Geology of Green River Formation and associated Eocene rocks in southwestern Wyoming and adjacent parts of Colorado and Utah

By W. H. BRADLEY

THE GREEN RIVER AND ASSOCIATED TERTIARY FORMATIONS

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GEOLOGY OF GREEN RIVER FORMATION AND ASSOCIATED EOCENE ROCKS IN SOUTHWESTERN WYOMING AND ADJACENT PARTS OF COLORADO AND UTAH

By W. H. Bradley

ABSTRACT

Discussed in this report is the geology of the Eocene rocks in an area of about 17,000 square miles. The purpose of the report is to provide the geologic foundation necessary to understand and reconstruct the conditions under which the Green River, Wasatch, and Bridger Formations came into being and to provide a matrix in which geochemists and mineralogists studying parts of the area can set up their models. The report is based largely on the author's own fieldwork, which began in the early 1920's, but it also brings together the findings of many other geologists who have worked in the area.

Four large structural units dominate the area. The first two are the Green River and Washakie Basins, each of which is a large synclinal basin. These are separated by the third unit, an anticlinal uplift of comparable size known as the Rock Springs uplift. A fourth large unit, the Great Divide Basin, is perched on the Continental Divide; it is not only a structural unit but also a shallow topographic basin having centripetal drainage.

Large faults, flexures, and subsidiary faults bound the southern margins of the Green River and Washakie Basins and form part of the northern boundary of the Great Divide Basin. The Rock Springs uplift is cut by numerous faults that trend northeastward. The many faults and minor flexures in the Great Divide Basin show that its structure is complex and more diversified than that of the other three major features.

All the mountain ranges—Uinta, Wind River, Wyoming, and others—in the area studied were in existence at the beginning of the Eocene Epoch, as were also the Rock Springs uplift and several other anticlinal bulges now buried under Tertiary sediments.

Downwarping of the floors of these basins which began early in the Tertiary, apparently continued more or less intermittently all through the Eocene and was primarily responsible for the continuous sedimentation of the Wasatch, Green River, Bridger, Uinta Formations. The low stream gradients between this region and the ocean apparently prevented the margins of these basins from being cut downward.

Uplift of the marginal mountains, or deformation in the form of faulting or gentle warping of the sedimentary rocks, occurred during the early Eocene, sometime between the end of the Eocene and the beginning of the Miocene, and sometime after the Miocene.

Fluviatile and lacustrine rocks of Eocene age cropout over most of the area and occupy large parts of the Green River, Washakie, and Great Divide Basins. Upper Cretaceous rocks are exposed in the Rock Springs uplift.

Most of the Eocene rocks belong to three formations—Wasatch, Green River, and Bridger. The Green River Formation is of lacustrine origin and has the form of a great lens, or pile of lenses, within an enormous volume of fluviatile sediments. The fluviatile sediments have been divided into the Wasatch and Bridger Formations. Though the Bridger Formation is predominantly fluviatile, it contains a considerable number of thin extensive layers of lacustrine sediments. Most of the Wasatch Formation underlies the Green River Formation, and most of the Bridger Formation overlies it; but locally around the margins, the Bridger rests directly on the Wasatch. The green River interfingers and intertongues with both fluviatile formations. Three tongues of the Wasatch, as well as the main body of the formation, have been defined and mapped. The Green River Formation has been subdivided into three members and three tongues, all of which have been mapped. The Bridger Formation has not been subdivided, but it contains several thin extensive zones called white layers, which have been mapped only in part.

Along the mountainward margins of basins are conglomeratic piedmont deposits, which are equivalent to part or all of several of these Eocene formations or their members and tongues. One of these conglomeratic deposits has been defined as a formation and mapped. The others are designated Eocene undifferentiated and have been mapped only locally.

Gosiute Lake, in which the Green River Formation was deposited, changed considerably and repeatedly in size and characteristics during the Green River epoch; but it had three major stages, each of which corresponds to a member of the Green River Formation. During the first stage, the lake was a large fresh-water lake that had an outlet. The Tipton Shale Member and the Luman, Tipton, and Fontenelle Tongues were formed during this stage. After their formation the climate became more arid, and the lake shrank, so that it occupied only part of the Green River Basin, at times only a small part of it, and had no outlet. During this the second stage the middle, or Wilkins Peak Member, was deposited. Because Gosiute Lake had no outlet during this entire second stage, enormous quantities of salts accumulated also. At least 25 beds of trona [Na_2CO_3 $NaHCO_3 \cdot 2H_2O$] ranging in maximum thickness from about 3 feet to about 38 feet, and in area from a few hundred to more than 725 square miles, have been found in this member. These beds constitute a great economic resource and in 1963 were being mined by two different companies. Comparable volumes of shortite [$Na_2CO_3 \cdot 2CaCO_3$] also occur in the Wilkins Peak Member; but this mineral, which is unique to the Green River Formation, occurs mostly as single crystals or aggregates of crystals rather than

