestone, gray; weathers gray	4
Limestone, brown, with corals; weathers cream	5
Limestone, gray; weathers gray	5
Limestone, black, laminated	4
Limestone brown, with calcite blebs and veinlets; has strong fetid odor	128
Limestone, gray, with calcite veinlets	8
Limestone, brown, fetid	88
Total, estimated	660
Covered below, but total thickness of supposed Devonian rocks exceeds 1,000 ft.	

Section on the southeast flank of Feather Woman Mountain

[Calculated from Harold Masursky's field notes]

	Feet
Mississippian system:	
Black limestone, thin-bedded; weathers gray and tan; contains chert and crinoid stems; forms cliff	200
Buff limestone, with pink and tan clayey flakes; talus covered; possibly in part shaly	285
Devonian system:	
Limestone, gray and buff, alternating	70
Limestone, gray	3
Limestone, buff	17
Limestone, gray, resistant	10
Limestone, buff, thin-bedded, increasingly shaly upward; weathers tan and yellow in alternating bands	115
Limestone, gray	5
Limestone, black, thin-bedded, resistant; weathers brown	105
Limestone, gray	5
Limestone, black, fetid; weathers brown with irregular white blebs	600
Total thickness of Devonian strata	930
Cambrian system:	
Limestone, black, thin-bedded	25
Limestone, black, massive, thick-bedded, with yellow blebs and laminae	50
Total at bottom of canyon	1,490

Discrimination between the Devonian strata and those that overlie and underlie them is based primarily on lithologic characteristics, as few fossils were collected. *Atrypa missouriensis* was identified by G. Arthur Cooper in specimens from near Hurricane Mountain and from a small fault block on Spike Creek, a small tributary of the Middle Fork of Birch Creek. In the field the upper 268 feet of the section near Phone Creek was thought to belong to the Hannan limestone, but it seems more probable that the brecciated beds in this part of the section correspond to the breccia near the top of the Devonian sequence farther south. These breccias are reported in the papers cited above as resulting from solution of extensive anhydrite deposits. It is somewhat strange that no such breccia was recorded from the section on Feather Woman Mountain in which the Devonian rocks are overlain by beds of definitely Mississippian characteristics and that similar breccias are absent or inconspicuous in the exposures of Devonian rocks seen in other localities.

Evidently the exposed part of the section near Phone Creek corresponds essentially to the upper half of the Devonian section on Feather Woman Mountain. There are numerous differences in detail between these two sections, and similar differences exist between all recorded sections of Devonian rocks in this part of Montana. For that matter, there are differences among the various recorded sections of other Paleozoic units in the region also. These differences result in part from lateral variations in the beds. They can be evaluated and understood only after more complete and detailed geologic mapping has been accomplished.

UPPER PALEOZOIC ROCKS

The Paleozoic rocks above the Devonian rocks are here grouped as the Hannan limestone in accord with Deiss' usage (1943a, p. 227–231). This formation is of Mississippian age and, according to Deiss, is partly correlative to both the Madison and the Brazer limestones. It includes all the beds in the region under discussion which lie between the Devonian and Jurassic rocks. In the eastern part of the Flathead region, the Hannan constitutes the principal formation exposed in a band of northwesterly trend that extends from the southern border of the mapped area to Mounts Baldy and Pablo, a distance of about 28 miles (figs. 22, 23). The northeastern border of this band throughout its extent is at or near the boundary between the mountains and the plains, and the width of the band is about 10 miles. Another line of outcrops of Hannan limestone subparallel to this band and almost as long but much narrower appears im-

FIGURE 17.—Closeup of Hannan limestone with chert layers, gorge of Gateway Creek, Heart Butte quadrangle, Flathead region.

mediately east of the Lewis overthrust near the middle of the region covered by plate 2.

The Hannan limestone constitutes one of the most easily recognized and best exposed units in the region. It is composed of thick- and thin-bedded gray limestone, in part dolomitic. Many of the beds contain abundant chert (fig. 17). Thin beds are especially conspicuous near the base of the formation in most localities. Some of the beds throughout the formation are healed breccias. Shale is not plentiful but is reported to be abundant at some horizons in the Hannan south of the region here reported on. Fossils are fairly common, and crinoid stems and corals are the most conspicuous. Data on the fossils in the Hannan farther south are given by Deiss in the paper just cited and by Sloss and Laird (1945).

Only a few collections from the Hannan were made during the present investigation. These were examined by James Steele Williams and Helen Duncan, of the Geological Survey, who report that the fossils are not positively diagnostic but have a Mississippian aspect and contain nothing incompatible with assignment to the Hannan limestone. While the evidence of the fossils, taken alone, may thus not be conclusive, the field relations leave no doubt that the unit is to be correlated with the Hannan limestone of Deiss. Deiss (1943a, p. 230) gives a list of fossils collected from the Hannan limestone south of the Flathead region. The collections made during the present investigation and identified by J. S. Williams and Helen Duncan include the forms listed below:

Brachythyris? cf. B. *suborbicularis* (Hall)
Brachythyris? sp. indet.
Crinoid columnals
Spirifer of the *S. rostellatus* Hall type
Other spiriferoid shells
Rynochopora? sp. indet.
Orthoceroid cephalopod?
Fenestellid bryozoans, 2 species
Polypora sp. indet.
Rhomboporoid bryozoans, indet.
Sulcoretepora sp. indet.
Camarotoechia? sp. indet.

In the two papers by Deiss that deal with the Saypo quadrangle, the thickness of the Hannan is about 1,400 feet. The formation was not measured during the present examination, but the thickness within the area mapped is thought to be at least as great as that in the Saypo quadrangle. A few of the sections drawn by Sloss and Laird show thicknesses of Mississippian rocks in excess of 1,500 feet, but most are thinner. It seems from their sections and description that breccias are more conspicuous in the mountains west of Choteau than in any of the outcrops in the Flathead region.

MESOZOIC ROCKS

JURASSIC ROCKS

The only beds of Jurassic age known are thought to belong to the Ellis group (Middle and Upper Jurassic). If the Morrison formation exists, it was not recognized during the fieldwork and may have been grouped with the Kootenai formation on the map. The distribution of the Ellis is similar to that of the Hannan limestone just described, but the Ellis generally occurs as narrow, inconspicuous bands, which are masked in places by hill wash and talus, in strong contrast to the great cliffed ridges formed by the Hannan. The Ellis consists of soft fissile nearly black shale interbedded with more resistant beds of sandy limestone that weather in conspicuous shades of yellowish brown and dark yellowish orange (fig. 18). In places the basal beds are yellow or yellowish-orange quartzitic sandstone. As a result of faulting, few of the exposures seen in 1948 contain more than a couple of hundred feet of beds, and most of them contain less; but the Ellis group is nearly 400 feet thick in the Saypo quadrangle (Deiss, 1943b, p. 1136–1140), and in the area here discussed the thickness is probably even greater. At the lower end of Swift Reservoir (NE¼ sec. 27 and SW¼ sec. 26, T. 28 N., R. 10 W.) and other nearby areas, the thickness is reported to be 480 feet (Imlay, 1948).

A fossil collection made from the Ellis group near the head of Crazy Creek by Harold Masursky proved when examined by Ralph W. Imlay to consist of fragments of *Belemnites* and plant stems indicative of the Swift formation, the uppermost formation in the Ellis. A collection made by Masursky through a vertical range of 20 feet about 300 yards downstream from the first one is reported by Imlay to contain *Pleuromya subcompressa* (Meek), *Pleurom-*

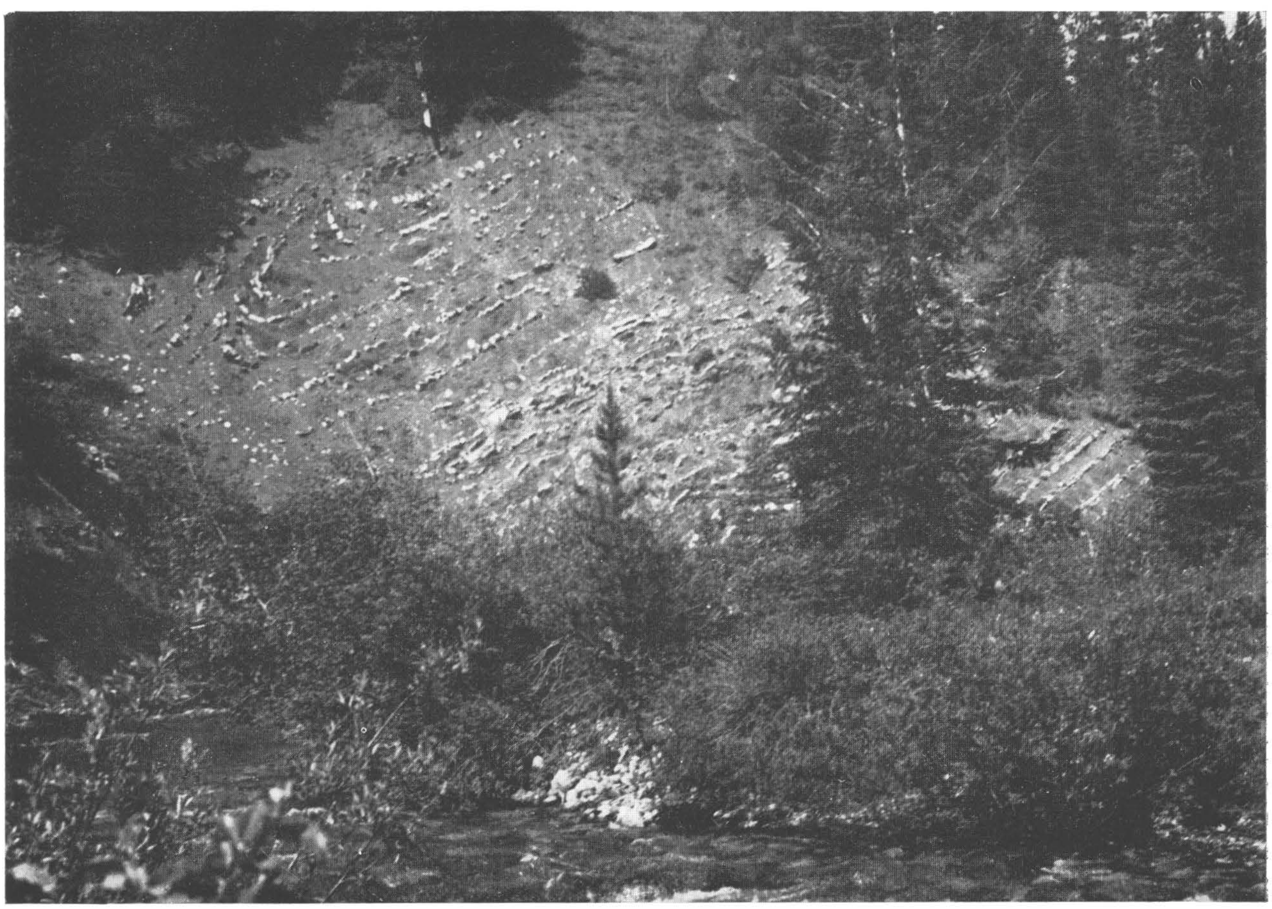

FIGURE 18.—Contorted shale and limestone of the Ellis group on Badger Creek near the mouth of Red Poacher Creek, Marias Pass quadrangle, Flathead region. The exposure is in a small mass overridden by a large block of Hannan limestone.

FIGURE 19.—The north side of the Middle Fork of the Flathead River below Double Mountain, Marias Pass quadrangle, Flathead region. The cuts close to the river expose nearly white, calcareous beds of early Tertiary age, overlain by undeformed, younger gravel and sand. The hill slopes above expose part of the Missoula group.

ya obtusiprorata (McLearn), *Grammatodon*? sp., and ammonite fragments. Imlay regards these fossils as probably from the Sawtooth formation because of the presence of *Pleuromya obtusiprorata* (McLearn). The Sawtooth is the lowest of the three units into which the Ellis group is divided in this region. The middle one of the three, called the Rierdon formation, is probably represented by a collection made by C. P. Ross at the head of Canyon Creek. Imlay reports that this collection contains *Trigonia* sp., a belemnite fragment, *Meleagrinella* sp., *Gryphaea nebrascensis* (Meek and Hayden), and *Camptonectes* sp. A collection made by C. P. Ross in the west bank of Badger Creek above the mouth of South Badger Creek (fig. 18) was found by Imlay to contain *Gryphaea impressimarginata* (McLearn) and an ammonite, *Gowericeras*. According to Imlay, the first named has been found in abundance elsewhere in western Montana in the upper part of the Sawtooth and lower part of the overlying Rierdon formation, but not in association with *Gowericeras*, which commonly occurs at a slightly higher position. The collection came from a narrow, much deformed fault sliver, and the ammonite may have been moved from its normal position as a result of the deformation. It is possible, also, that *Gowericeras* has a longer range than previously known.

While more complete stratigraphic studies are needed, the collections listed above serve to indicate that the subdivisions of the Ellis group that have been recognized (Imlay, 1945, 1948; Cobban, 1945) in nearby areas are present in the region here described. It is impractical on the basis of the present incomplete information to subdivide the Ellis group on the map herewith. Many of the exposures are too narrow to show subdivisions on a map of the scale of plate 2 even if full information was at hand.

CRETACEOUS ROCKS

KOOTENAI FORMATION

Several narrow exposures of the Kootenai formation (Lower Cretaceous) stretch diagonally across the mountainous southwestern corner of the Heart Butte quadrangle. The widest and most continuous of these is along the mountain front and connects to the northwest with a broad expanse of Cretaceous rocks in the Marias Pass quadrangle. These latter merge westward with a broad band that reaches from the extreme southwest corner of the Heart Butte quadrangle northwest at least as far as Marias Pass and Summit Creek. This band consists mainly of strata belonging to the Kootenai formation and is so designated on plate 2. It is possible that infolded or infaulted parts of higher Cretaceous units may be present in it and have escaped recognition. On the other hand, beds of Kootenai age are present near the boundary of Glacier National Park northeast of Marias Pass and are presumably exposed farther north as well. Available data in regard to the Cretaceous rocks east of the Lewis overthrust are not sufficiently complete to make it practicable to show subdivisions on plate 1.

The Kootenai formation, of continental origin, is made up principally of red-purple, reddish, gray, and green sandstone and sandy shale. Some of the shale is carbonaceous and is brown to nearly black. The carbonaceous shale is especially plentiful near the South Fork of Two Medicine Creek. Tiny fragments of black chert are fairly plentiful in the sandstone. Some of the sandstone beds contain numerous cherty and limonitic concretions that weather dark brown. Some of these are fully 2 feet long. In other places the concretions are arenaceous and calcareous. Coarse grit and fine conglomerate are present locally but are nowhere conspicuous. Near Cox and Winter Creeks, and less conspicuously east of Strawberry Creek, several beds of fine-grained limestone occur. These contain fragments of fossils, but identifiable material was not obtained. In other localities, where limestone is absent, some of the sandstone is calcareous. Deiss' (1943b, p. 1143) estimate of maximum thickness of about 1,500 feet for the Kootenai in the northern part of the Saypo quadrangle is probably applicable to the southern part of the Marias Pass quadrangle also. The thickness farther east appears to be somewhat less, which is in accord with Stebinger's (1918, p. 156) estimate of approximately 900 feet for the Kootenai formation in the plains. Direct measurement of thickness in this soft, highly deformed formation would, at best, be subject to a large margin of error.

COLORADO SHALE

No Cretaceous beds younger than the Kootenai were recognized in the mountains of the Flathead region. If any are present they are mapped with the Kootenai. In the plains east of the mountains, however, many Upper Cretaceous strata are known as a result of Stebinger's work, from which most of the data given below are abstracted. He has mapped several masses of Colorado shale immediately east of the mountains in the Heart Butte quadrangle. Beneath the overburden, these masses probably form a nearly continuous band, which is broken and offset in places by faults.

The basal part of the formation, known as the Blackleaf sandy member, is reported to be present but was not mapped separately by Stebinger within the area of plate 2. It consists of grayish black shale, in part arenaceous, with intercalated dark-gray to black sandstone. Deiss (1943a, p. 238–240; 1943b, p. 1144–1145) has described this member in the Saypo quadrangle in some detail. Some of the upper part of the Colorado shale is also present there. This upper part is generally composed of soft, somewhat fissile, brownish- and grayish-black shale, with subordinate sandstone. Some limestone is included. The Colorado shale, according to Stebinger, has a total thickness in excess of 1,800 feet, but all of this may not be present within the area of plate 2. Unlike the underlying Kootenai formation, the Colorado shale is of marine origin.

MONTANA GROUP

Most of the bedrock in the plains of the Heart Butte quadrangle belongs to the Montana group. These rocks extend into the northeastern corner of the Marias Pass quadrangle also, but in most places they are masked by detritus, which is mainly of glacial origin.

Close to the mountains in the Heart Butte quadrangle, Stebinger has distinguished, in ascending order, the Two Medicine formation, Bearpaw shale, and Horsethief sandstone; but in the southeastern part of the quadrangle, he maps the group as undifferentiated. He says that in many places facies changes make the component formations unrecognizable. In and near the northeast corner of the Marias Pass quadrangle, small areas underlain by Virgelle sandstone near the base of the Montana group are distinguished on unpublished maps prepared by Stebinger; and these are shown on plate 2.

As the Montana group was not studied during the 1948–50 fieldwork nothing can be added to published descriptions of its character. In general, the group consists of dark-gray and greenish sandstone and shale beds of marine origin, many of which weather brownish. Fossils are plentiful in some beds. The Virgelle sandstone includes beds in which magnetite is so abundant that Stebinger (1918, p. 165, 1912, p. 329–337) speaks of it as a low-grade, siliceous iron ore. The thickness of the group differs from place to place but is approximately 3,000 feet.

ST. MARY RIVER FORMATION

A few exposures of the St. Mary River formation, which here constitutes the uppermost Cretaceous unit, are shown on plate 2 on the basis of Stebinger's published and unpublished work. The St. Mary River formation is present within the area of plate 1 but is not distinguished on that map. The formation consists, according to Stebinger (1912, p. 330–332), of light-gray fresh and brackish-water clay and sandstone with some red and varigated shale in the upper part. The total thickness of the formation is somewhat less than 1,000 feet. The formation in Canada north of the area of plate 1 has recently been described in some detail (Williams, 1951).

UNDIFFERENTIATED CRETACEOUS DEPOSITS

Along the eastern and southeastern borders of Glacier National Park numerous outcrops of beds of Cretaceous age project through the cover of material of Cenozoic age; the Cenozoic deposits are largely glacial. The Cretaceous rocks include all of the formations mentioned above, but the formations are not distinguished on the maps of the present report because of inadequate information.

In the Blacktail Hills and from there northeastward for several miles in the vicinity of the trace of the Lewis overthrust, beds of the Kootenai formation are abundantly exposed. From near Glacier Park

Station northward along the mountain border, the Colorado shale is exposed in numerous places and probably constitutes the principal formation present. Near the international boundary in the general vicinity of Belly River, exposures of the lower part of the Montana group were recognized by members of M. R. Campbell's field parties. Farther east in the greatly faulted rocks in and east of the northeast part of plate 1, higher units of the Montana group and also the St. Mary River formation are present.

CENOZOIC STRATA

The deposits of Cenozoic age in the part of Montana here described need more detailed study than they have yet received. As available data do not warrant use of formal formation names and require that unlike materials be mapped together in places, the map units chosen are based solely on characteristics readily recognizable in the field and will require modification when further work is done. The six units employed include old alluvium and associated deposits mapped in and west of the mountains described, remnants of deposits on the benches east of the mountains, two kinds of glacial deposits, modern alluvium, and landslide detritus. All are poorly consolidated or unconsolidated, and good exposures are rare except in stream bluffs and roadcuts. The probable range in age is from late Eocene to the present.

OLD ALLUVIUM AND ASSOCIATED DEPOSITS

As mapped on plates 1 and 2 the old alluvium and associated deposits consist of old valley fill of various kinds, mantled by unconsolidated deposits, mostly of glacial origin (fig. 19), all of which are grouped together on the maps. In most places the mantle is thin, and the old fill is widespread and fairly thick, but the fill is actually exposed in such limited outcrops that it would be difficult to depict the exposures accurately on maps of the scale of those in the present report. T. A. Link (1932, fig. 1) maps a small amount of Mesozoic rocks, the southern end of a large wedge, which crosses the international boundary and extends as far south as Kintla Lake. If Mesozoic rocks crop out here, they are included with the old alluvium on plate 1; a search for them made in the summer of 1951 failed to reveal any exposures. Much of the old fill is equivalent to the Kishenehn formation of Daly (Wilmarth, 1938, p. 1105–1106), but present data do not warrant use of the formal name. Eventually, the presence of beds equivalent to the Kishenehn formation and to other formations may be established. For instance, the old fill may include equivalents of the Willow Creek formation, which has not been recognized within the regions here mapped but is rather widespread just east of the area of plate 1 (Stebinger, 1916, pl. 15; Andrews and others 1944; Ross and others, 1955).

The old alluvium and the mantling deposits mapped with it are found principally as valley fill along the Flathead River and its principal tributaries. A few patches of apparently similar material are present along minor streams in the Flathead River drainage basin; in the hills south of Big Meadows, for example. The deposits are extensive along the part of the Flathead River from the internationl boundary downstream to the Apgar Mountains. Near the northern end of these mountains, the river enters a narrow valley in which the old alluvium has not been recognized. However, the old alluvium continues southeast past the Apgar Mountains and into the valley of the Middle Fork of the Flathead. From near the mouth of Lincoln Creek to near Spruce Park, the valley of the Middle Fork of Flathead River is so nearly in line with that of the main stream north of the Apgar Mountains that from vantage points in the mountains nearby they might be mistaken for a single valley, notwithstanding the fact that the water flows in opposite directions in the two valleys. This part of the valley of the South Fork contains extensive old-alluvium deposits, which narrow upstream. Patches of the same material are exposed at intervals along the Middle Fork from Spruce Park at least as far upstream as Schafer Meadows, as well as in some localities in the valleys of other streams in the drainage basin of the Middle Fork. The old alluvium and associated deposits are abundant throughout the segment of the valley of the South Fork of the Flathead River that has been mapped. They extend distances up the principal tributaries of this part of the South Fork and are believed to be present on both sides of Firefighter Mountain and in the depressions in the vicinity of Abbott Ridge. It may be emphasized that all the deposits are confined to topographic depressions, mainly the valleys of the major streams. They extend up the valley sides to altitudes close to 6,000 feet above sea level near the international boundary and lower farther south. In a few places in the Flathead region, they reach altitudes of about 5,000 feet, but more commonly their upper surfaces in that region are nearer to 4,500 or 4,000 feet above sea level.

The old alluvium or valley fill in the drainage basin of the Flathead River consists of fairly well-bedded and, on the whole, rather fine-grained deposits of sand, silt, clay, and calcareous material, all thoroughly compacted and, particularly in the lower part, somewhat cemented. Lignite is present in many localities, and much of the clay and silt is carbonaceous. Conglomerate beds are reported in several places along the main Flathead River. Gravel and boulders are very abundant on the terraced and thickly forested flanks of the valley of the South Fork of the Flathead. Some of this coarse material is loose and belongs to the mantle over the old alluvium, but much is embedded in fairly well-indurated clay and constitutes an integral part of the old alluvium. Most of the exposures are in small partly slumped bluffs, in gullies and along trails. In the course of studies made in connection with the Hungry Horse dam site C. E. Erdmann (1947, p. 64–72) measured sections near the confluence of the Flathead River with its South Fork. At the time the work was done, the material measured was supposed to be of Pleistocene age, but later studies have shown that all except the upper part is Tertiary (Erdmann, C. E., letter of July 16, 1951). Hence Erdmann's sections, especially those on pages 66–67 of his published report, constitute the most detailed record at hand of the character of the old alluvium. They show that coarse gravel and boulders are fairly abundant in the vicinity of the mouth of the South Fork. The poor sorting and other features that originally led Erdmann to suppose that they are glacial deposits of Pleistocene age raise a question as to whether they record glacial activity in early Tertiary time. The Atwoods (1945) report that farther south in Montana glaciation took place during the Eocene.

Available data on the lignite are summarized briefly in the description of resources given early in the present report. Where lignitic coal is plentiful, most of the enclosing sedimentary rocks are fine grained. The large bluffs cut in old alluvium along the Middle Fork of the Flathead and some of its tributaries show little gravel, and most exposures are fairly fine grained and evenly bedded, although some contain gravel lenses and some large cobbles. In most exposures the old fill is tilted, in places as much as 60°. In the upper parts of some of the bluffs and in less perfect exposures in other places, the beds are coarser, less indurated, and more irregularly stratified and lie nearly or quite flat. Even in these beds, bouldery accumulations like those noted near and along the South Fork are scarce.

Beneath the mantle of younger, unconsolidated detritus, the old alluvium itself consists of accumulations of at least two different ages, separated locally by angular unconformities. This is in agreement with Erdmann's statement (1947, p. 134), that 2 or 3 distinct facies of the Tertiary rocks have been recognized. It is supported by the fact that, as noted below, fossils found in its upper part appear to be younger than those associated with the coal beds. It may be emphasized that in some exposures, beds like those containing these young fossils are deformed almost as much as any of the beds of early Tertiary age.

Available data on the fossils in the old alluvium are outlined below. Roland W. Brown, of the Geological Survey, has collected plant remains from outcrops of the alluvial material in the regions here described. The details of his own collections have not yet been published, but in a report dated October 17, 1950, on fragmentary plant remains collected by C. P. Ross and E. C. Stoever, Jr., from the south bank of the Middle Fork of the Flathead above the mouth of Paola Creek, Brown says: "The age is presumably that of better material, which I collected at a nearby locality, namely, late Eocene or Oligocene." This opinion is one of the most reliable so far available as to the age of the old fill in the drainage basin of the Flathead River, as it is based on much study by Brown. The collection was made near the exposures shown in figure 19 from rocks similar to the tilted beds shown in that view.

Two collections obtained in 1950 by C. P. Ross and E. C. Stoever, Jr., on the bank of the Middle Fork of the Flathead were examined by Teng-Chien Yen. In one he found *Amnicola* cf. *A. truckeensis* Yen, *Fluminicola* cf. F. *yatesiana inflata* Yen, *Goniobasis*? sp. (young form), *Vorticifex* cf. *V. tryoni* (Meek), *Pisidium* cf. *P. woodringi* Yen, *Sphaerium* sp., and undetermined forms of gastropods, ostracodes and fish teeth. In the other he found *Valvata* sp., *Vorticifex*? sp., *Menetus* sp., *Lymnaea* sp., *Sphaerium* cf. *S. andersonianum* Hannibal, and undetermined forms of gastropods, pelecypods, ostracodes, and oogonia of *Chara*-like algae. Yen regards these fossils as "possibly of late Tertiary age," but they came from the same outcrop, near Paola Creek, as the plant remains that Brown regards as early Tertiary. These collections are from the locality numbered 2206 by Dwight Taylor, who assigns an Eocene age.

Tilted and compacted, but poorly cemented sandy silt in the west bank of Flathead River along the road near the mouth of Kintla Creek yielded nonmarine mollusks which Yen regards as of middle to early Pleistocene age. This collection is numbered 20205 by Taylor, who regards the fossils as of Oligocene age. Yen says that the larger forms are represented only by fragments of shells and dentations on the inner wall of the aperture but that gastropods of minute size are better preserved. The forms he recognized are listed below. He comments that, with the exception of the *Lymnaea* sp., all are of terrestrial habitat and comparable forms range in age from Pleistocene to Recent.

Forms identified

Hendersonia cf. *H. occulta* (Sag)
Lymnaea sp. undet.
Succinea sp. undet.
Vertigo cf. *V. tridentata* Wolf.
Vallonia cf. *V. gracilicosta* Reinhardt
Heliodiscus sp. undet.

Invertebrate fossils collected from the Kishenehn formation in the valley of the Flathead River in British Columbia by L. S. Russell (1952, p. 125–126) yielded 6 species but they are all new; they are not of value in dating, and 3 forms were identified generically only. The assemblage is reported to be characteristic of small lakes or ponds, although two forms may have lived in streams. The age was thought by Russell to be Eocene—probably middle Eocene. Later Russell (1954, 1955) made additional collections, some of which are within the region of plate 1 of the present report (Russell, L. S., 1955). He lists moluscan fossils from seven localities and concludes that the age is latest Eocene. He also obtained mammalian fossils from 3 localities north of the international boundary (Russell, L. S., 1954). On the basis of these he decided to retain the Kishenehn formation in the uppermost part of the Eocene, but noted that it could with equal merit be regarded as basal Oligocene.

