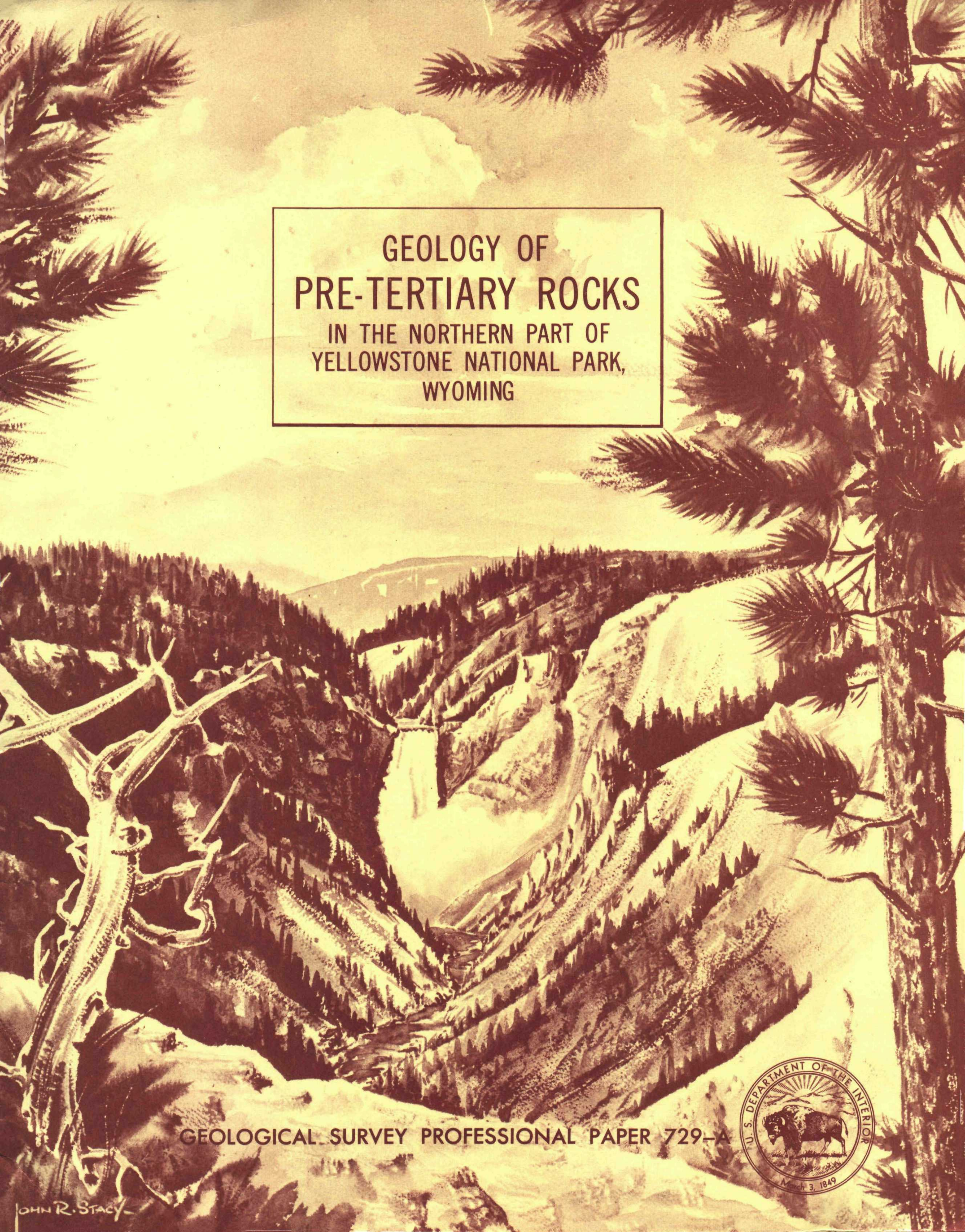

GEOLOGY OF PRE-TERTIARY ROCKS IN THE NORTHERN PART OF YELLOWSTONE NATIONAL PARK, WYOMING

GEOLOGICAL SURVEY PROFESSIONAL PAPER 729–A

Geology of Pre-Tertiary Rocks in the Northern Part of Yellowstone National Park, Wyoming

By EDWARD T. RUPPEL

With a section on Tertiary laccoliths, sills, and stocks in and near the Gallatin Range, Yellowstone National Park

GEOLOGY OF YELLOWSTONE NATIONAL PARK

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Yellowstone National Park, the oldest of the areas set aside as part of the national park system, lies amidst the Rocky Mountains in northwestern Wyoming and adjacent parts of Montana and Idaho. Embracing large, diverse, and complex geologic features, the park is in an area that is critical to the interpretation of many significant regional geologic problems. In order to provide basic data bearing on these problems, the U.S. Geological Survey in 1965 initiated a broad program of comprehensive geologic and geophysical investigations within the park. This program was carried out with the cooperation of the National Park Service, and was also aided by the National Aeronautics and Space Administration, which supported the gathering of geologic information needed in testing and in interpreting results from various remote sensing devices. This professional paper chapter is one of a series of technical geologic reports resulting from these investigations.

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GEOLOGY OF PRE-TERTIARY ROCKS IN THE NORTHERN PART OF YELLOWSTONE NATIONAL PARK, WYOMING

By EDWARD T. RUPPEL

ABSTRACT

Metamorphic and sedimentary rocks of pre-Tertiary age are exposed over an area of about 200 square miles in the northern part of Yellowstone National Park, Wyo. and Mont., mostly in remote and seldom-visited parts of the park along its north boundary. The main outcrops are in the Gallatin Range in the northwest corner of the park, where the entire section of rocks from Precambrian to Late Cretaceous age is exposed; in the area around Mammoth Hot Springs and Mount Everts, where Jurassic and Cretaceous rocks are exposed; and in the north-central and northeastern parts of the park where rocks of Precambrian and Paleozoic age are exposed.

These outcrops consist of crystalline metamorphic rocks of Precambrian age and sedimentary rocks that represent every system except the Silurian. The Precambrian crystalline rocks are mainly granitic gneiss and quartz-biotite schist, but they also include amphibolite and pegmatite. These rocks are overlain by a mostly conformable sequence of sedimentary rocks about 8,000 feet thick, consisting of about 3,000 feet of marine rocks of Paleozoic age, a few hundred feet of Triassic and Jurassic nonmarine and marine rocks, and about 4,000 feet, or half the exposed sequence, of marine and nonmarine Cretaceous rocks. The Paleozoic rocks—limestone, dolomite, and, in subordinate amount, clastic rocks—range in age from Middle Cambrian to Permian.

The Mesozoic sedimentary rocks consist of marine deposits of Triassic and Jurassic age—mainly shale, sandstone, and, in subordinate amount, limestone—and overlying nonmarine mainly clastic rocks of later Jurassic and Early Cretaceous age and a thick sequence of marine and nonmarine clastic rocks of later Cretaceous age. Triassic and Jurassic rocks together are only a little more than 500 feet thick. The 4,000 feet of Cretaceous rock is a monotonous sequence of shale, mudstone, and sandstone, broken by a few beds of conglomerate and limestone, and, in the upper part of the section, by a few beds of coal, carbonaceous sandstone, and shale. The youngest exposed pre-Tertiary sedimentary rocks are sandstone and conglomerate of the Landslide Creek Formation, which consists mainly of volcanic fragments.

The sedimentary rocks in the northwestern part of the park have been intruded by igneous rocks that form stocks, laccoliths, sills, and a few dikes. The oldest of these intrusives is the Mount Holmes stock of fine-grained biotite quartz monzonite, a steep-sided stock that domed its roof of Middle Cambrian sedimentary rocks and intensely hornfelsed both the roof rocks and its own chilled margin. It apparently was emplaced in early Tertiary time.

The laccoliths, sills, and related dikes were emplaced after the Mount Holmes stock, but still in early Tertiary time, and these bodies of biotite rhyodacite porphyry and biotite quartz latite porphyry are the most widespread intrusive masses in the northern part of Yellowstone National Park. The Indian Creek laccolith, emplaced in Cambrian rocks near the south end of the Gallatin Range, is the largest of the group and is about 3 miles in diameter and more than 1,000 feet thick. The Snowshoe and Gray Peak laccoliths, emplaced in Jurassic and Cretaceous rocks in the Gallatin Range, are each about 1 mile in diameter and before erosion were probably each about 1,000 feet thick; they are surrounded by multiple sills that extend out for several miles from the laccolithic core to form an intrusive field 6–8 miles in diameter. The Snowshoe and Gray Peak laccoliths, thus, are the trunk, and the broad connected sills are the branches of a very large Christmas-tree laccolithic complex. The multiple thin sills and their interconnecting dikes on Electric Peak were emplaced in Cretaceous rocks. The laccoliths and sills were emplaced in shaly horizons. Their ultimate shape was possibly determined by depth—a comparatively simple laccolith if deep, multiple thin sills if shallow, and a combination of these, a Christmas-tree laccolith, if intermediate in depth.

The Electric Peak stock, of Eocene age, is an irregular complex, about 1 mile across, on the east side of Electric Peak; it intrudes Upper Cretaceous sedimentary rocks and comprises several varieties of fine- to medium-grained rocks ranging in composition from calcic granodiorite to near granite, although most of the rock is granodiorite. The stock has long been considered the neck through which the volcanic rocks of Sepulcher Mountain were erupted.

The faults and folds in the pre-Tertiary rocks of northern Yellowstone National Park appear outwardly to have little relation to structural features in surrounding areas, probably because the park is in an unusual setting where several structural provinces come together. The Precambrian crystalline rocks reflect extreme deformation in Precambrian time. The sedimentary rocks are in parallel beds, which imply structural quiet throughout Paleozoic and most of Mesozoic time and to the latest Cretaceous, when they were folded at the beginning of a period of deformation that probably is still going on. The folding formed the broad, poorly defined northwest-trending Gallatin anticline, which was intruded in its axial part by both the Mount Holmes stock and the

Indian Creek laccolith. Doming over the laccolith apparently caused the massive upper Paleozoic rocks to slide northward on the gently dipping Crowfoot fault zone.

In late Paleocene and Eocene time, the rocks in the northern part of Yellowstone Park were broken by steep northwest-trending reverse faults, which include (1) the faults of the north-dipping Gardiner fault zone and the associated reverse faults northeast of the Gallatin Range and (2) the south-dipping Grayling Creek fault southwest of the Gallatin Range. The Gallatin block was depressed between these bounding faults. Displacement on the Gardiner fault zone exceeds 10,000 feet, and that on the Grayling Creek fault is uncertain, but it probably exceeds 1,000 feet. The Gardiner fault zone is the southwest boundary of the uplifted Beartooth block, which is the dominant structural feature in the north-central and northeastern parts of the park.

In later Tertiary time, pre-Tertiary and younger rocks in the north-central and northeastern parts of the park were broken by northwest-trending normal faults, which now define the Lamar Valley and the south front of the Buffalo Plateau. Still later, perhaps in middle or late Pliocene time, the reverse faults and northwest-trending normal faults were broken by north-trending near-vertical normal faults, some of which have displacements of thousands of feet. These faults bound the Gallatin Range and are represented in the north-central part of the park by the Buffalo Creek faults, and they probably control many of the thermal areas in the park. They may be reflected through younger volcanic rocks elsewhere in the park by a striking series of north-trending lineaments. The East and West Gallatin faults, major faults in the north-trending group, perhaps are continuous with somewhat similar faults south of Yellowstone National Park; north of the park they appear to merge into the northeast-trending Emigrant fault. The present Gallatin Range is an uplifted block much like the Teton Range and probably is genetically related to it. The structural features in the northern part of the park, however, do not appear to be related to most structural features in adjacent areas in Montana, and the structural pattern in and near the northern part of the park appears to reflect intersection and termination of the Snake River downwarp against the older, reverse-fault-bounded blocks of the Middle Rocky Mountains tectonic province.

INTRODUCTION

Although Yellowstone National Park is noted mainly for its widespread Cenozoic volcanic rocks, it also includes older (pre-Tertiary) sedimentary and metamorphic rocks that crop out in remote and seldom-visited parts of the park along its north and south borders. Such rocks in the northern part of the park (fig. 1) are the concern of this report.

The prevolcanic metamorphic and sedimentary rocks in the northern part of the park are exposed over an area of about 200 square miles (fig. 1). In the northwest corner of the park, Precambrian metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks, intruded by sills, laccoliths, and stocks of younger igneous rocks, constitute the south end of the Gallatin Range and underlie all the high rugged peaks of this range. The Gallatin Range provides an almost complete section of sedimentary rocks ranging in age from Middle Cambrian to Late Cretaceous. Between the Gallatin Range and the west boundary of the park, Witkind (1964, 1969) mapped a few small outcrops of sedimentary rocks. East of the range, sedimentary rocks crop out near Mammoth Hot Springs and in several small areas from Bunsen Peak south to Whiterock Springs and Lemonade Creek. East of Mammoth Hot Springs, sedimentary and metamorphic rocks crop out almost continuously from Mount Everts across the Buffalo Plateau to the northeast corner of the park, an outcrop area almost as large as that of the southern part of the Gallatin Range.

These areas of metamorphic and sedimentary rocks are skirted by the major highways of the region (fig. 1): U.S. Highway 191, between Bozeman and West Yellowstone, Mont.; the West Entrance and Northeast Entrance Roads; and part of the Grand Loop Road. However, only a few outcrops can be reached easily from these highways, and most of the area is accessible only by foot or on horseback, using pack trails maintained by the National Park Service.

The geology was mapped on a topographic base (scale 1:62,500) in 1966 and 1967. About 5 months was spent in field mapping, mostly in the areas of sedimentary rocks; the metamorphic rocks were mapped only in reconnaissance.

PREVIOUS WORK

The principal early works on the metamorphic and sedimentary rocks in the northern part of the park are those by Iddings and Weed (1899) and by Weed (1896). Hayden (1873) had earlier noted many areas underlain by these rocks, and in 1878 Holmes (1883) had partly mapped most of the areas of pre-Tertiary rocks and had briefly described them. Holmes had also recognized and named the Indian Creek laccolith (Holmes, 1883, p. 24–26) and a major fault (Holmes, 1883, p. 5–6), now known as the Gardiner fault, along the valley of the Yellowstone River near its junction with the Gardner River. The studies in 1878 by Holmes (1883) and his colleagues, under the direction of Hayden, followed the earlier geological surveys made principally in thermal areas in the park in 1871 and 1872, also under Hayden's direction (Hayden, 1872, 1873). In turn, these studies were followed in the 1880's and 1890's by the complete geologic mapping of Yellowstone National Park by geologists of the U.S. Geological Survey, including Iddings and Weed (1899), under the direction of Arnold Hague.

The remoteness of most outcrops of pre-Tertiary rocks and the physical problems of working in such remote areas made the early explorations difficult

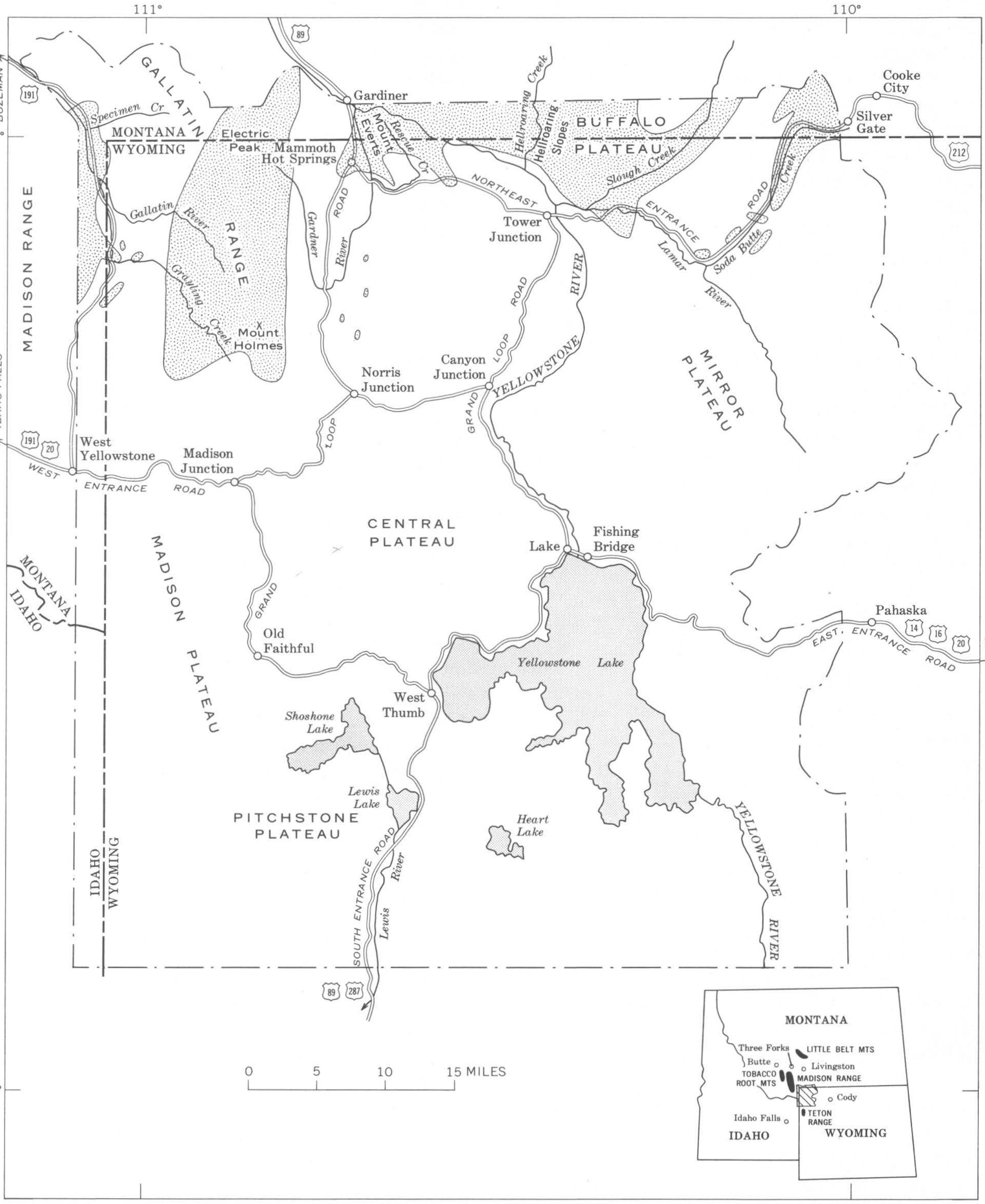

FIGURE 1.—Areas of pre-Tertiary rocks (coarse stipple pattern), northern part of Yellowstone National Park, Wyo.

(Hayden, 1872, p. 99) and also discouraged later mapping. To a large extent the work later than that by Iddings and Weed was limited to special stratigraphic studies on selected formations (Crickmay, 1936; Deiss, 1936; Cressman, 1955; Richards and Nieschmidt, 1961; McMannis, 1962; Grant, 1965; Benson, 1966). C. W. Brown (1961) published the only geologic map more recent than the maps by Iddings and Weed (1899) for the area between Mammoth Hot Springs and the Northeast Entrance;

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Brown's map shows the distribution of the pre-Tertiary rocks, but the emphasis of his study was on Cenozoic stratigraphy and structure, and he did not discuss the older rocks at any length. Love (1961) recently made a reconnaissance study of Quaternary movement on faults in Yellowstone National Park and examined many of the faults that cut the pre-Tertiary rocks in the northern part of the park.

Geologic reports on areas adjacent to the northern part of the park include maps and descriptions of pre-Tertiary rocks that have been most helpful to me. Witkind (1964, 1969) mapped the Tepee Creek quadrangle, which includes a small part of Yellowstone National Park but is mostly in the Madison Range west of the park. Hall (1961) mapped the Gallatin Valley northwest of Yellowstone. Calvert (1912), Wilson (1934a, b), Seager (1944), L. E. Brown (1965), Brookins and Brown (1966), and Fraser, Waldrop, and Hyden (1969) have studied various aspects of the geology of the area from Cinnabar Mountain, just north of Electric Peak, to the Jardine–Crevasse Mountain mining district east of Gardiner, Mont. Lovering (1930) mapped the Cooke City, Mont., mining district near the Northeast Entrance of the park, an area visited earlier by Hayden (1873, p. 47).

ACKNOWLEDGMENTS

I am indebted to Joseph H. Fraser, subdistrict Park Ranger, National Park Service, for his helpful advice on working in the remote areas of Yellowstone National Park. John M. Good, former Chief Park Naturalist, arranged the details of cooperation with the National Park Service. Bob Schellinger of Johnson Flying Service, Missoula, Mont., provided logistic support that significantly shortened the time required for mapping.

Reuben J. Ross, Jr., Ralph W. Imlay, and William A. Cobban of the U.S. Geological Survey visited outcrops in the Gallatin Range with me, identified fossils, and advised on stratigraphic terminology — Ross for lower Paleozoic rocks, Imlay for Jurassic rocks, and Cobban for Cretaceous rocks; I am particularly grateful for their help. I was assisted in 1966 by Robert B. Amonson and Mike F. Gregorich, and in 1967 by Paul W. Schmidt and George M. Fairer. Fairer also assisted in petrographic studies of the igneous rocks.

TOPOGRAPHY AND DRAINAGE

Almost all of the northern part of Yellowstone National Park is mountainous, and most of it shows the effects of glaciers that have sharpened the peaks and carved the valleys. In general, the area can be divided into four distinctive topographic units: (1) the southern part of the Gallatin Range; (2) the Mount Everts–Rescue Creek area; (3) the Buffalo Plateau; and (4) the Slough Creek–Soda Butte Creek area.

GALLATIN RANGE

Only the south end of the Gallatin Range (fig. 2) is within the boundaries of Yellowstone National Park, but that part includes some of the highest peaks in the park, as well as magnificent cirques. The peaks rise half a mile or more above the glaciated canyons that separate them (fig. 3). Because much of the erosion has been controlled or limited by nearly flat beds of rock, the uplands surrounding the sharp peaks and the floors of cirques and valleys tend to be broad, gently north sloping surfaces that are heavily timbered where veneered with glacial debris or are magnificent alpine meadows where covered with thin and rocky mountain soil.

Glacial deposits are largely restricted to the valleys, but the effects of glacial erosion, such as stripped rock surfaces and oversteepened and unstable valley walls and cirque headwalls, dominate the landscape and continue to influence alpine erosion. The cliffs yield abundant rock waste that, in turn, contributes to landslides, talus, protalus ramparts, and the large prominent rock streams that flow out of some cirques. The cliffs and cirque headwalls, too, provide a setting peculiarly susceptible to rockfalls; wherever north-facing cirques or valley walls are cut into the gently north dipping beds of rock, large blocks bounded by joints and bedding surfaces are wedged out of position by gravity, frost action, and the frequent small earthquakes that shake this tectonically active region. The clifftops are cut by great cracks, ranging from a few inches to many feet wide, parallel to the cliff face, that show how the blocks are separating and moving outward, ultimately to fall into the valley below. Indeed, the number of incipient rockfalls is so great that many cliff edges are unsafe, and a strong earthquake would cause wholesale landsliding and probably significantly alter the appearance of some cirques and valleys.

A similar, but less catastrophic, movement of rock is taking place on the western part of Quadrant Mountain, where an entire unit, the Shedhorn Sandstone, is breaking apart and moving downslope on thin beds of shale lubricated by melt water. The motive force again is gravity, for the northward dipslope that forms the great alpine meadow on the top of Quadrant Mountain favors such mass landsliding. North-dipping formations composed largely of shale intruded by many sills have broken and slid in much the same way to form the very large landslides south of Sportsman Lake.

The Gallatin and Gardner Rivers and Grayling Creek drain the southern part of the Gallatin Range (pl. 1, west half) ; all empty into the Missouri River drainage system. Mountain lakes are scattered throughout the range, but only a few are directly connected to the streams. Most lakes, such as those at the head of Panther Creek, those just north of Trilobite Point, and Gallatin Lake, drain through moraine dams and glacial deposits. Other lakes, such as those east of Crowfoot Ridge, flow into large sinks and disappear underground, where — although conclusive evidence is lacking — their underground flow is thought to follow the flat faults that cut the rocks, and the subsurface water is believed to join the Gallatin River through the large swamps at the north end of Crowfoot Ridge.

MOUNT EVERTS–RESCUE CREEK

Mount Everts forms the east wall of Gardner Canyon (pl. 1, west half), and rises abruptly 2,000 feet from the river to an altitude of 7,841 feet at the mountaintop. At the top, however, the topography changes to an ice-scoured gently rolling eastward dipslope, developed on Upper Cretaceous sandstone, pocked with abundant glacial lakes, ponds, and bogs, and mostly covered with a veneer of glacial debris. This surface gradually drops eastward to Rescue Creek, where the Gardiner fault zone (pl. 1, west half) places Precambrian schist and gneiss against Cretaceous rocks. Northeast of this major fault zone a rugged topography, deeply incised by the Yellowstone River and its tributary streams, extends eastward to Hellroaring Creek and the Hellroaring Slopes that are an approach to the Buffalo Plateau.

BUFFALO PLATEAU

The Buffalo Plateau is a high, nearly flat mountain upland 2,000–3,000 feet above Hellroaring Creek on the west, Slough Creek on the east, and Lamar and Yellowstone Rivers on the south (pl. 1, east half). The slopes that rise to the plateau are steep — in places, cliffs — and are underlain by gneiss that is mantled, in part, by glacial deposits or volcanic rocks. The flat top of the plateau reflects an ancestral surface, once covered by the Cambrian Flathead Sandstone; most of the sedimentary cover has been removed, and the exhumed surface was partly covered with volcanic rocks and glacial deposits, but enough remnants of the Flathead Sandstone are preserved to clearly identify the plateau as a part of the pre-Flathead erosion surface. In the southern part of the plateau, only a few outcrops of Flathead Sandstone break its rolling evenness; in its northern part, however, outcrops of other Paleozoic sedimentary rocks and of younger volcanic rocks are abundant, and the plateau surface is hilly.

All of Buffalo Plateau and the south-facing slopes that approach it have been glaciated, and the resulting widespread glacial deposits smooth its irregularities, mask the bedrock, and fill most of the stream valleys. Much of the plateau surface is swampy, and glacial lakes and ponds are abundant. Most of the drainage is through Hellroaring Creek and Buffalo Creek. These two creeks flow in parallel, north-trending deep valleys: Buffalo Creek, in a valley controlled by the Buffalo Creek fault (pl. 1, east half) ; and Hellroaring Creek, in a valley that may be fault controlled.

SLOUGH CREEK–SODA BUTTE CREEK

The mountains of the northeast corner of Yellowstone National Park (pl. 1, east half), from Slough Creek eastward to Soda Butte Creek and Abiathar Peak, are fairly linear, and trend northeast. They rise to altitudes of about 10,000 feet and are separated by subparallel valleys that drain southwest and join the Lamar River valley at altitudes of 6,200–6,500 feet. The valleys have all been glaciated, and the distribution of moraine indicates that glacier ice extended far up on the mountains. Small cirques high on the mountains once held glaciers that contributed ice to the great ice streams in the valleys. The lower slopes of the mountains are underlain by almost flat-lying Paleozoic sedimentary rocks, which give these slopes a stepped appearance, even though the rocks themselves are generally buried beneath glacial deposits or landslides. The upper slopes are underlain by volcanic rocks, which are also flat-lying but better exposed, and which form all the peaks and mountain crests.

GEOLOGY

Pre-Tertiary rocks in the northern part of Yellowstone National Park range in age from Precambrian through Cretaceous and include rocks representative of every Paleozoic and Mesozoic system except the Silurian. Paleozoic sedimentary rocks unconformably overlie gneiss and schist of Precambrian age; the Precambrian Belt Supergroup that is so widespread in western Montana and Idaho is not present in or near the park. The sequence of sedimentary rocks is summarized in figure 4. The aggregate thickness of the sedimentary rocks is about 8,000 feet, of which about half are of Cretaceous age. All the Paleozoic rocks are marine, but the Mesozoic rocks consist of both marine and continental units.

The Precambrian rocks crop out in the southern part of the Gallatin Range and around the Buffalo Plateau; the Paleozoic rocks crop out in the Gallatin Range, on the Buffalo Plateau, and in the northeast corner of the park; and the Mesozoic rocks crop out only in the Gallatin Range, near Mammoth Hot

FIGURE 2. — The Gallatin Range, viewed from the southeast, with Gibbon Geyser basin in the foreground. From Holmes (1883) : *a*, White Peaks; *b*, Mount Holmes; *c*, Trilobite Point; *d*, Dome Mountain; *e*, Antler Peak; *f*, Indian Creek laccolith; *g*, Joseph Peak; *h*, Quadrant Mountain; *i*, Electric Peak; *j*, Valley of Gardner River.

FIGURE 3. — Southward view of cirques and glaciated valleys, Gallatin Range, Yellowstone National Park.


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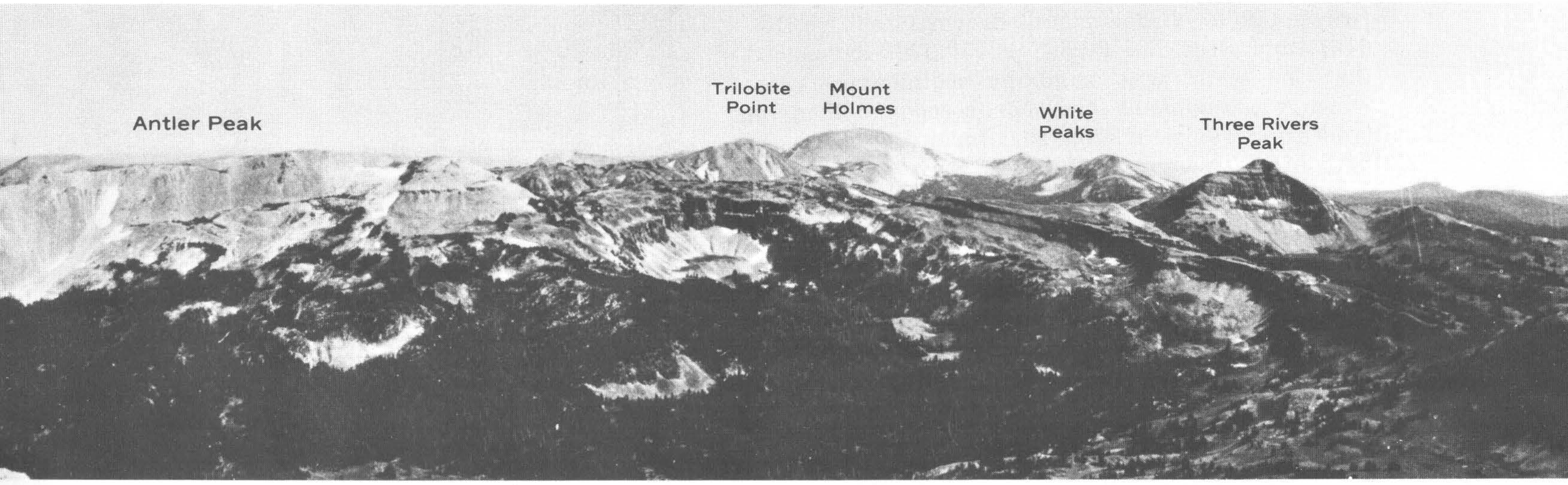
Antler Peak
Trilobite Point
Mount Holmes
White Peaks
Three Rivers Peak

Springs, and on and just east of Mount Everts. The Precambrian rocks are strongly jointed and in most places foliated, and rocks of all ages are cut by faults of differing trends. In general, though, the sedimentary rocks are little deformed and dip gently toward the north boundary of the park.

In the Gallatin Range, the sedimentary rocks have been intruded by rhyodacitic and quartz latitic rocks that form laccoliths and sills, dioritic rocks that form dikes and a stock, and by a quartz monzonite stock at Mount Holmes. Despite the great volume of molten rock represented by these intrusive bodies, few contact metamorphic changes are visible except in the aureole surrounding the stock at Mount Holmes.

To simplify future work by others on the sedimentary rock units that are described in the text, the best exposed and least deformed sections noted in the course of my geologic mapping are identified in the text as suggested reference sections. Some of these sections have been measured and are described at the end of the report. Locations of other sections that could not be measured in the time available for fieldwork are given in the text.

The geology of pre-Tertiary sedimentary rocks in the south-central part of Yellowstone National Park has been studied by J. D. Love and W. R. Keefer. Their nomenclature differs somewhat from mine, and the stratigraphic units are correlated in figure 4.

PRECAMBRIAN METAMORPHIC ROCKS

Precambrian metamorphic rocks crop out discontinuously in the northwestern and north-central parts of the park, from The Crags on the west side of the Gallatin Range (pl. 1, west half) east to Slough Creek and Lamar Canyon (pl. 1, east half). The Precambrian rocks in most of this area are mainly granitic biotite gneiss, but quartz-biotite schist predominates between Rescue Creek (pl. 1, west half) and Garnet Hill (pl. 1, east half). The relations of the schist and gneiss in the Jardine–Crevasse Mountain area just north of the park were described by Seager (1944, p. 21–34, 40–42), L. E. Brown (1965), Brookins and Brown (1966, p. 613–615), and Brookins (1968, p. 5). They concluded that the schist was originally sedimentary rock, which was regionally metamorphosed and then intruded by granitic magma that formed a very large batholith. The granitic rocks were later metamorphosed to form the present granitic gneiss. Seager (1944, p. 28) pointed out that the granitic rocks crosscut the schist and occur as apophyses extending into the schist from the main granitic mass, evidence which supports his conclusion that the granitic gneiss was originally an intrusive igneous mass.

Age	Northern part of park (this report)	Terminology of Iddings and Weed (1899)	South-central part of park (J. D. Love and W. R. Keefer, written commun., 1971)
Quaternary or Tertiary			Heart Lake Conglomerate
Paleocene		Pinyon Conglomerate	Pinyon Conglomerate
Cretaceous	Landslide Creek Formation (part)	Laramie Formation	Harebell Formation
	Everts Formation		
	Eagle Sandstone		Bacon Ridge Sandstone
	Telegraph Creek Formation	Montana Formation	
	Cody Shale		Cody Shale
	Frontier Sandstone	Colorado Formation	Frontier Formation
	Mowry Shale		Mowry Shale
	Thermopolis Shale: Upper sandstone member		Thermopolis Shale: Muddy Sandstone Member
	Thermopolis Shale: Middle shale member		Thermopolis Shale
	Thermopolis Shale: Lower sandstone member	Dakota Formation	Thermopolis Shale: Rusty beds member
	Kootenai Formation		Cloverly and Morrison(?) Formations
Jurassic	Morrison Formation		
	Ellis Group: Swift Formation	Ellis Formation	Sundance Formation
	Ellis Group: Rierdon Formation		
	Ellis Group: Sawtooth Formation		Gypsum Spring Formation
Triassic	Thaynes(?) Formation	Teton Formation	Lower part Chugwater Formation
	Woodside Formation		
	Dinwoody Formation		Dinwoody Formation
Permian	Shedhorn Sandstone		Phosphoria Formation and related rocks
Pennsylvanian	Quadrant Sandstone	Quadrant Quartzite	Tensleep Sandstone
	Amsden Formation		Amsden Formation
Mississippian	Madison Group: Mission Canyon Limestone	Madison Limestone	Madison Limestone
	Madison Group: Lodgepole Limestone		
Devonian	Three Forks Formation	Three Forks Formation	Darby Formation
	Jefferson Formation	Jefferson Formation	
Ordovician	Bighorn Dolomite	Gallatin Formation	Not exposed but present in subsurface: Bighorn Dolomite
Cambrian	Snowy Range Formation: Grove Creek Ls. Mbr.; Sage Ls. Mbr.; Dry Creek Shale Mbr.		Gallatin Limestone
	Pilgrim Limestone		
	Park Shale	Flathead Formation	Gros Ventre Formation
	Meagher Limestone		
	Wolsey Shale		
	Flathead Sandstone		Flathead Sandstone

FIGURE 4. — Nomenclature of sedimentary rock units in Yellowstone National Park.

The uniformity of the Precambrian rocks exposed in the park contrasts with the variety of rocks of similar age reported in adjacent areas. In the Madison Range, west of the park, Witkind (1964, 1969) mapped six units of metamorphic rocks beneath the Flathead Sandstone: granite gneiss, dolomite, amphibolite, mica schist, tremolite marble, and quartzite. In the Jardine–Crevasse Mountain mining district, east of Gardiner and north of the area of schistose rocks in Yellowstone National Park, Seager (1944) and Brookins and Brown (1966) recognized biotite quartzite, quartz-biotite schist, quartz cummingtonite schist, quartz-hornblende schist, gabbro diabase, biotite-muscovite granite, pegmatite, and aplite. This greater variety of rocks in areas adjacent to the park is partly a reflection of the greater detail of the studies made of the Precambrian crystalline rocks in these areas; for example, some of the varieties of schist reported in the Jardine–Crevasse Mountain district certainly extend into the park to the vicinity of Garnet Hill. But the quartzite and marble reported in these adjacent areas are not present in the park, and the dominant Precambrian crystalline rock is granitic gneiss.

SCHIST

Most exposures of schistose rocks in Yellowstone National Park were mapped in reconnaissance fashion by H. J. Prostka, and much of the description of these rocks is drawn from Prostka (written commun., 1968) and from reports by Seager (1944, p. 21–28), Brookins and Brown (1966, p. 613–615), and L. E. Brown (1965).

The Precambrian schists exposed from Garnet Hill westward along the Black Canyon Of The Yellowstone River (pl. 1, west half) and northward to and beyond the park boundary appear to be mainly quartz-biotite schist equivalent to the quartz-biotite schist of Seager (1944, p. 21–24) and Brookins and Brown (1966). The biotite quartzite, quartz-cummingtonite, and quartz-hornblende schist described by Seager in the Jardine–Crevasse Mountain district were not recognized in Yellowstone National Park, but certainly these rocks are present locally.

The quartz-biotite schist is well foliated, its abundant biotite oriented parallel to the schistosity. The rock is medium gray to medium dark gray or brownish gray, but in places it may be as light as greenish gray. Color terms used in rock descriptions follow terminology used in the "Rock-Color Chart" by Goddard and others (1948). The lighter colored rocks contain chlorite and muscovite in contrast to the darker rocks, which are dominantly biotitic. Grain size ranges from 0.1 to 0.2 mm (millimeter) and seems to be uniform throughout the outcrop area. According to Seager (1944, p. 23, 67), the rock consists of as much as 70 percent quartz, 30 percent biotite, and sparse alkalic feldspar and andesine (An_{45}). In places near the schist's contact with the gneiss, the alkalic feldspar increases, and the rocks are banded and migmatitic. The schist contains abundant garnets at Garnet Hill (pl. 1, east half), as do the schist layers that are intercalated in the gneiss at the head of Gneiss Creek (pl. 1, west half), south of The Crags. The garnets at Garnet Hill are as much as 5 mm in diameter; those near the head of Gneiss Creek are as much as 3 cm (centimeter) in diameter. The garnets are grayish red to very dusky red purple, and Seager (1944, p. 63) identified the minerals almandite and spessartite. Seager (1944, p. 24, 62–64) stated that garnet is abundant only near vein zones, but that it also occurs in zones that cut across relict bedding in the schist; he considered the garnet to have been formed by reaction of hydrothermal solutions with the schist. The garnet at Garnet Hill is in a setting similar to that outlined by Seager; however, the very large garnets at Gneiss Creek apparently are not related to vein zones but, rather, to Precambrian metamorphism.

Layers as much as 15 feet thick of garnetiferous mica schist, some of which contains iron-rich garnets as much as 3 cm in diameter, are also included in the granitic gneiss. The schist layers parallel the foliation and are themselves foliated. Schist layers are common near Little Buffalo Creek (pl. 1, east half) and, in general, increase in abundance from that area westward to the contact of gneiss and schist near Garnet Hill (pl. 1, east half). They are not common in the Gallatin Range (pl. 1, west half). The composition of the schist is similar to that of the schist in the main outcrop area along the Yellowstone River.