as solid beds. Common salt (NaCl) is distributed unevenly through several of the trona beds and is abundant in the thick salt beds in the southern part of the Green River Basin. Along with these saline minerals are other saline minerals and a growing number of new or unusual authigenic minerals—silicates, borosilicates, fluorides, phosphates, oxides, and complex carbonates. Minerals containing the sulfate radical are extremely rare.

At the end of the second stage, the climate became humid again, and Gosiute Lake expanded to its maximum size (about 15,000 sq mi). In this large fresh-water lake, which had an outlet, the uppermost member of the Green River Formation, the Laney Shale Member, was deposited.

Gosiute Lake came into existence because the basin floor warped downward and continued, apparently at rather short intervals, to warp downward at a rate greater than the rate at which sediments accumulated. But at the end of the Laney stage, sedimentation evidently won out, for the lake became filled and so vanished. Smaller and much shorter lived lakes, however, repeatedly formed in the central parts of the Green River and Washakie Basins during the following Bridger epoch.

In the Washakie Basin deposition of the post-Bridger Uinta Formation apparently continued until about the end of the Eocene Epoch. This formation is not known to be present elsewhere in the area.

Volcanic activity began early in the Green River epoch and increased in frequency and intensity at least until the end of the Eocene. Most tuff beds in the lower parts of the Green River Formation are thin and rather widely spaced, but stratigraphically upward they increase in number and thickness; the upper part of the Bridger Formation is dominantly tuffaceous. The tuffs range from highly siliceous rhyolitic types to andesitic. In general, the less siliceous tuffs are thicker. Crystal and lithic tuffs are common from the basal part of the Laney Shale Member on up through the section.

Volcanism was again active during the Oligocene and Miocene. Formations of these ages consist largely of volcanic ash.

A long interval of erosion followed the deposition of the Eocene rocks. Still later, the extensive erosion surfaces cut on the Eocene and earlier formations were covered with a sheet of gravel known as the Bishop Conglomerate, whose exact age is not known. During or after the deposition of the conglomerate and later rocks, the area was gently deformed and locally faulted. In some of the down-faulted areas and on some of the erosion surfaces, a few hundred to more than 1,000 feet of beds of Miocene, and probably also Oligocene, age are still preserved. The Miocene formations include the Browns Park and Split Rock Formations, but the beds of Oligocene age have not been adequately defined and in this area have been locally grouped into an unnamed unit of Oligocene and Miocene ages.

Most of these Oligocene and Miocene beds were deeply eroded for a long interval of time after their deposition.

Late in the Pliocene, a small amount of the highly distinctive lava, wyomingite, flowed out from several vents at the north end of the Rock Springs uplift and from one vent a few miles north of the town of Green River. A potassium-argon age determination on the phlogopite mica from this leucite-rich lava gives the age as about 1.25 million years.

INTRODUCTION

ORIENTATION AND PURPOSE

Successive discoveries of natural gas, petroleum, and enormous deposits of sodium carbonate (trona) have focused an intensive commercial interest on a large part of southwestern Wyoming. Also, discoveries of new, or rare, and exotic authigenic minerals in the Green River Formation have attracted to that formation the attention of increasing numbers of mineralogists, geochemists, and geologists. My own interest was drawn to this area in the early 1920's when my imagination was sparked by the possibility of reconstructing a satisfying picture of the ancient great lake in which the Green River Formation accumulated. Such a reconstruction seemed within reach from what was even then known of the formation's extensive exposures, variety of rock types, and content of remarkable fossils. Perhaps most significant was the fact that the lake beds and their enclosing formations have been little disturbed by post-Eocene geologic events.

The purpose of this report is to provide the geologic foundation necessary to understand and reconstruct the conditions under which the Green River, Wasatch, and Bridger Formations came into being; to provide a matrix in which geochemists and mineralogists can set up their models; and, finally, to provide a framework that may be useful to those interested in exploring further for additional mineral or mineral-fuel resources.