Dwight W. Taylor has recently made a study of fossils along the Flathead River and his written report dated June 6, 1957 is quoted here. He notes that the fossils can be divided into 4 general categories of the following probable ages; (1) Late Eocene (localities 6834, 12844, 14776, 20196, 20197, 20198, 20199, 20200, 20201, 20202, 20203, 20204, 20206), (2) Oligocene (locality 20205), (3) Miocene (locality 14778), and (4) Pliocene (locality 20207). The collection from Taylor's localities 20205 and 20206 are the same as those reported on earlier by T. C. Yen and cited above but, as noted above, the age determinations differ.

Taylor's report is quoted, except his introductory statement, which is paraphrased above.

The first category can be dated as middle Eocene to very early Oligocene on molluscan evidence alone, that is, the known range of *Australorbis pseudoammonius*. It is restricted to late Eocene only because of the mammals found by L. S. Russell in the Kishenehn formation, in southeastern British Columbia. Some of the localities may be as old as middle Eocene, but there is no evidence for this as yet.

At locality 20206 occurs a very limited assemblage (four species), with only one well preserved species, probably representing a new genus. This form is not very helpful stratigraphically, but is related to later Tertiary genera. The locality is given an Eocene age primarily because R. W. Brown (personal communication, 1957) believes it to lie lower than localities 20200-20204 in a conformable sequence. If there are faults in between these localities, then 20206 may possibly be younger, of Oligocene age. The age implications of this new genus are hardly compelling, however.

An Oligocene age seems more likely than a late Eocene for locality 20205. In addition to the genera listed in the table, there are two or three indeterminate land snails. The assemblage is thus almost exclusively terrestrial, in marked contrast to those from the Eocene, although it is geographically close to them. Furthermore, the assemblage is generally similar to that from the early Oligocene Dunbar Creek formation (in process of being proposed by G. D. Robinson) of the Three Forks quadrangle of Southern Montana in the large land snails and generally terrestrial composition. The helicinid is like an Oligocene form, although related to one in the Kishenehn formation. All these reasons are far from giving a definite age assignment, but they do suggest an Oligocene age.

The Miocene age assignment of locality 14778 is the weakest of the four dates, despite the excellent preservation of the fossils. About all one can say is that it seems to represent an assemblage different from the others. The *Promenetus* is distinct from known Pliocene or Recent species, and seems to combine characters of now-distinct subgenera. A Miocene or perhaps late Oligocene age is most likely, and a younger date less probable than an older.

Locality 20207 is very likely of Pliocene age. Only three species are known, but two are helpful. *Promenetus umbilicatellus* is a living species known as early as the mid-Pliocene, although it may range further back in time. *Lymnaea albiconica* is surely known only from the middle Pliocene of Idaho, Wyoming, and Arizona, with a possible Pliocene occurrence in Oklahoma. Not only the species, but the assemblage and even lithologic character of the matrix are like those of the Teewinot formation of Jackson Hole (see Wyoming Geol. Assoc. Guidebook 11, 1956).

The fairly strong suggestion of late Tertiary as far north as Glacier Park is most interesting. This occurrence is well north of any others in the later Tertiary, and might give ecological information unobtainable elsewhere. Furthermore, there is now the possibility of dating events much later than one could have hoped. Further collecting, especially in these later Tertiary localities, would probably add significantly to the history of the area.

	6834	12844	14776	14778	20196	20197	20198	20199	20200	20201	20202	20203	20204	20205	20206	20207
Freshwater clams:																
Elliptio cf. *Elliptio salissiensis* Russell			x					x								
Sphaerium		x													x	
Pisidium			x												x	
Freshwater snails:																
Valvata		x		x												
Hydrobiidae indet			x					x							x	
Oxytrema?	x							x								
Lymnaea (*Stagnicola*) *newmarchi* (Russell)						x										
(*S.*) aff. *L. palustris* (Müller)			x													
(*S*) cf. *L. albiconica* (Taylor)																x
(*S.?*) n. sp			x													
(*Fossaria?*) n. sp			x													
indet	x			x									x	x		
Australorbis pseudoammonius (Schlotheim)		x	x		x				x	x	x	x	x			
Planorbidae n. gen			?												x	
Gyraulus						x	x									
Promenetus umbilicatellus (Cockerell)																x
Promenetus n. sp				x												
Physa								x								
Aplexa				x												
Land snails:																
Helicinidae cf. "*Triodopsis*" *buttsi* Russell														x		
Pupillidae indet														x		x
Vallonia														x		
cf. *Succinea*				x												
Holospira								x								
Polygyrella	x															
Oreohelix?	x															

Systematic paleontology

Family Unionidae

cf. *Elliptio salissiensis* Russell. Localities 14776, 20199. Only one specimen was found at each locality. The preservation is poor, and hinge characters are not observable. The size and shape, however, are like those of *Elliptio salissiensis* as described by Russell.

Family Sphaeriidae

Sphaerium indet. Localities 12844, 20206. The poorly preserved material may be referable to *S. progrediens* Russell, but may also represent other species.

Pisidium indet. Localities 14776, 20206.

Family Valvatidae

Valvata indet. Localities 12844, 14778. *Gyraulus procerus* Russell is apparently a *Valvata,* judged by the original description and illustrations. The badly crushed material from locality 12844 can be identified to genus only, but may well be Russell's species.

Family Hydrobiidae

Indeterminate. Localities 14776, 20199, 20206. The material represents a small, high-spired, many-whorled species which cannot be identified generically.

Family Pleuroceridae

Oxytrema? indet. Localities 6834, 20199. So far as the poor material indicates, this might be the species reported by Russell as *Goniobasis* sp.

Family Lymnaeidae

Lymnaea (*Stagnicola*) *newmarchi* (Russell). Locality 20197.

L. (*Stagnicola*) aff. *L. palustris* (Müller). Locality 14776. Species similar to the living *L. palustris* have been known from the Eocene of Europe for some time. *L. newmarci* and this species are the only American early Tertiary representatives of the *palustris* group, however. Discovery of these two has been made only recently, however; MacNeil was acting on the only available information when he thought this modern-looking *Lymnaea* indicated a mid-Tertiary age.

L. (Stagnicola) cf. *L. albiconica* Taylor. Locality 20207. This species, characterized by its peculiar sculpture, has heretofore been known only from Arizona, Oklahoma, Wyoming, and Idaho (see Wyo. Geol. Assoc. Guidebook 11, p. 123-125). The diagnostic sculpture of *L. albiconica* is not present on the Glacier Park material, but the coarse striae of these specimens suggest a relationship. Better material might show their specific identity.

L. (*Stagnicola?*) n. sp. Locality 14776.

L. (*Fossaria?*) n. sp. Locality 14776.

L. indet. Localities 6834, 14778, 20204, 20205.

Family Planorbidae

Australorbis pseudoammonius (Schlotheim). Localities 12844, 14776, 20196, 20200, 20201, 20202, 20203, 20204.

Several names have been applied previously to American specimens that represent this species, known up to now only in the Eocene of Europe and Asia. These names have been proposed without adequate consideration of variability in freshwater snails, and without comparison with the European species.

The only adequate study of variation in fossil *Australorbis* is that by Gutzwiller (1906, Schweizerische palaeontologische Gesellschaft, Abhandlungen, v. 32). He demonstrated convincingly the previously unappreciated amount of variation within single populations, and showed that other named species were synonyms of *A. pseudoammonius.* By this same token, the following also seem to be synonyms:

Planorbis convolutus Meek and Hayden, 1856
Planorbis utahensis Meek, 1860
Planorbis spectabilis Meek, 1860
Planorbis kishenehnensis Russell, 1952.

The precise range of *A. pseudoammonius* in America is still uncertain. There are no records in the Paleocene or early Eocene; many in the middle Eocene, a few in the late Eocene, and one in the very early Oligocene. The relatively few late Eocene records with independent dates (from fossil mammals) are as follows:

(1) Kishenehn fm., Flathead County, Mont., and southeastern British Columbia.
(2) Climbing Arrow fm., Jefferson County, Mont.
(3) Tepee Trail fm., northeastern Wind River Basin, Wyo.
(4) Unnamed unit, Beaver Divide, Fremont, County, Wyo.

Considering the small number of areas where late Eocene rocks are known, these four independently dated occurrences are a reasonably good representation. They certainly establish the late Eocene occurrence of *Australorbis*.

There is only one Oligocene record of *Australorbis*, in the Beaver Divide conglomerate member, Fremont County, Wyoming (dated by mammals). In evaluating this, however, one must recall that Oligocene mollusks are poorly known, and that the early Oligocene is even more poorly known. Outside the Three Forks quadrangle, Montana, there are only six mollusk localities assignable to the early Oligocene; these are scattered in Wyoming and Nebraska, and none is the result of thorough search. *Australorbis* thus occurs in one-sixth of all known early Oligocene localities. Furthermore, the Beaver Divide occurrence may be earlier than some of the other sites.

Planorbidae, new genus. Locality 20206; also 14776? This new form is related to *Helisoma* and *Carinifex*, and hence does give a later Tertiary aspect to the locality where it occurs. The collection at locality 20206 is adequate to show its distinctness from these other genera, however. A few poorly preserved specimens at locality 14776 may possibly be the same species.

Gyraulus indet. Localities 20197, 20198. This species is related to the living *G. parvus* (Say), and quite distinct from what Russell called *G. procerus*. As stated above, Russell's species is probably a *Valvata*.

Promenetus umbilicatellus (Cockerell). Locality 20207. This living species is known from deposits only as far back as the middle Pliocene. It may extend into the Miocene, and probably into the early Pliocene. On present evidence it definitely suggests a late Tertiary, probably Pliocene, age for locality 20207.

Promenetus n. sp. Locality 14778. The genus *Promenetus* can be divided into two distinct subgenera, one with a carinate periphery and the other with rounded whorls. This new species appears to be intermediate between the two groups in this feature.

Family Physidae

Physa indet. Locality 20199. This may be the same species reported by Russell as *Physa* sp.

Aplexa indet. Locality 14778.

Family Helicinidae

Helicinidae cf. *"Triodopsis" buttsi* Russell. Locality 20205. The species described from British Columbia as the polygyrid genus *Triodopsis* is much more probably helicinid. The heavy callus over the umbilicus, the pattern of apertural projections, size, and sculpture all agree more with the Helicinidae than Polygyridae. Peripherally carinate shells are known in the Polygyridae but are more common in the Helicinidae.

The single shell from locality 20205 is imperfect; although smaller than *"Triodopsis" buttsi* as described by Russell it is similar in shape and sculpture. Shells similar to that from locality 20205 are known also from the Oligocene in Sioux County, Nebraska (USGS localities 19093, 19094).

Family Pupillidae

Indeterminate. Localities 20205, 20207. The very poor material cannot be assigned even to genus.

Family Valloniidae

Vallonia indet. Locality 20205.

Family Succineidae

cf. *Succinea*. Locality 14778.

Family Urocoptidae

Holospira indet. Locality 20199. This species is distinct from *H. adventicia* Russell, described from British Columbia.

Family Ammonitellidae

Polygyrella indet. Locality 6834. Russell has not reported this genus from the Kishenehn formation, but it is known from other parts of western Montana. In the Three Forks quadrangle G. D. Robinson found it in the latest Eocene (and earliest Oligocene?) Climbing Arrow formation (USGS localities 20008, 20009).

Family Oreohelicidae

Oreohelix? indet. Locality 6834.

Localities

The first number listed is in the U. S. Geological Survey Cenozoic series, followed in parentheses by field numbers and Mesozoic locality numbers.

6834. Glacier Natl. Park, Mont. Bowman Creek about 1 mile from mouth. Sec. 14, T. 35 N., R. 21 W. M. R. Campbell, 1911.

12844. Flathead County, Mont. Sec. 33, T. 34 N., R. 20 W. West bank of North Fork of Flathead River. J. D. Northrop coll. This collection is cited by Alden (U.S.G.S. Prof. Paper 231, p. 29) as Eocene rather than Cretaceous according to W. C. Mansfield.

14776. Glacier Natl. Park, Mont. North side NE1/4 sec. 8, T. 31 N., R. 17 W. Scarp of sandstone on north side Halfmoon lake 2 miles north of Nyack Ranger Station. W. C. Alden, 1936, Alden (U.S.G.S. Prof. Paper 231, p. 27) listed identifications by MacNeil, who believed the collection to be of mid-Tertiary age

14778. Glacier Natl. Park, Mont. Indian Ridge, north of Bowman Creek and lower part of Bowman Lake. C. L. Groghan collection (transmitted by W. C. Alden). Report by F. S. MacNeil, Jan. 10, 1938.

20196. (C 3). British Columbia, valley of North Fork Flathead River. South side of Couldrey Creek a short distance upstream from Burnham Creek. L. S. Russell, 1952.

20197. Glacier Natl. Park, Mont. Sec. 30, T. 36 N., R. 21 W. East side of North Fork of Flathead River just below mouth of Mud Creek.
L. S. Russell, 1952.
20198. Flathead County, Mont. Sec. 30, T. 36 N., R. 21 W. West side of North Fork of Flathead River just above mouth of Whale Creek.
L. S. Russell, 1952.
20199. (FM 304). Glacier Natl. Park, Mont. Near Halfmoon Lake, sec. 8, T. 31 N., R. 17 W. C. P. Ross, 1950. Shipment GG–50–26.
20200. (K. USGS Mesozoic loc. 24769). Glacier Natl. Park, Mont. SW1/4SE1/4SE1/4 sec. 6, T. 30 N., R. 16 W. Right bank of Middle Fork of Flathead River downstream from Tunnel Creek. Stratigraphic section C. C. E. Erdmann and V. K. Koskinen, 1953. Report by J. B. Reeside, Jr., Jan. 18, 1954.
20201. (L. Mesozoic loc. 24770). Same loc.
20202. (M. Mesozoic loc. 24771). Same loc.
20203. (N. Mesozoic loc. 24772). Same loc.
20204. (O. Mesozoic loc. 24773). Same loc.
20205. Flathead County, Mont. NE1/4 sec. 1, T. 36 N., R. 22 W. West bank of Flathead River along road near mouth of Kintla Creek. Tilted and compacted but poorly cemented sandy silt. C. P. Ross and Richard Rezak, 1951. Shipment GG–51–11. Report by T. C. Yen, Dec. 20, 1951.
20206. (FM 138). Flathead County, Mont. Southwest bank of Middle Fork of Flathead River above mouth of Paola Creek. C. P. Ross and E. C. Stoever, Jr., 1950. Shipment GG–50–19. Report by T. C. Yen, Sept. 25, 1950.
20207. (Mesozoic loc. 24774). Glacier Natl. Park, Mont. NE1/4NW1/4 sec. 13, T. 35 N., R. 21 W. Bowman Lake road about 1¾ miles east of junction with Kintla Lake road. C. E. Erdmann and V. K. Koskinen, 1953. Report by J. B. Reeside, Jr., Jan. 18, 1954."

Shells and fish remains have been collected at times from the beds under discussion. In the valley of the Flathead River, presumably near the international boundary, Daly (1912, p. 87) collected fossil shells among which T. W. Stanton identified the following: *Sphaerium* sp., related to *Sphaerium subellipticum*, Meek and Hayden, *Valvata*? sp., resembling *Valvata subumbilicata* M. and H., *Physa* sp., *Planorbis* sp., related to *Planorbis convolutus* M. and H., *Lymnaea* sp. The locality is probably a short distance up the Flathead River from that near the mouth of Kintla Creek that yielded the younger fossils commented on by Teng-Chien Yen. The beds from which the fossils identified by Stanton came were named by Daly the Kishenehn formation. On his geologic map this formation stops at the international boundary, but in his report he notes that an oil well penetrated 700 feet of soft shale and sandstone containing thin seams of coal that probably form the southern extension of the beds at the boundary. Willis (1902) described the same beds along the Flathead River but found no fossils. Campbell's parties do not record the discovery of diagnostic fossils in the Tertiary beds, but Alden in later visits did find some. In 1930 near the mouth of Tunnel Creek about 7 miles northwest of Walton, W. C. Alden and C. L. Gazin found the remains of a well-developed teleost fish which Gidley said was doubtless Tertiary and might be either Eocene or Miocene in age. In 1936 near Halfmoon Lake above Nyack Creek, Alden (written communication) collected gastropod and pelecypod shells which F. S. MacNeil identified as *Helisoma* sp., *Amnicola* sp., *Lymnaea* sp. (both high and low spired types), *Pisidium* sp., and *Elliptio* sp. MacNeil thought that the high spired *Lymnaea* was not older than middle Tertiary. He reported that the earliest known species of this group is from the White River beds and the species from near Halfmoon Lake is of even more recent aspect. It might well be that the shells from near Halfmoon Lake are similar in age to those near the north of Kintla Creek. Note that there is another and lower Halfmoon Lake southwest of West Glacier.

The fossils listed above range in age from Eocene to the lower part of the Pleistocene. The loose mantling deposits are largely related to the Pleistocene glaciers. Most of the old alluvium or valley fill has associated with it the plant remains which Brown regards as of late Eocene or Oligocene age, and this assignment is accepted, for the present, for the greater parts of the beds here mapped as "Old alluvium and associated deposits." However, deposition has recurred at intervals from the early Tertiary to the present, so that part of the map unit must be young.

TERRACE ALLUVIUM

East of the mountains certain of the flat-topped hills are remnants of formerly more extensive benches and terraces. For present purposes deposits that occur on distinct benches but are not known to be of glacial origin are mapped together. On the plains in the general vicinity of the mountain front, W. C. Alden (1932, p. 12–18, 44–45, 70–71) has discussed and mapped bench deposits that he regards as of several different ages. M. Y. Williams and W. S. Dyer (1930, p. 91–113) also give a convenient summary of data on bench deposits in Alberta and northern Montana. The field notes and maps of geologists whose work has been utilized in the present report do not permit mapping distinctions between the different bench deposits satisfactorily, and the mapping done during the present investigation was not extended into the plains area. The bench deposits are poorly consolidated or uncemented gravel and sand that were laid down by streams in erosion cycles earlier than the present one. Fossils have not been found in the bench deposits within the two regions here reported on, but the relations are such as to lead Alden to regard most of them as of Pliocene(?) and early Pleistocene age—an inference which seems in accord with all data now available although some of the bench deposits may be of pre-Pliocene age.

GLACIAL DEPOSITS

In recognition of the incompleteness of available knowledge, different kinds of glacial deposits are not distinguished on the maps. At least four kinds are present and have been shown in parts of Alden's maps, published and unpublished, but further fieldwork is needed to map satisfactorily the different deposits. The four kinds include remnants of the deposits of pre-Wisconsin glaciers, deposits left in the mountains by glaciers of Wisconsin age, ground moraines spread by mountain glaciers that reached the Great Plains, and deposits left by continental ice sheets.

On the plains east of Glacier National Park, a diverse assemblage of highly deformed rocks is overlain by a mantle, which is thin in many places, of unconsolidated material that is largely ground moraine from mountain glaciers of Wisconsin age. This mantle is not shown on plate 1. Too little is known about it to permit the mapping of its components or accurate delineation of its limits. It is widespread between the mountains and St. Mary Ridge, but numerous outcrops of the underlying rocks are present in this area. Between St. Mary Ridge and Milk River Ridge, deposits assignable to ground moraine are scanty, and outcrops are so poor that little has yet been learned as to the pre-Pleistocene rocks. Therefore, it has seemed wise to show east of the mountains on plate 1 only those Cenozoic deposits that are in discrete, relatively easily recognizable units. The areas shown on plate 1 as containing undifferentiated Cretaceous deposits have rocks of that character either in outcrops or under thin cover. In these areas future detailed work should yield much more detailed information in regard to the Cretaceous rocks than is now at hand.

Although little is known of the rocks in the plains east of the park, on the plains in the eastern part of the Flathead region, the limits of the morainal deposits are known with sufficient accuracy so that it has seemed desirable to show them on plate 2, even though it is appreciated that future work will result in modifications. Where Cretaceous rocks are shown in the part of plate 2 east of the mountains, Stebinger and his associates, in work already cited, have obtained so much information that the attempt to record it has been made on pl. 2.

Glacial deposits in topographically high situations on the plains east of Glacier National Park are known from the studies of Alden and his associates to have been laid down relatively early in the Pleistocene and probably in more than one stage. Alden (1912, 1932, Alden and Stebinger, 1913) has described these deposits and mapped them in a general way. From his work it is clear that Swiftcurrent Ridge, Boulder Ridge, Saint Mary Ridge, and other uplands east of the park are in part capped by early Pleistocene glacial deposits, which are now somewhat cemented and much weathered. Drift similar in age to that on these ridges must have been deposited within the mountains but has not yet been recognized there.

In unpublished manuscripts Alden speaks of the spur crests east of the upper reaches of the Flathead River (the part locally called the North Fork) as correlative with his Flaxville Plain. He regards most of the material mantling the spur crests as stream gravel but adds that in places it may be glacial drift. Any drift here would be in positions analogous to those of the early glacial drift east of the park. Surely comparably old drift must have been deposited here and in the valleys of other forks of the Flathead. Although most exposures are poor and little detailed work has been done, it is suggested that most of the drift grouped on plates 1 and 2 with the old alluvium may be of early Pleistocene rather than Wisconsin age. Most of it is in topographic locations that indicate it is older than the drift low in modern valleys. Presumably all drift mapped as such in the western parts of plates 1 and 2 is of Wisconsin age.

The drift in the northeast corner of plate 1 was deposited along the western border of one of the broad ice sheets that once covered much of North America. This drift is reported to include boulders that must have come from far to the north in Canada. In contrast, all the remaining drift in the two regions here described is composed of material like that of the bedrock in the neighboring mountains.

Most of the glacial deposits that are widespread in the mountains of both regions are of Wisconsin age. So far as has proved practicable, these have been mapped on plates 1 and 2. Many of the individual moraines, especially those in the vicinity of the cirques, are too small to be mapped or have not been recorded with sufficient accuracy to be shown. This probably applies also to all glacial deposits of post-Wisconsin age, including those of existing glaciers. In addition, in the stream valleys the products of glacial action merge with alluvial deposits that have little relation to glaciers. The deposits in the mountains mapped as of glacial origin, especially in those areas seen by the present writer, are mainly those whose surface form marks them as of that character. Necessarily, however, the distinction between glacial and alluvial deposits is somewhat arbitrary.

MODERN ALLUVIUM

In the mountains most of the streams have flood plains, the largest of which are terraced. Those flood-plain deposits that are wide enough to be shown have been mapped in all areas visited during the present investigation as modern alluvium. In most of the areas seen only by Campbell's parties, data for showing the extent of the modern alluvium are incomplete. Everywhere, the deposits of unconsolidated sand, silt, and gravel are thin, and in most valleys they are narrow. In general, the modern alluvium is later than the deposits related to the Pleistocene glaciers, but most of it is older than the present erosion cycle. This is proved by the fact that, in the mountains, the streams are in narrow gorges that have cut into and in many places through the modern alluvium and other poorly consolidated material into the hard rocks. Mostly the inner rock-walled gorges are too narrow to be shown, but some of the most conspicuous of them are represented on the maps. One example is along Nyack Creek south of Red Eagle Mountain.

LANDSIDE DETRITUS

Small landslides are fairly numerous, but only those that interfere with tracing bedrock boundaries have been mapped. These include two areas in the southeastern part of the park, one along the aptly named Debris Creek near the head of Ole Creek, and one along an unnamed tributary of Park Creek. A third area, near Dolly Varden Creek south of Gable Peak, is in the southern part of the Flathead region.

STRUCTURE

STRUCTURAL HIGHLIGHTS

The rocks in and south of Glacier National Park have been subjected to diastrophic forces at intervals from Precambrian time to the present. Most of the disturbances are reflected only in upwarps, which are so broad and gentle as to be inconspicuous but none the less significant in interpretation of the geologic history. In addition, but more locally, the rocks are intricately folded and broken by faults of several kinds and magnitudes. Igneous activity has left no recognized record since the close of the Precambrian era. The region is best known for its many overthrusts, which formed shortly after the close of the Mesozoic era. The largest, most widely known of these is the Lewis overthrust. This thrust did not, as has been supposed, emerge at the surface close to the border of the present park. Closely spaced, in part asymmetric, folds are associated with the overthrusts. The folding began considerably before the major thrusting took place. Steep faults associated with topographic depressions are major, much discussed features of northwestern Montana and adjacent regions. Features of this kind are present just west of Glacier National Park. Like the more famous ones still farther west, the faults are so poorly exposed that their character and origin are obscure. The simplest and most probable explanation of the features here mapped is that the valleys are graben-like and bordered by normal faults. However, zones of complex folding close to some of the faults suggest that the simple explanation may not give the complete story.

In the pages following pertinent information in regard to each of the structural features is summarized, with a minimum of theory and inference. The descriptive section is followed by one devoted to interpretation of the phenomena.

BROAD FLEXURES OR WARPS

PRECAMBRIAN STRUCTURAL FEATURES

Throughout northwestern Montana and adjacent regions the Belt series shows little evidence of deformation prior to the deposition of Cambrian strata. The lack of clean-cut evidence of unconformity on Cruiser Mountain was noted in the description of that mountain. Similar conditions exist in many places in northwestern Montana. For example, south of Missoula the passage from beds of the Belt series into the Flathead quartzite of middle Cambrian age is made without noticeable hiatus. When that area was visited in fieldwork related to compilation of the new geologic map of Montana (Ross, Andrews and Witkind, 1955), much doubt was felt as to the existence of any stratigraphic break at the top of the Belt series there. However that may be, such conditions emphasize the fact that any deformation that occurred prior to the deposition of Paleozoic strata must have been gentle.

In the part of the State here described the igneous rocks of Precambrian age afford evidence that even before deposition of the Belt series ceased gentle deformation took place. The small intrusions of metagabbro, which are related to the Purcell lava, presumably had to take advantage of paths of easy access. That is, if the great thickness of resistant strata of the Belt series had been undisturbed and unbroken, the gabbroic magma might well have been unable to penetrate into the positions it did. Probably enough diastrophism occurred to produce long tension cracks, now filled by thin dikes of metagabbro. The sills of similar rock (figs. 3, 16) may have occupied places where warping had tended to buckle the beds and thus to produce weaknesses or even actual openings between beds. As the magma reached the surface and produced lava flows, the load of sedimentary rocks above the sills was not great. The irregular intrusive masses of metagabbro in the Flathead region and the small exposures of effusive basalt west of the Apgar Mountains are at stratigraphically higher horizons than the dikes, sills, and flows in the northern and central parts of Glacier National Park. Hence, igneous activity persisted even after the principal flows had erupted. The character of much of the Missoula group is in harmony with the idea that, through uplift or otherwise, the Belt seas were retreating.

The conclusion to be drawn from the character and distribution of the bodies of igneous rock is that gentle but widespread diastrophic disturbances began fairly early in the deposition of the Missoula group. Deiss (1935) has assembled data in favor of the concept of an unconformity between the Belt series and the lowest Paleozoic strata in and near western Montana. His evidence indicates that, whether or not sedimentation was interrupted everywhere, there was uplift and perhaps some flexure of the rocks of the Belt series. The paucity of evidence of marked angular discordance anywhere in Montana indicates that the diastrophism was not intense. At the most, it effected regional uplift and gentle warping without sharp folding or faulting. In the regions here described, no evidence of discordance at the top of the Belt series has been obtained, but the inference from the ideas expressed by Deiss (1935) and widely held among geologists is that some uplift took place. Presumably it was a continuation of that commented on above.

PALEOZOIC STRUCTURAL FEATURES

The only record available of diastrophic disturbances during the Paleozoic era in Glacier National Park and the Flathead region is the absence of sedimentary rocks that might otherwise have been deposited. The crustal fluctuations that began during the Precambrian may have continued into Early Cambrian time, but conclusive evidence on this point was not obtained during the present investigation.

At higher horizons, hiatuses can be demonstrated by means of fossils even though angular discordances are not recorded. Thus, the fact that Devonian strata rest on those of late Cambrian age implies retreat of the seas during that interval, which in turn suggests widespread relative uplift. Similarly interruptions of deposition in Late Devonian and late Carboniferous time may result from relative uplift of broad regions. The crustal movements were so broad and gentle that other results from them have not been detected. The regional flexures were not, however, of continental scope, for they did not take place during the same intervals in Alberta to the north.

