Geology of the Fort Hill Quadrangle Lincoln County Wyoming

GEOLOGICAL SURVEY PROFESSIONAL PAPER 594-M

Geology of the Fort Hill Quadrangle Lincoln County Wyoming

By STEVEN S. ORIEL

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 594-M

Surface and subsurface data of an area along the eastern margin of the Idaho-Wyoming thrust belt establish the geometry and times of movement of two major frontal thrust faults

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLE

GEOLOGY OF THE FORT HILL QUADRANGLE, LINCOLN COUNTY, WYOMING

By STEVEN S. ORIEL

ABSTRACT

The Fort Hill quadrangle lies along the boundary between the Idaho-Wyoming thrust belt and the Green River Basin. A sequence of Paleozoic and Mesozoic sedimentary rocks about 24,000 feet thick has been intensely deformed along the front of the thrust-belt mountain system. Only Cambrian to Ordovician and Triassic to Cretaceous rock units are exposed now within the quadrangle. Middle and upper Paleozoic rocks are covered by partly deformed, but well exposed, Tertiary strata that help date some of the tectonic events.

Drilling within the quadrangle has provided data which help outline the third dimension of structures mapped. Westerly dipping lower Paleozoic to Mesozoic units overrode gently folded Cretaceous rocks eastward along the Hogsback fault in Paleocene time; all movement along this fault in the quadrangle ended before latest Paleocene time, for the fault trace is overlain by the Chappo Member of the Wasatch Formation. In outcrops the dip of the Hogsback fault is about 50°; but in the subsurface the dip declines westward to 10°, as shown in boreholes. The Hogsback fault is a bedding-plane glide surface that rode on claystones near the middle of the Cambrian Gros Ventre Formation; lateral transport eastward may have been about 20 miles.

Above the Hogsback fault are three other thrust faults, here named, in ascending order, the Fort Hill, the Meridian, and the Pine Ridge faults. All three are interpreted as slices of the Hogsback fault that cut across the section moderately abruptly. Movements along these faults are not well dated but may have been in latest Paleocene and earliest Eocene time, when detritus in the Chappo Member of the Wasatch Formation was deposited. Movement may have been later on the higher slices than on the lower.

Below the Hogsback fault is the La Barge thrust fault, along which the Cretaceous Hilliard and Frontier Formations overrode the Tertiary Hoback(?) and the Cretaceous Adaville(?) and Hilliard Formations. Movement along this fault was in early, possibly middle early, Eocene time.

Thrusting was followed in the area by block faulting in late early Eocene time—which may explain, in part, intertonguing of the Wasatch with the Green River Formation—and later.

Billions of cubic feet of natural gas and millions of barrels of oil have been produced from stratigraphic traps, in part controlled by structure in the northeastern part of the quadrangle and adjoining areas. Lenses and tongues of Cretaceous and lower Tertiary sandstone bounded by claystone and mudstone have been especially productive. Many more such stratigraphic traps are likely to be found in Cretaceous, Tertiary, and possibly also in Paleozoic rock units within the region.

Other natural resources of the area include helium, oil shale, coal, and phosphate.

INTRODUCTION

Exposed rocks along the western margin of the Green River Basin have received comparatively little attention from geologists since the extensive reconnaissance studies by the U.S. Geological Survey very early in this century. Yet study of these rocks and of data from deep drilling for oil and gas provides a rare opportunity to gain understanding of the front of a thrust-belt mountain system. Moreover, the presence of upper Mesozoic and lower Cenozoic strata makes it possible not only to date tectonic events in the region, but also to relate the structural and stratigraphic history of the basin to the structural and erosional history of the adjoining mountains to the west.

Study of the Fort Hill quadrangle, which lies along the western margin of the Green River Basin, has been one project of a broader program aimed at utilizing basin deposits to interpret the orogenic history of the western Wyoming thrust belt. Other projects have included mapping, along the northern part of the Fossil basin, of the Kemmerer quadrangle (Rubey and others, 1968b), the Sage quadrangle (Rubey and others, 1968a), and the Cokeville quadrangle. A detailed report is also in preparation on the uppermost Cretaceous and Tertiary stratigraphy of the Fossil basin. The program is an outgrowth of detailed studies of the thrust belt begun by W. W. Rubey several decades ago.

Additional aims of the program have been to examine, in detail, facies relations evident in Tertiary strata, to determine the structural relations in the various areas, and to interpret the geologic relations of known and potential economic deposits.

PURPOSE OF REPORT

The purpose of this report is to record observations and data gathered during study and mapping of the Fort Hill quadrangle, a small unit of a continuing research program. Emphasis here is on new structural interpretations of the area required by recently gathered surface and subsurface data. These interpretations may help guide continuing oil and gas exploration in the region, which in turn will produce additional data and no doubt require modifications of the interpretations. This paper, therefore, is a progress report, but it may also be of academic interest for it deals with one of the few structurally complex regions in which available drilling makes outlines of the third dimension evident.

Additional aims are to summarize stratigraphic and other observations of the rocks present, particularly the Tertiary strata exposed in most of the quadrangle, and to aid in the search for mineral resources and in land-use studies.

PREVIOUS WORK

Although the area included in the Fort Hill quadrangle was crossed in 1872 by an expedition led by E. D. Cope (1873, p. 545), it was not mapped systematically until 1877. During a 4-month season, A. C. Peale (1879) geologically mapped a region of some 13,000 square miles. Despite the hastiness of his reconnaissance, the gross outline of the western margin of the Green River Basin and of the region to the west was shown moderately accurately on his pioneer maps at scales of 4 and 8 miles to the inch (Peale, 1883; Peale and others, 1883).

Most maps currently in use for the region that includes the Fort Hill area, however, are based on the 1906 reconnaissance mapping by Schultz (1914, pl. 1). Some 2,500 square miles were mapped by him at a scale of 1:125,000 (about 2 miles to the inch) in one season, despite the structural and stratigraphic complexity of the region. Schultz's map is far more sophisticated than Peale's, because Schultz had data of the territorial surveys at his disposal, because he had the benefit of the rapid advance of science in the intervening period, and because his map is a northward extension of the significant contributions by Veatch (1907), whom he assisted. American recognition of the thrust-fault concept, for example, is evident in his report, as well as the great advance in stratigraphic paleontology. His report remains an outstanding contribution.

Although the entire Fort Hill quadrangle had not been remapped since Schultz's time, parts had been remapped in recent regional studies that have contributed significantly to geologic understanding of the area. Intertonguing relations between the Green River and Wasatch Formations were pointed out by Sears and Bradley (1924). Lithologic, biologic, and genetic aspects of the Green River were considered in the fundamental studies by Bradley (1926 and later). Information from unpublished maps of the Green River Basin by Bradley and of the thrust belt by Rubey were incorporated in the current geologic map of Wyoming (Love and others, 1955).

Geologic maps for theses by graduate students have included two areas in the Fort Hill quadrangle. The southern end of La Barge Ridge, in the northeastern part of the quadrangle, was mapped by Bertagnolli (1941). The middle part of the quadrangle was included by Donavan (1950) on the geologic map that accompanied his detailed description of the relations between the Green River and Wasatch Formations.

Drilling and supporting studies in the exploration for oil and gas have contributed significantly to knowledge of subsurface relations in the region. Although economic factors have inhibited publication of a comprehensive summary of the resulting abundant data, important information has been published by the Wyoming Geological Association (1950, 1955, 1960) and the Intermountain Association of Petroleum Geologists (1953, 1959).

PRESENT WORK AND METHODS

Fieldwork within the Fort Hill quadrangle was begun during the summer of 1957 and concluded in 1960. Some 225 square miles was mapped geologically during a total of about 4 months, most of which time was devoted to detailed studies of Tertiary strata. Because W. W. Rubey had planned to extend his detailed mapping of Mesozoic and older rocks in the Cokeville quadrangle eastward, into the Fort Hill area, relatively little time was spent in areas underlain by these rocks. An effort was made, however, to determine gross structural relations, and results of this reconnaissance are included in the present report.

Both topographic maps and aerial photographs were used as bases during mapping. Field sheets at a scale of 1:31,680, prepared by enlarging the U.S. Geological Survey's 1:62,500 topographic sheet of the Fort Hill quadrangle, were mounted on sketching boards and used with open-sight alidade for some mapping. Geologic contacts were traced directly from field sheets to a transparent stable compilation sheet. Many contacts were placed in the field on paper prints of the Geological Survey's aerial photographs at a scale of 1:27,700. Transfer of these contacts to the compilation sheet was indirect. Positions of the contacts were determined, in the office, by inspection of stereoscopic models of high-altitude aerial photographs projected at a scale of 1:12,000 by a Kelsh stereoplotting instrument (Ray, 1960, p. 47). These positions were then delineated using a tracing table attached to a reduction pantograph that recorded contacts on the compilation sheet.

Some contacts on the resulting geologic map are not precisely placed planimetrically. The topographic sheet of the Fort Hill quadrangle was prepared by field and early photogrammetric methods and does not conform to current standards of accuracy. The method chosen during geologic mapping for this report was to place contacts at correct elevations to attempt accurate depiction of Tertiary rock structure. Some contacts may lie as much as several hundred feet horizontally from places shown on the geologic map. Most parts of the map, however, are considered to conform to highest current accuracy standards.

ACKNOWLEDGMENTS

D. W. Young and R. W. Lester contributed to this study as able field assistants during the summers of 1957 and 1960, respectively.

Fossils collected were identified by C. L. Gazin, U.S. National Museum, and by R. W. Brown, W. A. Cobban, G. O. W. Kremp, E. B. Leopold, Helen Pakiser, J. B. Reeside, R. A. Scott, I. G. Sohn, D. W. Taylor, and J. A. Wolfe, all of the U.S. Geological Survey. Visits in the field by Gazin, Leopold, Sohn, and Taylor are gratefully acknowledged, as they proved stimulating and resulted in additional fossil collections.

Many ideas presented here stem from discussions held in the field with numerous geologists from both industry and government. Especially provocative were discussions with V. C. Kelley, V. K. Koskinen, V. E. McKelvey, F. E. Murray, N. C. Privrasky, M. A. Reynold, R. L. Rioux, and G. D. Robinson. Unpublished manuscripts by W. H. Bradley and N. C. Privrasky were placed at my disposal. Also gratefully acknowledged are the courtesies shown me by M. L. Krueger, A. J. Gosar, J. R. Taylor, T. C. Woodward, D. P. Rothrock, and R. L. Rayl.

My debt to my companionable and knowledgeable colleagues, William W. Rubey and Joshua I. Tracey, Jr., is immeasurable.

GEOGRAPHY

LOCATION

The Fort Hill quadrangle lies in the northeastern part of Lincoln County, western Wyoming, astride the western margin of the Green River Basin as recently redefined (Love, 1961, p. 1752). The gas- and oil-producing Big Piney–La Barge area extends southward into the northern part, and the Willow Creek gas area lies near the middle of the quadrangle. The relation of the quadrangle to adjoining and nearby areas described in current and forthcoming reports of the U.S. Geological Survey is shown in figure 1. The position of the quadrangle along the front of the central part of the western Wyoming thrust belt is shown in figure 2.

LANDFORMS

Landforms in the Fort Hill quadrangle reflect its position along the western margin of the Green River Basin. The east half of the quadrangle consists of eastward-dipping cuestas which are moderately dis-

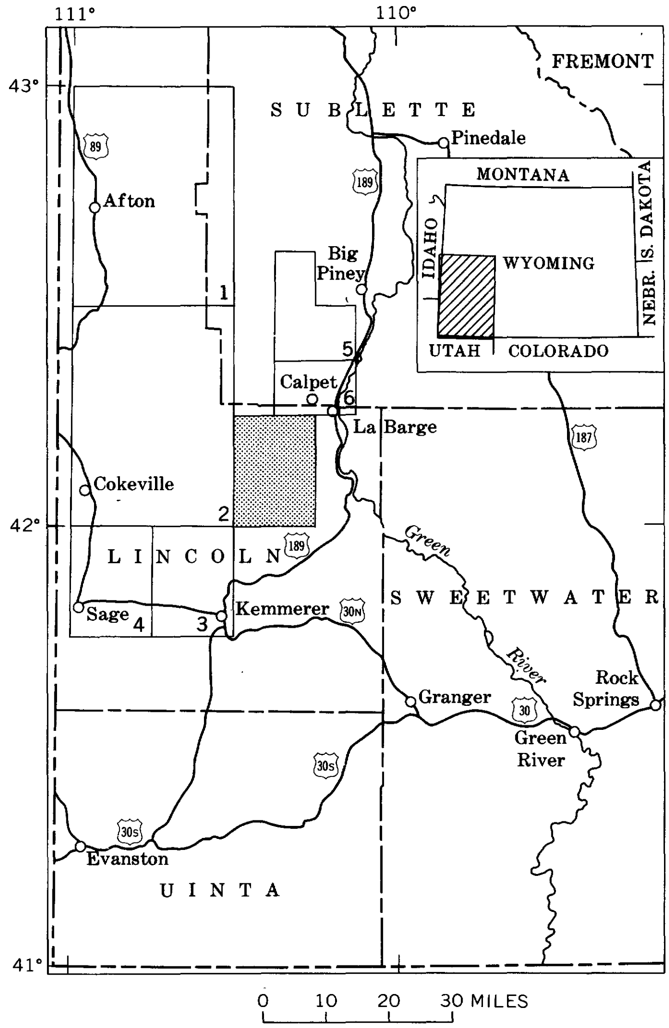


FIGURE 1.—Southwestern Wyoming showing the location of the Fort Hill quadrangle (stippled). Also shown are other areas recently mapped or being mapped by the U.S. Geological Survey; these include the (1) Afton quadrangle, (2) Cokeville quadrangle, (3) Kemmerer quadrangle, (4) Sage quadrangle, (5) Big Piney area, and (6) La Barge area.

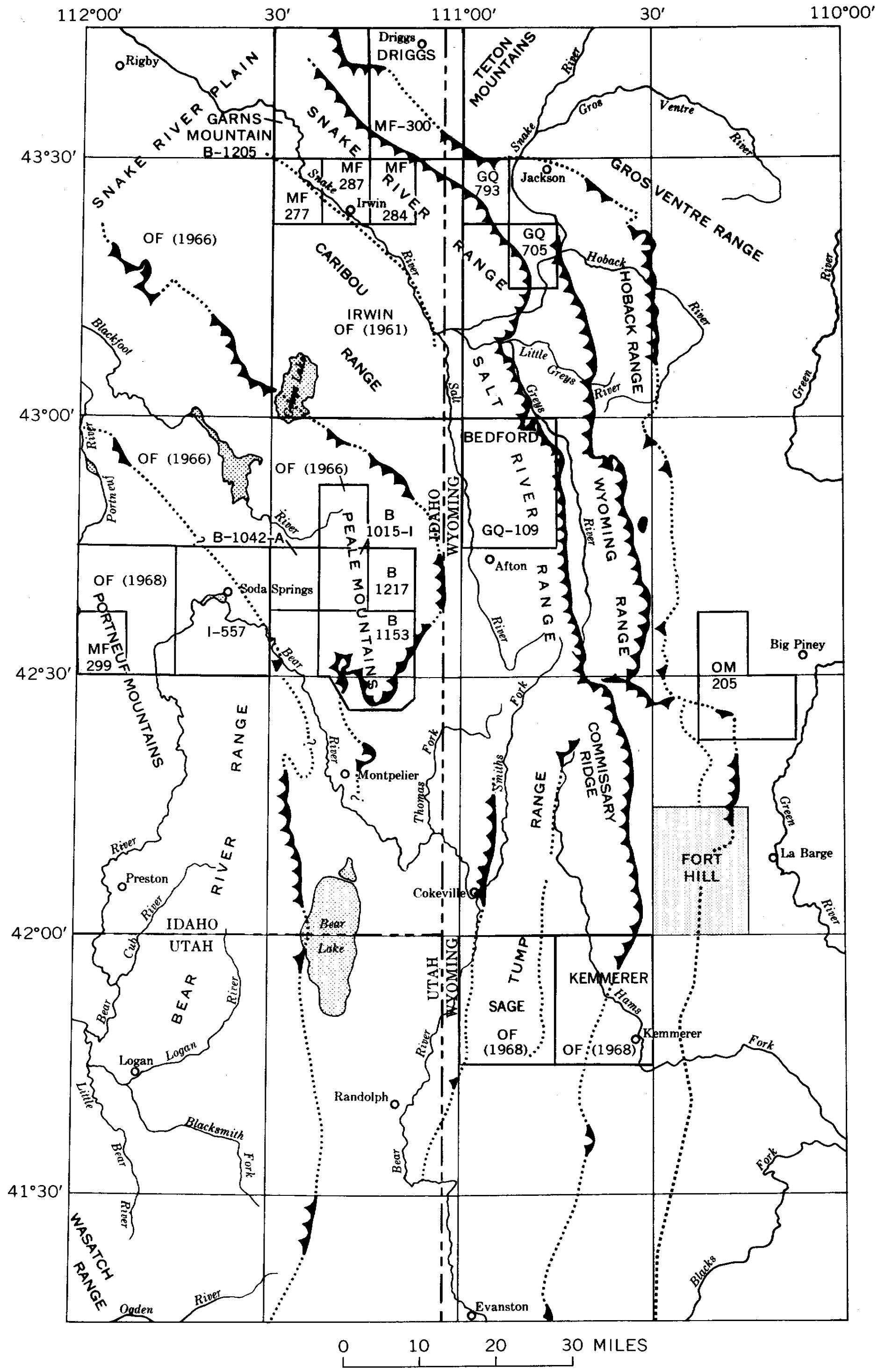


FIGURE 2.—Central part of thrust belt of western Wyoming, southeastern Idaho, and northeastern Utah. Principal thrust faults indicated by sawteeth; dotted where concealed. Recently published U.S. Geological Survey maps: B, bulletin; GQ, geologic quadrangle map; I, miscellaneous geologic investigations map; MF, mineral investigations map; OM, oil and gas investigations map; OF, open-file map. Modified from Rubey (1958).

sected by eastward-flowing streams. Gentle dips in the middle of the quadrangle flatten eastward, where flat-topped mesas and buttes predominate. An exception is La Barge Ridge, in the northeastern part of the area, which is underlain by resistant Paleozoic rocks dipping steeply to the west to form a feature called Hogsback Ridge on the U.S. Geological Survey's published preliminary topographic map of the La Barge quadrangle.

The land surface rises gently and smoothly westward from the middle of the quadrangle up the eastern slopes of Slate Creek Ridge and Miller Mountain (pl. 1), which together form the southern end of Meridian Ridge (Peale, 1879, p. 536; Schultz, 1914, pl. 1). This smooth surface is a stratum bench underlain by resistant eastward-dipping conglomerate beds and, where the rocks are weathered, gravel pavements. Exposed locally is a somewhat lower surface that truncates steeply dipping Mesozoic strata, from which the deposits underlying the stratum bench have been removed; this lower surface is an exhumed Eocene pediment.

The crest of Meridian Ridge consists of both rounded hills, where underlain by limestone, and more rugged topography, where underlain by quartzite. The western flank of the ridge is a steep slope that roughly parallels high-angle displacements in Mesozoic rocks.

The western margin of the quadrangle is formed of hogbacks typical of the Western Wyoming thrust belt. These hogbacks consist of alternating resistant and weak Mesozoic stratigraphic units dipping steeply to the west and are part of the Fontenelle Hogbacks of Peale (1879, p. 537).

Altitudes in the quadrangle range from less than 6,650 feet along Fontenelle Creek to more than 9,100 feet on Miller Mountain—a total relief of about 2,500 feet. Maximum local relief is about 1,200 feet along the Fontenelle Gap of Slate Creek Ridge.

DRAINAGE

The Fort Hill quadrangle lies entirely in the Green River drainage basin. The main streams, La Barge and Fontenelle Creeks, head in the mountains northwest and west of the quadrangle, flow in gorges that cut transversely across northerly trending strike ridges, and empty into the Green River to the east.

Drainage patterns of intermediate and tributary streams in the quadrangle are closely related to landforms described above. In the eastern part, streams flow eastward (down eastward-sloping cuestas), directly into the Green River. Except for Little Coal Creek, streams in the western part of the quadrangle flow northward or southward, along strike valleys, into larger transversely flowing streams. Little Coal Creek drains westward, nearly along the axial trace of a syncline that plunges steeply to the west, and joins Fontenelle Creek.

The average discharge of Fontenelle Creek measured by the U.S. Geological Survey (1961, p. 165; 1954a, p. 169; 1954b, p. 286–287) is about 68 cfs (cubic feet per second) or 49,300 acre-feet per year, and the maximum flow measured was 922 cfs in 1938. Average discharge of La Barge Creek is about 90 cfs or 65,000 acre-feet per year, and a maximum flow of 682 cfs was measured in 1914 (1954b, p. 284). Discharges are greatest in late May and early June when surface-water flow is 10–20 times greater than during the minimums in January.

CLIMATE AND VEGETATION

Climate in the Fort Hill area is semiarid and cool temperate. Although no weather stations are maintained in the quadrangle, conditions in the eastern part at lower altitudes are probably similar to those recorded by the U.S. Weather Bureau at Kemmerer and at Big Piney. Annual precipitation probably averages about 9 inches, ranging from 3 to 14 inches. Much of it falls as snow which averages 45 inches per year. Precipitation is greatest during May and early June, whereas September and February are commonly the driest months. The highest temperatures occur in July when the mean high is about 80°F and the mean low about 41°F; the lowest, in January when the mean high is 26°F and the mean low about 0°F. The highest temperature recorded in the region was 96°F; the lowest, −45°F. Length of the growing season—between the last spring and the first fall killing frosts—averages about 2 months, although it varies considerably.

Data are not available for interpreting conditions in the western part of the quadrangle, at higher altitudes. Precipitation is somewhat greater and temperatures are lower. Snowfalls and frosts have been recorded for every month of the year.

Natural vegetation at lower altitudes consists of wild grass, bunchgrass, sagebrush, rabbitbrush, and pricklypear. Willows are common along stream bottoms, and cottonwood trees along the larger streams. Along hillsides and the lower slopes of mountains, chokecherry, serviceberry, and other bushes are abundant. A few small stands of trees are present in the mountains, particularly on Miller Mountain where timber has been removed, and include quaking aspen, lodgepole and limber pines, Douglas and alpine firs, and Engelmann spruce.

SETTLEMENT AND ACCESSIBILITY

Ranchers in the quadrangle dwell in permanent homes built along stream bottoms, especially along La Barge and Fontenelle Creeks. They are served by bus-

324-263 O—69——2

inessmen in the nearby towns of La Barge, Kemmerer, and Big Piney. Oil and gas field workers in the area live mainly in mobile or trailer homes concentrated in the three towns. Kemmerer, the Lincoln County seat, is the largest of the three with a population of 2,028 (in 1960).

Despite the absence of State or Federal highways within the quadrangle, accessibility to motor vehicles is excellent. Three well-graded county-maintained roads enter the quadrangle from U.S. Highway 189 (fig. 1) on the east. Two of these roads, along the north side of La Barge Creek and along the south side of Fontenelle Creek, have been paved recently. The third, along Muddy Creek to the Facenelli Ranch, is unsurfaced. Many more dirt ranch roads and geophysical-party trails traverse the area than is evident from the topographic sheet of the quadrangle, and many of them, though recently constructed, are rutted in places. Where trails are absent, the general sparsity of timber and the relative gentleness of grades permit travel by four-wheel-drive vehicles almost everywhere in the quadrangle.

The nearest rail shipping center is Kemmerer, along the Oregon Short Line of the Union Pacific Railroad. A spur extending northward from Kemmerer for several miles, built originally to the Willow Creek coal mine, was used recently to ship lumber from a sawmill near the abandoned mine. Hydrocarbons produced in the region are moved by pipelines, which are directly east, northeast, and south of the quadrangle, and by rail from Opal, a few miles east of Kemmerer.

GEOGRAPHIC NAMES

The variety of local names evident on the various maps available for the region raises questions about proper usage and proper spelling. Geographic names used here conform in general to decisions of the U.S. Board of Geographic Names as reflected in topographic sheets published by the U.S. Geological Survey for the Fort Hill and La Barge quadrangles. For some large geographic units, not labeled on the topographic sheets, names used by Peale (1879) and Schultz (1914) have been adopted—for example, Meridian Ridge.