GRANITIC GNEISS

Granitic biotite gneiss, called mica gneiss by Iddings and Weed (1899) and mica granite by Seager (1944), is medium gray or medium light gray to pale red or moderate orange pink, and its grain size ranges from about 1 to 5 mm and commonly is 2–3 mm. The most obvious minerals are quartz, alkalic feldspar, and biotite, but microscopic study suggests the following composition is more representative: quartz, 35–45 percent, in anhedral strained composite grains; plagioclase, 20–40 percent, in twinned complexly zoned idioblastic crystals, average composition An_{25-35} (oligoclase to andesine), typically somewhat saussuritized and partly replaced by alkalic feldspar; alkalic feldspar, 10–25 percent, mainly microcline in large idioblastic grains and locally in porphyroblasts, commonly 2 cm long and

as much as 5 cm long, but partly alkalic feldspar intergrown with quartz and replacing plagioclase; biotite, 5–15 percent, in idioblastic crystals paralleling foliation; muscovite, from a trace to 5 percent, occurring with biotite; and alteration products, 5–10 percent. The composition of the gneiss generally is closer to that of granodiorite than to that of granite, particularly in the north-central part of the park. The gneiss is everywhere strongly jointed and in most places is foliated. It tends to be deeply weathered except in places where glaciers have exposed the rocks in cliffs and cirques, and most of the area underlain by it is gently rolling, with few outcrops but with broad expanses of grus.

In the Gallatin Range (pl. 1, west half) the gneiss commonly contains layers of medium-grained amphibolite, typically a few inches to a few feet thick, and layers and small pegmatitic clusters of coarse-grained granite pegmatite. The amphibolite is dark gray to grayish black and is composed chiefly of hornblende in grains 0.5–1 mm across; oligoclase (An_{25}) in grains 0.2–0.5 mm across; sparse rounded grains of quartz about 0.2 mm in diameter; and a few percent of opaque minerals.

The pegmatite is light gray to pale red or pale reddish brown and is very coarse grained, containing crystals of alkalic feldspar as much as 2 cm long. It consists almost entirely of alkalic feldspar and interstitial quartz and occurs both in well-defined layers from a few inches to many feet thick paralleling the foliation in the gneiss and as clusters of coarse alkalic feldspar crystals and quartz in the gneiss. Typically, it is cut by thin veins of muscovite and milky quartz. The pegmatites are strongly sheared parallel to the foliation.

Gabbro, similar to that described by Seager (1944, p. 30–32) in the Jardine–Crevasse Mountain area, was recognized in the park only near Junction Butte at the junction of the Yellowstone and Lamar Rivers (pl. 1, east half). The gabbro is medium dark gray to dark gray, fine grained (0.2–0.4 mm), and appears to be similar to the fine-grained rocks of diabasic texture that Seager (1944, p. 32) described as being composed of about equal amounts of labradorite (An_{52}) and uralitic hornblende or actinolite derived from pyroxene, plus accessory biotite, quartz, zoisite, epidote, magnetite, chlorite, calcite, and zircon. C. W. Brown (1961, pl. 1) mapped the rock near Junction Butte as noritic gabbro.

AGE AND REGIONAL RELATIONS

The gneiss and schist underlie the Flathead Sandstone of Middle Cambrian age on Crowfoot Ridge and on the Buffalo Plateau, and their Precambrian age was recognized by Hague (1896, p. 1), who assigned them to the Archean. L. E. Brown (1965) and Brookins (1968, p. 6–7) reported rubidium-strontium ages on whole-rock samples of granitic gneiss from the Jardine-Crevasse Mountain district and potassium-argon ages on alkalic feldspar, biotite, and muscovite from granitic gneiss, and Brookins (1968, p. 7) concluded that the granitic rocks were emplaced 2.66±0.08 b.y. (billion years) ago and that they were affected by a fairly strong metamorphic event about 1.6–1.8 b.y. ago. Brown (1965, p. 37) suggested that this metamorphic event converted the granitic rocks to gneiss. McMannis and Chadwick (1964, p. 5) compiled radiogenic ages from various sources for similar rocks in the area north of Yellowstone National Park; these ages ranged from 2,070 to 2,750 m.y. (millions years) and included an age of 2,420 m.y. for rocks at Jardine.

The age of the schist remains obscure, but must exceed, perhaps greatly, the age of the granite. On the basis of admittedly meager rubidium-strontium data from two whole-rock samples, Brookins (1968, p. 7) suggested that the metamorphism producing the schist occurred at least 2.66 b.y. ago and possibly as much as 3.3–3.4 b.y. ago. The age of the original sedimentary rocks is unknown, but they are clearly the oldest rocks, by far, in the park.

Similar Precambrian crystalline rocks are widespread in southwestern Montana, north and west of Yellowstone; and Tansley, Schafer, and Hart (1933, p. 8–12) subdivided them into the Pony Series, which is mainly gneiss and schist, and the younger Cherry Creek Series, which consisted of garnetiferous gneiss, schist, quartzite, and limestone. Reid (1957, p. 1872) found, however, that the Cherry Creek seems to be older than the Pony in the Tobacco Root Mountains of Montana, near the type area of both series. Robinson (1963, p. 8–9) pointed out that the regional relations of Precambrian crystalline rocks in southwestern Montana are almost as poorly known and little understood as they were in the days of Hayden (1873, p. 67), and because of this, it seems unwise to use formal names for these rocks in Yellowstone National Park.

In summary, Seager (1944, p. 21–34) concluded that the schist is clearly of sedimentary origin, and he believed the original rocks to have been quartz-rich sandstone and subordinate amounts of interbedded siliceous iron carbonate. These rocks were converted to schist and quartzite as a result of regional metamorphism at least 2.6 b.y. ago, and perhaps as much as 3.3–3.4 b.y. ago, and later were intruded by gabbro and by the much more widespread granitic magma about 2.66±0.08 b.y. ago (Brookins, 1968, p. 7). The present gneissic texture was imposed on the granite by a later episode of regional

metamorphism about 1.6–1.8 b.y. ago (Brookins, 1968, p. 7).

PALEOZOIC SEDIMENTARY ROCKS

Paleozoic sedimentary rocks in the northern part of Yellowstone National Park have a total thickness of about 3,000 feet, and are divided into 13 map units, some of which include recognizable formations too thin to be shown separately on the geologic map (pl. 1, both halves). More than two-thirds of the total thickness is limestone or dolomite — the rocks that form most of the conspicuous cliffs in the Gallatin Range, along Slough Creek, and on the lower slopes of Baronnette and Abiathar Peaks.

The oldest Paleozoic rocks, of Middle Cambrian age, are overlain by formations that represent every system except the Silurian. Although almost every system is represented, significant interruptions in deposition occurred, and no rock unit reflects deposition through more than part of a system.

In their discussion of the sedimentary rocks in the northern part of Yellowstone National Park, Iddings and Weed (1899, p. 6–8) described a measured section of Paleozoic rocks on Crowfoot Ridge (pl. 1, west half) and established this section as a reference sequence that has since been cited in many publications. Unfortunately, the Crowfoot Ridge section is cut by a zone of flat faults that destroy its usefulness as a reference sequence except for some of the Cambrian formations. To replace the Crowfoot Ridge section, other sections are suggested in the following pages.

CAMBRIAN

Cambrian rocks are among the most widespread sedimentary rocks in Yellowstone National Park; they crop out in the southern part of the Gallatin Range, on the Buffalo Plateau, and along Slough and Soda Butte Creeks. These rocks are separable into the Flathead Sandstone, Wolsey Shale, Meagher Limestone, Park Shale, Pilgrim Limestone, and the Dry Creek, Sage and Grove Creek Members of the Snowy Range Formation. Of these, the Flathead and Wolsey were mapped as a single unit and the Dry Creek, Sage, and Grove Creek were mapped together as the Snowy Range Formation. The aggregate thickness of the Cambrian rocks is about 1,100 feet.

The nomenclature of Cambrian rocks in Montana and Yellowstone National Park, long subject to controversy, has been reviewed by Deiss (1936), Dorf and Lochman (1940), Lochman-Balk (1950), Sloss and Moritz (1951), Hanson (1952), and Robinson (1963). In the northern part of the park, the Cambrian rocks were originally divided into the Flathead Formation and the Gallatin Limestone by Weed (1896, p. 4), and the Crowfoot Ridge section was established as a reference sequence for these formations by Iddings and Weed (1899, p. 6–8). Deiss (1936) remeasured and described the Crowfoot Ridge section as part of a general study of Cambrian rocks in Yellowstone National Park and in Montana; he concluded (1936, p. 1325–1326) that the Flathead as originally used in the park had to be redefined and that the name Gallatin should not be used. To replace these names, Deiss proposed that the nomenclature used by Weed (1900, p. 285–286) for Cambrian rocks in the Little Belt Mountains, Mont., be adopted for Cambrian rocks in central and southern Montana and in Yellowstone National Park. Dorf and Lochman (1940) restudied the Cambrian rocks in south-central Montana, and, though they agreed with Deiss that the name Gallatin Limestone should not be used in this area, they proposed three new formations — the Maurice, Snowy Range, and Grove Creek. They (Dorf and Lochman, 1940, p. 551) specifically stated that these new names were applied to the section redefined by Deiss (1936, p. 1318) on Crowfoot Ridge — the Maurice to replace the unit called Pilgrim, and the Snowy Range to include, in its lower part, rocks that Deiss called the Dry Creek Shale. Sloss and Moritz (1951, p. 2144–2145), Hanson (1952, p. 16), Lochman-Balk (1956, p. 603), and Robinson (1963, p. 15) pointed out that the Maurice is the lithologic equivalent of the Pilgrim and that, because the name Pilgrim was first applied to these rocks, the name Maurice should be dropped. Accordingly, the name Pilgrim is used in this paper, as are the names applied by Deiss (1936, p. 1318–1325) to the older Cambrian formations below the Pilgrim, which are, in ascending order, the Flathead Sandstone, Wolsey Shale, Meagher Limestone, and Park Shale.

The Cambrian rocks above the Pilgrim on Crowfoot Ridge were included in the Dry Creek Shale by Deiss (1936, p. 1318–1319), but the nomenclature of these uppermost Cambrian rocks has been extensively revised since then, principally by Dorf and Lochman (1940), by Lochman-Balk (1950, 1956), and most recently by Grant (1965). Dorf and Lochman (1940, p. 545–547) intended that the Snowy Range Formation and Grove Creek Formation include the Upper Cambrian rocks above the Maurice Formation (Pilgrim Limestone of this report), and they included the shale and limestone of Deiss' (1936) Dry Creek Shale on Crowfoot Ridge in the Snowy Range Formation. Lochman-Balk (1950, p. 2212), in a study of the Dry Creek Shale of central Montana, divided the Snowy Range Formation into a lower member (the Dry Creek Shale Member) and an upper member (the Sage Limestone Member). The name Dry Creek was reduced from for-

mation to member rank. The Sage, a new name in her report, was derived from Lower Sage Creek and a stratigraphic section near Mill Creek, in the N½ SE¼ sec. 13, T. 6 S., R. 9 E., in the Livingston quadrangle, Montana, was selected as the type locality. And in 1956 the Grove Creek Formation was reduced to a member of the Snowy Range Formation by Lochman-Balk (1956, p. 609–613). In this report the Cambrian rocks above the Pilgrim Limestone are included in the Snowy Range Formation and are divided in accordance with the terminology proposed by Dorf and Lochman (1940) and as revised by Lochman-Balk (1950, 1956) and Grant (1965). This revised terminology is herein adopted for Yellowstone National Park and the surrounding region.

The ages of the various Cambrian rocks have been well established in many of the reports referred to above.

The Cambrian rocks measured and described by Deiss (1936, p. 1318–1325) on Crowfoot Ridge (pl. 1, west half; fig. 5) crop out in a well-exposed, almost complete section, and Deiss' descriptions are so complete that the section was not remeasured. For Cambrian rocks between the base of the Flathead Sandstone and the top of the Pilgrim Limestone, the Crowfoot Ridge section is the most complete and best exposed reference sequence in the northern part of Yellowstone National Park. The Cambrian rocks above the Pilgrim — the Snowy Range Formation — are disrupted by faulting on Crowfoot Ridge, and the section is incomplete. However, both the Snowy Range Formation and the Pilgrim Limestone are well exposed on Three Rivers Peak (fig. 6), at the head of the Gallatin River, and this section (stratigraphic sections, p. A59–A60) is here designated the reference section for the Pilgrim Limestone and Snowy Range Formation. Grant (1965, p. 67–69) measured sections of the Snowy Range Formation in the northeast corner of the park, and Lovering (1930, p. 18–24) described Cambrian rocks near Cooke City, Mont., a short distance from the Northeast Entrance to the park. Another excellent exposure of the Snowy Range Formation is half a mile southeast of the Buffalo Patrol Cabin on the west side of the Buffalo Plateau.

FLATHEAD SANDSTONE

The Precambrian crystalline rocks are overlain by the Middle Cambrian Flathead Sandstone, which crops out in many places in the southern part of the Gallatin Range, on the Buffalo Plateau, and west of Bison Peak near Slough Creek, its easternmost exposure (pl. 1, east half).

FIGURE 5. — Sedimentary rocks exposed on Crowfoot Ridge, Gallatin Range, Yellowstone National Park, viewed from the east. Cliff on left is Meagher Limestone, low cliff in center is Pilgrim Limestone, and high ridge on right is Madison Group. Crowfoot fault zone occupies swale between the Pilgrim and the Madison.

FIGURE 6. — Three Rivers Peak, viewed from the northeast. Measured section of Pilgrim Limestone and Snowy Range Formation is on the northeast (left) shoulder of peak. Flat shelf at base of main cliff is top of Pilgrim Limestone, upper shelf is top of Jefferson Formation, and top of peak is Lodgepole Limestone.

Most of the Flathead is quartzitic sandstone that is yellowish gray to very pale orange or grayish orange pink, fine to medium grained (0.1–0.3 mm), well sorted, and in beds 0.2–3 feet thick, although some beds on the Buffalo Plateau are as much as 5 feet thick. Locally, the Flathead weathers to pale red, grayish red, or pale reddish brown. Many beds are laminated or cross-laminated. The lower part of the formation is characterized by dark-reddish colors and coarse-grained rocks that are not common in the higher beds. On Crowfoot Ridge, conglomerate is especially plentiful in the lower 30 feet of the formation. Here, the basal 2–3 feet of the formation is grayish-red to light-gray very coarse (1–2 mm) poorly sorted sandstone interbedded with conglomerate that contains subangular to subrounded pebbles of glassy white quartz as much as 3 inches long. The overlying beds, 0.1–3 feet thick, are graded, with thin conglomeratic zones or very coarse sandstone zones at the base of each bed, grading upward into fine-grained (0.1 mm) clean, partly cross-laminated quartzitic sandstone. The upper part of the formation in the Gallatin Range contains thin interbeds of greenish-gray fissile shale similar to that in the overlying Wolsey Shale, and the contact is placed at the highest bed of quartzitic sandstone.

The Crowfoot Ridge section of the Flathead also includes a unique 1-foot-thick zone of sandy oolitic hematite beds that contain small brachiopods of Middle Cambrian age (Deiss, 1936, p. 1325), the only known fossils in the Flathead Sandstone.

On Crowfoot Ridge the formation is 160 feet thick (Deiss, 1936, p. 1315–1316), and on the Buffalo Plateau it is about 120 feet thick. At Cooke City it is about 100 feet thick (Lovering, 1930, p. 19), or a little less, depending on where the upper contact is placed. The formation is well exposed only on the crest of Crowfoot Ridge and on the Buffalo Plateau; elsewhere only the upper part of the formation crops out, in low rounded ledges.

WOLSEY SHALE

Although the Wolsey Shale of Middle Cambrian age is as widely distributed as the underlying Flathead Sandstone, it is exposed in only a few places in the Gallatin Range. On the Buffalo Plateau and near Slough Creek, its presence is suggested here and there by shale fragments in the soil, but no outcrops are known.

Most of the Wolsey is greenish-gray slightly micaceous sandy shale, but interbeds of soft rusty-weathering argillaceous calcareous thin-bedded sandstone and siltstone and of glauconitic sandy thin-bedded limestone are common throughout the formation. The upper third of the formation contains the more abundant limestone interbeds, and the upper contact with the Meagher Limestone is gradational through a thickness of about 20 feet; the contact is placed at the first bed of yellow and gray mottled limestone, typical of the Meagher. Thus, both the upper and the lower contacts of the Wolsey are gradational in the Gallatin Range. The formation is characterized by its abundant grayish-green fissile shale, by rusty-weathering dirty calcareous sandstone, and by glauconitic sandy limestone interbeds. Many beds throughout the formation are marked by worm trails.

On Crowfoot Ridge, as elsewhere in the Gallatin Range, the Wolsey is 150 feet thick (Deiss, 1936, p. 1321–1322). It probably is only about 100 feet thick on the Buffalo Plateau, and farther east, near Cooke City, the lower shale member of the Gros Ventre Formation — the approximate equivalent of the Wolsey — is 90 feet thick (Lovering, 1930, p. 20).

MEAGHER LIMESTONE

The Meagher Limestone, of Middle Cambrian age, is the lowest thick unit of carbonate rock in the northern part of Yellowstone National Park, and it forms conspicuous light-colored massive cliffs and ledges. The formation is widely exposed in the southern part of the Gallatin Range, on the Buffalo Plateau, and west of Slough Creek.

The Meagher is a distinctive formation that everywhere includes the mottled limestone beds so characteristic of the formation in southwestern Montana. The limestone that makes up most of the formation is medium gray to medium dark gray, is very fine grained, occurs in beds 0.1–3 feet thick, and is mottled with light-gray, yellowish-gray, or yellowish-orange slightly coarser grained limestone or dolomitic limestone. The upper part of the formation is not so conspicuously mottled as the middle and lower parts. The rocks weather medium light gray or light gray mottled with yellowish orange, pinkish gray, or lighter shades of gray. The origin of the mottling in the Meagher Limestone, and in similar rocks of the Upper Cambrian Pilgrim Limestone, was discussed by Hanson (1952, p. 14) and, most recently, by Robinson (1963, p. 19–20). The limestone commonly contains small twiggy calcite crystals and, in many places, is cut by thin (1–2 mm) veinlets of crystalline calcite that both parallel and cut across the bedding. Most beds in the lower part of the formation are 0.1–0.2 foot thick and are not so well exposed as the thicker, overlying beds. Shaly partings between limestone beds are common throughout the formation, and thin interbeds of grayish-green shale are widespread in the lower part of the formation in the Gallatin Range and throughout the entire formation in the north-central and northeastern part of the park. The top of the formation in the Gallatin Range is a unit, about 10 feet thick, of limonitic sandy calcareous shale containing thin beds and abundant concretions 3–5 feet in diameter of dark-gray to brownish-gray very finely crystalline ferruginous limestone (Deiss, 1936, p. 1320, 1323–1325). As Deiss pointed out, the unit is not found in the Meagher except in the Gallatin Range in Yellowstone National Park.

On Crowfoot Ridge, the Meagher is 388 feet thick in the section described by Deiss (1936, p. 1320–1321), and is about the same at Dome Mountain and south of Mount Holmes. On the Buffalo Plateau and near Buffalo and Slough Creeks, it appears to be 175–200 feet thick. In these areas, 25–50 feet of thin-bedded limestone in the lowermost part of the formation is generally concealed, and the thicker, upper limestone beds form a cliff or series of ledges about 150 feet high. At Cooke City, rocks about equivalent to the Meagher were included in the Gros Ventre Formation by Lovering (1930, p. 19–21) as a middle limestone member, 200 feet thick. However, Lovering included shaly and sandy beds in the base of the middle limestone member of the Gros Ventre that I would include with the Wolsey Shale, so the part of the middle limestone member equivalent to the Meagher is somewhat less than 200 feet thick, and perhaps is a little thinner than the Meagher near Slough Creek. West of the park, in the Madison Range, the formation is about 450 feet thick (Witkind, 1964, 1969). The Meagher Limestone is only half as thick in the northeastern part of the park as it is in the northwestern part, and it clearly thickens westward.

PARK SHALE

The Park Shale conformably overlies the Meagher Limestone and is the uppermost unit of Middle Cambrian age. The formation is widespread but poorly exposed in the Gallatin Range. It is concealed by glacial deposits almost everywhere on the Buffalo Plateau, and only the uppermost few feet of the formation are exposed at its easternmost outcrops near Slough Creek.

The formation is made up mainly of grayish-green shale that, in the lower half, is papery and, in the upper half, becomes a thinly platy mudstone. Some medium-dark-gray to grayish-red beds occur throughout the formation, but the dominant color is

grayish green. The lower half of the formation contains a few lenses, less than 0.5 foot thick, of limestone coquina and interbeds about 0.5 foot thick of greenish-gray rusty-weathering glauconitic finely crystalline limestone. Locally, a few thin beds of limestone pebble conglomerate are present in the basal part of the formation. In the Gallatin Range the upper 20–30 feet of the formation includes thin interbeds of yellowish-gray argillaceous limestone and shale, but near Slough Creek the uppermost beds are grayish-yellow-green pisolitic glauconitic coarse-grained limestone, 0.1–0.3 foot thick, interbedded with greenish-gray shale and mudstone.

The only well-exposed sections in the Gallatin Range are on the crest of Crowfoot Ridge, where the formation is 120 feet thick (Deiss, 1936, p. 1320), and south of Mount Holmes, where it is about 100 feet thick. It appears to be about 100 feet thick on the Buffalo Plateau and near Slough Creek. Equivalent rocks in the Gros Ventre Formation near Cooke City, Mont., are about 90 feet thick (Lovering, 1930, p. 21).

PILGRIM LIMESTONE

The Pilgrim Limestone, of Late Cambrian age, conformably overlies the Park Shale. The formation is well exposed and forms a conspicuous light-gray cliff at many places in the Gallatin Range. It forms cliffs on the upper part of the Buffalo Plateau, on the east canyon wall of Buffalo Creek near Slough Creek, and in the upper reaches of Soda Butte Creek near the Northeast Entrance to the park.

The Pilgrim includes three main lithologic units: (1) a lower unit of interbedded ribboned limestone, oolitic limestone, and less common limestone pebble conglomerate and shale; (2) a middle unit of limestone pebble conglomerate; and (3) an upper unit of mottled oolitic limestone. The three units are persistent throughout the northern part of the park.

The lower unit, which forms almost half the formation, is mostly medium gray very fine grained thin-bedded (0.2–0.5 ft) limestone that is ribboned with yellow-brown to grayish-orange silty limestone and irregular layers as much as 0.1 foot thick of silt and very fine sand. Interbeds as much as 3 feet thick of medium-gray glauconitic oolitic limestone rich in trilobite fragments are common in the ribboned limestone. The unit also contains a few interbeds, less than 1 foot thick, of medium-gray medium- to coarse-grained fossiliferous glauconitic limestone pebble conglomerate and, in the north-central and northeastern part of the park, a few thin interbeds of grayish-green shale.

The middle unit, about 60 feet thick, is medium-gray medium- to coarse-grained glauconitic limestone pebble conglomerate that contains abundant fossil fragments. The unit includes a few yellowish-gray sandy pisolitic glauconitic limestone beds where it is exposed in Slough Creek and Soda Butte Creek.

The upper unit is medium-gray largely oolitic fine- to medium-grained limestone that is mottled yellowish gray to pale yellowish brown. Although most of the unit is massive or thick bedded, it also includes zones of thin-bedded to platy dolomite, particularly in the northeastern part of the park. It is 40–60 feet thick in the Gallatin Range and 100–150 feet thick on the Buffalo Plateau and near Soda Butte Creek. This is the "mottled limestone" of Iddings and Weed (1899, p. 8; Weed, 1896, p. 4), and the most conspicuous part of the formation, for it forms prominent cliffs.

On Crowfoot Ridge, the Pilgrim Limestone is 172 feet thick (Deiss, 1936, p. 1320). On Three Rivers Peak it is 160–175 feet thick, but at that locality the upper part of the Park Shale and the lower part of the Pilgrim are intruded and metamorphosed by the Indian Creek laccolith, and placement of the contact is uncertain over a thickness of about 40 feet. On the Buffalo Plateau and near Buffalo Creek, Slough Creek, and Soda Butte Creek, the formation is about 250 feet thick, as are equivalent rocks near Cooke City, Mont. (Lovering, 1930, p. 21–24), where they were included by Lovering in the upper part of the Gros Ventre Formation and the lower part of the Gallatin Formation.

SNOWY RANGE FORMATION

The Snowy Range Formation, of Late Cambrian age, conformably overlies the Pilgrim Limestone, and is the uppermost Cambrian unit in Yellowstone National Park. The formation typically consists of three members, the Dry Creek Shale (base), the Sage Limestone, and the Grove Creek Limestone (top), but only the Dry Creek and Sage Members are present in most of the northern part of the park. The Grove Creek Member crops out on Three Rivers Peak and also in the upper part of the canyon of Soda Butte Creek north of the Northeast Entrance.

The thickness of the Snowy Range Formation differs considerably from place to place. On the west side of Crowfoot Ridge (pl. 1, west half), the Dry Creek Shale Member is about 40 feet thick, and the Sage Limestone Member is perhaps 75 feet thick, although its thickness can only be estimated because of crumpling associated with faulting. On the crest of Crowfoot Ridge, Grant (1965, p. 64) measured about 15 feet of Dry Creek and about 65 feet of Sage, but there the Dry Creek is cut by a fault. On Three Rivers Peak (stratigraphic sections, p. A59) the Dry Creek is about 40 feet thick, the Sage is about 45 feet thick, and the Grove Creek is about 40 feet thick. Near the Buffalo Patrol Cabin

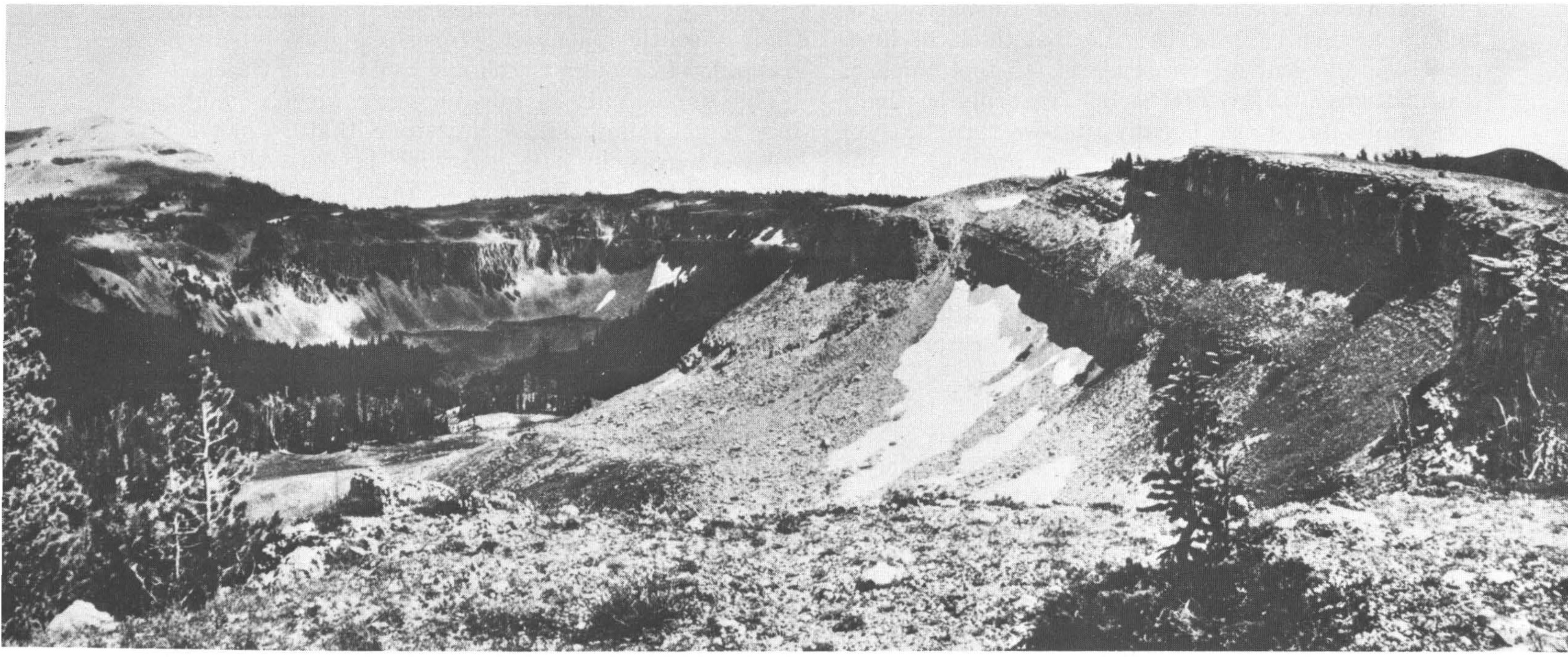

FIGURE 7. — Cliff outcrops of Cambrian and Ordovician rocks, viewed southward from Bighorn Pass, Gallatin Range. On right, lower cliff is Pilgrim Limestone; middle platy beds are Sage Limestone Member of Snowy Range Formation; upper cliff is Bighorn Dolomite. Cliffs in cirque headwall (center left) are part of Indian Creek laccolith.

on the Buffalo Plateau, the Dry Creek is about 50 feet thick, and the Sage is about 60 feet thick. North of the Northeast Entrance, Grant (1965, p. 67–69) measured about 50 feet of Dry Creek, 220 feet of Sage, and 25 feet of Grove Creek. Nearby on the southwest slope of Meridian Peak, the Dry Creek is about 50 feet thick, the Sage is about 150 feet thick, and the Grove Creek is absent. Grant (1965, p. 13–14, 17) suggested that the differences in thickness of the Sage and Grove Creek Members are due to erosion, which in most places in Yellowstone National Park had removed the Grove Creek Member and much of the Sage Limestone Member before deposition of the Bighorn Dolomite of Late Ordovician age.

DRY CREEK SHALE MEMBER

The Dry Creek Shale Member of the Snowy Range Formation is mainly greenish-gray to light-olive-gray paper-thin shale, with thin (less than 1 ft thick) interbeds of light-olive-gray calcareous very fine grained sandstone and siltstone. The upper 10 feet or so of the member contains interbeds of medium-gray to medium-light-gray very fine grained to oolitic glauconitic limestone and limestone pebble conglomerate. The base of the member in the Gallatin Range is marked by a 1-foot-thick bed of yellowish-orange to yellowish-brown platy calcareous very fine grained sandstone or siltstone, which overlies the mottled limestone at the top of the Pilgrim Limestone.

SAGE LIMESTONE MEMBER

The thin and crinkly limestone beds of the Sage Limestone Member of the Snowy Range Formation are distinctive rocks that typify the member wherever it is exposed (fig. 7). These rocks, in beds about 1 foot thick, are pale yellowish brown to medium gray, partly glauconitic, very fine grained, and laminated and are irregularly, or "crinkly," ribboned with grayish-orange to dark-yellowish-orange very fine grained sandy limestone and calcareous sandstone. Typically, they contain interbeds, as much as 3 feet thick, of similarly colored mottled limestone. From the Buffalo Plateau eastward to the Northeast Entrance, the base of the member is marked by a bed, 10–15 feet thick, of limestone that is made up of algal columns as much as 1 foot in diameter — the *Collenia magna* beds described by Grant (1965, p. 12–14) — but similar algal beds are not present in the Gallatin Range. In its eastern outcrops, the member also includes many thin interbeds of grayish-green shale and of yellowish-gray limestone pebble conglomerate that are absent at Three Rivers Peak (stratigraphic section, p. A59), and only a few occur in the Gallatin Range. The member

includes many fossiliferous beds, some of them coquinas, and the upper part is generally more glauconitic than the lower.

Grove Creek Limestone Member

The Grove Creek Limestone Member of the Snowy Range Formation has been recognized in Yellowstone National Park only on Three Rivers Peak. It does crop out, however, south of Silver Gate, Mont., only a short distance from the Northeast Entrance and may well be present in some places locally along the east canyon wall of Soda Butte Creek, where the Snowy Range Formation is largely concealed by glacial and landslide deposits. At the Silver Gate outcrops, the Grove Creek Member (Grant, 1965, p. 67–69) is mostly yellowish-orange fine- to medium-grained algal dolomitic and pyritic limestone interbedded with dusky-blue hard blocky calcareous or dolomitic shale. Typically, the member includes much limestone pebble conglomerate, but only a few thin beds are preserved in the thin remnants near Silver Gate.

On Three Rivers Peak (stratigraphic sections, p. A59) the member consists of light-brownish-gray very fine grained, partly algal, thin and irregularly bedded dolomite, dolomitic limestone, and limestone that form the base of the cliff above the softer rocks of the Dry Creek and Sage Members.

ORDOVICIAN

Although Ordovician rocks forming light-gray cliffs and ledges are widespread in the northern part of Yellowstone National Park, they were not recognized in the early geological studies by Iddings and Weed (1899) and apparently remained unknown until Lovering (1930, p. 24–26) identified the Upper Ordovician Bighorn Dolomite in the Cooke City mining district. Wilson (1934b, p. 374) later recognized the Bighorn north of the park at Cinnabar Mountain, and Richards and Nieschmidt (1961) measured a section of Bighorn Dolomite on Antler Peak in the Gallatin Range. C. W. Brown (1961, pl. 1, p. 1175) mapped the Bighorn on the Buffalo Plateau and farther east in the park. The principal stumbling block in recognition of the Ordovician rocks in the Gallatin Range has been the widespread acceptance of the Crowfoot Ridge reference sequence (Iddings and Weed, 1899, p. 6–8; Deiss, 1936, p. 1318–1325; McMannis, 1962, p. 8, pls. 4, 5; Grant, 1965, p. 63–64). The Bighorn Dolomite, in fact, is not present on the crest of Crowfoot Ridge, as has been recognized by most who have measured this section, but its absence is due to faulting, rather than to erosion or nondeposition.

The Bighorn Dolomite is completely exposed on Three Rivers Peak, at the head of the Gallatin River (pl. 1, west half), and is included in the Three Rivers Peak measured section (stratigraphic section p. A59), which is designated as a new reference section for the Bighorn Dolomite in the northwestern part of Yellowstone National Park. The most complete exposures of the formation in the northeastern part of the park are on the southwest slopes of Meridian Peak (pl. 1, east half), west of the Northeast Entrance.

BIGHORN DOLOMITE

The rocks included in the Bighorn Dolomite unconformably overlie the Snowy Range Formation and are much alike wherever exposed. Most of the formation is light-brownish-gray dolomite that weathers pale yellowish brown to light gray and has a distinctive irregular or pitted surface. In the Gallatin Range, much of the formation is thin bedded (0.1–0.3 ft); these thin-bedded rocks (stratigraphic section, p. A59) are provisionally included in the Bighorn, but they are thinner bedded than is typical of the formation. On the Buffalo Plateau and near the Northeast Entrance, the formation is more massive, and many cliff outcrops show virtually no bedding throughout thicknesses of as much as 125 feet; the upper half of the formation at these localities includes more thin beds than the lower half, but thick-bedded or massive rocks are dominant even in the upper half. The dolomite is very fine grained to fine grained, partly laminated, and partly cherty, containing lenses that are as much as 0.1 foot thick and 5 feet long of light-gray to yellowish-orange chert. Lovering (1930, p. 25–26) described fetid rocks from the base of the Bighorn near Cooke City, Mont., but such rocks were not found at this stratigraphic position in Yellowstone National Park.

At Three Rivers Peak, the Bighorn is about 100 feet thick. On Antler Peak, only the lower part of the formation — some 55 feet — is exposed (Richards and Nieschmidt, 1961). East of Buffalo Creek and near Slough Creek and Soda Butte Creek, the formation is about 200 feet thick, and near Cooke City, it is about 175 feet thick (Lovering, 1930, p. 25).

DEVONIAN

Rocks of Late Devonian age, 300–350 feet thick, are separated into the Jefferson Formation and Three Forks Formation, a division that follows that of Iddings and Weed (1899, p. 7–8; Weed, 1896, p. 4). The regional stratigraphy of these rocks has been the subject of many reports (Sloss and Laird, 1947; McMannis, 1962; Robinson, 1963, p. 24–38; Sandberg, 1965; Benson, 1966). Devonian rocks in areas immediately adjacent to the northern part of Yellowstone National Park have been described by several geologists: in the Madison Range to the west

by Witkind (1964, 1969), on Cinnabar Mountain to the north by Wilson (1934b, p. 373–374), and near Cooke City, Mont., to the northeast by Lovering (1930, p. 37–38).

The Crowfoot Ridge section is widely cited as a reference sequence for Devonian rocks in northwestern Yellowstone National Park (Iddings and Weed, 1899, p. 6–8; McMannis, 1962, pl. 4; Benson, 1966, p. 2578). However, the flat faults that cut across Crowfoot Ridge have removed most of the Jefferson and part of the Three Forks from the ridge crest. On the west side of the ridge, part of the Jefferson is apparently repeated by faulting, but much of it and the Three Forks are gone. The formations are well exposed on Three Rivers Peak (stratigraphic sections, p. A58), where the section is designated a reference section for the Jefferson and Three Forks Formations in northwestern Yellowstone National Park.

JEFFERSON FORMATION

The rocks of the Jefferson Formation in the northwestern part of the park differ considerably from those in the northeastern part. In the Gallatin Range the formation is mainly brownish-gray to pale-brown, or various shades of gray, very fine grained to fine-grained sugary dolomite, in beds from 0.1 to 3 feet thick, with the thinnest beds commonly thinly laminated. A few beds are dark gray, and most of these darker rocks are fetid. Here and there, a few thin beds of dark-gray very fine grained limestone occur near the base. Thin and platy beds of yellowish-brown dolomitic siltstone and silty dolomite are intercalated throughout the formation, and a single 3-foot-thick bed of greenish-gray shale is near the top. The shale is overlain by a 30-foot-thick massive unit of yellowish-brown to brownish-gray very fine grained dolomite that marks the top of the formation and is correlated with the Birdbear Member of the Jefferson Dolomite (Sandberg, 1965, p. 7).

In the northeast corner of the park, the Jefferson is pale-brown to pale-yellowish-brown fine-grained sugary dolomite and dolomitic limestone in beds 0.2–4 feet thick. The thicker beds are in the lower third of the formation, and the uppermost beds are thinner and finer grained than those in the rest of the formation. In this area, there are few, if any, dark fetid rocks, and the section differs not only from that in the Gallatin Range, but also from that of the Devonian rocks measured by Lovering (1930, p. 27) near Cooke City, Mont., which was dominantly dark-gray fetid limestone. Similar light-colored rocks occur in the single outcrop of Jefferson west of Slough Creek, and this atypical Jefferson appears to be widespread in the north-central and northeastern parts of Yellowstone National Park.

On Three Rivers Peak, the Jefferson Formation is about 240 feet thick. On Meridian Peak, it is about 175 feet thick, but it is only 125 feet thick near Cooke City, Mont., a few miles farther east (Lovering, 1930, p. 27). Lovering attributed this westward thickening to the erosional unconformity at the base of the Jefferson.

The following fossils were identified by W. A. Oliver, Jr. (written commun., 1965, 1967), who considered them to be of Late Devonian, probably early Late Devonian age:

USGS fossil loc. 7567–SD (5Y3F Ruppel), head of Gallatin River valley.
- Massive stromatoporoids
- *Alveolites* sp.
- Thamnoporoid corals
- *Acinophyllum*? sp.

USGS fossil loc. 8141–SD (6Y27 Ruppel), Crowfoot Ridge.
- *Pachyphyllum* sp.
- *Thamnophyllum* sp.