MESOZOIC STRUCTURAL FEATURES

The diastrophic movements of Mesozoic time were much like those of the Paleozoic. No sedimentation took place from the end of deposition of the Hannan limestone late in Carboniferous time until some time in the Jurassic period. The presence of the Ellis group suggests that downwarp occurred in Late Jurassic time, but the Ellis is thin compared to many of the older units. Whatever warping may have permitted ingress of the Ellis sea must have been slight, especially as the beds next formed are of terrestrial origin. After deposition of the Kootenai formation (Lower Cretaceous), another downwarp may have occurred because marine deposition was resumed and continued without major interruption throughout the rest of the Cretaceous period. Presumably the region rose gently late in that period, for parts of the St. Mary formation and all of the Willow Creek formation have been interpreted as of continental origin. The uplift that was to give rise to the mountains may have begun during the Cretaceous period, but there is no evidence of violent diastrophism in the region until after the deposition of the Willow Creek formation in Paleocene time.

MOUNTAIN-BUILDING STRUCTURAL FEATURES

In the Paleocene or somewhat afterwards, conditions changed drastically from those outlined above. Broad warpings of the earth's crust so gentle that the resulting structural features have to be inferred rather than seen were succeeded by violent movements in which the rocks were tightly folded and eventually extensively fractured. Thrusts and normal faults of the first magnitude resulted from a series of earth movements that have not entirely ceased even yet. In the summary that follows, the structural features are not described strictly in the order of their age. Many of the features formed before the Lewis overthrust, but that great fracture is such a dominant feature of the region that it seems desirable to outline its extent and character first. Associated folds and fractures, both older and younger than the Lewis thrust, are described in relation to it.

LEWIS OVERTHRUST

By far the largest and most famous of the thrust faults is the Lewis overthrust, named by Bailey Willis (1902, p. 331). Most of the visible structural features of the two regions described in the present report are related, more or less directly, to this great fault. The total exposed length of the Lewis thrust and fractures essentially coextensive with that thrust is more than 300 miles, with possible minor interruptions. It has been mapped in essential continuity from latitude 50° to latitude 47°30′. Beyond these parallels the same thrust zone continues both north and south. Such apparent interruptions as exist are in part the result of inadequate information, in part the result of changes in attitude and of cross faults. The zone is essentially continuous from latitude 57° south to latitude 47°. For Canada, data on the Lewis thrust have been summarized by Mackenzie (1922, p. 97–132) and are shown on a geologic map of part of Alberta (Canada Dept. Mines, Geol. Survey 1928), a more recent map of the province (Canada Geol. Survey, 1951), and in more generalized fashion on the recent tectonic map of Canada (Derry, D. R., 1950a, b). For this country, the geologic map of Montana (Ross, Andrews, and Witkind, 1955) has been drawn upon.

At the border of Glacier National Park, the Lewis overthrust is at the eastern edge of the mountains; but both to the north and to the south, it swings rather abruptly westward into the mountains. On the north the bend in the thrust trace begins close to the international boundary (Hume, 1932). On the south the trace turns abruptly in the north central part of T. 31 N., R. 13 W, continues southwest for 15 miles, then, equally abruptly, resumes a southeasterly trend fully 10 miles within the mountain mass. Thus, the mountains in the park are carved in an eastward bulge in the block above the Lewis overthrust.

Mackenzie notes that in Canada the dip of the overthrust is moderate to low. Willis (1902, p. 237, fig. 4) shows that south of Chief Mountain east of Glacier National Park the westward dip ranges from 3° to 7°45′. Figure 20 shows by means of contour lines the attitude of the principal thrust surface as mapped on plate 1. The area within which the overthrust can be seen is too narrow, in a direction normal to the strike, for the contours to have much quantitative significance. They do however, indicate that the thrust surface is far from being a geometric plane, the average strike is close to N. 30° W., and the dip is to the southwest at low angles. In a few places it may be as much as 20°, but generally it is less than 10°, and long stretches are nearly flat. Figure 20 suggests that the thrust bends downward to the east, so that the part eroded away may have been even flatter than that now exposed. Farther south, in the Flathead region, the opportunity for measurement is even less, but it is obvious from plate 2 that the dip is relatively steep. The maximum dip in the Flathead region may be as much as 50° southwest, and the strike is about N. 30° W., essentially the same as in Glacier National Park. Still farther south, in the Silvertip and Saypo quadrangles (Deiss, 1943b, p. 1123–1168; 1943a, p. 205–262, also unpublished geologic maps of Saypo and Silvertip quadrangles by Charles Deiss), the dip continues to be steep, but the strike swings to more nearly north. South of the Saypo quadrangle present information is scanty, but there is some evidence that the average dip decreases and the strike varies in different localities.

The Lewis overthrust within the country described in the present report is, in a broad way, a single, continuous fracture, but in detail there are many departures from this simple picture. On and near Chief Mountain and Sherburne Peak in the northern part of plate 1, at least two thrusts of some magnitude are present. Similarly, in the vicinity of Schafer Meadows in the southern part of the Flathead region, two thrusts are mapped. One, interpreted as the main Lewis overthrust, passes around the

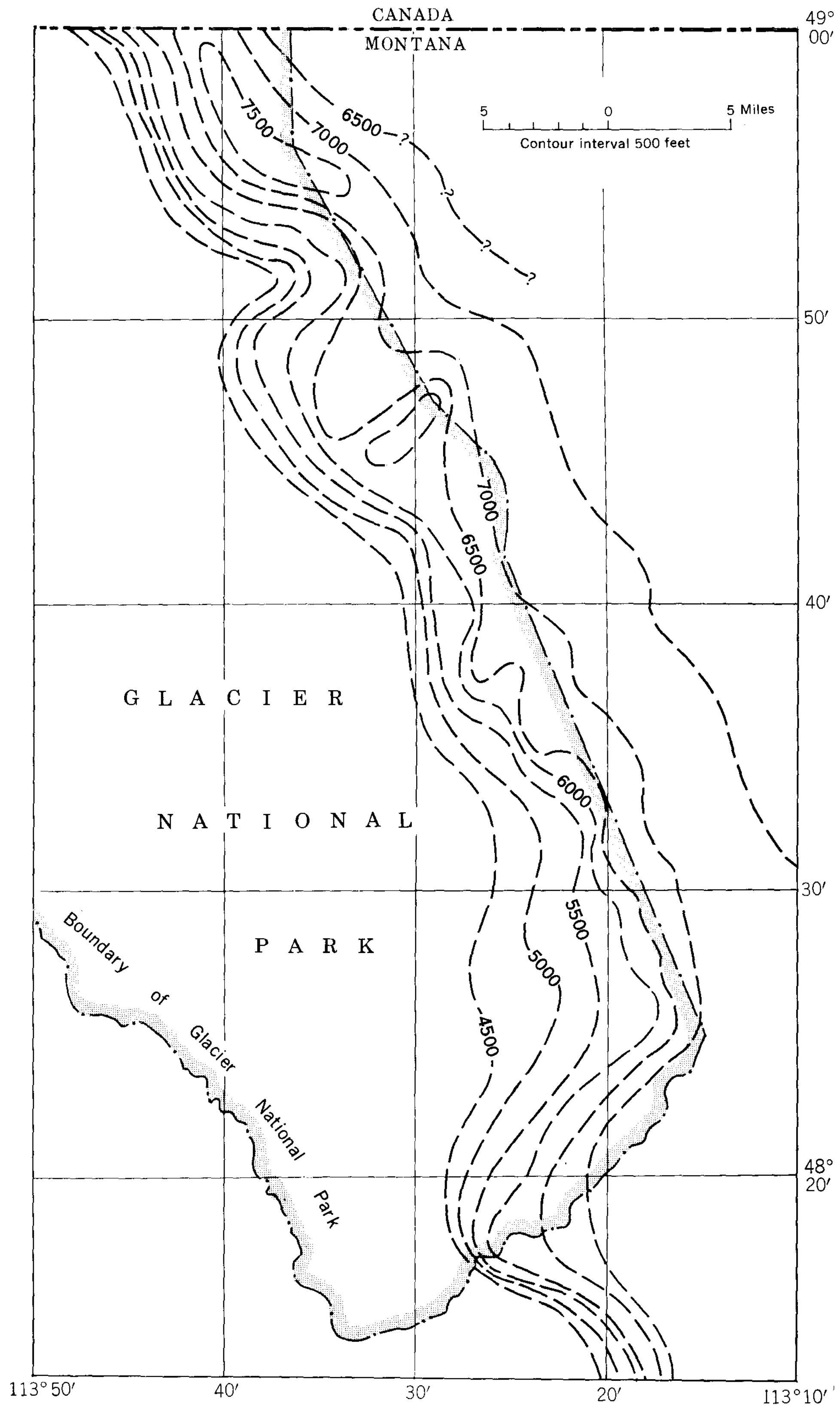

Figure 20.—Sketch contours on the major surface of the Lewis overthrust near the eastern border of Glacier National Park.

east side of Lodgepole Mountain and continues southward along the valley of the Middle Fork of the Flathead. The other, apparently much shorter, is exposed on the lower slopes of Union Peak and continues up Roaring Creek and past Argosy Mountain. Willis' (1902, p. 322–335, figs. 5 and 6) descriptions and drawings and the field notes of Campbell's men show that a variety of minor thrust fractures, too small to show on plate 1, accompany the Lewis thrust in Glacier National Park. G. C. Ruhle (1949, p. 55) notes that at one place on Yellow Mountain repeated thrusts have piled a thickness of strata, each slice not more than 500 feet thick, to a thickness of 2,400 feet. At another place he records that a single assemblage of strata low in the Belt series is repeated nine times by thrusts. Plate 1 shows several short fractures cutting or bordering the main thrust. Most of these are of normal displacement and represent adjustment subsequent to the thrusting, but some may be thrusts. The old field maps of Campbell's men from which these short faults were copied do not in all cases indicate their character or the direction of displacement. All the fractures noted above, and similar but unrecorded features, are best regarded as components of the Lewis thrust zone.

The Lewis thrust in Glacier Park underlies a block of rocks belonging to the Belt series and rests on Cretaceous rocks. Even though slopes are steep, exposures of the rocks immediately beneath the thrust are commonly unsatisfactory. Extensive talus slopes are common, and small landslides in the soft Cretaceous rocks are plentiful, so that many details are hidden. The slides gave trouble in the construction of roads and continue to contribute to the difficulty of maintaining roads in the eastern part of the park. In some exposures the Cretaceous rocks beneath the thrust are nearly parallel to those of the Belt series above, but in others the Cretaceous rocks are intricately crumpled and broken. This latter feature is especially well displayed along the steep mountain front north of U. S. Highway No. 2 from near Blacktail to False Summit (fig. 21). In the Flathead region the beds beneath the overthrust are more competent, and comparatively little crumpling has been observed.

In Glacier National Park the Flathead region and areas just south of the latter the rocks immediately above the Lewis overthrust belong to the Belt series. In the park they are close to the bottom of the exposed part of that series, whereas farther south they are at higher horizons and Paleozoic rocks are present short distances west of the thrust trace. In Canada, Paleozoic rocks appear above the main thrust roughly 45 miles northwest of the point where the thrust crosses the international boundary. The block of Paleozoic strata begins at the west end of the sharp westward bend in the thrust trace corresponding to that at the southwestern corner of Glacier National Park. (Canada Dept. Mines, Geol. Survey, 1928, Hume, 1933). In contrast, the rocks beneath the thrust in Glacier Park are largely of late Cretaceous age, whereas much of the rock in corresponding position to the north and south is Paleozoic. Thus, the greatest stratigraphic hiatus in or near the territory covered by the present report is in Glacier National Park, especially its northern part.

THRUSTS IN THE EASTERN DISTURBED ZONE

Throughout the extent of the Lewis overthrust, a belt of disturbed strata lies east or northeast of the trace of the main overthrust. In the latitude of Glacier National Park, this belt is in the plains east of the mountains and, according to Eugene Stebinger (1916, p. 281–305), extends into the Blackfeet Indian Reservation for about 20 miles. Within this disturbed belt the rocks are mostly of Cretaceous age and have been intricately folded and thrust faulted. In many places, according to Stebinger, the rocks have been so much crushed and broken that it is impossible to identify the different formations. This, coupled with the fact that much of the terrain is mantled with unconsolidated material, has made it impractical with present data to show formational contacts on plate 1. The amount of deformation, especially of thrusting, decreases eastward according to Stebinger. Stebinger places the eastern border of the disturbed zone, in the latitude of Glacier National Park, about at the western border of the area underlain by the Willow Creek formation. However, the Willow Creek formation appears to be conformable with and gradational into the Cretaceous rocks beneath it, and Stebinger's structure sections show it to be folded with them although all of the rocks so far to the east of the mountains are relatively slightly deformed. Stebinger concludes that deformation in the disturbed belt is related to the Lewis overthrust, which is along the western margin of the belt.

The disturbed belt east of the Lewis overthrust continues a long distance to the northwest in Canada, where T. A. Link (1949) has summarized many structural details. Link speaks of the larger faults in the region he describes as "major sole faults." It is clear, however, that none of these underlies all

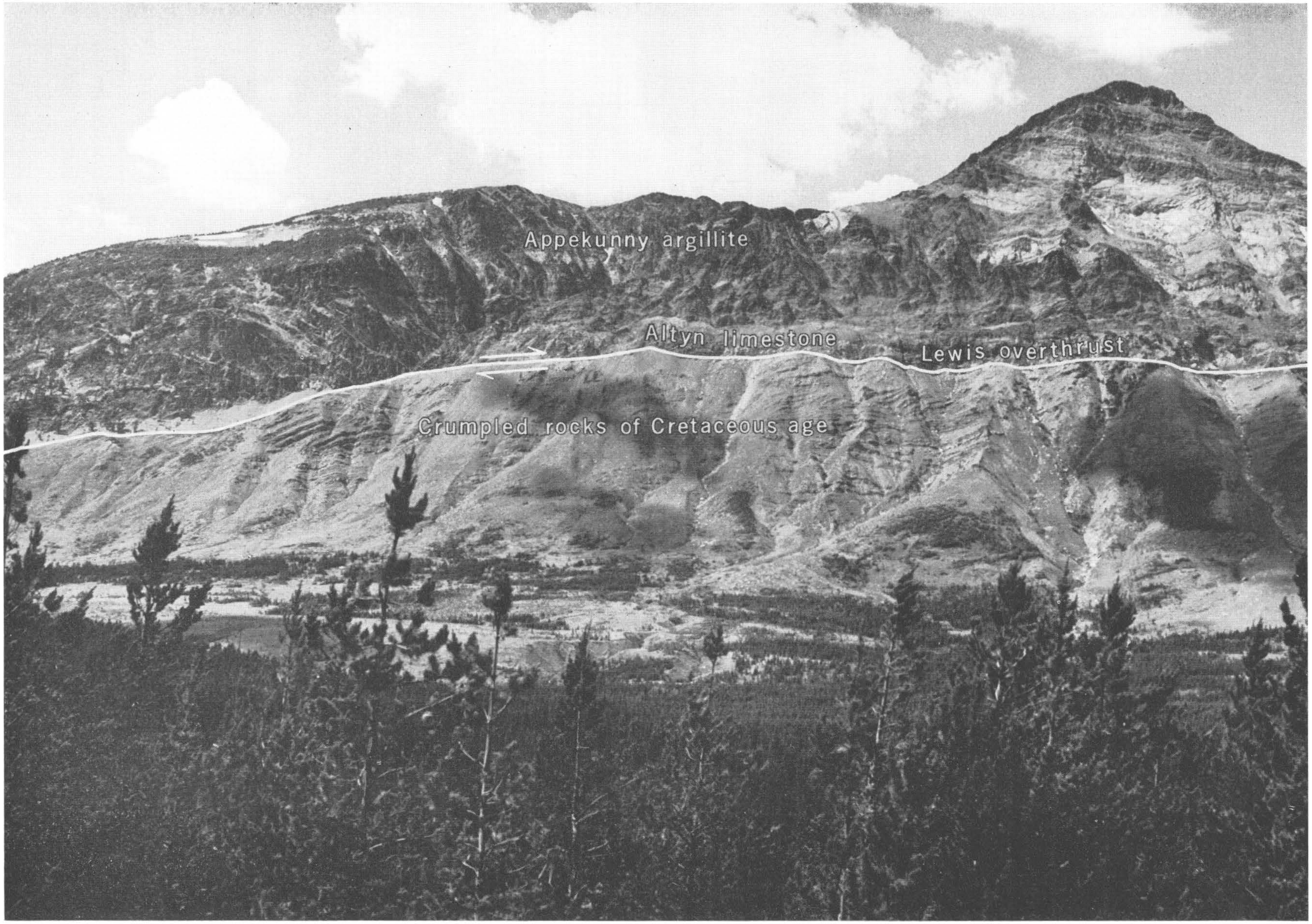

FIGURE 21.—The trace of the Lewis overthrust as seen from Marias Pass. The dark mountains on the skyline consists of Appekunny argillite. The light-colored rather massive rock near the middle of the slope is Altyn limestone, with the Lewis overthrust immediately beneath it. The lower slopes, in part mantled with talus, are composed of intricately contorted Cretaceous strata. Photograph by Richard Rezak.

the thrusts of the disturbed zone. That is, he does not use the term "sole" in the sense employed by J. D. MacKenzie (1922) and others. This difference in terminology needs to be borne in mind in connection with the following discussion of the origin of the structural features. Link says that the structure is complex and includes tight folds commonly overturned eastward but locally and on a minor scale westward. Warping, upbowing, and folding of overthrust faults and sheets are recognized features of the area, less common near the eastern edge, but more pronounced westward toward the Rocky Mountains. He describes "underthrusting or apparent overthrusting from the east" as a near surface feature. So much geologic work in the search for oil has been done in the area Link describes that he has many more facts at his disposal than are available for the disturbed belt in Montana or than were available to MacKenzie.

South of Glacier National Park part of the disturbed belt is in the mountains, but it does extend some miles out into the plains. Here it is close to 30 miles wide and includes most of the eastern half of the Flathead region. The mountainous area in the western part of the belt is not highly deformed although rocks regarded as belonging mainly to the Kootenai formation predominate and the more competent Paleozoic strata are subordinate. Its northern part contains broad areas in which no thrusts have been recognized. Farther south the rocks in the mountains are more intensely broken, but, even here, thrusts of mappable size are spaced, on the average, fully a mile apart. In the intensely deformed parts of the disturbed belt, the spacing is much closer than this. The part of the Flathead region that is in the plains was not studied during the present investigation, but Stebinger's work shows that faults, mostly thrusts, are closely spaced there. For example, his structure section drawn north of east from the bend in the Blackfeet Indian Reservation south of the railroad station of Glacier Park (Stebinger, 1917, pl. 25, sec. *E–F*) shows 46 thrusts in a distance of 30 miles. Here, under a cover of almost unconsolidated Cenozoic material, relatively noncompetent beds of late Cretaceous age predominate.

The character of the folds and thrusts east of the Lewis overthrust within the Flathead region can be seen from the map and structure sections of plate 2. (See also figs. 22, 23.) A few thrusts are continuous for more than 10 miles, but most are much shorter. Some of the thrusts converge both along the strike, and along the dip, but many are discontinuous in both directions. Most trend northwest and are rather closely parallel to each other and to the folds. A few, such as those between Family Peak and Mount Fields, in unsurveyed T. 28 N., R. 11 W., trend nearly east. Accurate measurements of the displacements are difficult to obtain, but it is clear that none have displacements comparable in magnitude to the Lewis overthrust. The dip of the thrusts is varied but generally rather high. Dips of 30°–50° are common. In a few places, such as along the lower reaches of Schafer Creek west of the Lewis overthrust, nearly flat thrusts are exposed. Another may be present on the top of Goat Mountain in unsurveyed T. 28 N., R. 12 W., but the available evidence for this is not conclusive. There are, of course, spots where the faults are so intricate and closely spaced that they are necessarily generalized on plate 2.

In the mountains south of the Flathead region, deformation east of the Lewis overthrust is severe and intricate as shown by C. F. Deiss' (1943b, p. 1123–1168) structure sections. In one typical east-trending structure section in the mountains of the Saypo quadrangle, he shows 20 thrusts in a distance of less than 9 miles. Deiss postulates that the thrusts decrease in dip downward "* * * and merge with one or more soles along which the imbricated fault blocks rode eastward." His structure sections show the postulated sole some distance above sea level, but an oil well in Blackleaf Canyon a short distance north of the northern boundary of the Saypo quadrangle was drilled to more than 2,000 feet below sea level without passing out of disturbed and fractured rocks. The theoretical concept of a sole under the disturbed belt east of the Lewis overthrust is not supported by any recorded observations.

FOLDS OF THE DISTURBED ZONE

Many details are lacking in regard to the folds in the plains. Eugene Stebinger (1917) shows that they have a fairly uniform northwesterly strike. Most are tightly compressed and overturned toward the northeast, but some minor folds appear to be overturned toward the southwest. As already noted, faults are closely spaced, some are close to the crests of overturned anticlines.

Within the mountains the folds of the disturbed zone in the Flathead region are better exposed. In the southwestern part of the Heart Butte quadrangle, thrusts are so closely spaced that the folds cannot be shown satisfactorily on plate 2. Here the folds trend approximately parallel to the thrusts,

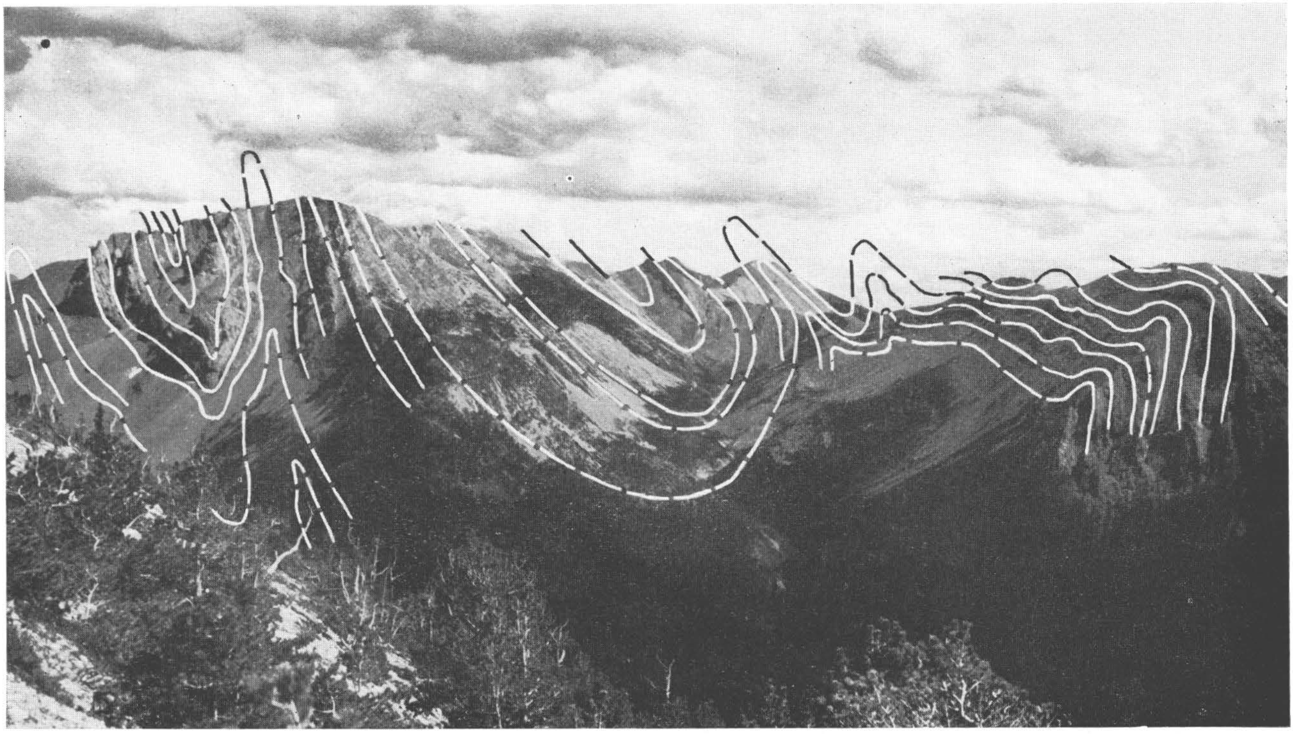

FIGURE 22.—View south from below Bennie Hill Lookout, Heart Butte quadrangle, Flathead region. Shows closely folded and overturned Paleozoic strata, mostly Hannan limestone.

about N. 25°–30° W., and are tightly compressed and overturned towards the northeast (fig. 22). Nearly all the anticlinal crests are broken by thrusts, or by incipient thrusts, many of which are too small to map. Within this part of the region almost every mountain peak contributes evidence that the steep thrusts represent failure at and near anticlinal crests (fig. 23). Whereas all the major folds have the features just indicated, there are irregularities of many kinds. Among these may be cited the peculiar folds illustrated in figure 24, which are overturned toward the west. Some of the fault slivers, notably those in incompetent beds of the Ellis group (fig. 18) are crumpled and fractured without apparent system. These are not directly associated with anticlinal crests.

In the relatively broad area of Lower Cretaceous rocks in the southwest corner of the Marias Pass quadrangle and in areas farther north, underlain mainly by Cretaceous and Mississippian rocks, the folds are more gentle as can be see from structure section *B–B′*, and parts of the other sections on plate 2. In these areas some anticlinal and synclinal axes are plotted on plate 2, but other, less persistent folds are present. Even in these areas most of the folds tend to be assymetric, with the steeper flanks on the northeast. Strikes are commonly between N. 45° W. and N. 55° W.

STRUCTURAL FEATURES IN THE OVERTHRUST BLOCK

The part of the block of rock above the Lewis overthrust that extends from the exposed trace of the thrust westward as far as the eastern side of the northern part of the valley of the Flathead River is composed mainly of strata of the Belt series. The small masses of Paleozoic rocks included in it in the Flathead region do not materially alter its character as a mass of competent strata that would yield reluctantly to deformative stresses. In harmony with this, the first impression one gets of the block is that it consists of flat to gently inclined beds that have successfully resisted the successive attacks of diastrophic forces. Closer inspection shows that this impression is only partly correct—the whole block has been flexed, and parts of it have been buckled and fractured.

In Glacier National Park the most readily seen and persistent fold is the shallow syncline whose axis extends from near Boulder Glacier through Flattop Mountain between Clements Mountain and Mount Cannon to near Tinkham Mountain, a distance of almost 40 miles. Plate 1 shows the axis, and figure 27 illustrates the character of the gentle fold. The average trend is N. 40° W., but in the southern part the syncline is both more curved and less clearly defined than it is in the general vicinity of Flattop Mountain, where it is 10 miles wide, a fact that is

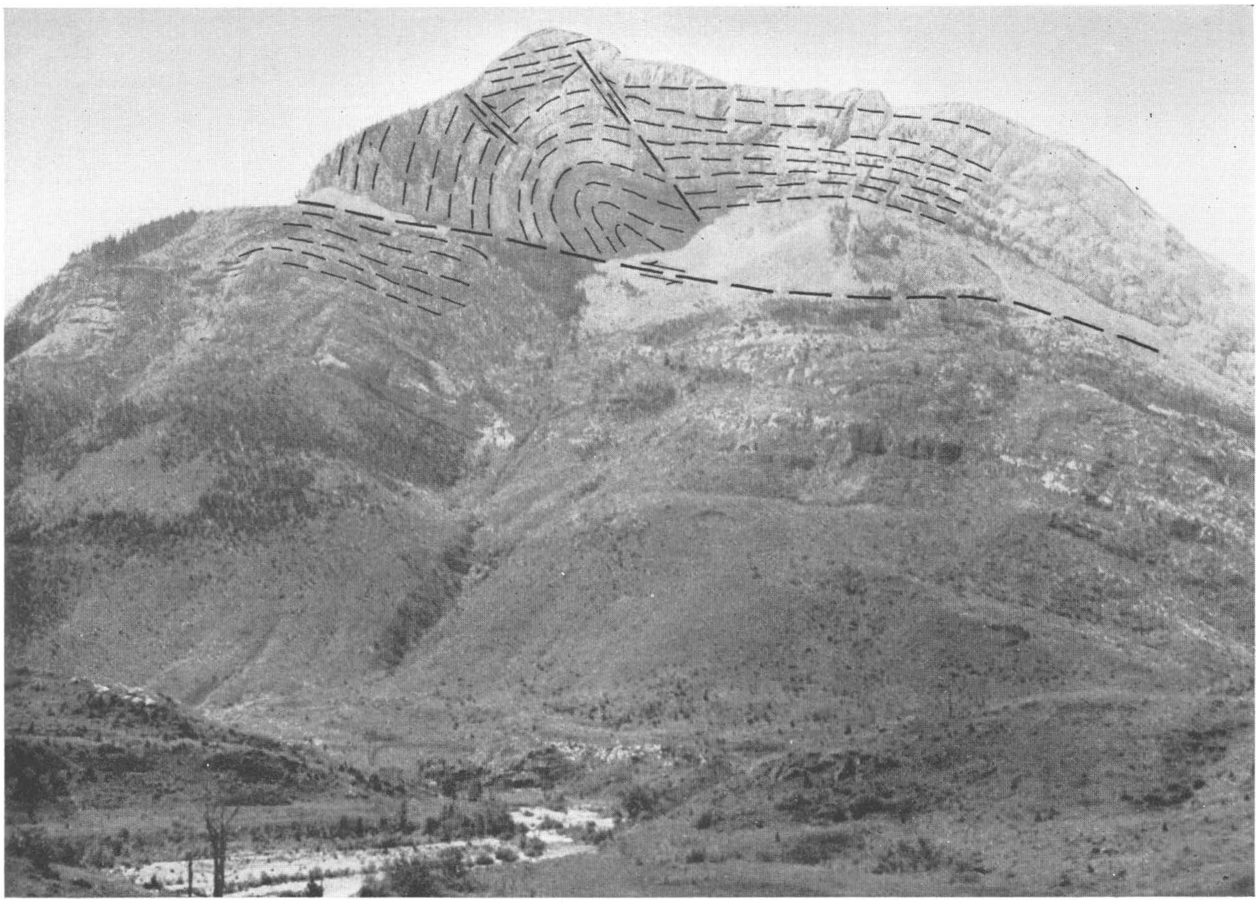

FIGURE 23.—Crooked Mountain, Heart Butte quadrangle, Flathead region. Shows an anticline in Hannan limestone overturned toward the northeast and broken by small thrusts. The principal thrust is concealed in the talus at the foot of the cliffs below the peak. Retouched to emphasize structure.

illustrated in structure section *C–C′*, plate 1. The syncline is bordered on both sides by less uniform groups of folds. Each group constitutes a poorly defined compound anticline or anticlinorium bounding the shallow syncline, as can be seen from the structure sections on plate 1 and from the traces of axial planes of the component folds plotted on that map.