STRATIGRAPHY

A moderately complete sequence of sedimentary rocks, ranging in age from Middle Cambrian to Eocene, is present along the western margin of the Green River Basin. Rocks ranging from uppermost Ordovician to lowest Triassic, however, are not exposed in the Fort Hill quadrangle, although they are exposed a few miles north and have been penetrated by drilling within the quadrangle.

Tertiary strata are more extensively exposed in the Fort Hill quadrangle than are the older Paleozoic and Mesozoic rocks. The older rocks, which were examined only briefly, are assigned to long-established units and are therefore only briefly summarized in the paragraphs that follow, whereas Tertiary strata are assigned to newer units and are described more fully. Paleozoic and Mesozoic units described are limited, except as otherwise noted, to rocks in the thrust sheet above the Hogsback fault.

CAMBRIAN SYSTEM

GROS VENTRE FORMATION

The oldest rocks in the Fort Hill quadrangle are assigned to the Gros Ventre Formation (Blackwelder, 1918, p. 417) of Cambrian age. Excellent exposures lie along the southern end of Hogsback Ridge in sec. 19, T. 26 N., R. 113 W. The formation is incompletely represented, however, because the lowest parts now present, in about the middle of the formation, are cut by the Hogsback thrust fault.

The Gros Ventre Formation in most of western Wyoming is divisible into three units: a lower shale, a middle limestone, and an upper shale (Rubey, 1958) called (for example, by Lochman-Balk, 1960, p. 102) the Wolsey Shale, Death Canyon Limestone, and Park Shale Members, respectively. Although the units have long been assigned member rank, they were regarded as formations and the Gros Ventre was regarded as a group by Shaw (1954).

The middle limestone, or Death Canyon Limestone Member, is the lowest unit of the Gros Ventre present in the mapped area. It consists of 120 to more than 300 feet of medium to finely bedded and thinly laminated dark-blue gray to medium-gray, tan, and rusty-brown very finely to medium-crystalline limestone and dolomitic limestone. It also contains a few beds of oolitic limestone, limestone breccia, limestone conglomerate, and green shaly claystone, and a few poorly preserved brachiopods. Weathered surfaces of the unit consist of alternating bands of medium- to light-gray and tan to brown laminae. Age of the Death Canyon is Middle Cambrian (Lochman-Balk, 1960, p. 102).

The upper shale of the Gros Ventre in the mapped area consists of about 400 feet of micaceous and glauconitic green shale with thin, Lingula- and trilobite-bearing interbeds of limestone. From 100 to 200 feet below the top of the unit are several prominent ledges of strata indistinguishable from the Death Canyon Limestone Member except that the ledges contain a slightly greater proportion of limestone conglomerate. The boundary between Middle and Upper Cambrian strata is believed to lie in the upper part of the shale unit (Lochman-Balk, 1960, p. 102).

GALLATIN LIMESTONE

Above the Gros Ventre Formation is about 180 feet of limestone commonly assigned (for example, Rubey, 1958) to the Gallatin Limestone (Peale, 1893), despite objections (Deiss, 1936, p. 1341; Lochman-Balk, 1956, p. 615) to usage of the name and the fact that the name is no longer used in the Three Forks region (Robinson, 1963, p. 15). The Gallatin was recently elevated to group status in western Wyoming with recognition of three extensive formations: the Du Noir Limestone, at the base, the Dry Creek Shale, and the Open Door Limestone (Shaw, 1954; Shaw and DeLand, 1955, p. 38). The Du Noir and Open Door are recognized as members of the Gallatin in the Wind River Basin (Keefer and Van Lieu, 1966). Mapping of these units in the Fort Hill quadrangle has been impracticable; therefore, the rocks are assigned to the Gallatin Limestone.

The formation consists of thinly bedded brown-mottled dark-blue-gray limestone and medium-gray limestone to dolomitic limestone with beds of intraformational conglomerate, oolitic limestone, and limestone consisting of bioclastic debris. The rusty-brown mottling on weathered surfaces of the Gallatin is an aid in distinguishing it from the more uniform rusty-brown banding in limestones of the Gros Ventre Formation. The Gallatin is assigned a Late Cambrian age (Lochman-Balk, 1960, p. 106).

ORDOVICIAN SYSTEM—BIGHORN DOLOMITE

The Bighorn Dolomite (Darton, 1904, p. 395) consists of about 400 feet of subaphanitic very light to medium-gray, but mostly light-gray, dolomite and dolomitic limestone in thick to massive beds that weather to very light gray, almost white, very roughly pitted surfaces. Some beds are buff to tan on fresh surfaces, and some have a sucrose texture. Greater thicknesses previously reported in the area (Bertagnolli, 1941, p. 1733) may have resulted from measurements across unrecognized faults. Though commonly assigned a latest Ordovician age (Twenhofel, 1954, pl. 1; Hintze, 1959, p. 49), these rocks have also been considered mainly of Middle Ordovician age (Kay, in Twenhofel, 1954, p. 282) and of both Middle and Late Ordovician age (Flower, 1956a, b).

DEVONIAN AND MISSISSIPPIAN SYSTEMS—DARBY FORMATION

Silurian rocks are absent in western Wyoming (Berdan and Duncan, 1955), and the Bighorn Dolomite is overlain by about 500 feet of strata assigned here to the Devonian and Mississippian Darby Formation (Blackwelder, 1918, p. 420), although they have also been assigned (Bertagnolli, 1941, p. 1733) to the Jefferson Formation of Montana.

Four units have been recognized in the sequence here included in the Darby. In a 430-foot-thick section measured on La Barge Mountain, about a mile north of the Fort Hill quadrangle, Benson (1965; 1966, pl. 10) assigned the lower 265 feet to the lower member of the Jefferson Formation; this lower member is correlated with the Duperow Formation of Sandberg and Hammond (1958). The lower member consists of dark-brownish-gray fetid dolomite and limestone and thin detrital units that include light-gray to white sandstone and siltstone and green and red claystone and mudstone; a solution breccia about 90 feet above the base of the unit gives way in the subsurface to anhydrite. The next higher unit, about 110 feet thick, consists of massive ledge-forming brownish-dark-gray dolomite assigned by Benson to the Birdbear or upper member of the Jefferson Formation. The Birdbear is overlain by about 50 feet of greenish-gray, gray, and brown dolomitic and partly sandy claystone, mudstone, and siltstone assigned by Benson to the Three Forks Formation. The top 5 feet consists of dark-gray purple-weathering carbonaceous claystone, mudstone, and silty crinoidal dolomite assigned to the dark shale unit of Sandberg (1963). The lower three units are assigned to the Upper Devonian, whereas the upper unit is regarded as both Upper Devonian and Lower Mississippian.

MISSISSIPPIAN SYSTEM—MADISON LIMESTONE

Some 1,100 feet of carbonate rocks in the area is assigned here to the Madison Limestone. Although the name Brazer Dolomite has been applied to upper strata of this sequence in parts of western Wyoming, it is now restricted (Sando and others, 1959, p. 2768) to the facies exposed in the Crawford Mountains along the Utah-Wyoming boundary. Madison strata in the region have also been assigned to the Lodgepole Limestone and the overlying Mission Canyon Limestone (Sando and Dutro, 1960) and to a third, unnamed unit (Strickland, 1956). These subdivisions were not recognized during brief examinations of broken and deformed exposures in Hogsback Ridge, north of the quadrangle. The Madison is assigned an Early and early Late Mississippian age (Sando and Dutro, 1960, p. 122).

The Madison includes both limestone and dolomite. The limestone is thickly to thinly layered, thin bedded, very dark to light gray, brown and tan, coarsely bioclastic to subaphanitic, partly oolitic, and partly cherty. The dolomite is thicker bedded, mainly light gray to tan, though partly dark gray, and sucrose to microcrystalline.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS—AMSDEN FORMATION

Boreholes drilled in the quadrangle show that the Madison Limestone, whose top is not exposed either in the area mapped or along Hogsback Ridge farther north, is overlain by a unit about 400 feet thick assigned here to the Amsden Formation (Darton, 1904, p. 394–401), although the strata have also been included in the overlying Wells Formation by some stratigraphers. Fossils have not been reported from the unit in this area, but studies in other parts of Wyoming (Love, 1954; Shaw, 1955; Shaw and Bell, 1955; Sando and Dutro, 1960, p. 125) indicate that both Mississippian and Pennsylvanian rocks are present. The position of the systemic boundary has not been ascertained, and at least part of the unit may be equivalent to the evaporite facies of the Mission Canyon Limestone, as suggested by Sando and Dutro (1960, p. 124, pl. 1).

Heterogeneity of the unit makes generalizations about its composition hazardous. Variously colored mudstone, limestone, dolomite, sandstone, and some beds of anhydrite are present. Carbonate rocks are abundant in the lower part of the unit whereas sandstone is dominant in the upper part. In the quadrangle, some 50 feet of maroon, red, brown, purple, green, and gray mudstone with a few thin interbeds of dolomite is overlain by about 50 feet of gray, buff, and tan, sucrose to microcrystalline dolomite. Above the dolomite about 50 feet of interbedded mudstone, sandstone, limestone, and dolomite is overlain by about 30 feet of salmon, pink, tan, gray, and white sandstone. The sequence above the sandstone consists of brightly colored interbedded sandstone, mudstone, dolomite, limestone, anhydrite, and cherty dolomite, in about that order of abundance.

PENNSYLVANIAN AND PERMIAN SYSTEMS—WELLS FORMATION

The names Wells Formation (Richards and Mansfield, 1912, p. 689ff), Weber Quartzite (King, 1876, p. 477–479), and Tensleep Sandstone (Darton, 1904, p. 394–401) have been applied in subsurface stratigraphic work to a 450-foot-thick sequence of sandstone and quartzitic sandstone above the Amsden Formation. Removal of the upper siliceous limestone of the Wells Formation of Mansfield (1927, p. 72) and its recent reassignment to the Grandeur Tongue of the Park City Formation (McKelvey and others, 1959, p. 15) possibly makes the Wells Formation (restricted) synonymous with the other two terms. Though previously assigned to the Weber Quartzite (Schultz, 1914, p. 42), the strata are assigned in this report to the Wells Formation with no great conviction but mainly because of relative proximity to type area. Fusulinids found in subsurface strata within the quadrangle establish a Middle Pennsylvanian (Des Moines) age (Verville and Momper, 1960, p. 127) for rocks slightly below the middle of the formation. Although the base of the formation is undated, it too is believed to be of Pennsylvanian age in this area. The top of the formation is limestone probably of Permian age.

The formation consists mainly of gray to very light gray and buff calcareous and quartzitic sandstone with some buff, tan, and gray dolomite and cherty dolomite and a few thin interbeds of gray to dark-gray mudstone.

PERMIAN SYSTEM—PHOSPHORIA FORMATION AND EQUIVALENT STRATA

The Phosphoria Formation (Richards and Mansfield, 1912) and equivalent strata are about 330 feet thick in the Fort Hill quadrangle, although drilled thicknesses are apparently greater because of structural complexities commonly found in the unit. The rocks have also been assigned to the Park City Formation (Schultz, 1914, p. 43). Included in this map unit are rocks that have been assigned (McKelvey and others 1959) to the following units, in ascending order: The Meade Peak Phosphatic Shale and the Rex Chert Members of the Phosphoria Formation, the Franson Member of the Park City Formation, the Retort Phosphatic Shale and Tosi Chert Members of the Phosphoria Formation, and the Ervay Member of the Park City Formation. On the structure sections (pl. 2), only the formational designation is used, because the units are too thin to be shown at the scale of the sections. These rocks are Permian, but their range in age has not been established (McKee, Oriel, and others, 1967; Yochelson, 1968, p. 572, 628).

This map unit is composed of medium- to dark-gray mudstone and phosphatic mudstone, phosphorite, dark-gray and brown dolomite and cherty dolomite, dark-gray, brown, and light-gray chert, and very dark brownish black to almost white phosphorite. Genetic interpretations based on the petrography and stratigraphy of these rocks in western Wyoming, as well as detailed nearby sections with accompanying chemical analyses, were presented by Sheldon (1957, 1963).

TRIASSIC SYSTEM

DINWOODY FORMATION

The Dinwoody Formation (Blackwelder, 1918, p. 425–426; Newell and Kummel, 1942, p. 941) is represented in the subsurface within the quadrangle by about 250 feet of strata. Exposures of these rocks northwest of the quadrangle were included in the Park City Formation by Schultz (1914, p. 43). The Dinwoody is of very Early Triassic age (Kummel, 1954, p. 183).

The formation is composed of interbedded light- to dark-gray and greenish-gray calcareous siltstone and mudstone and greenish-gray, gray, buff, and tan argillaceous and sandy dolomite. Traces and beds of light-colored anhydrite lie in the upper part of the unit.

WOODSIDE FORMATION

The Woodside Formation (Boutwell, 1907, p. 446) is the lowest Mesozoic unit exposed in the quadrangle. Though the base is concealed, the formation is about 500 feet thick in boreholes. Despite the absence of fossils, the unit is assigned an Early Triassic age on the basis of its position between fossiliferous units of the same age and its regional relations (Kummel, 1954, p. 168).

Distinctively colored red beds make up the formation. Bright-red, brownish-red, and orange partly anhydritic and partly dolomitic siltstone and claystone are dominant, but a few thin layers of orange very fine to fine-grained sandstone are also present.

THAYNES LIMESTONE

Exposures assigned to the Thaynes Limestone (Boutwell, 1907, p. 448) are about 1,100 feet thick in the Fort Hill quadrangle. The formation has been subdivided in various ways (Mansfield, 1916; Kummel, 1954, p. 173), but the informal twofold subdivision by Rubey (1958) proved most practicable for mapping. About the lower third of the sequence is assigned to a lower, dark-brown-weathering somewhat manganiferous limestone member, whereas the remainder is included in the upper, pale-yellowish-gray-weathering limestone member. The Thaynes Limestone is commonly assigned an Early Triassic age (Reeside, 1957, pl. 1) although the upper part is known to intertongue eastward with red beds of the Ankareh Formation (Kummel, 1954, pl. 34) assigned an Early and Late Triassic age. The lower part of the formation contains ammonites of undisputed Early Triassic age (Kummel, 1954, p. 184–188). The upper part may be Middle Triassic—although this series commonly has not been recognized in most of the Western Interior (Oriel, 1962a)—or possibly Late Triassic (McKee and others, 1959, p. 21).

Although the Thaynes Limestone is moderately distinctive, its strata occasionally have been erroneously assigned to other formations. The formation consists of interbedded resistant light- to dark-gray and tan to brown muddy and sandy limestone and calcareous siltstone, and nonresistant red, brown, green, and gray calcareous mudstone. Limestone beds in the lower member weather dark brown with manganiferous stains and in some places form talus slopes that have been mistaken for those of the Nugget Sandstone. Muddy and sandy limestone in the upper member weathers light gray and forms light-gray to buff slopes that have been mistaken for those of the Twin Creek Limestone, but fresh exposures of the two differ. Almost all exposed rocks of the Thaynes consist of mixtures of limestone, mudstone, and siltstone with some sand grains, so that choice of the correct lithologic name is difficult for many samples. No doubt this fact explains differences in descriptions of subsurface as well as surface sections—most of the differences are between descriptions rather than between rocks in different sections. On the other hand, subsurface samples include a moderate amount of anhydrite and gypsum not preserved in exposures and a somewhat greater proportion of mudstone than is evident in exposures dominated by more resistant limestone layers. The presence of some red mudstone in the upper part of the formation results in the common placement of the top of the formation some 300–400 feet lower stratigraphically in subsurface sections than the contact used here in surface mapping.

ANKAREH FORMATION

Usage of the name Ankareh Formation, first defined by Boutwell (1907, p. 453), has been varied and not always consistent (Kummel, 1954, p. 179–181; Anderman, 1956, p. 56–58). The term is used here for a red-bed unit some 400 feet thick between the underlying Thaynes Limestone and the overlying Nugget Sandstone. In many parts of western Wyoming the formation includes discontinuous lentils of conglomerate equivalent to the Higham Grit of Idaho and a few beds of red, purple, to greenish-gray aphanitic limestone equivalent to the Deadman Limestone of Idaho (Rubey, 1958). Only the limestone, in about the middle of the formation, was seen in the Fort Hill quadrangle. The age of the Ankareh Formation, as used here, is not known from fossils but is commonly regarded as Early and Late Triassic (Reeside, 1957, pl. 1), although it is probably Late Triassic in this region.

The Ankareh consists mainly of bright-red, purple, maroon, and brown calcareous mudstone, but includes interbeds of red to orange siltstone and red, orange, and buff fine-grained sandstone and quartzite, and the limestone beds described above.

TRIASSIC(?) AND JURASSIC(?) SYSTEMS—NUGGET SANDSTONE

The Nugget Sandstone (Veatch, 1907, p. 56; Boutwell, 1912, p. 58–59) is 600 feet thick in the quadrangle.

The age of the unit is in dispute. Long assigned an Early Jurassic age (Imlay, 1952a, pl. 1), it has recently been reclassified by the U.S. Geological Survey. When the lower part of sandstone assigned to the Nugget was found to intertongue with beds assigned to the Upper Triassic Popo Agie Member of the Chugwater Formation in central Wyoming (Hubbell, 1954, p. 27), all the Nugget was reassigned by some geologists to the Triassic System (Love, 1957; Reeside, 1957, p. 1481). Regional relations may also be interpreted as indicating that the formation includes rocks of both Jurassic and Triassic age (McKee and others, 1959, p. 23), but, in the absence of identifiable diagnostic fossils, this age assignment is queried.

The Nugget consists of tan, buff, white, pink, and salmon crossbedded fine- to medium-grained well-sorted quartzitic and slightly calcareous sandstone. A few beds of maroon, red, and brown mudstone are present in the lower part of the formation. Weathered slopes of the formation consist mainly of manganese-coated angular talus blocks of quartzite.

JURASSIC SYSTEM

TWIN CREEK LIMESTONE

The Twin Creek Limestone (Veatch, 1907, p. 56) is about 1,000 feet thick (Imlay, 1967, p. 9, 11) and is exposed in a continuous belt extending northward across the quadrangle. The age of the formation is Middle and early Late Jurassic (Imlay, 1950; 1952a, pl. 1, p. 965–966).

Directly above the Nugget Sandstone is a 60-foot-thick, mainly red unit that has commonly been assigned (Rubey, 1958) to the basal part of the Twin Creek Limestone (member A of Imlay, 1950, p. 38). The unit is similar in composition and appearance to the Gypsum Spring Formation (Love, 1939, p. 45–46) and is reported to have been traced by J. D. Love into that formation from the Jackson Hole area eastward (Imlay, 1950, p. 38). Although almost too thin to be shown at the scale used, without exaggeration of thickness, mapping of the beds as a separate stratigraphic unit proved necessary in the Fort Hill quadrangle to establish structural relations. Lithologic similarity makes use of the name Gypsum Spring desirable (Imlay, 1967, p. 17), although the unit is probably equivalent to only the lower part of the formation in central and eastern Wyoming. The unit is therefore regarded as the Gypsum Spring Member of the Twin Creek and is assigned a Middle Jurassic age (Imlay, 1952a, pl. 1; 1967, p. 19).

The member is composed of red, brown, and orange claystone and siltstone with some green layers and gray to tan and yellow mainly brecciated but partly honeycombed limestone. White anhydrite beds are also found in the unit where it is preserved in the subsurface.

The remainder of the Twin Creek is distinctive and consists mainly of very dark gray, almost black, thin-bedded sublithographic argillaceous and partly silty limestone and very calcareous siltstone and mudstone with some beds of thicker bedded medium- to dark-gray and brown oolitic limestone and coarsely bioclastic limestone. Red to brown mudstone, with some green layers, is also present in the unit. The thin-bedded and finely crystalline rocks weather to very light gray and yellowish gray and form extensive bare slopes on Slate Creek Ridge (which derives its erroneous name from the abundant chips of thin-bedded Twin Creek Limestone) and on the ridge west of Miller Mountain. Most of the Twin Creek is, in general, darker colored on fresh exposures, lighter colored on weathered surfaces, and finer grained and more finely crystalline than the Thaynes Limestone; it also differs in containing moderately abundant *Pentacrinus* fragments.

PREUSS REDBEDS

The Twin Creek is overlain by the Preuss Sandstone (Mansfield and Roundy, 1916, p. 76) or Redbeds (Rubey, 1958), a unit formerly included in the Beckwith Formation of Veatch (1907, p. 57–58). The name "Redbeds" is preferred here because most of the rocks are finer grained than sandstone. The unit, which is 340 feet thick, has been assigned an early Late Jurassic age (Imlay, 1952b, p. 1747, 1750).

The Preuss consists of red, purplish-red, maroon, brown, and orange siltstone, mudstone, and sandstone with a few thin layers of green mudstone. The unit is moderately calcareous and, in the subsurface, partly anhydritic.

STUMP SANDSTONE

The Stump Sandstone (Mansfield and Roundy, 1916, p. 81) is a distinctive green unit 90 feet thick in the quadrangle. It consists of interbedded pale-greenish-gray and light-green medium- to thin-bedded glauconitic sandstone, siltstone, mudstone, and limestone. Marine invertebrates in the unit establish its Late Jurassic age (Imlay, 1952a, p. 965).

CRETACEOUS SYSTEM

GANNETT GROUP

The Gannett Group (Mansfield and Roundy, 1916, p. 82) is composed of the sequence of rocks formerly included in the Beckwith Formation (Veatch, 1907, p. 57) except that the Preuss Redbeds and Stump Sandstone are excluded. Five formations have been included in the Gannett Group in Idaho and adjoining parts of Wyoming: the Ephraim Conglomerate (at the base), the Peterson Limestone, the Bechler Conglomerate, the Draney Limestone, and an uppermost red-bed unit. In the author's opinion the Tygee Sandstone, assigned to the top part of the group by Mansfield and Roundy (1916) and by the U.S. Geological Survey, should be considered not as part of the Gannett, but as a member of the overlying Bear River Formation (Cobban and Reeside, 1952a, p. 1030). Only a threefold subdivision was recognized in the Fort Hill quadrangle—a lower detrital unit is separated from an upper unit by a thin limestone unit in about the middle of the group. Whether the middle limestone unit is correlative with the Peterson or the Draney, if either, is not established, but the greater regional extent of the Peterson possibly justifies tentative use of this name. The group is about 800 feet thick. Fossils from the Draney and Peterson Limestones and from the middle of the Ephraim Conglomerate in Idaho establish an Early Cretaceous age (Cobban and Reeside, 1952a, p. 1030; Peck, 1956, p. 97; 1957, p. 12) for most of the group, but strata in the basal part of the unit may be Jurassic (Mansfield, 1952, p. 42; McKee and others, 1956, p. 3).

The group is particularly well displayed in exposures along La Barge Creek north of the quadrangle in the center of sec. 17, T. 27 N., R. 115 W. Red beds are dominant in the Gannett Group, but their hues are characteristically more orange, from a distance, than the purplish red of the Preuss Redbeds. The group consists mainly of red, orange, brown, and maroon mudstone and siltstone with some buff, tan, and light-gray sandstone, especially below the middle limestone unit. Unlike older sandstones, numerous scattered grains of dark chert among the more dominant lighter colored quartz grains give the rock a spotted appearance which has resulted in its designation as "salt and pepper sandstone." A few sandstone beds are partly conglomeratic with granules of medium- to dark-gray chert. The middle limestone unit is composed of tan, buff, pale-red, purple, and green aphanitic limestone with interbeds of brightly colored mudstone.

BEAR RIVER FORMATION

Exposures of the Bear River Formation (Hayden, 1869, p. 91; Stanton, 1892) in the thrust sheet above the Hogsback fault consist of dark-colored strata some 900 feet thick. The formation is exposed in a southerly trending belt along the western margin of the quadrangle and is especially well displayed along Little Coal Creek where its apparent thickness seems excessive, due to structural complexities. The formation is assigned a late Early Cretaceous age (Cobban and Reeside, 1952a, pl. 1).

The Bear River consists mainly of claystone with interbeds of sandstone and limestone. Most of the claystone is distinctively very dark gray to black and fissile, locally forming bare black slopes unlike those of any other formation; these contain thin beds of ironstone. Some mudstone is light gray and bentonitic; some is sandy and brownish gray. The sandstone is quartzitic and green to greenish brown and lies mainly in the lower part of the formation. The limestone is dark brown to gray and abundantly fossiliferous. A few thin beds of porcellanite are present near the top of the formation.