This report, which covers about 17,000 square miles, is focused on the geology of the Eocene formations in southwestern Wyoming and small adjacent parts of Colorado and Utah; but it also touches on all the Tertiary history and formations, including the Pliocene flows of the leucite-rich rock, wyomingite. It does not deal with the Quaternary geology.

The report is based mainly on my own fieldwork, which began in the early twenties and has continued intermittently ever since. But the report also brings together the findings of many other geologists who have worked in the area in increasing numbers as the search for natural gas, petroleum, and sodium salts has increased in intensity.

This account of the geology is the first of a series of closely related papers. The second paper, on the paleoecology of the Wasatch and Bridger Formations of southwest Wyoming will be an effort to reconstruct the physical environment in which these two thick and extensive fluviatile formations came into being. The third paper, on the paleolimnology of the Green River Formation in Sweetwater and adjacent counties in Wyoming, Colorado, and Utah, will be an effort to reconstruct as fully as possible not only the various stages of Gosiute Lake in which the Green River Formation accumulated but also the Eocene climate and the composition of the streams and the lake water; the depth, circulation, and stratification of the lake; the aquatic environment and rates of accumulation of the various kinds of sediments; and the trophic history of the lake. The third paper of the series also will include a discussion of the organic constituents of the sediments and a consideration of the energy regimen. This third chapter will draw much from the first two chapters and depends heavily on them.

A fourth paper dealing more comprehensively with the Wilkins Peak Member of the Green River Formation is being prepared jointly with Prof. Hans Eugster of the Johns Hopkins University and the U.S. Geological Survey. This paper will discuss the origin of the carbonates, sodium salts, and trona beds and will attempt to give, in part at least, an explanation of the remarkable suite of authigenic minerals.

LOCATION AND EXTENT OF THE AREA

The area discussed in this report is mostly in southwestern Wyoming but extends a little way into northern Utah and northwestern Colorado. (See fig. 1.) In Wyoming it includes nearly all of Sweetwater County and part of five adjacent counties—Uinta, Lincoln, Sublette, Fremont, and Carbon. In Utah it includes a narrow strip along the north edge of Daggett and Summit counties. That part of the area in Colorado is in Moffat County. The total area is nearly 17,000 square miles, all of which lies within the Wyoming Basin physiographic province except a narrow strip in northern Utah and northwestern Colorado.