East of the major syncline the folds in the compound anticline are open. No extensive zones of crumpled or overturned beds are recorded outside of the locally thick zones of fracture constituting the Lewis overthrust itself. Local crinkles and minor thrusts are present; for example, the field notes of Corbett and Stebinger refer to two probable thrust faults in the upper part of the drainage basin of Belly River. One of these is on the ridge south of Helen Lake, but has not been mapped. The other is on the point of the ridge west of Mokowanis Lake and is shown on plate 1. Both are in Siyeh limestone and about 5 miles southwest of the trace of the Lewis overthrust. In addition, two small thrusts, one of which is shown on plate 1, are visible in cliffs near Ptarmigan Creek. Undoubtedly other minor thrusts than those recorded are present here and there.

The most severely deformed zones in the rocks of the park are west of the major syncline. Crumpled and locally overturned beds, with minor overthrusts in a few spots are visible near Brown Pass. The high parts of the Livingstone Range north and south of Brown Pass have not received enough study to determine the extent of the deformation. Farther south, complex folds of greater magnitude are present in numerous places, notably on Nahsukin Mountain, Rogers Peak, McPartland Mountain and mountains immediately southwest of it, and on and near Mount Thompson. Closely crumpled but not overturned beds are conspicuous near the head of Coal Creek south of Marthas Basin. The rocks along the lower part of Muir Creek are intricately contorted on a small scale. The two adjacent ridges that include Rogers Peak and McPartland Mountain contain folds of especially great magnitude and complexity. The extent of deformation here is fully as great as in

FIGURE 24.—Irregular folds in Cambrian limestone south of Swift Reservoir, Heart Butte quadrangle, Flathead region. Most of the folds are pinched at the crests and open in the troughs. Also, they are overturned to the west, opposite to the regional structure.

most localities in the crumpled rocks beneath the Lewis thrust. Figure 28, taken from the northwest and at fairly close range, shows details of the folds on McPartland Mountain. Figure 26, taken from Sperry Glacier, shows a cross section of most of the crumpled zone from the edge of the major synclines exposed on Heavens Peak westward. Stanton Mountain, just west of the area shown in figure 26, is included in the sharply folded zone. In Mount Thompson, 13 miles southeast of McPartland Mountain, the rocks are similarly intensely deformed, as plate 1 indicates. Figure 25 shows some of the tightly folded rocks in this locality. The Appekunny argillite on the slopes of Mount Thompson has responded to the intense pressures by development of more slatey cleavage than it displays in most localities. Two Medicine Pass is another locality where crumpled beds are conspicuous.

The observations summarized above show that from Nahsukin Mountain southeast to Two Medicine Pass irregular and somewhat discontinuous zones of intense deformation mark a disturbed and uplifted belt on the western flank of the central syncline. This belt is about 3 miles wide and fully 35 miles long. It may continue northward more than 10 miles farther into Canada. In most places the folds are overturned toward the northeast, but here and there the opposite is true. In some places, such as Nahsukin Mountain, the contorted beds are so unsystematic as to give no clue regarding the directing stress.

While individual folds and contorted zones are discontinuous, the compound anticlines or anticlinoria on both flanks of the central syncline extend from the Canadian boundary to the southern part of Glacier Park. The compound anticline on the west crosses from the Livingston Range to the Lewis Range near the upper end of Lake MacDonald and merges into a group of folds in the Flathead region. In the southern part of the park, these folds are crossed by faults, but there and farther south they do not have the fractured crests so plentiful in the disturbed zone east of the trace of the Lewis overthrust. In Glacier Park this compound anticline is roughly 15 miles back of the outcrop of the Lewis overthrust, but the corresponding folds in the Flathead region constitute the first major structural feature to the west of that great fault. This comes about as a result of the sharp deflection in the trace of the overthrust near Marias Pass. The major syncline and the compound anticline east of it do not continue as far south as that pass.

Within the Flathead region the rocks west of the

FIGURE 25.—Contorted Grinnell argillite on the north wall of the cirque on the south slope of Mount Thompson, Glacier National Park. Photograph by Eugene Stebinger.

outcrop of the Lewis thrust are flexed into open folds that locally are overturned toward the northeast. An example is illustrated in structure section *B–B* (pl. 2) west of Battery Mountain in the southern part of the Nyack quadrangle. Here many of the beds within a narrow zone are so tightly crumpled as to suggest an incipient high-angle thrust of southwesterly dip. No fault displacement has been detected, however.

In the northern part of the Flathead Range, especially along the range crest from Mount Liebig northward to Great Bear Mountain, the Siyeh limestone is more intricately deformed than in any other part of the Flathead region. This part of the range has not been mapped, but the sharply contorted beds in it are plainly visible from distant vantage points.

In the general vicinity of Mount Bradley, Hematite Peak, and Twin Mountain, east of Long Creek, the rocks are sharply and irregularly folded. One short anticline is shown on plate 2, but in most places the folded rocks do not seem to fall into any systematic structural pattern. The disordered folds in this zone may account for the apparently abrupt ending of the fault mapped along Bergsicker Creek.

STEEP MASTER FAULTS

Long faults of large displacement are major features of the structure along the valleys of the principal branches of the Flathead River both in Glacier National Park and in the Flathead region. The character of these faults is obscured by the fact that long segments of them are buried under alluvium and other kinds of unconsolidated material. Some students regard the faults as thrusts; others, as normal faults. Conclusive evidence is not available, but the concept of normal displacement seems the most logical one. Similar faults are outstanding features of the geology farther to the west; so the problem is of regional significance. Numerous opinions have been expressed; but, in many localities, the question as to character and direction of displacement remains open. Existing data on the subject are reviewed below. As a reflection of doubt, the conventional symbols indicating relative displacement have been omitted, in most places, from plates 1 and 2, and many of the faults are represented noncommittally on the structure sections as vertical. On plate 4, which is diagrammatic, the fault along the upper reaches of the Flathead River is represented as normal. This conforms with the ideas gained during

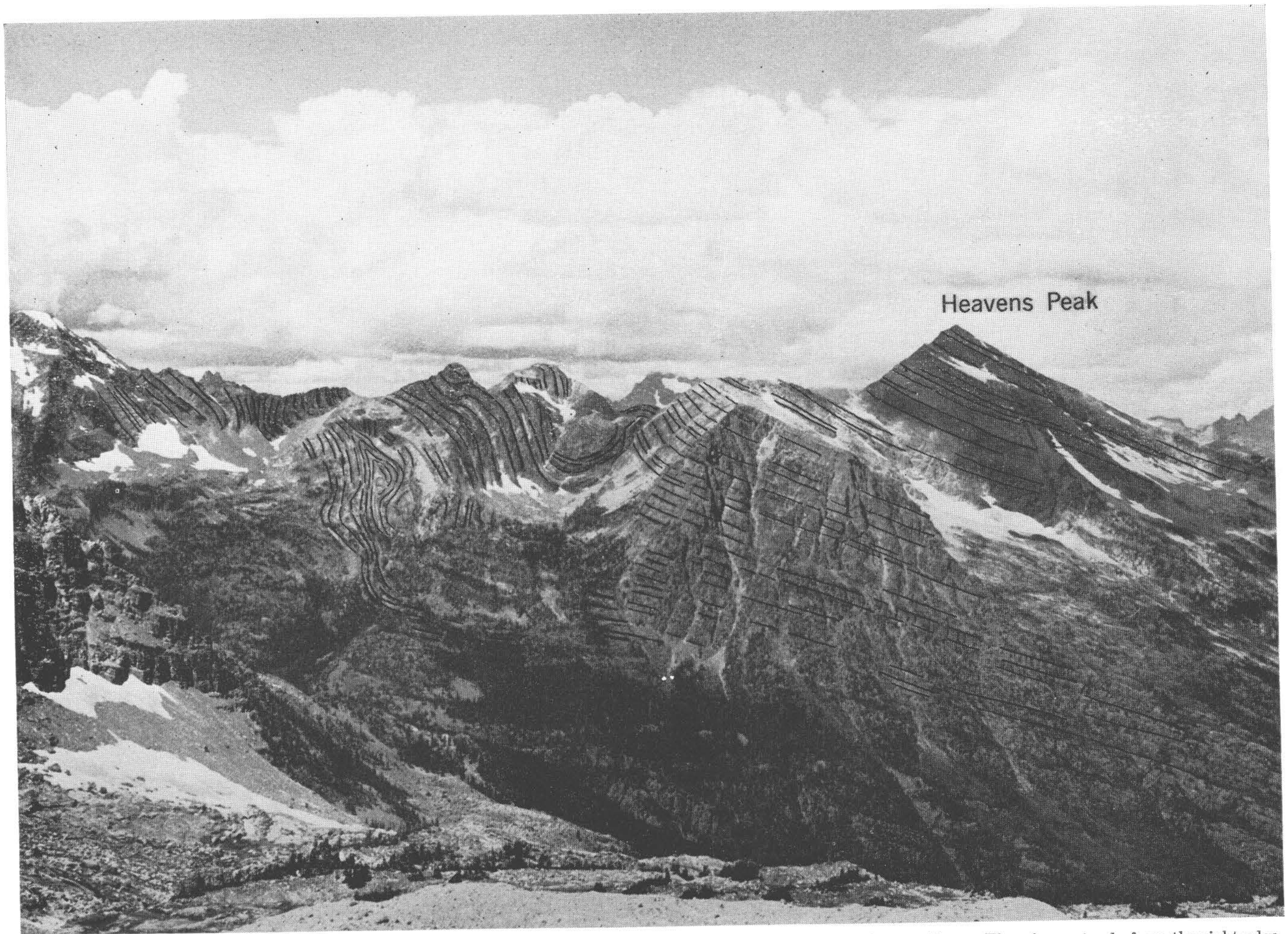

FIGURE 26.—View northwest from Sperry Glacier showing part of the intensely folded rocks west of the major syncline. The view extends from the right edge of Heavens Peak almost as far as Stanton Mountain. (Retouched to emphasize structure.)

the present investigation, but is not to be regarded as proved.

Both in the two regions here reported on and in neighboring areas in western Montana and in Canada, direct observations of the faults are possible in few places. Even where the faults cut slopes in bedrock, few actual fault surfaces, susceptible of measurement, are known. In consequence, the mapping had to be guided in part by float and by the interpretation of topographic forms. In most places the result has been that the fault trace as mapped accords with the concept of a steep fault dipping valleyward. As the pre-Tertiary rocks under the valleys are, where known, stratigraphically higher than those in the mountains beyond the fault zones, the valleys would be grabenlike and bounded by normal faults. Unfortunately, the data on which the fault lines are based are too scanty to permit the shapes of the mapped fault lines to be regarded as conclusive evidence regarding the actual shapes of the faults. Similar difficulties in interpretation have confronted all those who have studied the steep faults in and west of the two regions here described. Consequently, in spite of much discussion in the literature, positive evidence remains scanty. In a later section of the present report, which concerns interpretation of the structure, pertinent papers are cited, including a number that relate to parts of western Montana and Canada. That section may be anticipated here by the statement that most of the geologists who have worked in Glacier National Park and contiguous areas regard the steep faults along major valleys as of normal displacement. However, some of those who have worked farther west think the comparable faults there are thrusts, and most of the more recent workers in Canada favor that view. Probably a single and simple explanation will not hold for all of the faults. Available information on the faults under discussion in and close to the Glacier National Park and Flathead regions is summarized below.

The longest and apparently the most dominant of the steep faults mapped during the present investi-

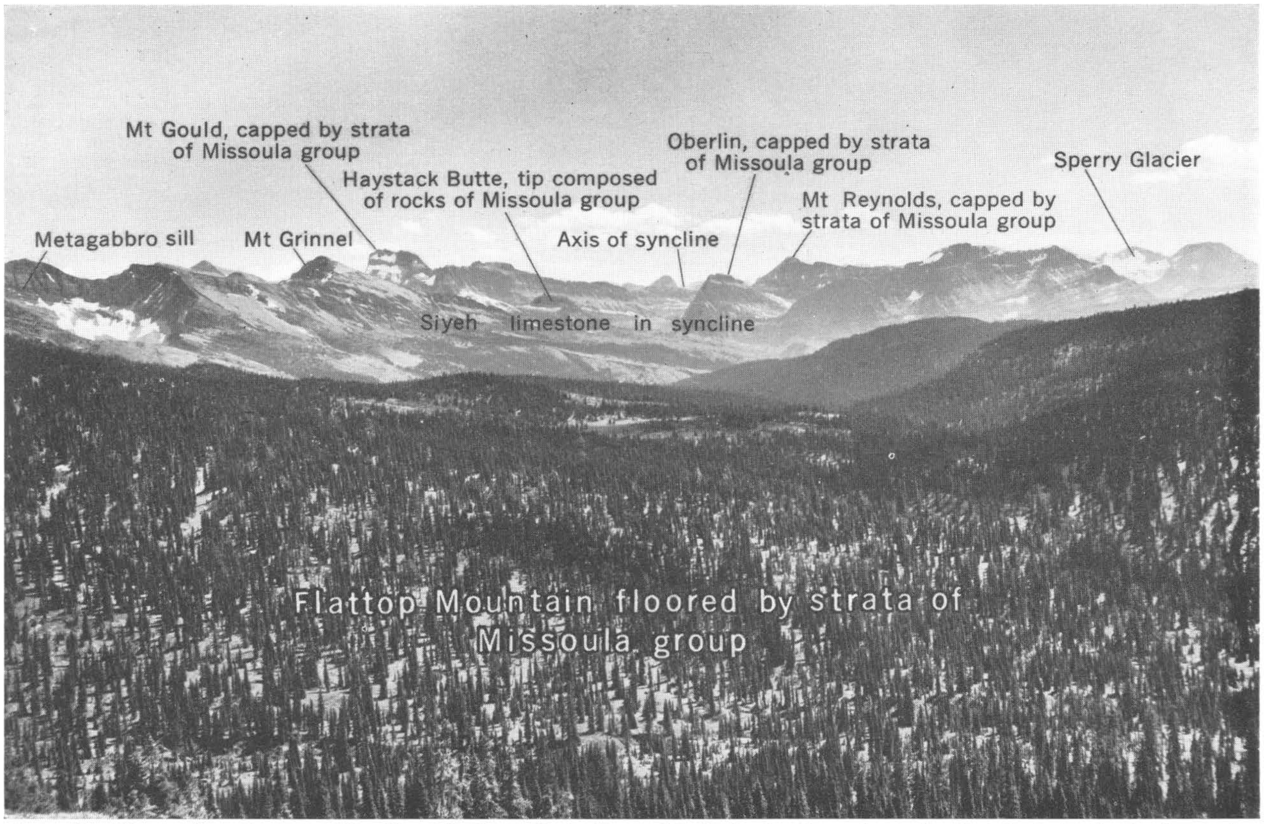

FIGURE 27.—View southeast from near Fifty Mountain Camp, Glacier National Park, showing the gentle syncline that dominates the structure in the central part of the park. This major fold is visible from few viewpoints. The Missoula group floors the top of Flattop Mountain in the foreground and forms most of the pinnacles on the skyline. Most of the rest of the rock in the view is Siyeh limestone. The flat surface of Flattop Mountain shows in the foreground, contrasting sharply with the glaciated pinnacles and cliffs south of it. Flattop Mountain is the most conspicuous remnant of an old, high erosional surface in the region. Photograph by Richard Rezak.

FIGURE 28.—Overturned Grinnell argillite on McPartland Mountain, Glacier National Park, viewed from the northwest. Photograph by R. H. Chapman.

gation trend N. 20° W. to N. 45° W., with local variations beyond these extremes. One of the largest extends from beyond the international boundary north of Kintla Lake southeastward past the southern border of plate 1. This fault borders the valley of the Flathead River 6 or 8 miles northeast of that stream, continues in the hills northeast of the Middle Fork of the Flathead, and crosses Bear Creek near the railroad station of Blacktail. Throughout this long stretch the pre-Cenozoic rocks southwest of the fault belong to units several thousand feet higher stratigraphically than those northeast of the fault. In most places the fault plane is concealed beneath deposits of Cenozoic age. In the few places where not so buried the shape of the fault trace as mapped indicates a steep southwesterly dip. Even in these places exposures are not good. If true, both the dip and the relative displacement fit the concept of a major normal fault, but so much of the fault trace is concealed that the possibility of a very steep reverse fault of northeasterly dip cannot be eliminated. Some support to the hypothesis of a reverse fault is afforded by intricately crumpled beds exposed between the fault and the mouth of Muir Creek and by small steep faults, in part clearly reverse, in railroad cuts about halfway between the stations of Red Eagle and Hidden Lake along the Middle Fork below the mouth of Coal Creek. One such exposure is shown in figure 29. All the faults in the railroad cut are steep, curved, and appear to have displacements of only a few feet. Some, as figure 29 indicates, are thrusts; others are indeterminate.

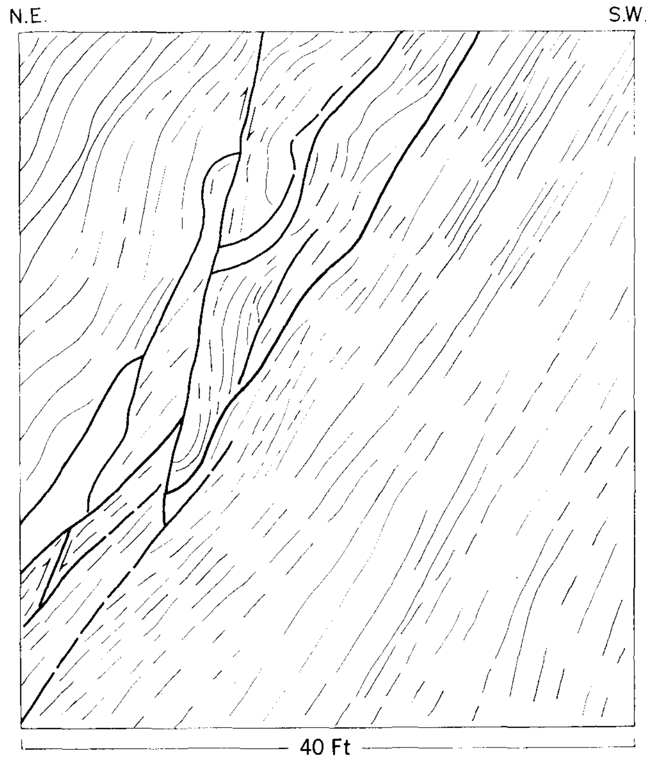

FIGURE 29.—A railroad cut along the Middle Fork of the Flathead below the mouth of Coal Creek showing exposure of minor fractures.

In the valleys of the northern part of the Flathead River and of the Middle Fork of the Flathead, the Tertiary rocks are disturbed. Figure 19 shows some of them tilted about 30° NW. In other localities, such as along the lower reaches of Lincoln and Coal Creeks, they are locally contorted. C. E. Erdmann (1944, p. 62–67, 112–114; 1947, p. 134) noted inclined Tertiary strata in several places along the Flathead and its Middle and South Forks. The beds in the bank of the Flathead near the mouth of Kintla Creek that, as noted in the stratigraphic descriptions earlier in this report, have yielded Oligocene fossils are also tilted. Thus the Tertiary and later beds that underlie the valleys bordered by the steep master faults are extensively deformed. The movements that affected the valley fill of Tertiary and later age (the old alluvium of pls. 1 and 2) must have been related to the bordering faults. Hence, disturbances along these faults have occurred far more recently than the date of the Lewis overthrust. Erdmann (1947, p. 139–141, 188–190), who is among those who think of the long faults as thrusts, calls attention to two normal faults bounding a horst cut into by the Flathead River near the mouth of the Canyon Creek in sec. 23, T. 32 N., R. 20 W.

Prospecting for oil near the international boundary (Link, 1932, p. 789; Erdmann, 1947, p. 210–212) has yielded little information of value in the present connection. Small quantities of oil have been reported from wells and seepage in localities short distances east of the probable position of the major fault on the northeast side of the valley of the upper Flathead River. The nearest outcrops consist of Appekunny argillite. Presumably the oil rose along fault fractures from a source in concealed rocks of post-Belt age, but it is impossible to determine from available data whether these fractures belong to an east-dipping thrust that passes beneath the exposed rocks of Precambrian age or to branches of a normal fault. One test well explored the ground near a seep in the Cenozoic deposits close to the river below the mouth of Kintla Creek. This well was west of the fault but yielded no data as to the pre-Cenozoic rocks there.

With respect to the long fault east of the northern part of the Flathead River and near the western border of Glacier National Park, the field notes of the geologists in M. R. Campbell's parties show that they regarded the fault as normal. They give no specific details in support of the assumption, which was doubtless based on such general features as topographic forms and the fact that rocks in the hills west of the river are stratigraphically higher than those in the mountains east of the river. Most of the mountains west of the river are beyond the limits of plate 1, but they are underlain largely by beds of the Missoula group, while the Ravalli group crops out east of the river valley (Ross, Andrews, and Witkind, 1955). J. T. Pardee (1950, p. 397–398) has the same opinion and says that at the international boundary the valley has a graben structure. He thinks the fault on the west side of the graben, although less well defined than that on the east, extends south almost as far as Lake McDonald. This fault was not studied during the present investigation. Most of it is west of the area represented on plate 1. Perhaps the fault that is doubtfully indicated east of the Apgar Mountains is a segment or branch of that which Pardee speaks of as on the west side of the graben. Plate 1 shows that the fault inferred to exist east of the Apgar Mountains is sketched mainly on the basis of topographic forms, and its character is indeterminate. As indicated below, it seems to be a northward continuation of the big fault southwest of the Flathead Range.

J. L. Dyson's (1949a, p. 17 and 19) structure section shows a normal fault on the east side of the valley of the Flathead. His text refers to this structure noncommittally as of "the high-angle variety," but he adds that the faults bounding the Apgar Mountains and Belton Hills are normal. The fault east of the Belton Hills is, as can be seen from plate 1 of the present report, a segment of the fault along the northeast side of the valleys of the Flathead River and the Middle Fork of the Flathead.

In the general vicinity of Blacktail, the long steep fault described above is in the same topographic depression as the Lewis overthrust, and the two fractures must lie very close together. To the south they diverge. The steep fault appears to die out, but the Lewis overthrust continues southeast past the southern border of the Flathead region. South of Blacktail, in the Flathead region, the steep fault has been traced on plate 2, with some uncertainty, as far as the confluence of Lynx Creek with Twentyfivemile Creek.

The above summary shows that most geologists who have worked near the western border of Glacier National Park favor the concept that the valley of the northern part of the Flathead River is a graben bounded by normal faults. The Canadian geologists who have worked in southwestern Alberta are more inclined to regard the faults as thrusts. In an early summary, Link (1932) said that "* * * the generally accepted structural interpretation * * *" of the valley of the Flathead was that of an "* * * inverted wedge or modified ramp * * *" bounded on either side by thrusts dipping valleyward. In later papers he (1935, p. 1464–1465) gives different explanations of the structure along the Flathead but continues to favor thrusts of some kind rather than normal faults. This paper and that of G. S. Hume (1933), which expresses similar ideas, are further discussed in the interpretive part of the present report. Pierre de Bethune (1936), whose fieldwork was about 25 miles north of the international boundary, also favors the concept of thrusting for structural features bordering the valley of the Flathead.

Another great fault of northwesterly trend extends from McGees Meadow past the lower end of Lake McDonald, down the upper part of the valley of Emery Creek, between Firefighter Mountain and the Flathead Range, and thence along the northeast side of the valley of the South Fork of the Flathead River past the southern border of plate 2. The general relationships of this fault, as shown on the maps, are similar to those of the fault just described. That is, the dip appears to be southwest, and the rocks now west of the fault are higher stratigraphically than those east of it. If the dip was definitely known, these relationships would prove that the fault was normal and of great vertical displacement with the down-dropped block on the South Fork side. However, the dip has not been thus established because the fault surface itself is hidden under Cenozoic materials and vegetation. No contorted rocks or minor thrusts like those close to the fault described above have been recognized near this one, with the exception of the thrust near the southern border of the Flathead region southeast of the lower Twin Creek. Pardee (1950, p. 398–399, pl. 1, sec. *B–B′*) agrees that the fault northwest of the South Fork is normal, but he does not draw it the full length of the valley. Farther north a fault trending west of north is shown. The limestone west of the upper reaches of Lower Twin Creek is shattered in such a way as to support strongly the concept of faulting, but that east of the stream appears to be conformable with the argillite above. Both masses are represented as belonging to the Siyeh limestone, but this is open to some question. They might be limestone bodies low in the Missoula group.

An inferred fault is mapped from north of Abbott Ridge along the southwest side of the valley of the South Fork of the Flathead River past the southern border of plate 2. This fault is inferred in part from the topography, in part from the presence of Tertiary deposits east of Abbott Ridge and in the depression north of that ridge through which the road passes, and in part from the presence of green argillite at the place where the road crosses the South Fork about a mile and a half northwest of Coalbank. If the green argillite is correctly interpreted as part of the basal unit, greenish calcareous argillite of the Missoula group, some such fault as that sketched is required. C. E. Erdmann in his study of the Hungry Horse dam site (Erdmann, 1944, p. 79–80) found two shear zones so close to the position of the inferred long fault as to add to the evidence of fault movement in the locality. These zones are on either side of the position of the inferred fault as plotted on plates 1 and 2. He reports that the northwestern of the two is well exposed in a roadcut "* * * near the north center of sec. 36, T. 30 N., R. 19 W. It begins just below the top of the Siyeh limestone downward through a stratigraphic range of at least 1,400 feet." His description indicates that much disturbance has taken place in this zone. The limestone is much jointed and sheared and contains gouge seams up to 6 feet thick, some of which includes a jumble of limestone blocks as much as 5 by 10 feet in exposed dimensions. He interprets the zone as a result of thrust from the southwest but evidently regards the aggregate displacement as small because he shows no fault or displacement along the line of the shear zone (Erdmann, 1944, pls. 10, 11). The second shear zone crosses Hungry Horse Creek 1,300 feet west and 2,150 feet north of the southeast corner of sec. 30, T. 30 N., R. 18 W. Erdmann says it apparently separates an area of low dips from a more thoroughly compressed zone east of it. Some movement and brecciation have taken place and small drag folds nearby "* * * indicate strong compression from the west."