THREE FORKS FORMATION

The distribution of the Three Forks Formation is similar to that of the Jefferson Formation, which it conformably overlies. Although the rocks in the formation differ across the park, the Logan Gulch Member (Sandberg, 1965, p. 10–14) can be tentatively identified in the Gallatin Range, and the Logan Gulch and Trident Members can be tentatively identified near the Northeast Entrance.

In the Gallatin Range, where all of the rocks included in the formation are considered equivalent to the Logan Gulch Member, the lower 30–35 feet is mainly light-olive mudstone that weathers pale orange to grayish orange. It includes a few interbeds, each about 0.5 foot thick, of light-olive-gray yellowish-weathering very fine grained dolomite. The upper 45–50 feet of the formation is light-olive-gray grayish-orange- to light-gray-weathering very fine grained dolomite and silty dolomite, in 0.1- to 0.2-foot-thick beds.

In the northeast corner of the park, the Three Forks includes three units — lower shale, middle limestone, and upper shale. The lower shale and middle limestone are probably equivalent to the Logan Gulch Member and to the rocks included in the formation in the Gallatin Range, and the upper shale is probably equivalent to the Trident Member. The lower shale, about 50 feet thick, is made up of interbedded grayish-green to yellowish-brown to dark-gray paper-thin shale and calcareous mudstone, and yellowish-brown fine-grained limestone, in beds 0.1–1 foot thick. The middle limestone, about 30 feet thick, is light-olive-gray to pale-yellowish-brown very fine grained, typically brecciated limestone and dolomite. It weathers light brown to pale reddish brown and locally forms a conspicuous red cliff. The

upper shale, about 50 feet thick, is yellowish-brown to grayish-green mudstone and shale in its lower half, grading upward into grayish-red calcareous mudstone and interbedded grayish-green shale. The upper 10 feet of this unit includes thin interbeds of light-gray or pale-yellowish-brown fossiliferous limestone. The Three Forks Formation at Cooke City, Mont. (Lovering, 1930, p. 28), appears to be almost identical to the formation in the northeastern part of the park.

In the Gallatin Range, the formation is about 80 feet thick (stratigraphic section, p. A58). In the northeast corner of the park it is about 130 feet thick, and near Cooke City, Mont., it is about 100 feet thick (Lovering, 1930, p. 28). The upper shale unit in the northeast corner of the park apparently was eroded farther west before deposition of the Lodgepole Limestone.

MISSISSIPPIAN

The thick sequence of limestone and dolomite of Mississippian age in the northern part of Yellowstone National Park is divided into two formations, the Lodgepole and Mission Canyon Limestones that together form the Madison Group. The thickness of the group is about 1,300 feet. These thin-bedded to massive carbonate rocks underlie much of the central part of the Gallatin Range (pl. 1, west half) and crop out intermittently to the Northeast Entrance (pl. 1, east half). The regional stratigraphy of the Madison Group, and the development of the nomenclature followed in mapping these rocks in the park, was recently reviewed by Roberts (1966), Robinson (1963, p. 38–44), and Sando (1967a); the characteristics of the Madison Group in the Madison Range, west of the park, were discussed by Witkind (1969).

Iddings and Weed (1899, p. 7, 32, 35) measured and described several sections of Madison Limestone in the Gallatin Range and described the formation where it crops out near Soda Butte Creek and on Abiathar Peak. Their main sections were on the crest of Crowfoot Ridge, now known to be faulted, and from Panther Creek through the cirque on the east side of Bannock Peak. Both sections are useful, but they are not so well exposed as a section measured on the south face of Bannock Peak (fig. 8) by W. J. Mapel, A. E. Roberts, and E. K. Maughan (written commun., 1967; this report, stratigraphic section, p. A60–A61), which is designated here as a reference section both for the Mississippian Madison Group and for its individual formations, the Mission Canyon and Lodgepole Limestones.

LODGEPOLE LIMESTONE

The characteristic thin-bedded limestones of the Lodgepole overlie the Three Forks Formation with seeming conformity, although the absence of both the Sappington Member of the Three Forks (Sandberg, 1965, p. N14–N17) and the upper shale unit of the Three Forks in the Gallatin Range (p. A19) suggests that some of the Three Forks sediments were eroded before the Lodgepole was deposited. The Lodgepole commonly forms a series of low cliffs and ledges separated by grassy slopes, and it is not so well exposed as the cliff-forming massive rocks of the overlying Mission Canyon Limestone.

The limestone is light brownish gray or pale yellowish brown to light olive gray and medium gray

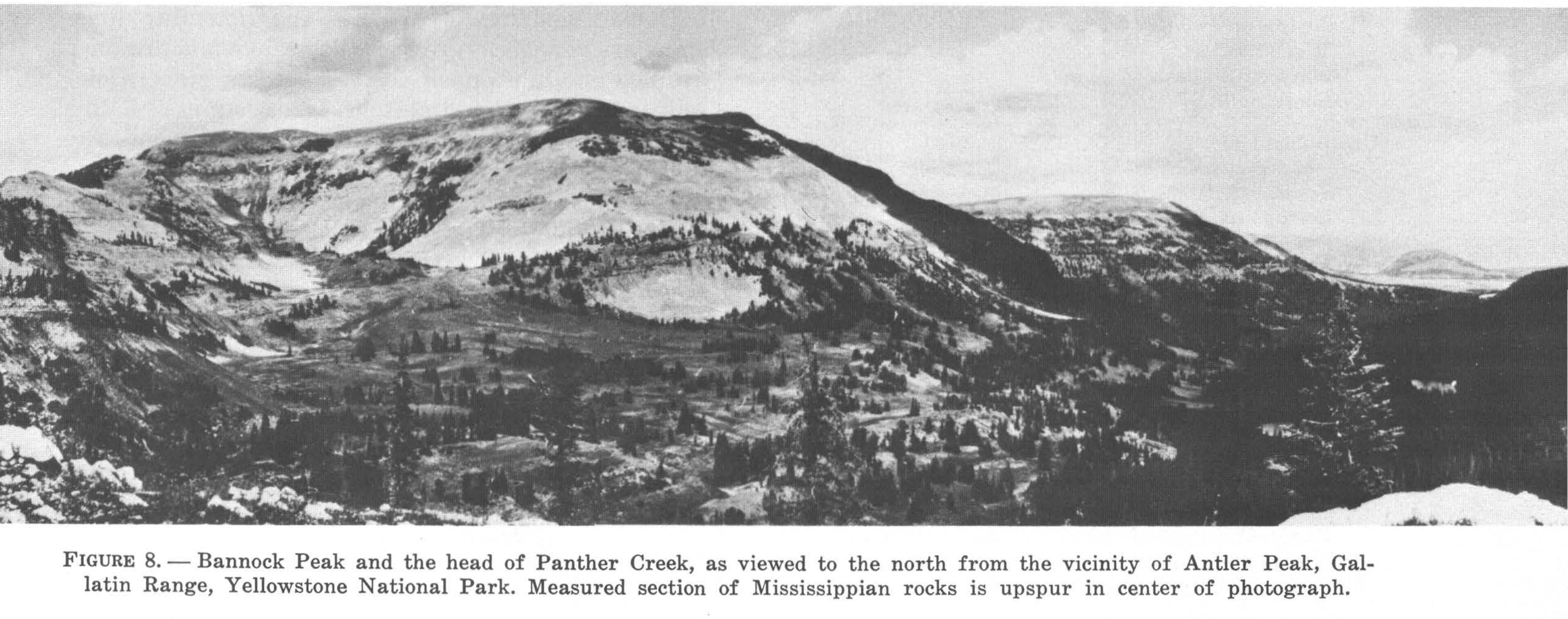

FIGURE 8. — Bannock Peak and the head of Panther Creek, as viewed to the north from the vicinity of Antler Peak, Gallatin Range, Yellowstone National Park. Measured section of Mississippian rocks is upspur in center of photograph.

and fine to medium grained; it occurs in beds 0.1–2 feet thick that are separated by partings, 0.1–0.2 foot thick, of yellowish-gray to pale-reddish-brown calcareous siltstone and silty limestone. In places in the lower part of the formation, the limestone beds may be as much as 5 feet thick and generally form units as much as 60 feet thick of mixed thin and thick beds. The limestones typically weather light gray or yellowish gray with a distinctive bluish tint. The lower half of the formation contains locally abundant yellowish-brown to dark-gray chert, both as irregular nodules, 0.2–0.3 foot thick and as much as 2 feet long, and as irregular beds, 0.1–0.2 foot thick.

The Lodgepole Limestone is about 485 feet thick on the south face of Bannock Peak (stratigraphic section, p. A61), and it maintains this thickness throughout the Gallatin Range. Near the Northeast Entrance it is at least 550–600 feet thick, but at that locality it is the youngest sedimentary rock exposed beneath the blanketing volcanic rocks, so its total thickness is uncertain.

The formation contains abundant fossils, mainly corals, brachiopods, and crinoid fragments; coarse-grained beds made up almost entirely of fossils or fossil fragments are common. The following fossils were identified by W. J. Sando and J. T. Dutro, Jr. (written commun., 1968).

USGS fossil loc. 23282–PC (6Y28F Ruppel), crest of Crowfoot Ridge, upper part of Lodgepole Limestone.
- *Cleistopora placenta* (White)
- *Syringopora surcularia* Girty
- *Rhipidomella* sp.
- *Streptorhynchus*? sp.
- Rhynchonellid brachiopod, indet.
- *Rugosochonetes loganensis* (Hall and Whitfield)
- "*Spirifer*" *biplicoides* Weller, abundant
- *Martinia*? sp.
- *Composita humilus* Girty
- "*Eumetria*" sp.
- Platyceratid gastropod, indet.
- Euomphalid gastropod, indet.

USGS fossil loc. 23283–PC (6Y85 Ruppel), northwest flank of Crowfoot Ridge, middle part of Lodgepole Limestone.
- *Schuchertella* sp.
- *Leptagonia analoga* (Phillips)
- Rhynchonellid, indet.
- *Rugosochonetes loganensis* (Hall and Whitfield), abundant
- "*Spirifer*" cf. "*S.*" *biplicoides* Weller, abundant
- "*Torynifer*" cf. "*T.*" *cooperensis* (Swallow)
- "*Eumetria*" sp.

USGS fossil loc. 23286–PC (6Y109 Ruppel) northwest flank of Antler Peak, Madison Group undivided, lithology suggests lodgepole Limestone.
- Homalophyllites
- *Vesiculophyllum* sp.
- *Rugosochonetes loganensis* (Hall and Whitfield)
- "*Productus*" *gallantanensis* Girty
- productoid, indet.
- "*Torynifer*" cf. "*T.*" *cooperensis* (Swallow)
- "*Eumetria*" sp.
- *Beecheria*? sp.

The Lodgepole probably includes units 24 through 28 of Iddings and Weed's Crowfoot Ridge section (1899, p. 7; Girty, 1899, p. 483) and units 1 through 10 of their Bannock Peak section (Iddings and Weed, 1899, p. 32). The stratigraphic positions of fossils described and illustrated by Girty (1899, p. 483–599) were located by reference to the numbered beds of Iddings and Weed's Crowfoot Ridge section.

MISSION CANYON LIMESTONE

The dominantly thick to massive limestone and dolomite beds of the Mission Canyon Limestone form cliffs above the less resistant thinner beds of the Lodgepole in the Gallatin Range (pl. 1, west half) and crop out in a few places farther east in the park (pl. 1, east half) partly in isolated outcrops surrounded by volcanic rocks.

Most of the Mission Canyon is limestone, but dolomite and dolomitic limestone form some of the most distinctive units and compose about one-fourth of the formation. The limestone is medium gray to medium light gray, light olive gray, and pale yellowish brown and is fine to coarse grained; it generally occurs in beds 1–5 feet thick or massive, although some are as thin as 0.2 foot, and there are some zones of thinly laminated beds. Brownish-gray chert in nodules, as much as 0.2 foot thick and 2 feet long, and siliceous encrustations are common in the limestone. The coarser grained limestones are bioclastic, some beds are coquinas made up of fossil trash, and many beds are fossiliferous, containing abundant brachiopods and corals.

Dolomite, dolomite breccia, and dolomitic limestone are very light gray to pale orange and are finer grained and more massive than the limestone. Dolomite and dolomitic limestone form a massive unit 80–100 feet thick at the base of the formation. The upper half of the formation includes two conspicuous units of dolomite breccia that persist throughout the Gallatin Range. The lower dolomite breccia unit, about 300 feet below the top of the formation, is 60 feet thick and forms a prominent cliff that is pocked with small caverns. The upper dolomite breccia unit, about 100 feet thick, forms a light-colored massive cliff at the top of the formation.

The following fossils were identified by W. J. Sando and J. T. Dutro, Jr. (written commun., 1968):

USGS fossil loc. 23284–PC (6Y101 Ruppel) crest of Crowfoot Ridge, lower part of Mission Canyon Limestone.
- *Syringopora surcularia* Girty
- *Vesiculophyllum* sp.

USGS fossil loc. 23285–PC (6Y107 Ruppel) top of Antler Peak, Madison Group undivided, lithology suggests Mission Canyon Limestone.
Vesiculophyllum sp.
Leptagonia sp.
Unispirifer sp.
"Spirifer" cf. *"S." biplicoides* Weller

The Mission Canyon Limestone is 814 feet thick on the south face of Bannock Peak (W. J. Mapel, A. E. Roberts, and E. K. Maughan, written commun., 1967; this report, stratigraphic section, p. A60–A61); pl. 1, west half). Farther east on Bannock Peak, Iddings and Weed (1899, p. 32) measured 810 feet of rocks — units 11 through 22 of their Madison Limestone — which is equivalent to the Mission Canyon of this report. The Crowfoot Ridge section of Iddings and Weed (1899, p. 7) includes about 1,200 feet of rocks — units 29 through 32 — that are about equivalent to the Mission Canyon, but these rocks are cut by a strand of the flat Crowfoot fault (p. A45) — the "red limestone conglomerate" of their unit 30b is actually fault gouge and breccia — and by steeply dipping fracture zones that probably are faults. Unfaulted sections of the Mission Canyon nearest the Crowfoot Ridge section of Iddings and Weed are on the east valley wall of the Gallatin River, where they are about 800 feet thick, and the Crowfoot Ridge section is about 400 feet too thick as a result of duplication by faulting. Units 29 and 30 of Iddings and Weed's section are probably the lower part of the Mission Canyon, but part of unit 31 is Lodgepole repeated above the Crowfoot fault. Hence, unit 31 probably includes part, or all, of unit 28, as well as all of units 29 and 30 and younger rocks (fig. 9). W. J. Sando (written commun., 1967) recognized the anomalous thickness of the Crowfoot Ridge section, and has pointed out the difficulties in stratigraphic interpretation resulting from Crowfoot Ridge having been used as the type locality for many of the Mississippian species described by Girty (1899, p. 483–599).

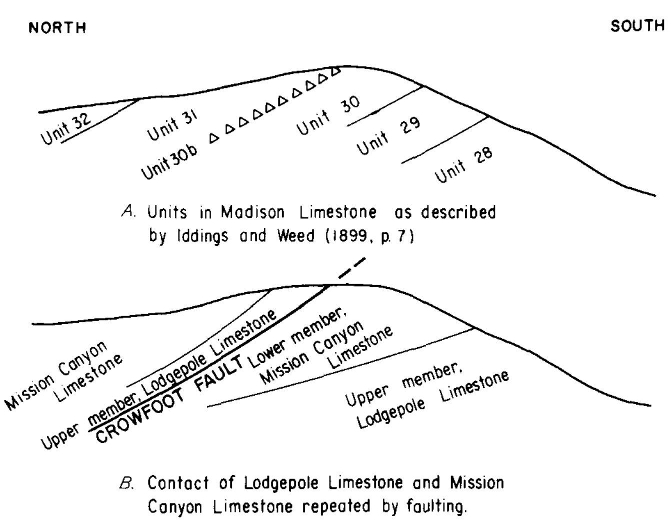

FIGURE 9. — Schematic cross section, viewed toward the east, of part of Crowfoot Ridge, showing interpretation of units of Madison Group.

PENNSYLVANIAN

Pennsylvanian rocks include the Amsden Formation and the overlying Quadrant Sandstone, which together have a maximum thickness of almost 400 feet. These rocks are in the Gallatin Range, on Horseshoe Hill, and on the ridge to the north, and in slices of the Gardiner fault zone where the zone is crossed by the Grand Loop Road (pl. 1, west half). Farther east, the Pennsylvanian rocks were removed either by erosion or by faulting before eruption of the volcanic rocks that now blanket most of the eastern part of the park. No rocks younger than Mississippian are known in the north-central or northeastern parts of the park.

Quadrant Mountain, in the Gallatin Range, is the type locality of the Quadrant Sandstone (Weed, 1896, p. 5; Iddings and Weed, 1899, p. 33–34), although the name was first used by Peale (1893, p. 39) for rocks near Three Forks, Mont. As originally defined, the Quadrant Sandstone of Quadrant Mountain included all rocks between the top of the Madison Limestone and the base of the cherty sandstone (Shedhorn Sandstone of this report) that was the basal part of the Teton Formation. A section of the formation on the southeast spur of Quadrant Mountain measured by Iddings and Weed (1899, p. 34) was about 400 feet thick. The basal part of the formation, 100 feet thick, was shown in the original measured section as concealed, and it is clear that Iddings and Weed did not recognize that at least part of the concealed beds are not sandstone, but, rather, are red shale and limestone — the Amsden Formation of this report. Condit (1919, p. 112, 117–118) recognized the presence of red beds, but he included them in the basal Quadrant when he redefined the overlying Teton Formation. Scott (1935) remeasured the type Quadrant section and recognized the Amsden in northern Yellowstone National Park for the first time. His section (Scott, 1935, p. 1017) includes about 230 feet of Quadrant and about 100 feet of Amsden. Scott's Quadrant Mountain section was later revised (Thompson and Scott, 1941, p. 350; Scott, 1945), and 43 feet of the beds that he had originally placed in the Amsden were assigned to Sacajawea(?) Formation of Mississippian age. The name Amsden was thus dropped completely from the Quadrant Mountain section. The rocks added to the Quadrant belonged there because of their lithologies; the name Sacajawea(?) was applied by Thompson

and Scott following the usage of Branson (1937), to rocks in which unspecified megafossils thought to be of Mississippian age were found. The name Sacajawea Formation, however, has not been widely or consistently used (Sando, 1967b, p. 546–550; 1968), and because these rocks are lithologically most like the Amsden exposed in adjacent areas, I assign them to the Amsden Formation.

The regional stratigraphy of the Amsden and Quadrant in southwestern Montana was discussed by Sloss and Moritz (1951, p. 2158–2160, 2164–2165), Robinson (1963, p. 38–39, 47–52), and more recently by Maughan and Roberts (1967); Maughan and Roberts also considered the long-standing problem of placement of the Mississippian-Pennsylvanian boundary in this region. Because specific Mississippian fossils were not found in the Amsden of the northern part of Yellowstone National Park, I follow the usage of Maughan and Roberts and consider the Amsden to be entirely of Pennsylvanian age, rather than partly Mississippian and partly Pennsylvanian, as in most earlier reports.

Neither the Amsden nor the Quadrant Formations were remeasured during the fieldwork leading to this report. The formations are well exposed at many places on Quadrant Mountain and Bannock Peak (pl. 1, west half), but the best exposures are on the arête that connects Bannock Peak to Quadrant Mountain. The Amsden is also well exposed on the eastern summit of Bannock Peak.

AMSDEN FORMATION

The dominantly red rocks of the Amsden Formation, of Early and Middle Pennsylvanian age (Maughan and Roberts, 1967, p. B6, B20–B23), were deposited on an irregular karst surface developed on the Mission Canyon Limestone, a surface that is well exposed on Bannock Peak.

In its thickest sections, on Bannock Peak, the Amsden consists of a lower and an upper unit. The lower unit is pale-red or grayish-red to yellowish-orange chippy mudstone, siltstone, and shale containing interbeds of similarly colored to light-gray fine-grained to very fine grained calcareous sandstone. The upper unit is grayish- and pale-red calcareous or dolomitic siltstone and contains a few thin beds of dolomite and shale. The basal rock of the lower unit typically is grayish-red conglomeratic sandstone, 0.5–1 foot thick. In other parts of the Gallatin Range, and north of Horseshoe Hill, the formation consists of only the lower unit; the upper unit apparently was removed by erosion before deposition of the Quadrant Sandstone.

The thickness of the formation ranges from 0 to about 60 feet. Because the changes in thickness are erratic, they probably partly reflect irregularities on the underlying karst surface. The greatest thickness is on Bannock Peak; the formation is absent or only a few feet thick on the east face of Quadrant Mountain. Elsewhere, it is generally 20–50 feet thick. Its outcrop width on the map (pl. 1, west half) is exaggerated so that the formation can be shown.

The two units of the Amsden Formation on Bannock Peak are lithologically similar to formations included in the Amsden Group in central Montana, as summarized by Maughan and Roberts (1967); the lower, most widespread unit is tentatively correlated with the Lower Pennsylvanian Tyler Formation, and probably with the Stonehouse Canyon Member of that formation. The upper, dolomitic unit resembles the Middle Pennsylvanian Devils Pocket Formation. The middle formation, the Lower and Middle Pennsylvanian Alaska Bench Limestone of the Amsden Group, does not seem to be represented in the Amsden of the northern part of Yellowstone National Park, and its absence may reflect the regional erosion that Maughan and Roberts (1967, p. B15) suggested took place before deposition of the Devils Pocket Formation.

QUADRANT SANDSTONE

The red rocks of the Amsden Formation are unconformably overlain by the light-brown sandstones and carbonate rocks of the Quadrant Sandstone of Middle Pennsylvanian age. These resistant rocks and the overlying Shedhorn Sandstone form the largest of the cliff-rimmed dipslopes of the Gallatin Range: Quadrant Mountain, the slope dipping north from Bannock Peak, and many smaller, similar slopes and bedrock-controlled benches.

The Quadrant Sandstone is composed mainly of yellowish-brown to very light gray fine-grained clean quartz sandstone and quartzitic sandstone in beds that commonly are 0.5–3 feet thick but in places are as much as 8 feet thick. The thicker beds are mainly in the middle part of the formation. Much of the sandstone is conspicuously cross-laminated and consists of well-sorted subrounded to subangular clear glassy quartz grains about 0.2 mm in diameter. Most of the sandstone in the lower half of the unit is calcareous. Interbeds of medium-light-gray to light-gray fine-grained dolomite, mostly less than 1 foot thick but in places as much as 3 feet thick, are common in the basal part and upper half of the formation, but are not common in the rest of the formation. On the east side of Quadrant Mountain, the basal part of the formation contains several lenses, from 20 to 40 feet thick and a few hundred feet long, of light-gray very fine grained dolomite. The uppermost bed included in the formation is a very light

gray very fine grained dolomite, 3–10 feet thick; this bed is underlain by the clean fine-grained sandstones of the Quadrant and is overlain by shale and the dirty sandstones of the Shedhorn Sandstone of Permian age.

The thickness of the Quadrant appears to be fairly uniform in the Gallatin Range—about 300–325 feet. This thickness is about the same as that measured by Iddings and Weed (1899, p. 34) if the Amsden rocks are excluded from their section, but it is substantially less than that given by Condit (1919, p. 117–118), which was almost 400 feet if the Amsden rocks are excluded. It is a little thicker than the 279 feet measured by Thompson and Scott (1941, p. 350).

PERMIAN

Rocks of Permian age, a little more than 100 feet thick, were originally included as the basal unit of the Teton Formation (Weed, 1896, p. 5; Iddings and Weed, 1899, p. 34; Stanton, 1899, p. 600) of "supposed Triassic" age, forming the "cherty beds" of limestone and sandstone in the lower half of that formation. Condit (1919, p. 113–114, 117; Condit and others, 1928, p. 188) examined these rocks on Quadrant Mountain and Bannock Peak, recognized them as Permian, and included them in the Phosphoria Formation. He measured and described a section in The Pocket, a small cirque on the north side of Quadrant Mountain, which is one of the best exposed sections of Permian rocks in the northern part of the park. The rocks were later included in the Shedhorn Sandstone (Cressman, 1955) in the revised nomenclature of Permian rocks in the western phosphate field (McKelvey and others, 1956, p. 2852). In accordance with this revised nomenclature, the name Shedhorn Sandstone is used in this report for the sandy, phosphatic and cherty rocks of Permian age that disconformably overlie the Quadrant Sandstone and that underlie rocks of Triassic age.

SHEDHORN SANDSTONE

Even though the Shedhorn Sandstone is a relatively thin formation, about 115 feet thick, it is widely exposed in the Gallatin Range, where its outcrop pattern conforms to that of the underlying Quadrant Sandstone.

The Shedhorn Sandstone is especially distinguished by a few beds of phosphate rock, by phosphatic oolites, pellets, and glauconite scattered through many of the rocks, by abundant chert in beds and nodules and in tubular concretions normal to bedding, and by phosphatized fishbones common in some beds. The lithologic details of the formation differ somewhat from outcrop to outcrop because of lateral changes in the rocks, but in a general way the formation is in three parts: (1) the lower half is dominantly sandstone, but includes a few beds of phosphate rock and is the main phosphatic zone; (2) the middle part is a conspicuously cherty group of beds that make up about one-fourth of the formation; and (3) the rest of the formation is interbedded sandstone and dolomite. The sandstone beds in the lower half of the formation are yellowish gray, pale yellowish brown, or medium gray to light olive gray; they are fine grained, are commonly at least slightly calcareous, and contain sparse grains of glauconite and from a few percent to 50 percent phosphatic oolites and pellets. Beds are 0.1–3 feet thick. Some beds contain irregular nodules, commonly about 0.2 foot thick and 1 foot long, of brownish-black phosphatic chert that weathers yellowish gray. The basal part of the formation, above a thin basal bed of sandstone, includes a 10-foot-thick bed of yellowish-gray shale capped by a 1- to 2-foot-thick bed of yellowish-gray fine-grained dolomite. The thickest bed of phosphate rock or of very phosphatic sandstone, about 3 feet thick, is a few feet above the shale. The beds of phosphate rock grade laterally into phosphatic sandstone, and the more phosphatic sandstone beds commonly contain abundant phosphatized fishbones. The top of the lower sandstone unit is marked by a 5- to 10-foot-thick sandstone bed that contains tubular concretions of brownish-gray chert, normal to bedding, as much as 0.3 foot in diameter and 4 feet long. The overlying cherty beds, about 30 feet thick, are brownish-gray to grayish-yellow phosphatic chert in beds 0.1–1 foot thick; they include a few light-gray to pale-yellowish-gray phosphatic and glauconitic quartz sandstone beds that contain abundant chert nodules.

The upper part of the formation is mostly medium- to light-gray fine-grained to very fine grained partly calcareous quartz sandstone that contains only sparse grains of chert, phosphate, and glauconite and, as a result, is much cleaner than the lower sandstones. The sandstone is in beds 0.1–0.5 foot thick and includes some equally thin interbeds of dolomite, which is medium light gray to brownish gray, fine grained to very fine grained, siliceous, locally cherty, partly fossiliferous, and vuggy.

MESOZOIC SEDIMENTARY ROCKS

Mesozoic sedimentary rocks, more than 4,000 feet thick, crop out only in the Gallatin Range and near Mammoth Hot Springs. Although most of them are not as resistant to erosion as the older rocks, they are well exposed in many places, perhaps because they have been intruded by many sills that form resistant layers and control the steep, cliff-circled slopes common from Little Quadrant Mountain north

to Electric Peak and the Yellowstone National Park boundary.

The oldest Mesozoic rocks, marine deposits of Triassic and Jurassic age, are overlain by nonmarine rocks of later Jurassic and Early Cretaceous age and a thick sequence of marine and nonmarine clastic rocks of later Cretaceous age. Triassic and Jurassic rocks constitute about 10 percent of the total Mesozoic section, and although these rocks are dominantly clastic, they include marine limestones of Jurassic age. The remaining 90 percent of the Mesozoic section, of Cretaceous age, is a monotonous sequence of shale, mudstone, and sandstone, which includes a few conglomerate beds and, in the upper part of the section, a few beds of coal and carbonaceous sandstone and shale.

The Mesozoic rocks in the Gallatin Range were originally divided into the Teton Formation of "supposed Triassic" age, the Ellis Formation of Jurassic age, and the Dakota, Colorado, Montana, and Laramie Formations of Cretaceous age (Iddings and Weed, 1899, p. 36–55; Stanton, 1899, p. 600–607; this report, fig. 4). Extensive collections of fossils from these formations were described and illustrated by Stanton (1899) and by Knowlton (1899). In the present report, the rocks are separated into units that include one unit of Triassic age, two of Jurassic age, and 10 of Cretaceous age. Some of these units include several formations that in other areas have been mapped separately, but which, for cartographic reasons, could not be shown separately here.

TRIASSIC

Triassic rocks, in outcrops made conspicuous by the red color of some of the rocks, are present in the Gallatin Range (pl. 1, west half), and the best exposed sections are between Bannock Peak and Fawn Pass. These rocks were first mapped as the upper part of the Teton Formation (Weed, 1896, p. 5). Condit (1919, p. 113–114, 117–118), who recognized that both Permian and Triassic rocks were included in the "Teton Formation," suggested that the name be discontinued, and it was subsequently abandoned (McKelvey and others, 1956, p. 2835). The upper 145 feet of the rocks originally included in the Teton Formation (Iddings and Weed, 1899, p. 34, units 34–38), for cartographic reasons, is here treated as an undivided unit of rocks that includes the Dinwoody, Woodside, and Thaynes(?) Formations of Triassic age.

DINWOODY FORMATION

The Dinwoody Formation of Early Triassic age (Kummel, 1954, p. 167–168; Condit and others, 1928, p. 187) is exposed south of Fawn Pass (pl. 1, west half), but apparently is absent farther east. The formation is light-gray to yellowish-gray limestone that is very fine grained and thin bedded and characteristically weathers pale brown or pale yellowish brown. It is 0–50 feet thick. Condit, Finch, and Pardee (1928, p. 187) described about 30 feet of thin-bedded white limestone of Triassic age on top of Quadrant Mountain, rocks that would be equivalent to the Dinwoody Formation, but I could not identify this white limestone in my mapping, and I believe that on Quadrant Mountain the younger Woodside Formation unconformably overlies the Shedhorn Sandstone, although erosional remnants of the Dinwoody may be present in some places.

WOODSIDE FORMATION

The red rocks of the Woodside Formation of Early Triassic age (Condit and others, 1928, p. 187; Kummel, 1954, p. 181, pl. 37) are conspicuous and form the red hills that crown Quadrant Mountain and a bright-red band that extends from the upper valley of Fawn Creek into the Gallatin River valley. The lower 10–20 feet of the formation is greenish-gray shale that grades upward into 1- to 5-foot beds of grayish-red to moderate-reddish-brown mudstone, siltstone, and very fine grained micaceous sandstone, and a few interbeds as much as 3 feet thick of greenish-gray mudstone and siltstone. The red rocks form most of the unit, and the greenish-gray rocks in the lower part are commonly not exposed. Iddings and Weed (1899, p. 34) described a 10-foot-thick calcite-cemented conglomerate at the base of the formation near the southeast spur of Quadrant Mountain, but the conglomerate does not appear to be present any place else. The Woodside is 75–100 feet thick.

The Woodside overlies the Dinwoody Formation south of Fawn Pass, but a short distance to the east on Quadrant Mountain, it unconformably overlies the Shedhorn Sandstone. The disappearance of the Dinwoody and the local presence of conglomerate, as noted by Iddings and Weed (1899, p. 34), suggest that part or all of the Dinwoody in this area was eroded before deposition of the Woodside and that the Woodside is unconformable on the Dinwoody, as well as on the Shedhorn Sandstone.

THAYNES(?) FORMATION

The Thaynes(?) Formation forms a ledge above the Woodside Formation near Fawn Creek and south of Fawn Pass. The unit commonly is 15–50 feet thick, but in some places it is absent, and the overlying Jurassic rocks rest unconformably on the Woodside. The sandstone is light gray, fine grained, clean, and calcareous, is made up of well-sorted well-rounded quartz grains, and occurs in beds 0.2–5 feet thick. The rock weathers pale yellowish brown, and

the weathered beds yield a blocky talus that fringes the cliffy outcrops.

The age of the sandstone is uncertain, as no fossils were found. The Lower Triassic Thaynes Formation, however, is predominantly calcareous sandstone in adjacent, southwestern Montana (Kummel, 1954, p. 177), and Witkind (1969) recognized in the Madison Range a unit of calcareous siltstone about 10 feet thick that he thought might be part of the Thaynes. Furthermore, Kummel (1954, p. 177) pointed out the widespread effects of pre-Jurassic erosion, perhaps reflected by the erratic changes in thickness of this sandstone. These regional considerations suggest to me that the sandstone is most probably a thin, eastward erosional edge of the Thaynes Formation, and, accordingly, I have mapped it with Triassic rocks. Fraser, Waldrop, and Hyden (1969, p. 20), however, studied the same unit near Gardiner, Mont., the only other area where it has been recognized, and considered it to be a basal sandstone representing marine onlap in Jurassic time. Crickmay (1936, p. 549–552) also assigned the sandstone to the Jurassic and stated that its regional continuity and lithologic contrast with the underlying Triassic red beds indicate that it was a basal Jurassic unit. However, the regional relations of the sandstone are unknown, and its lithology differs considerably from that of the overlying rocks, as well as from that of the underlying ones.

JURASSIC

Jurassic rocks crop out in the Gallatin Range and near Mammoth Hot Springs and in slices along the Gardiner fault zone (pl. 1, west half). These rocks are separable into four formations—the marine Sawtooth, Rierdon, and Swift Formations, all in the Ellis Group, and the nonmarine Morrison Formation—which have a total thickness of about 400 feet. For cartographic reasons, the three formations of the Ellis Group are mapped as a single unit in this report. Iddings and Weed (1899, p. 37–38, 51) included most of the Jurassic rocks in the "Ellis limestone" and "Ellis sandstone," but their descriptions of these units differ from place to place, and at some localities they seemingly included part of the Morrison Formation in the Cretaceous Dakota Formation. The Jurassic rocks in Fawn Pass and at the head of Fan Creek were measured and described by Crickmay (1936, p. 549–552), who also reported on fossils collected from them. He assigned these rocks to different formations—Morrison(?), Sundance (formerly the upper part of the Ellis), and Ellis (formerly the lower part of the Ellis)—from those used in this report, but his generalized lithologic descriptions are clear, and the lists of fossils contained in the rocks are extensive. Crickmay's section (1939, p. 549–550) at the head of East Fork Fan Creek is the best exposed section of Jurassic rocks in the northern part of Yellowstone National Park and is a reference sequence for Jurassic rocks, even though the Morrison Formation is somewhat thinner there than in most other places in the Gallatin Range. Fossils collected from Jurassic rocks in various places in the Gallatin Range were also described by Stanton (1899).

ELLIS GROUP

SAWTOOTH FORMATION

The Sawtooth Formation in Yellowstone National Park consists of the three lithologic units that characterize the formation in south-central Montana (Imlay and others, 1948; Imlay, 1952, p. 968; Peterson, 1957, p. 404–408): a lower red-bed member, a middle limestone member, and an upper red-bed member. The lower red-bed member, 20–30 feet thick and consisting of grayish-red and grayish-green siltstone, mudstone, and shale, unconformably overlies Triassic rocks; the member commonly is concealed by soil and float. The middle limestone member, 60–75 feet thick, is medium light gray to medium dark gray, very fine grained, and platy to chippy; it weathers light gray to olive gray. The limestone commonly is in beds 0.1–1 foot thick, many of which contain abundant fossils. Interbeds of medium-dark-gray calcareous shale, less than 1 foot thick, are common, and Crickmay (1936, p. 549) showed a 14-foot-thick shale bed in the upper part of the member. The upper red-bed member, 25–40 feet thick, is pale-red to grayish-red siltstone, mudstone, and shale that almost everywhere is concealed by red soil.

The beds that Crickmay (1936, p. 549–552) labeled units Yb through Yj and included in the Ellis Formation and the "Lower Sundance formation," constitute the Middle Jurassic Sawtooth Formation of this report. The section measured by Crickmay (1936, p. 549–550) is about 140 feet thick.

The limestones contain a rich fauna that was described by Crickmay (1936, p. 549–564. The following assemblage from the upper part of the middle limestone member was identified by R. W. Imlay (written commun., 1966), who noted that it contains:

> certain species of mollusks that in nearby areas are characteristic of member C (Rich Member) of the Twin Creek Limestone and of the middle limestone member of the Piper Formation. These species include the ammonites *Sohlites spinosus* Imlay, *Parachondroceras* spp., and the pelecypod *Gryphaea planoconvexa* Whitfield. In addition, *Thracia weedi* Stanton has been found in the Twin Creek Limestone only in the basal limestone members (B and C) and has not been found above the middle limestone member of the Piper Formation. *Myophorella montanaensis* (Meek) has not been found below member C of the Twin Creek Limestone. The age

of member C of the Twin Creek Limestone and of the middle limestone member of the Piper Formation is probably late Bajocian. (See Imlay, 1967, p. 2–3, 30–35.)

Fossil loc. 29442 (66Y193 Ruppel) Sawtooth Formation, from upper part of middle limestone member, Fawn Pass, about 1 mile west of Patrol Cabin, Yellowstone National Park.

Sohlites spinosus Imlay
Parachondroceras cf. *P. andrewsi* Imlay
Parachondroceras sp.
Idonearca haguei (Stanton)
Myophorella (Promyophorella) montanaensis (Meek)
Pleuromya subcompressa (Meek)
Gryphaea planoconvexa Whitfield
Pholadomya inaequiplicata Stanton
Camptonectes platessiformis White
Corbula cf. *C. munda* McLearn
Thracia weedi Stanton
Grammatodon haguei (Meek)
Solemya sp.
Mactromya? sp.

Another collection from a small erosional remnant of the lower part of the middle limestone member on Quadrant Mountain (pl. 1, west half) yielded *Camptonectes, Ostrea,* and the coral *Actinastrea hyatti* (Wells) (R. W. Imlay, written commun., 1966). Imlay noted that *Actinastrea hyatti* (Wells) is

> fairly common in the limy lower member of the Carmel Formation of Utah, the middle limestone member of the Gypsum Spring Formation in the Bighorn Basin, Wyo., and in the middle limestone member of the Piper Formation in central and southern Montana. It is fairly common in the limestone of the Piper Formation as far west as Livingston, Mont., and in Yellowstone Canyon south of Livingston. There is also one occurrence in the basal limestones of the Twin Creek Limestone. Many of these occurrences are dated as of late Bajocian age on the basis of ammonites. (See Imlay, 1967.)

Rierdon Formation

The upper red-bed member of the Sawtooth Formation is conformably overlain by the basal oolitic limestone of the Rierdon Formation, a resistant rock that almost everywhere forms a low ledge or is represented by abundant float. The Rierdon Formation, 40–60 feet thick, consists mostly of mudstone, siltstone, and shale. The basal limestone is 1–6 feet thick, medium gray, fine grained, and very oolitic and weathers medium light gray. It is overlain by pale-red to grayish-red calcareous mudstone, siltstone, and shale, about 20–25 feet thick, which, in turn, is overlain by 20–30 feet of medium-gray calcareous mudstone, the uppermost unit of the Rierdon. A few medium- to light-gray partly oolitic limestone beds, generally less than 0.5 foot thick, are interbedded in the middle and upper parts of the formation, but they are generally concealed beneath the soil-covered smooth slope developed on the formation.

The Rierdon Formation is not as richly fossiliferous as the underlying Sawtooth Formation, but it does contain many fossils (Crickmay, 1936, p. 549–551, units Yk and Yl) that date it as Late Jurassic (Crickmay, 1936, p. 550; Imlay, 1952, p. 968).