The two largest towns, Rock Springs and Green

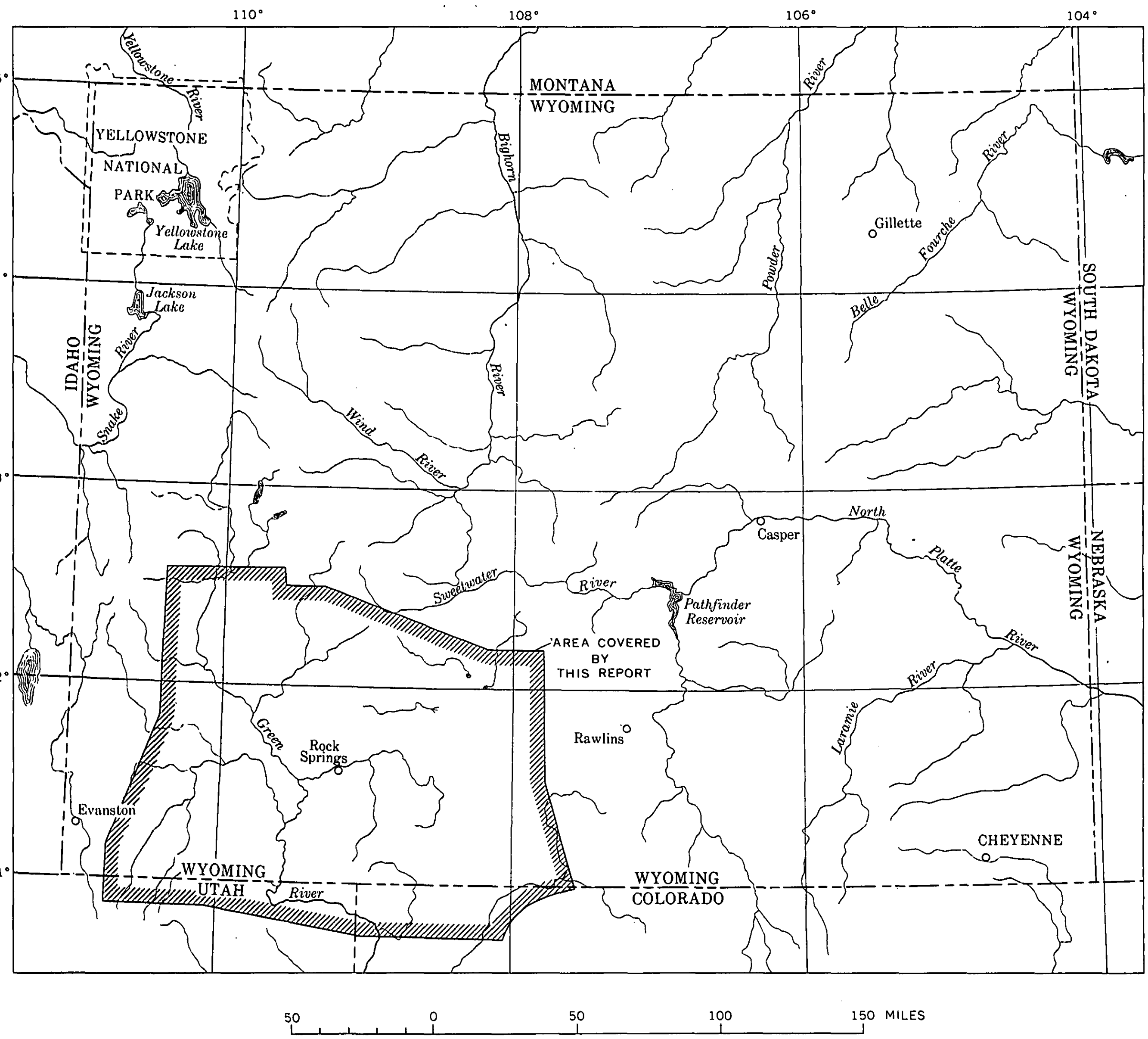

FIGURE 1.—Location of the area discussed in this report.

River, are near the geographic center of the area on the Union Pacific Railroad and U.S. Highway 30. At the west edge of the area is Kemmerer, which is on the Oregon Short Line of the Union Pacific.

EARLIER GEOLOGIC SURVEYS

In this sketch of previous geologic surveys, no attempt has been made to summarize the results of all the geologic work that has been done in this area. Only those reports are cited here that are accompanied by geologic maps of parts of the area described in this report. Scientific papers and reports treating pertinent phases of the Tertiary geology are referred to at appropriate places in the text.

Many years ago, that part of the area south of lat 41°45′ N. was mapped by Powell (1876), Hague and Emmons (1877), and King (1878); that part north of this parallel was explored and mapped by Peale and Endlich (1879). In these early surveys the Tertiary rocks were divided into the Wasatch, Green River, and Bridger Formations, but the maps showing the areal distribution of these units are of little value today. Many years later, Veatch (1907) and Schultz (1914) mapped in considerable detail a strip a little more than 30 miles wide west of the Green River Basin. In 1907 and 1908 Schultz (1909, pl. 14; 1910, pl. 14) mapped the Cretaceous and Tertiary rocks of the Rock Springs uplift and some of the adjacent country. Later he (Schultz, 1920, pl. 1) made a reconnaissance survey of the area south and southeast of the Rock Springs uplift and combined in one map all the data obtained. Gale (1907) mapped a small area along the Wyoming-Utah boundary in the vicinity of Henrys Fork in 1907. Schultz (1918), in outlining the phosphate resources of northern Utah in 1914, made a reconnaissance map of the Uinta Mountains. In 1918 Winchester (1923, pl. 18) mapped the outcrop of the principal oil shale zone of the Green River Formation along the Green River southward from the mouth of Currant Creek nearly to the Utah State line. A few years later Sears (1924b, pl. 35) mapped in detail an area in northwestern Colorado and southern Wyoming, and in the following year, 1923, I (Bradley, 1926, pl. 58) mapped a small area in the vicinity of Steamboat Mountain. Two other reports (Bradley, 1935, fig. 1; 1936, pl. 34) dealing with special features of the area have been published by me since the fieldwork on this project was begun in 1928. The first of these reports contains a map of a folded and faulted zone along the southern margin of Washakie Basin, whereas the other contains a map showing the geomorphic features superposed on a generalized geologic map of the southern part of the Green River and Washakie Basins and part of the Uinta Mountains and adjoining areas to the east. In 1945, I published a preliminary geologic map (Bradley, 1945) of the Washakie Basin that included a brief description of the stratigraphy and structure of the area.