A concealed fault of northwesterly trend is shown in the southwest corner of plate 2. This is a segment of a much longer fault mapped by Clapp (1932, pl. 1) which bounds the Swan Range on the southwest. Just as in the case of the faults on the northeast sides of the valleys of the Middle and South Forks of the Flathead, topographic features are compatible with the idea that it is normal, with a southwesterly dip. The sharply truncated ends of many of the spurs from the range crest might readily be supposed to be triangular fault facets dipping valleyward. This feature, which might otherwise be regarded as conclusive proof of a normal fault of southwest dip, is negated by Davis (1921, p. 87–89). He pointed out that a large glacier once occupied the Flathead Valley and ground off the spur ends of the Swan Range. Davis does not oppose the idea of a fault that outlined the Swan Range but implies that such features as fault facets would have been obscured or obliterated by the action of the glacial ice. Coarse glacial debris is mingled with the hillwash on the southwest flank of the range. Pardee (1950, p. 395–396, pl. 1) agrees in part with Davis but thinks fault facets rise above the level of the glacially truncated spurs in places. Pardee maps and describes the fault bordering the Swan Range as a normal fault of westward dip. He cites Clapp's concept (1932, p. 24–27, pl. 1) of a thrust fault of eastward dip in this position and calls attention to Clapp's suggestion that later normal faulting may have occurred. However, Clapp thought of the normal faults as minor features and of the steep thrust (or reverse fault) as dominant, whereas Pardee regarded normal faulting as dominant. It is unlikely that a normal fault of westerly dip would coincide in position and strike with an earlier reverse fault of opposite inclination. Along the part of the southwest face of the Swan Range seen during the present investigation, glacial deposits mantle some slopes to heights above the truncated spur ends. Much of the hillwash mapped on plate 2 includes glacial debris, and the hillwash extends to between 500 and 1500 feet above Flathead Valley. It would be difficult to map the glacial material separately or to determine how much of it came from a glacier in Flathead Valley. Some, of course, came from glaciers originating high in the Swan Range.

One bit of evidence opposed to the view that the fault on the southwest flank of the Swan Range is normal has been found. The north end of this range is at Bad Rock Canyon, a rock-cut gorge west of the region mapped during the present investigation but which was visited in the course of the work. Roadcuts in Bad Rock Canyon show fractured folds in Grinnell argillite that are overturned toward the west or northwest. Such features might have been formed in connection with a steep reverse fault of northeast dip along the southwest flank of the Swan Range. Taken alone, they are insufficient to prove such a fault or to disprove the assumption of a normal fault of opposite dip in this position.

Because the evidence in regard to the long, steep fault summarized above is inconclusive, data in regard to other faults bordering major valleys in the same general region were sought. Much has been written, but the difficulties encountered in assembling positive evidence during the present investigation are shared by all of the investigators. The principal studies have been along the Rocky Mountain Trench, a conspicuous topographic feature in Canada and western Montana some distance west of Flathead Valley (pl. 3). Early workers (Daly, 1912, p. 25–26, 137–139, 600; Schofield, 1920, p. 73–81) regarded the faults as normal and the trench as grabenlike. Shepard (1922, p. 16–139) originally regarded most or all of the faults in the vicinity of the Rocky Mountain Trench as steep thrusts dipping away from the topographic depression on both sides. However, nearly all of his drawings show the faults dipping west, or, more strictly, southwest. In his first paper, Shepard (1922) concludes with the remark that the Rocky Mountain Trench is less of a unit than Daly and Schofield thought. It was produced "* * * partly by normal erosion, partly by erosion along lines of weakness resulting from intersection of numerous faults, and partly by the escarpment of a fault, inferred to be a thrust." In a later paper, (Shepard, 1926) concerned largely with an area 120 miles north of the international boundary he regards the trench as an eroded horst, bounded on the east by a west-dipping thrust, rather than a normal fault. In this paper he discounts Daly's idea of a graben.

Several other geologists who discuss the structure of the region from the trench eastward as far as Glacier National Park think that some of the faults are steep thrusts with easterly dips. Among these Wilson (cited by Chamberlain, 1925, p. 759–760 and Flint, 1924, p. 411–415) reports small east-dipping faults on the west flank of the Mission Range (pl. 3) and between there and the Continental Divide in the southern extension of the Lewis Range. Clapp's small-scale generalized map (1932, p. 24, pl. 1) shows steep, east-dipping thrusts at the borders of several ranges from longitude 114°30′ to the western border of Glacier National Park, although his abbreviated text cites little evidence in support of his interpretation. Pardee (1950, p. 393–395, pl. 1) maps the trench in Montana as bordered by normal faults. Most of those cited above who advocate east-dipping thrusts do so primarily on theoretical grounds.

C. S. Evans 1933, p. 145–170 A II) has summarized published information on the Rocky Mountain Trench in connection with his study of a part of the trench about 120 miles north of the international boundary. At one locality in his area where opportunities for observation are especially good, Evans says that thrust faults and overturned folds in the mountains dip away from the trench on both sides. His interpretation is that the structures result predominantly from thrust toward the northeast. The east-dipping structural features east of the trench would thus be underthrusts. Evans thinks there may have been two periods of deformation that resulted in a much-sheared zone in which the rocks yielded readily to erosion. At an early stage the trench may have been in part a structural depression, but the present form results largely from erosion in rock weakened by deformation, including fracture. The difference between Evans' conclusions and the earlier ones of F. P. Shepard (1922) is in interpretation rather than observation. Both speak of thrusting and overturning toward the trench from both sides. Evans, however, rejects Shepard's suggestion, made after a second study (Shepard, 1926, p. 640), that the trench was eroded along a horst. D. R. Derry (1950a, b, p. 42–43) in a summary issued in connection with the tectonic map of Canada favors the concept of a steep west-dipping reverse fault zone, without any east-dipping faults. The observations cited above are of interest because they give details not available for much of the Rocky Mountain Trench or for areas between there and Glacier National Park, but it must be remembered that the area involved is far west and north of the park.

T. A. Link (1935, p. 1464–1466; 1949, p. 1475–1501) and A. J. Goodman (1951) discuss structure in the valley of the Flathead River and in the foothills in nearby parts of Canada. They make use of the extensive information on the region that has accumulated in the course of exploration for oil and agree that east-dipping faults and folds overturned to the west do occur in the Canadian foothills. This fact lends some support to the idea that similar structural features may be present farther west, where less information is available. As will be shown below, Link and Goodman differ in their interpretations of the east-dipping structural features, leaving doubt as to the significance to be attached to them in the present connection.

In summary, review of published reports, some of which include summaries of papers not here specifically cited, shows that most of the more detailed studies so far accomplished that are pertinent to the present discussion have been done in Canada. Thrusts in and bordering the individual ranges (mostly west-dipping) are favored by most of the writers, but enough of them advocate normal faults, so that the possibility cannot be ignored, even for the specific areas described. None of the detailed work is in and most of it is distant from the regions described in the present report.

STEEP MINOR FAULTS

Within the two regions discussed in the present report there are numerous short, steep faults not directly connected with the long ones described above. Such data as are at hand in regard to these are summarized below.

Plate 1 shows two short faults of northwesterly trend. One of these is southwest of Upper Kintla Lake close to the international boundary, and the other is south of Marthas Basin in the southern part of the park. Both appear to be normal faults and have apparent downthrows on the northeast side, a relation opposite to that on the long faults of similar trend. The fault near Marthas Basin is within a zone nearly half a mile wide in which the Grinnell argillite is crinkled into numerous, closely spaced steep folds. There seems, however, to be no direct relation between the fault and the folds.

Steep faults of northeasterly trend are shown on plates 1 and 2, and others may be concealed in valleys of similar trend. Two inferred faults of this trend are shown in the southwest part of plate 1. While these are buried under Cenozoic deposits and no direct evidence of either is known, they appear to be required by the offsets in the long faults of northwesterly trend, especially the one that follows the northeast side of the valley of the South Fork of the Flathead and may die out in McGees Meadow. However, the position of this latter fault is sketched mainly on the basis of the topography. Detailed work may show that it curves more than is at present appreciated or modify the position of the fault trace in other respects.

In the northern tier of sections in unsurveyed T. 28 N., R. 18 W., the rocks are disturbed and show such abrupt variations in attitude that a sharp structural break must be present. This is represented on plates 1 and 2 by a fault striking a little north of east, north of Clayton Creek. Available data are insufficient to determine either the displacement or the exact strike of this fracture, which may be merely a branch of the longer one in the valley of Clayton Creek. This longer fault also is an inferred fault about which little is known. The distribution of the mapped masses of the basal part of the Missoula group near Clayton Creek requires some such a fracture. Further, rocks in outcrops that project through the glacial debris in the headwater basin of Noisy Creek are fractured and have variable attitudes. This zone of disturbance is in line with the inferred fault along Clayton Creek.

Several short faults of easterly and northeasterly trends in the plains in the Heart Butte quadrangle are plotted on plate 2 on the basis of observations by Eugene Stebinger (1916). These appear to result from minor adjustments that broke some of the longer thrust faults of northwesterly trend.

The principal fault of northeasterly trend recorded in the mountains of the Flathead region east or northeast of the Middle Fork of the Flathead is that along Ole Creek in Glacier Park. This fault is mostly concealed under alluvium but has a branch that cuts the Appekunny argillite near Sheep Mountain. The fault along Ole Creek seems required by the lack of accord in the geology on the two sides of the valley. This is more evident when irregularities in the attitude of the bedding are observed in the field than it can be by inspection of the map alone. The displacement must be small, as is proved by the fact that, as the map shows, none exists along the lower reaches of Ole Creek. A zone of fracture is exposed north of the narrow outcrop of Altyn limestone nearly opposite the place where Debris Creek joins Ole Creek. The same thing is true of the fault sketched in dashed line south of Flotilla Lake in the southern part of the Marias Pass quadrangle (pl. 3). Inspection from vantage points shows that the beds along the line sketched are disturbed and fractured, but large scale studies would be required to determine the exact position and character of the fault. Farther west a fault is mapped along Bergsicker Creek. This one crosses the Flathead Range and is lost to view under the Cenozoic deposits in the valley of the South Fork of the Flathead. The lack of accord in the geology on the two sides of this fault is obvious from a glance at plate 2. Possibly the fault crosses the valley of the South Fork and extends up Sullivan Creek, but evidence to support this idea has not been found. Disturbance in the beds on the shoulder of Mount Baptiste is evident from a distance, but it has not been traced otherwise. Two short faults that strike more nearly north than those just mentioned are mapped at the head of Aeneas Creek.

The faults described in the preceding paragraph are the only ones of their trend and character for which evidence has been found in bedrock exposures. Long, straight stream valleys trend approximately parallel to these faults. It is possible that some or all such valleys follow lines of faulting or of shearing that facilitated erosion but are not so exposed as to have been detected.

The above summary calls attention to various faults in both regions that have been detected and mapped with different degrees of precision. It is probable that many fractures have escaped detection. Many of the larger tributary streams that flow northeast or southwest are approximately parallel to each other and normal to some of the master streams and to faults that parallel those streams. A few faults along the valleys of such tributaries have been mapped, but studies to date have not yielded enough evidence to warrant sketching faults along most of them. The drainage pattern is so regular as to suggest structural control. The suggestion made by Billings (1938, p. 263) that major valleys are developed along the crests of folds in the plane of the Lewis overthrust may have some validity, but it is supported by little specific evidence so far. Some of the valleys may have been alined along faults not yet detected, and others may be along zones of weakness in the rocks that correspond to fractures or shear zones without significant displacement. Large stretches of the valley sides are mantled by soil, talus, and glacial and other debris that permit few outcrops to be found. Also, particularly in the Flathead region, the forest cover is so dense on some slopes and valley bottoms as to interfere seriously with observation. As noted below, the concept that some of the tributary valleys are carved along zones of weakness and fracture in the underlying rocks would help to explain topographic features whose origin is otherwise puzzling.

INTERPRETATION OF THE STRUCTURE

GENERAL STRUCTURAL FEATURES

In the foregoing, available data in regard to the structural features present are summarized. Much remains unknown or obscure, but enough facts have accumulated to form a basis for discussion and to cast serious doubt on some of the concepts suggested by previous workers, who were under the disadvantage of having only the results of preliminary reconnaissances to work with. The concepts advanced below constitute attempts at interpretation of the observed structural features. Speculations as to the fundamental reasons for the formation of the structural features involve consideration of the origin and constitution of the earth and are beyond the scope of this report.

The accumulation of great thicknesses of sedimentary rocks in the two regions described and the broad undulations of the crust that have interrupted that accumulation from time to time set the stage for the events that gave rise to the structural features observable in the present landscape. More than half a billion years were occupied in preparation for the single period of drastic deformation thus recorded. Readjustments in the rocks deformed at that time are still in progress. In one sense the period of sharp deformation corresponds to what has commonly been called the Laramide revolution. Terms of this kind result from our desire to classify and correlate imperfectly understood parts of gradational processes not strictly subject to such treatment. Thus, the expression Laramide revolution is convenient, provided one keeps in mind that it refers not to a single disturbance but to a series of orogenic episodes separated in time and space (Gilluly, 1949). The major structural features in and near Glacier National Park result from one such episode. Processes more or less directly contributory to the production of the Lewis overthrust and allied structural features probably began long before the part of geologic time to which the Laramide revolution is commonly assigned. Repercussions of that disturbance have continued to the present day.

In the Glacier Park and Flathead regions, the outstanding structural feature is the Lewis overthrust. In front of the present trace of that great fracture is a broad disturbed zone containing many folds and thrusts. Above the main thrust is a massive block that is itself folded. Faults have broken this block and are among the conspicuous and puzzling features of the regional geology. In an attempt to understand the Lewis overthrust and related features, it is necessary to consider (1) the long-held concept that the Lewis is an erosion thrust in which a great block of rock slid over the then-existing ground surface, (2) the date of thrusting, (3) the concept that one or more soles similar to those of the Northwest Highlands of Scotland were produced, (4) the depths involved in the thrust movements, (5) the amount of horizontal displacement, (6) the part played by the folds and, more especially, the faults in the overriding block, (7) the present shape of the Lewis thrust, and (8) adjustments after the thrusting. Each of these will be considered below, but as a preliminary summary, it may be stated that the results of the present investigation indicate that the Lewis thrust is a major fracture that originated deep within the earth and carried a great block of rock a long distance eastward. The thrust is not believed to have reached the surface of the ground anywhere in the vicinity of the region studied and may have played out well below the surface. In any case, the east edge of the thrust is now eroded away. The rocks overridden by the thrust were folded and perhaps broken in the early stages of the deformation and were further crumpled and fractured as the great mass of the overthrust block passed over them.

The different steps in the formation of the Lewis overthrust are shown diagrammatically in plate 4. Steep faults roughly parallel in strike to the overthrust cut the overriding block and may record late-stage adjustments after the major thrust had taken place. Plate 4 is necessarily diagrammatic and generalized. It was drawn with conditions in Glacier National Park in mind, and the last of the diagrams (*D*) is generalized from a block near the center of the park. The dates assigned to the three drawings are relative rather than precise. For example the broad warps shown in the first diagram (*A*) are indicated as of Late Cretaceous age because a fairly continuous record of Cretaceous deposition without angular unconformities is known in nearby areas such as the Flathead region. However, at least in localities west of the park, it is possible, even probable, that the uplift and warping that constituted early events leading to the formation of the Lewis overthrust may have been started earlier in the Mesozoic era. The second diagram (*B*) shows the relatively intense folding that followed the warping. Its date is close to the beginning of the Tertiary. Diagram *C* shows conditions after the thrust had occurred. Here the rocks caught beneath the thrust are more highly contorted than they were at the time represented by diagram *B*. This resulted in part from pressures during thrusting and may have been accompanied by some downward movement of the deformed mass as the heavy overthrust block passed over it. In some localities, notably north of Marias Pass, relatively intense crumpling of the beds is so localized beneath the thrust plane that genetic relationship seems demonstrated. Compression and contortion in the decidedly incompetent Cretaceous strata beneath a thick slab of highly competent Belt rocks would be greater than might be expected in many thrust zones, where the rocks above and below the thrust plane were more nearly equal in strength.

Diagram *C* is necessarily noncommittal as to the manner in which the thrust terminated eastward. The most easterly part of the thrust that is shown consists of several, spreading fractures, in contrast to the single fracture shown (very diagrammatically) farther west. Continuation of the process of splitting up into groups of progressively smaller fractures would permit the Lewis overthrust to die out eastward without anywhere reaching the surface. Whether it did this or actually cracked the surface of the ground somewhere far to the east of the present mountains is unknown. No evidence in support of the second alternative has been recorded nor can it be expected as the whole of the eastern part of the thrust has been eroded away, at least in the latitude of Glacier National Park.

EROSION THRUST CONCEPT

The Lewis overthrust was first recognized and named by Bailey Willis (1902, p. 331–343) as a result of a brilliant reconnaissance that contributed greatly to knowledge of the geology of northwestern Montana. He thought that the thrust plane had emerged near the present mountain front and moved over the then-existing surface of the ground east of the break and that the surface at that time was a peneplain. His ideas have been modified by later investigators, notably Billings (1938), who concludes that the Lewis overthrust is not an erosion thrust, that the part of it now visible was probably a subsurface fault, and that the thrusting is older than the erosion surface over which Willis supposed it to have moved. While his own observations were confined mostly to a small area in the vicinity of Chief Mountain, he utilized much information accumulated by others since Willis made his reconnaissance.

Billings notes that, while in places the thrust approximately corresponds in altitude to ridge tops regarded by Willis as remnants of the supposed erosion surface or peneplain, there are numerous places where it is much higher than these remnants (pl. 4, diagram *D*). Billings rejects the possibility that an older, largely obliterated peneplain may have furnished the surface on which the thrust moved. The erosion thrust concept would be invalidated if no sufficiently flat surface was available for the thrust block to move over. Rough topography would probably halt or break up the moving block. Thus the lack of accord between the probable position of the thrust surface and the ridge crests discussed by Billings casts serious doubt on Willis' interpretation. Further, Billings calls attention to the faults and folds in the disturbed zone in the plains, which are truncated by all remnants of old erosion surfaces there. This fact strongly implies that all erosion surfaces (peneplains or psuedopeneplains) of which traces remain on the high plains east of Glacier National Park are of later origin than the deformation that culminated in the Lewis overthrust.

Another point made by Billings is that if, under any circumstances, a thrust did break through and move along the surface, debris from the thrust block should have been dumped in front of it as it moved over the surface of the ground. Billings searched for such debris without avail, and notes that no previous investigators have reported any; this is one of the most cogent arguments against Willis' original concept of an erosion thrust.

The studies made in 1948–50 did not include detailed observations of the thrust trace in Glacier National Park, where both Willis and Billings worked. However, the mapping in the Flathead region adds evidence opposed to Willis' concept. It would be agreed by all that the steep dips of nearly all of the thrust planes in that region, including the Lewis, imply that they formed at depth; and if any part of the Lewis overthrust emerged from the ground as an erosion thrust, it must have been far to the east of the outcrops of that fault.

Remnants of the supposed peneplain that Willis appears to have regarded as the surface on which the Lewis overthrust emerged near Glacier Park are also present on the plains of the Flathead region. The trace of the Lewis thrust is well within the mountains and generally crops out low on valley slopes. Mountains east of the outcrops of the thrust tower thousands of feet above the highest remnants of old erosion surfaces on the plains as can be seen from the structure sections on plate 2. In order for the thrust to reach these remnants, it would have to bend sharply downward east of the mountains. Figure 20 shows that there are irregularities in the thrust surface and some tendency for the surface to bend downward to the east in the Glacier Park region. Similar irregularities are present in the Flathead region, but the flexure that would be required to extend the Lewis overthrust from its present outcrop over the mountains east of it and down to a position corresponding to the erosion remnants capping ridges rising from the present plains would be fantastic. The inevitable conclusion is that the erosion remnants on the plains bear no genetic relation to the Lewis overthrust. If this is true of the Flathead region, it is hard to imagine how it could fail to be true of the adjacent Glacier Park region. In the Flathead region, just as in the Glacier Park region, all such remnants truncate the folds and faults in the underlying rocks and are younger than these structural features and the Lewis thrust.

The above discussion casts serious doubt on any hypothesis that the Lewis overthrust emerged at the surface anywhere near the localities where it is now exposed. Almost certainly, at the time it was formed, this portion of the thrust surface or zone was deep within the crust. We do not know what happened to the front of the thrust. To the north and south, along the strike, the thrust petered out in minor fractures and folds, but over a hundred miles in each direction was required to accomplish this. In the direction in which the thrust moved, it is not so easy to visualize how a similar process could take place. At the border of Glacier National Park the oldest rocks in the region rest on Upper Cretaceous rocks with a stratigraphic hiatus of more than 30,000 feet. When thrusting occurred, the thickness of deposits of post Late Cretaceous age was small, probably 1,000 feet. Thus, the concept that the unhealed fracture emerged at the surface somewhere to the east is a natural one. However, this concept has no direct evidence to support it. The alternate idea that the fracture zone broke up into successively smaller fissures and terminated without reaching the surface is also plausible. Although the thrust persists far along the strike in both directions, the stratigraphic hiatus is greatly reduced within a short distance. In the central part of the Flathead region (pl. 2), beds of the Missoula group are thrust over Hannan limestone. Similar changes in the shape and attitude of the thrust surface or zone east of Glacier National Park could produce similar decrease in the stratigraphic hiatus. Decrease in the thickness of the Belt series eastward may help to close the gap between the beds above and below the fracture. In the Sweetgrass Hills about 100 miles east of the park and only a short distance beyond the area included in plate 3, it seems probable that Paleozoic rocks rest directly on gneiss of pre-Belt age (Ross, 1950, p. 87), and in Alberta (Burwash, R. A., 1957, p. 101) a similar situation has been found to exist close to the main mountain front. It is not necessary to assume complete juncture of the beds above and below the fracture zone. Perhaps the outer edge of the overthrust block came to rest against a cushion of crumpled Mesozoic rocks.

DATES OF DEFORMATION

The Lewis overthrust must be younger than the Willow Creek formation (Paleocene) (Russell and Landes, 1940, p. 93), which is folded with the other units in the disturbed belt associated with the thrust. On the other hand, the overthrust is older than the beds that have filled structural depressions in the overthrust block. These beds constitute the greater part of the unit mapped on plates 1 and 2 as "old alluvium and associated deposits." The oldest part of this unit has yielded fossils that on the basis of present information are regarded as of Eocene age. On this basis the Lewis overthrust took place in the latter part of the Paleocene or during the Eocene epoch. Of course, preparation for the thrust, including part of the folding, took place earlier, and adjustments of various kinds continued after the thrusting had occurred. The adjustments took place mainly through fracturing of the rocks that were disturbed by the thrusting and by recurrence of movement along the fractures thus produced. The old alluvium and associated deposits have been tilted and locally even crumpled as a consequence of the recurrrent adjustments. The earliest deposits were probably of Eocene date, but some Pleistocene strata are deformed, and minor movements may have occurred more recently. Earthquakes thought to be along old faults have occurred from time to time in northwestern Montana in historic times. None of these very recent disturbances are known to have originated along the faults here discussed (Erdmann, 1947, p. 80–81), but the possibility of slight movements along the faults in the vicinity of Glacier National Park cannot be eliminated entirely.

The concept advanced above that the Lewis overthrust took place late in Paleocene or during Eocene time is in approximate agreement with other estimates for the date of thrusting in the Glacier National Park and neighboring regions. The concept would make the thrust one of the effects of the Laramide revolution, which is the conclusion reached by all previous students of Glacier National Park and its vicinity, although this is expressed in various ways by the different writers on the regions that have been cited above. The reports by Canadian geologists dealing with areas in and near southern Alberta are in accord with this dating, although few of them specifically assign dates to the structural features they describe. Loris Russell (1952, p. 126) stated that the major orogeny in the foothills and plains was post-Paleocene and pre-Oligocene. He regards the postthrust deposits in the valley of the northern part of the Flathead River as of Eocene, probably Middle Eocene, age.

THE CONCEPT OF A SOLE

The discussion above implies that the Lewis overthrust and related fractures were formed under much pressure. The structure has been likened by J. D. MacKenzie (1922), for areas in Canada, and by C. F. Deiss (1943b, p. 1147–1162), for the Saypo quadrangle, to that of the Northwest Highlands of Scotland. The resemblance to the regions here reported on appears to be not nearly as close as the discussions by MacKenzie and by Deiss imply. As the regions are close to known oil fields their structure has practical as well as theoretical interest.

In the Scottish mountains (Caldwell, 1890; Peach and others, 1907, p. 463–476) major, nearly flat thrusts, called soles (Billings, 1942, p. 183) are overlain by blocks cut into segments by numerous, steeper thrusts thought to merge at depth with the soles. The major overthrust farthest back from the front of each disturbed and fractured block is inferred by Peach and his coworkers, in conformity with Cadwell's laboratory experiments, to have been the first to form. They note, however, that at an early stage in the investigation the thrust farthest back from the front was regarded as the last to form, a hypothesis that is still adhered to by E. M. Anderson (1942, p. 102). In subsequent advances this thrust and those in front of it moved forward along the lowest basal thrust or sole which itself was produced by the pressure that resulted in these advances.

In northern Montana, as Deiss has pointed out for the Saypo quadrangle, minor steep thrusts are locally so closely grouped that the structure is imbricate and has enough resemblance to that above the soles in the Scottish Highlands to have attracted attention. However, the imbricate masses are below, not above, the Lewis overthrust. The rock mass above the Lewis thrust has locally crumpled, but on the whole is far from being imbricate. Even in the imbricate masses below the Lewis thrust details of the structure differ from those in the Scottish Highlands. In the Highlands the beds composing each thrust slice in the imbricated masses are approximately parallel to the bounding thrust planes, whereas in Montana the beds are commonly at variance in attitude with the thrusts. Further, in many places in the mountains of the Flathead region, where exposures are especially good, the minor thrusts are fractures on or near anticlinal crests. Some of these can be seen to die out downward rather than to merge at depth with a sole. No such relation to folds has, however, been recorded for the Lewis overthrust. The mylonite zones and other features that testify to extreme compression in the Scottish Highlands are absent in Montana. Also, several major thrusts are recorded in the Scottish Highlands; but in the part of Montana under discussion, the Lewis is the only one known to be of major magnitude.

In the papers cited above neither MacKenzie nor Deiss record direct evidence of the presence of master soles. Deiss pictures such soles in several of his structure selections—but at altitudes a little more than 1,000 feet above sea level, which is far below the limit of observation at the surface. The well near the mouth of Blackleaf Canyon, referred to above, p. 80, extended to a much greater depth than the soles in Deiss' sections without penetrating below the disturbed and faulted zone. In T. A. Link's descriptions of structural features in front of the Rocky Mountains north of Glacier National Park (Link, 1935, 1949) several of the thrusts are referred to as soles. Some of these may be of greater magnitude than any, other than the Lewis, so far recognized south of the international boundary. However, his descriptions and structure sections indicate that the faults he calls soles are not such dominant features of the structure as the soles in the Scottish Highlands are postulated to be. Link's structure sections, based largely on data from wells, corroborate the data from the single deep well in the Flathead region by showing that the disturbed zone in front of the present outcrop of the Lewis overthrust extends to depths far below sea level.

In summary, it now appears that the structure is not as nearly as analogous to that inferred from Cadell's experiments as it was once supposed to be. Possibly some of the thrusts east of the Lewis overthrust deserve to be termed "sole faults" with reference to the minor thrusts immediately above them, but no major underlying regional sole is known. Present data encourage the idea that the Lewis overthrust is the only major, persistent thrust within the regions mapped and the thrusts east of it are subordinate and, on the whole, discontinuous fractures caused by pressures set up during the movements that culminated in the Lewis overthrust. Many are mere fractures along the crests of more or less overturned anticlines. The disturbed zone contains many irregularities in structure and many faults. It includes incompetent rocks and began to be deformed long before movement along the Lewis overthrust began. As the great block of strata above the Lewis thrust was carried forward, the rocks beneath (those of the present disturbed zone) must have been further deformed, and the results of that deformation extend to depths below present sea level. Many of the thrusts within the disturbed zone may have formed during the period of active movement along the Lewis thrust and in doing so may have aided in that movement. This agrees with the suggestion (Peach and others, 1907, p. 472) that "The wedges of piled-up strata showing imbricate structure may be said to have acted like rollers for the transport of advancing masses on higher thrust planes," and that "eventually" friction may have accumulated to such an extent as to produce sharp plication of all the structures overlying the sole. The suggestion just quoted does not seem in close agreement with Cadell's conclusions, but it receives support from the descriptions and structure sections in the chapter that follows it (Peach and others, 1907, p. 477–492).