Swift Formation

The uppermost formation in the Ellis Group is the Swift Formation, which consists of 15–60 feet of pale-yellowish-brown to light-olive-gray fine- to medium-grained calcareous sandstone and very sandy limestone. These distinctive rocks are a mixture of subangular to subrounded quartz grains, subrounded grains of brownish chert, glauconite, oolites, and abundant fragments of fossils, all cemented by calcite. Locally, the rocks are sandy coquinas. Beds are generally 0.1–1 foot thick and are cross-laminated. Almost the entire thickness of the Swift is commonly exposed in a cliff that is made by prominent by the adjacent smooth slopes developed on the underlying and overlying mudstones.

Some of the fossils in the Swift Formation in Yellowstone National Park were described by Crickmay (1936, p. 549–564, unit Ym), who included the unit in the Sundance Formation, and these fossils established the formation as Late Jurassic.

Morrison Formation

The Morrison Formation, of Late Jurassic age, is poorly exposed in northwestern Yellowstone National Park. In most places it forms a gentle slope between ledges of the Swift sandstone below and the basal conglomerate and sandstone of the Kootenai Formation above. The formation is about 200 feet thick and consists mainly of grayish-red, dark-gray, and grayish-green partly calcareous shale, mudstone, and siltstone. The basal part of the Morrison is grayish-red shale and mudstone that overlies the Swift Formation, and there are at least a few beds, 1–2 feet thick, of olive-gray fine-grained limestone in the lower part of the formation. The upper half includes lenticular interbeds, as much as 3 feet thick, of yellowish-brown to light-gray siltstone and fine-grained to very fine grained calcareous cross-laminated quartz sandstone. The uppermost part of the formation is mainly dark-gray shale and platy mudstone, but contains many sandstone interbeds and a few thin interbeds of medium-light-gray chippy limestone. Northwest of Fawn Pass (pl. 1, west half) at the head of Stellaria Creek, these upper beds yielded fragments from the end of a leg bone of a moderately large dinosaur, but the bone pieces were too fragmentary to permit more positive identification (G. Edward Lewis, written commun., 1967). The same beds contain abundant fossil wood.

CRETACEOUS

About half the sedimentary rocks exposed in the northern part of Yellowstone National Park are of Cretaceous age. This sequence, almost 4,000 feet thick, consists, in ascending order, the Kootenai Formation, Thermopolis Shale, Mowry Shale, Frontier Sandstone, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Everts Formation, and Landslide Creek Formation (fig. 4). The rocks between the base of the Kootenai and the upper part of the Eagle are best exposed on the ridge southwest of Electric Peak (pl. 1, west half; fig. 10); the Cody Shale and all the younger Cretaceous formations are exposed on Mount Everts (pl. 1, west half). These formations were studied and described in great detail in the adjacent Gardiner, Mont., area by Fraser, Waldrop, and Hyden (1969). The Cretaceous rocks in the two areas do not differ in any significant respect, so only summary descriptions of them are given in this report; complete descriptions and measured sections are given in the report on the Gardiner area by Fraser, Waldrop, and Hyden (1969).

The regional relations, stratigraphy, and age of Cretaceous rocks in other nearby areas were recently discussed by Roberts (1965).

The Cretaceous rocks in the northern part of the park were divided by Iddings and Weed (1899, p. 37–38, 50–55) into the Dakota, Colorado, Montana, and Laramie Formations. The descriptions and measured sections by Iddings and Weed do not permit specific correlations with the present mapped units. Moreover, their assignments of the rocks are not consistent. The Cinnabar Mountain measured section (Iddings and Weed, 1899, p. 53–54), which was given as typical for the Gallatin region, does, however, suggest that equivalent units are about as shown in figure 4.

FIGURE 10. — Electric Peak, showing outcrops of Cretaceous sedimentary rocks. Rocks in foreground are Frontier Sandstone; those on crest of Electric Peak are Eagle Sandstone. View toward the northeast, from vicinity of head of Fan Creek, Gallatin Range, Yellowstone National Park.

LOWER CRETACEOUS FORMATIONS

Lower Cretaceous formations crop out in the Gallatin Range and in fault slivers along the Gardiner fault zone. They are the Kootenai Formation, Thermopolis Shale, and Mowry Shale (fig. 4) and have an aggregate thickness of about 1,000 feet. Units of comparable age mapped by Fraser, Waldrop, and Hyden (1969, p. 22–25) near Gardiner, Mont., are the Cloverly Formation, which includes equivalents of the Kootenai and the lower sandstone member of the Thermopolis of this report, the Thermopolis Shale, which includes equivalents of the middle shale and upper sandstone members of the Thermopolis of

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this report, and the Mowry Shale, which is the same as the Mowry of this report.

The base of the Kootenai — oldest unit of the Cretaceous sequence—is a gray massive cross-laminated partly calcareous chert-pebble conglomerate and quartz-chert sandstone and conglomerate sandstone, 20–50 feet thick. This basal unit, assigned to the Pryor Conglomerate Member of the Kootenai near Livingston, Mont., by Roberts (1965, p. B55), unconformably overlies the Morrison Formation. The basal conglomerate is overlain by medium-dark-gray and grayish-red shale and mudstone containing a few thin interbeds of light-gray limestone and sandstone. The upper part of the formation contains the distinctive "gastropod limestone," a medium- to light-gray fine-grained limestone, 20–30 feet thick, that in many places is made up almost wholly of poorly preserved molds of gastropod shells. This limestone is overlain by 10–20 feet of medium- to light-gray shale that is the uppermost part of the Kootenai Formation. The formation is from 250 to 300 feet thick.

The Kootenai is overlain with apparent conformity by the Thermopolis Shale, which includes a lower sandstone member, 75–100 feet thick; a middle shale member, about 300 feet thick; and an upper sandstone member, about 100 feet thick. The lower sandstone member is medium light gray to yellowish gray, clean, medium to thick bedded, and fine grained and includes subordinate interbeds of medium-dark-gray shale and siltstone. The member forms a cliff above the Kootenai. The middle shale member is dark-gray very fissile shale containing a few interbeds, 1–3 feet thick, of olive-gray fine-grained sandstone. The upper sandstone member is mainly yellowish-gray to grayish-brown fine-grained partly glauconitic calcareous feldspathic cross-laminated sandstone. Some of the sandstone contains chips of mudstone, and the upper member also contains a few interbeds of dark-gray shale and mudstone. These dirty sandstones and interbedded finer grained rocks contain *Ostrea anomioides* Meek (W. A. Cobban, oral commun., 1967), which is restricted to the Taft Hill Member of the Blackleaf Formation or its equivalents.

The youngest of the Lower Cretaceous units, the Mowry Shale, conformably overlies the upper sandstone of the Thermopolis, and consists of about 300 feet of medium- to dark-gray hard chippy to pencilly mudstone and shale. Some beds in the upper part of the formation contain abundant fish scales. The formation includes a few interbeds of olive-gray fine- to medium-grained sandstone, generally less than 1 foot thick, and a few distinctive light-gray bentonite beds, as much as 3 feet thick. The bentonite beds are made especially conspicuous by the abundant ground-squirrel holes dug in the soft rock.

UPPER CRETACEOUS FORMATIONS

Upper Cretaceous rocks consist, in ascending order, of the Frontier Sandstone, Cody Shale, Telegraph Creek Formation, Eagle Sandstone, Everts Formation, and part of the Landslide Creek Formation (fig. 4). The Everts Formation and the Landslide Creek Formation that overlies it (Fraser and others, 1969, p. 32–34) are equivalent to rocks that elsewhere in Montana have been included in the Livingston Group. (See Roberts, 1965, p. B59–B60, for summary.)

The Frontier Sandstone, lowest of the Upper Cretaceous formations, conformably overlies the Mowry Shale and is mainly yellowish-gray to medium-gray fine-grained sandstone speckled with abundant grains of heavy minerals; the Frontier is partly calcareous, partly tuffaceous, ripple marked and cross-laminated. It is in 1- to 5-foot-thick beds that are marked by worm trails and burrows. The sandstone beds are separated by 0.1- to 0.2-foot-thick interbeds of dark-gray fissile shale. Fish teeth are in some of the sandstone beds, and small iron concretions and glauconite are in the uppermost beds. The beds at the top of the formation typically are stained reddish brown or yellowish brown. The formation is a little more than 100 feet thick on the southwest spur of Electric Peak, but is only 40–60 feet thick on the southeast spur of Electric Peak and on Mount Everts, where it forms a low cliff. The Frontier Sandstone mapped in Yellowstone National Park is correlative with the lower sandstone member of the Frontier in the Gardiner area.

The Frontier is conformably overlain by the Cody Shale, which is dominantly dark-gray shale and lenticular brownish-gray dirty sandstone. It is separable into three units: a lower shale member, 350–400 feet thick; a middle sandstone member, about 50 feet thick, equivalent to the Eldridge Creek Member near Livingston, Mont. (W. A. Cobban, oral commun., 1967; Roberts, 1965, p. B58); and an upper shale member, about 800 feet thick.

The lower shale member is medium- to dark-gray and yellowish-gray shale and mudstone, interbedded with minor amounts of gray and yellowish-gray siltstone and fine-grained sandstone (stratigraphic sections, p. A61).

The middle sandstone member—dominantly glauconitic sandstone — is yellowish gray to brownish gray, very fine grained, and rusty weathering and is speckled with heavy minerals and glauconite. It occurs in beds, 1–2 feet thick, that are partly cross-laminated. The member includes some interbeds of

dark-gray shale, generally only about 1 foot thick. It contains a distinct *Inoceramus* fauna (W. A. Cobban, oral commun., 1967) and is much more fossiliferous than the rest of the Cody Shale.

The upper shale member is mainly medium- to dark-gray platy to chippy mudstone and shale, but it includes some interbeds of dark-greenish-gray to brownish-gray very fine grained sandstone and siltstone. The sandstone beds become more abundant in the upper 150 feet of the member, as the Cody Shale grades into the overlying Telegraph Creek Formation.

The Cody Shale on Mount Everts was studied in detail by Fox (1939), who described the faunal zones and discussed some of their regional relations. The formation is about 1,200 feet thick (Fox, 1939) on Mount Everts and about the same on Electric Peak. On Electric Peak, however, its apparent thickness is almost doubled by the many intruded sills.

The lower shale member and middle sandstone member were included in the Frontier Formation in the Gardiner area by Fraser, Waldrop, and Hyden (1969). The lower shale member of the Cody as mapped in Yellowstone National Park is the same as the middle shale member of the Frontier in the Gardiner area, and the middle sandstone member in Yellowstone National Park, or the Eldridge Creek Member of the Cody near Livingston, Mont., is the same as the upper sandstone member of the Frontier in the Gardiner area.

The Telegraph Creek Formation, about 300 feet thick, is composed mainly of sandstone, and is a gradational unit between the underlying Cody Shale and the overlying Eagle Sandstone. The Telegraph Creek is dominantly brownish-gray to medium-light-gray fine-grained to very fine grained calcareous sandstone, in beds 0.2–0.5 foot thick, with interbedded medium-gray platy mudstone and shale. Medium-light-gray beds of sandstone are predominant in the upper part of the formation. The formation grades into the overlying Eagle Sandstone, by decrease in mudstone and shale beds and increase in clean thick-bedded to massive sandstone.

The Eagle Sandstone, about 800 feet thick, is the youngest Cretaceous formation present on Electric Peak, where it caps the peak and forms the long dip-slope that reaches northward to the park boundary. The Eagle also forms the lowest massive cliffs on Mount Everts, where it was measured and described by Fraser, Waldrop, and Hyden (1969). The base of the formation, the Virgelle Sandstone Member, about 160 feet thick, consists of medium-light-gray thick-bedded to massive cross-laminated fine-grained arkosic sandstone beds that form a prominent cliff on Mount Everts. Above the Virgelle Member, the Eagle is mainly sandstone, but it is less massive and includes many beds, as much as a few feet thick, of dark-gray carbonaceous shale and thin lenticular beds of coal. The sandstone beds are light gray to medium gray, thin to thick bedded, fine to medium grained, calcareous, and cross-laminated and are speckled with abundant grains of heavy minerals. The top of the formation on Mount Everts consists of a massive cliff-forming sandstone, about 20 feet thick, that lies above the highest coal bed (Fraser and others, 1969).

An erosional unconformity separates the Eagle from the overlying Everts Formation, the type section of which is on Mount Everts (Fraser and others, 1969). The Everts Formation, about 1,200 feet thick, forms the upper cliffs on Mount Everts and is mainly light- to medium-gray thin-bedded cross-laminated fine- to medium-grained calcareous and tuffaceous sandstone speckled with grains of heavy minerals. It contains interbeds, 1–2 feet thick, of dark-gray to olive-gray shale, mudstone, and siltstone. The upper half of the formation is dominantly sandstone, and the finer grained interbeds are most abundant in the lower half.

The Everts Formation is overlain, probably unconformably, by the Landslide Creek Formation (Fraser and others, 1969, p. 34). In the report area, only remnants of this formation are preserved on the northeast slope of Mount Everts, where the rocks are more or less concealed by glacial debris. All these limited exposures are of drab greenish-gray poorly sorted sandstone and conglomerate, made up principally of sand, pebbles, and cobbles of andesitic volcanic rocks.

TERTIARY IGNEOUS ROCKS

The sedimentary rocks in the northern part of Yellowstone National Park have been intruded by laccoliths, sills, dikes, and small stocks of several varieties of igneous rock. Although these igneous rocks are of Tertiary age and are younger than any of the sedimentary rocks, they are intimately associated with the sedimentary rocks and are best mapped and described with them. The volcanic rocks for which the park is famous surround and locally overlie the pre-Tertiary metamorphic and sedimentary rocks; however, only their boundaries were mapped in this study, and they are not discussed in this report.

The intrusive igneous rocks in the northern part of Yellowstone National Park are all in the Gallatin Range and on Mount Everts (pl. 1, west half), and no intrusive rocks are known in the areas of pre-Tertiary metamorphic and sedimentary rocks in the

north-central and northeastern parts of the park. However, various Tertiary intrusions have been described (Lovering, 1930, p. 32–40) that cut the older metamorphic and sedimentary rocks near Cooke City, Mont., and a monzonitic stock that intrudes Paleozoic sedimentary rocks in Slough Creek immediately north of the park has metamorphosed those rocks along the park boundary.

PETROGRAPHY

Iddings and Weed (1899, p. 12–20; Iddings, 1899, p. 60–142) described the intrusive rocks of the Gallatin Range and Mount Everts in great detail and named most of these intrusions. The petrographic discussions given here supplement, but certainly do not replace, the excellent descriptions given by Iddings. The geographic names given by Iddings and Weed to the different intrusive bodies are followed in this report to avoid confusion and to facilitate cross-comparison with Iddings' detailed descriptions of the rocks. The main intrusive rocks are quartz monzonite in the Mount Holmes stock, rhyodacite and quartz latite in the laccoliths and sills, and granodiorite, quartz diorite, and related rocks in the Electric Peak stock[1] (fig. 11). Chemical analyses and thin-section modes of representative samples of the intrusive rocks are given in table 1, and the chemical analyses are graphically compared in figure 12.

QUARTZ MONZONITE

The igneous rocks that make up the main part of the Mount Holmes stock are light-gray to very light gray fine-grained (typically 0.1–0.2 mm) porphyritic biotite quartz monzonite. These hypidiomorphic porphyritic rocks typically contain 35–45 percent plagioclase, 27–38 percent alkalic feldspar, 20–25 percent quartz, and 1–5 percent biotite (fig. 13; table 1). The plagioclase occurs both as euhedral to subhedral phenocrysts, as much as 4 mm long, and as subhedral laths, 0.1–2.0 mm long, in the groundmass; typically, its composition is An_{25-35} (oligoclase to andesine), and most of it is conspicuously twinned. The plagioclase phenocrysts are rarely zoned, and, as rarely, are enclosed by a thin envelope of plagioclase very slightly more calcic than most of the crystal. Plagioclase phenocrysts retain their well-

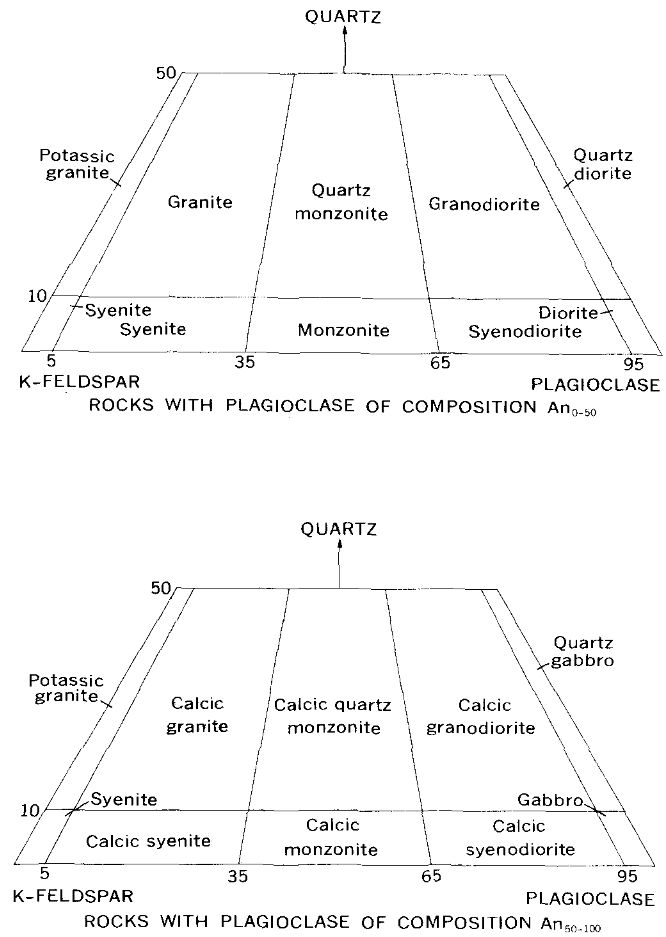


FIGURE 11.—Nomenclature of coarser grained igneous rocks.

developed crystal form, and although the edges of the crystals commonly are slightly corroded, they are not deeply embayed by groundmass minerals. The phenocrysts show patchy extinction, and both phenocryst and groundmass plagioclase has been strongly saussuritized. Alkalic feldspar is in interstitial anhedral grains, 0.1–0.3 mm in diameter, and in very sparse subhedral phenocrysts, as much as 2 mm long; much of the alkalic feldspar appears to replace other rock-forming minerals. Quartz occurs both as 0.1–0.2 mm interstitial grains and as micrographic intergrowths with alkalic feldspar. Biotite is an ubiquitous and conspicuous component, although it generally makes up only a small percentage of the rock; it occurs in euhedral crystals, typically 0.1–0.2 mm in diameter, and in larger, ragged subhedral crystals, as much as 5 mm long. It commonly contains, or is clustered with, grains of magnetite, which also occurs in small, 0.05- to 0.5-mm euhedral grains scattered throughout the rock. Accessory minerals are apatite, zircon, rutile, local cordierite,

[1]The nomenclature used in the present report for igneous rocks that are coarse grained enough for thin-section modes to be determined is shown in figure 11. Finer grained rocks for which modes cannot be determined are named on the basis of chemical composition of representative samples, in accordance with the system proposed by Rittmann (1952). The term "porphyry" is used for rocks of both hiatal and seriate texture if a substantial part of their groundmass is too fine grained to identify by conventional microscopic methods. Coarser grained rocks that contain conspicuous phenocrysts are termed "porphyritic." The term "phenocryst" is used without genetic connotation for those crystals that stand out from a finer grained groundmass.

TABLE 1.—*Chemical analyses and thin-section modes of intrusive rocks, Gallatin Range, Yellowstone National Park*

	Mount Holmes stock	Indian Creek laccolith			Gray Peak laccolith		Electric Peak sill	Electric Peak stock
Field No.	7Y296c	6Y260	6Y294	6Y295	6Y212	6Y291	7Y239c	7Y280c
Lab. No.	W 169454	W 168746	W 168748	W 168749	W 168745	W 168747	W 169452	W 169453
Rock type[1]	Quartz monzonite	Rhyodacite	Rhyodacite	Rhyodacite	Contaminated dacite	Quartz latite	Rhyodacite	Granodiorite
Locality	South flank Echo Peak	Indian Creek	Gallatin Lake	Trilobite Lake	South of Fawn Pass	Snowshoe Pass	Electric Peak	Electric Peak
Rapid-method chemical analyses (percent) [Analysts: P. L. D. Elmore, Gillison Chloe, Lowell Artis, H. Smith, John Glenn, Samuel Botts, and James Kelsey]								
SiO_2	72.2	62.5	60.9	63.3	58.0	68.1	62.2	58.3
Al_2O_3	15.1	16.5	16.6	16.5	14.9	15.4	15.8	15.6
Fe_2O_3	.82	2.7	3.5	2.9	2.1	1.7	1.8	2.3
FeO	.80	1.9	1.9	1.6	3.5	1.1	3.5	5.0
MgO	.40	1.5	2.2	1.5	4.5	.90	3.1	5.0
CaO	1.1	4.1	3.1	3.0	4.7	2.3	4.3	6.3
Na_2O	4.3	4.0	4.4	4.6	3.3	4.2	4.0	3.1
K_2O	3.2	2.5	2.1	2.2	1.6	2.6	2.2	1.8
H_2O-	.32	.40	1.3	.39	.61	.41	.44	.17
H_2O+	.88	2.3	2.5	2.3	2.3	2.1	1.5	.72
TiO_2	.23	.47	.52	.44	.56	.26	.55	.75
P_2O_5	.07	.08	.13	.20	.04	.14	.17	.24
MnO	.05	.08	.02	.11	.02	.00	.10	.13
CO_2	<.05	.12	.26	.36	3.5	<.05	.18	<.05
Sum	99	99	99	99	99	99	100	99
Quantitative spectrographic analyses for minor elements[2] [Analysts: W. B. Crandell and J. L. Harris]								
Silver (Ag)	0	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0	0
Barium (Ba)	.3	.1	.07	.1	.1	.1	.2	.15
Beryllium (Be)	.0002	.0001	<.0001	<.0001	0	.0001	.0001	.0001
Cerium (Ce)	.01	.02	.02	.02	.01	.02	.015	.01
Cobalt (Co)	0	.001	.001	.001	.002	.0007	.0015	.003
Chromium (Cr)	0	.002	.0015	.0015	.015	.0015	.007	.015
Copper (Cu)	.0005	.0002	.0007	.0007	.005	.0007	.003	.005
Gallium (Ga)	.002	.001	.0015	.0015	.001	.001	.002	.002
Lanthanum (La)	.007	.01	.01	.01	.005	.01	.01	.007
Molybdenum (Mo)	.0007	.0003	.0003	.0003	.0003	.0003	.0003	.0003
Niobium (Nb)	.001	0	0	0	0	0	.0005	.0005
Nickel (Ni)	0	<.003	<.003	<.003	.01	<.003	.005	.007
Lead (Pb)	.003	.0005	.0005	.0007	.0005	.001	.002	.0015
Scandium (Sc)	0	.0005	.0005	.0005	.001	.0003	.0015	.002
Strontium (Sr)	.07	.07	.05	.05	.03	.05	.15	.15
Vanadium (V)	.0015	.005	.005	.005	.007	.003	.015	.02
Yttrium (Y)	.0007	.0015	.002	.002	.0015	.0015	.002	.002
Ytterbium (Yb)	0	.0001	.0002	.0002	.0001	.0001	.0002	.0002
Zirconium (Zr)	.015	.01	.015	.015	.01	.015	.015	.01

Modes
[Tr, trace]

	7Y296c	6Y260 *Phenocrysts*	6Y260 *Groundmass[3]*	6Y294 *Phenocrysts*	6Y294 *Groundmass[3]*	6Y295 *Phenocrysts*	6Y295 *Groundmass[3]*	6Y212 *Phenocrysts*	6Y212 *Groundmass[3]*	6Y291	7Y239c *Phenocrysts*	7Y239c *Groundmass[3]*	7Y280c
Plagioclase	42.0 (An_{24})	[4]24.8 (An_{44})	Plagioclase laths, minor apatite, magnetite, quartz, and chlorite; saussuritized.	[4]31.2 (An_{45})	Plagioclase laths, minor apatite, magnetite, quartz, chlorite, and epidote; saussuritized.	[4]30.6 (An_{45})	Plagioclase laths, minor apatite, chlorite; saussuritized.	[4]15.0	Plagioclase laths, minor apatite, potassium-feldspar, and chlorite; saussuritized. 12 percent calcite.	41.6 (An_{40-45})	[4]20.1 (An_{40-45})	Plagioclase laths, minor apatite, chlorite, and calcite; saussuritized.	47.8 (An_{70-80})
Potassium feldspar	31.4	....		....		....		....		28.8	....		2.6
Quartz	23.4	....		Tr.		....		2.0		21.2	1.7		10.2
Biotite	2.6	1.6		1.2		3.2		....		4.6	Tr.		8.4
Hornblende	....	3.6		3.6		2.4		5.8		....	9.8		24.4
Augite	....	....		....		....		....		....	....		2.0
Other[5]	1.0	2.2		2.0		4.4		3.6		4.0	1.0		4.8
Total	100.4	32.2	68.0	38.0	62.0	40.6	59.4	26.4	62.0	100.2	32.6	67.8	100.2

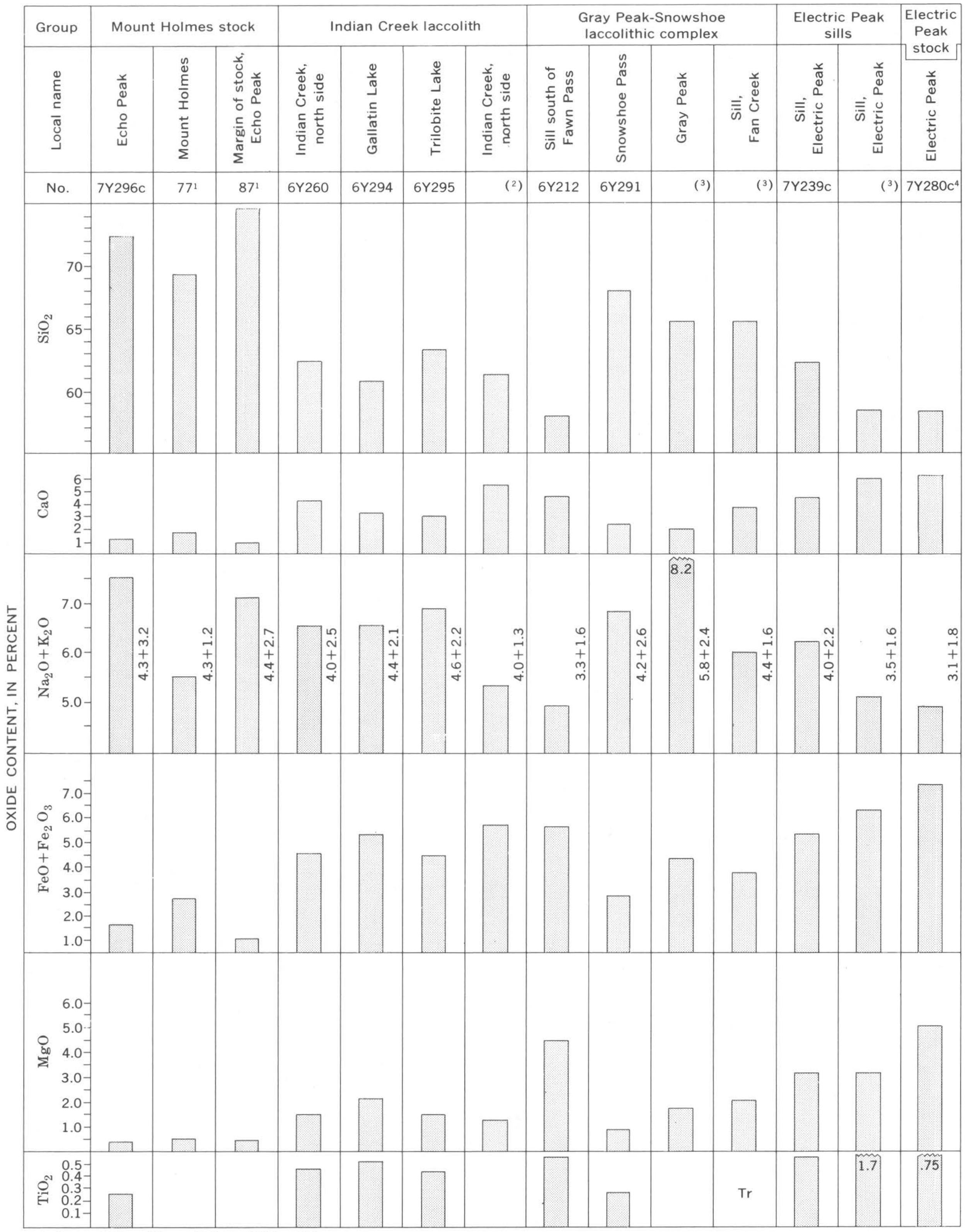
[1]Rocks that contain phenocrysts in an irresolvable groundmass are named in accordance with Rittmann's classification (1952). Coarser grained rocks are named on the basis of their modes.

[2]Quantitative spectrographic analyses are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, and so forth; which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value about 30 percent of the time. Symbols used are 0, looked for but not detected; <, with number, less than number shown — here, usual detectabilities do not apply. Elements looked for but not detected: As, Au, B, Bi, Cd, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Lu.

[3]Felted and not completely resolvable under the microscope.

[4]Largely saussuritized; composition approximate.

[5]Magnetite, apatite, zircon, chlorite derived from the mafic minerals calcite, tremolite, and hematite.



[1] Iddings, (1899, p. 65).
[2] Iddings, (1899, p. 61).
[3] Iddings, (1899, p. 81).
[4] See Iddings, (1899, p. 116).

FIGURE 12. — Comparison of oxides in intrusive rocks, Gallatin Range, Yellowstone National Park. See table 1 for complete rapid-method and quantitative spectrographic analyses of rocks collected in this study. Tr, trace.

and chlorite and epidote derived largely, if not entirely, from alteration of biotite. Sericite, in small radiating tufts, is associated with altered feldspar in some specimens.

RHYODACITE AND QUARTZ LATITE

The rock forming the laccoliths and sills is medium-light-gray to light-gray fine-grained rhyodacite and quartz latite porphyry (fig. 12; table 1) and contains abundant phenocrysts of plagioclase, 2–4 mm in diameter; biotite in conspicuous shiny black euhedral crystals, 0.5–2 mm in diameter; and less abundant thin laths of hornblende, 0.5–5 mm long. Microscopic study shows that phenocrysts make up 25–50 percent of the rock and that they are mainly plagioclase (10–45 percent), biotite (1–5 percent), hornblende (1–10 percent), magnetite (1–2 percent), and quartz (trace to 2 percent); they are set in a microcrystalline groundmass that cannot be resolved

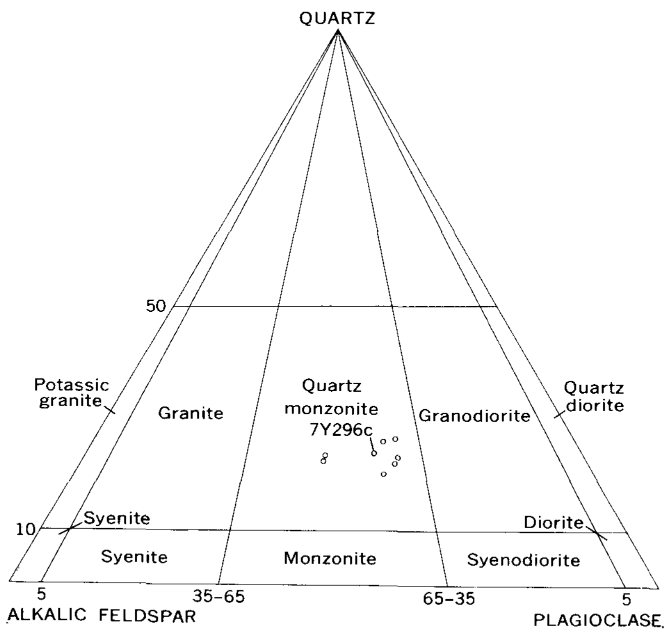


FIGURE 13. — Thin-section modes of rocks of the Mount Holmes stock, Gallatin Range, Yellowstone National Park. Mafic minerals were subtracted and the modes recalculated to 100 percent. 7Y296c, chemically analyzed sample. (See table 1.)

completely by microscopic methods. The plagioclase is andesine (An_{30-50}) in embayed euhedral, twinned and complexly zoned crystals, some of which are partly to completely saussuritized. Hornblende is partly or completely chloritized, and much of the biotite is chloritized along crystal margins. Magnetite is in 0.01- to 0.2-mm euhedral and subhedral crystals associated with the altered mafic minerals and disseminated throughout the rock. Quartz is in interstitial anhedral grains as much as 2 mm in diameter. The groundmass is holocrystalline — felted or pilotaxitic — and is composed mainly of minute (0.02–0.05 mm) anhedral to subhedral crystals of saussuritized plagioclase, alkalic feldspar in interstitial anhedral grains and replacing plagioclase, and quartz, surrounded by cloudy indeterminate minerals that appear to be mainly products of deuteric alteration. Apatite and zircon are present as accessory minerals, and alteration products are epidote, chlorite, calcite, hematite, albite, and saussurite.

GRANODIORITE, QUARTZ DIORITE, AND RELATED ROCKS

The composite Electric Peak stock is made up of rocks that range in composition from calcic granodiorite to near granite and range in grain size from microcrystalline to 3 mm in diameter. The greater part of the stock is fine- to medium-grained granodiorite (figs. 12, 14; table 1) (Iddings, 1899, p. 97–105).[2] The different varieties of rock occur as

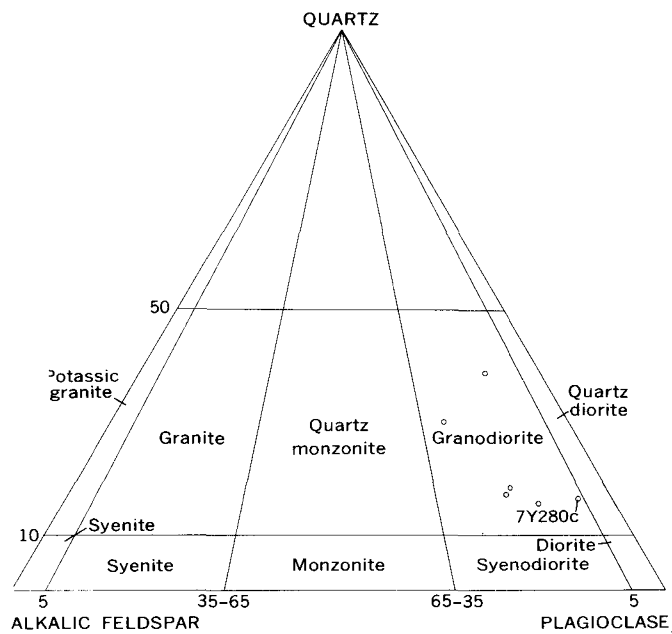


FIGURE 14. — Thin-section modes of rocks of the Electric Peak stock, Gallatin Range, Yellowstone National Park. Mafic minerals subtracted and modes recalculated to 100 percent. 7Y280c, chemically analyzed sample. See table 1.

irregular masses that are partly gradational and partly in sharp contact; inclusions of the more mafic varieties, which apparently are the oldest, occur locally in other varieties. The granitic rocks form aplite dikes, 3–10 feet thick, that cut all the more mafic rocks in the central part of the stock. Inclusions of hornfelsed sedimentary rocks are common in the margins of the stock. Thin-section modes

[2]Iddings considered most of the stock rocks to be varieties of diorite, roughly comparable to the granodiorite (fig. 11) of this report.

of rocks representative of most of the stock are shown graphically in figure 14. A modern chemical analysis is given in table 1. Other analyses from Iddings (1899, table 9) are given in table 2.

Microscopic study of the granodiorite that forms the main part of the stock shows that the rock is hypidiomorphic granular and is composed of plagioclase (35–55 percent), quartz (10–25 percent), alkalic feldspar (10–15 percent), hornblende (5–20 percent), augite (trace to 5 percent), hypersthene (0–3 percent), biotite (5–10 percent), and small amounts of magnetite, hematite, apatite, and zircon.

TABLE 2. — *Chemical analyses, in percent, of intrusive rocks from Electric Peak*

[From Iddings (1899, p. 116): Analyses 272 and 309 by W. H. Melville; all others by J. E. Whitfield. Analyses 295, 267, 273, and 272, from main body of stock, group a. Analyses 309, 313, 311, and 303 from modifications of main body of stock and from one of lighter colored dikes that traverse it, group b. Analyses 323 and 321 are siliceous varieties from main stock, group c. Analyses 329 and 326, quartz-mica-diorite porphyry of Iddings. Tr., trace.]

Constituent	295	267	273	272	309	313	311	303	329	323	321	326
SiO_2	56.28	57.38	58.05	61.22	64.07	64.85	65.11	65.60	65.97	66.05	67.54	69.24
TiO_2	.84	Tr.	1.05	.61	.45	.91	.71	.75	.42	.34	.80	.65
Al_2O_3	14.23	16.86	18.00	16.14	15.82	16.57	16.21	17.61	16.53	16.96	17.02	15.30
Fe_2O_3	4.69	2.49	2.49	3.01	3.40	2.10	1.06	.95	2.59	2.59	2.97	1.72
FeO	4.05	5.17	4.56	2.58	1.44	2.15	3.19	2.76	1.72	1.38	.34	.69
NiO	....	....	....	.09	.05	....	....	....	....	....	....	....
MnO	.16	Tr.	None	Tr.	Tr.	None	None	None	None	None	Tr.	Tr.
CaO	7.94	7.32	6.17	5.46	4.43	4.01	3.97	3.72	3.37	3.37	2.94	2.98
MgO	6.37	5.51	3.55	4.21	3.39	2.14	2.57	1.49	2.11	2.08	1.51	.95
Li_2O	.01	.39	None	....	....	None	.04	.03	.09	None	.03	None
Na_2O	2.98	3.33	3.64	4.48	4.06	3.71	4.00	4.36	3.41	4.20	4.62	4.46
K_2O	1.23	1.45	2.18	1.87	2.27	3.10	2.51	2.36	2.67	2.53	2.28	2.52
P_2O_5	.40	Tr.	.17	.25	.18	.14	.02	.16	Tr.	Tr.	Tr.	Tr.
SO_4	Tr.	.21	.07	....	....	Tr.	Tr.	Tr.	.13	.03	.26	.27
Cl	.17	.17	Tr.	....	....	None	None	None	.09	Tr.	.15	Tr.
H_2O	.93	.42	.86	.44	.52	.35	.94	.59	1.23	.69	.55	1.30
Total	100.28	100.70	100.79	100.36	100.08	100.03	100.33	100.38	100.33	100.22	101.01	100.08
Less O for Cl	.04	.04	....	....	....	....	....	....	.02	....	.03	....
	100.24	100.66							100.31		100.98	

The plagioclase ranges in composition from bytownite (An_{75-85}) to andesine (An_{35-40}) and is in complexly twinned euhedral to subhedral laths. Quartz is in interstitial anhedral grains. Alkalic feldspar, probably orthoclase, forms scattered small anhedral to subhedral grains and also partly replaces plagioclase. Hornblende occurs as euhedral to subhedral crystals and as a replacement of augite and hypersthene; augite and hypersthene are in euhedral to subhedral crystals that most commonly are partly replaced by uralitic hornblende. Biotite occurs as euhedral crystals. Iddings (1899, p. 97–105) described these rocks in great detail, and discussed several other varieties of rock containing more abundant feldspar or quartz that represent either marginal phases of the intrusion or separate intrusions. He concluded that the last magma intruded into the stock formed quartz-mica-diorite porphyry, a rock intermediate between granodiorite and the aplite dike rocks and containing abundant phenocrysts of feldspar — mostly oligoclase, quartz, and biotite.