W. T. Nightingale (1930) presented an argument for including a thick section of carbonaceous beds in the basin of Vermilion Creek in the Green River Formation instead of in the uppermost part of the Wasatch as Sears and Bradley (1924) had done. Reconnaissance maps showing the areal geology and structural features of the Uinta Mountains were published in 1937 by Forrester (pls. 3, 4). Nace, then of the Wyoming Geological Survey, published in 1939 a detailed map of a small but critical area around Oregon Buttes and from there northward to the outcrops of metamorphic rocks along Sweetwater River. The intertonguing relationships between the Green River and Wasatch Formations in the vicinity of La Barge, Wyo., were mapped and described by Donavan (1950). The area studied by Donavan and a larger area west of it were mapped in more detail in 1957 by Stephen S. Oriel of the U.S. Geological Survey. Oriel generously sent me (written communication, Aug. 16, 1957) a copy of his field map showing the various tongues of the Wasatch and Green River Formations in the La Barge and Fontenelle Creeks area. His information has been incorporated in the geologic map (pl. 1) of the present report.

In 1955 McGrew and Berman (1955; also McGrew and others 1959, p. 121–129) published a geologic map of a small but critical area between Big and Little Sandy Creeks (north of Farson, Wyo.). This mapping and the vertebrate fossils collected there demonstrated the age relationships of the faults in that part of the Green River Basin and established the Bridger age of the thick tuffs north of the faults. George Pipiringos (1962) of the U.S. Geological Survey made a significant contribution to our knowledge and understanding of the Green River and related formations in the Great Divide Basin and along the north side of the Washakie Basin. Among other things, he discovered another tongue of the Green River Formation below the Tipton Tongue and separated from it by a unnamed tongue of the Wasatch Formation. His map is included on plate 1 in somewhat generalized form, and his report is referred to many times later in this paper. A small part of Harold Masursky's (1962, pl. 1) map which adjoins Pipiringos' map on the east, is also included. Anderman (1955) published a geologic map of a rather large area around Manila, Utah, and gave a good account of the tectonic history, especially of the relations between the Uinta and Henrys Fork faults. Hansen and Bonilla (1954, 1956) and Hansen (1961 a, b) also added appreciably to our knowledge of the orogenic history of the southern margin of the Green River Basin.

FIELDWORK

The fieldwork upon which this report is based was begun in 1928. In that year, 4½ months was spent mapping and measuring sections in the Green River Basin. Mr. Joseph Jacoby was engaged for 1 week to serve as rodman. A few days was spent in the area in 1929 revising the mapping of the post-Eocene beds in the Valley of Sweetwater River. During 1930 about 4 months was spent in the field mapping the erosion surfaces and the bedrock geology along the north flank of the Uinta Mountains and in the southern part of the Green River Basin, and about 1 week was spent with C. W. Gilmore, of the U.S. National Museum, and his party, who were collecting vertebrate fossils from the Bridger Formation. Later that summer, planetable maps were made of two areas to show the location and stratigraphic position of the principal quarries from which vertebrate fossils had been taken. In 1933 Frank S. Parker, then of the U.S. Geological Survey, and I spent 2 months mapping the rock formations along the east and south sides of the Washakie Basin.

Nearly all the mapping was done by triangulation, using planetables and geologist's alidades, on a scale of 1:500,000 or approximately 8 miles to the inch in the Green River Basin and 1:250,000 in the Washakie Basin. In the Green River Basin the mapping was done almost wholly from the primary triangulation points established by topographic engineers of the Geological Survey. As nearly all these points are on prominent and easily recognized features that have a wide range of visibility, it was necessary to establish only a minor amount of secondary control. Primary triangulation established by topographic engineers of the Geological Survey and by the Coast and Geodetic Survey was available along the east side of the Washakie Basin, but secondary control had to be established along the southern margin of the basin. A narrow strip in northern Utah was mapped on topographic maps (Marsh Peak, Gilbert Peak, and Hayden Peak quadrangles) published by the Survey. The drainage, land net, and cultural features shown on plate 1 were taken from the Army Map Service (U.S. Army Corps of Engineers) 1:250,000 topographic maps (Rock Springs NK 12–9, and parts of Rawlins NK 13–7, Vernal NK 12–12, Salt Lake City NK 12–11, Ogden NK 12–8, Preston NK 12–5, and Lander NK 12–6).