On this basis, no evidence exists to support the idea that in the Glacier National Park or Flathead regions drilling would penetrate a sole at depth and reach relatively undisturbed beds beneath. In the oil fields in Alberta east of the outcrop of the Lewis and its branches, some of the slices between thrusts in the disturbed zone have proved to be large enough and to possess within themselves the necessary features of structure and of access to source beds so as to retain oil in commercial quantity. In the disturbed zone south of the international border, no such conditions have yet been found although oil fields exist a short distance to the east. Conceivably the broad zone of Cretaceous beds that stretches diagonally across the southern part of the Marias Pass quadrangle would warrant examination by oil men. In general, however, the disturbed zone east of the outcrop of the Lewis overthrust in the two regions discussed in the present report presents many complications and difficulties to petroleum prospectors. Drilling in those parts of the mountains where the Lewis overthrust has not yet been eroded away would seem to be so hazardous as to be futile in the present state of knowledge.

DEPTH OF FRACTURE

The disturbance that resulted in the Lewis overthrust must have originated fairly deep in the earth's crust. Rocks of Late Cretaceous age lie beneath the thrust in Glacier National Park, and these are conformable with beds of probable Paleocene age farther east. The thrust cuts the lowest exposed formation in the Belt series. Thus, it appears that at the time fracture began the whole known thickness of the Belt series, most or all of the Paleozoic and Mesozoic strata and some Cenozioc strata were present in the vicinity of the present eastern border of the park. Deformation and erosion have made it impossible to measure the thickness of all the rocks at this locality, but a conservative estimate would place the aggregate at about 40,000 feet of beds. This estimate includes about 10,000 feet of strata of post-Belt age, corresponding approximately to the thicknesses of corresponding beds in the Flathead region. Similar thicknesses of Paleozoic and Mesozoic strata are known in nearby parts of Canada east of the Lewis overthrust (Webb, 1951).

The rocks caught beneath the thrust include a large thickness of Upper Cretaceous strata. This implies that erosion following the retreat of the last of the Mesozoic seas had not accomplished a great deal in the area near the present eastern border of Glacier National Park before the thrusting took place. If, as is probable, folding preceded the development of the Lewis thrust, areas within the site of the present mountains may have been vigorously eroded. The presence of beds of variegated clay and soft sandstone, with limestone lenses locally (Stebinger, 1916, p. 124–128), of supposed Paleocene age (Russell and Landes 1940, p. 93), east of the park is not in harmony with the concept of intensive denudation in the park area at the end of the Mesozoic. Hence, diagram *C* in plate 4 shows some of the Mesozoic and older strata still present in the overthrust block, although none are left in that block in diagram *D*.

Perhaps erosion after the Cretaceous rocks were uplifted and before the thrusting took place was largely confined to valleys in uplifted areas, and any resulting decrease in load above the thrust zone may have been more than compensated for by thickening of the crust by folds. Certainly the beds above the Belt series yielded to folding before the thrusting began.

Immediately north and south of Glacier National Park, the Lewis thrust cuts horizons far higher than the Altyn limestone that is disrupted by the thrust in the park. However, to the south especially, the dip of the thrust is so steep that the distance beneath the surface must increase rapidly. West of the Glacier Park and Flathead regions, the upper part of the Belt series and all Paleozoic and Mesozoic strata have been eroded, but formations broadly like those described in the present report are thought to have once extended over much or all of northwestern Montana, and many of them are thought to have thickened west of the longitude of Glacier National Park. That this is true as far as the Belt series is concerned is indicated by the large thicknesses reported near the Idaho border (Gibson, Jenks, and Campbell, 1941) and in at least one area in British Columbia (Rice, 1941). The complex structure and extensive erosion in western Montana and in British Columbia hinder the obtaining of data on aggregate thicknesses. Perry (1945) indicates that the Jurassic rocks thickened westward and Reeside (1944) records the same thing for the Cretaceous units. In nearby parts of Canada the thickening of the column from the Cambrian upward was great, according to recent isopach maps (Webb, 1951). Eardley's maps (1951, p. 14, pls. 2–16) show various fluctuations but in general support the concept of basins of deposition that extended into western Montana during much of Paleozoic and Mesozoic time.

The concept that seems to fit the known data best is that the fracturing that led to the Lewis overthrust took place at a depth of some miles, perhaps as much as 10 miles, beneath the then-existing surface of the ground. The estimate is rough because of scanty information and because both the surface of the ground and the fracture zone presumably had significant irregularities. Neither uplift nor erosion was uniform, and the attitude of the fracture zone that constituted the incipient overthrust may have had variations similar to those of the present overthrust.

UPLIFT

Once thrusting began, the block above the Lewis overthrust moved upward and eastward. One of the factors that interferes with attempts to estimate the results is that, at least locally, fracturing was distributed through a zone of considerable thickness. The descriptions given above show that in places thrust surfaces are grouped in zones hundreds or even thousands of feet in vertical extent. A more serious cause of uncertainty is the lack of quantitative data as to the competence of the rocks beneath the thrust zone to resist the pressures developed during the fault movement. The block above the fracture zone did not merely slide forward and upward at angles corresponding to the dip of the thrust surface. The amount of uplift that might be estimated on such an assumption would be decreased

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by the amount that the rocks beneath the thrust failed to resist the pressures exerted on them. Only a faint idea of this can be obtained by direct field observation. Near Marias Pass the soft Cretaceous rocks are crushed and intricately crumpled through a range of 1,000 feet or more (pl. 1 and fig. 21). Most of this deformation is a direct result of pressures during thrusting, but the amount of compression thus recorded may be only a fraction of the downward movement that occurred. Some of the overturning and fracturing recorded in the rocks of the eastern part of the Flathead region and in similar localities probably took place during the major thrusting. In addition to the compression recorded by crenulated zones, fractures, and related structural features, the mass beneath the fracture zone may have been shoved downward as a whole. How much downward movement of this sort occurred depends on factors beyond the limits of observation. It seems safe to assume, however, that downward movements were sufficient for a significant decrease of the net uplift. Even so, uplift sharper and more concentrated than anything previously recorded in the region must have taken place. The result would be accelerated erosion and the carving of mountains. The differences in the topography shown in diagrams *C* and *D* is intended to bring this out.

That erosion after the thrusting was vigorous and effective is proved by the Tertiary deposits that remain. M. D. Billings (1938, p. 270) has called attention to the fact that gravel of supposed Oligocene age derived mainly from rocks of the Belt series mantles remnants of a surface in the Cypress Hills in southeastern Alberta near longitude 110° described by W. C. Alden (1932, p. 4–8). This is evidence that Precambrian rocks were exposed to erosion during the geologic epoch succeeding that in which thrusting occurred. So far as recorded, the gravel immediately east of Glacier National Park contains no material derived from post-Belt rocks; so the latter must have been removed from the site of the park before the late Tertiary, when that gravel began to be deposited.

DISPLACEMENT

Evidence as to the amount of horizontal displacement along the Lewis overthrust is scanty. The most frequently cited distance is 12–15 miles, as a minimum (Campbell, 1914, p. 12; Clapp, 1932, p. 25; Dyson, 1949a, p. 14); this is based on Campbell's assumption that the westward swing of some such distance of the overthrust trace near Marias Pass is a measure of the displacement. The bend in the trace in this locality is related to the sharp change in the dip of the thrust rather than to the distance that the block overlying the thrust has moved forward. The stratigraphic hiatus along the exposed trace of the thrust is, as indicated above, markedly different from one locality to another. Everywhere, however, the hiatus is so great as to suggest that the horizontal displacement was larger than Campbell's estimate. Under one of several hypotheses advanced by T. A. Link (1935, p. 1466), the Lewis overthrust has a displacement of at least 44 miles. This is in harmony with C. E. Erdmann's (1947, p. 78) estimate of " * * * not less than 40 miles." Erdmann's statement was in a summary given in a report on dam sites, and his reasons were not stated. Pierre de Bethune (1936) estimated 40 miles for an area in Canada, based, however, on a somewhat radical interpretation of the structure. At a much earlier stage in the study of the region, R. A. Daly (1912, p. 91) suggested a displacement of "* * * at least 40 miles."

The abrupt westward deflection of the thrust trace north and south of Glacier National Park, referred to in the descriptions given above, shows that the overthrust block within the park is at least 15 miles wide, which is what Campbell had in mind. Surely the block has been much eroded, and it originally extended eastward over at least part, perhaps all, of the disturbed zone. Westward, likewise, it did not terminate immediately beyond the present exposure of the thrust trace. The disturbed zone near the park is about 20 miles wide, and an area of similarly disturbed beds has been reported in Alberta (Williams, M. Y., and Dyer, 1930, p. 88–89) over 60 miles from the mountain border. With these facts, plus the great length of the trace of the Lewis overthrust in mind, the estimates of over 40 miles of horizontal displacement quoted above seem conservative. A much larger displacement is possible.

STRUCTURAL FEATURES ABOVE THE THRUST

A large part of the mountain mass here described has been carved from the great body of rocks above the Lewis overthrust; that is, from the block that was shoved forward over the fractures that make up that thrust. Even though it is so deeply carved and in many places so devoid of soil cover that the rocks are locally very well exposed, much remains doubtful about the genesis of the structural features. The rocks now present are thick bedded and so competent that, except in a few localities, they have escaped the crumpling and intricate faulting characteristics of much of the far less competent rock beneath the main thrust zone. Most of the major folds are broad and open. They might well have originated from simple compression without complexities related to faulting. Perhaps the shallow syncline in Glacier National Park and the uplifts that border it originated in that fashion before the fracturing related to the Lewis overthrust had proceeded far enough to have significant effect.

The extensively crumpled beds near the western border of the park (figs. 26, 28) and similar but less impressive features in other localities may be more closely related to the overthrusting. No overthrusts have been demonstrated in the principal zone of sharp deformation in the western part of the park, but the dips are steep and in part overturned toward the northeast. Little more deformation would be required to give rise to thrusts like those in the eastern part of the Flathead region. Some of the scattered minor zones of sharp deformation that have been described differ in that they show that some westward movement has taken place. The significance of these is a matter for debate. Perhaps they correspond to local irregularities in a region where the dominant pressures were toward the east and northeast.

Perhaps, as some geologists have postulated (Chamberlain, 1925; Flint, 1924; Clapp, 1932), they are related to large thrusts of northeasterly dip. These investigators base their concept primarily on the wedge theory of diastrophism, which attributes the uplift of the mountain ranges or of groups of ranges to the formation of huge downward-pointing wedges bounded by thrusts that dipped under the uplifted wedges from both sides. As noted above, little direct evidence in support of the application of this theory to northwestern Montana has been published. In Canada, as noted above, overturned and overthrust zones have been recognized through a broad region that extends far to the west and north of the vicinity of Glacier National Park. Some of the thrust features dip east, but most students agree that the major pressures came from the opposite direction. Thus, recent studies in Canada give little support to the wedge theory.

The significance of the remarks just made to the two regions described here lies in their bearing on the interpretation of the long, steep faults of northwesterly trend that border many of the master stream valleys. The group represented by R. T. Chamberlain, R. F. Flint and C. H. Clapp would regard the long faults as thrusts, mostly or entirely of easterly or northeasterly dip. Recent Canadian work, such as that reviewed by C. S. Evans (1933) and T. A. Link (1935, 1949), does not rule out thrusts of more or less easterly dip but shows that the principal known thrusts are of westerly dip. If the long faults are thrusts at all, the dip must be easterly as can be seen readily from plates 1 and 2. The simpler and, on the whole, more logical explanation is that they are normal faults. According to this view, those on the northeast sides of the master valleys would dip southwest and those on the southwest sides of the valleys would dip northeast. The scanty direct evidence as to the attitudes of the fault surfaces is in accord with this interpretation. Few of the faults on the southwest sides of valleys are included in the mapped regions. Where they exist, the valleys would be grabens. Topographic depressions like that occupied by the northern reaches of the Flathead River are certainly grabenlike in that the bedrock buried in their floors belongs to units stratigraphically much higher than that on their flanks. The net effect has been that of sharp down drop in elongate zones. The depressions thus produced are now partly filled by relatively younger materials. On the whole, the theory of grabens bounded by normal faults seems best to explain the data at hand.

In the above discussion, necessarily inconclusive, emphasis has been laid on the wedge theory of diastrophism. This is mainly because so much of the previously published discussion has involved consideration of that theory. Other theories, such as the ramp hypothesis that has been applied to certain African and Asiatic valleys (Willis, 1927, 1936; Rich, 1951, p. 1119–1222), or J. L. Rich's idea of deformation through sliding off a dome above a magma mass could be entertained; but in the absence of more complete information, detailed discussion would not be profitable.

There are a number of faults and zones of weakness in the block above the Lewis overthrust not involved in the discussion given above. Most of these are of northeasterly trend and are inferred from such things as lack of harmony between the rocks exposed on the two sides of a mountain valley. Most, probably all, of the faults of northeasterly trend are of moderate to small displacement. They are minor features in comparison to the great faults of northwesterly trends. Some may be tear faults. All, presumably, are related to the great overthrust beneath them at least to the extent that it set up strains in the block above it.

PRESENT SHAPE OF THE LEWIS THRUST

The Lewis overthrust departs drastically from a geometric plane in two respects. First, it is a fracture zone that in many places is surely hundreds and perhaps locally over a thousand feet thick. Second, this zone, or the principal fracture surface, is irregularly curved. Limitations of scale and of available information have masked these features on plates 1 and 2.

In spite of the inevitable generalization, the two geologic maps record essentially all available data as to the fractures that together make up the Lewis overthrust. They indicate that most of the fractures that make up the fracture zone are subordinate in varying degrees to a main fracture represented in essential correctness by a single line on the map. Features like those east of Two Medicine Lake are exceptional. At that locality the fracture zone has at least two major components and has a maximum mapped width of about three-quarters of a mile.

Departures from a plane surface that result from differences in the inclination of the thrust surface (or zone) are of more genetic significance. Within Glacier National Park the dip near the exposed trace is so low that in most exposures it seems almost flat. Both north and south of the park, the dip steepens very sharply. As these changes in dip involve equally wide differences in the stratigraphic units cut by the thrusts, they must correspond to original variations in the shape of the fracture zone. The steeply dipping parts of the thrust zone are in younger rocks and represent a smaller stratigraphic hiatus than the gently dipping part of the thrust zone, which lies between them. No satisfactory explanation of this anomalous situation is at hand. One possibility is that the low-dipping segment within the park, which involves the lowest part of the Belt series known in the region, has been shoved forward and upward along tear faults on either side. This explanation calls for a large fault approximately along the valley of Bear Creek, extending northeast through Marias Pass, and a similar fault in Canada (Link, 1935, p. 1462–1463; Allan, 1937). No such faults are recorded. The mapping along Bear Creek (pl. 1) is directly opposed to the hypothesis as all contacts cross the valley without measurable offset. None of the postulated faults of northeasterly trend, such as that along Ole Creek, has sufficient displacement to accord with the hypothesis of major movement in tear faults. The most probable alternative hypothesis is that the original fracture zone was so extremely irregular in shape as to account for the broad differences in attitude and stratigraphic relations now present at the outcrop.

Minor variations in attitude such as those represented in figure 20 do not involve such significant differences in the stratigraphic breaks along the fault zone as the larger features just commented on. They have been attributed (Willis, 1902, p. 332; Billings, 1938, p. 263) to folding after the thrusting had taken place. In a locality in Canada just north of Glacier National Park, Hume (1933, p. 9) came to the same conclusion. It is at least equally possible that they, like the larger irregularities, are original. This second hypothesis is favored by the lack of system displayed by the contours in figure 20 and by failure of the rocks in the block above the thrust to show comparable features. Folds corresponding to the contours in figure 20 would be roughly at right angles to the regional folds and faults. As there is no evidence of major deformation in that direction, folds of that trend would be results of adjustment during or following the thrusting.

The variations in the shape of the thrust zone discussed above are related to present exposures of that zone in the eastern parts of the two regions mapped. Other variations must exist in parts of the zone west of these exposures. Suggestions have been made that such variations, presumably the result of folding after the thrust took place, have brought the thrust to the surface along the upper valley of the Flathead River. Folds of this character would parallel the regional structure, and it would be difficult to determine whether they formed during the thrusting, immediately after it, or as a result of distinctly later and unrelated pressures. The question of the date is significant in connection with problems of origin, but whether or not the Lewis overthrust is exposed at the surface somewhere west of its well-known trace at and near the mountain front has several connotations. It affects interpretation of the structure in the vicinity of the upper reaches of the Flathead River and the character, thickness and origin of the deposits there, and it also has a bearing on the possible presence of oil.

In Canada the concept of thrusts folded approximately parallel to their strike has attained wide acceptance. G. S. Hume (1933, p. 7–12) believes that the Lewis overthrust in Waterton Lakes Park (immediately north of Glacier National Park) is warped, and he quotes an oral statement by V. R. D. Kirkham that the valley of the northern part of the Flathead River may be a window in that thrust. Pierre de Bethune (1936) had similar ideas about the area farther north. T. H. Link (1935, p. 1464–1466) mentioned the concept of a window in the Lewis thrust as one of several possible explanations of the structure along the Flathead River but expressed doubt as to its validity. J. C. Scott (1951) has summarized data on folded thrusts in the foot hills of the Rocky Mountains in Alberta and shows conclusively that in several localities thrust faults have been sharply folded. His paper cites 23 previous papers, many of which present similar ideas having varying degrees of probability. With such widespread evidence that thrusts in Alberta have been drastically folded, the Lewis thrust in the Glacier National Park region might well be expected to have been folded similarly. This does not necessarily follow because, as has already been pointed out, conditions in that region appear to be different from those farther north. In the Glacier National Park region, a single thrust of exceptionally low dip dominates the structure. It is overlain by a block of competent rock. East of that block the far less competent rocks beneath the thrust are folded and faulted. Few details are known, but no thrusts at all comparable to the Lewis have been found east of that thrust either in the Glacier National Park region or in the better known area in the Flathead region.

If, in accord with conditions farther north, the Lewis overthrust in the regions here described has been drastically folded, the most probable places to look for evidence of that folding is in the big valleys of northwesterly trend. The valley of the northern part of the Flathead River (locally termed "the North Fork") would seem to be an especially favorable place to look. The evidence at hand is far from conclusive but, so far as it goes, is opposed to the concept that any of the northeastward-trending valleys are windows in a folded thrust. This concept requires that the faults on either side of each of the valleys would dip toward the mountains, whereas they seem to dip in the opposite direction—toward the valleys. If the valleys are windows, beds of Mesozoic and perhaps also of Paleozoic age, which are comparable to those known to underlie the thrust farther east, should be present in them. None have been found. On the contrary, beds later than the thrusting underlie the mantle of Quaternary deposits in the valleys. To be sure, early Canadian maps (Link, 1932; Daly, 1912, map 74A, sheet 1) show beds of Mesozoic age in the valley of the Flathead extending south to or across the international boundary. These were sought for without success during the present investigation and do not appear on recent geologic maps of Alberta and British Columbia (Canada Geol. Survey, 1928, 1948, 1951).

ADJUSTMENTS AFTER THE THRUSTING

The block of rock that overlies the Lewis overthrust is cut by faults both approximately parallel to and approximately normal to the strike of the thrust. Available data leave much in regard to the faults open to question, but the most probable hypothesis is that most are steep normal faults. Those of northwesterly trend include many with thousands of feet of vertical displacement, whereas those of northeasterly trend have such small displacements that they are difficult to recognize. If these concepts are accepted it seems evident that much or all of the movement on both sets, but especially on those of northwesterly trend, is later than the thrusting. The rock remaining above the Lewis thrust consists almost entirely of beds of the Belt series. The very fact that this rock is so competent that much of it did not yield enough to be closely folded before and after the thrusting implies that the block as a whole did not accommodate itself to irregularities in the thrust zone over which it was shoved. Hence, strains must have been set up in it. Relief of such strains after much or all of the thrust movement had ceased might well result in normal faulting. The faults under discussion are inferred to have resulted from adjustments of this character. None of the apparently normal faults carried any rock of Paleozoic or Mesozoic age down into positions now exposed. Such rocks might be buried under the Cenozoic deposits in the larger valleys, but this is improbable as none of the Cenozoic rocks are known to contain detritus eroded from them. Thus, much or all of the normal faulting may have taken place long enough after the thrusting, so that erosion had had time to lay the strata of the Belt series bare. When the thrusting began, much of the Mesozoic material was still in place. In terms of geologic time the interval between thrusting and relief of strains by normal faulting was not great. Some of the Cenozoic deposits in the valleys are probably at least as old as Oligocene.

Faulting on the large scale believed to have taken place where the major valleys of northwesterly trend now are must have interfered seriously with whatever drainage existed at the time. As a result the principal valleys bordered by faults are floored by extensive deposits. These include some coal and some fine-grained sediments; so parts of the valleys at times contained swamps and lakes. On the other hand, coarse sediments are abundant enough to show that through-flowing streams occupied the valleys much of the time. There must have been repeated shifting along the faults with resulting modifications in the drainage, for the beds of early Tertiary to early Pleistocene age that constitute the valley fill are all tilted, and some are crumpled.

SUMMARY OF STRUCTURAL INTERPRETATION

The greatest accumulation of sediments in the regions described took place during the latter part of the Precambrian era, but the deposition was not followed by marked diastrophism. From the close of the Precambrian through the Mesozoic era, sedimentation continued with interruptions that probably resulted from broad crustal upwarps. At some time late in the Mesozoic, preparations began for the single period of intense deformation recorded in the rocks of northwestern Montana. The first movements may have been broad upwarps similar to the earlier ones, but as diastrophism continued the rocks were folded. During the Paleocene the folding continued until, late in Paleocene or early in Eocene time, a major fracture zone developed, presumably much to the west of the present location of Glacier National Park and at a depth of some miles below the then-existing surface of the ground. The block of rocks above the fracture zone was thrust forward as a unit toward the northeast. Some of the anticlines beneath the overthrust block may well have been broken before the major overthrusting took place, but fracturing and crumpling continued in them as the overthrust block passed over and pressed down on the deformed strata, the upmost of which were much less competent than the lowest and thickest part of the overthrust block. In places intense crumpling and crusting of incompetent, shaly beds took place immediately beneath the moving block. The fracture zone itself varied in original shape and in the number of component fractures. It may have been further folded in the course of the thrusting although evidence in support of this is inconclusive. Direct measurement is impossible, but it is reasonable to estimate that the overthrust block was shoved northeast at least 40 miles. The zone of fracture was well below the surface in the longitude of the eastern border of Glacier National Park at the time that the overthrust movement ceased. Whether or not that zone, or a part of it, reached the surface somewhere farther east has not been determined. Possibly pressure dissipated eastward, and the fracture zone broke up into minor fissures and finally feathered out without emerging at the surface.

When the overthrusting ended, the block of rock above the fracture, or thrust zone, was left in a state of strain and had been raised sufficiently to make much of it subject to active erosion. Normal faults relieved the major strains, but complete equilibrium may not have been attained even yet.

GEOMORPHOLOGY

GENERAL FEATURES OF THE GEOMORPHOLOGY

The deformation that reached a climax in the Lewis overthrust was followed by uplift and accelerated erosion early in Tertiary time. The major structural features trend northwest and had a marked effect on the development of the initial drainage pattern. Erosion by the streams thus started has produced ranges and groups of ridges with trends that are influenced by structure. The steep faults that border several of the ranges made great contributions to outlining the mountain masses. Irrespective of whether these faults are normal or reverse, they constitute large, persistent fractures that, relatively speaking, dropped blocks of the earth's crust along the sites of certain major valleys. The depressions thus formed became sites of deposition for soft rocks of Tertiary and later age, whose relatively easy excavation by streams has tended to perpetuate the topographic forms. Subsidiary fractures of northeasterly trends produced weak zones in hard rocks that also facilitated the work of the streams. The present reticulate drainage pattern is, to a degree, a survival of the pattern that originated along structural lines, modified in various ways by incidents that accompanied the removal by erosion of thousands of feet of rock. On the plains the rocks above the Lewis thrust have been almost completely removed by erosion. The vulnerability to erosion that permitted this is still operative and is resulting in the relatively rapid retreat of the mountain front, with consequent steep slopes and cliffs.

No summit peneplain is thought to exist, but the gradual rise of the mountainous region was checked sufficiently to permit formation of a surface of mature relief, termed the "Blackfoot surface." This surface reached its greatest degree of maturity late in the Tertiary. It was still little modified when the earliest of the glaciers of the Pleistocene epoch formed. After one or more glacial episodes, renewed erosion cut deep valleys into the modified Blackfoot surface. Glaciers of Wisconsin age occupied and reshaped these valleys. Later, revived stream erosion cut gorges ranging in depth from a few score to over 100 feet. Within the last few thousand years new glaciers have appeared in the cirques left by the far larger glaciers of Wisconsin age. During the present century these have declined, but it seems quite possible that fluctuation of the climate will revive them before they are all gone.

EFFECTS OF THE EARLY TERTIARY UPLIFT

The Lewis overthrust left most of the two regions here described at altitudes much above those before the diastrophism. Carving of the present mountain masses began at that time. Erosion was guided by structure, and in a general way this has continued to the present. Most ranges and major components thereof correspond rather closely to structural trends, and their crests coincide reasonably well with anticlines and upthrown fault blocks. The major syncline in Glacier National Park lies in part between the Lewis and Livingstone Ranges, and there are many similar correspondences between structural and topographic depressions. Fault scarps have retreated enough to obscure the character of the fractures, but there has been little of the tendency to that inversion, as a result of which, in many other regions, mountains are underlain by synclines and valleys by anticlines as a result of long-continued erosion. This situation has persisted in spite of the removal from the overthrust block of nearly all the Paleozoic and Mesozoic strata. Because of the large amount of rock that has been eroded away, present topographic features probably should be regarded as resequent rather than consequent, resulting from adjustments to structure at levels far below the original surface.

One probable major modification in the topography results from the retreat of the mountain front, especially in the latitude of the park. In that latitude a block of resistant, but in part extensively fractured, rock originally had been shoved at low angles over far less resistant rocks to a distance far east of the present mountains. As soon as the leading edge of the block was exposed to erosion, it must have been vulnerable to sapping because of the great difference in the character of the rocks above and below the thrust zone. Lateral corrasion by streams would have progressed faster in the yielding Cretaceous rocks beneath the fracture zone than in the hard rocks of the Belt series. Landslides similar to those that now interfere with road maintenance in the vicinity of the thrust trace must have been frequent and large. They would have aided stream erosion in the removal of the overthrust block and, hence, in promoting the retreat of the mountain front. Wherever streams succeeded in cutting through the hard rocks of the overthrust block into the soft, clayey rocks beneath, new areas subject to sapping were exposed, and destruction of the outlying part of the overthrust block was correspondingly hastened.

Some of the largest valleys are related in origin to faults that are, at least in part, later than the Lewis overthrust. These are the valleys cut by the principal forks of the Flathead River. Each of these valleys is, in varying degree, associated with large faults which appear to have moved at times subsequent to the major thrusting. The faults tended to produce grabenlike depressions of northwesterly trend that were filled with sediments, the oldest of which may be of Eocene or Oligocene age. The South Fork of the Flathead and the part of the Flathead River locally called the North Fork still occupy faulted and filled depressions. The same is true of the Middle Fork, but the relation is less obvious because hills of hard rock intervene between the faults and the river channel. The fact that the faulted depressions were filled to depths of thousands of feet by clastic material shows that the faulting disturbed the then-existing drainage. It seems a logical assumption that streams corresponding fairly closely to the three forks of the Flathead River were present after the thrusting but were interfered with sufficiently by the later faulting, so that they could not keep their valleys cleaned out. Perhaps the streams were merely checked enough so that marshes and ponds developed in places along the faulted parts of their valleys. Perhaps at intervals during the Tertiary period and the early part of the Pleistocene epoch, the streams were blocked entirely, and lakes filled their valleys. Such interference with drainage could be brought about in various ways, such as renewal of movement along the faults, landslides, or glacial activity.

Some transverse valleys within mountain masses are believed to have formed along zones of weakness related to faults. Even where faults of marked displacement cannot be detected, shearing parallel to the regional system of transverse faults may have facilitated erosion. Many valleys originated before the post-Belt rocks were removed and may have been controlled by structural features in those rocks not detectable in the resistant rocks that remain.

CONCEPTS AS TO A SUMMIT PENEPLAIN

If a peneplain or similar feature once extended over the summits of the mountains, no evidence of it remains. Such relatively flat erosion remnants as exist are far below the peaks. Both Daly (1912, p. 599–642) and MacKenzie (1922, p. 105–106, 118–119) oppose the concept of a high-level peneplain in the mountains near the international boundary. Even though some of their arguments may be open to doubt, it is abundantly clear that these two independent observers of the mountains just north of Glacier National Park found no topographic features that they regarded as remnants of a peneplain at or near present summits. Much of Daly's discussion is devoted to showing that many factors in the history of a mountain range tend toward accordance of summit levels. In and south of Glacier National Park, however, the peaks have such a wide range in altitude that any surface passed through them would have a relief of the order of fully 3,000 feet. Daly's discussion suggests that the actual relief on the original surface from which the peaks were carved could have been much greater because normal mountain erosion has some tendency to produce equality of summit levels.