ASPEN FORMATION

The Aspen Formation (Veatch, 1907, p. 64) forms the westernmost belt of exposures in the quadrangle and is about 1,800 feet thick. The boundaries of this formation are not agreed upon by all geologists. The contacts shown on plate 1 mark the base of the lowest and the top of the highest prominent and mappable porcellanite beds recognized in the area. A few thin porcellanite beds are present in underlying black claystone of the Bear River Formation and in strata assigned to the overlying Frontier Formation. The Aspen Formation is latest Early Cretaceous (Cobban and Reeside, 1952a, pl. 1).

The Aspen Formation is heterogeneous in composition and parts resemble both underlying and overlying formations. It includes black to light-gray claystone and mudstone, light- to medium-gray calcareous to siliceous fine-grained sandstone, and mainly white to light-gray but locally pinkish porcellanite. The porcellanite, formed by silicification of volcanic tuff of about quartz latite composition (Rubey, 1958), weathers into small angular fragments that impart a characteristic silver-gray appearance to relatively bare slopes.

FRONTIER FORMATION

Exposures of the Frontier Formation (Knight, 1902, p. 721; Veatch, 1907, p. 65) barely extend into the western part of the Fort Hill guadrangle where only a few basal strata are present. A complete sequence is present to the west and southwest. Thicknesses reported for the unit along this belt of exposures are about 2,000 feet near Kemmerer (Cobban and Reeside, 1952b, p. 1935) and about 2,900 feet in the old coal area on Willow Creek (Andrews, 1944), a few miles south of the southwest corner of the quadrangle. The formation is of early Late Cretaceous age (Cobban and Reeside, 1952b).

The Frontier consists mainly of light- to medium-gray locally brown weathering fine to very fine grained sandstone; medium- to dark-gray and brownish-gray mudstone, claystone, and siltstone; dark-gray to almost black carbonaceous mudstone; brown to gray limestone; coal; and a few thin layers of light-gray porcellanite and bentonite. Although sandstone forms only about a third of the unit, its resistance results in greater relative abundance in exposures.

CRETACEOUS ROCKS BELOW THE HOGSBACK FAULT

Descriptions of Paleozoic and Mesozoic units in the foregoing paragraphs are of rocks in the thrust sheet lying above the Hogsback and below the Absaroka thrust faults. Only topmost Cretaceous units are exposed below the Hogsback fault along Hogsback Ridge. Few holes have been drilled into rocks below the Cretaceous System beneath the fault. These few boreholes, however, are significant, for they permit one to ascertain differences in rock units above and below the fault. In general, these differences are minor for Jurassic and older rocks and striking for Cretaceous rocks. Paleozoic and lower Mesozoic units below the fault (Marzolf, 1965) are somewhat thinner than, but quite similar in composition to, those above, except possibly for the increased proportion of mudstone in the Triassic and Jurassic limestone units. The same rock-stratigraphic names are applicable to these units on both sides of the fault.

Cretaceous rocks below the Hogsback fault, however, differ markedly in composition and in thickness from those above; these differences are so great that stratigraphic names used for units in the Rock Springs uplift and central Wyoming have been applied to them (Howe, 1955, p. 174–175; Krueger, 1960, p. 195–197), rather than names defined in adjoining parts of westernmost Wyoming. The relation of subsurface Cretaceous units below the fault to exposed Cretaceous units above the fault is a problem of considerable scientific and economic significance whose resolution should be reflected by nomenclature finally adopted for the region. Regrettably, time was insufficient during the present study to deal adequately with subsurface stratigraphic relations critical to the problem.

An attempt is made in the paragraphs that follow to report stratigraphic terms most commonly used for rocks below the fault by petroleum geologists in the region. My knowledge of the rocks is inadequate to form a basis for comment on this usage.

GANNETT GROUP

The Jurassic Stump Sandstone, about 35 feet thick below the thrust fault, is overlain by an 800-foot-thick stratigraphic unit. The unit consists mainly of varicolored mudstone with interbedded sandstone, especially in its lower part, and limestone, near its middle. The mudstone is maroon, purple, red, orange, green, and gray, but in the uppermost part of the unit it is mainly greenish gray; the sandstone is white, light gray, and buff, fine to very fine grained; the limestone is pale red, tan, and light gray, and it is microcrystalline. The unit has been assigned to the Morrison (Krueger, 1960, p. 196), to the Morrison and Cloverly Formations (Stokes, 1955, p. 81), and to the Gannett Group (Anderman, 1956, sections 60–62; Hallock, 1960, pl. 1). Because the rocks are similar in composition, thickness, and stratigraphic position (as indicated by available sample descriptions) to those described in the unit above the thrust fault, use of the name Gannett Group probably is preferable.

BEAR RIVER AND ASPEN FORMATIONS OR DAKOTA SANDSTONE AND MOWRY SHALE

The sequence between the Gannett Group and the Frontier Formation below the thrust fault is not so distinctive that subsurface stratigraphers have reached agreement on subdivisions of the 1,000-foot-thick sequence or on nomenclature. Moreover, the names commonly in use imply correlations that are not yet well supported by either physical or paleontologic data.

Study of the records for the relatively few boreholes that have penetrated this sequence in the Fort Hill area suggests that at least the following five subdivisions are possible locally.

1. *Basal black claystone.*—65–70 feet thick. Very dark gray to black fissile very finely micaceous claystone; locally contains a few thin beds of dark-gray siltstone.

2. *Lower sandstone and mudstone unit.*—260–280 feet thick. Interbedded light- to medium-gray and white very fine to medium-grained mainly subangular poorly to moderately well sorted calcareous locally quartzitic sandstone; light- to dark-gray, greenish-gray, and buff mudstone with medium-gray siltstone partings. In a few sections the lower and upper parts of this unit are mainly sandstone and are separated by a mainly mudstone part, but in other sections this pattern is not discernible.

3. *Middle black claystone.*—80–100 feet thick. Very dark gray to black fissile to splintery very finely micaceous claystone with a few thin beds of dark-gray siltstone locally.

4. *Upper sandstone and mudstone unit.*—About 300 feet thick. Interbedded light- to medium-gray very fine to medium-grained mainly subangular poorly sorted quartzitic but partly calcareous sandstone; light-gray to very dark gray mudstone with interbeds of medium-

gray siltstone, carbonaceous mudstone, and bentonite. Sandstone is relatively abundant (forming as much as 50 percent of the strata) in the upper 20–30 feet and in the lower half of the unit in some boreholes, but thin layers are also present between these two parts.

5. *Upper dark-gray mudstone and bentonite.*—About 270 feet thick. Dark-gray to very dark gray micaceous mudstone with numerous thin interbeds of bentonite; medium-gray siltstone; light- to medium-gray very fine to fine-grained quartzitic and calcareous sandstone; carbonaceous mudstone.

Unit 1 of the foregoing subdivisions has been assigned by some geologists (for example, Krueger, 1960, p. 196) to the Fuson Shale. Where sandstone is present in some sections at the base of the unit or in the top of the Gannett Group, the name Lakota Formation has been used. Unit 2 has been assigned to the Dakota Sandstone, unit 3 to the Thermopolis Shale, unit 4 to the Muddy Sandstone, and unit 5 to the Mowry Shale (Howe, 1955, p. 175; Krueger, 1960, p. 196; Michael, 1960, p. 213). Units 1, 2, 3, and 4 have also been assigned to the Bear River Formation, and unit 5 to the Aspen Formation (Anderman, 1956, sections 61, 62; Krueger, 1960, p. 196; Hallock, 1960, pl. 1), although geologists of some companies place unit 4 in the Aspen, possibly because it, too, includes bentonite.

In a recent thesis study of this part of the sequence in the western Green River Basin, Horstman (1966) concluded that the Bear River Formation is almost precisely correlative with the Dakota Sandstone of the Rock Springs uplift and the Aspen Formation with the lower part of the Mowry Shale. Units 1, 2, 3, and the basal part of 4, described above, are assigned by him to the Bear River and Dakota Formations, and much of unit 4 and almost all of 5 to the Aspen and Mowry Formations; he assigns the top part of unit 5 to the Frontier.

Units 1 through 5 are shown on the structure sections (pl. 2) as Aspen and Bear River Formations undivided.

FRONTIER FORMATION

Some 1,100 feet of strata beneath the Hogsback fault is assigned by most petroleum geologists (for example, Howe, 1955, p. 174; Krueger, 1960, p. 196) to the Frontier Formation, but this usage is not universally accepted. By this usage, which seems consistent with that of Cobban and Reeside (1952b, p. 1933), the formation consists mainly of mudstone with three prominent sandstone units that are informally designated, in descending order, the first, second, and third Frontier sands. The top of the first and the base of the third are used as the formation's contacts. Where the upper sandstone is not well developed or evident, electric-log properties are used to select the top.

324-263 O—69——3

Sandstone in the formation, as thus defined, is light to medium gray, fine to medium grained, angular to subangular, poorly to moderately well sorted, and calcareous, and it contains numerous thin layers of medium- to dark-gray mudstone. Mudstone in the formation is medium to dark gray and mainly poorly sorted, and it contains numerous layers of light- to medium-gray siltstone and very fine to fine-grained sandstone, bentonite, carbonaceous mudstone, and traces of coal. The upper 100–150 feet of the formation consists mainly of sandstone that is glauconitic. The top of a 200- to 250-foot-thick dominantly sandstone unit lies in about the middle of the formation, whereas the basal sandstone unit is 50–100 feet thick.

Only the upper part of these strata was assigned to the Frontier Formation by Anderman (1956, sections 60–62), who placed the base of the formation at the bottom of the middle sandstone unit and the beds below in the Aspen Formation. Another, even more restrictive, usage (Hallock, 1960, pl. 1) limits the formation to the middle sandstone unit and assigns the beds above its top to the Hilliard Shale.

Thinning, from the type area in the thrust sheet above the Hogsback fault to the rocks below the fault and eastward, has been attributed to eastward pinching out of uppermost sandstones, so that the top of the formation is progressively older eastward (Cobban and Reeside, 1952b, p. 1933). Thinning has also been attributed to the absence eastward, especially in the Rock Springs uplift, of strata equivalent to the lower part of the type Frontier (Cobban and Reeside, 1952a, pl. 1; Hale, 1960a, p. 133, 1960b, figs. 2, 3; Horstman, 1966). Another interpretation (Love, 1950) is that the Frontier Formation of central Wyoming is equivalent to the lower part of the type Frontier and to the upper part of the Aspen Formation.

HILLIARD SHALE

About 3,300 feet of dark-gray marine mudstone with siltstone and sandstone interbeds overlies the Frontier Formation beneath the thrust fault. The upper part of the unit is exposed along the east side of Hogsback Ridge. The mudstone is dark to very dark gray and weathers light gray; it contains very fine mica flakes and interbeds of bentonite. The thin interbeds of siltstone and very fine and angular-grained sandstone are thinly laminated, light to medium gray, and calcareous. A few prominent units of sandstone with siltstone and mudstone interbeds are present near the middle of the unit and are as much as 40 feet thick.

The thick mudstone sequence has been assigned to both the Hilliard (Schultz, 1914, p. 64; Christensen and Marshall, 1950, p. 106; Hallock, 1960, pl. 1; Murray, 1960, p. 182) and the Baxter (Howe, 1955, p. 174; Krueger, 1960, p. 196) Shales. The type Hilliard in southwesternmost Wyoming is universally regarded as having formed, before thrusting, a continuous rock-stratigraphic unit with the type Baxter in the Rock Springs area. The upper third or so of the Baxter, however, is commonly regarded (Cobban and Reeside, 1952a, pl. 1; Weimer, 1960, fig. 4; Hale, 1960a, p. 134; Smith, 1965, pl. 1, fig. 2), as younger (Montana) than the entire far thicker Hilliard (Colorado). The units have also been regarded as virtually contemporaneous (Dorf, 1955, fig. 1).

The name Hilliard has been used on plate 1 with no strong conviction but in conformance to earlier U.S. Geological Survey mapping (Schultz, 1914, pl. 1) and because of proximity to type locality.

ADAVILLE(?) FORMATION

The highest Cretaceous unit beneath the fault was initially assigned to the Adaville Formation (Schultz, 1914, pl. 1), but more recently it has been almost universally assigned to the Mesaverde Group (Howe, 1955, p. 174; Hallock, 1960, pl. 1; Murray, 1960, p. 182; Krueger, 1960, p. 196) despite infelicitous connotations of that name in Wyoming (Weimer, 1960, p. 18). Choice of a name commonly has implications regarding age. Strata assigned to the Mesaverde Group in the Rock Springs area have been regarded by Cobban and Reeside (1952a, pl. 1), Hale (1960a, p. 133), and Weimer (1960, fig. 4) as younger than those in the Adaville, but they have not been so regarded by Dorf (1955) or Smith (1961, pl. 1).

The name Adaville(?) is tentatively used on plate 1 in conformance to Schultz's mapping (1914, pl. 1) and because of proximity to type locality. Exposures on the east side of La Barge Ridge and directly below the Hogsback thrust fault cannot be traced westward into the belt containing the type Adaville, above the fault, because of structure; the exposures may represent the Shurtliff Member of the Hilliard Shale of Smith (1965, p. 14, fig. 2, pl. 1) rather than the Adaville, although the reported possible Judith River age of identified plants (Privrasky, 1963) suggests otherwise. Relating the sequence to strata eastward, in the Rock Springs area, is hazardous because of rapid lateral facies changes in this dominantly nonmarine unit. The proper stratigraphic designation remains open to more than one interpretation.

Rocks included here in the Adaville(?) Formation are buff- to brown-weathering light- to medium-gray fine- to medium-grained sparsely conglomeratic calcareous sandstone, and light- to dark-gray partly micaceous and partly carbonaceous mudstone with some coal. The proportions of sandstone and mudstone are about equal. Descriptions and analyses of the coal were given by Schultz (1914, p. 98, 111). Irregularity of the unconformity that separates the formation from overlying Tertiary strata results in markedly divergent thicknesses. The formation is commonly less than 500 feet thick, but it is as much as 1,000 feet in some subsurface sections (possibly reflecting tectonic duplication), and it is absent in others where different parts of the Hilliard Shale are directly overlain by Tertiary rock.

TERTIARY SYSTEM

HOBACK(?) FORMATION

The Hilliard Shale and the Adaville Formation are overlain in the subsurface by a thick drab-colored sequence of Tertiary continental strata that is not exposed within the quadrangle. This sequence has been assigned to the Almy Formation (Krueger, 1960) or Almy Member of the Wasatch Formation (Michael, 1960), to the Evanston Formation (Murray, 1960), and to the Fort Union Formation (Berg, 1961; Asquith, 1966). Another unit to which the sequence may be assigned is the Hoback Formation.

The drab-colored sequence consists dominantly of mudstone, claystone, and siltstone with moderate amounts of sandstone, some conglomerate, and a little coal. The mudstone and claystone are mainly very pale greenish gray and light to medium gray but also partly dark green, light to medium brown, maroon, purple, dark gray, and black. The siltstone and sandstone are medium to very light gray, calcareous to friable, angular, partly micaceous and feldspathic, and include both light quartz and dark chert grains ("salt and pepper" sandstone). Pebbles in the conglomerate consist mainly of light-gray to buff quartzite and light- to dark-gray, brown, and tan chert, but include limestone, dolomite, and sandstone. The thin coal seams are lignitic to subbituminous. A few thin beds of light-gray to tan very finely crystalline limestone are also present.

The sequence is 2,500 feet thick in several boreholes within the quadrangle and about 3,000 feet thick to the south in the Pan American Petroleum Co. Slate Creek unit 3 test in the NW¼NW¼ sec. 15, T. 23 N., R. 114 W.

The basal few hundred feet of the sequence differs from the remainder in several holes, particularly along the westernmost part of the Green River Basin. This basal part contains a higher proportion of brown mudstone and includes red to orange-red mudstone and far more abundant conglomerate than the mainly gray to gray-green part of the sequence. The basal part, therefore, resembles beds tentatively assigned by Asquith

(1966, p. 2180) to a lower tongue of the Chappo Member of the Wasatch Formation farther north in the Birch Creek oil and gas field. The basal red unit is present as far south as the Phillips Bridger Lake East 1A in Utah, in sec. 25, T. 3 N., R. 14 E., on the southernmost margin of the Green River Basin. The basal part has not been distinguished from the remainder on the structure sections (pl. 2).

The correct stratigraphic designation for the drab-colored sequence is problematical. Use of the name Almy is inappropriate and is rejected for reasons cited previously (Oriel, 1962b, p. 2163). Moreover, compositions differ markedly from those at the type locality of the Almy.

Many parts of the drab-colored sequence resemble strata of the Evanston, although the Evanston has more siltstone and sandstone and very little pale-green mudstone. Assignment to the Evanston is regarded here as undesirable because the type Evanston lies in the Fossil basin, and the Fossil basin and Green River Basin are not known to have been connected during deposition of these strata. The name Evanston, however, has been used (Schultz, 1914, p. 69) for drab-colored beds exposed near Fall River in the Green River Basin.

Assignment to the Fort Union Formation seems a defensible alternative, for drab-colored detrital strata have been so designated along the south flank of the Green River Basin (Hansen, 1955, 1957). Moreover, compositions in the Fort Hill area resemble those described (Keefer, 1965, p. A28) for the Shotgun Member of the Fort Union in the Wind River Basin. The name Fort Union, however, has been applied widely to very diverse sequences of strata in many individual basins and unfortunately is largely a synonym for Paleocene (for example, Wood and others, 1941; Keefer, 1965, p. A21).

A provisional assignment to the Hoback Formation seems most desirable. The Hoback Formation, named by Eardley and others (1944) and defined by Dorr (1952, p. 64–71), is a thick unit, more than 15,000 feet in its type locality at T. 38 N., R. 114 W., along the Hoback River, Sublette County, Wyo. It extends southward from the northern Green River Basin and undoubtedly connects in the subsurface with strata in the Fort Hill area. Rocks described for both areas are similar, although pale-greenish-gray mudstone is not among the lithologies described in the type locality (Dorr, 1952, p. 66–67), but is among those described from nearby boreholes. As more data become available for the drab-colored sequence, no doubt distinct subfacies and other units will be recognized; perhaps these can be assigned member rank within the Hoback. Distinctive units unlike the one assigned here to the Hoback(?) Formation are present, for example, in the Phillips Bridger Lake East 1A directly north of the Uinta Mountains. The basal red unit there is overlain by a unit of very dark gray thinly laminated claystone and siltstone reminiscent of the Waltman Shale Member of the Fort Union Formation (Keefer, 1965). The dark-gray claystone is overlain by a unit of well-indurated partly siliceous sandstone.

The upper part of the Hoback (?) Formation in the Fort Hill area probably grades westward into red beds and variegated mudstones assigned to the Chappo Member of the Wasatch Formation. This relation, suggested but not proved by discontinuous exposures along Chappo Gulch and by subsurface lithologies, is depicted on the structure sections (pl. 2).

Few fossils have been found in strata assigned to the Hoback(?) Formation, and these suggest a late Paleocene age. Mollusks from drill cores are cited by Privrasky (1963, fossil loc. 7) and resemble those in the Chappo Member of the Wasatch Formation (Oriel, 1962b, p. 2167–2168). Pollen grains have been identified in rotary cuttings from depths of 2,940–2,960, 3,390–3,415, 3,680–3,700, and 3,800–3,830 feet in the Pan American Petroleum Corp. Slate Creek unit 2, in sec. 11, T. 23 N., R. 114 W. The pollen grains include *Inaperturopollenites dubius*, *I. hiatus*, *Triporopollenites*, *Subtriporopollenites*, *Momipites*, and "*Verrucatopollenites*" sp. These were assigned (G. O. W. Kremp, written commun., Sept. 21, 1960) a Paleocene age; the last form is not known from horizons older than the Sentinel Butte Member (late Paleocene) of the Fort Union Formation. Unpublished oil company studies confirm a late Paleocene age for most of the strata but suggest that some may be as old as middle Paleocene. The age of the unit, therefore, is the same as for much of the type Hoback (Dorr, 1952, p. 68; 1958, p. 1229–1232).

WASATCH FORMATION

Exposures of the Wasatch Formation are among the most extensive in the quadrangle. Five members, previously described (Oriel, 1961, 1962b), have been mapped (pl. 1; fig. 3): (1) the Chappo Member at the base, (2) the La Barge Member, (3) a middle tongue of the Wasatch, designated the New Fork Tongue, bounded by Green River strata, (4) an upper tongue not formally named, and (5) an unnamed conglomerate member. A brief summary description of each is included here for the reader's convenience.

The Chappo Member (Oriel, 1962b, p. 2164) is the lower part of the main body of the Wasatch Formation and includes heterogeneous sequences of red, maroon, reddish-brown, orange, ocher, tan, and gray mudstone; white, tan, brown, gray, and red sandstone and siltstone; gray, brown, and red conglomerate; and white to med-

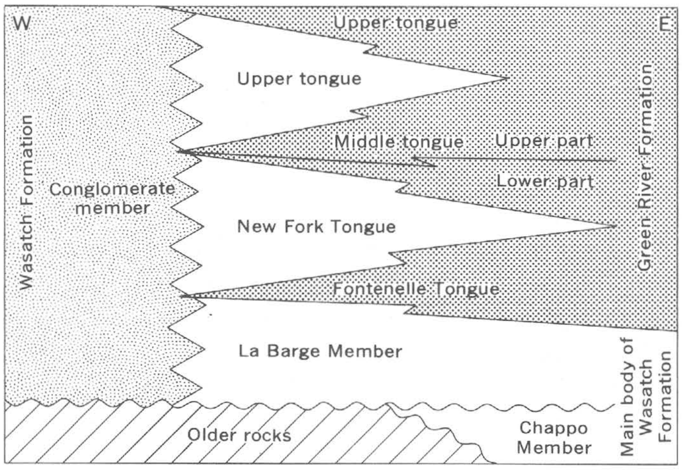


FIGURE 3.—Idealized section of Wasatch and Green River Formations in the Fort Hill quadrangle.

FIGURE 4.—Pisolites in limestone of the Chappo Member on La Barge Ridge in sec. 18, T. 26 N., R. 113 W.

ium-gray pisolitic and conglomeratic limestone. The pisolites are commonly 1 inch or less in diameter but are as much as 5 inches (fig. 4), and many have nuclei of gastropod shells or pebbles of older limestone or quartzite. The Chappo, which is more than 1,200 feet and possibly 2,000 feet thick, is separated from the overlying La Barge Member by an angular unconformity well exposed along the south fork of Chappo Gulch in the NW¼SE¼NE¼ sec. 17, T. 26 N., R. 113 W. (fig. 5). The age of the Chappo, based on fossils (Oriel, 1962b, p. 2167–2168), is latest Palocene and earliest Eocene.