DESCRIPTIONS OF INTRUSIVE MASSES

MOUNT HOLMES STOCK

The Mount Holmes quartz monzonite stock underlies an area about 3 miles long and 2 miles wide on Mount Holmes and the White Peaks at the south end of the Gallatin Range (pl. 1, west half). Its form and intrusive relations were discussed in detail by Iddings and Weed (1899, p. 16–20), and its petrography was described by Iddings (1899, p. 64–69). Iddings and Weed named the intrusive mass the Mount Holmes bysmalith, pointing out that the mass had sharply domed its roof and that, for almost two-thirds of its circumference, the mass is in nearly vertical contact with the enclosing rocks. They interpreted these relations to be the result of vertical displacement of roof rocks on a circumferential fault formed as the intrusion was emplaced. They suggested that the bysmalith was intruded along or near the contact of Precambrian crystalline rocks and the overlying sedimentary rocks, but they pointed out that the shape of the bottom of the bysmalith was unknown. The term "bysmalith" was coined in 1898 (Iddings, 1898), and the Mount Holmes bysmalith was cited as a typical example.

The Mount Holmes intrusive mass is indeed bounded on the east and west by faults (pl. 1, west half), as Iddings and Weed (1899, p. 18) noted, but the faults are parts of widespread fault systems, discussed later in this report, that have regional tectonic significance. Although they cut the Mount Holmes intrusion and its marginal rocks, they are not genetically related to them. The westernmost fault, the Grayling Creek fault, appears to cut off the western part of the intrusion and to place Precambrian granitic gneiss in fault contact with igneous rocks that are characteristic of the central

part of the Mount Holmes intrusive mass. Several subparallel faults cut the igneous rocks on the west flank of the White Peaks. The easternmost fault, on the east flank of Mount Holmes, separates the intrusive mass and its roof rocks from unmetamorphosed sedimentary rocks and younger intrusive rocks of the Indian Creek laccolith on Trilobite Point.

The Mount Holmes mass, on Mount Holmes and Echo Peak, is bordered by a chilled marginal zone beneath the Cambrian rocks that form the roof. Both the marginal igneous rocks and the roof rocks are thermally metamorphosed, and the map pattern of the metamorphic border (pl. 1, west half) suggests that the eastern contact of the intrusive mass is nearly vertical. Hornfelsed sedimentary rocks occur as inclusions in a thin, inclusion-choked zone at the top of the intrusion on Echo Peak, but are sparse or absent elsewhere. The south border of the intrusion is exposed at the south end of the White Peaks, where the igneous rocks are in nearly vertical intrusive contact with Precambrian granitic gneiss; the contact zone is about 50 feet wide and grades from intrusive rock, through a zone choked with inclusions of gneiss and amphibolite, into the Precambrian rocks.

The combined field evidence seems to suggest that the Mount Holmes intrusive mass is a steep-sided stock that intensely metamorphosed both the sedimentary rocks that form the roof and its own chilled margin. The bounding faults cut the intrusive rocks, and the intrusive mass does not have the faulted roof typical of a bysmalith.

The contact of the sedimentary rocks and the underlying massive Precambrian crystalline rocks could well have provided a favorable zone for intrusion of sills or laccoliths satellitic to the main stock, and such an offshoot of the Mount Holmes stock probably underlies the middle part of the valley of Indian Creek. In that area the attitudes of sedimentary rocks exposed on both of the valley walls suggest a northeast-trending elongate dome, and the lowest Cambrian rocks exposed on the north valley wall, beneath the Indian Creek laccolith, are hornfelses that closely resemble the metamorphosed roof rocks on Mount Holmes, Dome Mountain, and Echo Peak (Iddings, 1899, p. 68). This alteration of the sedimentary rocks cannot be attributed to the younger Indian Creek laccolith, which has scarcely changed any of its marginal sedimentary rocks. Probably either the stock itself underlies a more extensive area than the present outcrops suggest or a tabular offshoot is present beneath the valley of Indian Creek. The inferred offshoot, whether stock-like or laccolithic, probably is rather small, for the Precambrian and Paleozoic rocks are exposed in normal contact on the south side of Indian Creek, the dips that suggest the doming in the middle reaches of Indian Creek are low, and the hornfelsed sedimentary rocks are not widespread.

Metamorphism

The zone of thermally metamorphosed rocks adjacent to the Mount Holmes stock is unique in the Gallatin Range in Yellowstone National Park, where it consists of both metamorphosed marginal igneous rocks and intensely hornfelsed sedimentary rocks. The distinction between rocks originally igneous in the marginal zone and rocks originally sedimentary is uncertain at best, and so they were mapped together.

The thermally metamorphosed sedimentary rocks overlying the Mount Holmes stock are the Flathead Sandstone, about 150 feet thick, the Wolsey Shale, about 150 feet thick, and the lower part, perhaps 100 feet thick, of the Meagher Limestone, all of Cambrian age. The lower part of the Flathead Sandstone appears to have been partly disaggregated and incorporated into the marginal igneous rocks. The rest of the Flathead and the Wolsey have been converted into banded quartz-feldspar hornfels spotted with cordierite, magnetite, and sparse flakes of biotite. These rocks are light gray or very light gray near the margin of the stock and grade into dark-gray hornfels in the upper part of the Wolsey. On the north flank of Echo Peak, the lower part of the Meagher is a light-gray calc-silicate hornfels, which grades through bleached limestone in the middle part of the formation to unmetamorphosed limestone too thin to be mapped separately. Microscopic study shows that the hornfelses are granoblastic aggregates of 0.03- to 0.1-mm grains of quartz and plagioclase (An_{10-25}) that contain different amounts of biotite, cordierite, magnetite, sericite, and secondary chlorite, epidote, and calcite. The quartz occurs as rounded, deeply embayed grains or in interstitial clusters of anhedral grains. Plagioclase occurs as anhedral nontwinned grains and twinned ragged laths and is partly saussuritized. Cordierite is in anhedral masses, as much as 0.5 mm in diameter, that are choked with inclusions of quartz and feldspar. Biotite and magnetite are scattered throughout the rocks in subhedral grains 0.03–0.05 mm in diameter.

The hornfelsed marginal igneous rocks around the Mount Holmes stock are light-gray extremely fine grained rocks that can be distinguished from the adjacent hornfelsed sedimentary rocks only by microscopic study. They grade into the central part of the stock through a zone in which the grain size becomes greater and the texture changes from granoblastic

in the hornfelsed marginal igneous rocks to hypautomorphic granular in the unmetamorphosed central part of the stock. The texture of these igneous rocks is clearly metamorphic and not simply that of a chilled marginal zone around the stock. Their composition is generally similar to that of the quartz monzonite in the main part of the stock, and they contain sparse small, euhedral but embayed, plagioclase crystals. In places, however, they also contain 40–60 percent alkalic feldspar, which replaces plagioclase and appears to have grown during metamorphism. Locally, the igneous rocks include as much as 40 percent quartz which occurs partly as rounded, deeply embayed grains apparently derived from disaggregation of the Flathead Sandstone. Cordierite is common in the hornfelsed igneous rocks but is not as abundant as in the hornfelsed sedimentary rocks. Small flakes of biotite and grains of magnetite are disseminated throughout the rock.

LACCOLITHS AND SILLS

Most of the intrusive igneous rocks in northern Yellowstone National Park are medium-light-gray to light-gray rhyodacite and quartz latite porphyries described above. These rocks form the laccoliths near Indian Creek and Gray Peak and the numerous sills that extend from Gray Peak to Electric Peak and to the north boundary of the park (pl. 1, west half). They also form the sills near the crest of Mount Everts (pl. 1, west half). Similar rocks that are part of the Gallatin River laccolith crop out in the northwest corner of the park (pl. 1, west half), but the main part of the laccolith, described most recently by Witkind (1969, p. 39), is west of the park boundary.

The form taken by the different bodies of laccolithic and sill rocks ranges from the thick, comparatively simple lens shape of the Indian Creek laccolith to the multiple thin sills exposed on Electric Peak. Intermediate are such complex bodies as the Gray Peak–Snowshoe Christmas-tree laccoliths and the thick Fan Creek sills. The differences in shape of the intrusive masses appear to be due mainly to the depth of emplacement, but they probably also reflect the bedding characteristics of the sedimentary rocks. The Indian Creek laccolith is the most simple in form and was emplaced at the greatest depth, principally in the lower part of the Park Shale, which separates two massive units of Cambrian rocks. The preserved thickness of sedimentary rocks above the Park Shale is about 7,000 feet, which is the minimum depth of emplacement of the Indian Creek laccolith. The Gray Peak–Snowshoe laccoliths and their connected sills and the Fan Creek sills were emplaced at intermediate depth in shaly zones in Jurassic and Lower Cretaceous rocks, and the multiple Electric Peak sills were emplaced at comparatively shallow depth in shaly and sandy Upper Cretaceous rocks.

The Christmas-tree laccoliths seemingly were emplaced low on the flanks of domes formed over deeper, more simple laccoliths. At the head of the East Fork of Fan Creek, the sedimentary rocks are arched into a symmetrical dome more than 2 miles in diameter, with the Gray Peak–Snowshoe laccoliths low on the south flank (pl. 1, west half, section *A–A'*) and the Fan Creek sills on the north flank (pl. 1, west half, section *D–D'*). Considering the number of known laccoliths in and near the southern part of the Gallatin Range, the most reasonable explanation for the symmetrical doming seems to be that it reflects arching of the sedimentary rocks over a buried laccolith probably intruded into Cambrian shaly units and roughly comparable in size to the Indian Creek laccolith. The doming, as well as the location of the Christmas-tree laccoliths and sills on the flanks of the dome, suggests that laccolithic intrusions were stacked one above the other, somewhat as shown in figure 15. Shaly horizons clearly controlled lateral emplacement of the magma. Depth appears to have controlled the ultimate shape of the emplaced body: a comparatively simple laccolith

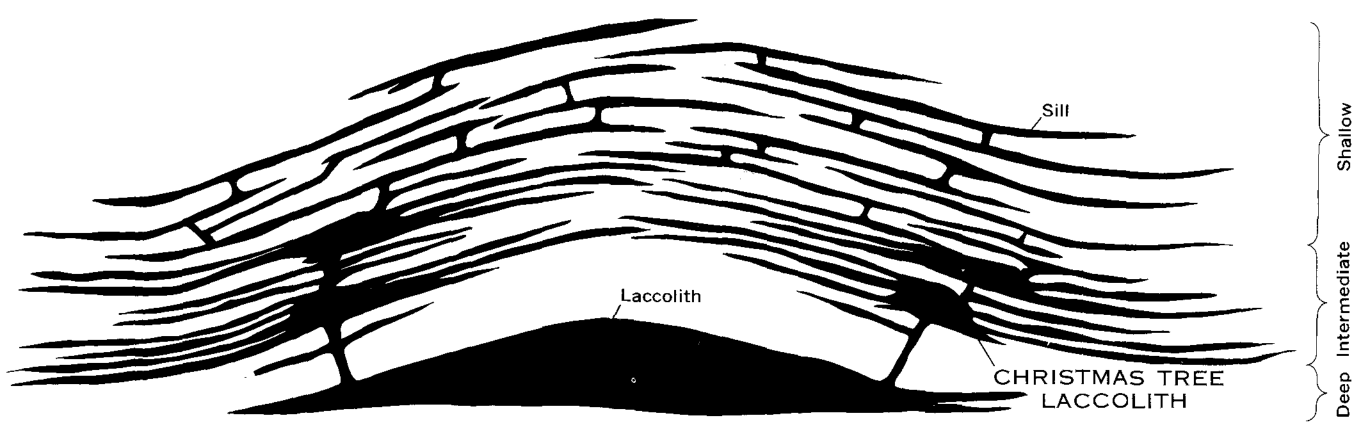


FIGURE 15. — Inferred relations between laccoliths and sills, Gallatin Range, Yellowstone National Park, Wyo.

resulted if emplacement was deep, multiple thin sills resulted if emplacement was shallow, and a combination of these — a Christmas-tree laccolith — resulted if emplacement was intermediate in depth.

Metamorphism

The sedimentary rocks that enclose the laccoliths and sills (and which are locally enclosed as septa by the igneous rocks) have not been strongly metamorphosed. The Meagher Limestone adjacent to the Indian Creek laccolith has been bleached at the contact and has been bleached where it forms septa in the laccolith; however, it generally retains its characteristic mottling and is readily identifiable as the Meagher. The Park Shale above this laccolith has been hardened and is blocky fractured for a few feet above the contact, but retains its dark-gray color. The Wolsey Shale, intruded on Trilobite Point, has been changed to a calc-silicate hornfels, which is to be expected for this impure sedimentary rock, but the adjacent Flathead Sandstone and Meagher Limestone are scarcely affected. The Jurassic and Cretaceous sedimentary rocks, which are intruded by the Gray Peak–Snowshoe laccoliths and their connected sills, locally have been bleached and hardened adjacent to the contact for thicknesses ranging from a few inches to a few feet, but even the Jurassic limestones have rarely been bleached to more than a lighter shade of gray, and they have retained, unchanged, their original texture and characteristic fossils. And the sills in Cretaceous rocks on Electric Peak have hardened the sedimentary rocks for only a few inches adjacent to the contact. The metamorphism accomplished by the great volume of magma that formed the laccoliths and sills is virtually insignificant and suggests that the magma was both comparatively cold and comparatively dry. Most of the gaseous and liquid products of crystallization must have been retained in the igneous masses, to have caused the deuteric alteration that is pervasive there.

Indian Creek Laccolith

The great Indian Creek laccolith underlies much of the southern tip of the Gallatin Range. The laccolith was named by Holmes (1883, p. 24–25), who first studied it and recognized its form; the name was given for the magnificent cliff exposures, about 1,000 feet high, of the thick central part of the laccolith on the north canyon wall of Indian Creek (fig. 16). The laccolith was later mapped and described by Iddings and Weed (1899, p. 13–16), and the petrography of the rocks was discussed in detail by Iddings (1899, p. 60–64). After 1899 the Indian Creek laccolith and the related laccoliths and sills farther north in the Gallatin Range in Yellowstone National Park were largely forgotten, an undeserved fate for these classic bodies of igneous rock.

The central part of the Indian Creek laccolith is a comparatively simple lens-shaped mass of rhyodacite porphyry emplaced in the upper part of the Meagher Limestone and the Park Shale (pl. 1, west half; fig. 16); septa, as much as 50 feet thick, of Meagher Limestone are included in the laccolith, and most of the Park Shale is present in the arched roof. The entire thickness, about 1,200 feet, of the central part of the laccolith is exposed above Indian Creek on the south flank of Antler Peak, where the Meagher Limestone, forming the floor, is a prominent cliff and the Park Shale at the upper contact weathers back so that a ledge is formed on the top of the laccolith. The roof and the upper part of the laccolith are also well exposed (1) south of Bighorn Pass on the flanks of the ridge that separates the headwaters of Panther Creek from those of the Gallatin River (fig. 7), (2) near Gallatin Lake (fig. 17), and (3) at Three Rivers Peak. On the south flank of Dome Mountain, the laccolith splays into thick bulbous sills in the Wolsey and Park Shales and Meagher Limestone. South of Trilobite Point, the main sill, in the Wolsey, is only a few hundred feet thick, and near the low pass south of Mount Holmes there are two thin sills, one each in the Park and Wolsey, that completely pinch out about a mile farther south.

The laccolith thins abruptly to the west near Three Rivers Peak and the edge of the Mount Holmes stock, and, originally, the laccolith and its connected sills probably formed an intrusive mass that was crescent shaped in plan view on the north and east flanks of the dome over the Mount Holmes stock. The conduit that fed the laccolith is not exposed; presumably, it remains buried beneath the central part of the dome.

The rhyodacite porphyry in the laccolith (fig. 12; table 1) contains 30- to 50-percent phenocrysts of plagioclase (An_{30-45}), as much as 4 mm long; biotite in conspicuous black crystals, as much as 2 mm across; and less abundant hornblende laths, 1–2 mm long. It also includes abundant micropoikilitic quartz enclosing minute feldspar crystals in the microcrystalline groundmass, a characteristic that is especially pronounced in the sill offshoots on Dome Mountain. (See Iddings, 1899, p. 61–62.) On Trilobite Point and south of Mount Holmes, the thinning sills are finer grained and darker colored than most of the laccolithic rocks, and the pilotaxitic structure is more pronounced, features that are also characteristic of the margins of the laccolith and thicker sills.

Small inclusions of sedimentary rock and of Precambrian crystalline rock are sparsely distributed throughout the Indian Creek laccolith, but are no-

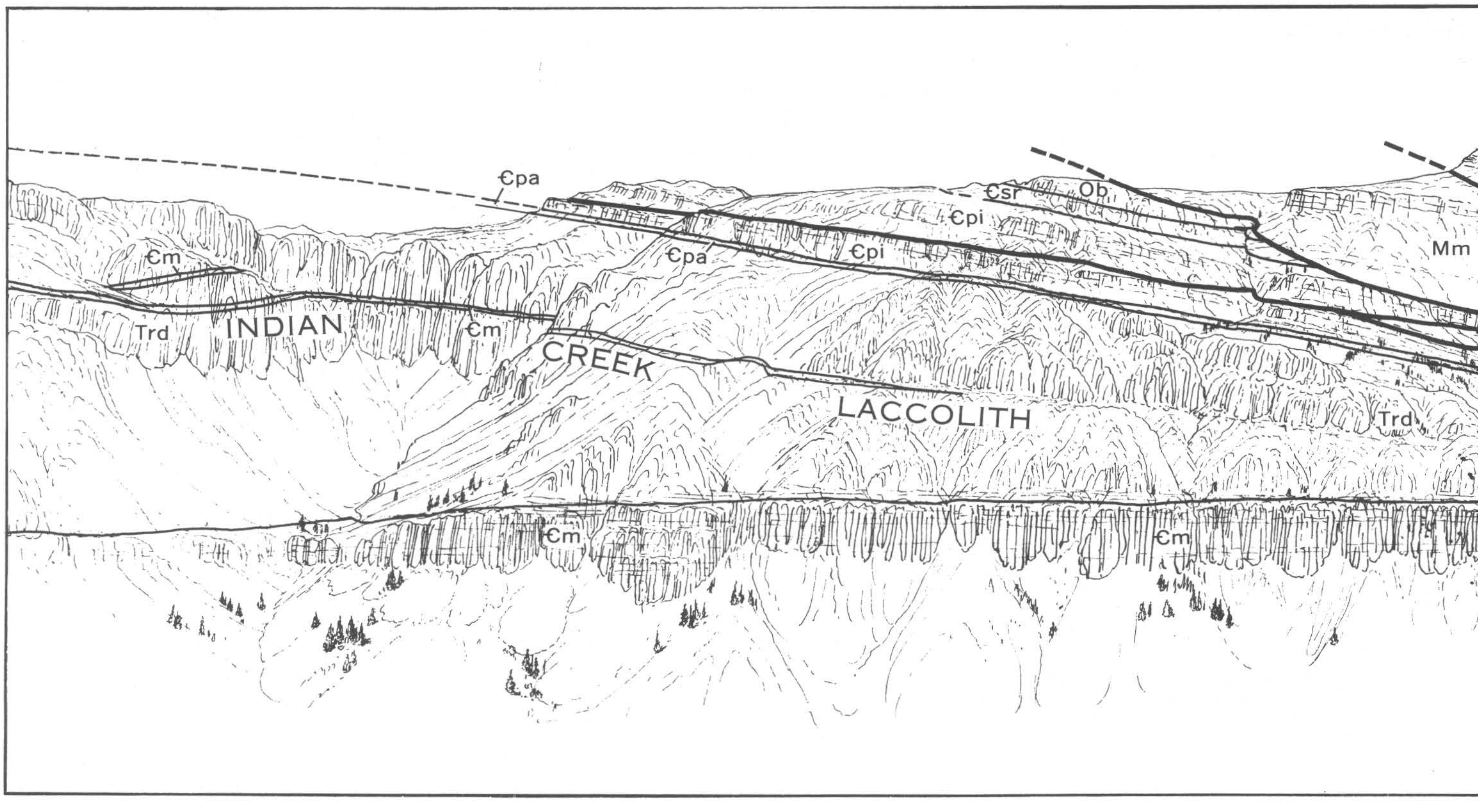


FIGURE 16. — Part of Indian Creek laccolith, viewed to the north across the valley of Indian Creek. Sketched in 1878 by IPq, Quadrant Sandstone; Mm, Madison Group; Ob, Bighorn Dolomite; Ꞓsr, Snowy

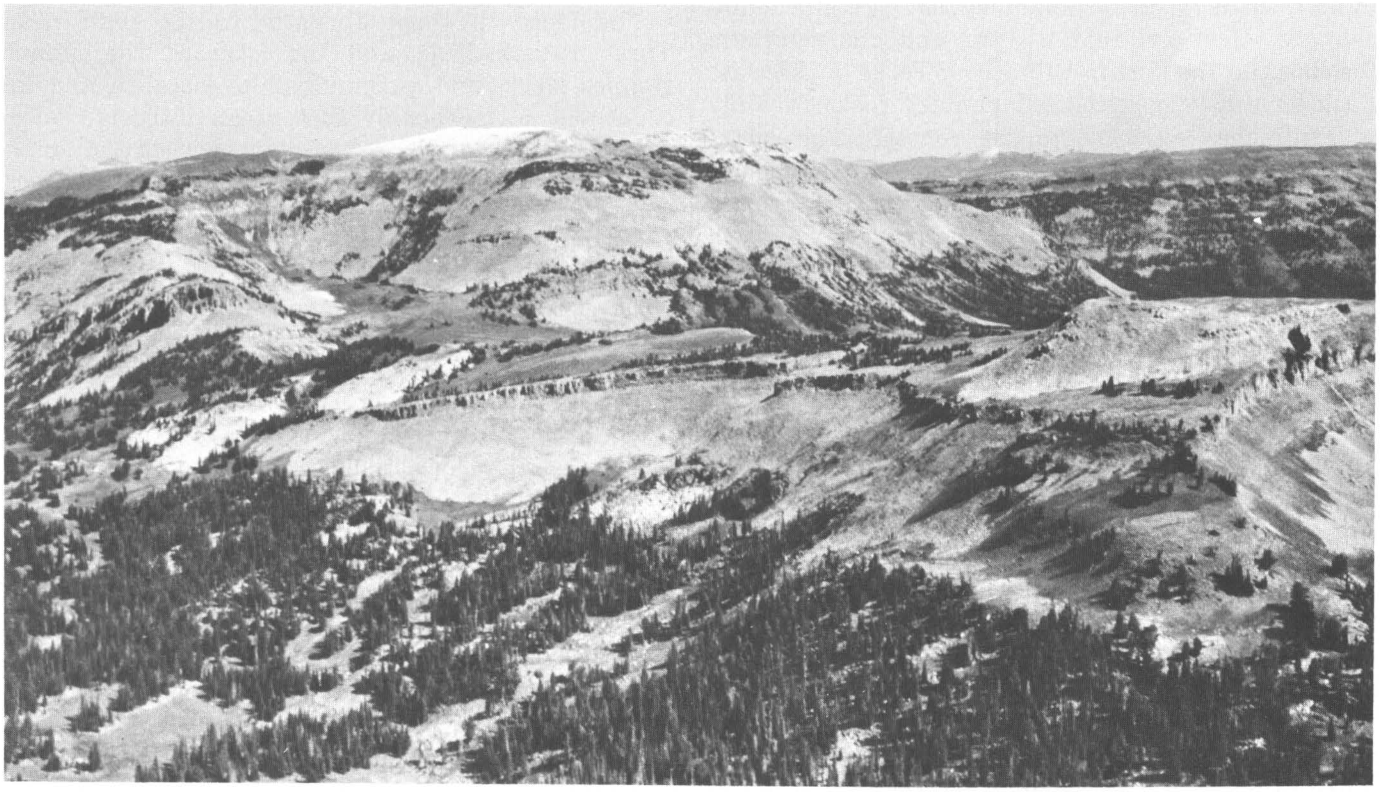
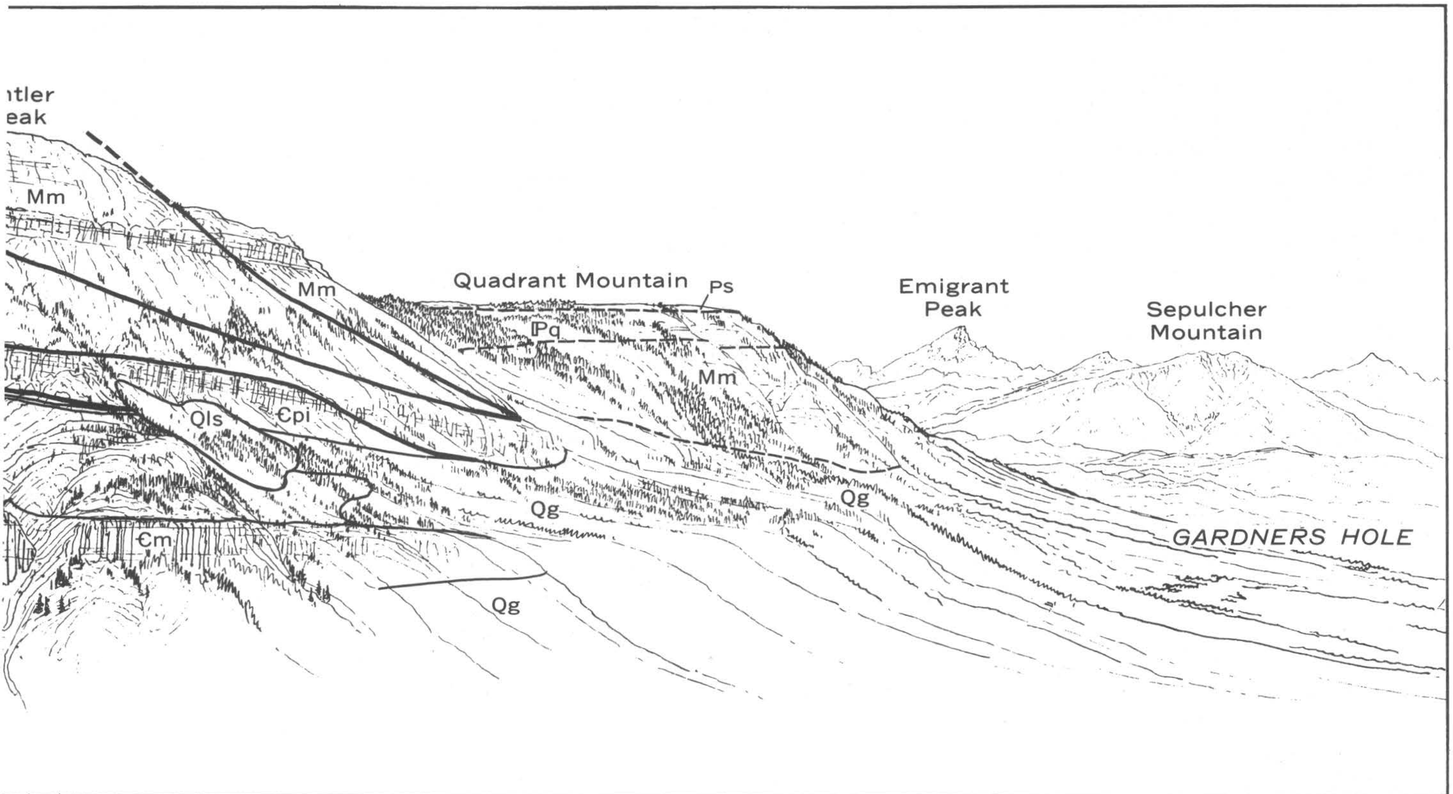


FIGURE 17. — Roof of the Indian Creek laccolith northeast of Gallatin Lake, viewed toward the northeast. Laccolith underlies slide-rock-covered slope in lower part of photograph, beneath prominent cliff of Pilgrim Limestone; snowcapped peak, left center, is Bannock Peak, underlain mainly by the Madison Group; timbered, cliffy slope near right edge is south face of Quadrant Mountain.



Holmes (1883). Geology modified in 1968. Qls, landslide; Qg, glacial deposits; Trd, rhyodacite; Ps, Shedhorn Sandstone; Range Formation; €pi, Pilgrim Limestone; €pa, Park Shale; €m, Meagher Limestone.

where abundant. Most of the sedimentary rocks are in small angular fragments so little altered that their parent formation, mainly the Meagher Limestone, can still be determined. The inclusions of Precambrian rocks are rounded, unaltered, and typically a few inches in diameter — somewhat larger than those of sedimentary rocks.

Gallatin River Sills

Two small sills of extremely fine grained porphyry crop out on the ridge between the Gallatin River valley and Crowfoot Ridge (pl. 1, west half), one in the Madison Group, and the other in the Quadrant Sandstone. Iddings and Weed (1899, p. 20) suggested that these rocks were related to those in the Mount Holmes stock, but the composition of the rocks indicates a closer kinship to the rocks of the laccoliths and sills. These two sills are the only igneous rocks that are intruded into upper Paleozoic sedimentary rocks in this part of the Gallatin Range.

Gray Peak–Snowshoe Laccoliths and Sills

The Gray Peak–Snowshoe laccoliths underlie Snowshoe Pass, Gray Peak, and Joseph Peak, and sills connected to the laccoliths extend east to Little Quadrant Mountain, south beyond Fawn Pass, west beyond the head of Stellaria Creek, and north to Sportsman Pass, where they form the lower part of the Electric Peak sills. Iddings and Weed (1899, p. 42–43, pl. 9; Iddings, 1899, p. 73–82) combined all the intrusive rocks of this area in the Gray Mountain intrusive mass and connected sills, a mass which they evidently considered to be a stock. The petrography of the rocks was discussed in detail by Iddings (1899, p. 73–77, 81), who recognized their resemblance to the rocks in the Indian Creek laccolith.

The Gray Peak–Snowshoe laccoliths and sills together form an intricate complex of laccoliths and sills that have been emplaced mainly in Jurassic and Lower Cretaceous sedimentary rocks. The central part of the intrusive complex, composed of homogeneous light-gray and medium-light-gray biotite quartz latite porphyry (fig. 12; table 1), extends from Snowshoe Pass to Joseph Peak and includes the Snowshoe and the Gray Peak Christmas-tree laccoliths. The multiple sills in the surrounding rocks were fed from this core, which is only about 2 square miles in area. The Snowshoe laccolith intrudes the Sawtooth Formation, and the overlying rocks are domed across Snowshoe Pass where the laccolith is best exposed. The floor of the laccolith is concealed by landslides and rock streams, but it is inferred to be the Thaynes(?) Formation because this unit floors the thick peripheral sill near Fawn Pass and north of Fawn Creek. The top of the laccolith locally crosscuts the roof rocks north of Fawn Pass and

probably is connected to the higher Gray Peak laccolith by an irregular feeder dike that cuts through Jurassic and Cretaceous rocks beneath the large landslide east of Snowshoe Pass. The laccolith is at least 800 feet thick in its core, and probably is about 1,000 feet thick.

The Gray Peak laccolith is mainly in the Kootenai Formation and the Thermopolis Shale and rests on the basal sandstone and conglomerate of the Kootenai, although to the southeast it overlies the lower sandstone member of the Thermopolis. The sedimentary rocks that form the laccolithic floor north of Gray Peak are on the south flank of a dome, 2–3 miles in diameter, at the head of East Fork Fan Creek. As earlier discussed, the dome suggests a buried laccolith comparable in size to the Indian Creek laccolith. As a result of erosion, only about 500 feet of the Gray Peak laccolith remains, but the original maximum thickness probably was not much greater.

The rocks in the Gray Peak and Snowshoe laccoliths are quartz latite porphyry that contain 25–30 percent phenocrysts of plagioclase (An_{35-45}), 2 to 4 mm in diameter; biotite in conspicuous shiny black euhedral crystals, 0.5–2 mm in diameter; and less abundant hornblende crystals, as much as 4 mm long, all set in a microcrystalline groundmass. The plagioclase is moderately to almost completely saussuritized. The hornblende is completely chloritized, but the biotite is fresh and unaltered. Quartz occurs as 0.1-mm interstitial anhedral grains and as larger poikilitic masses. The grain size of the groundmass of the Snowshoe laccolith rock (0.1 mm) is appreciably coarser than that of the Gray Peak laccolith rock (0.01–0.05 mm). Both in outcrop and microscopically, the Gray Peak–Snowshoe rocks closely resemble those of the Indian Creek laccolith, but chemical analyses (fig. 12; table 1) indicate that the Snowshoe and Gray Peak laccoliths are appreciably more silicic and perhaps more sodic than most other laccolith and sill rocks. Perhaps they represent a slightly later differentiate of the magma emplaced during the intrusive episode that formed the laccoliths and sills.

The sills that now extend out for several miles from the Snowshoe and Gray Peak laccoliths suggest that the original diameter of the Christmas-tree laccoliths was 6–8 miles. The sills thin away from the laccoliths and typically are from a few feet to 100 feet thick. The thickest sill, near Fawn Pass, is about 200 feet thick near the Snowshoe laccolith, but it thins abruptly to the south, partly by splaying out into multiple sills. The sills range from quartz-latite porphyry, such as that in the Gray Peak and Snowshoe laccoliths, to the more common rhyodacite porphyry, such as that in the Indian Creek laccolith; their range in composition was discussed by Iddings (1899, p. 73–84). Most of the sill rocks are very fine grained to aphanitic porphyries that contain 20–35 percent phenocrysts of plagioclase (An_{40-50}), biotite, and hornblende. The plagioclase is in crystals, as much as 2.5 mm long, that are partly to completely saussuritized. Hornblende, sparse in most of the sill rocks but locally abundant, is in lathlike subhedral crystals, 1–5 mm long, that are completely chloritized in most rocks. Biotite is in fresh crystals as much as 1 mm across. The rocks in sills only a few feet thick typically are darker colored — about medium gray — and much finer grained than those in thicker sills, and they are not as conspicuously porphyritic; but in representative specimens studied microscopically, the only difference between rocks from thin sills and those from thick sills is the finer grained groundmass of the rocks in the thin sills. The exceptional chemical composition of the sill south of Fawn Pass (specimen 6Y212, fig. 12; table 1) apparently is due to assimilation of limestone from the adjacent Jurassic sedimentary rocks, for this rock contains about 12 percent calcite.

Fan Creek Sills

The two thick sills that were emplaced in Lower Cretaceous shales north of the East Fork Fan Creek (pl. 1, west half) are quartz-latite porphyry, such as that in the Gray Peak and Snowshoe laccoliths. The rocks from the two areas look the same in outcrop and are very similar chemically (fig. 12) and microscopically. The lower sill is about 300 feet thick, and the upper sill has a preserved thickness of about 500 feet. Both are conformable intrusive masses; and even though the roof of the upper sill has been eroded away, the great thickness of the sills and their compositional similarity to the Gray Peak and Snowshoe laccoliths suggest that they are remnants of another laccolithic complex similar to the Gray Peak–Snowshoe laccolithic complex.

Electric Peak Sills

The Electric Peak sills, from a few feet to about 100 feet thick, were emplaced in Cretaceous sedimentary rocks on Electric Peak and northward beyond the boundary of Yellowstone National Park (pl. 1). The sills are best exposed on the southwest spur of Electric Peak, from the Sportsman Lake trail to the crest of the peak, and on the steep, west side of Electric Peak, where they form stepped cliffs separated by only slightly less steep slopes that are underlain by the shaly and sandy sedimentary rocks. The sills are composed of fine-grained to very fine grained rhyodacite porphyry, similar chemically (fig. 12; table 1) and mineralogically (except for their

mafic minerals) to the porphyries that form the Indian Creek laccolith and the Gray Peak–Snowshoe laccolithic complex. The rocks were described in detail by Iddings (1899, p. 77–84), who also recognized their similarity to other laccolith and sill rocks in the Gallatin Range and on Mount Everts.

The individual sills are remarkably uniform in thickness and closely conform to bedding in the sedimentary rocks; their aggregate thickness must exceed 1,000 feet. They are connected by short dikes and provide the erosion-resistant framework that helps make Electric Peak one of the highest peaks in Yellowstone National Park. The sills are tightly folded and are locally overturned with the sedimentary rocks on the southeast spur of Electric Peak; also, they have been hydrothermally altered and pyritized adjacent to the younger Electric Peak stock, which cuts them. The sills are shown only to the park boundary on plate 1 (west half), but they continue northward to Cinnabar Mountain and the junction of Cinnabar and Mol Heron Creeks, where both the sills and their enclosing sedimentary rocks are deformed in the drag zone beneath the Gardiner reverse fault.

The rocks that form the Electric Peak sills are rhyodacite porphyry (fig. 12; table 1) that contains 25–35 percent phenocrysts of plagioclase (An_{40-50}), hornblende, biotite, and quartz; pyroxene occurs in a few sills, associated with hornblende, but it is neither a widespread nor a common constituent (Iddings, 1899, p. 80). Plagioclase phenocrysts are typically 0.5–2 mm long, although they are as much as 5 mm long in some rocks; the plagioclase is either almost completely unaltered or almost completely saussuritized. Hornblende occurs as euhedral to subhedral crystals 0.5–5 mm long, and it typically is fresh or only partly chloritized along fractures. Biotite is present only in trace amounts in most of the sill rocks and occurs as small (< 0.5 mm) completely chloritized crystals.

In general, the rocks of the Electric Peak sills do not show quite such pervasive effects of dueteric alteration as do the other laccolith and sill rocks of the park area; saussuritization of the plagioclase is not common, and hornblende is little altered, in contrast to the widespread partial to complete saussuritization of plagioclase and complete chloritization of hornblende in other laccolith and sill rocks. The sills on Electric Peak near the younger Electric Peak stock have been so strongly altered, apparently by hydrothermal solutions from the Electric Peak stock, that almost no original minerals other than quartz remain, except as pseudomorphs after phenocrysts of plagioclase, hornblende, and biotite. The hydrothermally altered rocks contain abundant euhedral crystals 0.2–0.5 mm across of pyrite that weathers to a distinctive yellowish-brown crust.

A differentiated sill about 30 feet thick that crops out on the southeast spur of Electric Peak was mapped with the Electric Peak sills in this study because of its similar relations to the enclosing sedimentary rocks. The chemistry and mineralogy of the rock in the sill were discussed in detail by Iddings (1899, p. 82–84), who described a lower part, about 10 feet thick, crowded with large (3–5 mm long) crystals of augite, which grades upward into the uppermost 10 feet of the sill, composed largely of plagioclase — probably oligoclase. He attributed the gradational changes through the sill to differentiation and crystal settling. The chemical composition (Iddings, 1899, p. 83) and mineralogy of the rock suggest that it is dioritic and perhaps more closely related to the Electric Peak stock than to the sills and laccoliths.

Gallatin River Laccolith

The Gallatin River laccolith is in the northwest corner of Yellowstone National Park, mainly in an area mapped by Witkind (1964; 1969, p. 39–42). A small part of the laccolith and its related sills extends northward near Wickiup Creek (pl. 1, west half). The laccolith was described briefly by Iddings (1899, p. 84–85). Both Witkind and Iddings described the laccolith as emplaced at and near the base of the Paleozoic sedimentary rocks. Witkind (1964) showed it to be floored by Precambrian crystalline rocks, more or less conformably roofed by limestones of the Madison Group, and crosscutting, at a low angle, the sedimentary rocks below the Madison. In the area north of that mapped by Witkind, only the upper part of the laccolith is exposed, beneath the Madison, but several sills of similar composition are present in upper Paleozoic, Triassic, and Jurassic sedimentary rocks (pl. 1, west half). The laccolith and related sills are made up of rocks that are generally similar to the hornblende-rich rocks in the Electric Peak sills; Witkind (1964) described them as light-gray to dark-gray dense dacite porphyry containing abundant phenocrysts of zoned plagioclase (An_{60} in the core and An_{30} in the rim), altered hornblende, and rounded quartz in an exceedingly fine grained groundmass rich in quartz, feldspar, and magnetite.