W. C. Alden (1932, p. 4–10) has described remnants of an extensive surface of Oligocene age, called the Cypress Plain, east and northeast of Glacier National Park but identified nothing correlative with that plain in the immediate vicinity of the Park. He concluded that there are no known "* * * remnants of land forms of Oligocene time in the mountains of the Glacier National Park region, unless they are the peaks of the mountains themselves, and even these have probably been greatly modified by erosion in subsequent ages."

A. C. Lawson (1925), using data presented by Alden (1932, p. 4–17) as to erosion surfaces in eastern Montana has attacked the problem from the standpoint of the theory of isostasy. Using assumed data for the specific gravity of the rocks involved, he derives figures for conditions in Canada just north of Glacier National Park, though he emphasizes they can be approximations only. His calculations indicate a removal of a prism of rocks 9,075 feet thick from the mountains since Oligocene time, with a resulting uplift of 5,675 feet. This would give a net reduction in altitude of the mountains of 3,400 feet. If anything like 9,000 feet of rock has been removed from the mountains since the Cypress plain was formed, it is obvious that no traces of that surface would be preserved in the present mountains. Alden's estimates are not as large as Lawson's and might permit remnants of a surface correlative with the Cypress plain to lie below the present mountain peaks, but he recognized no such surface.

The various lines of argument outlined above appear to justify the assertion that since the Lewis overthrust and related phenomena disturbed the region, plains topography has at no time succeeded in extending itself over the site of the present mountains. In other words, there is no summit peneplain.

BLACKFOOT EROSION SURFACE

Although the mountains have been actively eroded since near the beginning of the Tertiary period, the process has not been continuous. Flat-topped ridges on the plains just east of the mountains have been interpreted by various observers, notably Willis (1902, p. 310, 336) and Alden (1932, p. 13–17) as remains of old erosion surfaces. Their counterparts must be present in the mountains, although the evidence is not everywhere as clear as could be desired. Willis called the oldest erosion surface he recognized the Blackfoot surface, whereas Alden spoke of the same surface as equivalent to his Flaxville plain or No. 1 bench and proposed to drop the name "Blackfoot surface." As the present report concerns areas in and adjacent to that for which Willis originated that name and areas far from the type locality of the Flaxville plain, it is proposed here to revive the use of the term "Blackfoot surface" for the general vicinity of Glacier National Park. It is not intended, thereby, to question the validity of the use of the term "Flaxville plain" in its type locality, which is in northeastern Montana, or in areas sufficiently near that locality so that the plain can be traced fairly continuously. The erosional remnants close to the mountains that are tentatively postulated by Alden to represent the Flaxville plain are isolated features. Their correlation with the Flaxville plain is based on assumed gradients projected many miles westward from definitely recognizable parts of that plain. Alden recognizes erosional remnants at one or more levels below his No. 1 bench near the mountains, which adds to the uncertainty as to the correlation of any set of benches with the Flaxville plain of eastern Montana. Alden is in a better position than anyone else to make broad correlations of erosion surfaces in the general region, and the term "Blackfoot surface" is revived in the present report solely for the purpose of being cautious, a caution which is shown to some extent by Alden in his latest published paper (1932, p. 15). As the name "Blackfoot" is taken from the name of the Indian Reservation east of the park and the tribe living there, it might be more appropriate to spell it "Blackfeet". This would be in accord with local usage and apparently with the usage favored by F. W. Hodge (1910, p. 570–571); but as usage is not strictly standardized, the change would serve no useful purpose.

Whether one chooses to speak of the Blackfoot surface, the No. 1 bench, or the Flaxville plain, the oldest erosion remnants immediately east of the park described by Willis and by Alden are the same topographic features. Concepts as to the age and origin of the old surface of which these features are modified remnants have varied since Willis proposed the name Blackfoot surface, but his name nevertheless has priority for the region close to the park. Willis (1902, p. 340), in line with his concept of the structural history of the region, thought that the Blackfoot surface was warped and that correlatives of it within the mountains have been elevated out of harmony with the surface in the plains area as a result of the Lewis overthrust. Present concepts as to the regional structure require the feature Willis called the Blackfoot peneplain, or surface, to be younger instead of older than the thrusting, so that his assignment of an early Tertiary age requires revision. Alden's discussion (1932, p. 4–17) indicates an age of Miocene or Pliocene. Apparently the plain had been essentially completed by the end of Miocene time, but streams did not dissect it extensively until much later.

The remnants of the Blackfoot surface and other similar surfaces on the Great Plains are so flat and so nearly at the same altitude that the term "peneplain" has been applied to them. However, the remnants at some distance from the mountains are mantled by gravel interpreted as deposits made by swift streams in the course of eroding the plains. They originated far from the sea and at altitudes thousands of feet above sea level. It would appear that the Blackfoot, Flaxville and similar surfaces were made up mainly of stream valleys that had widened and coalesced as a result of lateral planation by active streams. Wasting away of interstream areas by soil creep and similar processes undoubtedly occurred, but there is no evidence that stream erosion had become so feeble that such wastage processes were dominant. Hence, none of these surfaces seems to fit strictly the concept of a peneplain as advanced by W. M. Davis (1899, p. 207–239; 1902). They are more nearly panplains (Crickmay, 1933, p. 337–347) or, close to the mountains, pediments (Bryan, 1925, p. 93–97). A significant difference in the present connection is that the production of panplains or mountain pediments by active corrasion would require much less time than the wastage that would culminate in a peneplain (Cotton, 1948, p. 273–275). Perhaps even more significant is the fact that panplains and pediments are more local, restrictive features than peneplains, strictly defined. The Blackfoot surface, and associated surfaces, may have been broad expanses in the region of the present Great Plains, but they came into abrupt contact with the ancestral Rocky Mountains. Areas of subdued topography are believed to have anastomosed into the mountains, but there is no evidence that the mountains were obliterated or even extensively subdued as they would have been by peneplanation.

To a degree, the hesitation to apply the term "peneplain" to surfaces in the Glacier National Park and Flathead regions may result from inadequacies in present general concepts as to how peneplains may originate and as to the expectable land forms related to them. Difficulties in accepting conventional views as to peneplains have been pointed out by L. C. King (1953). This is not the place to discuss his paper in detail, but it may be remarked that his proposal to substitute "pediplain" for "'peneplain" is of fundamental interest. If regional surfaces of low relief can be thought of as resulting from the coalescence of many pediments, difficulties in comprehending, correlating, and interpreting features currently spoken of as peneplains might be lessened.

Both Willis and Alden regarded the numerous relatively flat-topped ridges just east of the mountains as remnants of the Blackfoot surface (No. 1 bench or Flaxville plain). These include Kennedy Ridge, Swiftcurrent Ridge, St. Mary Ridge, Milk River Ridge, Two Medicine Ridge, and numerous similar ridges farther south in the Flathead region. The ridge tops are mantled by gravel which Willis (1902, p. 310, 315, 328–330) interpreted as debris carried from the mountains by streams. Alden (1912, 1914; Alden and Stebinger, 1914), in part in company with Stebinger and others, has reexamined the high-level benches east of the park mentioned by Willis and accumulated data on similar benches to the north and south. He presents much evidence in support of his contention that the gravel on these benches is glacial drift of early Pleistocene age, rather than the alluvial deposits that Willis envisaged. Nevertheless Alden's most recent publication on the subject (Alden, 1932, p. 14, 15, pl. 1) mentions and maps similar benches a little farther east capped by gravel of nonglacial origin and regarded by him as the probable equivalent of the Flaxville gravel (Miocene or Pliocene). Thus, in spite of Alden's discovery that some of the high-level gravel is of glacial origin, it seems clear that benches whose tops represent the Blackfoot surface and which are in part still mantled by alluvial gravel of suitable age remain on the plains close to the mountain border.

If the Blackfoot surface east of the mountains is the product of lateral stream corrasion coupled with the deposition of alluvial fans, then that surface must have tended to extend itself back into the mountains, and remnants may be expected there. M. P. Billings (1938) has disproved Willis' thesis that such a surface within the mountains would be out of harmony with the part in the plains area. Remnants of the Blackfoot surface are believed to be present within and west of the mountains in and south of Glacier National Park although the evidence in many places is obscure. The topographic feature that most attracts attention in this connection is the top of Flattop Mountain, between the Lewis and Livingstone Ranges. This feature has been vividly described by F. E. Matthes (1904), who, however, did not speculate as to its origin. Its possible relationship with the Blackfoot surface has been pointed out in the papers by Willis and Billings above cited. In the unpublished report on the work of Campbell's parties in Glacier National Park, Alden expresses his opinion that the top of Flattop Mountain, some other relatively flat surfaces within the mountains, and the spurs east of the Flathead River (North Fork) north of West Glacier are all to be correlated in age and origin with the Blackfoot surface (his Flaxville plain). He speaks of them as having been affected by early Pleistocene glaciation although he cites no drift of comparable age remaining on them.

Observations made during the present investigation are in agreement with those of Alden as to preservation of erosion remnants of Blackfoot age in and near the mountains. In the descriptions that follow the data obtained during the fieldwork under Campbell (assembled and interpreted by Alden) are freely drawn upon. The general conclusion is that the highest flat-topped ridges on the plains to the east, the prominent bench-tops in the principal valleys of the Flathead drainage system, and numerous high-level benches and related features within the mountains at high altitudes are all remnants of the Blackfoot surface. That surface was fairly level on the plains and in the largest valleys, but it spread through the mountains as a flood-plain system with many and prominent unreduced elevations between the streamways. That is, the area now occupied by mountains was hilly but contained broad, gently sloping valleys. The first of the three views in figures 30–32 represent a landscape near the crest of the Lewis Range in Blackfoot time. The illustration is based on an oblique aerial photograph by the U. S. Army Air Corps taken from the northeast and showing the head of Red Eagle Creek with Blackfoot Mountain in the background. The third of the views in figures 30–32 represents modern conditions and is essentially a copy of the photograph. For the purpose of bringing out pertinent features, all three views show more of the foreground than was included in the original photograph.

Probably the summits of Flattop and West Flattop Mountains together represent the largest single intramountain plain of Blackfoot time. It formed and has been preserved in large part because of the aid to erosion afforded by the structure of the underlying rocks. The two mountain tops lie along the trough of the major syncline in the region, which is here exceptionally wide and gently dipping. Presumably the undulating plain preserved on their summits originally merged with the relatively flat areas now known as Granite Park, the bench north of Glacier Wall, the Hanging Gardens, and others. It may well have extended northward over the present Waterton Valley, remnants being preserved in the flat south of Kootenai Peak, the nearly flat crest of Porcupine Ridge, the bench south of Campbell Mountain, and similar features. The tops of Flattop and West Flattop Mountains have benches that may record incomplete attempts at leveling through lateral corrasion by streams that have now vanished. Few and generally feable streams now traverse them. Undrained depressions, in part occupied by ephemeral ponds, are common. Kip Creek, which flows southeast through marshes not recorded on the map and which swings abruptly east down the cliffs on the flank of Flattop Mountain into the canyon of Mineral Creek, is obviously abnormal to the present drainage pattern. Perhaps its ancestor flowed northwest over the Blackfoot surface through the present Kootenai Pass. There are many benches in nearby parts of the Lewis Range such as the one utilized by the trail from Logan Pass to Granite Park; these benches may be remnants of the old Blackfoot surface. Some of these have been modified

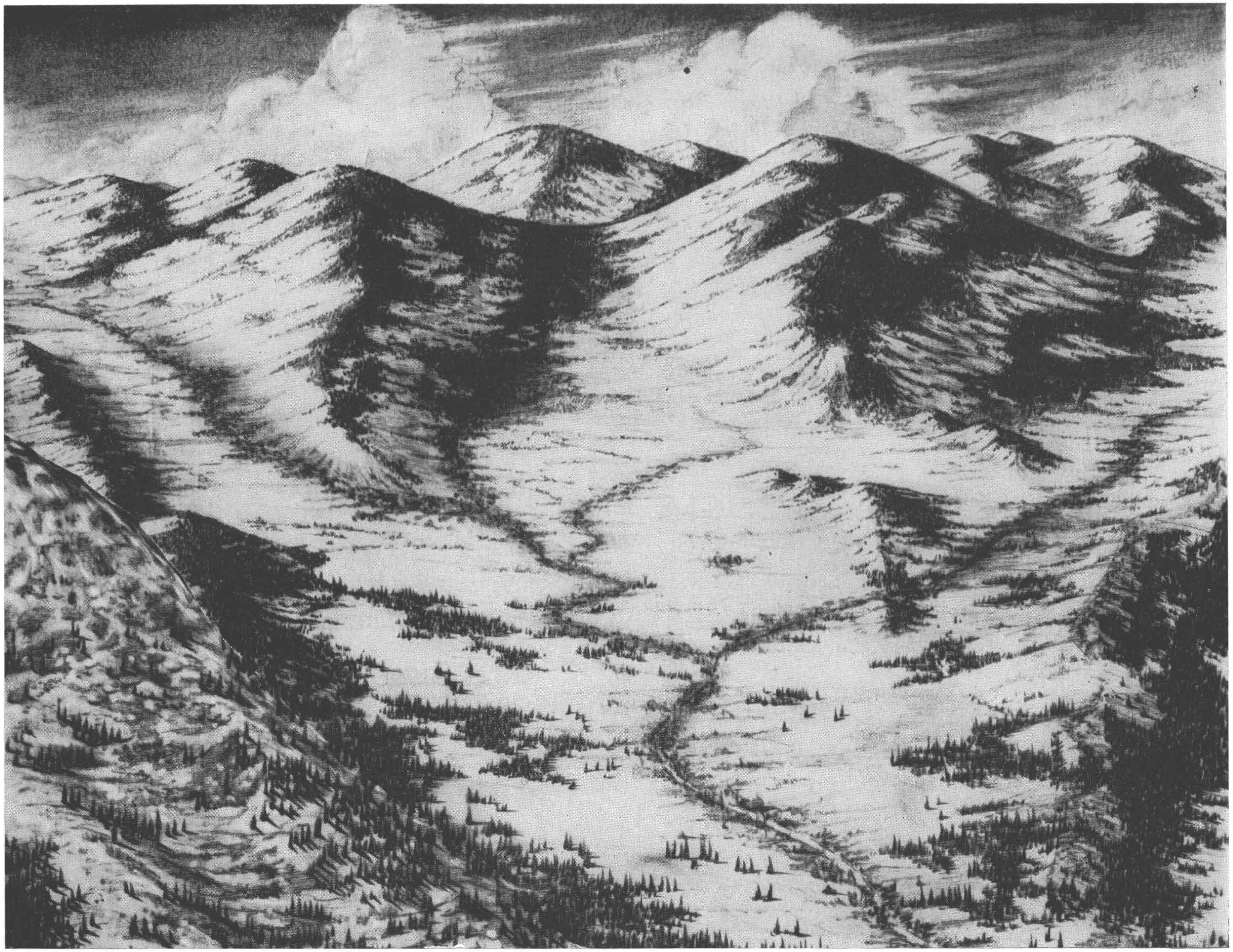

Figure 30.—View showing topography after the Blackfoot surface had formed in the area of Glacier National Park. Based on an oblique aerial photograph by the U. S. Army Air Corps; taken from the northeast and showing the crest of the Lewis Range in the vicinity of the head of Red Eagle Creek.

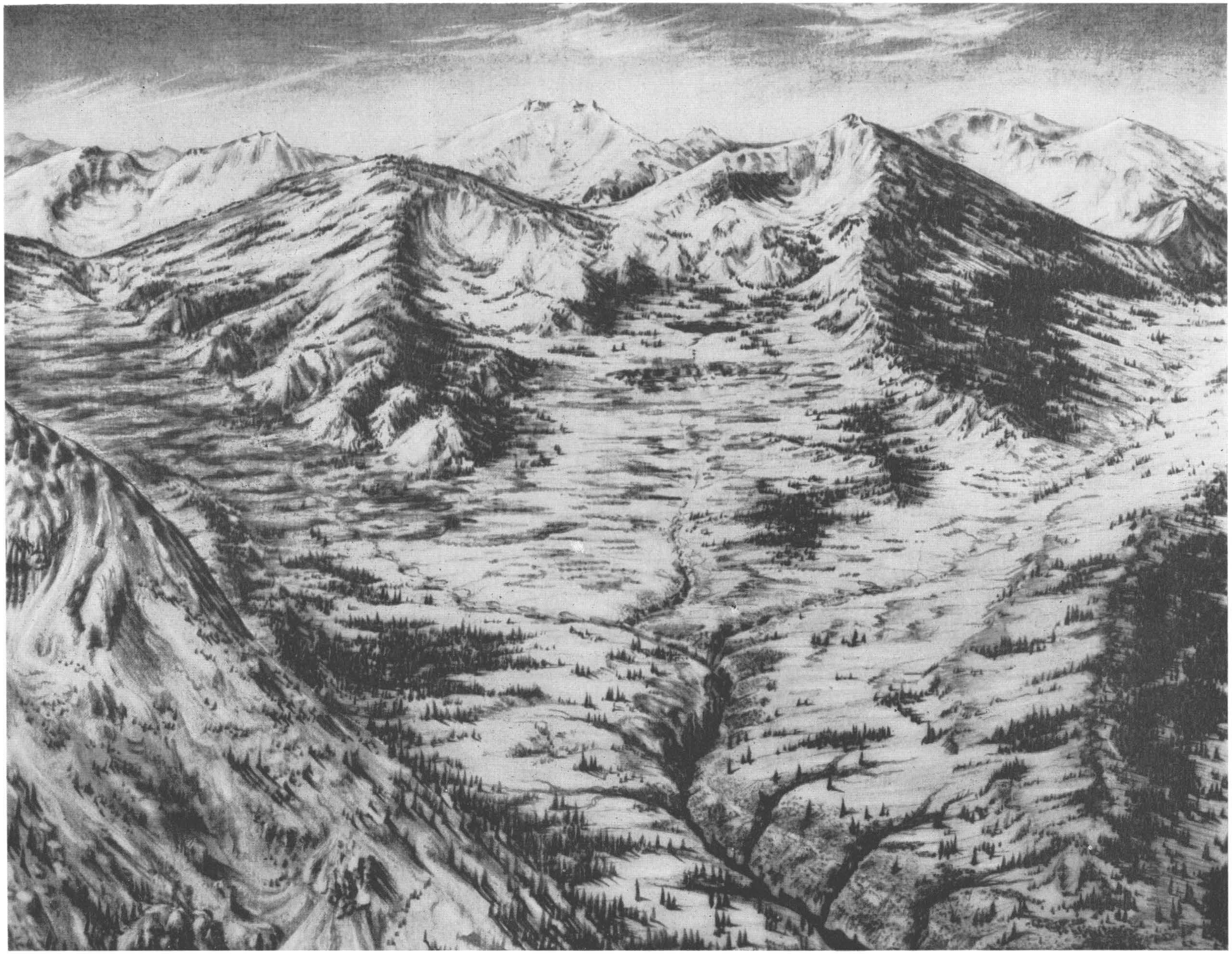

FIGURE 31.—View showing topography in the area of Glacier National Park at about the middle of Pleistocene time, during the stage of accelerated erosion that preceded the main Wisconsin glacial advance. Based on an oblique aerial photograph by the U. S. Army Air Corps; taken from the northeast and showing the crest of the Lewis Range in the vicinity of the head of Red Eagle Creek.

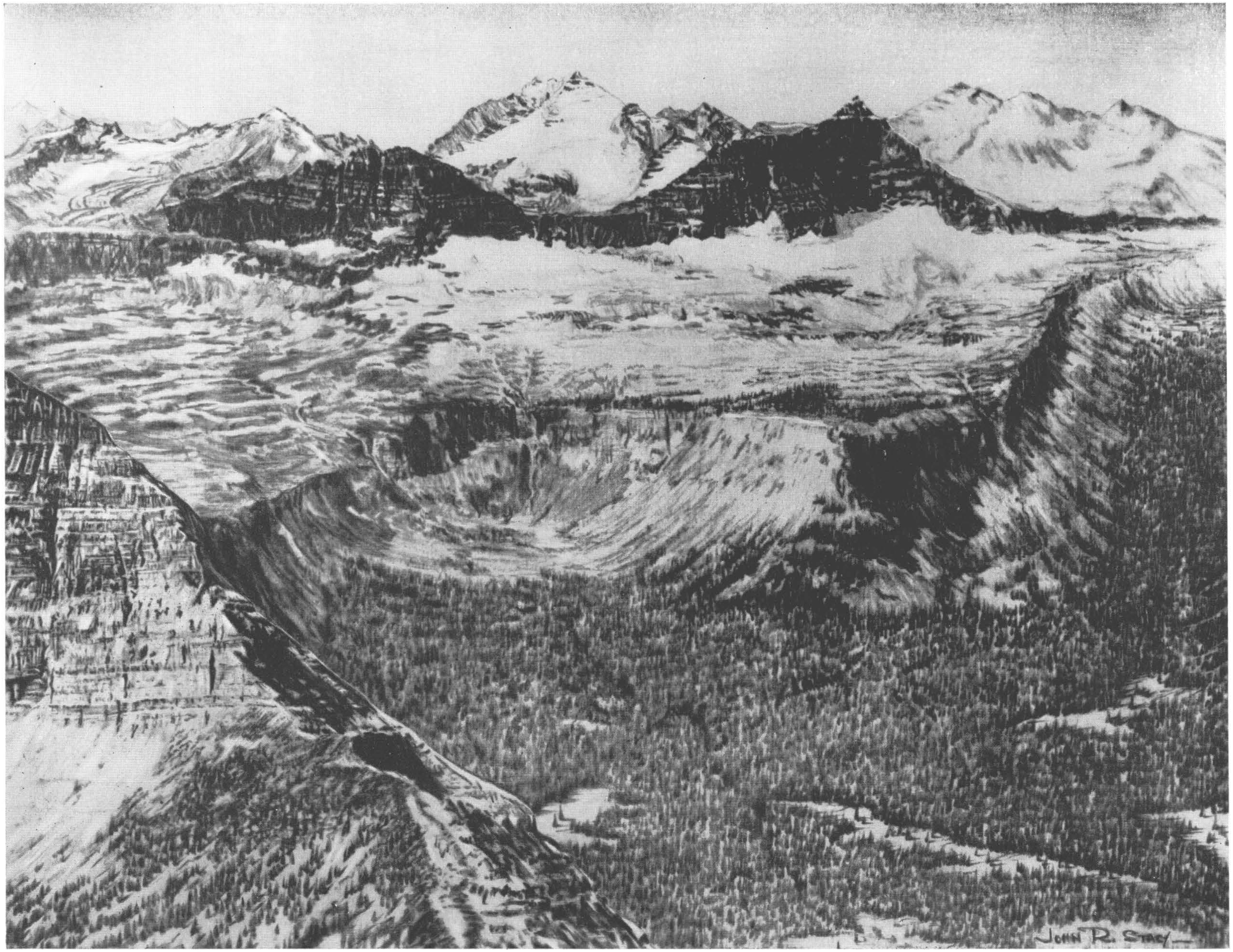

FIGURE 32.—View showing topography in Glacier National Park at the present time. Based on an oblique aerial photograph by the U. S. Army Air Corps; taken from the northeast and showing the crest of the Lewis Range in the vicinity of the head of Red Eagle Creek.

by glaciation and are now occupied by cirque lakes or even by small glaciers such as Chaney Glacier. Many of the wind gaps that now serve as passes are at altitudes sufficiently comparable to the benches to suggest that they originated in Blackfoot time, or approximately so. Erosion by streams and glaciers has been so active in Pleistocene and later time that many details are obliterated.

Figure 33 is intended to give an idea of the topography in Blackfoot time. It is drawn on the assumption that erosional remnants already cited and others to be mentioned below are parts of the Blackfoot surface, which was lowered and modified by later events. The map shows the principal areas thought to be correlatable with the Blackfoot surface—the contours correspond to altitudes greater than the present altitudes of the erosional remnants. This is to allow for the fact that most or all the remnants have been lowered by weathering, glaciation, and other processes that have occurred since the Blackfoot surface was first formed. The altitudes assigned to the diagrammatic contours are referred to present sea level without regard to any oscillations of the land that may have taken place between Blackfoot time and the present. Figure 33 is intended to represent the surface at the time of its maximum extent. The various erosional episodes from the end of the disturbances related to the Lewis overthrust to the time when gravel of late Miocene age was deposited on the plains to the east contributed to the carving of the Blackfoot surface. According to Alden's concepts of erosional history east of the mountains (Alden, 1932, p. 4–17), that surface may have persisted with only minor modification until the close of the Tertiary period.

Figure 33 contrasts the topography of the Blackfoot surface with that of the present day (taken from pl. 1). Relative to present sea level, the Blackfoot surface was at greater altitudes than comparable parts of the present surface. It was, however, far less irregularly and sharply dissected.

The long smooth-topped spurs on the southwest side of the Livingstone Range are so different from the rugged mountains immediately east of them as to demand an explanation. They are composed mainly of the sediments of early Tertiary age that fill the ancient fault-outlined valley of the northern part of the Flathead River. The old fill is deeply dissected by streams from the mountains. The resultant spurs are now mantled by unconsolidated debris that has lost its original topographic forms to such an extent that the details of origin are obscure. Data collected by Campbell and his men lead Alden (written communication) to the opinion that, in various localities unconsolidated material includes stream gravel on the spur crests and glacial drift, probably of two or more ages. The topographic form induced Daly (1912, p. 538–584, pl. 2) to suggest that the spurs are moraines, but this idea is entirely at variance with the facts since discovered. Alden's ideas accord with the concept gained during the present study that the spur crests are modified remnants of an erosion surface carved on the old fill, itself somewhat deformed, before the rejuvenation that gave rise to the present incised valleys.

Alden in his unpublished manuscript on the park postulates that certain high-level cirques and bench remnants at the heads of the stream valleys now cut into the old fill east of the Flathead River mark the approximate positions of the upper reaches of these streams before incision. One of the best preserved of the upland benches is at the head of Logging Creek. This bench has about a dozen small rock-bound lakes on it, part of which drain north into Waterton River. It is thus a relatively level area that straddles the continental divide and is out of harmony with the present topography. Any sediments or soil that may have formed on it in a previous erosion cycle have been removed by glacial action, but in other respects the form may be little modified. Alden, largely on the basis of the field notes of E. M. Parks and C. S. Corbett, cites also a remnant of a smooth high-level bench at the head of Quartz Creek. This bench, which is about 1,000 feet above the one at the head of Logging Creek, has 9 small lakes on it and small glaciers above it on the northeast flank of Vulture Peak. The bench is transected by a narrow gulch whose V-shape indicates that it was cut by a stream but whose rock walls have been smoothed and striated by glacial ice. The benches at the heads of Logging and Quartz Creeks and similar benches elsewhere along the crest of the Livingstone Range, like benches and wind gaps farther east, are regarded as erosion remnants broadly correlatable with the Blackfoot surface.