The La Barge Member (Oriel, 1962b, p. 2168) is the upper part of the main body of the Wasatch. It consists of mainly red, purple, and orange but also green, yellow, tan, brown, and gray mudstone (fig. 6); light-gray, yellow, buff, red, and brown sandstone and silt-

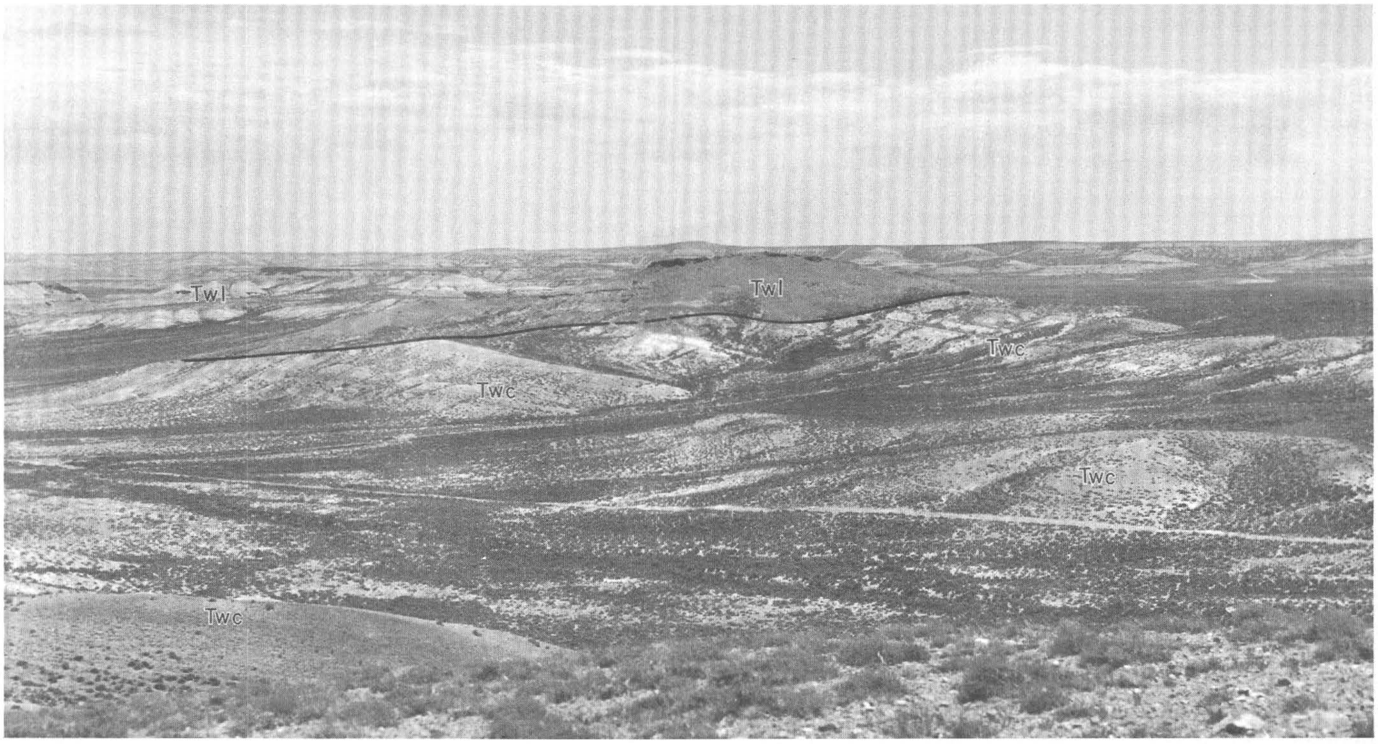


FIGURE 5.—Angular unconformity in the Wasatch Formation between the La Barge Member (Twl), dipping gently eastward, and the underlying Chappo Member (Twc), dipping more steeply southward along the south fork of Chappo Gulch, in the NW¼SE¼NE¼ sec. 17, T. 26 N., R. 113 W. View southeastward.

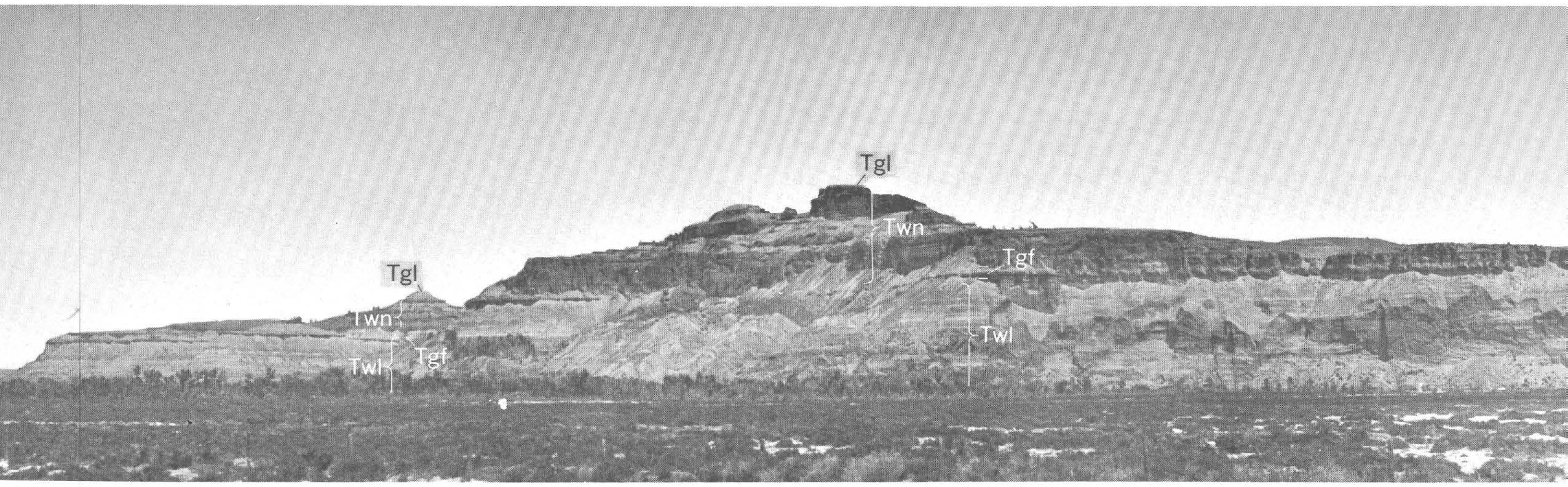


FIGURE 6.—Excellent but partly slumped exposure of units of the Wasatch and Green River Formations on the east side of Green River opposite the town of La Barge. View is northeastward. The lower half consists of banded mudstone and sandstone in the La Barge Member of the Wasatch Formation (Twl). The upper half consists of the very thin ledge-forming Fontenelle Tongue of the Green River Formation (Tgf), the New Fork Tongue of the Wasatch Formation (Twn), dominated by ledges of brown-weathering sandstone, and a cap of algal limestone at the base of the middle tongue (Tgl) of the Green River.

stone; gray to brown conglomerate (fig. 7) with rounded fragments of Paleozoic and Mesozoic rock; and light-gray marlstone and limestone. The La Barge Member, which is as much as 1,500 feet thick, is bounded above by the lowest beds of the Green River Formation. The age of the La Barge Member is middle (?) (Lysite (?)) and late (Lost Cabin) early Eocene.

The New Fork Tongue (Donavan, 1950, p. 64) is separated from the La Barge Member by the Fontenelle Tongue of the Green River Formation. The New Fork Tongue consists of red, maroon, orange, and gray (on the west) and green and gray (on the east) mudstone with numerous layers and lenses of yellow, buff, brown, and gray partly micaceous and partly feldspathic locally conglomeratic very fine to medium-grained sandstone (figs. 8, 9) (Oriel, 1961). The composition of the tongue is affected locally by the composition of older units, which it overlaps (Bradley, 1964, p. A27). The unit is about 250–300 feet thick where it is fully developed, and it is late early Eocene (Lost Cabin) in age (Gazin, 1952, p. 12–13; 1962). Whether the New Fork Tongue is precisely correlative with the Cathedral Bluffs Tongue on the east side of the Green River Basin or with an older unit is not agreed on (Bradley, 1964, p. A27–A28). Correlations of subsurface sections led W. C. Culbertson (oral commun., Apr. 26, 1966) to conclude that the New Fork is largely older than the Cathedral Bluffs. Fossil vertebrates found in the New Fork during the present study included *Hyracotherium* sp., *Phenacodus* sp., *Lepisosteus* sp., and *Baptemys* sp. (D. H. Dunkle and P. H. Vaughn, written commun., Oct. 15, 1957). Fossil pollen grains and spores included *Monoletes* sp., *Triletes* sp., *Pityosporites* cf. *labdacus*, *Inaperturopollenites* cf. *incertus*, *Monocolpopollenites*, *Tricolpopollenites asper*, *T. densus*, *T.* sp., *Triporopollenites simpliformis*, *Trivestibulopollenites betuloides*, *T.* sp., *Alnipollenites*, *Polyporopollenites* cf. *validus*, *P. carpinoides*, *Periporopollenites* (E. B. Leopold, written commun., Jan. 27, 1959), *Aralia*, *Pinus* cf. *Salix* (E. B. Leopold, written commun., Sept. 23, 1958), *Aquilapollenites "symetricus,"* cf. *Rhoiptelia*, *Thouinia*, and *Lomatia* (E. B. Leopold, written commun., Oct. 9, 1958). Mollusks found southeast of the quadrangle, in beds assigned to the New Fork but believed to be intertonguing with the Green River Formation, include *Unionidae?* undet., *Bellamya paludinaeformis* (Hall), *Elimia?* cf. *E. nodulifera* (Meek), and *Physa* (Cenozoic locs. 22012 and 22013, D. W. Taylor, written commun., Apr. 13, 1960).

The unnamed upper tongue of the Wasatch is separated from the New Fork by the middle tongue of the Green River Formation (fig. 10). The upper tongue is about 200 feet thick and consists of green and gray mudstone and yellow to brown and gray partly micaceous and partly feldspathic locally conglomeratic fine- to medium-grained sandstone (fig. 11). The strata are assigned to the Wasatch despite the absence of reds (Oriel, 1961) as in other parts of the region (Bradley, 1964, p. A21; Culbertson, 1965, p. D140). Fossil snails found within the unit (Cenozoic loc. 22007) were identified as *Glypterpes veternus* (Meek and Hayden) which "does not have a firmly established range but is so far known only from early Eocene deposits" (D. W. Taylor, written commun., Apr. 13, 1960). *Rhizophagites* spores and pollen grains of Gramineae have also been recognized in the unit (E. B. Leopold, written commun., Sept. 23, 1958). The age of the upper tongue is not firmly established; it may be either latest early or early middle Eocene. The upper tongue has been inferred, conflictingly, to be restricted to the northwestern part of the Green River Basin (Bradley, 1964, p. A20) and to connect southward with a thick wedge of detrital strata derived from the Uinta Mountains (Lawrence, 1963, p. 157).

The unnamed conglomerate member of the Wasatch Formation (Oriel, 1962b, p. 2170–2171) is a coarse peripheral facies along the western margin of the Green River Basin. The member consists of dark-brownish-red and brick-red interbedded diamictite (Tracey and others, 1961), conglomerate (fig. 12), sandstone, and mudstone. Abundant pebbles, boulders, and blocks were apparently derived from nearby exposures of the Nugget, Ankareh, Wells, Twin Creek, Thaynes, Phosphoria, and Madison Formations, and from several Cretaceous formations. Incomplete sections suggest that the member may be several thousand feet thick in places. The member grades eastward into the La Barge Member and into the New Fork Tongue; although available exposures do not demonstrate it, a similar relation is inferred for the upper tongue of the Wasatch. Conglomeratic parts of the Chappo Member are not included in the conglomerate member on plate 1. The conglomerate member yielded no fossils and is assigned, on the basis of stratigraphic relations (fig. 3), a late

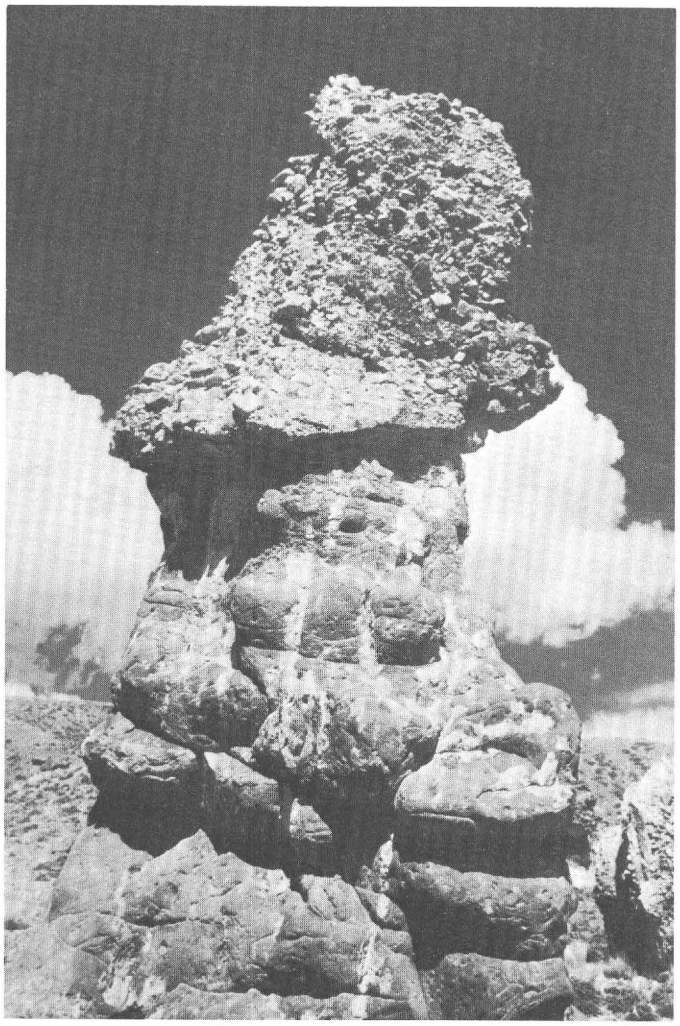


FIGURE 7.—Pedestal formed by resistant conglomerate layers above less resistant red muddy siltstone of the La Barge Member of the Wasatch Formation in the SW¼NE¼ sec. 14, T. 27 N., R. 114 W., north of the Fort Hill quadrangle.

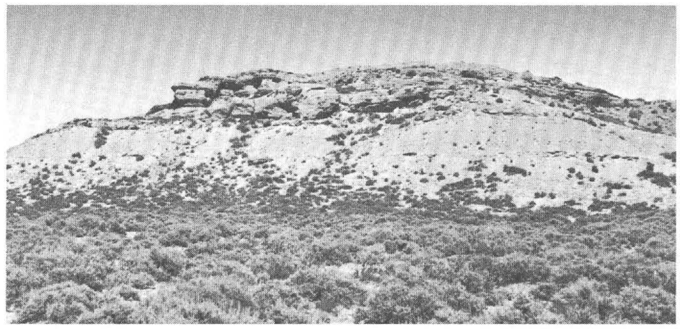


FIGURE 8.—A common type of exposure of the New Fork Tongue of the Wasatch Formation. Green and gray mudstone is overlain by lenticular beds of brown- and gray-weathering gray sandstone in the NE¼ sec. 22, T. 25 N., R. 114 W.

FIGURE 9.—Sandstone in the New Fork Tongue of the Wasatch Formation containing loglike concretionary zones somewhat better cemented with calcite than surrounding rock; exposure in the center of sec. 5, T. 24 N., R. 114 W.

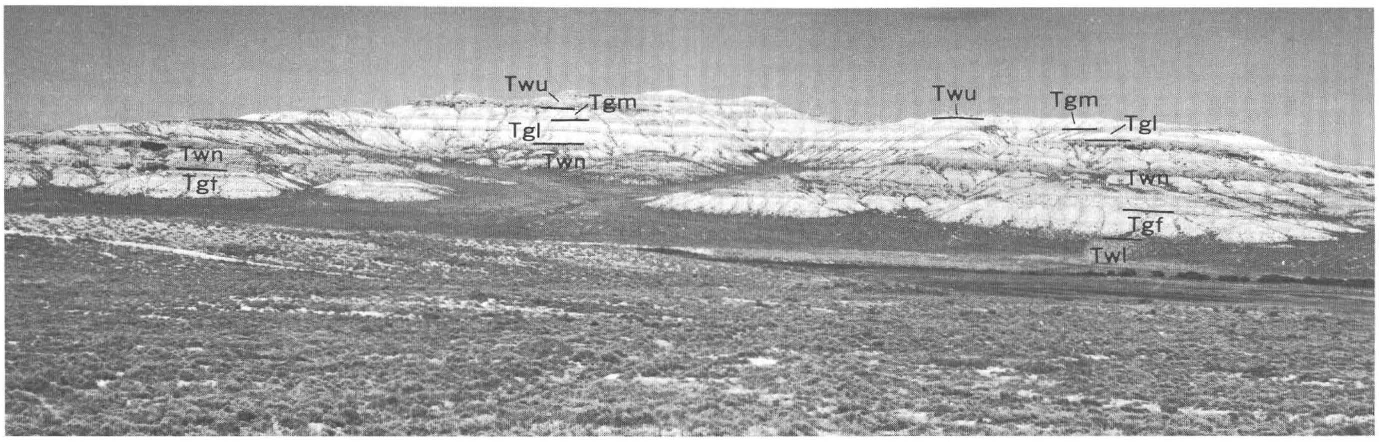


FIGURE 10.—Sequence of Wasatch and Green River stratigraphic units exposed in the butte in secs. 5 and 6, T. 25 N., R. 113 W., and secs. 31 and 32, T. 26 N., R. 113 W. Poor exposures of the La Barge Member (Twl) at the base are overlain successively by the Fontenelle Tongue of the Green River (Tgf), the New Fork Tongue of the Wasatch (Twn), the lower (Tgl) and upper (Tgm) parts of the middle tongue of the Green River, and the upper tongue of the Wasatch (Twu). View is northeastward from a point 200 yards northwest of the Facenelli Ranch.

early Eocene (Lost Cabin) age, although parts may be older and parts may be younger.

GREEN RIVER FORMATION

Three tongues of the Green River Formation were mapped in the Fort Hill quadrangle. Further subdivision seems desirable in view of the contrasting lithologies in the lower and upper parts of the middle tongue of the Green River (fig. 3).

The Fontenelle Tongue (fig. 13; Donavan, 1950, p. 63–64; Oriel, 1961; Bradley, 1964, p. A34–A35) is the lowest of the Green River tongues and conformably overlies the La Barge Member of the Wasatch Formation. The tongue consists of very thinly laminated light-gray to white muddy limestone (fig. 14), light-gray to buff and tan marlstone, buff to gray calcareous very fine grained sandstone, and light-gray calcareous mudstone. These lithologies grade southward (Lawrence, 1963, p. 153) and westward into light-gray to tan ostracodal and gastropodal limestone in which the snails *Goniobasis* and *Viviparus* are abundant. The thickness of the tongue ranges from an edge to about 150 feet; thicknesses of 50–60 feet are most common in exposures along the western margin of the basin. The Fontenelle Tongue is late early Eocene (Lost Cabin) in age, based on vertebrate fossils found in bounding units of the Wasatch Formation. The fossil snail *Elimia*(?) *nodulifera* (Meek) was found in the Fontenelle Tongue (Cenozoic loc. 22006, D. W. Taylor, written commun., Apr. 13, 1960). Well-preserved pollen grains and spores identified (E. B. Leopold, written communs., Sept. 23, 1958; Jan. 27, 1959) from the unit include the following: *Eucalyptus*, *Platycarya*, *Quercus* cf. *velutina*, *Alnus*, *Ostrya* cf. *guatemalensis*, cf. *Sterculia*, *Euphorbia*, *Zelkova* cf. *carpinifolia*, *Celtis* cf. *occidentalis*, *Triletes*, *Pityosporites* cf. *labdacus*, *Sequoi* sp., *Ephedra* "*assymetrica*" Scott, *Tricolpopollenites asper*, *T. densus*, *Triporopollenites simpliformis*, *Triatriopollenites* cf. *rurensis*, *T. excelsus*, *Trivestibulopollenites betuloides*, *Alnipollenites*, *Polyporopollenites* cf. *validus*, *Periporopollenites*, *Subtriporopollenites* cf. *simplex*, *Intratriporopollenites* cf. *kettigensis*, and *Polyadopollenites* cf. *multipartitus*. Also recognized was the dinoflagellate *Wetzeliella* cf. *glabra* Cookson. Ostracodes identified from the unit include *Cypridea bisulcata*? Swain and "*Hemicyprinotus*" *watsoensis* Swain (I. G. Sohn, written communs., May 1, 1958; Feb. 12, 1964).

The twofold subdivision of the middle tongue of the Green River is strikingly apparent in the quadrangle. The lower part of the tongue forms brilliantly bluish-white-weathering slopes that are perceptible from distances of several miles (fig. 10) and are easily traced on aerial photographs. The lower part was distinguished and mapped by Donavan (1950, pl. 1, p. 65), who correctly assigned the beds to the Laney Member, before the evaporite-bearing part of the Green River Formation was renamed the Wilkins Peak Member (Bradley, 1959). The upper part of the middle tongue, in contrast, forms tan- to brown-weathering slopes.

The lower part of the middle tongue consists of abundant white-weathering mainly low-grade but partly high-grade oil shale; white to light-gray limestone and marlstone; light-gray to tan calcareous mudstone and "papery shale" (Bradley, 1964, p. A19); light- to medium-gray very fine to coarse-grained thinly laminated calcareous sandstone; light-gray to tan calcareous chert and siliceous limestone; and tan to brown buff-weathering ash beds (fig. 15). A few of the siliceous

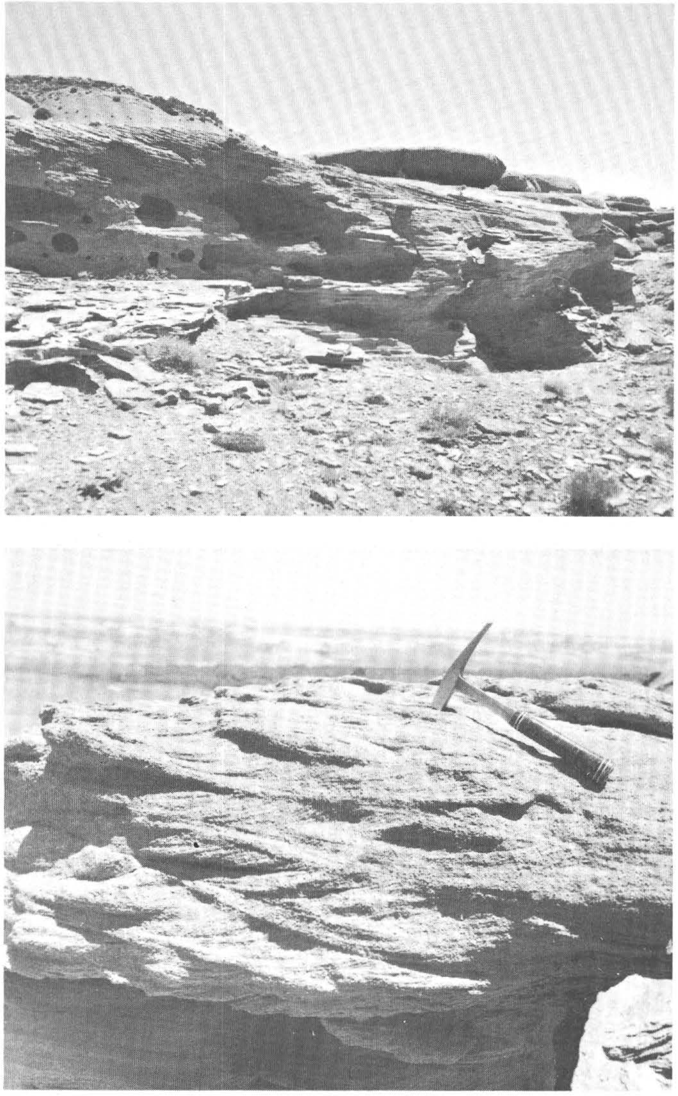


FIGURE 11.—Crossbedded partly conglomeratic sandstone in the upper tongue of the Wasatch Formation. Upper photograph, southeast of road junction in sec. 9, T. 24 N., R. 113 W.; lower, near base of unit in SE¼ sec. 5, T. 24 N., R. 114 W.

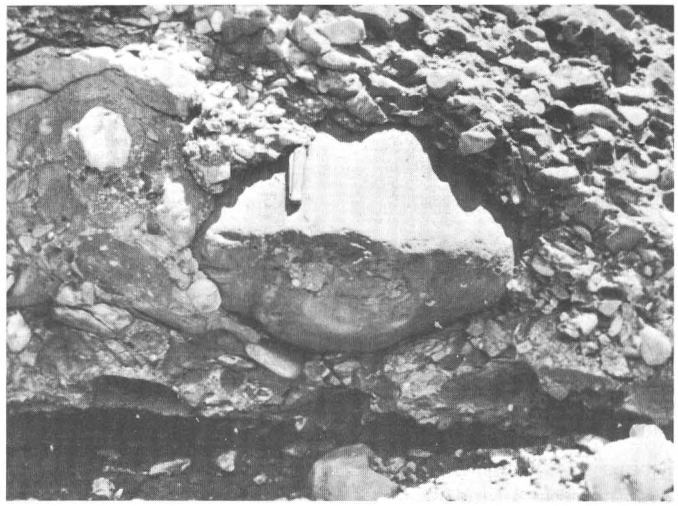


FIGURE 12.—Very poorly sorted conglomerate in the conglomerate member of the Wasatch Formation near Graphite Hollow, NW¼NW¼NW¼ sec. 26, T. 27 N., R. 114 W.