Mount Everts Sills

The discontinuous and partly crosscutting sills, as much as 40 feet thick, near the crest of the west cliff face of Mount Everts (pl. 1, west half) were first described by Holmes (1883, p. 10–11), who noted their dark prominence in this cliff of otherwise light-colored beds of sandstone now included in the

Everts Formation. Iddings (1899, p. 85–86) described the rocks and pointed out their similarity to the Electric Peak sills, suggesting that they were originally part of the same intrusive group and that they are continuous across the area now occupied by the downdropped Sepulcher Mountain fault block. The rocks are dark greenish gray to dark gray, aphanitic or very fine grained, and not conspicuously porphyritic; they most closely resemble some of the very fine grained rhyodacite in thin sills on Electric Peak and in the Gray Peak–Snowshoe laccolithic complex.

ELECTRIC PEAK STOCK

The Electric Peak stock is a small complex stock on the east side of Electric Peak (pl. 1, west half). Iddings (1899, p. 89–148) made an extensive and very detailed study of this stock and related it to the volcanic rocks on Sepulcher Mountain. The stock is exposed over an area of about half a square mile in a small cirque high on the east side of Electric Peak, where it has intruded and metamorphosed both the Upper Cretaceous sedimentary rocks and the Electric Peak sills. The outline of the stock is irregular, with dikes extending west and north from the main mass; its center is concealed by talus. Iddings considered the stock to be a volcanic neck surrounded by a dike swarm of rocks genetically related to those in the neck and to be separated from its pile of volcanic rocks on Sepulcher Mountain by the north-trending fault here called the East Gallatin fault. He supported the relation between the rocks of the stock and the volcanic rocks with field, chemical, and petrographic data that amply demonstrated his conclusion that the volcanic rocks were erupted through the Electric Peak stock. The relation between dikes and the stock is not so well defined; the rocks that Iddings (1899, pl. 16, p. 94–97) included in the dike swarm are hornblende- and (or) biotite-rich rhyodacite porphyries that have been hydrothermally altered and pyritized. These "dikes" conform to the bedding in the sedimentary rocks, which are strongly deformed and are nearly vertical south and west of the stock. The field relations and character of the rocks suggest to me that most of the dikes shown south and west of the Electric Peak stock on Iddings' map (1899, pl. 16) are deformed sills related to, and best mapped as part of, the Electric Peak sills, rather than dikes that are related to the Electric Peak stock.

Although the Electric Peak stock includes rocks that range from calcic granodiorite to granitic aplite, most of it consists of granodiorite and quartz diorite. Iddings (1899, p. 97–105) described these rocks and their many textural variations and concluded that the earliest intrusion was calcic granodiorite and that the last intrusion was quartz-mica diorite, except for small aplite dikes that represent late solutions derived from the cooling magma.

Metamorphism

The Electric Peak stock is surrounded by metamorphosed, hydrothermally altered, and hardened sedimentary rocks. The sandstones of the Telegraph Creek and Eagle typically are bleached very light gray, are hardened, and break with a blocky fracture. In thin section these rocks show incipient granoblastic texture and complete hydrothermal alteration of feldspar grains to masses of saussurite. The Cody Shale is converted to a dark-gray hard blocky-fracturing argillite. The rhyodacite Electric Peak sills near the stock are more intensely altered, probably hydrothermally, than similar rocks away from the stock, and they typically contain disseminated small euhedral crystals of pyrite.

BIGHORN PASS SHEET

The Bighorn Pass sheet is a tabular mass, about 75 feet in maximum thickness, of dark-gray fine-grained lamprophyric rock that contains abundant phenocrysts of pyroxene and biotite; it intrudes the flat Crowfoot fault zone at Bighorn Pass (pl. 1, west half). The sheet follows the fault zone for a short distance on the west side of the pass and extends about 1 mile to the east at the head of Panther Creek. The rock is unique among the intrusive rocks in the northern part of Yellowstone National Park. Iddings (1899, p. 69–72) described the rock as kersantite and considered it to be younger than the Indian Creek laccolith, a relative age also suggested by its presence in the Crowfoot fault zone, which may have formed as the laccolith dilated. (See p. A45.)

The rock in the sheet is homogeneous, and microscopic study shows that it is an automorphic-granular aggregate of plagioclase, alkalic feldspar, and quartz containing pyroxene and biotite as phenocrysts, and abundant magnetite. The groundmass minerals are 0.1–0.2 mm in diameter, and the phenocrysts are as much as 4 mm long. Plagioclase, perhaps 30–40 percent of the rock, is labradorite (An_{55-60}) in euhedral to subhedral partly twinned crystals; much of it is saussuritized. Alkalic feldspar, forming 20–25 percent of the rock, is in subhedral to anhedral untwinned grains that rim or enclose plagioclase crystals. Quartz, about 5 percent of the rock, occurs partly as interstitial anhedral grains and partly as subhedral to euhedral composite crystals as much as 0.5 mm across. Biotite, 5–10 percent of the rock, occurs as euhedral to subhedral crystals 0.1–1 mm across and typically is at least partly chloritized. Diopside, forming about 5 percent

of the rock, occurs as large euhedral crystals, 1–4 mm long, that are fractured and partly altered to chlorite, calcite, magnetite, hematite, and zeolites. Also, Iddings (1899, p. 72) reported generally sparse microscopic crystals of hornblende. Magnetite forms about 5 percent of the rock and occurs as euhedral to subhedral crystals 0.01–0.1 mm across, partly associated with altered diopside and partly disseminated throughout the rock. Apatite occurs as abundant minute crystals. Alteration products make up about one-third of the rock and comprise saussurite, chlorite, hematite, zeolites, and calcite that probably is partly derived from adjacent carbonate rocks. A chemical analysis of the rock, reported by Iddings (1899, p. 70), is as follows:

[Analyst, J. E. Whitfield]

Constituent	*Weight percent*
SiO_2	48.73
Al_2O_3	11.92
Fe_2O_3	4.79
FeO	4.56
MgO	5.93
CaO	9.24
Na_2O	2.62
K_2O	2.47
H_2O	1.52
TiO_2	1.34
P_2O_5	.32
MnO	.36
CO_2	5.80
Sum	99.6

The mineralogy of the rock, as far as it can be determined, suggests that it is a calcic monzonite or syenodiorite (fig. 11) lamprophyre.

AGE OF INTRUSIVE ROCKS

Iddings (in Hague, 1896, p. 6) considered the laccoliths and sills to be the oldest intrusive masses in the Gallatin Range, the Mount Holmes stock to be next younger, and the dioritic rocks of the Electric Peak stock to be the youngest. Also, Iddings (1899, p. 89–148) considered the Electric Peak stock to be a volcanic neck, related to the volcanic rocks of Sepulcher Mountain, as discussed above. Hague (1896, p. 2) suggested that emplacement of the laccoliths and sills accompanied eruption of early andesitic breccias and flows, and that emplacement of the Electric Peak stock was accompanied by eruption of the basic volcanic breccias on Sepulcher Mountain. But Iddings remained silent on the problem of extrusive equivalents of the laccoliths and sills, perhaps believing, as Gilbert (1877, p. 95–97) evidently did, that magmas forming laccoliths are not likely to also cause extensive volcanism.

Geologic evidence gained during my mapping suggests, however, that the Mount Holmes stock is the oldest instrusion, the laccoliths and sills are slightly younger, and the Electric Peak stock is the youngest. The Mount Holmes stock was emplaced before the earliest faulting, for the west margin of the stock is cut by the Grayling Creek fault, and it probably was emplaced more or less contemporaneously with folding. The Indian Creek laccolith was probably emplaced after the Mount Holmes stock, for near Echo Peak laccolithic rocks in contact with the hornfelsed roof rocks above the Mount Holmes stock are not themselves metamorphosed. Further, the magma of the Indian Creek laccolith was injected into the Wolsey Shale only where the Wolsey was not intensely hornfelsed; rhyodacite sills were emplaced in the Wolsey on Trilobite Point and the lower reaches of Indian Creek, but in the middle reaches of Indian Creek, where the Wolsey is hornfels, the laccolithic rocks are all in the unmetamorphosed Park Shale. No laccolithic rocks, metamorphosed or otherwise, are present in the metamorphic aureole of the Mount Holmes stock on Mount Holmes, even though much of it was originally Wolsey Shale. These relations suggest to me that the metamorphic aureole of the Mount Holmes stock was formed before the Indian Creek laccolith. The other laccolithic and sill rocks probably are of about the same age as the Indian Creek laccolith rocks, for they are all of roughly the same composition, and most probably were emplaced in the same intrusive episode. The sills on Electric Peak and Mount Everts intrude rocks as young as the Eagle Sandstone and the Everts Formation (Roberts, 1965, p. B56; Fraser and others, 1969, p. 28–33) and, so, are younger than mid-Late Cretaceous. Sills related to those on Electric Peak have been tightly folded with the sedimentary rocks in the drag zone beneath the Gardiner fault at Cinnabar Mountain north of the park (Holmes, 1883, p. 6; Calvert, 1912, p. 415; Wilson, 1934a), and the laccoliths and sills, therefore, probably were emplaced during the late stages of broad folding and before the development of the Gardiner and Grayling Creek faults, which are subparallel and are probably related to each other.

The Electric Peak stock is appreciably younger than the other intrusive rocks in the Gallatin Range. The stock cuts rhyodacite sills on Electric Peak, and the sill rocks are hydrothermally altered and pyritized near the stock.

Geologic evidence therefore suggests that the laccoliths and sills and the probably older Mount Holmes stock were emplaced after deposition of the Upper Cretaceous Eagle Sandstone and Everts Formation, but before major movement on the Gardiner fault of late Paleocene or early Eocene age (Foose and others, 1961, p. 1164) and on the Grayling Creek fault of probable similar age. The Electric Peak

stock probably is contemporaneous with the volcanic breccias on Sepulcher Mountain, which were dated as Eocene by Dorf (1960). The direct relation of early andesitic breccias and flows to laccoliths and sills as suggested by Hague (1896, p. 2) seems improbable, for eruption of the early volcanic rocks seems mainly to have been later than the principal movements on reverse faults, and the emplacement of laccoliths and sills seems to have been earlier.

STRUCTURE

The faults and folds in the pre-Tertiary rocks of northern Yellowstone National Park (fig. 18) appear outwardly to have little relation to most faults and folds in surrounding areas, partly because comparatively little is known of the structural framework in much of the area immediately north of the park, but mostly because the park is in an unusual setting, where very different structural provinces come together. The earliest structural events involved the folding, intrusion by granitic magma, and metamorphism of the Precambrian rocks—in essence, several separate events that eventually converted both sedimentary and granitic rocks to the existing gneisses and schists. These periods of extreme deformation were followed by a long period of Precambrian time for which there is no record in the park. Presumably, the area was deeply eroded and furnished sediments to the Belt Supergroup rocks that were being deposited to the north and west. At any rate, the Precambrian crystalline rocks had been worn down to a nearly flat surface, littered with quartz fragments, when the Flathead Sandstone of Middle Cambrian age was deposited. The Paleozoic and Mesozoic sedimentary rocks, lying in parallel beds, show that comparative structural quiet, broken only by repeated broad epeirogenic movements, continued until latest Cretaceous time, when the area was folded and faulted during a period of deformation that probably has not yet ended.

The faults in the northern part of the park may be conveniently separated into (1) low-angle north-dipping faults, (2) northwest-trending high-angle

FIGURE 18. — Structural features in pre-Tertiary rocks, northern part of Yellowstone National Park.

reverse faults, (3) northwest-trending basin-range normal faults, and (4) north-trending steep normal faults. In general, the faults appear to have been formed in the order given, but almost all of them have been recurrently active to the present time.

STRUCTURE OF PRECAMBRIAN CRYSTALLINE ROCKS

The Precambrian gneisses and schists so widespread in the Gallatin Range and in the north-central part of the park owe much of their present appearance to intense deformation, but mapping detailed enough to yield more than suggestive information was far beyond the scope of my study. In general, relict bedding in the schists along the Yellowstone River strikes about north and dips eastward at angles that commonly are low but locally are as much as 80° (Seager, 1944, p. 21–28, 38–40). The strike and dip differs from place to place, however, and Seager (1944, p. 32, 38–40) suggested that the rocks were asymmetrically folded and converted to schist before emplacement of the Precambrian granitic magma. Both during and following the granitic intrusions, the schist was crossfolded almost at right angles to the earlier, northtrending folds, and the schist and granitic rocks later were regionally metamorphosed to their present form (Seager, 1944, p. 38–40).

Both schist and gneiss are jointed, and the pronounced foliation in schistose rocks is also evident in many outcrops of granitic gneiss. The joints are not continuous into the overlying sedimentary and igneous rocks, implying that most or all of them were formed during Precambrian time. Despite their antiquity, however, they have influenced the development of landforms and drainage patterns in areas where Precambrian rocks are exposed; the rectilinear pattern of Maple Creek and other creeks in the southwestern part of the Gallatin Range reflects such joints.

Trends of foliation and joints measured on Precambrian rocks in the Gallatin Range and in the north-central part of the park are summarized in equal-area diagrams (figs. 19, 20). Measurements taken in the Gallatin Range are included on the diagram with the measurements taken in the north-central part of the park, partly because comparatively few foliation and joint measurements were taken in the Gallatin Range, but mainly because there appear to be no significant differences in the foliation and jointing in the two areas.

FOLDS IN SEDIMENTARY ROCKS

The sedimentary rocks in the northern part of Yellowstone National Park commonly dip gently northward or eastward, but in many places the attitudes of the rocks differ from this dominant trend. On Cinnabar Mountain, north of the park boundary, the general northward dip is abruptly reversed near the Gardiner reverse fault (Wilson, 1934a, p. 657) to form a northwest-trending asymmetric syncline, the result of folding and drag along the fault. In the Gallatin Range, the rocks on, and south of, Mount Holmes dip south, and most of those north of Mount Holmes dip north, thus suggesting a broad gentle anticline that trends about northwest. This anticline, here named the Gallatin anticline, is the major fold in the northwestern part of the park and probably was once continuous with the large anticline on the east side of the Madison Range along the upper part of the Gallatin River—the Buck Creek anticline of Hall (1961). The anticline is wrinkled by many small gentle folds of diverse trends; these folds reflect drag along faults or doming over laccoliths or over the Mount Holmes stock, which intrudes the axial part of the anticline. The sedimentary rocks of the Gallatin Range are most strongly folded on the southeast spur of Electric Peak, where they are overturned in places by drag along the East Gallatin fault.

On the Buffalo Plateau most of the sedimentary rocks dip to the east, probably as a result of the tilting of this mountain block when it was uplifted on the Gardiner reverse fault. However, low westward dips on the west side of Buffalo Creek and on the west side of Soda Butte Creek outline broad northeast-trending synclines in these areas, and they suggest that the consistent northeast trend of the major stream valleys in this part of the park is controlled by the fold pattern of the underlying sedimentary rocks.

The broad folds are broken by all the faults that cut the pre-Tertiary rocks in the northern part of the park, and they reflect the regional folding that preceded reverse faulting in early Tertiary time (Foose and others, 1961, p. 1148).

CROWFOOT FAULT ZONE

The Crowfoot faults are a zone of gently north dipping faults that extend across the Gallatin Range from Crowfoot Ridge to Antler Peak. The main zone of faults—generally two or three separate faults—occupies the stratigraphic interval between the top of the Pilgrim Limestone and the middle of the Lodgepole Limestone; all intervening strata are partly or entirely missing. Imbricate faults also cut the Madison Group, but in general they lack the continuity of the faults in the underlying main zone. The fault zone ranges in strike from about west to northwest, and dips range from about 15° to 20° N. The rocks in the main fault zone and along imbricate flat faults are brecciated in many places, and the

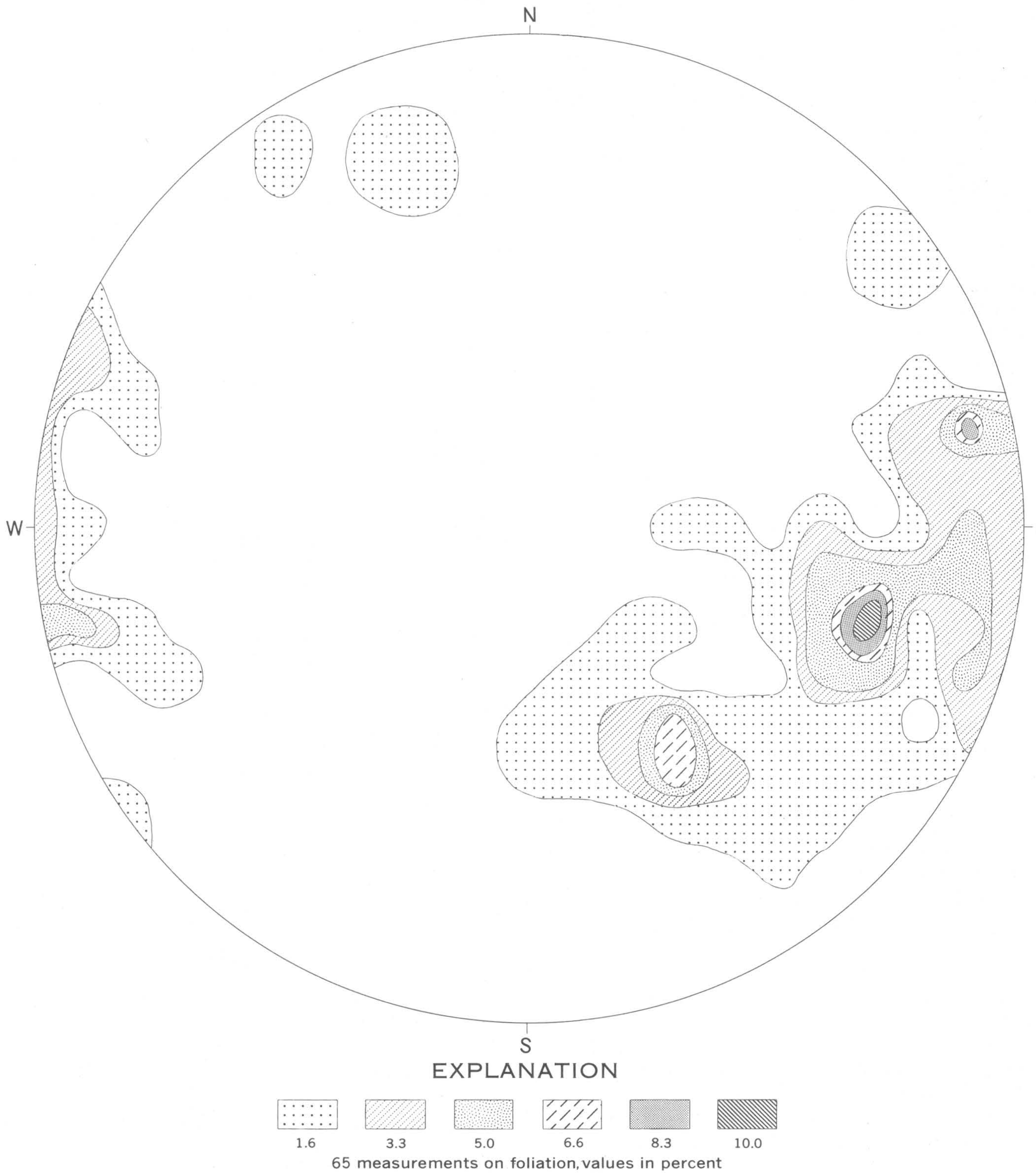


FIGURE 19. — Contour diagram of foliation in Precambrian rocks; equal-area projection of poles on lower hemisphere.

principal fault on Crowfoot Ridge is marked by about 20 feet of clay gouge. In other places, mainly in the Gallatin River valley, the carbonate rocks involved in the faulting are neither brecciated nor sheared, and the fault zone is reflected only by missing stratigraphic units. None of the rocks in or near the fault zone are crumpled or dragged, perhaps because much of the fault zone nearly parallels the

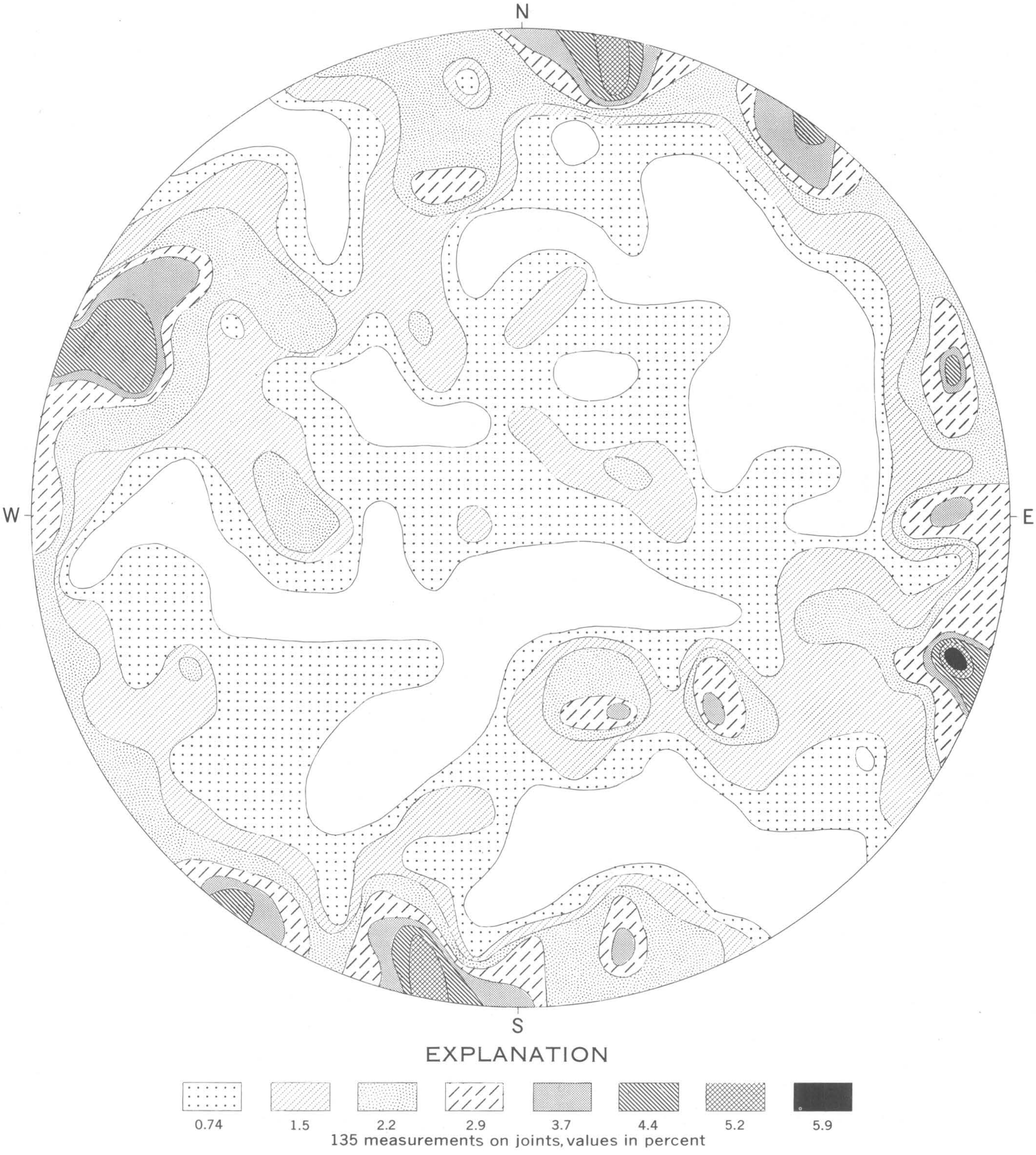
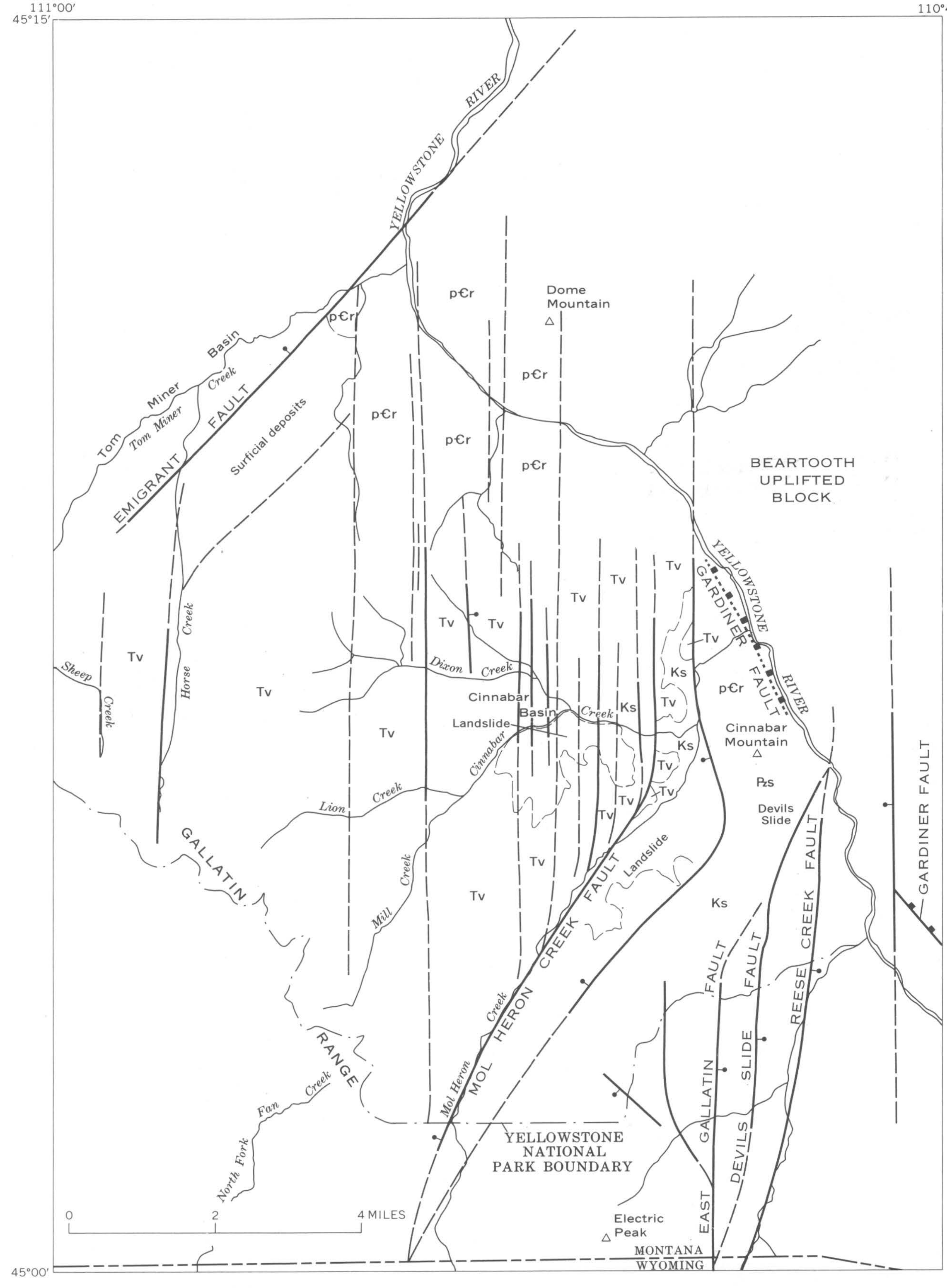


FIGURE 20.— Contour diagram of joints in Precambrian rocks; equal-area projection of poles on lower hemisphere.

bedding. The displacement on the fault zone probably is not large, but the effects on the stratigraphic record are striking, for these are the faults that disrupt the Crowfoot Ridge stratigraphic section (Iddings and Weed, 1899, p. 6–8), which has been cited as a reference for many fossil collections (Girty, 1899), often quoted, and almost as often remeasured. And these faults are responsible for the


111°00′
45°15′
110°45′
45°00′
YELLOWSTONE RIVER
EMIGRANT FAULT
Tom Miner Basin
Tom Miner Creek
Surficial deposits
p€r
Dome Mountain
BEARTOOTH UPLIFTED BLOCK
YELLOWSTONE RIVER
GARDINER FAULT
Tv
Ks
Sheep Creek
Horse Creek
Dixon Creek
Cinnabar Basin
Cinnabar Creek
Landslide
Cinnabar Mountain
Pzs
Devils Slide
Lion Creek
Mill Creek
GARDINER FAULT
GALLATIN RANGE
MOL HERON CREEK FAULT
Mol Heron Creek
REESE CREEK FAULT
DEVILS SLIDE FAULT
EAST GALLATIN FAULT
Fan Creek
North Fork
YELLOWSTONE NATIONAL PARK BOUNDARY
Electric Peak
MONTANA
WYOMING
0
2
4 MILES

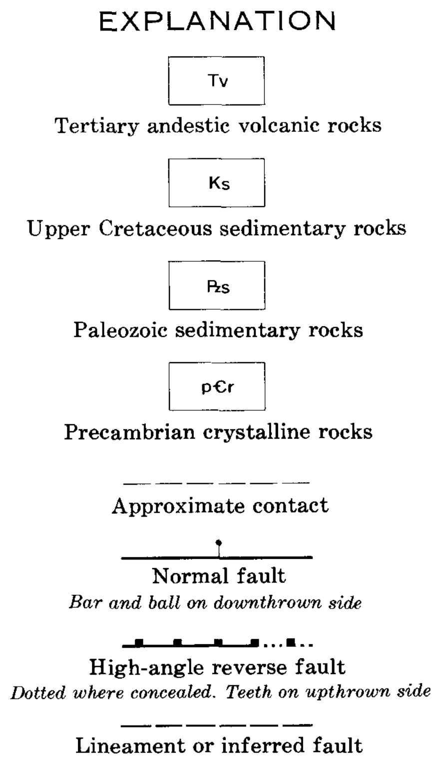


FIGURE 21 (facing page and above). — Structural sketch map of Cinnabar Mountain and vicinity, Miner quadrangle, Park County, Mont. Reconnaissance geology mapped by E. T. Ruppel, 1968. Base from U.S. Geological Survey, 1955, 1: 62,500.

surprising thinness of the Paleozoic section on the east flank of Antler Peak that was mentioned by Holmes (1883, p. 26).

The faults are interpreted, for several reasons, as glide faults rather than as flat thrust faults resulting from compression. They are steepest near the dome over the Indian Creek laccolith and tend to flatten northward. (See geologic sections on pl. 1, west half.) From the Gallatin River valley eastward, the faults are on the flank of the dome over the Indian Creek laccolith; farther west near Crowfoot Ridge, they are on the north-dipping flank of the Gallatin anticline. They are restricted to a rather thin stratigraphic interval, in which their major movement has been along shaly zones that probably served as lubricating layers. The evidence suggests to me that the faults of the Crowfoot fault zone formed as a result of the dilation of the Indian Creek laccolith. As the sedimentary beds were domed, masses of Mississippian rocks slid northward along flat faults lubricated by Cambrian and Devonian shales. The faults probably steepened further and surfaced over the central part of the dome, and the steep faults that break the dome at the head of East Fork Fan Creek may be comparable faults at a much higher level above a laccolith.

REVERSE FAULTS

The northwest-trending Gallatin anticline is broken on both flanks by steep reverse faults that parallel it and that may have formed about contemporaneously with the late stages of folding and with movement on the Crowfoot faults. The northernmost of these faults, the Gardiner fault zone (Holmes, 1883, p. 5–6; Wilson, 1934a; Calvert, 1912, p. 415) extends southeast from near Gardiner, Mont., where it was recently studied by Fraser, Waldrop, and Hyden (1969, p. 63–69), to Rescue Creek and the Grand Loop Road (pl. 1, west half). The fault zone forms the southwest margin of the Beartooth uplift (Foose and others, 1961). Northwest of Gardiner, the fault zone is broken by younger north-trending normal faults (fig. 21); its continuation is shown on earlier maps (Calvert, 1912; Wilson, 1934a) as separating the Precambrian rocks and Paleozoic rocks at the north end of Cinnabar Mountain, but reconnaissance mapping suggests that this contact is a depositional one and that the fault more probably is farther north, in the Yellowstone River valley. Northwest of Cinnabar Mountain, the Gardiner fault is buried by Tertiary volcanic rocks; it probably reappears as the high-angle reverse fault designated by Iddings (1904, p. 99) as the Spanish Peaks fault in the Madison Range. Southeast of the Grand Loop Road in Yellowstone National Park, the Gardiner fault is again buried beneath Tertiary volcanic rocks. Wilson (1934a, p. 653) suggested that it reappeared near Cody, Wyo., but its actual continuation, if any, east of the volcanic blanket is unknown.

The characteristics of the Gardiner fault near Gardiner were first described by Holmes (1883, p. 5–6), who estimated the displacement to be about 15,000 feet. The fault was studied recently by Fraser, Waldrop, and Hyden (1969, p. 63–69), who stated that it is a steeply northeast dipping imbricate reverse fault zone on which the net shift must be considerably more than 10,000 feet. The fault strikes about N. 60° W. at Gardiner, and Fraser calculated the dip to be 75° NE. Near Rescue Creek and the Grand Loop Road, the fault strikes about northwest and probably is at least as steep as 75°. The fault zone is about half a mile wide and has brought granitic gneiss of Precambrian age north of the fault zone nearly in contact with the Eagle Sandstone of Late Cretaceous age south of the fault zone, a displacement comparable to that at Gardiner. Sedimentary rocks of many ages are present in the fault zone in a complex of fault slices that can only be shown schematically on the geologic map; the

slices include rocks of almost every formation of Mississippian to Early Cretaceous age.

The Gardiner fault at Gardiner is paralleled by the Everts fault, which Fraser, Waldrop, and Hyden (1969, p. 65) described as a smaller reverse fault marking the outer, southwest edge of the drag zone along the Gardiner fault. The equivalent fault at Rescue Creek and the Grand Loop Road is the reverse fault that bounds the imbricate Gardiner fault zone on the southwest. Other reverse faults, largely concealed by glacial deposits (pl. 1, west half, section *F–F′*), parallel the imbricate Gardiner fault zone and cut Upper Cretaceous rocks on the northeast slope of Mount Everts; amounts of displacement on these faults are uncertain, but the displacement on the fault south of Rescue Creek must be several thousand feet, in order to bring the Eagle Sandstone back to the surface. Another parallel reverse fault, the Lava Creek fault (pl. 1, west half, section *F–F′*), is concealed along the foot of Mount Everts and northwest to the limits of Mammoth; farther northwest it probably is cut off by the younger Mammoth fault. The displacement on the Lava Creek fault is about 2,000 feet.

The Gallatin anticline is broken on its south limb by the Grayling Creek reverse fault, which is parallel to the Gardiner fault but dips steeply south (pl. 1, west half, sections *C–C′*, *D–D′*, *E–E′*). The uplifted southern block brings Precambrian granitic gneiss into fault contact with Meagher Limestone of Cambrian age in the hills at the south end of the Gallatin Range. The Meagher Limestone in the downdropped block has been dragged into a tight asymmetric syncline adjacent to the fault (pl. 1, west half, section *E–E′*). The minimum displacement is 500–1,000 feet; the actual displacement may well be several times greater. Farther northwest, the fault is largely in Precambrian rocks, and most of its trace is covered by glacial deposits. Like the Gardiner fault, the Grayling Creek fault appears to be broken by later, north-trending normal faults, which apparently cut it off at the edges of the Gallatin Range.

Three steep faults between Crowfoot Ridge and the Gallatin River merge into the Grayling Creek fault on the west flank of the White Peaks and appear to be part of the Grayling Creek fault zone. The displacement on the two westernmost faults is reverse in their southern parts but is normal farther north, suggesting rotational, or scissor, movement on these faults. The easternmost fault, just west of Three Rivers Peak and in the Gallatin River valley, is now a normal fault. The overturning of the sedimentary rocks and the comparatively extreme deformation along all three of these faults suggest, however, that these faults originally were all formed as part of the Grayling Creek zone of reverse faults and that the present local normal fault relations have resulted partly from original scissor movements and partly from subsequent normal fault movement along older reverse faults.

The southern part of the Gallatin Range in Yellowstone National Park, thus, was originally a broad northwest-trending anticline, the flanks of which were broken by high-angle reverse faults probably in the late stages of folding. As a result, the Gallatin anticline was depressed between the Beartooth uplift on the northeast and the Grayling Creek uplift on the southwest.

AGE OF REVERSE FAULTING

The principal movement on the Gardiner fault zone followed the deposition and gentle folding of the youngest Cretaceous sedimentary rocks in Yellowstone National Park and emplacement of laccoliths and sills and related glide faulting. The Upper Cretaceous rocks are cut in many places by the reverse faults, and Upper Cretaceous sedimentary rocks and included sills on Cinnabar Mountain are tightly folded beneath the Gardiner fault zone (Calvert, 1912, p. 415; Wilson, 1934a). The major faulting preceded eruption of the lower Tertiary volcanic rocks that cover much of trace of the fault zone. Foose, Wise, and Garbarini (1961, p. 1164, 1167) stated that major uplift began on the Beartooth block, which the Gardiner fault zone bounds on the southwest, in Paleocene (Fort Union) time and culminated in early Eocene time. The principal movement on the Grayling Creek fault probably was at the same time as that on the Gardiner fault, but no direct substantiating evidence is available. The uplift on steep reverse faults was followed in early Eocene time (Foose and others, 1961, p. 1165) by eruption of the early volcanic rocks in the park, and concurrently by detachment faulting near the northeast corner of the park (Pierce, 1957, 1960). Indeed, it seems probable that the detachment sheets described by Pierce gained some of their motive force from the general eastward slope of the tilted block east of the Gardiner fault zone, a possibility that would also help explain why the lower Tertiary volcanic rocks on, and east of, the Buffalo Plateau rest on a surface that is stratigraphically controlled—by the Lodgepole Limestone in most places east of Slough Creek, and by the Bighorn Dolomite or, less commonly, by Cambrian limestones between Hellroaring and Slough Creeks.

Although the major movement on the reverse faults was in early Tertiary time, the faults have been active recurrently throughout Cenozoic time. Fraser, Waldrop, and Hyden (1969, p. 67) cited

evidence that the north block of the Gardiner fault near Gardiner has had about 400 feet of relative upward movement along it in Quaternary time. To the southeast, near Grand Loop Road, the Gardiner fault cuts Pleistocene glacial deposits, but at that locality the direction of movement is normal, north-side-down, and the opposite of the direction of principal movement; the total postglacial movement appears to be only a few tens of feet. H. J. Prostka (oral commun., 1968) mapped a zone of faults that extends southeast from the Gardiner fault zone at Grand Loop Road to cut the lower Tertiary volcanic rocks.

The Grayling Creek fault has had normal fault movement along its southern third in the Gallatin Range in postglacial time, for the trace of the fault is clearly defined by a scarp that continues through morainic deposits and by numerous slumps and sag ponds. This part of the Grayling Creek fault also appears to have been reactivated during movement of the East and West Gallatin normal faults.