Precise correlation among these widely scattered erosion remnants is obviously impractical, especially, as all have been modified in varying degree by post-Tertiary events—notably glaciation. With due allowance for this, it is believed that the Blackfoot surface on the plains to the east extended headward into the mountains in some such way as is indicated by the diagrammatic contours on figure 33. One of the larger intramountain valleys was at the site

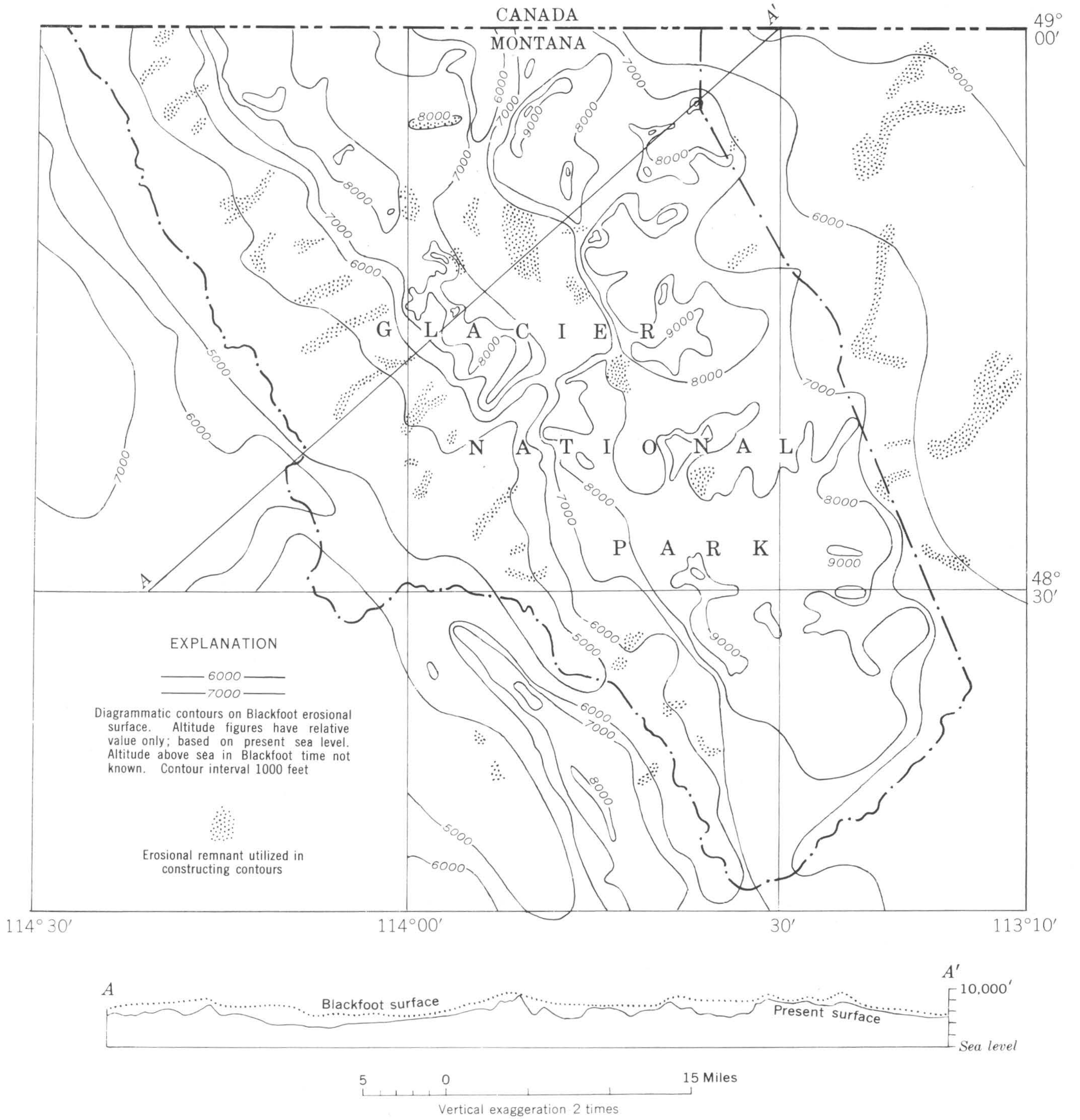

FIGURE 33.—Diagrammatic contour map of the Blackfoot surface in the region now occupied by Glacier National Park, with a section diagonally across Glacier National Park illustrating the difference in character between the topography of Blackfoot time and that of the present day.

of Flattop Mountain. Another broad valley was on the site of the present valley of the Flathead River, at altitudes corresponding to present altitude in the neighborhood of 5,000 feet. From this valley the surface rose within the mountains to above a present altitude of 6,500 feet, locally over 7,000 feet, and sloped off to merge with ridge tops in the plains area east of the Lewis Range at present altitudes of 5,500 to somewhat over 6,000 feet. Hills or small mountains near the crests of the present mountain ranges maintained themselves well above the broader expanses of the Blackfoot surface, which had gradients sufficient to permit transport of gravel (figs. 30–33). The present altitudes of a few upland remnants, such as East Flattop Mountain, are too great to fit the concept of a single erosional surface rising smoothly from the plains into the mountains. The explanations that might be thought of to account for apparent discrepancies of this kind are too numerous to warrant discussion on the basis of the incomplete data at hand.

In much of the Flathead region, the record of events of Blackfoot time is even more obscure than it is farther north. One reason for this is the much greater diversity in rocks and in structure. The part of the valley of the Middle Fork between West Glacier and the mouth of Bear Creek is essentially a continuation of the valley of the main Flathead River. Where the valley of the main Flathead River now swings southwest in a gorge at the north end of the Apgar Mountains, the major topographic depression continues southeast in line with the valley of the main stream farther north and with the valley of the Middle Fork above West Glacier. The part of the depression not now occupied by a master stream is underlain by Tertiary and later deposits like those in the valley of the main river farther north. An observer whose first impression of the country was gained from such vantage points as Garry Lookout or Double Mountain might easily get the idea that the Middle Fork of the Flathead maintained a northwesterly course over McGees Meadow between Howe Ridge and the Apgar Mountains and thence into Canada through the valley of the southeasternward-flowing Flathead River. Such a concept would, of course, now be a mistaken one, but it fits the general topography so well as to suggest strongly that in the geological rather recent past it would have been correct. Perhaps the ancestral Flathead River flowing on the Blackfoot surface had its head in the present valley of Bear Creek and discharged its waters into Canada.

Other features of the present topography indicate drainage changes of the first magnitude, which is in accord with the concept just expressed. The narrow gorge of the Flathead River that passes around the north and west sides of the Apgar Mountains into the open valley to the south is abnormal. Similarly, the Flathead River, west of the region mapped during the present investigation, cuts squarely across rock of the Belt series at the northern end of the Swan Range in the narrow rock-walled gorge called Bad Rock Canyon (pl. 3). There is a striking difference in the gradients of the different forks of the Flathead above and below this place (U. S. Geol. Survey, 1937, 1939, 1947, 1950). In Flathead Valley the river meanders over a nearly level plain. Its rise for the first 21 miles above the north end of the lake is almost imperceptible. Even at Bad Rock Canyon, a little over 45 miles along the river from the lake, the rise is only 135 feet. Above the canyon the gradients of all forks of the Flathead are much steeper. In a little less than 66 miles from the canyon to the international boundary, the main river rises 950 feet. In the 44.5 miles from its mouth to the confluence with Bear Creek, the Middle Fork rises 760 feet, and above Bear Creek the gradient is even steeper. The South Fork rises 1,700 feet in 105 miles. While these gradients are far less than those attained by mountain torrents, they are in strong contrast to the almost stagnant condition of the river for most of the distance from Bad Rock Canyon to Flathead Lake.

Conditions at Bad Rock Canyon have been mapped and described by C. E. Erdmann (1947, p. 124–128, 147, 160). He appreciated fully the complexities of the drainage pattern and offered explanations which differ from those given here principally in that Erdmann did not suggest a possible reversal of flow in the upper valley of the Flathead River and did suggest a series of drainage changes related to recurrent movements along the major faults. If the faults renewed their activity at intervals as he suggests, they would, doubtless, have influenced the drainage. Perhaps the tilted beds near the mouth of Kintla Creek reflect such movements. The earthquakes still felt in northwestern Montana occasionally have been attributed (Pardee, 1926; Scott, 1936) to renewed disturbances along old faults in modern times. If, as Erdmann's data indicate, Bad Rock Canyon contains no deposits of Tertiary age, it was probably cut after the Blackfoot surface was formed. He reports unconsolidated deposits, including material of glacial origin to a depth of several hundred feet below river level in the gorge, which is in accord with the idea that the gorge originated some time ago, quite possibly before the Pleistocene epoch. Anyone interested in possible drainage changes should explore the hills north of Bad Rock Canyon more than has yet been done. These hills have not been mapped geologically or topographically and may contain clues to some of the problems under discussion.

The idea that the Flathead River may once have flowed northwest requires testing in Canada; this has not yet been done so far as the writer knows. The present Flathead River heads a little south of latitude 49°30′. Maps show enough apparent abnormalities in drainage pattern to suggest that in southern Alberta and adjacent parts of British Columbia the erosional history has been fully as complex as it has been south of the international boundary.

Returning to consideration of the Flathead region, it may be said with assurance that the dissected erosion surface marked by spur crests close to the main Flathead River continues to the south in the valley of the Middle Fork. There the surface is carved largely on rocks of the Belt series and has more irregularities than remain on the soft materials of the spurs farther north. Even so, flat spur crests such as those topped by Loneman Mountain, Double Mountain, and others are striking features of the topography. Some of the spur crests exceed 6,500 feet in present altitude, but others, such as the one above Garry Lookout and that north of lower Dickey Creek, are lower. Along the spectacular gorge of the upper Middle Fork above the mouth of Bear Creek, the topography is more irregular and is dominated by the steep valleys of actively eroding streams. Even here, relatively level ridge tops, such as the one on which Spruce Lookout stands, may represent modified fragments of old erosion surfaces. Farther south, parts of the ridges topped by Lodgepole Mountain, Gable Peaks, and Union Peak could be easily traversed by a jeep, if such a vehicle could be gotten up to the crests. Most of the ridge crests in this part of the Flathead region are near or somewhat above an altitude of 7,000 feet.

The valley of the South Fork of the Flathead is more open than that of the Middle Fork. Like the latter it has relatively flat-topped spurs, which are well below the range crests. The altitudes of the more distinct spur tops are somewhat lower than in the vicinity of the Middle Fork. Pioneer Ridge, one of the largest, culminates somewhat above 6,000 feet above sea level. Kah Mountain, 6,485 feet, is a knoll surmounting a gently rolling upland just south of the boundary of the Flathead region. On the opposite side of the South Fork, corresponding ridge crests, such as those above Felix and Silver Basins, reach altitudes near 6,500 feet. Some of the benches near the crest of the Swan Range, such as Jewel Basin and those near Mount Orvis Evans, are probably analogous to the upland benches of the Livingstone Range already referred to. Benches of this kind, together with relatively flat-topped spurs, led Davis (1916, p. 271–276; 1921, p. 80–97) to suppose, on the basis of distant observations, that the Swan and Mission Ranges displayed remnants of a high-level surface, "* * * perhaps deserving to be called a peneplain." They are far below the summits and are here interpreted as corresponding essentially to the Blackfoot surface.

Throughout the valley of the South Fork, the soft Tertiary and later deposits wrap around the spur ends and are plastered against the slopes of the spur ends to altitudes that have not been fixed closely because of poor exposures and dense forest cover. They have been noted at altitudes above 4,500 feet but certainly do not reach the tops of the more prominent ridge crests. It would appear, therefore, that here, as well as along the Middle Fork, these deposits have been more extensively eroded than on the west side of Glacier National Park. If the spur crests there, where they are underlain by the Tertiary deposits, are correctly correlated with the spur crests along the Middle and South Forks as remnants of the same erosional surface, the Tertiary fill, which antedates that surface, must have reached comparable altitudes in all three valleys when originally laid down.

The old fill along the South Fork has in places a strathlike top that could represent a partial erosion surface carved on it at some time after the spur crests were formed. The old, largely abandoned trail that extends along the east side of the valley from near the former Riverside Ranger station to Devil's Corkscrew Creek took full advantage of this strath, and the proposed new road will, in part, do so also.

In the eastern part of the Flathead region, there are relatively flat uplands at various altitudes. Some of these doubtless are remnants of old erosion surfaces, but present data do not permit correlations that seem valid and significant. There is little to tie most of these level patches either to the spurs along the Middle and South Forks or to deposits of Tertiary age. For the present it is sufficient to say that the topography in the mountains of the eastern part of the Flathead region is not incompatible with the idea that the Blackfoot surface was once present there—much as it is supposed to have been farther north.

In summary, an erosion surface that may have been mature but was certainly far from being a peneplain extended throughout the Glacier Park and Flathead regions at some time late in the Tertiary. The higher mountains had so successfully resisted attack that even today correspondence between surface forms and rock structure can be discerned, but the principal stream valleys had been widened sufficiently, so that broad expanses of fairly level land ramified throughout the mountainous area.

Together these are spoken of as the Blackfoot surface. Eastward, this surface joined that represented by the highest of the erosional remnants on the western part of the Great Plains—the No. 1 bench of Alden. The Blackfoot surface must be much younger than the old alluvium that filled valleys in the Flathead drainage basin in the Oligocene epoch and later and was well developed at the time that the earliest of the Pleistocene glaciers occupied the mountains. Much of the Tertiary period was occupied in forming this surface, and conditions did not change enough to seriously deface it until some time in the Pleistocene. Hence the Blackfoot surface is broadly correlatable with the Flaxville surface of Alden. How nearly the two merge and can be considered identical is left for future workers to decide.

POST-BLACKFOOT EROSIONAL FEATURES

Although the Blackfoot surface may have reached its culmination as recently as the early part of the Pleistocene epoch, it has since been attacked so vigorously that in many places its remnants have not been identified with assurance. Only the major features of the somewhat complex post-Blackfoot history are known. Those features related primarily to stream erosion are described here; features of glacial origin being touched upon in later pages.

After the Blackfoot surface was formed, rejuvenation took place, and streams cut deep valleys in the mountains, reducing the nearby plains to a level close to the present one and well below the ridge tops regarded as remnants of the Blackfoot surface. As some of the ridges are capped by early Pleistocene drift, much of the rejuvenation that largely destroyed the Blackfoot surface took place after the first Pleistocene glaciation. The mountain valleys produced by this rejuvenation were modified by and hence are older than the glaciers of the Wisconsin stage. This indicates that much of the downcutting took place near the middle of the Pleistocene.

The larger mountain valleys contain terraces that record pauses in their formation. Most of the higher terraces are poorly preserved, and many are concealed or obscured by forest growth and landslides. Probably there are three and possibly more terraces between the flood plains and the Blackfoot surface. On the plains likewise, there are bevelled ridge tops that correspond to one or more pauses in downcutting later than the Blackfoot cycle (Alden and Stebinger, 1913, p. 532–542; Alden 1932, p. 14–15).

The fact that the downcutting did not extend to the heads of present streams is shown by the absence of incised gorges in most of the higher remnants of the Blackfoot surface. This is illustrated diagrammatically by figure 31, which shows a gorge in the foreground that dies out before reaching the higher part of the broad valley carved in Blackfoot time. In a few places the gorges of middle Pleistocene age must have reached almost to the range crests, for Alden mentions one such gorge. His unpublished manuscript on Glacier National Park calls attention to a place at the head of Quartz Creek in the northern part of the Livingstone Range. Here a valley whose shape testifies to its fluviatile origin is incised into relatively level terrain interpreted as a remnant of the headwater part of a surface of Blackfoot age. Although surrounded by cirques, the V-shaped stream valley bears no evidence of glaciation other than smoothed and striated surfaces on its rock walls.

GLACIAL FEATURES

Much of the spectacular character (figs. 3, 16, 27, 28, 30–32) of the present topography of the Glacier Park region results from glaciation. The Flathead region (figs. 1, 2, 22, 23) has also been glaciated, but with less spectacular results, which is largely because much of it is lower and some of the rocks are not adapted to the production and preservation of cliffed forms. While the principal glacial features of the two regions have long been known, the summaries in the present report can do no more than point out salient features. Detailed description and interpretation require much more information than is available.

Alden's descriptions prove that glacial deposits of early Pleistocene age are plentiful on ridge tops in a rather small area in the plains east of Glacier National Park that escaped later glaciation. Evidently when glaciers of the Wisconsin stage spread over the landscape, they removed, or at least rendered unidentifiable, the products of the early glaciers. The known remnants of the earlier deposits range up to more than 200 feet in thickness and reach altitudes of 7,000 feet; so the mountain glaciers that dumped these deposits on the plains may have been extensive. Most of the old drift now remaining lies on flat-topped remnants of the Blackfoot surface (the No. 1 bench of Alden), but some appears to be on surfaces which are over 100 feet lower and belong to Alden's No. 2 bench. Glaciation may have begun after erosion had reached the level of No. 2 bench, or there may have been two early glacial episodes, in one of which ice moved over the Blackfoot (No. 1) surface and the second of which did not take place until after that surface had begun to be dissected to depths of one or two hundred feet. In either case, the glaciers presumably extended headward to gathering grounds high on the peaks of that day and covered much of the mountainous region with ice. That region had topography like that shown in figure 30—much less rugged and less deeply incised than it was during Wisconsin time. This, coupled with the fact that all early Pleistocene drift seems to have been removed from the mountains, suggests that the early glaciers were not as thick as the later ones.

Information as to early glaciation west of the Continental Divide is even more scanty than it is to the east. It is a fair assumption that the western valleys contained glaciers similar in magnitude to those to the east. Presumably ice streams from the mountains poured into the valleys of the ancestral Flathead River and its major tributaries.

After the early glaciers retreated vigorous stream erosion, as already noted, incised the mountain valleys to close to their present depths—locally as much as 3,000 feet below the Blackfoot surface. Figure 31 illustrates the character of the topography that resulted close to the range crests at an early stage in the rejuvenation. Before the return of glaciation, the incisions were somewhat deeper than figure 31 indicates. The deepened valleys were filled with glacial ice, which widened and somewhat deepened them. Most of the spectacular topographic features for which Glacier National Park is noted were formed at that time, and the higher parts of the country came to resemble the scenery shown in figure 32. The glaciers poured far out into the lowlands beyond the mountains. The largest glaciers on the eastern slope were about 50 miles long. On the west the mountain glaciers of the Glacier National Park and Flathead regions joined ice streams from the north that extended as far as the present outlet of Flathead Lake, a distance along the course followed of more than 50 miles from the border of the park. All of the mountains except the higher peaks and ridge crests were buried under the ice streams. Probably few peaks rose more than 1,000 feet above the ice.

A general idea of conditions during the Wisconsin stage of glaciation can be obtained from Alden's map (1932, pl. 37), which shows much of the eastern part of the Glacier Park region and the country toward the east past the site of the town of Cut Bank. Glaciers extended into Canada along the valleys of Belly and Waterton Rivers. Another, fed largely from gathering grounds in the headwaters of Kennedy Creek and St. Mary River, reached the edge of the continental ice sheet near the international boundary. South and east of the site of St. Mary, a large area of the plains does not appear to have been covered by ice during Wisconsin time. The glacier that issued from the valley of Cut Bank Creek was able to push only a few miles east of the right of way of the present highway that skirts the mountain front. The glaciers emerging from the valleys of forks of Two Medicine Creek and from valleys farther south coalesced to form a large glacier that stretched more than 35 miles east of the mountain front and almost reached the lobe of the continental glacier that passed east of the site of Cut Bank. According to Alden, that town and much of the country north and west of it are within the limits of a lake that formed west of the continental ice sheet. It is somewhat strange that the glaciers that emerged from the southern tip of the present park and areas farther south were able to maintain themselves farther across the plains than those from the more rugged, intensely glaciated mountains farther north. The reason may be in part that numerous individual mountain glaciers were able to unite on the plains drained by Two Medicine Creek. Also, the glacial divide, according to Alden's unpublished data, was farther southwest in the general vicinity of Marias Pass than the present Continental Divide.

West of the Continental Divide the effects of mountain glaciation of the Wisconsin stage are somewhat less spectacular than they are to the east, where already steep slopes on hard rocks lent themselves to the formation of cliffs. Nevertheless, all of the valleys were filled almost to their tops, and the ice streams in each united to form large glaciers in the valleys of the principal forks of the Flathead River. Most, if not all, of the spurs whose crests mark the approximate position of the old Blackfoot surface were inundated by the ice and cloaked with morainal material. Data gathered by members of Campbell's parties and by Alden in later visits show that the ice covered the Apgar Mountains completely and left striae on their crests. Thus the glaciers must have attained thicknesses in excess of 3,000 feet. The ice streams joined and passed westward through Bad Rock Canyon and other gaps into Flathead Valley (pl. 3). There they joined large glaciers moving down from Canada. Together the ice streams pushed their way southward to the site of Polson. The terminal moraine near that town forms the southern shore of Flathead Lake and marks the most southerly point reached by the ice during the Pleistocene. According to J. T. Pardee (1942) the ice there met and dammed glacial Lake Missoula, a large water body that was fed by melting glaciers and in part contained by walls of glacial ice. Lakebeds supposed to have been deposited in Lake Missoula are plentiful south of Polson and extend somewhat north of that town on both sides of Flathead Lake. According to unpublished maps made in 1911 by Eugene Stebinger, the moraine at Polson is the younger of two terminal moraines deposited during Wisconsin time. The older moraine has its center about at Charlo, 18 miles farther south and is now surrounded by the deposits (largely silt) laid down by glacial Lake Missoula. The glacier that occupied Flathead Valley must have been one of the principal ones in the Rocky Mountains region. The great masses of ice from the vicinity of Glacier National Park were merely tributaries. Probably the largest single contribution to the ice in Flathead Valley came from Canada through the depression that has been termed "the Rocky Mountain Trench." Other substantial contributions came from the west. The glacier in Flathead Valley was in places more than 15 miles wide and presumably over 3,000 feet in maximum thickness; and according to W. M. Davis (1916), it was powerful enough to shear the ends off the spurs of the Swan Range.

In the preceding summary the glaciation of Wisconsin age has been treated essentially as a unit. This is because of lack of information on which to base division. Most of the glacial sculpture manifest in the present mountains was performed during the Wisconsin. Two or more major fluctuations must have occurred, but adequate discussion cannot be made until detailed studies with this objective in mind have been undertaken.

It appears that the glacial activity of the Pleistocene epoch came to an end roughly 10,000 years ago and was followed by a period of increasing warmth in which most of the glaciers in the Western United States, probably including all in the vicinity of Glacier National Park, melted (Matthes, 1942, p. 190–215; Dyson, 1949b, p. 7–11). About 4,000 years ago another climatic change permitted the reappearance of mountain glaciers in many parts of the Western United States. The present glaciers in and near Glacier National Park were born at that time. They have fluctuated in size but have never approached the dimensions of the glaciers of Wisconsin age. Mainly on the basis of comparison with data assembled by F. E. Matthes for other regions, they are thought to have reached their greatest extent during the middle of the nineteenth century. The glaciers in the park were certainly larger at the beginning of the 20th century (Dyson, 1949b, p. 7–16) than they were 48 years later. However, about 1950 such extensive snow banks began to be recorded during the winter that there is hope that the glaciers may have a period of renewed growth. Matthes (1942) states that retreat of the mountain glaciers at the rates observed during much of the first half of the 20th century might well mean their obliteration within a few decades. He emphasizes, however, that in Europe and elsewhere, where glaciers have been under observation for much of historic time, fluctuations are the rule. Whether or not it has already begun, resurgence of the glaciers in and near Glacier National Park is to be expected before the present ones have disappeared.

RECENT EROSIONAL FEATURES

When the glaciers of Wisconsin time retreated, they left the bottoms of the mountain valleys broadened and mantled by glacial debris. Streams, which were at first fed by melt water from the glaciers, reworked the debris and produced flood plains. Since then in nearly every valley the flood plain has been cut into by a narrow gorge one to several score feet in depth that contains the present stream. These inner gorges, rarely more than 75 feet deep except near and along the major branches of the Flathead River, commonly penetrate short distances into bedrock. They are too narrow to show distinctly in the contours of the topographic maps. In a few places such as upper Nyack Creek, the rock revealed in the gorges has been shown on the geologic maps (with slight exaggeration in width) (pls. 1, 2). Attention was first called to inner gorges of this character by Deiss (1943b, p. 1164), who worked south of the Flathead region. They are not uniformly developed, in part because of the difficulty experienced by some streams in cutting through thick and irregularly distributed glacial debris. Along some stretches of such tributaries as MacDonald, Nyack, and Ole Creeks, the inner gorges are quite large enough to attract the attention of travelers. They are not conspicuous in many parts of the Flathead region, but are, nevertheless, present there. Among the streams in that region that display them may be mentioned Graves and Sullivan Creeks in the southwest part of the Nyack quadrangle and Badger Creek and its tributaries in the eastern part of the Marias Pass quadrangle.

The inner gorges along the main branches of the Flathead River are over 100 feet deep and have in places been obscured as a result of the meandering of these powerful streams. Parts of the gorge walls have been cut back and even obliterated in places. Local flood plains have formed close to the modern rivers and within the inner gorges. Where these are broad enough, the river has meandered. The detailed topographic maps of the South Fork illustrate these features (U. S. Geol. Survey 1937, 1939, 1947, 1950). They also show the inner gorges along the lower reaches of some tributaries, although not as effectively as if the contouring had been carried a little farther above present channels. Similar features are shown by the detailed maps of the main river and of the Middle Fork. For several miles above West Glacier (Belton) the meanders of the Middle Fork are deeply incised in a rock gorge and thereby differ sharply from the wanderings of the river over modern flood plains farther upstream and from most meanders of the other branches of the Flathead River. Presumably the incised meanders originated on a former flood plain at an earlier date, perhaps when the stream flow was checked during one of the readjustments in drainage commented on above.

The present drainage pattern presents features of some interest. As already noted, it is in many aspects inherited from the pattern whose development began as a result of uplift after the deformation near the beginning of the Tertiary period. As no general peneplain has been produced and no regional mantle of deposits, either sedimentary or volcanic, has been laid down since that deformation, the concept of superposition is not applicable to any large part of the drainage pattern. Deiss (1943b, p. 1162–1163) has offered suggestions of that kind to explain features in the mountains south of the eastern part of the Flathead region. He calls attention to streams that flow toward the Great Plains directly across the major structure. His explanation is that these streams originated on an erosion surface that had attained maturity after the major deformation and which was subjected to broad upwarp near the end of the Tertiary period. He assumes that northeastward-flowing streams were established on a plain on the site of the present mountains, maintained themselves during uplift, and were accelerated when the mountain area rose above the level of the present plains to the east. If the Blackfoot surface, or a surface closely allied thereto, was very extensively developed in the area described by Deiss, it is possible that some streams that originated on the more thoroughly beveled parts of that surface might have survived in the manner he postulates. Both in his area and in the eastern part of the Flathead region, some of the major streams find their way to the plains through gorges that cut directly through large ridges in a manner that seems to call for some such explanation as the one he offers. However, that explanation, if valid at all, can be applied only to limited areas. Bear Creek, Ole Creek, and others that head close to the border of the plains but nevertheless flow southwest transverse to the regional structure do not fit Deiss' hypothesis. Ole Creek in part coincides with a transverse fault, and some of the others may have been excavated along similar lines of weakness. Transverse streams that flow either northeast or southwest are so numerous and demonstrated transverse faults are so rare that excavation along lines of weakness is not entirely satisfactory as a general explanation—especially as the faults are old and recent revivals of them are unproved. Probably the present drainage system has multiple origin. Many of the streams have survived, with modifications from those of early Tertiary age, related in one way or another to the structure of the rocks; some may have originated on the Blackfoot surface; many of the more abnormal-appearing ones may result from the linking together of parts of streams of diverse origin through piracy.

In a region of long-continued uplift, piracy is likely to be widespread. Probable examples of it are numerous, and the process is still going on. For example, Badger Creek and its forks, with numerous right-angled turns and an exit to the plains through an impressive gorge, seems clearly to be made up of parts of several streams. How the stream managed to cross the steep mountain front in the northeast corner of T. 29 N., R. 11 W., is not known. Some factor, possibly difficulty in traversing the glacial deposits so liberally dumped on the nearby plains, checked the flow of the creek in fairly recent time. Before it reestablished flow northeastward, the stream deposited a broad expanse of alluvium just inside of the mountain border. This alluvium is still dotted with marshes and small ponds, resulting from imperfect drainage. The interference with the development of Badger Creek thus recorded may explain why its tributaries have failed to extend themselves beyond Muskrat and Badger Passes in competition with the tributaries of the Middle Fork of the Flathead. The long distance the latter has to wander through the mountains would seem to put it at a disadvantage. Even so, its headwaters have penetrated country underlain by hard limestone, and it seems likely that the stream will soon acquire the upper tributaries of the South Fork of Badger Creek. The somewhat greater precipitation on the southwest side of the Continental Divide is a contributing factor. There is also a contest between Badger Creek and the South Fork of Two Medicine Creek. The undisturbed glacial deposits on the divide between them suggest that neither has made much headway against the other since the mountain glaciers retreated. The North Fork of Badger Creek is in an area of highly disturbed rocks. It may have been aided in excavating its canyon by a transverse zone of fracture. Many other oddities in the drainage pattern of the Flathead region suggest readjustments in the streams during the Quaternary period. Among these is Lodgepole Mountain, an island of hard rock surrounded by soft deposits.

The Glacier National Park region contains similar features. The transverse streams flowing southwest have made greater inroads on the mountain block than their counterparts with northeasterly flow—possibly because of the difference in precipitation on the opposite sides of the Continental Divide. Their headwaters are now spreading up longitudinal valleys. If this tendency persists, it seems possible that they may become so linked as to split the part of the Lewis Range in the southern part of the park by means of a series of longitudinal valleys, permitting the Livingstone Range to extend to the valley of Bear Creek. If so, the Livingstone Range would continue to be cut by McDonald Creek but would be a more impressive topographic feature than it now is.

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