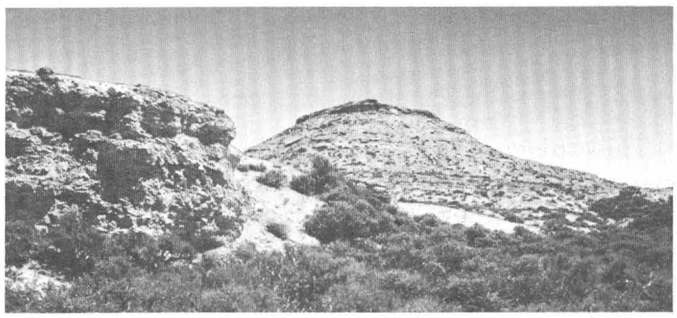


FIGURE 13.—Type locality of Fontenelle (Donavan, 1950, p. 63) Tongue of the Green River Formation in NW¼ sec. 13, T. 24 N., R. 115 W. Only the basal part (strata in left foreground) of Donavan's type Fontenelle is retained in this unit; the remainder (most of the rocks in the background) is assigned to the New Fork Tongue of the Wasatch Formation (Oriel, 1961).

beds (whose composition has not been checked either in thin section or by analysis) are so fine grained as to be porcellaneous. Slabs of marlstone with casts of the unknown salt illustrated by Bradley (1964, fig. 13) were found at several localities. The salt casts and the abundance of silica and of oil shale suggest that the lower part of the middle tongue is equivalent, both compositionally and temporally, to the Wilkins Peak Member of the Green River Formation, as suggested by Bradley (1964, p. A38) and W. C. Culbertson (oral commun., Apr. 27, 1966). Uraniferous phosphatic layers (Love, 1964) were sought with a scintillometer, but none were recognized in this unit or in other parts of the formation. The lower part of the middle tongue interfingers with the upper part, as depicted in figure 3, and is particularly well displayed in the bluffs along Fontenelle Creek in the SW¼ sec. 2, T. 24 N., R. 114 W. The lower part of the tongue is as much as 120 feet thick in the eastern part of the quadrangle.

The upper part of the middle tongue consists dominantly of marlstone, siltstone, and sandstone with some layers of limestone, claystone, and mudstone. Alternations of these compositions are in very thin laminae (fig. 16). The shades of light gray and buff of fresh rock give way to shades of brown—from very light tan to dark brown, pinkish tan, and reddish brown—on weathered surfaces. A few thin beds of oil shale and tuffaceous sandstone are also present, particularly near the base of the upper part of the middle tongue. Fossils found in the unit were well-preserved plants identified as *Lygodium kaulfussi* Heer, *Equisetum winchesteri* Brown, *Typha lesquereuxi* Cockerell, *Lemna scutata*

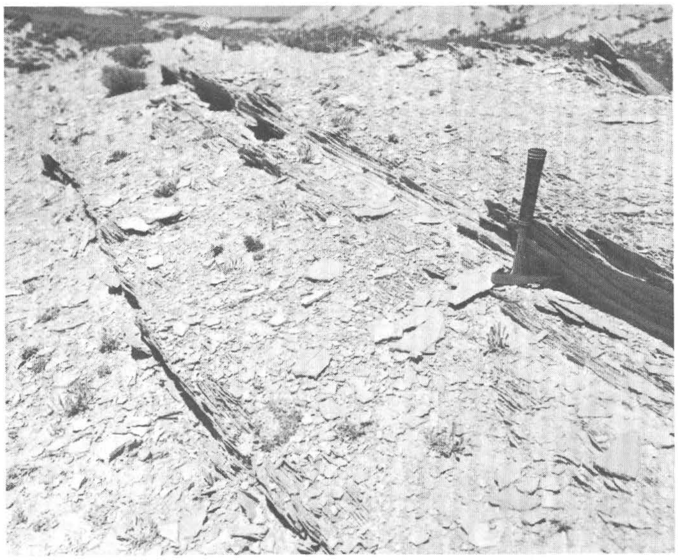
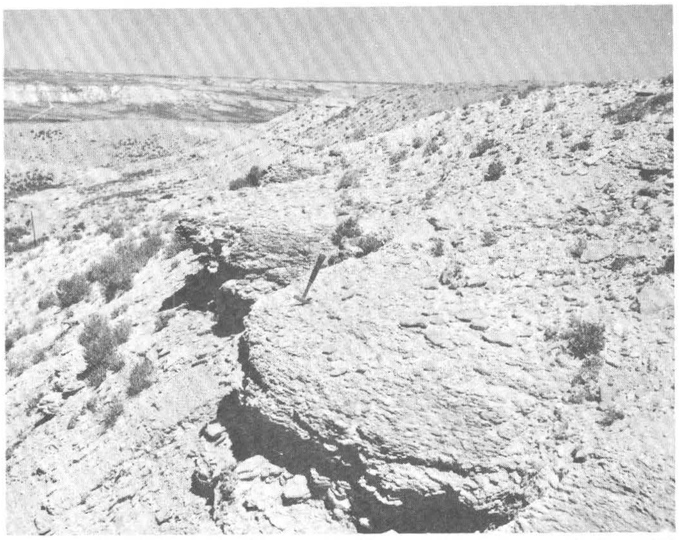


FIGURE 14.—Steeply dipping thinly laminated light-gray muddy limestone in the Fontenelle Tongue of the Green River Formation. The beds dip 25° E. in SE¼SW¼NE¼ sec. 22, T. 25 N., R. 114 W.



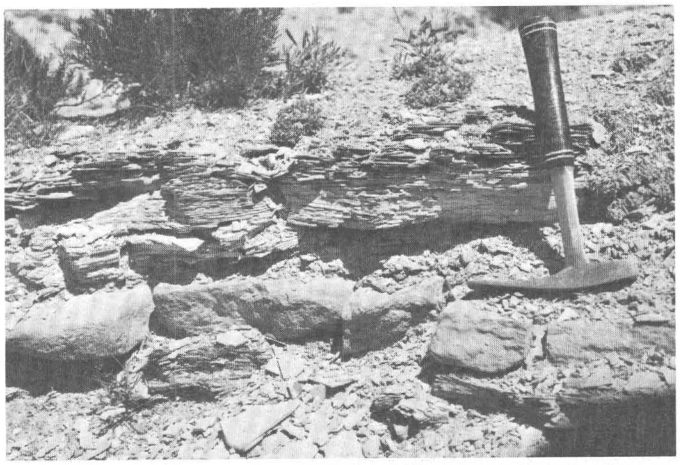


FIGURE 15.—Oil shale and volcanic ash in the lower part of the middle tongue of the Green River Formation. Upper photograph shows ledge of oil shale near the bottom of the unit east of the center of sec. 5, T. 24 N., R. 114 W.; lower photograph, ash bed within a sequence of calcareous laminated oil shale of low grade near the top of the unit in NW¼ sec. 4, T. 24 N., R. 113 W.

Dawson, *Juglans schimperi* Lesquereux, *Aralia wyomingensis* Knowlton and Cockerell, and *Cucurbita glandulosa* Brown (R. W. Brown, written commun., Aug. 11, 1957). Fossil insect cases have also been found in topmost limestone beds of the middle tongue. Although compositions in the upper part of the middle member resemble those common in the Laney Member of the Green River Formation, W. C. Culbertson (oral commun., Apr. 27, 1966) believes, on the basis of regional correlations, that the unit is temporally equivalent to the Wilkins Peak Member where the latter is most fully developed. Thicknesses of the upper part are as much as 175 feet.

Both parts of the middle tongue grade westward into ostracodal, gastropodal, and algal limestones of lacustrine near-shore facies (Bradley, 1926). Where the middle tongue and the Fontenelle Tongue lap onto older rocks (fig. 17), hillwash and talus of older rock are cemented by Green River limestone, recording an exhumed Eocene erosion surface. The middle tongue may be of either latest early or middle Eocene age.

The upper tongue of the Green River Formation is characterized by abundant tan- to medium-brown-weathering algal limestone (fig. 18) and calcareous sandstone and siltstone. Also present are thinly and evenly bedded to laminated tan, yellow to brown, and gray limestone, marlstone, and mudstone; ostracodal and gastropodal limestone; and siliceous limestone with some buff, purplish gray, brown, and gray chert. Rock compositions suggesting near-shore shallow-water environments (Bradley, 1926) are widely distributed, rather than restricted solely to westernmost exposures as in the underlying tongues; an inference is that the depositional lake was filled with sediment and was very shallow by the time the upper tongue was deposited. Fossils identified from the unit include pollen grains of *Picea*, *Celtis* cf. *occidentalis*, *Alnus*, *Platycarya*, and *Tsuga*, filamentous algae (E. B. Leopold, written commun., Sept. 23, 1958), the snail *Bellamya* indet. (D. W. Taylor, written commun., Apr. 13, 1960), and the ostracodes *Procyprois ravenridgensis* Swain, "*Hemicyprinotus*" *watsoensis* Swain, and an undescribed genus (I. G. Sohn, written communs., May 1, 1958; Feb. 12, 1964). The upper tongue, which has maximum thicknesses of 180–250 feet, probably is correlative with the

Laney Member of the Green River Formation and of middle Eocene age.

BRIDGER FORMATION

Where the Bridger Formation is exposed in the east-southeastern part of the quadrangle, only the lower part is present. Bridger exposures consist dominantly of dark- to light-green and greenish-gray mudstone, and brown-weathering, light-greenish-gray sandstone with abundant hornblende crystal laths, feldspar, and tuff fragments, but they also contain beds of very sandy muddy ostracodal limestone. The sandstone and mudstone consist of both volcanic and other detritus (Bradley, 1964, p. A49). Near the base of the unit are thin to medium laterally extensive beds of buff to tan algal limestone indistinguishable from that in the Green River Formation.

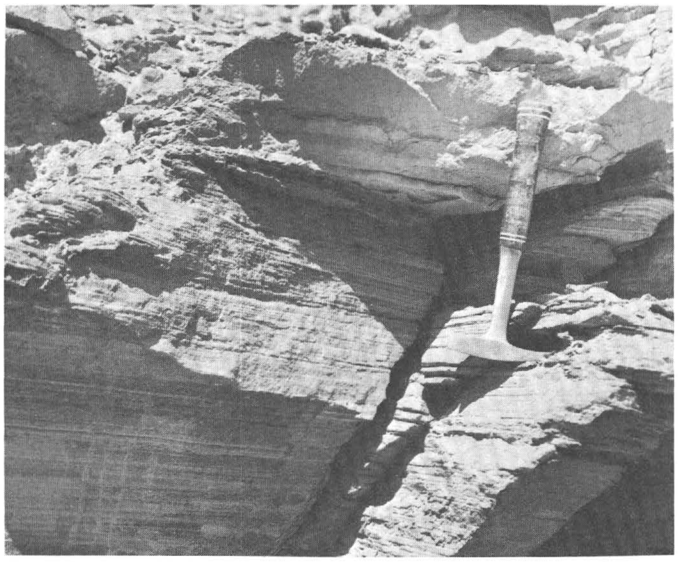


FIGURE 16.—Pink, tan, gray, and white laminae of marlstone, siltstone, sandstone, and limestone in the upper part of the middle tongue of the Green River Formation along Fontenelle Creek east of the Fort Hill quadrangle.

The base of the Bridger Formation is transitional with the underlying Green River Formation, and the position of the contact is subject to more than one interpretation. The mapped contact shown on plate 1 is the base of the lowest tuffaceous greenish-gray mudstone or sandstone, below which rocks consist dominantly of tan to brown limestone; the contact coincides with a prominent change in topographic slope.

Fossils found during the study included the ostracodes *Procyprois ravenridgensis* Swain, "*Hemicyprinotus*" *watsoensis* Swain, and an undescribed species of *Pseudocypris*? (I. G. Sohn, written communs., May 22, 1959; Feb. 12, 1964) and unidentified algae. The Bridger is of middle Eocene age.

QUATERNARY SYSTEM—UNCONSOLIDATED DEPOSITS

The unconsolidated Quaternary deposits shown on plate 1—alluvium, colluvium, and terrace gravels—are conventional units requiring no comment.

Several other Quaternary units were recognized but not mapped in this study. One consists of thin to thick accumulations of very light gray to white calcareous silt formed by the disaggregation of siltstone, marlstone, and mudstone in the Green River Formation. The presence of this material becomes strikingly apparent to one who drives over the formation, for clouds of the pervasive silt enter previously unrecognized crevasses of any motor vehicle.

Another unmapped Quaternary deposit is gravel on the conglomerate member of the Wasatch Formation. Ablation of sand and mud matrix produces lag concentrates or gravel pavements on exposed surfaces. Where these surfaces are extensive, as on the east side of Slate

FIGURE 17.—Overlap of the La Barge Member of the Wasatch Formation (Twl) by the Fontenelle Tongue of the Green River Formation (Tgf), which rests directly on the Thaynes Limestone (TRt) in the NW¼ sec. 22, T. 25 N., R. 114 W. View is northward across Dry Hollow.

FIGURE 18—Algal limestone mound, 8 feet in diameter, in the upper tongue of the Green River Formation on the east side of U.S. Highway 189, 1 mile south of Slate Creek (south of the quadrangle). Lower view is closeup of the surface of an algal mound.

Creek Ridge and of Miller Mountain, they resemble pediments.

Another unmapped Quaternary gravel deposit obscures parts of the Bridger Formation south of Fontenelle Creek. This gravel is interpreted as very high terrace gravel developed on both sides of the Green River, whose course lies east of the quadrangle. The gravel differs from any other in the quadrangle by the ubiquity of brown iron oxide staining of pebbles and by the abundance of gneiss, schist, and granitoid pebbles, derived, no doubt, from the Wind River Range. This gravel seems rather old; it probably is of Pleistocene age, but may be older.

STRUCTURE

Newly gained information in the Fort Hill area, as at other places along the front of the Idaho-Wyoming thrust belt, indicates that structural relations are more complex than recognized previously. The degrees of complexity manifest on the structure sections (pl. 2) are, in a sense, an index to available data. The sections are most complex and intricate where data are most abundant; they are simplest where information is lacking. The reader is cautioned, therefore, that smooth uninterrupted lines on parts of the sections may not reflect simple structure, but rather ignorance. Continued drilling in the region will no doubt reveal additional folds and faults not recognized here; their locations will be critical to further exploration.

The dominant structure, by far, is the Hogsback thrust fault. Overlying thrust faults have smaller stratigraphic throws; they probably moved shorter distances and no doubt are merely slices of the major fault. The presence of these overlying thrust slices and other factors greatly modify previous estimates of the amounts of closure along the Wyoming and Meridian anticlines, both of which have been drilled unsuccessfully for oil and gas. Beneath the Hogsback fault is another thrust fault, the La Barge, of considerable throw and extent. All these structures are cut by younger, more steeply dipping normal and reverse faults.

HOGSBACK THRUST FAULT

The Hogsback thrust fault (Armstrong and Oriel, 1965, footnote 4, p. 1857) is the same as that previously called the Darby fault south of Snider Basin by Schultz (1914, pl. 1) and by subsequent workers (for example, Bertagnolli, 1941, p. 1738).

The Hogsback fault is exposed in the northeastern part of the quadrangle, on the east flank of Hogsback Ridge, where the middle part of the Cambrian Gros Ventre Formation rests directly on the Adaville(?) Formation (fig. 19). The stratigraphic throw of the fault here is about 18,000 feet, depending upon thicknesses used for the Cretaceous units; thicknesses of the units above and below the fault have been averaged to arrive at the 18,000-foot figure. The magnitude of the throw, therefore, is comparable to that of other major thrust faults in Idaho and Wyoming (Rubey and Hubbert, 1959, fig. 7).

The Hogsback fault is easily recognized in at least three holes drilled within the quadrangle. In the Max Pray Government-Barbari 1 (map loc. 37, table 1), the middle part of the Gros Ventre Formation rests on the Adaville(?) Formation at a depth of 5,450 feet, or 1,698 feet above sea level; the stratigraphic throw is the same as at the exposures on Hogsback Ridge. In the Carter Meridian Ridge 1 (map loc. 38, table 1), the middle part of the Gros Ventre Formation rests on the top of the Frontier Formation at a depth of 12,952 feet,

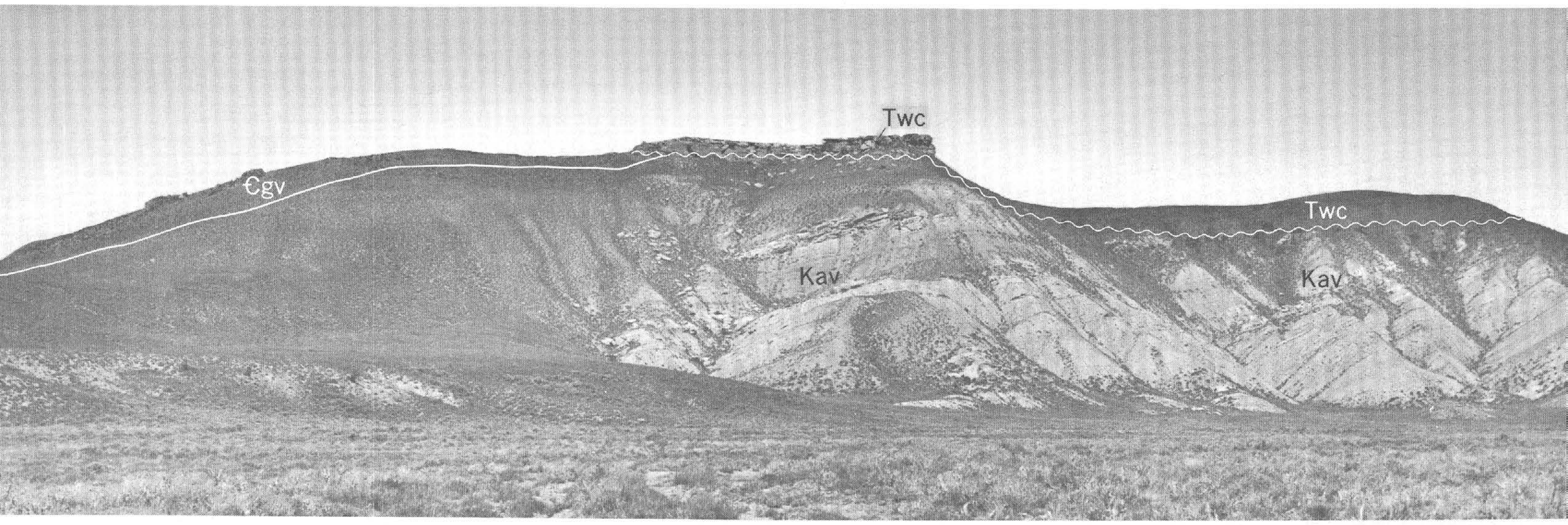


FIGURE 19.—The Hogsback thrust fault unconformably overlain by the Chappo Member of the Wasatch Formation (Twc). The Death Canyon Member or middle part of the Gros Ventre Formation (€gv) overlies a sequence of Cretaceous strata that includes the Adaville(?) Formation (Kav). Flat-lying Chappo strata cover Cambrian rocks above the fault, the trace of the fault, and Cretaceous strata below, all dipping to the west. West-northwestward view of east side of La Barge Ridge, the southern part of Hogsback Ridge, in secs. 18 and 19, T. 26 N., R. 113 W.

or 4,894 feet below sea level; the stratigraphic throw is about 13,000 feet. In the Phillips Fort Hill 1A (map loc. 35, table 1), the middle part of the Gros Ventre Formation rests on the middle part of the Frontier Formation at a depth of 13,694 feet, or 5,572 feet below sea level; the stratigraphic throw is about 12,500 feet.

The foregoing data help establish, beyond question, the gentle dip previously inferred (Schultz, 1914, pl. 3, sections *E–E′*, *F–F′*) for the fault within the quadrangle. The average dip between fault exposures and the Max Pray test is 29° over a distance of 1.9 miles. The average dip between exposures and the Carter test is 15° over a distance of 8.8 miles. The difference between the two average dips confirms the inferred sled-runner or listric (Bally and others, 1966, p. 349) form of the fault in section (pl. 2); the average dip of the fault between the two holes is only 10°. The average dip between the inferred pre-Tertiary trace of the fault (pl. 1) and the Phillips test is 22° over a distance of 5.2 miles. The dip of the Hogsback fault decreases from about 50° at the surface to 10° at moderate depth. No information is available for the dip of the fault west of the quadrangle. A possible inference, rejected here, is that the fault may steepen westward toward the axis of the Lazeart syncline. However, the syncline is probably considerably older than movement on the Hogsback fault (Oriel and Armstrong, 1966, p. 2616). The difference in dip between the east flank of the syncline and basal strata of the Hogsback fault probably reflects wedging out of the thrust sheets above the Hogsback fault.

The distance the Hogsback thrust plate moved eastward is obviously considerable. The effect of alternative interpretations in preparing structure sections on estimates of lateral transport is discussed by Rubey and Hubbert (1959, p. 186). Data provided by the Carter test well indicate that the minimum possible amount of lateral transport of the plate there is 8.8 miles plus the amount of throw, 3 miles, or about 12 miles; this estimate is extremely conservative. An alternative order of magnitude is suggested by the rate of decline in stratigraphic throw between the Max Pray and the Carter tests. The throw declines about 5,000 feet in 6.9 miles, or 725 feet per mile. If this rate of decline in throw remains constant downdip (for which there is neither any assurance nor necessity), then the minimum lateral transport of the plate was 25 miles. Neither estimate takes into account probable movement along bedding surfaces, across which there is no stratigraphic throw. The range in possible transport distances of the thrust plate of 12–25 miles is therefore regarded as conservative, and the figures are of the same order of magnitude as those for other faults in the thrust belt (Rubey and Hubbert, 1959, p. 187). A minimum distance of 20 miles seems both conservative and reasonable to me, although tectonic transport may have been considerably greater.

The Hogsback fault probably moved in Paleocene time. The youngest beds cut by the fault are the Adaville(?) Formation of Late, but not latest, Cretaceous age. Westward-dipping Cambrian rocks, the fault, and underlying Cretaceous rocks are overlain with angular

TABLE 1.—*Wells drilled for oil and gas in the Fort Hill quadrangle through mid-1966*

[Data are from files of U.S. Geological Survey Conservation Division and from Petroleum Information, Inc. Queries in "Total depth" and "Lowest rocks reported" columns indicate information not provided or uncertainties raised by inconsistencies in available data.]