NORTH-TRENDING NORMAL FAULTS

Large north-trending normal faults bound the Gallatin Range, flank Sepulcher Mountain along its east side near Mammoth Hot Springs, and smaller, apparently related faults control the valley of Buffalo Creek in the north-central part of the park. The East Gallatin fault, on the east side of the Gallatin Range, is the most prominent, and was first recognized by Holmes (1883, p. 27). Iddings and Weed (Hague and others, 1899, p. 55, 90, 139) named it the Gallatin fault and suggested that the Sepulcher Mountain block east of the fault had been downdropped more than 4,000 feet. Iddings (1904, p. 101) named the northern part of the fault between Electric Peak and Sepulcher Mountain the Reese Creek fault and stated the displacement to be more than 6,000 feet, east-block-down. The name East Gallatin fault seems more appropriate, for, as Holmes early recognized, the fault bounds the entire east face of the Gallatin Range in Yellowstone National Park. Wilson (1934a, p. 659–660) described the Reese Creek part of the fault and stated that it had a stratigraphic displacement of more than 4,000 feet, a figure that closely agrees with the 4,300 feet given by Fraser, Waldrop, and Hyden (1969, p. 77).

In the area between Electric Peak and Sepulcher Mountain, the main displacement is along the strand of the East Gallatin fault that controls Reese Creek (pl. 1, west half), but several other strands cut across the lower slopes of Electric Peak, extending southward to merge into the main fault east of Little Quadrant Mountain. This system of faults is more than 1 mile wide near Cache Lake, and it widens northward (pl. 1, west half). These faults control the east face of Cinnabar Mountain north of the park, and with a parallel fault extending northward from Sepulcher Mountain and a related fault west of Cinnabar Mountain, clearly offset the older Gardiner reverse fault. South of Cache Lake, part of the fault zone is exposed in a gorge several hundred feet deep cut by the Gardner River. The fault zone controls the scarp front of the Gallatin Range, but it is generally concealed by colluvial deposits or is poorly defined in glacial deposits—even though the latest movements on the fault cut the glacial deposits. The East Gallatin fault is vertical where it is exposed by the Gardner River and its straight trace suggests that it remains vertical, or nearly so, both to the north and to the south. The zone of faults west of Cache Lake is a zone of extreme deformation, and the sedimentary rocks and included rhyodacite sills on the southeast spur of Electric Peak are nearly vertical; they are locally overturned and are broken by many subsidiary faults in and along the major splits of the East Gallatin fault. The displacement on the fault south of Reese Creek probably at least equals the more than 4,000 feet determined in Reese Creek. The minimum displacement represented by the scarp front of the Gallatin Range is about 2,500 feet, and the downdropped Gardners Hole block east of the fault, is buried beneath volcanic rocks that are at least partly younger than the major displacement of the fault, and that may be several thousand feet thick, as judged from the thickness of exposed volcanic rocks nearby.

The probable trace of the East Gallatin fault can be extended far south of the Gallatin Range along a major lineament (fig. 22) in the rhyolitic volcanic rocks. The main movement on the fault occurred before eruption of the rhyolitic volcanic rocks, however, and the lineament suggests only shattering or very slight offset of the rhyolite over the inferred buried fault. The Upper, Midway, and Lower Geyser basins, and Old Faithful itself, lie along this inferred extension of the East Gallatin fault, and so perhaps the thermal activity is structurally controlled at depth by the fault. The lineament becomes obscure south of the upper part of the Firehole River, but the fault probably continues southward beneath the rhyolite and joins the extension of the Teton fault (Love, 1961, p. 1751) near Beula and Hering Lakes, at the south boundary of the park.

The West Gallatin fault, which bounds the Gallatin Range on the west, is poorly exposed through rhyolitic and basaltic volcanic rocks and glacial deposits. These younger deposits are only slightly offset or shattered by small late movements along the fault, but outcrops of sedimentary rocks on Crowfoot

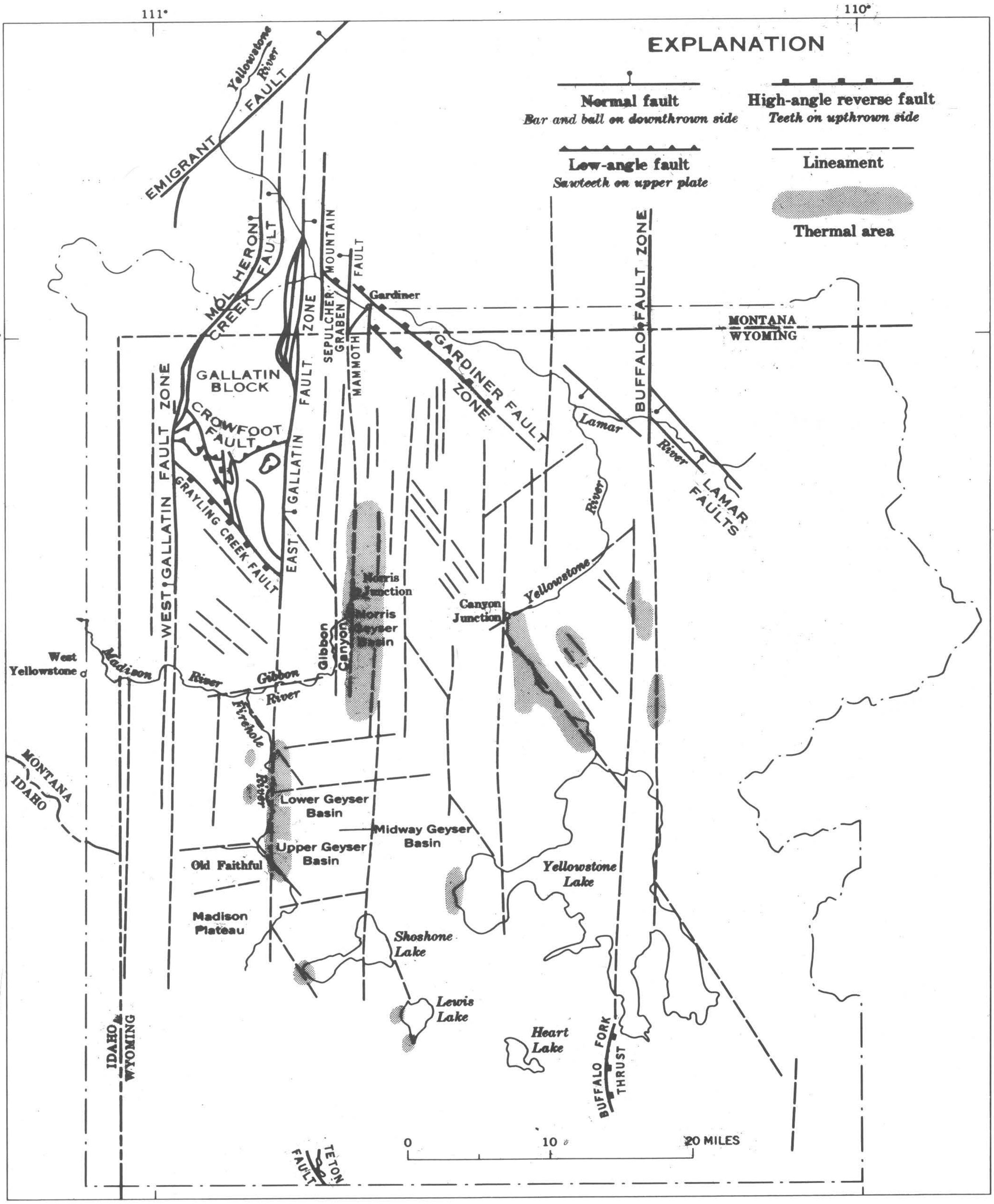


FIGURE 22. — Lineaments in part of Yellowstone National Park.

Ridge (pl. 1, west half, sections *A–A′*, *B–B′*) east of the fault and across the fault zone to the west (Witkind, 1964) suggest that the aggregate displacement on the two faults in the zone here is 2,500–3,000 feet, west block relatively down. The fault is vertical, or nearly so, and it probably cuts the Grayling Creek reverse fault, although the area of intersection is concealed. Between Maple Creek and Grayling Creek, the fault is paralleled on the east by several smaller faults that cut Precambrian rocks and basaltic volcanic rocks that have been deposited in that area on the Precambrian rocks. Most of these smaller faults apparently die out northward. Most of the displacement took place before the eruption of the young rhyolitic and basaltic volcanic rocks (which probably are offset only a few tens of feet, if at all) but after the eruption of the lower Tertiary pyroclastic rocks, as did the displacement on the East Gallatin fault (Iddings, 1899, p. 90).

The West Gallatin fault has been mapped only along the west side of the Gallatin Range (pl. 1, west half), but a prominent lineament continues both north and south of the known fault trace (figs. 21, 22). To the south, this lineament extends along the east side of the basin around West Yellowstone, Mont. It is obscured by very young rhyolitic volcanic rocks on the Madison Plateau, but it may be represented by one or all of the lineaments that continue southward along the park boundary. Love (1968, p. E9) suggested that a normal fault bounds the west flank of the Teton uplifted block south of the park (Love, 1956, p. 141), and Pampeyan, Schroeder, Schell, and Cressman (1967) suggested that a north-trending fault, which was interpreted on geophysical data as a thrust or reverse fault upthrown on the east, underlies Teton Basin farther south along the west flank of the Teton Range.

To the north, the West Gallatin fault swings north east near Fan Creek (pl. 1, west half) and controls the upper part of Mol Heron Creek (fig. 22; H. W. Smedes, oral commun., 1970). Also, a prominent lineament continues northward across Fan Creek, perhaps reflecting a continuation of the West Gallatin fault in that direction as well. Earlier maps (Iddings and Weed, 1899; Iddings, 1904; Calvert, 1912; Wilson, 1934a) indicate that the fault at Mol Heron Creek extends northeastward to Cinnabar Mountain, but reconnaissance mapping (fig. 21) in this area suggests rather that the fault resumes a northward trend southwest of Cinnabar Mountain and continues northward to control the east side of Cinnabar basin and ultimately to merge into the Emigrant fault (Pardeè, 1950, p. 377–379).

The Mammoth fault is a north-trending near-vertical fault that controls the east front of Sepulcher Mountain near Mammoth Hot Springs (pl. 1, west half). The fault, first recognized by Iddings (1904, p. 101), was mapped and named by C. W. Brown (1961, p. 1186). Fraser, Waldrop, and Hyden (1969, p. 75) applied the name to a northeast-trending fault in the Gardiner, Mont., area and stated that it had a stratigraphic displacement of more than 2,000 feet, east-side-up. But the fault mapped by Fraser, Waldrop, and Hyden (1969, p. 75) is a strand from the main north-trending fault and part of a complex of related faults near Mammoth Hot Springs. Consequently, in this report the name "Mammoth fault" is used, as C. W. Brown (1961, p. 1190) defined it, for the north-trending near-vertical normal fault on the east side of Sepulcher Mountain, which bounds the Sepulcher Mountain graben on the east (fig. 18). The displacement on the Mammoth fault is not known, but it certainly must equal or exceed the 2,000 feet determined on the fault strand at Gardiner. Although partly obscured by rhyolitic volcanic rocks, the Mammoth fault is probably represented farther south by the striking lineaments (fig. 22) that extend southward along Obsidian Creek to Gibbon Canyon, and from west of Horseshoe Hill to the vicinity of Roaring Mountain and Norris Geyser basin. The outcrops of sedimentary rocks east of Obsidian Cliff and Roaring Mountain suggest that the displacement here was at least of the same order of magnitude, more than 4,000 feet, as that on the related East Gallatin fault, which bounds the west side of the Sepulcher Mountain graben. The inferred southward projection of the Mammoth fault along the Obsidian Creek zone of lineaments coincides with the area of intense thermal activity that extends from the vicinity of Obsidian Cliff to Norris Geyser basin, and it suggests that the thermal activity is controlled at depth by the Mammoth fault.

Near Mammoth Hot Springs the Mammoth fault is flanked on the east by a complex of related faults that include (1) the northeast-trending strand mapped near Gardiner, Mont., by Fraser, Waldrop, and Hyden (1969, p. 75), on which the relative movement is east-block-up more than 2,000 feet (the same sense of movement as on the main Mammoth fault), and (2) by at least four north-trending vertical faults on which the east block has dropped down from a few hundred to a thousand feet. Recurrent movements on these smaller, north-trending faults have broken the hot spring deposits of Mammoth Hot Springs and the landslides that mantle much of this area. The terrace levels so conspicuous at Mammoth are largely determined by nearly horizontal

resistant layers of Jurassic and Cretaceous sedimentary rocks repeated on several levels by the north-trending faults, and the faults appear to control the hot springs.

Only a few north-trending normal faults can be recognized in the pre-Tertiary rocks of north-central Yellowstone National Park. One of these, mapped north of the park by Iddings and Weed (1894), controls part of the valley of Coyote Creek (pl. 1, east half) and extends southward across the upper part of the Hellroaring Slopes. The block west of the fault is downdropped, perhaps a few hundred feet. The fault cuts Precambrian metamorphic rocks and lower Tertiary volcanic rocks in the park, but farther north it drops the Cambrian Flathead Sandstone down on the west, where it is preserved on the top of Bull Mountain; the relation of volcanic rocks on opposite sides of the fault in Coyote Creek suggests some strike-slip movement. Farther east, the Buffalo fault, on the east side of the Buffalo Plateau (pl. 1, east half), has been recognized by C. W. Brown (1961, p. 1186) ; and similar faults have been mapped and described north of the Buffalo Plateau by Rubel (1964), who considered them to be early Tertiary in age. The Buffalo fault described by Brown is the middle fault of three parallel north-trending vertical normal faults that control much of the valley of Buffalo Creek both in and north of the park. These faults cross the valleys of Slough Creek and the Lamar River, both of which have been broken and uplifted, across the fault zone, about 300 feet on the east—a sense and amount of movement also suggested by the relations of the Cambrian sedimentary rocks on opposite sides of the fault zone. Lamar Canyon and the gorge near Slough Creek campground are sharp canyons entrenched in the resulting scarp.

AGE OF NORTH-TRENDING FAULTS

The north-trending vertical faults in the northern part of Yellowstone National Park all cut and displace Eocene volcanic rocks. The East and West Gallatin faults also appear to cut the Grayling Creek and Gardiner reverse faults, on which the major displacement culminated in Eocene time. Lineaments suggest that the major north-trending faults continue beneath the rhyolitic rocks in the central part of the park, but there appears to be little, if any, displacement of at least the Pleistocene rhyolitic rocks that now blanket much of this area, and perhaps the lineaments are controlled by shattering of the rhyolite induced by slight movements on buried faults. The principal movement on the faults was preglacial, for the glacial deposits across the fault traces are displaced only minor amounts. On the Buffalo Plateau, valleys controlled by north-trending faults have been occupied by major ice streams, and the Lamar Canyon–Slough Creek scarp has been glaciated.

The main movement on the north-trending faults, thus, was post-Eocene and pre-Pleistocene, but the time cannot be fixed much more closely from the evidence available in the northern part of the park. There is a suggestion, based on lineaments, that the East Gallatin fault is a northward extension of the Teton fault, the earliest movement of which was dated by Love (1956, p. 148) as late middle and late Pliocene, with recurrent movement through the Quaternary. The relation of structural features in the northern part of the park to those in surrounding regions, discussed later in this report, also suggests that the Gallatin and Teton mountain blocks have had a common history; and, on the basis of such tenuous relations, the main movement on the north-trending faults in the northern part of the park seems most likely to have taken place in late Tertiary, perhaps late Pliocene, time. Smaller movements, indicated by sag ponds and broken surficial deposits, have recurred along parts of the faults through the Pleistocene to the near present.

OTHER NORTH-TRENDING PROBABLE FAULTS AND LINEAMENTS

In addition to the north-trending faults just described, many lineaments (fig. 22) of similar trend, and probably fault controlled, are found in the northern part of Yellowstone National Park.

The Hellroaring lineament, occupied by the straight, deep gorge of Hellroaring Creek (pl. 1, east half) is probably a north-trending fault on which the block to the east has been downdropped, but glacial and alluvial deposits obscure the actual fault, if it exists, and the Precambrian rocks flanking Hellroaring Creek provide little help in determining whether or not a fault is present. The lineament continues northward for many miles beyond the park boundary, but no fault is shown by Iddings and Weed (1894) on the geologic map of this area.

North-trending lineaments, evident on topographic maps, color and black-and-white aerial photographs, and radar imagery (Ruppel, 1966), are abundant in the northern part of Yellowstone National Park (fig. 22), and, as earlier suggested, some of them extend south almost to the south park boundary. A few of these lineaments, already discussed in this report, appear to be continuations of mapped faults, but most of them are known only as more or less obscure lines on topographic maps, photographs, or images of various kinds, and their origin and meaning is uncertain at best. The north-trending lineaments

parallel major faults that cut pre-Tertiary metamorphic and sedimentary rocks and lower Tertiary volcanic rocks, but they are partly obscured by upper Cenozoic rhyolitic volcanic rocks. The major movements on known north-trending faults may have been in the Pliocene, but some movement seems to have continued intermittently through the Quaternary. The main movement, therefore, would have preceded eruptions of the rhyolitic volcanic rocks in late Cenozoic time, and the faults would have been buried by rhyolitic volcanic rocks. Even if recurrent movement along the faults cut the rhyolitic rocks later, the expectable displacement would be small — perhaps represented only by a shattered zone. At any rate, I suggest that the north-trending lineaments are controlled by buried faults and that north-trending, near-vertical faults are major structural elements in Yellowstone National Park.

NORTHWEST-TRENDING NORMAL FAULTS

Northwest-trending normal faults occur on the flanks of the Lamar River valley (pl. 1, east half). The faults are normal and appear to dip steeply toward the downdropped valley block. The segment of the Lamar River valley northwest of the junction of Soda Butte Creek and the Lamar River is a typical small fault-controlled valley, bounded on both sides by northwest-trending inward-dipping range-front faults. A fault control of the Lamar River valley was first recognized by Howard (1937, p. 71–74), and has since been discussed by Love (1961, p. 1758) and by C. W. Brown (1961, p. 1190–1191). The Lamar fault of these earlier reports is the range-front fault that forms the southwest boundary of the Lamar River valley; Love and Brown suggested that the valley had been dropped 1,300–1,500 feet along this fault in Pliocene and Pleistocene time, and Love indicated that as much as 1,000 feet of displacement could have occurred in Quaternary time.

The northeast-dipping Lamar fault on the south side of the Lamar River valley is paralleled by a southwest-dipping fault that controls the north side of the valley; and another southwest-dipping fault cuts granitic gneiss near Little Buffalo Creek. The trace of the fault on the north side of the Lamar River valley, between Slough and Soda Butte Creeks, is marked by a low scarp, by many springs and bogs, and by landslides and slumped areas.

As Howard (1937), Love (1961), and C. W. Brown (1961) stressed, there is ample evidence of late movements on the range-front faults of the Lamar fault system, and Love (1961) pointed out that the Lamar faults are paralleled by many normal faults farther south in Yellowstone National Park that break upper Cenozoic volcanic rocks and Quaternary glacial deposits. The Lamar faults are broken by north-trending normal faults near Slough and Hellroaring Creeks, however, and so originated earlier, but they have had substantial recurrent movement along them in Quaternary time. The north-trending faults are inferred to have been active mainly in late Tertiary time, an inference supported somewhat by the fact that they cut the northwest-trending faults. The time of earliest movement on the northwest-trending faults is uncertain; Love (1961, p. 1758) suggested that some of the movement on the Lamar fault was late Tertiary, and C. W. Brown (1961, p. 1191) suggested post-middle Eocene and pre-late(?) Pliocene.

REGIONAL IMPLICATIONS AND SPECULATIONS

Perhaps the most striking conclusions to be reached from the preceding discussion of structural features in pre-Tertiary rocks in the northern part of Yellowstone National Park are that the structural framework of this area is unlike that of any adjacent area and that the structural history, therefore, must also differ. Also, the conclusion that deformation has occurred repeatedly throughout Cenozoic time, with major pulses in Paleocene to Eocene and in Pliocene(?) time, departs from most earlier interpretations of the structural history of Yellowstone National Park, which either state or imply that all major deformation in the region was "Laramide" (broadly, equaling Late Cretaceous through Eocene time) (Iddings and Weed, 1899; Iddings, 1904; Hamilton, 1960; Fraser and others, 1969, p. 85).

The uplifted Beartooth block, east of the Gardiner fault, has been described by Fraser, Waldrop, and Hyden (1969); Foose, Wise, and Garbarini (1961); C. W. Brown (1961); Wilson (1934a); and Holmes (1883). Some of these authors have suggested that the Gardiner fault may extend southeast to near Cody, Wyo. But regardless of different interpretations on the possible extensions of the Gardiner fault — and there is no real evidence — an early uplifted block clearly extends far into the northeastern part of the park east of the Gardiner fault (fig. 23). A similar uplifted block east of the Buffalo Fork thrust (fig. 23; Love, 1961, p. 1751) dominates the southeastern part of the park. The eastern part of the park is, therefore, primarily an area of mountain blocks that were uplifted on steep reverse faults in early Tertiary time. Such high-angle reverse faults are typical structural features of the Middle Rocky Mountains tectonic province. (See Foose and others, 1961, p. 1148.) The northwest-trending boundary between the vertical uplifts and the folded and thrust-faulted rocks of southwestern Montana must

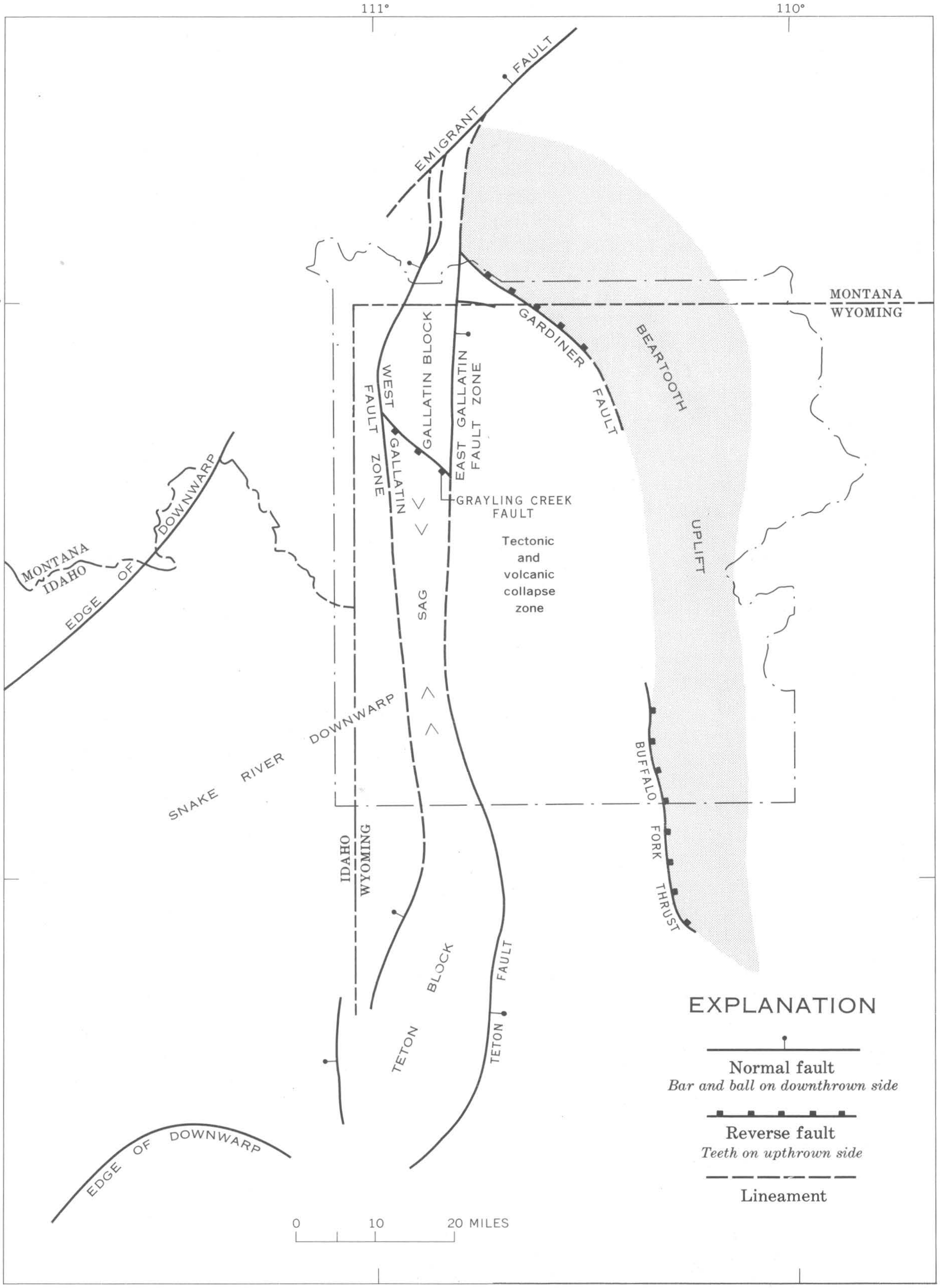


FIGURE 23. — Suggested relations of regional tectonic features near Yellowstone National Park.

originally — after early Tertiary deformation — have passed west of the present Gallatin Range and through the western part of the area that now is Yellowstone National Park. Thus, throughout most of early and middle Tertiary time, the Yellowstone region was dominated by northwest-trending fault blocks, such as those now partly preserved, from the uplifted block south of Grayling Creek fault, across the older Gallatin anticline (a depressed block between the Grayling Creek and Gardiner reverse faults) to the uplifted Beartooth block east of the Gardiner fault.

In later Tertiary time the structurally depressed Gallatin block was uplifted between the north-trending East and West Gallatin faults to form the present mountain range. The East and West Gallatin faults may continue northward to merge into the Emigrant fault, but their exact relation to that fault is not certain, for most of the area between the north boundary of Yellowstone National Park and that part of the Yellowstone River valley controlled by the Emigrant fault has been mapped only in reconnaissance (fig. 21). Pardee (1950, p. 377–379) described the Emigrant fault as a very steep normal fault along which the block west of the fault has been downdropped at least 5,000 feet; Horberg (1940, p. 293) dated this movement as principally late Tertiary. The Emigrant fault breaks the uplifted Beartooth block, and apparently extends southwest to control the lower part of the valley of Tom Miner Creek, which is cut largely in lower Tertiary volcanic rocks. Reconnaissance mapping (fig. 21) suggests that the Emigrant fault merges in that locality with the West Gallatin fault: it does not seem to extend farther west to the crest of the Gallatin Range, and it has no counterpart or possible extension near the Gallatin River (Witkind, 1964; Hall, 1961). In terms of the regional tectonic framework of southwestern Montana, the northeast-trending, very steep Emigrant fault is as anomalous as the fault-bounded Gallatin Range, which has almost no structural elements in common with those in the Madison Range a few miles farther west (Witkind, 1969; Hall, 1961) and which has nothing in common with the basin-ranges of southwestern Montana. In terms of the known tectonic framework of adjacent southwestern Montana, the Gallatin Range and the Emigrant fault are unique.

But if the structural elements in the Gallatin Range and the Emigrant fault are not related to the tectonic framework in adjacent areas in Montana, they seem to be nearly duplicated in and south of the Teton Range, south of Yellowstone National Park (fig. 23). Also, there is at least a suggestion, in lineaments, that the East and West Gallatin faults are continuations of the faults that are known to bound the late Tertiary uplifted Teton block on the east and that may bound part or all of it on the west. The symmetry and similarity in structural pattern, the suggested structural continuity between the Gallatin and Teton uplifted blocks, and the apparently synchronous development of most of the structural features suggest a common cause. I suggest that this cause is to be found in the development of the Snake River downwarp, which separates the structurally similar Gallatin and Teton blocks, and which is about the same age as these blocks.

The Snake River downwarp in eastern Idaho is a northeast-trending depression, of unknown origin and filled with volcanic rocks, that extends at right angles across the folded and thrust-faulted rocks of east-central and southeastern Idaho and southwestern Montana to end at the margin of the Middle Rocky Mountains block uplifts in Yellowstone National Park. The downwarp was named, and its time of origin discussed, by Kirkham (1927, 1931), who believed it to be a downward flexure of the crust because the flanking mountain ranges in Idaho and Montana plunge smoothly beneath the lavas that fill the depression. Hamilton (1963, p. 785), on the other hand, suggested that the depression results from tensional rifting or thinning of the crust in the lee of a northwestward-drifting Idaho batholith block; Christiansen and Blank (1969) suggested, further, that a series of rhyolitic caldera complexes developed successively northeastward in the opening rift. The upwarps, however, that Kirkham (1931) showed flanking the Snake River downwarp would seem to argue against tensional thinning and to support Kirkham's (1927, 1931) original concept of a downward flexure. At any rate, in the absence of any study more definitive than Kirkham's (1927, 1931), his term Snake River downwarp still is appropriate for the northeast-trending eastern half of this great but little-known tectonic feature. The nature of the forces that formed the downwarp is unknown, but the lava-filled depression itself is evidence of an effective downward resolution of forces, whatever their ultimate origin.

The development of the Snake River downwarp in late Tertiary time and the apparently synchronous development of the structurally unique Gallatin and Teton blocks in a symmetrical relation on opposite sides of the downwarp suggest that the tectonic events resulted from a common cause — the intersection of the Snake River downwarp and the reverse-fault-bounded block uplifts of the Middle Rocky Mountains in Yellowstone National Park. The net

effect of the forces of relative uplift on the east end of the downwarp appears to have been a splitting of the downwarp (fig. 23), with strands extending northeast, to form the downdropped block west and northwest of the Gallatin Range in Yellowstone National Park, and southeast to form the depressed block west and southwest of the Teton Range. The axial part of the downwarp may extend, too, in abbreviated form, into the central part of the park to cause a structural sag between the uplifted Gallatin and Teton blocks and tectonic fragmentation in this terminal part of the Snake River downwarp.

A thick sequence of rhyolitic rocks now blankets the central part of the park. The tremendous volume of magma erupted in that area led to volcanic collapse (Boyd, 1961, p. 412) and to the development of two large resurgent calderas (R. L. Christiansen and H. R. Blank, written commun., 1969). The faults that I suggest to be continuous across the park from the Teton Range to the Gallatin Range are buried by these upper Cenozoic rhyolitic rocks; their presence beneath the rhyolitic blanket is suggested by lineaments that perhaps reflect minor movements at depth on the faults and a shattering in the overlying rhyolite. Mapping in the central part of the park by R. L. Christiansen (oral commun., 1969), however, showed that the north-trending faults do not cut the rhyolite there.

In this view, then, many of the structural, volcanic, and thermal features of Yellowstone National Park owe their origin to the intersection of two major tectonic provinces — the Snake River downwarp and the Middle Rocky Mountains province of block uplifts. The hypothesis implies that the rhyolitic rocks in the central part of Yellowstone National Park blanket an area of earlier tectonic fragmentation and collapse and a terrane of faulted blocks of pre-Tertiary metamorphic and sedimentary rocks and lower Tertiary volcanic rocks, as was suggested by Howard (1937). The pattern of lineaments in the central part of the park suggests that the faults bounding such blocks still exist beneath the rhyolite blanket, and the lineaments themselves are the locus of many areas of thermal activity, suggesting that prerhyolite faults now provide the main channels through which hot solutions rise to the surface.

STRATIGRAPHIC SECTIONS

Section measured from top of Three Forks Formation to base of Pilgrim Limestone on northeast spur of Three Rivers Peak, Gallatin Range, Yellowstone National Park, Wyo.

	Thickness (feet)
Lodgepole Limestone:	
62. Limestone, medium-gray, medium-light-gray-weathering, fine-grained, fossiliferous; contains abundant medium-dark-gray chert in nodules as much as 0.2 ft thick and 0.1–3 ft long; in beds 0.2–0.5 ft thick	Not measured
Three Forks Formation (reference section):	
61. Dolomite, light-olive-gray, grayish-orange- or light-gray-weathering, very fine grained; in beds 0.1–0.2 ft thick. Lower part of unit strongly sheared and crumpled	48.2
60. Mudstone, light-olive, pale-orange- to grayish-orange-weathering	4.0
59. Dolomite; similar to unit 61	2.0
58. Mudstone; similar to unit 60; about 5 percent of unit is dolomite similar to unit 61; in interbeds 0.1–0.5 ft thick	22.0
57. Dolomite; similar to unit 61; in beds 0.3–0.5 ft thick	4.0
Total thickness, Three Forks Formation	80.2
Jefferson Formation (reference section):	
56. Dolomite, pale-yellowish-brown to brownish-gray, yellowish-gray- to light-olive-gray-weathering, very fine grained, massive	31.0
55. Shale, greenish-gray, fissile, papery	3.0
54. Dolomite, pale-yellowish-brown, grayish-orange-weathering, extremely fine grained, and dolomitic siltstone that is very pale yellowish brown, grayish orange weathering, and thinly platy	3.0
53. Sill; not measured	......
52. Dolomite, medium-dark-gray, medium-gray-weathering, fine-grained, sugary, fetid; faintly mottled medium light gray; laminated in some places	5.0
51. Dolomite and interbedded silty dolomite; dolomite is medium gray; weathers pale grayish orange to light-olive-gray; is extremely fine grained; has brittle blocky fracture; in crinkly beds 0.5–2.0 ft thick; some beds thinly laminated (0.1 mm); forms cliffy outcrop. Silty dolomite is very pale yellowish brown; weathers grayish orange; is thinly platy; grades into dolomitic siltstone	11.0
50. Sill; not measured	......
49. Dolomite, brownish-gray, dark-yellowish-brown- to pale-yellowish-brown-weathering, fine-grained (0.1 mm), sugary, fetid; in beds 0.1–3.0 ft thick; laminated in places. Uppermost 0.8 ft of unit bleached by sill	5.8
48. Dolomite; similar to dolomite in unit 51	17.5
47. Dolomite and interbedded dolomitic siltstone; dolomite is brownish gray; weathers grayish orange; is extremely fine grained; blocky weathering. Dolomitic siltstone is very pale yellowish brown; weathers grayish orange; is thinly platy	6.3
46. Dolomite; similar to unit 49	6.6
45. Dolomite and dolomitic siltstone; similar to unit 47; middle of unit includes 1.0-ft-thick bed of dolomite similar to unit 49	7.0
44. Dolomite; similar to unit 49; thinly laminated	1.5
43. Dolomite and dolomitic siltstone; similar to unit 47	6.5
42. Dolomite; similar to unit 49; massive; contains abundant stromatoporoids	13.0
41. Dolomite, brownish-gray, grayish-orange-weathering, extremely fine grained, blocky weathering	2.9

	Thickness (feet)
Jefferson Formation—Continued	
40. Siltstone, dolomitic, very pale yellowish brown, grayish-orange-weathering, thinly platy	3.5
39. Dolomite; similar to unit 49; becomes massive in upper half of unit; includes a few lighter colored beds of intraformational breccia	63.0
38. Dolomite, yellowish-brown and grayish-brown, pale-yellowish-brown- to light-gray-weathering, extremely fine grained; in beds 0.2–0.5 ft thick; laminated, blocky weathering; forms ledge	20.9
37. Dolomite, medium-dark-gray, brownish-gray-weathering, fetid; in beds 2.0–3.0 ft thick; laminated. Interbedded dolomite similar to unit 38. Unit includes a few thin beds of solution breccia	10.0
36. Limestone, dark-gray, medium-gray-weathering, extremely fine grained; contains fossil fragments	2.5
35. Dolomite, medium-gray; weathers light gray to very pale yellowish brown; very fine grained; in beds 0.5–1.0 ft thick; laminated	9.0
34. Limestone; similar to unit 36	1.0
33. Dolomite; similar to unit 35	1.0
32. Dolomite, pale-brown to brownish-gray; weathers same color; fine grained, sugary; in beds 1.5–3.0 ft thick; partly laminated. Unit is massive appearing; contains small horn corals and stromatoporoids	9.9
31. Dolomite, light-gray and medium-gray; weathers same color; in beds 0.1–0.5 ft thick; thinly laminated	2.9
Total measured thickness, Jefferson Formation	243.8
Bighorn Dolomite (reference section):	
30. Dolomite, light-brownish-gray; weathers very pale yellowish brown to light gray; extremely fine grained (< 0.1 mm); in beds 3.0 ft thick to massive; hackly weathering; contains large receptaculitids typical of Bighorn Dolomite (R. J. Ross, written commun., 1969)	28.0
29. Dolomite; similar to unit 30, but beds are 0.1–0.3 ft thick and laminated (0.1 mm); platy weathering; contains medium-light-gray to yellowish-orange chert in lenses 0.05–0.1 ft thick and 1.0–5.0 ft long. Dolomite in middle 20 ft of unit is medium gray; weathers medium light gray to light gray, but is otherwise similar to rest of unit	75.0
Total thickness, Bighorn Dolomite	103.0
Snowy Range Formation (reference section):	
Grove Creek Member:	
28. Dolomite, light-brownish-gray, fine-grained, fetid; upper part of unit contains lenses, 0.1 ft thick and as much as 1.0 ft long, of sandstone that contains fragments of brachiopods and trilobites not identifiable, but suggesting Cambrian age (A. R. Palmer, written commun., 1969)	10.0
27. Dolomite, light-brownish-gray, very fine grained; in beds 0.1–0.3 ft thick; irregularly bedded; upper half of unit is dolomitic limestone; includes 5-ft-thick unit of massive dolomite composed of vertical algal columns	17.0
26. Limestone, light-gray; weathers same color; very fine grained, ribboned; similar to unit 24; contains *Billingsella* fragments (A. R. Palmer, written commun., 1969)	1.0
25. Dolomite, light-brownish-gray, very fine grained; in beds 0.1–0.3 ft thick; irregularly bedded. Unit forms base of cliff	11.6
Total thickness, Grove Creek Member	39.6
Sage Limestone Member:	
24. Limestone, medium-gray, medium-light-gray-weathering, very fine grained, laminated; irregularly ribboned with grayish-orange to dark-yellowish-orange very fine grained sandy limestone and calcareous sandstone; in beds 1.0–1.5 ft thick. And alternating interbeds, 1.5–3.0 ft thick, of similar rocks that are mottled, rather than ribboned. Upper 9.0 ft of unit is massive mottled limestone. Locally coquinoid; contains silicified *Billingsella*, dolomoldic siliceous steinkerns of a moderately large *Pelagiella*, and a moderately high spired sinistral gastropod that could be *Scaevogyra* (A. R. Palmer, written commun., 1967)	31.0
23. Limestone; similar to ribboned rocks of unit 24; platy weathering; forms ledge. Bedding surfaces of upper beds contain abundant chitinous brachiopods. Unit contains assemblage of fossils from *Taenicephalus* zone, including *T. shumardi* (Hall), *Maustonia nasuta* (Hall), *Angulotreta* sp., *Pelagiella* and *Billingsella* (A. R. Palmer, written commun., 1967)	13.1
Total thickness, Sage Limestone Member	44.1
Dry Creek Shale Member:	
22. Shale, greenish-gray to light-olive-gray, papery	0.8
21. Limestone, medium-gray, medium-light-gray-weathering, very fine grained to aphanitic, sandy; in irregular beds 0.1–0.2 ft thick; includes thin beds of flat-pebble conglomerate	2.0
20. Shale; similar to unit 22	4.0
19. Limestone, medium-light-gray, light-gray-weathering, oolitic; coquinoid (contains trilobite fragments); glauconitic; contains moderately abundant limestone chips	2.6
18. Concealed; underlain by interbedded greenish-gray to light-olive-gray paper-thin shale and less common thin beds of light-olive-gray very fine grained calcareous sandstone. Base of unit is marked by 1.0-ft-thick bed of yellowish-orange to yellowish-brown very fine grained thinly platy calcareous sandstone	31.2
Total thickness, Dry Creek Shale Member	40.6
Total thickness, Snowy Range Formation	124.3

		Thickness (feet)
Pilgrim Limestone (reference section):		
17.	Limestone, medium-gray; weathers mottled medium gray to medium light gray and yellowish gray, pale yellowish brown, and light olive gray; fine to medium grained, oolitic, massive; forms prominent ledge	44.0
16.	Concealed; underlain mainly by limestone flat-pebble conglomerate that is medium gray; weathers medium light gray; medium to coarse grained and glauconitic; contains abundant fossil fragments and a few beds marked by silty ribbons. Center of unit includes 10.0-ft-thick bed of medium-gray light-gray-weathering very fine grained to aphanitic limestone. Top 6 ft of unit is light-gray very fine grained limestone, irregularly mottled with pale-yellowish-orange silty limestone	60.0
15.	Limestone, medium-gray, medium-light-gray-weathering, very fine grained; ribboned with medium-gray limestone that weathers moderate yellowish brown to grayish orange and contains abundant very fine sand and silt in irregular layers and seams 0.01–0.1 ft thick. Beds 0.2–0.5 ft thick. Includes interbedded oolitic limestone that is medium gray; weathers same color; is glauconitic; contains abundant trilobite fragments; in beds 0.3–1.0 ft thick	14.7
14.	Limestone, oolitic; similar to oolitic rocks in unit 15; in beds 0.3–3.0 ft thick	10.6
13.	Limestone flat-pebble conglomerate; similar to that in unit 16	.3
12.	Shale, light-olive-gray, fissile	.2
11.	Limestone, oolitic; similar to unit 14	1.3
10.	Limestone and interbedded oolitic flat-pebble conglomerate and ribboned rocks; similar to rocks in units 15 and 16	1.7
9.	Limestone, ribboned; similar to ribboned limestone in unit 15	3.9
8.	Limestone flat-pebble conglomerate; similar to unit 16	1.7
7.	Limestone, oolitic, medium-gray; weathers same color; contains moderately abundant layers of flat-pebble conglomerate as much as 0.1 ft thick; glauconitic, fossiliferous	4.4
6.	Concealed; underlain by ribboned limestone similar to that of unit 15	6.0
5.	Hornfels, greenish-gray to grayish-green; weathers same color; contains abundant lenses, as much as 0.1 ft thick and 0.1–0.3 ft long, of greenish-gray relict limestone that weathers very light gray	18.0
4.	Sill; not measured	....
3.	Hornfels; similar to that of unit 5. Upper part of unit includes a few thin interbeds of chippy medium-dark-gray argillite. Lower part of unit contains cordierite	40.0
	Total measured thickness, Pilgrim Limestone	206.8
Park Shale:		
2.	Shale, medium-dark-gray, chippy metamorphosed	5.0
Sill:		
1.	Indian Creek laccolith; not measured	....
Base of section.		