Map No. (pl. 1)	Location			Operator	Well No.	Farm, unit, or area	Date completed	Total depth (feet)	Lowest rocks reported	Production, reported producing formation
	T.N.	R.W.	Section							
1	24	113	C NW¼NW¼ sec. 28	Belfer-Justheim (Tom Golden).	J-2	Government (Fontenelle area).	1953	6,513	Mesaverde Fm	
2	24	114	C NE¼NW¼ sec. 2	Pan American Petroleum Corp.	3	Willow Creek unit	1959	3,450	Hilliard Sh	
3	24	114	C NW¼NW¼ sec. 3	H.R. Homer	1	Herschler	1949	2,456(?)	Wasatch Fm	
4	24	114	E½NE¼NW¼ sec. 3	Pan American Petroleum Corp.	1	Willow Creek unit	1957	3,010	Hilliard Sh	Gas, Fort Union Fm.
5	24	114	C NW¼NW¼ sec. 11	do	2	do	1958	3,651	do	Do.
6	24	114	C SE¼NE¼ sec. 11	George Perry and Son	1	Fontenelle area	1950	853	Wasatch Fm	
7	24	114	E½NW¼NW¼ sec. 25	Belco Petroleum Corp	4	Slate Creek unit	1959	4,071	Baxter(?) Sh	
8	24	115	NE¼SW¼NW¼ sec. 1	Chris Vollmer & A. Gorges	1	Wilde	1949	422	Wasatch Fm	
9	24	115	NE¼SE¼SE¼ sec. 5	Brack Drilling Co	1	Government	1956	541	Twin Creek Ls	
10	24	115	E½SE¼SE¼ sec. 8	do	1	Fontenelle (Creek area)	1957	6,052	Madison Ls	
11	25	113	N½NE¼NE¼ sec. 4	Belco Petroleum Corp	1	Rocking Chair Ranch unit	1960	9,625	Frontier Fm	
12	25	113	NE¼SW¼SE¼ sec. 8	A. D. Quaintance	1	E. M. Collins	1929	1,205	(?)	
13	25	114	N½SW¼SE¼ sec. 15	Continental Oil Co	1	Canyon Ranch unit	1954	2,915	Ankareh Fm	
14	25	114	C Lot 3, sec. 24	do	24-1	Dry Hollow unit	1959	7,701	Hilliard Sh	
15	25½	115	Lot 1, sec. 36	J. B. Robertson (Mountain Oil Corp.).	1	Wyoming anticline area	1947	2,386	Weber Ss	
16	25½	115	Lot 1, sec. 36	Zion Oil Co	2	do	1952	2,480	do	
17	26	113	NE¼SW¼SE¼ sec. 8	Reese Oil Co	1	C. Vrang	1926	510	Hilliard Sh	
18	26	113	SW¼SW¼SE¼ sec. 8	Patrick J. Quealy	1-8	South La Barge area	1945	1,400	do	
19	26	113	NW¼NW¼SE¼ sec. 9	Ute Royalty Corp	1	Government	1954	2,123	do	
20	26	113	SW¼SW¼SW¼ sec. 9	Transcontinental Oil Co	2	La Barge area	1927	4,700	do	
21	26	113	SE¼SE¼SE¼ sec. 9	Lynwood W. Davis	1	do	1936	(?)	(?)	
22	26	113	NW¼NW¼NW¼ sec. 15	Rainbow Oil Co	B-2	do	1928	1,224	Almy Fm	Gas, Almy Fm.
23	26	113	NE¼NW¼NW¼ sec. 15	do	B-12	do	1929	2,010	Hilliard Sh	
24	26	113	NW¼SW¼NW¼ sec. 15	Texas Production Co	1	do	1928	1,839	do	Shows of oil and gas.
25	26	113	W½SW¼NW¼ sec. 15	do	4	do	1927	1,200	Almy Fm	
26	26	113	NE¼SE¼SW¼ sec. 15	do	3	do	1927	1,744	Hilliard Sh	
27	26	113	E½SE¼NE¼ sec. 16	M. J. Goldberg	1	do	1928	930	(?)	
28	26	113	C NW¼ sec. 17	General Petroleum Corp	22X-17	Trojan (Hogsback area)	1966	8,275	Bear River Fm	Gas, Frontier and Bear River Fms.
29	26	113	NE¼SW¼NE¼ sec. 20	Davis-Apperson-Murphy	1	La Barge area	1926	1,506	(?)	Show of gas.
30	26	113	SW¼SW¼NE¼ sec. 20	Patrick J. Quealy	1-20	South La Barge area	1945	2,503	Almy Fm	
31	26	113	NE¼SE¼NW¼ sec. 22	Big Piney Oil Co	1	La Barge area	1925	720	(?)	
32	26	113	N½NE¼NW¼ sec. 27	Torgeson Oil Co	1	Mary McGinnis	1954	3,515	Hilliard Sh	
33	26	113	NW¼NW¼NW¼ sec. 27	Transcontinental Oil Co	1	McGinnis	1953	3,544	do	
34	26	113	NE¼NE¼NE¼ sec. 28	Sennat Oil Co	1	La Barge area	1927	1,470(+?)	(?)	
35	25	114	C SW¼ sec. 18	Phillips Petroleum Co	1A	Fort Hill unit	1963	17,345	Nugget Ss	
36	26	113	S½NW¼NE¼ sec. 34	Belco Petroleum Corp	2	Rocking Chair Ranch unit	1960	9,962	Beckwith Fm	Show of gas.
37	26	114	C NE¼SE¼ sec. 23	Max Pray	1	Government-Barbari	1959	7,935	Hilliard Sh	
38	26	115	C SW¼SW¼ sec. 10	Carter Oil Co	1	Meridian Ridge unit	1959	14,390	Mowry Sh	
39	24	114	C NE¼NE¼ sec. 29	Forest Oil Corp	29-1	Government	1964	3,072	Mesaverde Fm	
40	24	114	C SW¼NE¼ sec. 14	Davis Oil Co	1	Taliaferro-Federal	1964	3,770	Hilliard Sh	
41	24	114	C NE¼NW¼ sec. 1	Pacific Natural Gas & Wolf Land Co.	21-1-1	Fontenelle Creek	1964	6,356	do	
42	25	113	C NE¼NW¼ sec. 31	Belco Petroleum Corp	4	Willow Creek unit	1962	4,019	Almy Fm	
43	25	113	E½NE¼NW¼ sec. 20	Sinclair Oil & Gas Co	1	Federal 4000 Lincoln	1963	5,500	Hilliard Sh	
44	25	113	SE¼SE¼NW¼ sec. 15	Belco Petroleum Corp	1	Palisades unit	1961	4,725	do	
45	25	113	C NE¼NW¼ sec. 10	Mule Creek Oil Co	1-2110	Government-Wallace	1966	4,914	do	
46	25	113	C NW¼NE¼ sec. 8	Davis Oil Co	1	Belco-Federal	1963	4,997	do	
47	25	114	W½NE¼NW¼ sec. 25	British-American Oil Prod. Co.	B-1	Government-Davis	1964	1,952	do	
48	26	113	E½SW¼SW¼ sec. 21	Kerr-McGee Oil Industries	1	Chrisman	1964	2,515	do	
49	26	113	E½SW¼SE¼ sec. 17	Belco Petroleum Corp	2	South La Barge unit	1962	2,853	do	
50	26	113	N½SW¼NW¼ sec. 16	do	3-16	State	1966	8,077	Muddy Ss.	Gas, Muddy Ss.
51	26	113	E½NE¼NE¼ sec. 16	do	1	South La Barge unit	1962	1,953	Hilliard Sh	
52	26	113	S½NW¼SW¼ sec. 9	do	4-9	South Hogsback	1966	8,105	Muddy Ss	Gas, Muddy Ss.
53	26	113	W½SW¼NW¼ sec. 15	Marvel Oil Co	1	Custer Petroleum Co	1932	1,056	Almy Fm	
54	26	113	NE¼SE¼SW¼ sec. 15	Texas Production Co	2	Davis-Transcontinental Oil	1927	884	do	

unconformity by nearly horizontal beds of the Chappo Member of the Wasatch Formation along the crest of La Barge Ridge in sec. 8, T. 26 N., R. 113 W. (fig. 19). Movement along the Hogsback fault, therefore, ceased here before initial deposition of Chappo strata of latest Paleocene age. Development of a widespread unconformity in the western part of the Green River Basin between Upper Cretaceous and moderately conglomeratic middle(?) Paleocene Hoback(?) strata suggests that much of the movement (Oriel and Armstrong, 1966, p. 2615) along the Hogsback fault may have been in early to middle Paleocene time.

Farther north, in the Tip Top unit area, the Hogsback fault is reported to cut strata assigned to the Almy Member of the Wasatch (Michael, 1960, fig. 2; Howe, 1955, p. 176). If these strata are the same as those assigned to the Chappo Member in the Fort Hill area, then final movement was later in the Tip Top area than it was farther south in the Fort Hill area (Oriel and Armstrong, 1966, p. 2615). Alternative possible explanations are that the Tip Top strata assigned to the Almy are older than those here assigned to the Chappo, as suggested by a structure section by Murray (1960, p. 182, section *A–A′*), or that structural relations in the Tip Top area are more complex than previously recognized, for steep reverse faults as well as the thrust have been observed in that area.

A striking feature of the Hogsback thrust plate is the astonishing lateral persistence of the rocks on which it rides, confirming the parallelism of the fault surface to bedding (Rubey and Hubbert, 1959, p. 187). The plate rides on claystones near the middle part of the Gros Ventre Formation from the Tip Top area southward through the Dry Piney area to the Phillips Fort Hill unit test, from as far west as the Carter test to exposures on Hogsback Ridge, for a total known areal extent of almost 200 square miles. The extent is no doubt considerably greater, for the Hogsback fault extends much farther south than previously mapped. The fault was penetrated by the Belco Hamsfork unit 30–2 in the center of SE¼SE¼ sec. 30, T. 19 N., R. 115 W., at a depth of 9,182 feet, or 2,401 feet below sea level, where the middle part of the Gros Ventre Formation is reported to rest on the Hilliard Shale. Calculations suggesting that claystones near the middle of the Gros Ventre Formation may have sustained an abnormally high fluid pressure-overburden ratio during thrusting are cited by Rubey and Hubbert (1959, p. 193).

FORT HILL THRUST FAULT

The name Fort Hill is proposed here for the thrust fault penetrated at a depth of 10,912 feet, or 2,790 feet below sea level, by the Phillips Fort Hill 1A borehole. The middle part of the Gros Ventre Formation above the fault lies on the lower part of the Amsden Formation for a stratigraphic throw of about 2,600 feet.

The Fort Hill fault is not known to be exposed within the quadrangle. However, it probably has been drilled in two other places.

The Continental Canyon Ranch 1 (map loc. 13, table 1) penetrated a reverse or thrust fault at a depth of 1,958 feet, or 5,272 feet above sea level, where the Dinwoody Formation rests on the Nugget Sandstone. The stratigraphic throw of about 2,600 feet is similar to that of the Fort Hill fault in the Phillips hole, despite the difference in stratigraphic units bounding the fault. A few other facts support the inference that the faults in the two holes are the same. Another hole, the Continental Dry Hollow 24–1 (map loc. 14, table 1), entered Cretaceous rocks directly beneath the Tertiary, indicating that the sub-Tertiary trace of the Hogsback fault lies west of this point. The distance between the two Continental holes is barely sufficient to accommodate the thickness of section required from the Nugget Sandstone to the Gros Ventre Formation at the base of the Hogsback fault plate (pl. 2, section *D–D′*). If the fault drilled in the Canyon Ranch hole were a higher fault than the Fort Hill fault in the Phillips hole, there would be inadequate space between the two Continental holes to accommodate the required repeated section.

The Fort Hill fault is also believed to be the same as that drilled at a depth of 8,650 feet, or 592 feet below sea level, in the Carter Meridian Ridge 1, where the Gallatin Limestone overlies the Amsden Formation. The stratigraphic throw here, too, is about 2,600 feet. Confidence is high that this fault is indeed the same as that named the Fort Hill fault in the Phillips hole, because the throw is about the same, because approximately the same stratigraphic units are involved, and because the surface in both holes is the lowest significant fault above the Hogsback fault.

Correct identification of the Fort Hill fault in the Meridian Ridge, Fort Hill, and Canyon Ranch unit holes is critical to the interpretations made in accompanying structure sections. If an error has been made, then the sections require drastic modification. Reasons cited above may be sufficient to warrant correlation of the faults in the three holes; the correlation and the position of the sub-Tertiary trace of the fault (pl. 1) are apparently further supported by confidential seismic studies in the area by one of the major oil companies. The ensuing discussion assumes that the correlation is valid.

The average dip of the Fort Hill fault between the Canyon Ranch and Fort Hill unit holes is less than 24°. The amount of eastward lateral transport along the fault is inferred in the accompanying structure sections to range from 3 to 5 miles, but may be less or more. The Fort Hill thrust fault is interpreted as a subsidiary slice of the Hogsback fault that joins it toward the west.

Data are insufficient to indicate whether the Fort Hill fault plate moved during or after the time of principal movement along the Hogsback fault; it could not have moved before, if the fault is a slice of the Hogsback fault. A tenable inference is that the Fort Hill plate moved during or slightly later than a late stage of movement along the Hogsback fault.

Strata within the Fort Hill thrust plate are broken and bent. The repetition of 80 feet of Devonian strata, for example, is clearly evident on the gamma-ray log of the Phillips Fort Hill 1A at a depth of 8,797 feet (fig. 20). An abnormally thick sequence of Bighorn Dolomite in the same hole is also interpreted as repeated along a fault (pl. 2, section *D–D′*), although this fault is more difficult to prove. A repetition of strata of the Fort Hill plate is also evident in the Carter Meridian Ridge 1 at a depth of 9,845 feet, where Madison strata rest on the lower part of the Amsden; a change in dip direction here suggests an asymmetric fold (pl. 2, section *A–A′*), but the fold may be broken.

A corollary of correlating the fault in Continental's Canyon Ranch unit hole with the Fort Hill fault in the Phillips hole is that the fault cuts across stratigraphic units moderately rapidly, unlike the Hogsback fault which parallels bedding. In this respect, the Fort Hill fault may be analogous to back-limb thrust faults in Alberta (Douglas, 1950, p. 88–95). Probably the analogy is also close in terms of relative times of movement and possibly genesis.

Fault slices above the Hogsback fault, such as the Fort Hill fault, are apparently significant not only locally, but regionally. Such faults were drilled, for example, some distance south of the quadrangle in the Union Oil and Carter Little Round Mountain 1 in the

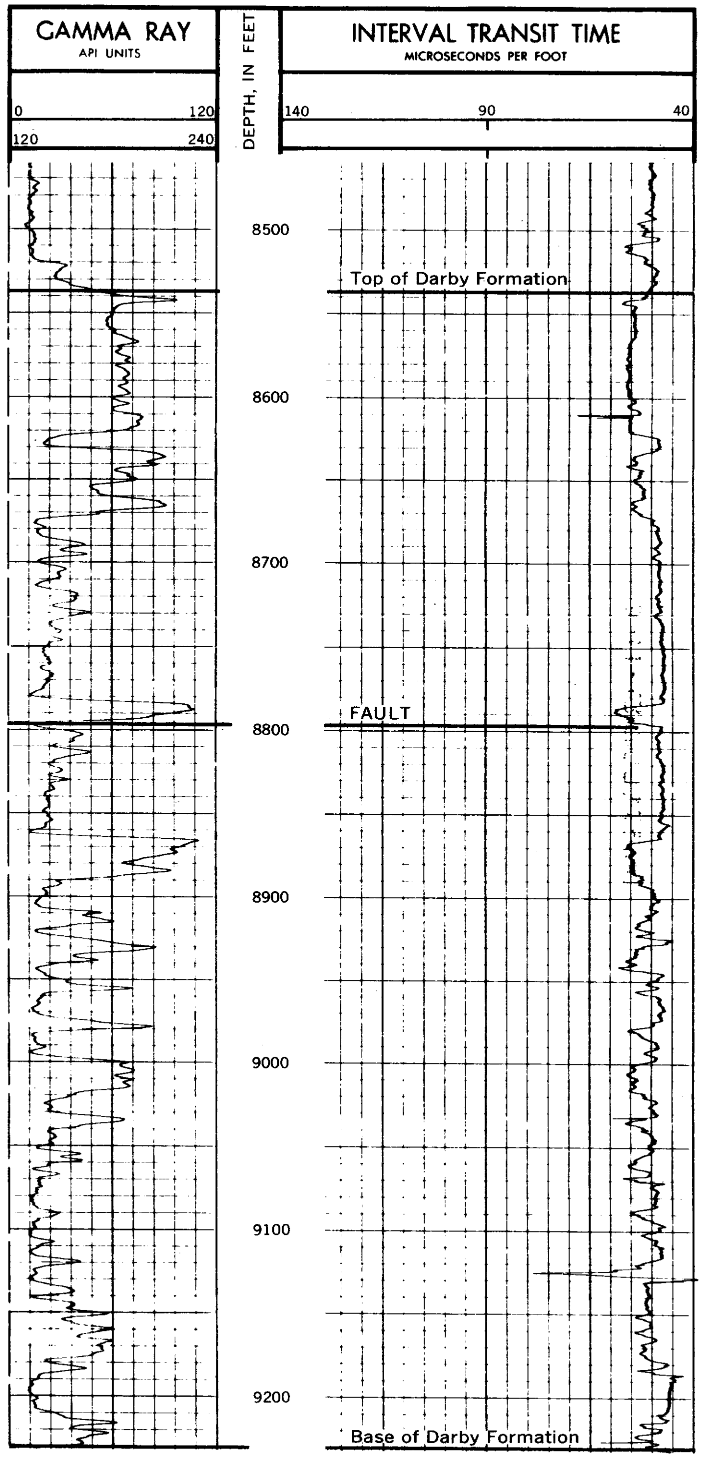


FIGURE 20.—Part of the gamma ray–sonic log for the Phillips Fort Hill 1A showing the repetition of 80 feet of the Darby Formation in the Fort Hill thrust plate.

NW¼NE¼ sec. 30, T. 20 N., R. 115 W. At a depth of 4,365 feet, or 2,744 feet above sea level, the Phosphoria Formation rests on the Woodside Formation for a stratigraphic throw of about 700 feet. At a depth of 5,355 feet, or 1,754 feet above sea level, the Wells Formation rests on the Phosphoria, for a stratigraphic throw of about 700 feet. Whether either of these faults, or both, correspond to the Fort Hill or a higher thrust fault in the Fort Hill area cannot be determined without considerably more subsurface data in the intervening area than is now available.

MERIDIAN THRUST FAULT

The name Meridian is proposed here for the thrust fault penetrated at a depth of 7,420 feet, or 702 feet above sea level, by the Phillips Fort Hill 1A borehole. The lower part of the Madison Limestone above the fault rests on the lower part of the Amsden Formation for a stratigraphic throw of about 1,300 feet.

This fault is believed to be the same as that penetrated at a depth of 4,772 feet, or 3,286 feet above sea level, by the Carter Meridian Ridge 1. In this hole the upper part of the Darby Formation rests on the Wells Formation for a stratigraphic throw of about 2,600 feet, or about twice that in the Phillips hole.

The "horse-tail" ends, or slices, of the Meridian fault (pl. 2, section *A–A′*) are present in the northwestern part of the quadrangle, in sec. 13, T. 26 N., R. 115 W., where exposed Nugget Sandstone masses (pl. 1) overlie the basal part of the Twin Creek Limestone along faults with 600–800 feet of throw. If these reverse faults are indeed exposures of the Meridian thrust fault, then the average dip between the exposed lowest slice of the fault and the Carter hole is 13°; of the highest slice, 28°. The average dip inferred in sections farther south is about 18°.

Movement was probably later along the Meridian fault than along the Fort Hill fault, although evidence is not available to demonstrate this convincingly. A reverse fault east of Miller Mountain in the northern part of the quadrangle may be related to the Meridian fault; the reverse fault apparently, but not certainly, cuts the conglomerate member of the Wasatch. It is possible that the reverse fault may reflect a very late minor pulse of compression related to Meridian fault movement; if so, this last pulse was in early Eocene time. But the reverse fault may also be a product of block faulting in the area after thrust movement ceased, an interpretation that is here regarded as more likely.

Strata within the Meridian thrust plate are broken and bent, as in the Fort Hill plate. About 690 feet of Madison Limestone is repeated in the Phillips Fort Hill 1A by a fault at a depth of 6,830 feet. A fold, possibly broken, is inferred west of the Carter Meridian Ridge 1 (pl. 2, section *A–A′*).

Lateral transport along the Meridian fault need not have been more than a mile or two, although it may have been more. The Meridian fault is regarded as a slice of the Hogsback fault.

PINE RIDGE THRUST FAULT

The name Pine Ridge is applied here to the trust fault penetrated at a depth of 5,124 feet, or 2,998 feet above sea level, in the Phillips Fort Hill 1A, where the upper part of the Madison rests on the upper part of the Amsden; stratigraphic throw is about 750 feet. Slices of the Pine Ridge fault are believed to be exposed on the west end of Pine Ridge, in secs. 28 and 29, T. 25 N., R. 114 W., where Nugget Sandstone overlies the lower part of the Twin Creek Limestone. If the faults at these localities are indeed the same, then the average dip of the fault between projections of the exposures and the borehole is 15°–20°.

The Pine Ridge fault, the highest thrust fault recognized in the Phillips Fort Hill 1A, is regarded here as not the same as the highest thrust fault drilled in the Carter Meridian Ridge 1. If the highest faults in the two holes were the same, the trace of the fault would almost certainly cross the belt of easterly trending rocks exposed east of Fort Hill. No thrust fault was recognized during the mapping of this area.

The presence of one more thrust plate south of Fort Hill than is evident north of Fort Hill helps explain the locally aberrant strikes of the easterly trending belt of Mesozoic rock. An explanation is needed, for almost everywhere else in the Idaho-Wyoming thrust belt rocks strike north or approximately north. The easterly strikes near Fort Hill are apparently the product of drag along the edge of the Pine Ridge thrust sheet.

Lateral transport along the Pine Ridge thrust fault may have been less than a mile, or considerably more.

LA BARGE THRUST FAULT

The La Barge thrust fault, beneath the Hogsback fault, has been referred to as both the La Barge (Davies, 1934, p. 692; Bertagnolli, 1941, p. 1741; Krueger, 1960, fig. 4) and the Hilliard (Christensen and Marshall, 1950, p. 107; Murray, 1960) fault. A locality name seems preferable to that of one of the stratigraphic units cut by the fault.

The presence of the La Barge fault is established beyond doubt by many wells drilled in the La Barge oil field. The Hilliard Shale is superposed on the Hoback(?) and Adaville(?) Formations and the Frontier Formation on the Hilliard Shale along the fault, for stratigraphic throws of as much as 3,000 feet. The fault is believed to dip very steeply near its sub-Wasatch trace, but its inclination decreases markedly downdip until the fault is almost horizontal. Whether the sole of the fault lies within the Aspen or Bear River Formation (Murray, 1960, p. 181) or in the Gannett Group (pl. 2), or some older unit, has not been established.

Lateral transport along the fault seems to have been as much as 3–4 miles.

The La Barge fault is younger than the Hogsback thrust fault. If the faults on the east side of Hogsback Ridge, shown as reverse faults on plate 1, are indeed slices of the La Barge thrust, as interpreted on plates 1 and 2, then the La Barge thrust fault cuts and offsets the Hogsback fault. The La Barge fault cuts both the Chappo Member of the Wasatch Formation and the Hoback(?) Formation. The fault is unconformably overlain by the La Barge Member of the Wasatch Formation. Movement along this fault, therefore, was in early, possibly middle early (Lysite), Eocene time. The fact that the Hogsback and La Barge faults moved at different times affects interpretations of the genesis of the La Barge fault; the La Barge thrust plate could not have been pushed to its present position by movement of the Hogsback plate, as envisioned by Murray (1960, p. 186).

WYOMING ANTICLINE

A structure of considerable early economic interest is the Wyoming anticline (Schultz, 1914, p. 86, pl. 1, pl. 3, sections *D–D′*, *E–E′*). Estimates of closure of the fold, based on both published and unpublished earlier geologic maps, have ranged from 2,000 to 5,000 feet, suggesting a possible structural trap for oil and gas of considerable extent.

The inferred magnitude of the structure has diminished greatly with increasing information. The Wyoming anticline is a rather minor, broken fold with no apparent root beneath the small thrust sheet in which it lies. Earlier estimates of closure were based in part on erroneous mapping. Exposures of limestone along Muddy and Little Muddy Creeks were assigned erroneously to the Twin Creek Limestone (Schultz, 1914, pl. 1); correct assignment to the Thaynes Limestone reduces considerably the potential trap on the east flank of the fold. Recognition of the Meridian thrust fault makes it evident that the fold need not be and probably is not present beneath the rather thin thrust sheet in which it lies. An early exploration target has all but disappeared.

MERIDIAN AND OTHER ANTICLINES

Another anticline formerly regarded as of regional extent is the Meridian anticline (Schultz, 1914, p. 86, pl. 1). The current mapping suggests that the axes of several rather small folds along the leading edges of several thrust sheets were misinterpreted as marking the crest of a single fold.

Another apparent error made in locating earlier drilling sites for exploratory holes was to rely too heavily on reversals in dip. The dominance of westward dips of bedding within the region has frequently resulted in more than passing interest in localities where strata dip eastward. Unfortunately, many such localities lie close to previously unrecognized block faults; they do not necessarily delineate simple folds.

The greater abundance of thrust faults in the area than formerly recognized, of course, reduces considerably the potential significance to be attached, in exploration, to surficial folds; they do not necessarily indicate similar folds in lower thrust sheets.

FOLDS IN TERTIARY STRATA

Tertiary strata within the quadrangle in general dip 1° or less to the east. In a few places the beds are horizontal; in other places beds dip gently to the west. Moderate dips, as much as 25° in a few places, are found only near contacts between Tertiary strata and older rock. These observations raise a question of some economic interest: are reversals in bedding and other structures in Tertiary strata a clue to more intensely deformed underlying structures in older rocks?

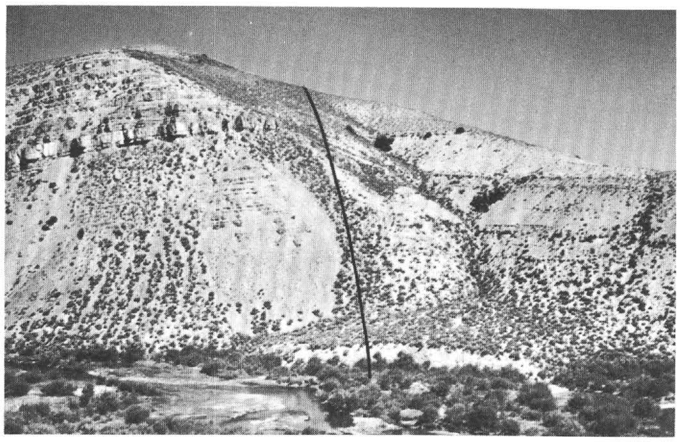
A conclusion of the present study is that both original dip and differential compaction (Bradley, 1964, p. A16–A17) account for almost all the observations; tectonic deformation probably did not produce the observed structures. The Tertiary strata are apparently draped over partly exhumed topographic, rather than structural, features.

NORMAL FAULTS

Many more normal faults (fig. 21) were mapped in the western part of the quadrangle than were evident on earlier maps. Stratigraphic throws on many of these faults are minor, less than 200 feet, but they may be as much as 1,500 feet. Dominant movement along these faults is believed to have been dip slip, but convincing evidence is lacking.

The mapped traces of the normal faults suggest very steep dips. One normal fault, with a trace lying less than 100 feet west of the drilling site of the Carter Meridian Ridge 1, was penetrated at a depth of 1,515 feet; the dip of this fault is about 86°.

An assumption made early in this study, that the normal faults dip more gently, possibly 60°–70° is apparently denied by available data. Normal faults were mapped east of both the Carter Meridian Ridge 1 and



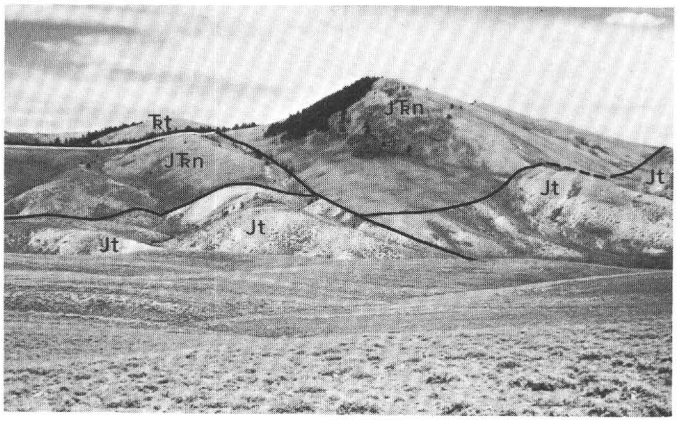


FIGURE 21.—Steeply dipping normal faults in the quadrangle. Upper view is northward across Fontenelle Creek and shows faulted Twin Creek Limestone in NE¼ sec. 5, T. 24 N., R. 115 W. Lower view is eastward and shows Fort Hill with Twin Creek Limestone (Jt) faulted down against Nugget Sandstone (JT̄Rn). Hill of Thaynes Limestone (T̄Rt) is in the background.

the Phillips Fort Hill 1A. Both these holes were drilled deeply enough to have penetrated the faults if the faults dip as gently as 65°. No omission of beds is evident in either hole to document penetration of a normal fault. An alternative explanation, that the normal faults are steeper, was adopted in preparing the sections (pl. 2), in which the normal faults are shown to dip about 85°.

Another possible explanation as to why the faults were not penetrated is that the normal faults may have been cut by the holes at their intersections with one of the thrust faults. Recognition of such an intersection would be difficult without additional data, because the repetition of strata along a thrust fault would more than offset omission of strata along a normal fault. That two such intersections could be drilled in two successive holes is regarded as so unlikely as to warrant no further consideration.

Still another possible explanation as to why the faults were not penetrated cannot be dismissed so easily. Most of the normal faults recognized in the quadrangle are shown on the sections (pl. 2) to offset all the thrust plates and the underlying autochthonous block; this interpretation cannot be proved by available data. At least one of the normal faults, that mapped as trending northward through secs. 18 and 7, T. 25 N., R. 115 W., cuts rocks in both the Pine Ridge and the Meridian thrust plates, thereby lending a little support to the interpretation shown. But at least some of the faults may be the products of relaxation within a single thrust sheet; if so, they may not extend beneath the thrust plate in which they lie. Indeed, the dips of normal faults have been inferred by some company geologists to diminish with depth so that their junction with underlying thrust faults may form very small angles; such faults have been called listric normal faults by Bally, Gordy, and Stewart (1966, p. 357). An inference drawn is that there may have been a reversal in the direction of movement along some parts of the thrust fault surface during a relaxation phase. Such inferences cannot be proved until the geometric relations are more accurately determined by much closer drilling or possibly by seismic surveys. An implication of such inferences is that the possible control by basement of observed block faulting is not only minimized, it is virtually obliterated. Therefore, whether observed normal faults cut more than one thrust sheet affects not only the accuracy of the structure sections (pl. 2) but also fundamental concepts regarding deformation in the region. The question is by no means settled.

Movement along most of the steeply dipping faults in the quadrangle was down to the west, as in other parts of the Idaho-Wyoming thrust belt (Rubey and Hubbert, 1959, p. 186).

Movement along the normal faults occurred both before and after deposition of upper lower Eocene strata. Some of the faults cut the conglomerate member and the New Fork Tongue of the Wasatch Formation and the Fontenelle Tongue of the Green River Formation (pl. 1). Other faults are covered by apparently unbroken strata of the conglomerate member of the Wasatch. Movement on the normal faults that do not cut the Wasatch clearly must have been after thrusting and before late early Eocene time, possibly in mid-early Eocene time. My own belief is that episodes of block faulting shortly before, during, and after deposition of the Wasatch Formation explain observed facies relations in that unit. Accompanying changes in relief and possible earthquakes may have triggered large landslides and rockslides to form the diamictite (Tracey and others, 1961) facies. Moreover, deposition of local and extensive tongues of the Wasatch Formation may better be explained by abrupt epeirogenic episodes, probably associated with block faulting, than by climatic variations resulting in regional contractions of Gosiute Lake in which the Green River Formation was deposited.

REVERSE FAULTS

Several steeply dipping reverse faults have been mapped along La Barge Ridge in the northeastern part of the quadrangle. These faults offset strata both above and below the Hogsback fault as well as the fault surface. Reconnaissance north of the quadrangle suggests that these reverse faults and other reverse faults continue northward for a moderate distance. They account not only for locally anomalous structural relations but for such aberrant stratigraphic data as excessively thick Bighorn Dolomite sequences reported previously (Bertagnolli, 1941, p. 1733). The available data are inadequate to ascertain either the dips of the reverse faults or the depths to which they extend. These reverse faults may be slices of the La Barge thrust fault, and they are so interpreted on plates 1 and 2.

Reverse faults have also been recognized in boreholes drilled in the eastern part of the quadrangle. They are documented by repetitions of strata in the Cretaceous Hilliard and Frontier Formations and stratigraphic throws of several hundred feet. My information on the dips along these faults is inadequate to support the interpretations shown on the structure sections (pl. 2). The apparent continuity of strata of the La Barge Member of the Wasatch Formation and higher rock units resting on inferred traces of these faults suggests that movement along them ended before late early Eocene time.

Reverse faults are also present in the western part of the quadrangle. Their associations suggest that they were formed with the normal faults during episodes of block faulting after thrusting.

STRUCTURE BENEATH LA BARGE FAULT

The paucity of information in the central, eastern, and southeastern parts of the quadrangle raises doubts about interpretations made for rocks east of and beneath the La Barge thrust fault. Few deep holes have been drilled in these localities, and Cretaceous and older strata are concealed by moderately thick Tertiary sequences.

The available data confirm the presence of a broad, somewhat broken anticline to which the name Moxa arch has been applied (Krueger, 1960, fig. 1). The anticline is believed to extend southward from the La Barge platform to beyond the Church Buttes field in Tps. 15 and 16 N., R. 112 W. The structure is moderately well delineated by a belt of positive magnetic anomalies on unpublished aeromagnetic maps of the region.

At least a few of the faults shown in the eastern parts of the sections (pl. 2) have been interpreted very differently by some company geologists. Their interpretation is that these faults are slices of a large easterly dipping thrust fault beneath, and possibly truncated by, the westerly dipping La Barge thrust fault. The interpretation leans heavily on many subsurface data provided by drilling east of the Fort Hill quadrangle. I have had inadequate time and opportunity to examine these data; moreover, the results of dipmeter surveys of some of these holes, which are particularly critical to the interpretation, are generally inaccessible. I am, therefore, unable now to evaluate the interpretation and, for this reason, have chosen not to show it on the sections (pl. 2).

The possible presence of easterly dipping thrust faults along the eastern margin of a belt dominated by westerly dipping thrust faults is not inconceivable. Such faults have been described along the east flank of the Alberta disturbed belt, where their genesis is attributed to mechanics comparable to that which produce back-limb thrusts (Douglas, 1950, p. 96). Eastward-directed forces may produce both the dominantly westerly dipping thrust faults and an easterly dipping thrust fault at the eastern margin.

SOME TECTONIC IMPLICATIONS

Study of the Fort Hill quadrangle has been especially rewarding in the amount of information it has yielded to some general concepts of the Idaho-Wyoming thrust belt. Some of this information is summarized in the following paragraphs.

The gentleness of dips of the several thrust faults within the quadrangle has been established beyond question. Dips are as high as 50° at the surface but decrease downdip westward to 10°.

The easternmost or lowest major westerly dipping thrust fault within the area, the La Barge, is the youngest, as at other places along the front of the Idaho-Wyoming thrust belt (Rubey and Hubbert, 1959, p. 191, 195–196; Armstrong and Oriel, 1965, p. 1860–1861; Oriel and Armstrong, 1966). Moreover, movement along the La Barge fault within the area is well dated as early Eocene, possibly middle early Eocene, just as it is for the Prospect fault farther north (Armstrong and Oriel, 1965, p. 1857).

The next higher major thrust fault, the Hogsback, is older than the La Barge. All movement along the Hogsback fault within the quadrangle ended before latest Paleocene time; major movement along the fault may have been in early to middle Paleocene time. Data available within the quadrangle, therefore, support the concept of an eastward progression, with time, of thrusting in the Idaho-Wyoming thrust belt.

The thrust faults above the Hogsback fault are not well dated. If they are indeed slices of the Hogsback fault, as inferred, movement along these faults may have accompanied or may have followed major movement along the Hogsback, as in the development of back-limb thrusts (Douglas, 1950, fig. 26). Such apparent local contradictions to eastward progression with time of major thrusting have been observed in other parts of the Idaho-Wyoming thrust belt (Oriel and Armstrong, 1966, p. 2619) and in the southern Canadian Rockies (Bally and others, 1966, p. 371). A belief, unsupported by convincing data, is that movement along the thrust faults above the Hogsback may have furnished the coarse detritus found in western exposures of the Chappo Member of the Wasatch Formation which now covers the trace of the Hogsback fault. If this belief is true, movement along such faults as the Fort Hill, the Meridian, and the Pine Ridge may have been in latest Paleocene and earliest Eocene time.

Information from the Fort Hill quadrangle and adjoining areas confirms that the major regional thrust fault here, the Hogsback, did indeed move along a bedding-plane glide surface (Douglas, 1950, p. 84; Rubey and Hubbert, 1959, p. 194) developed in Cambrian claystones rather than having formed by the rupture of an isoclinal fold.

Different parts of the Hogsback thrust plate may have yielded differently to stress, as suggested on plate 2. The lower part of the thrust plate is apparently little folded, but it is cut by several thrust slices; the upper part, in contrast, is moderately folded. The apparent simplicity of structure in the lower part of the thrust plate as shown on plate 2, however, may reflect paucity of data rather than true structure.

The possible control by basement of thrusting is not only not evident, but rather unlikely, despite the data available from deep drilling for parts of the quadrangle. Whether block faulting in the area is controlled by basement is neither proved nor denied.

Finally, the convincing evidence that different tectonic episodes took place at different times within the quadrangle and in the region is of economic interest. Structural deformation affects the migration and possible entrapment of such fluids as petroleum and natural gas. The sequence of structural events must be deciphered before one can trace the possible courses of such fluids through the rocks of the region.

ECONOMIC GEOLOGY

NATURAL GAS AND OIL

Natural gas and petroleum are by far the most valuable mineral resources within the area. In the eastern part of the quadrangle is the southern part of the Big Piney–La Barge oil- and gas-producing area with its several producing units (Wyoming Geol. Assoc., 1957, 1961, 1962) and the Willow Creek gas field (Woodward, 1960). Production from these fields has aggregated millions of barrels of oil and billions of cubic feet of combustible gas. The recoverable reserves of natural gas in the region are estimated by Krueger (1960, p. 208) to exceed a trillion cubic feet.

Oil reportedly was discovered in the area before 1907 (Schultz, 1914, p. 116). The discovery of both oil and gas in the La Barge field in 1924 led to the first oil field development on a moderate scale here during the years that followed (Krueger, 1960, p. 195). Construction in 1956 of the Pacific Northwest Gas Pipeline to supply the Northwestern States with natural gas from the La Barge region has led to increased exploration and to the discovery of significant new reserves during the past decade.

Only general information is included here, for the producing units have been described competently and in detail by Krueger (1955, 1960), Christensen and Marshall (1950), Howe (1955), Wyoming Geological Association (1957), Cochran (1959), Murray (1960), Michael (1960), Woodward (1960), and Asquith (1966).

The rocks that have been most productive thus far are sandstone lenses in the Hoback(?) Formation ("Almy" Formation of producers), unconformably overlain remnants of Adaville(?) Formation sandstone ("Mesaverde" of producers), and sandstone tongues in the Frontier Formation ("first, second, and third Frontier sands" of producers). Stratigraphic traps are critical in defining all the hydrocarbon fields, whereas structural closure is an aid in defining only a few. The Nugget Sandstone, with widely variable porosity and permeability, is another rock unit that is productive in the Tip Top and Birch Creek fields. Lenses and tongues of sandstone in the Aspen and Bear River Formations ("Muddy" and "Dakota" Sandstones of producers) have also been productive.

Producing sandstones in the Hoback(?) Formation have long been of interest, for they were among the first strata of undoubted Tertiary age and of continental origin to yield commercial oil and gas in the Rocky Mountain region. Moderately porous and permeable sandstone lenses (in section) are enveloped by relatively impermeable claystone and mudstone. The sandstone bodies are linear and somewhat sinuous in plan view (Krueger, 1960, figs. 5, 6). The origin of this sandstone is in doubt. The bodies are believed by Krueger (1960, p. 200) and Asquith (1966) to have been deposited in sand bars, deltas, and estuaries along the western margin of an ancient Paleocene lake. The sinuosity of the sand bodies and the presence of abundant micas and feldspar, which likely were derived from the northern and northeastern margins of the Green River Basin, led Privrasky and Oriel (Privrasky, 1963) and Robert E. McDonald (oral commun., June 1963) to conclude that deposition in alluvial channels is more likely. Sufficient subsurface data probably are available now to ascertain the correct interpretation of the origin of the sandstone.

Hydrocarbon-bearing traps in the underlying Adaville(?) Formation are attributed to erosional truncation of upturned littoral sandstones in a regressive marine sequence (Asquith, 1965, 1966). The total number and the thicknesses of such marginal marine sandstones increase both to the east, in the Rock Springs region where they are productive, and to the west, above the Hogsback fault, where they have not yet been productive. At least some of the sandstones to the west, however, probably are of continental origin.

Producing sandstones in the Frontier Formation were deposited as littoral sands, during regressions and transgressions of the sea, that resulted in tongues of sandstone that pinch out eastward (Cobban and Reeside, 1952b; Hale, 1960b). The highest standstone ("first Frontier sand") is thick north of the quadrangle but wedges out southward.

Coarse detrital strata are present in underlying Cretaceous units and increase in abundance westward. The presence of continental strata to the west and marine strata to the east is favorable for finding additional littoral sandstones. Eastward-pinching-out tongues of sandstone are abundant in the westward-dipping Cretaceous sequences, forming an ideal province for discovery of additional stratigraphic traps.

Although Paleozoic and lower Mesozoic rocks have been explored for oil and combustible gas, they have not yet been productive in the Idaho-Wyoming thrust belt. Reconstructions of the early tectonic history of the region clearly indicate moderate to great downwarping to the west; hydrocarbons that may have been present in many of the units have probably been flushed eastward. However, our knowledge of detailed stratigraphic relations of such Paleozoic units as the Madison Limestone, the Bighorn Dolomite, and the Laketown Dolomite (to the west) is inadequate to delimit possible stratigraphic traps that may have stopped the eastward flow of fluids. Additional exploration is warranted in rock units older than the Cretaceous.

The prospects, therefore, for the discovery of additional very large accumulations of natural gas and oil are quite favorable. A limiting factor is the great cost of exploration operations in a province as structurally complex as the Idaho-Wyoming thrust belt.

HELIUM

The discovery of large volumes of helium in a structural trap in the nearby Tip Top field suggests that additional reserves may be found in the Fort Hill area.

Significant quantities of helium were found by the Mobil Oil Co. in the Tip Top 22–19–G well in sec. 12, T. 28 N., R. 114 W. Helium-bearing gas was recovered in tests of the Phosphoria, Wells, Madison, and Bighorn Formations.[1] The gas from the Phosphoria is dominantly methane but contains nitrogen, carbon dioxide, hydrogen sulfide, and helium. The gases from the other formations are dominantly carbon dioxide, with methane, nitrogen, helium, and very little hydrogen sulfide. Despite the small proportion of helium in each of the gases recovered, potential reserves of helium have been estimated in terms of billions of cubic feet. No helium is now being produced; the discovery well was plugged back to produce combustible natural gas from Cretaceous units.

The helium-bearing gas accumulations at Tip Top are trapped along the crest of the Tip Top anticline. The amounts of closure in the various traps cannot be precisely defined, but they have been estimated to be several hundred feet.

The origin of the helium has not been determined. The helium is considered by U.S. Bureau of Mines engineers to be the product of radioactive decay of minerals in Precambrian crystalline basement rocks at great depth and to have moved upward along very steeply dipping faults cutting the Tip Top anticline. In contrast, the helium is considered by A. P. Pierce possibly to have been generated within the sequence of sedimentary strata in which it is now found, as suggested by the presence of moderately radioactive rock (Marzolf, 1965) in stratigraphic units within and close to the formations containing the helium-bearing gas.

The gas-bearing rock units of the Tip Top area are present in the Fort Hill area both above and below the Hogsback fault. They merit gas tests when drilled in anticlines. Analyses of noncombustible gases found in the region would also contribute greatly to knowledge of the ultimate helium reserves of the region. The associated gas, carbon dioxide, is known to be moderately abundant in the region.

[1] Most of the data on helium presented here were provided by R. D. Miller and B. J. Moore of the U.S. Bureau of Mines (written commun., June 2, 1965) and by A. P. Pierce, U.S. Geological Survey (oral commun., 1965). The stratigraphy of the discovery well is described by Marzolf (1965).

OIL SHALE

The Green River Formation contains a few thin units of moderately rich oil shale in the Fort Hill area. Although oil shale is present in the upper part, the richest oil shale beds are concentrated in the lower part of the middle tongue of the Green River. A few beds of low-grade oil shale are present in the Fontenelle Tongue of the Green River Formation, which consists mainly of limestone in this area. No oil shale was seen in the upper tongue of the Green River; this unit was apparently deposited when the Eocene lake was too shallow to permit the deposition of organic-rich muds. The oil shale beds in the middle tongue locally contain interbeds of marlstone, siltstone, limestone, and sandstone, and they weather very light buff to gray or white. The richest beds are darkest gray or brown or black on fresh surface, and weather to white with a blue efflorescence.

The number and thickness of oil shale beds range markedly from place to place. Exposed beds range in thickness from a few inches to sequences as thick as about 20 feet but with a few layers of other rock. Analyses of samples from nearby localities [2] are reported by the Laramie Petroleum Research Center of the U.S. Bureau of Mines (written commun., Sept. 28, 1962) to show a content of as much as 47 gallons of oil per ton. Most of the oil shale samples, however, yield less than 15 gallons per ton, and a few thin layers tested at 30–35 gallons per ton.

Oil shales become thicker, more numerous, and richer southeastward toward the center of the Green River Basin.

Although the eastern part of the Fort Hill area contains modest reserves of oil shale, exploitation is not likely to be economically feasible until the far richer deposits in western Colorado, eastern Utah, and southern Wyoming are mined.

COAL

Coal has been mined sporadically from the Adaville(?) Formation at the Salli mine (fig. 22) along

[2] I am indebted to R. L. Rioux, U.S. Geological Survey, for placing at my disposal data on samples he collected.

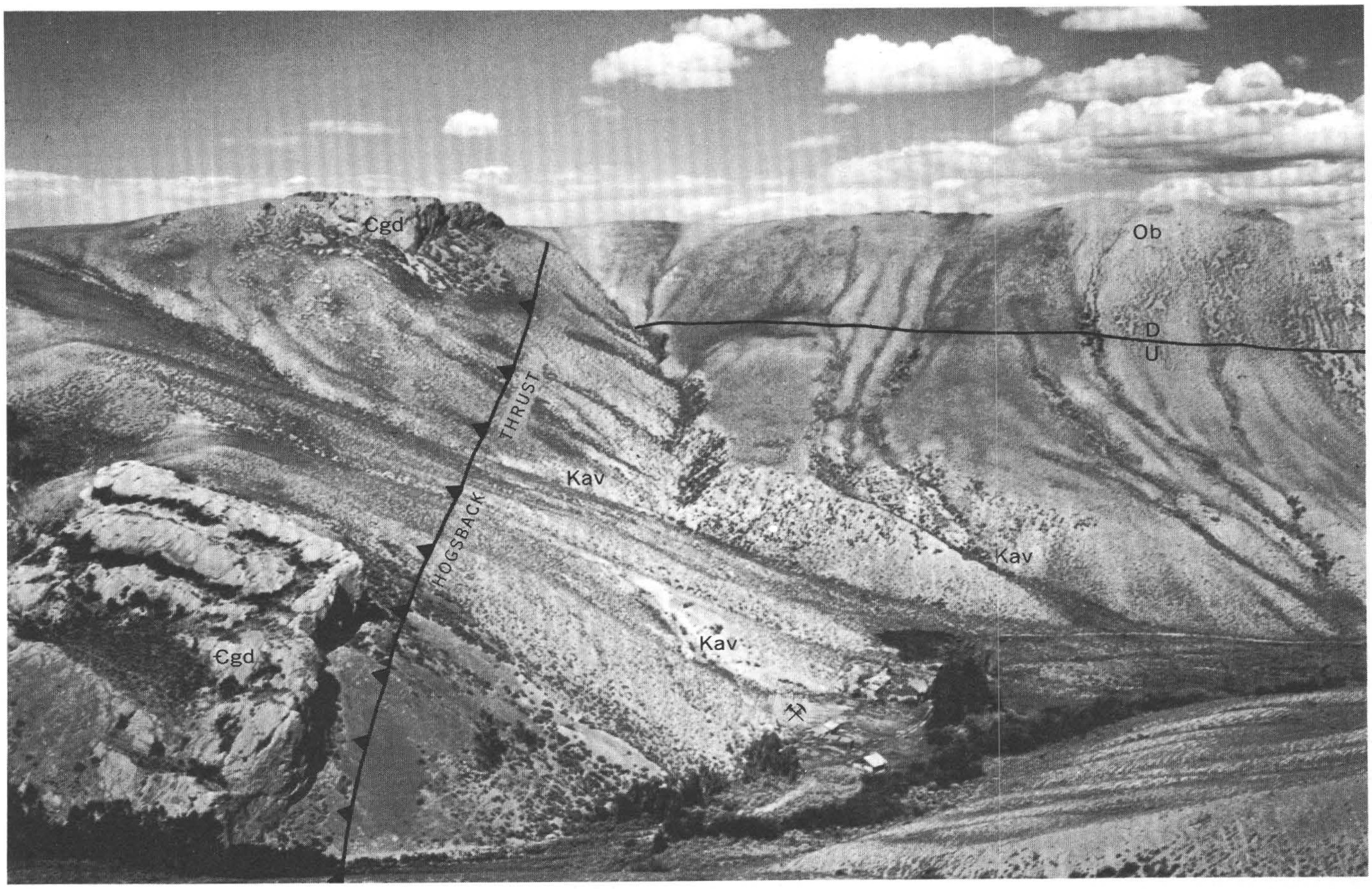


FIGURE 22.—Site of Salli coal mine along Chappo Gulch; view northward. The coal seam is within the Adaville(?) Formation (Kav), which is overlain by the Death Canyon Limestone Member of the Gros Ventre Formation (Ꞓgd) along the Hogsback fault. A steep reverse fault lies between the mountain on the east, with Bighorn Dolomite (Ob) along its crest, and the rocks in the foreground.