Measured section of Madison Group on south face of Bannock Peak, southern Gallatin Range, Yellowstone National Park, Wyo.

[Measured by W. J. Mapel, A. E. Roberts, and E. K. Maughan in 1964]

		Thickness (feet)
Amsden Formation.		
Madison Group (reference section):		
Mission Canyon Limestone (reference section):		
Upper member:		
24.	Dolomite, brecciated and very well recemented, very light gray, finely crystalline, cliff-forming; massively bedded. Light color is very conspicuous. Scattered lenses of quartzose sandstone. A few feet of pale-green to yellow dolomitic siltstone near base, mostly covered	97
23.	Limestone, cherty, fine to coarsely crystalline; abundant veins and vugs of very granular white calcite. Unit forms rubbly slope	210
22.	Breccia, dolomite; angular to subangular yellowish-brown fragments, as much as 1 ft, set in matrix of medium-gray limestone. Unit massive to poorly bedded; forms very cavernous cliff	60
	Total thickness, upper member	367
Lower member:		
21.	Dolomite, light-olive-brown; medium to thick bedded in lower part; thinly laminated in upper part and containing algal structures. Generally forms rubbly slope	23
20.	Dolomite, dark-olive-brown; forms small massive cliff	5
19.	Limestone, laminated, cherty, yellowish-gray to brownish-gray; some low-angle cross-laminae and yellowish chert stringers. Generally forms slope	41
18.	Limestone, brownish-gray, light-medium-gray-weathering, coarsely crystalline, abundantly fossiliferous; numerous vugs, as much as 4 in. in diameter, filled with calcite crystals. Generally forms massive cliff	26
17.	Limestone, brownish- to yellowish-gray, fine to coarsely crystalline; commonly laminated with light- and dark-gray bands; cherty; less cherty and less laminated and more thin and medium beds upward. Forms rubbly slope	20
16.	Limestone, brownish- to medium-gray, very fossiliferous; corals about 40 feet from base; thick bedded to massive; generally forms cliff	80
15.	Limestone, massive to medium-bedded, light-gray, arenaceous, laminated, fine to coarsely crystalline	19
14.	Limestone, laminated, cherty, light-gray	10
13.	Limestone, massive to medium-bedded, grayish-white, coarsely to finely crystalline; highly porous with abundant pinpoint vugs. Upper two-thirds of unit is arenaceous limestone; yellowish- to olive-gray alternate laminae, locally penecontemporaneously deformed. Forms slope	35

	Thickness (feet)
Madison Group—Continued	
Mission Canyon Limestone—Continued	
Lower member—Continued	
12. Limestone; dolomitic in lower 5 ft; medium dark gray; weathers medium-gray; medium to thin bedded; moderately to abundantly fossiliferous, mostly crinoid trash, colonial and horn corals; forms prominent cliff with ledges about 10–12 ft apart	82
11. Dolomite, medium-olive-gray, dense to very fine grained; thin bedded and shattered by vertical fractures; includes pods of crinoid coquina. Forms prominent reentrant on face of cliff	4
10. Limestone, slightly dolomitic, abundantly fossiliferous; composed mostly of crinoid trash, similar to coquina of unit 11; olive brown; thick and massive bedded. Forms part of cliff	20
9. Dolomite, massive, very light gray, greenish-white-weathering, medium to coarsely crystalline; limy in upper part. Intermixed porous and nonporous zones; some low-angle cross-stratification; in a few places porosity seems to be bedding controlled; some stylolites; forms prominent massive cliff; only slightly fossiliferous; a few thin moderately fossiliferous zones	82
Total thickness, lower member	447
Total thickness, Mission Canyon Limestone (reference section)	814
Lodgepole Limestone (reference section):	
8. Limestone, thin-bedded, grayish-brown, silty; fossiliferous throughout; generally forms rubble slope. Sample collected 25 ft from top of unit contains *Zaphrentites* sp., *Homalophyllites* sp., and *Vesiculophyllum* sp. (W. J. Sando, written commun., 1968)	46
7. Limestone and siltstone interbedded; thin beds less than 1 ft thick. About two-thirds limestone, one-third siltstone; cross-laminated; fine to coarsely crystalline; coarse material is mostly crinoid trash. Limestone is blue gray; siltstone is yellowish gray. Limestone is arenaceous. Basal 3–5 ft generally poorly exposed and forms slope, but most beds can be seen. Most of unit forms series of thin ledges. Silt gradually decreases upward	110
6. Limestone; almost coquina of crinoids and other fossiliferous trash; abundant brachiopods; scattered lenses of siltstone	2
5. Limestone, thin-bedded; fine to coarsely crystalline, coarse is mostly crinoid trash; fossiliferous, brownish gray; weathers yellowish gray. Slope poorly exposed	9
4. Limestone, fine to coarsely crystalline, fossiliferous; abundant crinoid trash; brownish gray; light gray weathering; some thin and some massive beds, but mostly medium to thick beds. Mostly cliff forming, but with a talus slope at base	60
3. Limestone, coarse to finely crystalline, grayish-brown. Abundant crinoid trash in many beds. Thin to medium bedded, with very thin siltstone partings	22
2. Limestone, cherty, medium-gray, medium-light-gray-weathering, very finely crystalline. Chert is medium gray; forms irregular nodules and lenses; weathers brownish gray; mostly thin, some medium bedded. Very thin siltstone partings. Forms cliff	125
1. Limestone, mostly covered, sandy, coarsely crystalline, pale-yellowish-brown to medium-light-gray; abundant crinoid columnals; thinly bedded to laminated; weathers to slope, generally talus covered	112
Total thickness, Lodgepole Limestone (reference section)	486
Total thickness, Madison Group (reference section)	1,300

Three Forks Formation.

Measured section of lower member of Cody Shale and Frontier Sandstone, Mount Everts, opposite Sheepeater Canyon Bridge, Yellowstone National Park, Wyo.

	Approximate thickness (feet)
Cody Shale:	
Lower member:	
17. Largely concealed; forms smooth slope underlain by interbedded shale, mudstone, siltstone, and sandstone. Shale is medium dark gray, papery. Mudstone and siltstone are medium dark gray to light olive gray. Sandstone is light olive gray to medium dark gray, very fine grained, and speckled with abundant heavy mineral grains; partly calcareous; platy weathering; in beds 1–4 ft thick. Unit is fossiliferous and contains numerous dark-yellowish-brown calcareous nodules	200
16. Shale, medium-dark-gray, papery	15
15. Siltstone, light-brown to dark-yellowish-brown, nodular, ocherous	3
14. Shale, medium-gray, papery; contains abundant veinlets of white calcite and gypsum	15
13. Sandstone, medium-gray to yellowish-gray, fine-grained, biotitic, glauconitic, platy, and interbedded dark-gray shale	35
12. Shale, dark-gray, papery to pencilly	20
11. Sandstone, yellowish-gray to light-olive-gray, very fine grained; contains abundant heavy minerals; glauconitic; contains abundant brown calcareous nodules; in beds 1.0 ft thick; platy weathering. Beds separated by partings of dark-gray shale	15
10. Shale, yellowish-gray to very light gray, bentonitic, papery to chippy	5

	Approximate thickness (feet)
Cody Shale—Continued	
Lower member—Continued	
9. Sandstone, medium-light-gray, very fine grained; speckled with heavy minerals; in beds 1–2 ft thick	5
8. Siltstone and mudstone, pale-yellowish-gray, bentonitic. Unit includes a few thin beds of very fine grained quartzite	12
7. Siltstone and shale, grayish-red to very dusky purple; nodular-weathering beds 0.1–0.2 ft thick	10
6. Siltstone and mudstone; similar to unit 8	20
5. Siltstone, mudstone, and shale; similar to unit 7. Upper 4 ft of unit is blocky and siliceous	16
Approximate thickness, lower member of Cody Shale	371
Frontier Sandstone:	
4. Sandstone, medium-gray to grayish-purple to pale-yellowish-brown, fine-grained to very fine grained; in beds 1–5 ft thick; partly glauconitic; and interbedded dark-gray shale	20
3. Sandstone, yellowish-gray to light-olive-gray, very fine grained to fine-grained; speckled with abundant heavy minerals; cross-laminated; partly calcareous; in beds 2–5 ft thick; beds commonly marked by worm trails and borings; beds separated by 0.1- to 0.2-ft-thick partings of dark-gray papery shale. Top of unit platy weathering	25
Approximate thickness, Frontier Sandstone	45
Mowry Shale:	
2. Sandstone, medium-dark- to medium-light-gray, very fine grained; speckled with heavy minerals; in beds 0.1–0.2 ft thick; and medium-dark-gray fissile shale, in beds 0.1–0.2 ft thick	10
1. Mudstone and shale, medium- to medium-dark-gray, fissile to platy, and interbeds, 0.2–2.0 ft thick, of medium-dark-gray siltstone and very fine grained sandstone; underlies smooth dark-colored slope ....about	200
Base of section.	

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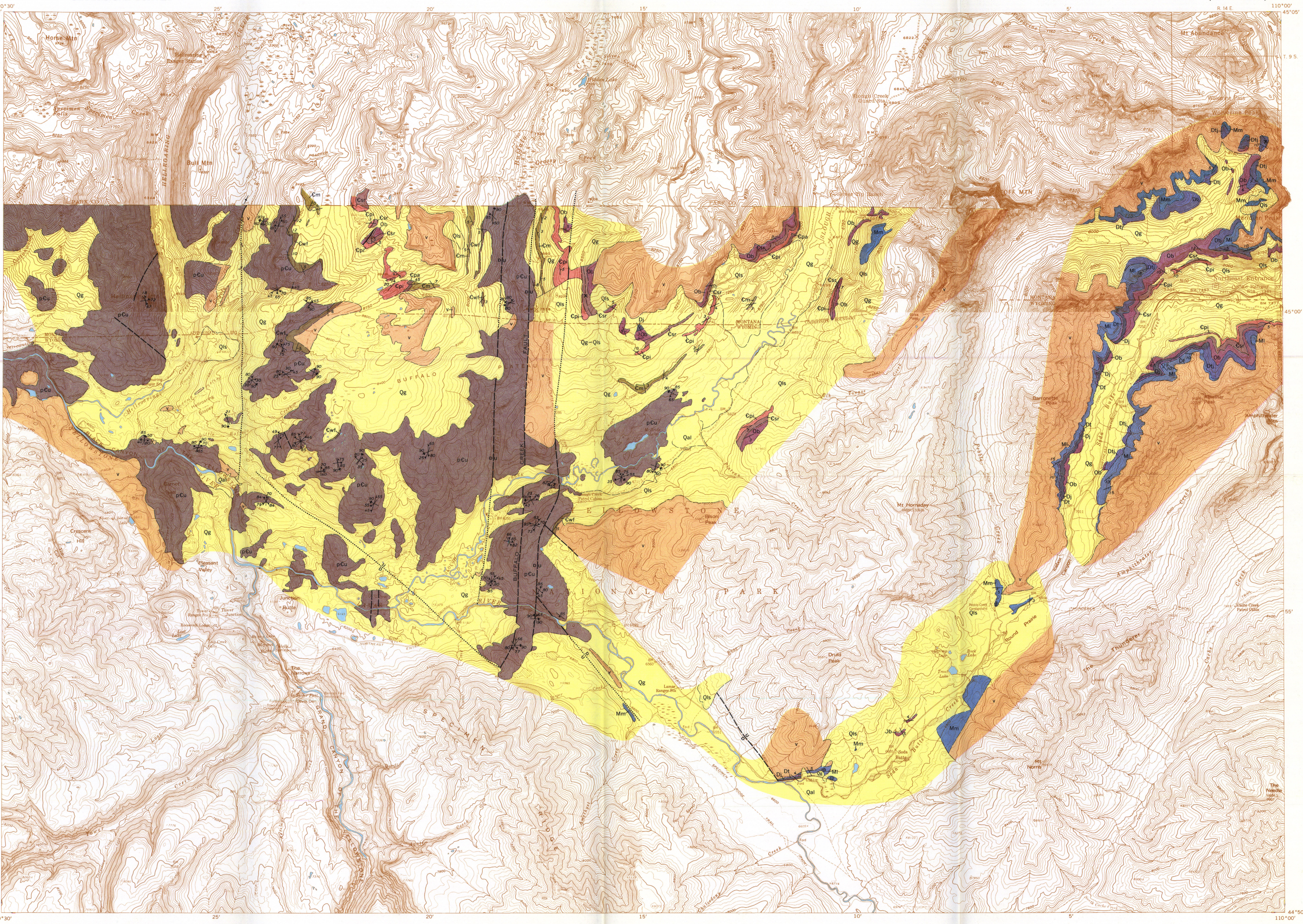
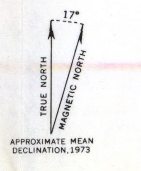




SCALE 1:62 500

1 ½ 0 1 2 3 4 MILES

1 .5 0 1 2 3 4 KILOMETERS

CONTOUR INTERVALS 40, 50, AND 80 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

QUATERNARY

Holocene

Qal | Qt | Qa | Qls | Qrs | Qc

Surficial deposits

Qal, *alluvial deposits of silt, sand, gravel, cobbles, and boulders*
Qt, *talus; angular fragments of waste rock fringing cliffs*
Qa, *avalanche deposits; angular fragments of waste rock from source area of avalanche*
Qls, *landslide deposits; angular fragments of waste rock from source area of slide; characterized by irregular hummocky topography*
Qrs, *rock streams; angular fragments of waste rock forming lobes characterized by flow wrinkles*
Qc, *colluvial deposits*

Pleistocene and Holocene

Qg

Glacial deposits

Chiefly till in cirques and glaciated valleys. Unsorted mixture of material ranging from clay to boulders; includes both young fresh undissected moraines and older moraines that are rounded and dissected

TERTIARY

Eocene

Tgd

Granodiorite and related rocks of Electric Peak stock

In complex stock; rocks are medium gray to medium dark gray, fine to medium grained, composed of different proportions of plagioclase (andesine to bytownite), quartz, potassium feldspar, biotite, hornblende, and augite

Eocene(?)

Tl

Lamprophyre of Bighorn Pass sheet

Dark-gray, fine-grained; consists of automorphic granular aggregate of potassium feldspar, plagioclase (An_{55-60}), quartz, biotite, diopside, magnetite, apatite, and alteration products; mafic minerals occur as phenocrysts

Paleocene

Trd

Porphyry laccoliths and sills

Biotite rhyodacite porphyry and biotite-quartz latite porphyry, medium-light-gray to light-gray, fine to very fine grained, porphyritic; contain abundant phenocrysts of plagioclase (An_{30-50}), biotite, and hornblende in a microcrystalline groundmass that is felted or trachytic and composed of minute crystals of plagioclase and commonly micropoikilitic quartz surrounded by products of deuteric alteration

Tqm

Biotite quartz monzonite of Mount Holmes stock

Light to very light gray, fine-grained, hypautomorphic porphyritic. Marginal zone (shown by dotted pattern) includes both very fine grained granoblastic quartz monzonite that is a hornfelsic chilled zone and quartz-feldspar hornfels derived from the Flathead Sandstone and Wolsey Shale that form the roof of the stock

CRETACEOUS

Upper Cretaceous

Kl

Landslide Creek Formation

Sandstone and conglomerate, greenish-gray, poorly sorted; composed mainly of fragments of andesitic volcanic rocks. Thickness not known

UNCONFORMITY

Kev

Everts Formation

Sandstone, light- to medium-gray, fine- to medium-grained, thin-bedded, tuffaceous and calcareous; interbedded dark- to olive-gray chippy shale, mudstone, and siltstone. Thickness about 1,200 feet

UNCONFORMITY

Ke

Eagle Sandstone

Sandstone, light- to medium-gray, fine- to medium-grained, thin- to thick-bedded, calcareous; interbedded dark-gray carbonaceous shale, in beds a few feet thick, and thin lenticular coal. Basal 160 feet, the Virgelle Sandstone Member, is medium-light-gray fine-grained thick-bedded to massive arkosic sandstone. Thickness about 800 feet

Ktc

Telegraph Creek Formation

Sandstone, brownish- to medium-light-gray, fine to very fine grained, thin-bedded, calcareous; interbedded, medium-gray platy mudstone and shale. Gradational into overlying and underlying formations. Thickness about 300 feet

Kc

Cody Shale

Upper shale member: medium- to dark-gray platy to chippy mudstone and shale; interbedded dark-greenish- to brownish-gray very fine grained sandstone and siltstone. Thickness about 800 feet
Middle sandstone member: yellowish- to brownish-gray very fine grained medium-bedded glauconitic sandstone; interbedded dark-gray shale. Thickness about 50 feet
Lower shale member: medium- to dark-gray and yellowish-gray shale and mudstone; interbedded, similarly colored siltstone and fine-grained sandstone. Thickness 350–400 feet

Kf

Frontier Sandstone

Sandstone, yellowish- and light-olive-gray to medium-gray, fine-grained, partly calcareous, partly tuffaceous; in beds 1–5 feet thick separated by thin interbeds of dark-gray shale. Thickness about 50–100 feet

Lower Cretaceous

Km

Mowry Shale

Shale, medium- to dark-gray, chippy to pencilly; a few interbeds of olive-gray fine- to medium-grained sandstone and of light-gray bentonite. Thickness about 300 feet

Kt

Thermopolis Shale

Upper sandstone member: yellowish-gray to grayish-brown fine-grained calcareous, partly glauconitic feldspathic sandstone; interbedded dark-gray chippy shale and mudstone. Thickness about 100 feet
Middle shale member: dark-gray very fissile shale; a few thin interbeds of olive-gray fine-grained sandstone. Thickness about 300 feet
Lower sandstone member: medium-light- to yellowish-gray fine-grained medium- to thick-bedded sandstone; interbedded medium-dark-gray shale and siltstone. Thickness 75–100 feet

Kk

Kootenai Formation

Mainly shale and mudstone, medium-dark-gray and grayish-red; a few thin interbeds of light-gray limestone and sandstone; medium- to light-gray "gastropod limestone," 20–30 feet thick, near top; massive chert pebble conglomerate and quartz-chert sandstone unit 20–50 feet thick at base. Thickness 250–300 feet

UNCONFORMITY

JURASSIC

Upper Jurassic

Jm

Morrison Formation

Shale, mudstone, and siltstone, grayish-red, dark-gray, and grayish-green; interbedded yellowish-brown to light-gray fine to very fine grained sandstone in lenticular beds as much as 3 feet thick, and, in upper and basal parts, olive- and medium-light-gray limestone. Thickness about 200 feet

Middle and Upper Jurassic

Je

Ellis Group

Swift Formation: calcareous sandstone and sandy limestone, pale-yellowish-brown to light-olive-gray, medium-grained, glauconitic, oolitic, locally coquinoid. Thickness 15–60 feet
Rierdon Formation: shale, mudstone, and siltstone, pale-red to medium-gray, calcareous; a few beds less than 0.5 foot thick of medium- to light-gray partly oolitic limestone. Base marked by 1- to 6-foot-thick bed of medium-gray fine-grained oolitic limestone. Thickness 40–60 feet
Sawtooth Formation:
Upper red-bed member: pale- to grayish-red siltstone, mudstone, and shale. Thickness 25–40 feet
Middle limestone member: medium-light- to medium-dark-gray very fine grained chippy fossiliferous limestone in 0.1- to 1.0-foot-thick beds; interbedded dark-gray shale. Thickness 60–75 feet
Lower red-bed member: grayish-red and grayish-green siltstone, mudstone, and shale. Thickness 20–30 feet

UNCONFORMITY

TRIASSIC

Lower Triassic

TRtd

Thaynes(?), Woodside, and Dinwoody Formations

Thaynes(?) Formation: light-gray fine-grained calcareous sandstone in beds 0.2–5 feet thick. Thickness 0–50 feet
Woodside Formation: grayish-red to reddish-brown shale, mudstone, siltstone, and micaceous sandstone, in beds 1–5 feet thick; lower part and some interbeds are greenish-gray shale. Thickness 75–100 feet
Dinwoody Formation: light- to yellowish-gray very fine grained thin-bedded limestone; weathers near pale brown. Thickness 0–50 feet

PERMIAN

Ps

Shedhorn Sandstone

Upper sandstone and dolomite: medium- to light-gray fine to very fine grained sandstone and medium-light- to brownish-gray fine-grained siliceous dolomite; beds 0.1–0.5 foot thick. Thickness about 30 feet
Middle chert and sandstone: brownish-gray to grayish-yellow phosphatic chert and cherty phosphatic glauconitic sandstone; beds 0.1–1.0 foot thick. Thickness about 30 feet
Lower phosphatic sandstone: medium- to yellowish-gray fine-grained slightly calcareous sandstone containing as much as 50 percent phosphatic oolites and pellets; beds 0.1–3.0 feet thick; basal part includes 10 feet of yellowish-gray shale. Thickness about 60 feet

UNCONFORMITY

PENNSYLVANIAN

Middle Pennsylvanian

IPq

Quadrant Sandstone

Sandstone and quartzitic sandstone, yellowish-brown to very light gray, fine-grained, in beds 0.5–8 feet thick; interbeds, commonly less than 1 foot thick, of light-gray fine-grained dolomite in upper half and basal part. Thickness 300–325 feet

UNCONFORMITY

Lower and Middle Pennsylvanian

IPa

Amsden Formation

Upper unit: grayish- and pale-red calcareous or dolomitic siltstone; a few thin interbeds of dolomite and shale. Thickness 0–30 feet; removed by erosion in some places
Lower unit: pale-red to yellowish-orange mudstone, siltstone, and shale; interbedded fine to very fine grained calcareous sandstone. Thickness 0–30 feet
Formation thickness typically 0–60 feet

MISSISSIPPIAN

Upper Mississippian
Lower Mississippian

Mm | Mmc | Ml

Madison Group

Mm, *Madison Group undivided*
Mmc, *Mission Canyon Limestone: medium-gray to pale-yellowish-brown fine- to coarse-grained limestone and dolomite in beds 1–5 feet thick or massive; nodules of brownish-gray chert common; massive dolomite at top and base. Thickness about 800 feet*
Ml, *Lodgepole Limestone: light-brownish- to medium-gray fine- to medium-grained limestone in beds 0.1–2.0 feet thick separated by partings and interbeds as thick as 0.2 foot of calcareous siltstone and silty limestone; contains abundant fossils; lower half locally contains abundant nodules and thin irregular beds of yellowish-brown to dark-gray chert. Thickness about 500–600 feet*

DEVONIAN

Upper Devonian

Dtj | Dt | Dj

Three Forks and Jefferson Formations

Dtj, *Three Forks and Jefferson Formations undivided*
Dt, *Three Forks Formation:*
Trident Member equivalent (in northeast part of park only): grayish-red and grayish-green calcareous mudstone and shale and interbedded light-gray fossiliferous limestone, grading downward into yellowish-brown to grayish-green mudstone and shale. Thickness about 50 feet
Logan Gulch Member equivalent:
In Gallatin Range: light-olive-gray very fine grained dolomite and silty dolomite, in beds 0.1–0.2 foot thick, in upper 15–30 feet; underlain by light-olive to yellowish-brown to dark-gray shale and mudstone in lower 20–25 feet. Thickness 40–50 feet
In northeast part of park: brecciated limestone and dolomite in upper 30 feet, underlain by light-olive to dark-gray shale and mudstone that includes interbeds less than 1 foot thick of yellowish-brown fine-grained limestone. Thickness 80 feet
Dj, *Jefferson Formation:*
In Gallatin Range: yellowish-brown to brownish-gray very fine grained massive dolomite 20 feet thick (equivalent to Birdbear Member), underlain by brownish- to light-gray (rarely dark-gray) very fine to fine-grained and sugary, partly fetid dolomite in beds 0.1–2.0 feet thick containing thin interbeds of yellowish-brown dolomitic siltstone and silty dolomite. Thickness 240 feet
In northeastern part of park: pale- and pale-yellowish-brown fine-grained sugary dolomite and dolomitic limestone in beds 0.2–4.0 feet thick. Thickness about 175 feet

UNCONFORMITY

ORDOVICIAN

Upper Ordovician

Ob

Bighorn Dolomite

Dolomite, light-brownish-gray, very fine to fine-grained, partly laminated; partly containing light-gray to yellowish-orange chert in lenses as long as 3 feet; in beds 0.1 foot thick to massive with massive units most common in upper part. Thickness 200–300 feet

UNCONFORMITY

CAMBRIAN

Upper Cambrian

Csr

Snowy Range Formation

Grove Creek Limestone Member: brownish-gray to yellowish-orange very fine to medium-grained dolomitic limestone, dolomite, and dusky-blue shale. Thickness 0–40 feet
Sage Limestone Member: pale-yellowish-brown to medium-gray very fine grained, partly glauconitic limestone, irregularly ribboned with grayish- or dark-yellowish-orange sandy limestone and dolomite; beds 0.1 foot to about 1 foot thick; includes as much as 2 feet of similarly colored mottled limestone; contains abundant fossils. Collenia magna bed at base only in north-central and northeast parts of park. Thickness 45–110 feet
Dry Creek Shale Member: greenish to light-olive-gray shale; interbeds less than 1 foot thick of very fine grained calcareous sandstone and siltstone and of grayish-yellow very fine grained oolitic limestone and limestone-pebble conglomerate at top; a 1-foot-thick bed of yellowish-brown platy calcareous siltstone or very fine grained sandstone at base in Gallatin Range. Thickness 40–50 feet
Formation thickness 110–200 feet

OCsp

Bighorn Dolomite, Snowy Range Formation, and Pilgrim Limestone undivided

Cpi

Pilgrim Limestone

Upper unit: medium-gray, mottled yellowish-gray and pale-yellowish-brown, largely oolitic fine- to medium-grained thick-bedded to massive limestone. Thickness 40–150 feet
Middle unit: medium-gray, mottled medium- to coarse-grained limestone containing abundant fossiliferous limestone pebble conglomerate. Thickness about 60 feet
Lower unit: medium-gray very fine grained limestone in beds 0.2–0.5 foot thick ribboned with grayish-orange silty limestone, interbedded with medium-gray oolitic glauconitic limestone in beds 0.2–2.0 feet thick; a few beds of limestone pebble conglomerate and grayish-green shale. Thickness 75–100 feet
Formation thickness 160–250 feet

Middle Cambrian

Cpk

Park Shale

Shale and mudstone, medium-to-dark-gray; upper part includes interbeds as much as 0.2 foot thick of yellowish-gray to grayish-green calcareous siltstone; lower part includes a few interbeds less than 0.5 foot thick of limestone coquina, glauconitic sandstone, and flat-pebble conglomerate. Thickness 100–150 feet

Cm

Meagher Limestone

Limestone, mottled medium-gray and dark-gray and yellowish-gray to grayish-orange, very fine to fine-grained; in beds 0.1–2.0 feet thick, separated by partings or thin interbeds of grayish-green shale. Thickness 175–888 feet

Cwf

Wolsey Shale and Flathead Sandstone

Wolsey Shale: greenish-gray micaceous and sandy shale; thin interbeds of argillaceous calcareous sandstone and siltstone and glauconitic sandy limestone; upper 20 feet gradational into overlying Meagher Limestone. Thickness 100–150 feet
Flathead Sandstone: yellowish-gray to grayish-orange-pink fine- to medium-grained quartzitic sandstone in beds 0.1–2.0 feet thick; partly laminated or cross-laminated; basal part includes poorly sorted sandstone and conglomerate. Thickness 100–160 feet

UNCONFORMITY

PRECAMBRIAN

p€u

Metamorphic rocks

Mainly granitic gneiss, medium-gray to moderate-orange-pink, medium to coarsely crystalline; composed of potassium feldspar, quartz, plagioclase, and biotite. Potassium feldspar locally forms porphyroblasts as much as 5 cm in length. Includes dark-gray to grayish-black amphibolite and light-gray to pale-red coarse-grained granite pegmatite. Partly medium- to medium-dark-gray fine-grained quartz biotite schist older than the gneiss, composed of quartz, biotite, and sparse potassium feldspar and plagioclase

v

Cenozoic volcanic rocks not mapped in this study

Contact

Dashed where approximately located or indefinite; dotted where concealed; K, *indicates formational boundary locally separated within larger mapped unit*

Fault

Dashed where approximately located or indefinite; dotted where concealed; queried where doubtful. U, *upthrown side;* D, *downthrown side*

Reverse fault

Dashed where approximately located or indefinite; dotted where concealed. R, *upthrown side*

Glide fault

Dashed where approximately located. Sawteeth on upper plate

Inclined — Horizontal — Overturned
Strike and dip of beds

Strike and dip of joints

Inclined — Vertical
Strike and dip of foliation

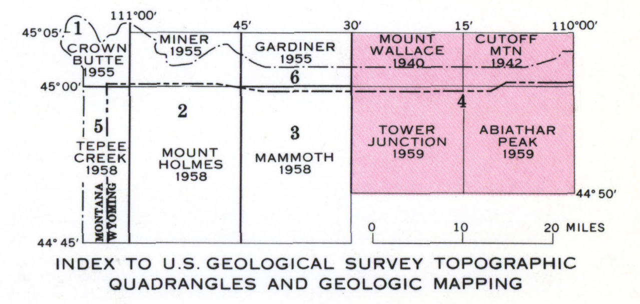
Anticline

Showing crestline. Dotted where concealed

Syncline

Showing crestline. Dotted where concealed

X
Limestone sink



INDEX TO U.S. GEOLOGICAL SURVEY TOPOGRAPHIC QUADRANGLES AND GEOLOGIC MAPPING

1. Geology mapped in 1967 by E. T. Ruppel, assisted by M. F. Gregorich.
2. Geology mapped in 1966–67 by E. T. Ruppel, assisted by R. B. Amonson, M. F. Gregorich, and G. M. Fairer.
3. Geology mapped in 1967–68 by E. T. Ruppel. Boundary of Precambrian rocks in northeast corner mapped in reconnaissance in 1967 by H. J. Prostka.
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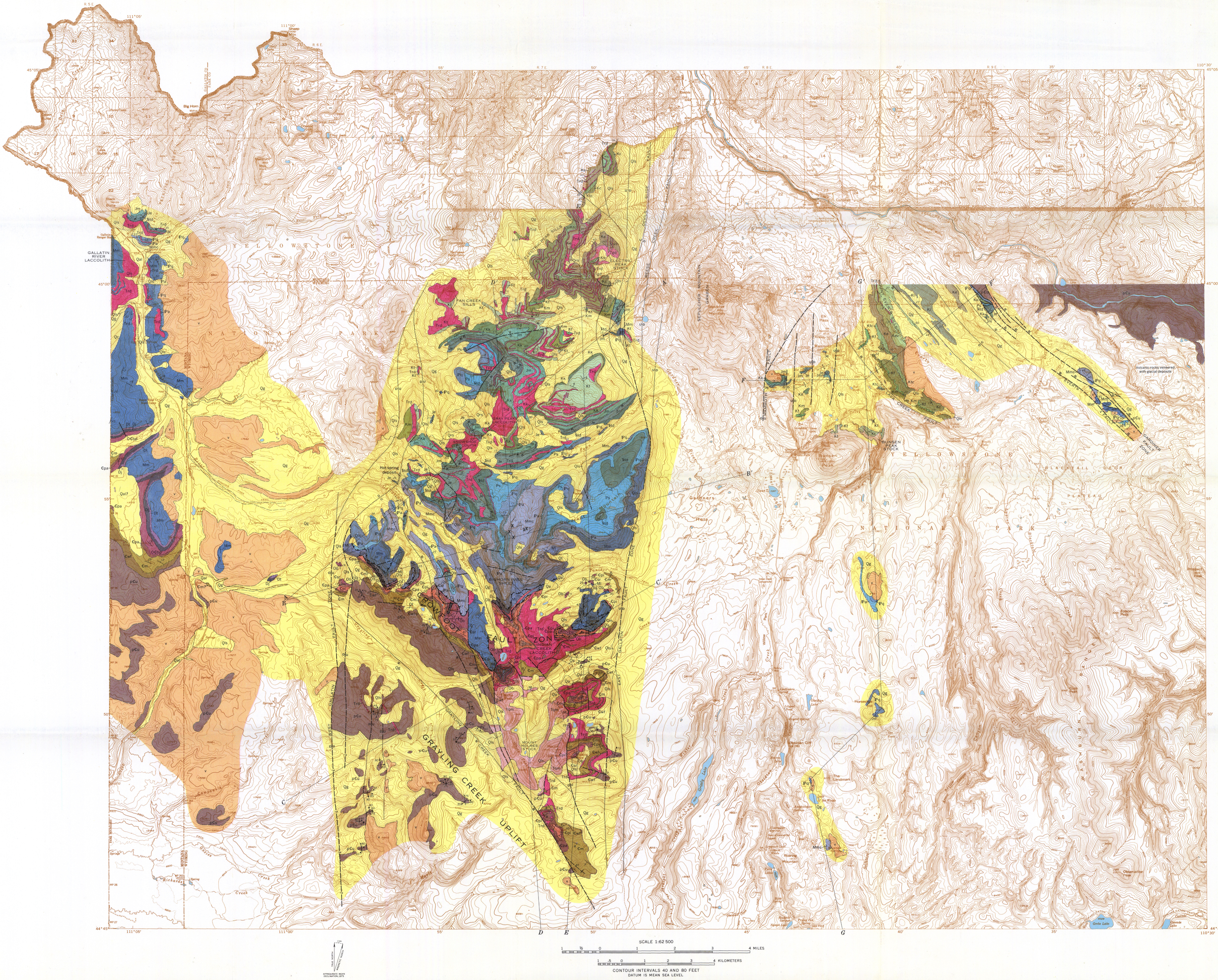
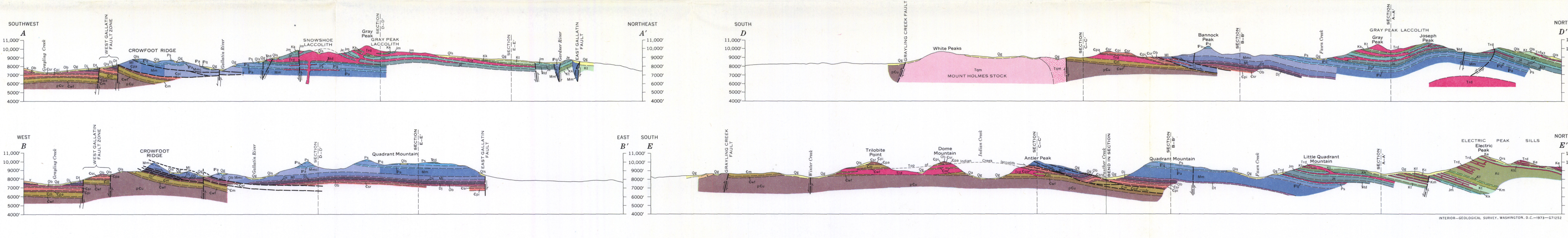
6. See map by Fraser, Waldrop, and Hyden (1969) for geology of Gardiner quadrangle.

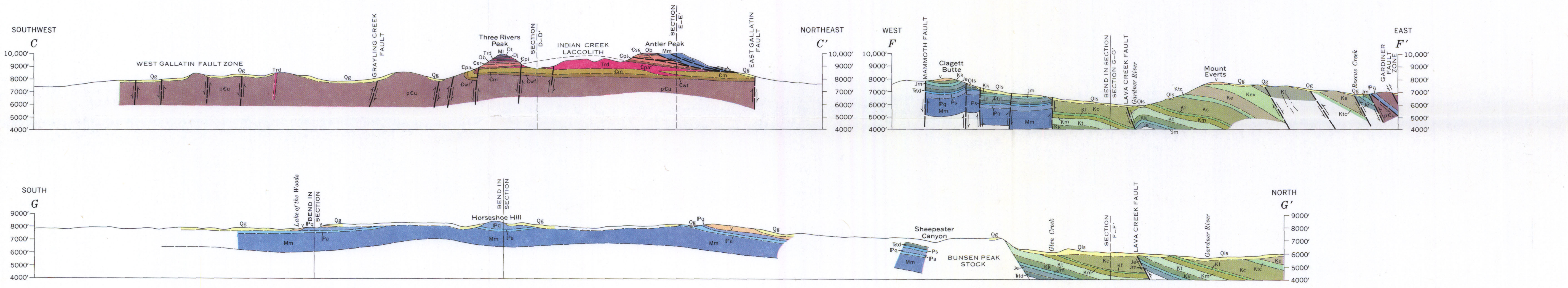
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1973—G71252

See west half for sections

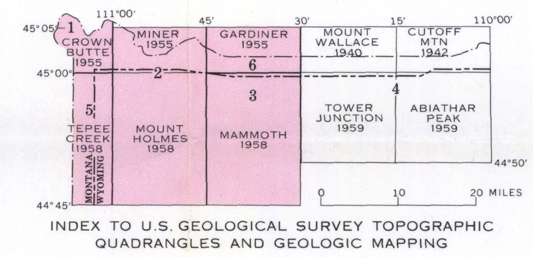
GEOLOGIC MAP AND SECTIONS OF PRE-TERTIARY ROCKS, NORTHERN PART OF YELLOWSTONE NATIONAL PARK







See east half for explanation



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GEOLOGIC MAP AND SECTIONS OF PRE-TERTIARY ROCKS, NORTHERN PART OF YELLOWSTONE NATIONAL PARK

Ruppel—GEOLOGY OF PRE-TERTIARY ROCKS, NORTHERN YELLOWSTONE NATIONAL PARK, WYO.—Geological Survey Professional Paper 729-A