Chappo Gulch just north of the quadrangle. The coal, which occurs in a seam 6 feet thick or less, is of relatively poor quality, and it slacks quickly when exposed. The coal formerly was used solely to serve the needs of nearby ranchers (Schultz, 1914, p. 97; Bertagnolli, 1941, p. 1742). Coal is mined on a large scale from the Adaville Formation to the south-southwest, in the nearby Kemmerer quadrangle.

PHOSPHATE

Another potential mineral resource of the Fort Hill area is phosphate in the Phosphoria Formation. The Phosphoria is exposed nowhere within the quadrangle, but its presence in subsurface has been established by drilling. Nearby exposures and subsurface sections of the formation are described by Sheldon (1963, p. 241–258) with accompanying analyses of the P_2O_5 content of the rock.

The Fort Hill area contains moderate reserves of fairly rich phosphate beds. The deposits are not likely to be mined soon, however, because richer beds are present at both the surface and shallower depths farther west. The formation may also be mined more economically at other localities closer to existing rail lines.

OTHER RESOURCES

Local residents have had water supplies from flowing streams in the area adequate for both domestic and irrigation use. The discharges of La Barge and Fontenelle Creeks are more than sufficient to meet the needs of the sparsely settled area. Ground water is largely undeveloped. If additional supplies of ground water should be needed, they likely could be found in modern alluvial channels and in the abundant porous and permeable sandstone beds throughout the sequence of Tertiary strata.

Sand and gravel are very abundant both in alluvium and in the coarser detrital Tertiary units. These deposits are too far from possible markets to be of use except for local highway needs.

REFERENCES CITED

Anderman, G. G., 1956, Subsurface stratigraphy of the pre-middle Niobrara formations in the Green River Basin, Wyoming, *in* Subsurface stratigraphy of the pre-Niobrara formations in Wyoming, pt. 1 *of* Wyoming stratigraphy: Wyoming Geol. Assoc., looseleaf, p. 49–68.

Andrews, D. A., 1944, Willow Creek coal area, Lincoln County, Wyoming: U.S. Geol. Survey Prelim. Coal Inv. Map.

Armstrong, F. C., and Oriel, S. S., 1965, Tectonic development of Idaho-Wyoming thrust belt: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1847–1866.

Asquith, D. O., 1965, Mesaverde and "Almy" production, Birch Creek unit, Sublette County, Wyoming [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 9, p. 1576–1577.

——— 1966, Mesaverde and "Almy" production, Birch Creek unit, Sublette County, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 10, p. 2176–2184.

Bally, A. W., Gordy, P. L., and Stewart, G. A., 1966, Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains: Canadian Petroleum Geologists Bull., v. 14, no. 3, p. 337–381.

Benson, A. L., 1965, The Devonian System in western Wyoming and adjacent areas: Ohio State Univ. Ph. D. thesis; available from University Microfilms, Inc., Ann Arbor, Mich., 141 p.

——— 1966, Devonian stratigraphy of western Wyoming and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 12, p. 2566–2603.

Berdan, J. M., and Duncan, Helen, 1955, Ordovician age of the rocks mapped as Silurian in western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955; p. 48.

Berg, R. R., 1961, Laramide tectonics of the Wind River Mountains, *in* Wyoming Geol. Assoc. Guidebook 16th Ann. Field Conf., 1961: p. 70–80.

Bertagnolli, A. J., Jr., 1941, Geology of southern part of La Barge region, Lincoln County, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 25, no. 9, p. 1729–1744.

Blackwelder, Eliot, 1918, New geological formations in western Wyoming: Washington Acad. Sci. Jour., v. 8, p. 417–426.

Boutwell, J. M., 1907, Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, v. 15, p. 434–458.

——— 1912, Geology and ore deposits of the Park City district, Utah, *with contributions by* L. H. Woolsey: U.S. Geol. Survey Prof. Paper 77, 231 p.

Bradley, W. H., 1926, Shore phases of the Green River formation in northern Sweetwater County, Wyoming: U.S. Geol. Survey Prof. Paper 140–D, p. 121–131.

——— 1929, Algae reefs and oolites of the Green River formation: U.S. Geol. Survey Prof. Paper 154–G, p. 203–223, pls. 28–48 [1930].

———1930a. The occurrence and origin of analcite and meerschaum beds in the Green River formation of Utah. Colorado, and Wyoming: U.S. Geol. Survey Prof. Paper 158–A, p. 1–7, pls. 1–3.

———1930b, The varves and climate of the Green River epoch: U.S. Geol. Survey Prof. Paper 158–E, p. 87–110, pls. 11–14.

———1931. Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168, 58 p. 28 pls.

———1948, Limnology and the Eocene lakes of the Rocky Mountain region: Geol. Soc. America Bull., v. 59, no. 7, p. 635–648.

———1959, Revision of stratigraphic nomenclature of Green River formation of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 5, p. 1072–1075.

———1963, Paleolimnology, Chap. 23 *in* Frey, D. G., ed., Limnology in North America: Madison, Wis.. Wisconsin Univ. Press, p. 621–652.

———1964, Geology of Green River Formation and associated Eocene rocks in southwestern Wyoming and adjacent parts of Colorado and Utah: U.S. Geol. Survey Prof. Paper 496–A, p. A1–A86.

Christensen, H. E., and Marshall, John, 1950, La Barge field, Lincoln and Sublette Counties, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., 1950: p. 105–108.

Cobban, W. A., and Reeside, J. B., Jr., 1952a, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1043.

———1952b, Frontier Formation, Wyoming and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 10, p. 1913–1961.

Cochran, K. L., 1959, Results of pre-Cretaceous exploration in the overthrust belt of southwestern Wyoming, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., 1959: p. 200–203.

Cope, E. D., 1873, On the extinct Vertebrata of the Eocene of Wyoming, with notes on the geology: U.S. Geol. Geog. Survey Terr. (Hayden) 6th Ann. Rept., p. 543–649.

Culbertson, W. C., 1965, Tongues of the Green River and Wasatch Formations in the southeastern part of the Green River Basin, Wyoming, *in* Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525–D, p. D139–D143.

Darton, N. H., 1904, Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., v. 15, p. 379–448.

Davies, H. F., 1934, Structural history and its relation to the accumulation of oil and gas in the Rocky Mountain district, *in* Wrather, W. E., and others, Problems of petroleum geology (Sidney Powers Memorial Volume): Am. Assoc. Petroleum Geologists, p. 679–693.

Deiss, C. F., 1936, Revision of type Cambrian formations and sections of Montana and Yellowstone National Park: Geol. Soc. America Bull., v. 47, no. 8, p. 1257–1342.

Donavan, J. H., 1950, Intertonguing of Green River and Wasatch formations in part of Sublette and Lincoln Counties, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., 1950: p. 59–67.

Dorf, Erling, 1955, Paleobotanical correlations of Late Cretaceous deposits in southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 96–99.

Dorr, J. A., Jr., 1952, Early Cenozoic stratigraphy and vertebrate paleontology of the Hoback Basin, Wyoming: Geol. Soc. America Bull., v. 63, no. 1, p. 59–94.

——— 1958, Early Cenozoic vertebrate paleontology, sedimentation, and orogeny in central western Wyoming: Geol. Soc. America Bull., v. 69, no. 10, p. 1217–1244.

Douglas, R. J. W., 1950, Callum Creek, Langford Creek, and Gap map-areas, Alberta: Canada Geol. Survey Mem. 255, 124 p.

Eardley, A. J., Horberg, Leland, Nelson, V. E., and Church, Victor, 1944, Hoback–Gros Ventre–Teton [Wyo.] field conference: 2 maps and sections [Michigan Univ.].

Flower, R. H., 1956a, Age of the Red River faunas (Ordovician), Manitoba to New Mexico [abs.]: Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1696.

——— 1956b, Montoya-Bighorn-Richmond correlations [abs.]: Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1793–1794.

Gazin, C. L., 1952, The Lower Eocene Knight formation of western Wyoming and its mammalian faunas: Smithsonian Misc. Colln., v. 117, no. 18, 82 p.

——— 1962, A further study of the lower Eocene mammalian faunas of southwestern Wyoming: Smithsonian Misc. Colln., v. 144, no. 1, 98 p.

Hale, L. A., 1960a, Annotations to accompany Cretaceous correlation chart [Wyo.-Colo.-Utah], *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 131–135.

——— 1960b, Frontier formation—Coalville, Utah, and nearby areas of Wyoming and Colorado, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 136–146.

Hallock, A. R., 1960, Stratigraphy and correlation of the Mesaverde group and Fort Union formation, southern Bridger Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 153–154 and plate.

Hansen, W. R., 1955, Geology of the Flaming Gorge quadrangle, Utah-Wyoming: U.S. Geol. Survey Geol. Quad. Map GQ–75.

——— 1957, Geology of the Clay Basin quadrangle, Utah: U.S. Geol. Survey, Geol. Quad. Map GQ–101.

Hayden, F. V., 1869, Preliminary field report [3d ann.] of the U.S. Geological Survey of Colorado and New Mexico: Washington, 155 p.

Hintze, L. F., 1959, Ordovician regional relationships in north-central Utah and adjacent areas, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf., 1959: p. 46–53.

Horstman, A. W., 1966, Correlation of the Lower and lower Upper Cretaceous rocks of a part of southwestern Wyoming, Utah, and Colorado: Colorado Univ. Ph. D. thesis; available from University Microfilms, Inc., Ann Arbor, Mich., 134 p.

Howe, R. A., 1955, Tip Top field, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955: p. 172–176.

Hubbell, R. G., 1954, Stratigraphy of the Jelm, Nugget, and Sundance Formations of northern Carbon County, Wyoming: Wyoming Univ. unpub. Master's thesis.

Imlay, R. W., 1950, Jurassic rocks in the mountains along the west side of the Green River Basin, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., southwest Wyoming, 1950: p. 36–48.

——— 1952a, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, no. 9, p. 953–992.

——— 1952b, Marine origin of Preuss sandstone of Idaho, Wyoming, and Utah: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1735–1753.

——— 1967, Twin Creek Limestone (Jurassic) in the western interior of the United States: U.S. Geol. Survey Prof. Paper 540, 105 p.

Intermountain Association of Petroleum Geologists, 1953, Guide to the geology of northern Utah and southeastern Idaho, 4th Ann. Field Conf., 1953: Salt Lake City, Utah, 143 p.

——— 1959, Guidebook to the geology of the Wasatch and Uinta Mountains transition area [Utah-Wyo.], 10th Ann. Field Conf., 1959: Salt Lake City, Utah, 235 p.

Keefer, W. R., 1965, Stratigraphy and geologic history of the uppermost Cretaceous, Paleocene, and lower Eocene rocks in the Wind River Basin, Wyoming: U.S. Geol. Survey Prof. Paper 495–A, p. A1–A77.

Keefer, W. R., and Van Lieu, J. A., 1966, Paleozoic formations in the Wind River Basin, Wyoming: U.S. Geol. Survey Prof. Paper 495–B, 60 p.

King, Clarence, 1876, Paleozoic subdivisions on the fortieth parallel: Am. Jour. Sci., ser. 3, v. 11, p. 475–482.

Knight, W. C., 1902, The petroleum fields of Wyoming: Eng. Mining Jour., v. 73, p. 720–723.

Krueger, M. L., 1955, Preliminary geological report, Big Piney gas field, Sublette County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., Green River Basin, 1955: p. 142–144.

——— 1960, Occurrence of natural gas in the western part of Green River Basin, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 195–210.

Kummel, Bernhard, Jr., 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas [Wyo.-Mont.]: U.S. Geol. Survey Prof. Paper 254–H, p. 165–194.

Lawrence, J. C., 1963, Origin of the Wasatch Formation, Cumberland Gap area, Wyoming: Wyoming Univ. Contr. Geology, v. 2, no. 2, p. 151–158.

Lochman-Balk, Christina, 1956, The Cambrian of the Rocky Mountains and southwest deserts of the United States and adjoining Sonora Province, Mexico, *in* Rodgers, J., ed., The Cambrian System, its paleogeography and the problem of its base—A symposium: Internat. Geol. Cong., 20th, Mexico 1956, pt. 2, p. 529–[661].

——— 1960, The Cambrian section of western Wyoming, *in* Overthurst belt of southwestern Wyoming and adjacent areas: Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 98–108.

Love, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geol, Soc. America Spec. Paper 20, 134 p.

——— 1950, Upper Cretaceous section from southwestern Wyoming to Yellowstone National Park, *in* Wyoming Geol. Assoc. Guidebook 5th Ann. Field Conf., 1950: facing p. 48.

——— 1954, Tentative diagrammatic correlation of Tensleep, Amsden, Casper, and Hartville Formations in Wyoming, *in* Wyoming Geol. Assoc. Guidebook 9th Ann. Field Conf., Casper area, 1954 (chart in pocket).

——— 1957, Stratigraphy and correlation of Triassic rocks in central Wyoming, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., 1957: p. 39–45.

——— 1961, Definition of Green River, Great Divide, and Washakie basins, southwestern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 10, p. 1749–1755.

——— 1964, Uraniferous phosphatic lake beds of Eocene age in intermontane basins of Wyoming and Utah: U.S. Geol. Survey Prof. Paper 474–E, p. E1–E66.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming: U.S. Geol. Survey.

McKee, E. D., and others, 1956, Paleotectonic maps of the Jurassic system, with a section on paleogeography by R. W. Imlay: U.S. Geol. Survey Misc. Geol. Inv. Map I–175, 6 p.

——— 1959, Paleotectonic maps of the Triassic System: U.S. Geol. Survey Misc. Geol. Inv. Map I–300, 33 p.

McKee, E. D., Oriel, S. S., and others, 1967, Paleotectonic maps of the Permian System: U.S. Geol. Survey Misc. Geol. Inv. Map I–450.

McKelvey, V. E., and others, 1959, The Phosphoria, Park City, and Shedhorn formations in the western phosphate field, *with sections by* J. Steele Williams, R. P. Sheldon, E. R. Cressman, T. M. Cheney, and R. W. Swanson: U.S. Geol. Survey Prof. Paper 313–A, 47 p.

Mansfield, G. R., 1916, Subdivisions of the Thaynes limestone and Nugget sandstone, Mesozoic, in the Fort Hall Indian Reservation, Idaho: Washington Acad. Sci. Jour., v. 6, p. 31–42.

——— 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 409 p.

——— 1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U.S. Geol. Survey Prof. Paper 238, 92 p.

Mansfield, G. R., and Roundy, P. V., 1916, Revision of the Beckwith and Bear River formations of southeastern Idaho; U.S. Geol. Survey Prof. Paper 98–G, p. 75–84.

Marzolf, J. E., 1965, Stratigraphy of the Mobil Oil Company Paleozoic test well No. 22–19–G, Tip Top Unit, Sublette County, Wyoming; U.S. Geol. Survey open-file report, 39 p.

Michael, R. H., 1960, Hogsback and Tip Top Units, Sublette and Lincoln Counties, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 211–216.

Murray, F. E., 1960, An interpretation of the Hilliard thrust fault, Lincoln and Sublette Counties, Wyoming, *in Wyoming* Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 181–186.

Newell, N. D., and Kummel, Bernhard, Jr., 1942, Lower Eo-Triassic stratigraphy, western Wyoming and southeast Idaho: Geol. Soc. America Bull., v. 53, no. 6, p. 937–995.

Oriel, S. S., 1961, Tongues of the Wasatch and Green River formations, Fort Hill area, Wyoming, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B151–B152.

——— 1962a, Middle Triassic problem [abs.]: Geol. Soc. America Spec. Paper 68, p. 242.

——— 1962b, Main body of the Wasatch Formation near La Barge, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 12, p. 2161–2173.

Oriel, S. S., and Armstrong, F. C., 1966, Times of thrusting in Idaho-Wyoming thrust belt—Reply: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 12, p. 2614–2621.

Peale, A. C., 1879, Report on the geology of the Green River district [Wyo.]: U.S. Geol. Geog. Survey Terr. (Hayden) 11th Ann. Rept., p. 509–646.

——— 1883, [Geologic map of] parts of western Wyoming, southeastern Idaho, and northeastern Utah: U.S. Geol. Geog. Survey Terr. (Hayden) 12th Ann. Rept., sheet 5.

——— 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull. 110, 56 p.

Peale, A. C., St. John, Orestes, and Endlich, F. M., 1883, Geological map of portions of Wyoming, Idaho, and Utah: U.S. Geol. Geog. Survey Terr. (Hayden) 12th Ann. Rept., sheet 2.

Peck, R. E., 1956, Rocky Mountain Mesozoic and Cenozoic nonmarine microfossils, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf., 1956: p. 95–98.

——— 1957, North American Mesozoic Charophyta: U.S. Geol. Survey Prof. Paper 294–A, p. 1–44.

Privrasky, N. C., 1963, Geology of the Big Piney area, Sublette County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–205.

Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geol. Survey Prof. Paper 373, 230 p.

Reeside, J. B., Jr., chm., 1957, Correlation of the Triassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 68, no. 11, p. 1451–1513.

Richards, R. W., and Mansfield, G. R., 1912, The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, v. 20, p. 681–709.

Robinson, G. D., 1963, Geology on the Three Forks quadrangle, Montana, *with sections on* Petrography of igneous rocks, by H. F. Barnett: U.S. Geol. Survey Prof. Paper 370, 143 p.

Rubey, W. W., 1958, Geologic map of the Bedford quadrangle, Wyoming: US. Geol. Survey Geol. Quad Map GQ–109.

Rubey, W. W., and Hubbert, M. K., 1959, Overthrust belt in geosynclinal area of western Wyoming in light of fluid-pressure hypothesis, [Pt.] 2 *of* Role of fluid pressure in mechanics of overthrust faulting: Geol. Soc. America Bull., v. 70, no. 2, p. 167–206.

Rubey, W. W., Oriel, S. S., and Tracey, J. I., Jr., 1968a, Preliminary geologic map of Sage quadrangle, Lincoln County, Wyoming: U.S. Geol. Survey open-file report.

——— 1968b, Preliminary geologic map of Kemmerer quadrangle, Lincoln County, Wyoming: U.S. Geol. Survey open-file report.

Sandberg, C. A., 1963, Dark shale unit of Devonian and Mississippian age in northern Wyoming and southern Montana, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C17–C20.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian system in Williston basin and central Montana: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p. 2293–2334.

Sando, W. J., and Dutro, J. T., Jr., 1960, Stratigraphy and coral zonation of the Madison group and Brazer dolomite in northeastern Utah, western Wyoming, and southwestern Montana, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960, p. 117–126.

Sando, W. J., Dutro, J. T., Jr., and Gere, W. C., 1959, Brazer dolomite (Mississippian), Randolph Quadrangle, northeast Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 12, p. 2741–2769.

Schultz, A. R., 1914, Geology and geography of a portion of Lincoln County, Wyoming: U.S. Geol. Survey Bull. 543, 141 p.

Sears, J. D., and Bradley, W. H., 1924, Relations of the Wasatch and Green River Formations in northwestern Colorado and southern Wyoming, with notes on oil shale in the Green River Formation: U.S. Geol. Survey Prof. Paper 132–F, p. 93–107.

Shaw, A. B., 1954, Correlation of the Paleozoic formations of Wyoming, *in* Wyoming Geol. Assoc. Guidebook 9th Ann. Field Conf. 1954: chart 2.

——— 1955, The Amsden formation in southwestern and south-central Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955: p. 60–63.

Shaw, A. B., and Bell, W. G., 1955, Age of Amsden formation Cherry Creek, Wind River Mountains, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 3, p. 333–337.

Shaw, A. B., and DeLand, C. R., 1955, Cambrian of southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955: p. 38–42.

Sheldon, R. P., 1957, Physical stratigraphy of the Phosphoria formation in northwestern Wyoming: U.S. Geol. Survey Bull. 1042–E, p. 105–185.

——— 1963, Physical stratigraphy and mineral resources of Permian rocks in western Wyoming: U.S. Geol. Survey Prof. Paper 313–B, p. 49–273.

Smith, J. H., 1961, A summary of stratigraphy and paleontology, Upper Colorado and Montanan Groups, southcentral Wyoming, northeastern Utah, and northwestern Colorado, *in* Wyoming Geol. Assoc. Guidebook 16th Ann. Field Conf., 1961: p. 101–112.

——— 1965, A summary of stratigraphy and paleontology, upper Colorado and Montanan Groups, southcentral Wyoming, northeastern Utah, and northwestern Colorado, *in* Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: Wyoming Geol. Assoc. Guidebook 19th Field Conf., 1965: p. 13–26.

Stanton, T. W., 1892, The stratigraphic position of the Bear River formation: Am. Jour. Sci., ser. 3, v. 43, p. 98–115.

Stokes, W. L., 1955, Non-marine Late Jurassic and Early Cretaceous formations [Wyo.], *in* Wyoming Geol. Assoc. Guidebook 10th Ann. Field Conf., 1955: p. 80–84.

Strickland, J. W., 1956, Mississippian stratigraphy, western Wyoming, *in* Wyoming Geol. Assoc. Guidebook 11th Ann. Field Conf., 1956: p. 51–57.

Tracey, J. I., Jr., Oriel, S. S., and Rubey, W. W., 1961, Diamictite facies of the Wasatch formation in the Fossil basin, southwestern Wyoming, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B149–B150.

Twenhofel, W. H., chm., 1954, Correlation of the Ordovician formations of North America: Geol. Soc. America Bull., v. 65, no. 3, p. 247–298.

U.S. Geological Survey, 1954a, Surface water supply of the United States, 1952, Pt. 9, Colorado River Basin: U.S. Geol. Survey Water-Supply Paper 1243, 496 p.

——— 1954b, Compilation of records of surface waters of the United States through September 1950, Pt. 9, Colorado River Basin: U.S. Geol. Survey Water-Supply Paper 1313, 749 p.

——— 1961, Surface water supply of the United States, 1959, Pt. 9, Colorado River Basin: U.S. Geol. Survey Water-Supply Paper 1633, 506 p.

Veatch, A. C., 1907, Geography and geology of a portion of southwestern Wyoming, with special reference to oil and coal: U.S. Geol. Survey Prof. Paper 56, 178 p.

Verville, G. J., and Momper, J. A., 1960, Pennsylvanian fusulinids and preliminary series correlation in southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 127–128.

Weimer, R. J., 1960, Upper Cretaceous stratigraphy, Rocky Mountain area: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 1, p. 1–20.

Wood, H. E., 2d, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.

Woodward, T. C., 1960, Willow Creek gas field, *in* Wyoming Geol. Assoc. Guidebook 15th Ann. Field Conf., 1960: p. 217–220.

Wyoming Geological Association, 1950, Southwest Wyoming, Guidebook 5th Ann. Field Conf., 1950: 196 p.

——— 1955, Green River Basin [Colo.-Utah-Wyo.], Guidebook 10th Ann. Field Conf., 1955: 243 p.

——— 1957, Wyoming oil and gas fields symposium, 1957: Wyoming Geol. Assoc. Symposium Comm., 484 p., looseleaf, with subsequent supplement additions, particularly in 1961 and 1962.

——— 1960, Overthrust belt of southwestern Wyoming and adjacent areas [Idaho-Utah], Guidebook 15th Ann. Field Conf., 1960: 285 p.

——— 1961, Symposium on Late Cretaceous rocks, Wyoming and adjacent areas, 16th Ann. Field Conf., Green River, Washakie, Wind River and Powder River Basins, 1961: 351 p.

——— 1962, Symposium on Early Cretaceous rocks of Wyoming and adjacent areas, 17th Ann. Field Conf., Casper arch, western Powder River and northern Big Horn basins, 1962: 337 p.

Yochelson, E. L., 1968, Biostratigraphy of the Phosphoria, Park City, and Shedhorn Formation, *with a section on* Fish, by D. H. Van Sickle: U.S. Geol. Survey Prof. Paper 313–D, p. 571–660.

INDEX

[Italic page numbers indicate major references]

U. S. GOVERNMENT PRINTING OFFICE : 1969 O - 324-263

Shorter Contributions to General Geology 1967

GEOLOGICAL SURVEY PROFESSIONAL PAPER 594

This volume was published as separate chapters A–M

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

CONTENTS

[Letters designate the separately published chapters]