The geologic map (pl. 1) is a composite of new and published information and was recompiled in 1956 and adjusted to the Army Map Service 1:250,000 topographic maps. The accuracy of the geologic mapping done specifically for this report is not uniform for all parts of the area.

In the years 1957–59 the geologic mapping was revised or remapped using the aid of high-altitude aerial photographs, new topographic maps of the Army Map Service, and photogeologic methods. R. J. Hackman, of the Geological Survey made a photogeologic map of the vicinity of Green River, Wyo., and Wilkins Peak (pl. 2) which was based on his own field sketching. He also made a photogeologic map of most of Hiawatha Basin (pl. 1) based on field sketching by Dwight Taylor, of the Survey, and me. Hackman remapped on aerial photographs all the Green River-Bridger boundary in Washakie Basin, on the basis of my field observations. J. D. Love, of the Survey, and I resketched on the Army Map Service 1:250,000 topographic base the Green River-Bridger boundary in the northeastern part of the Green River Basin and the upper and lower boundaries of the Tipton Shale Member of the Green River Formation south from Wilkins Peak to the north spurs of Little Mountain.

The Wilkins Peak–Laney Shale Members boundary from a few miles south of Wilkins Peak southward nearly to the Utah State line has recently been remapped on new topographic base maps by W. C. Culbertson, of the U.S. Geological Survey. His mapping is much superior to my own rapid reconnaissance mapping. My sketching of this boundary (pl. 1) places the contact too high; so the resulting pattern is more complex than it should be.

A large subjective element is involved in portraying the areal extent of the Bridger Formation because in most places its lithology grades gradually into the lithology of the underlying Green River Formation. No claim for accuracy, or even consistency, can be made for this boundary as mapped. On the other hand, the greater part of the data on other boundaries taken from published reports (see index map, fig. 1) was based on rather detailed surveys and is correspondingly more accurate than much of the new information. These maps required very little adjustment to fit the new topographic base maps. Nevertheless, some of the information taken from two published reports (Schultz, 1918; 1920, pl. 1) was based on rapid reconnaissance surveys that apparently were less well controlled than the mapping done specifically for this project during 1928 and in succeeding years.

ACKNOWLEDGMENTS

I am grateful to many of my colleagues of the U.S. Geological Survey who, over the years, have been generous with ideas, suggestions, and criticisms. I am especially grateful to J. D. Love for assistance in the field and for many discussions with him on problems relating to the geology of Wyoming. Few people are as conversant with so many aspects of the geology of a whole State as he is with the geology of Wyoming. I am grateful also to Steven S. Oriel for permission to use his hitherto unpublished geologic map of the northwestern part of the Green River Basin and for many helpful discussions. I wish to express my thanks to Dwight Taylor and George Pipiringos for assistance in the field and for helpful discussions about interpretations of the stratigraphy and paleoecology.

This report benefited materially in the manuscript stage from the thorough and constructive criticisms of J. D. Love and W. C. Culbertson, both of the Survey. For their generous help I am particularly grateful.

TOPOGRAPHY AND DRAINAGE

The topography of the region can be considered in four major units, each of which is rather well defined. These are the Green River Basin,[1] the Rock Springs uplift, the Washakie Basin, and the Great Divide Basin. (See pl. 1.) All these owe their form to the structure of the rocks. The Great Divide Basin, as its name implies, is a topographic depression literally perched on the Continental Divide. (See fig. 2.)

Green River Basin, the largest of the four units, occupies nearly all the western half of the area. Outward-facing escarpments of the Green River and Wasatch Formations mark the margin of this basin everywhere except for about 40 miles along the south end of the basin between Phil Pico Mountain and Elizabeth Mountain. There the Tertiary rocks are obscured by broad remnants of gravel-covered erosion surfaces that slope gently away form the Uinta Mountains and extend far out into the basin. As thus defined, the Green River Basin is a roughly rectangular area a little more than 100 miles long from north to south and about 60 miles wide.

At the southeast corner of the basin, where Little Mountain rises to a maximum altitude of about 9,100 feet, the escarpment of the Green River and Wasatch Formations is about 1,000 feet high. From Little Mountain northward along the east side of the basin, the height of the escarpment diminishes, so that where it is crossed by the Union Pacific Railroad it is about 500 feet high. For about 30 miles north from the railroad, the escarpment is a conspicuous bluff 400–500 feet high which is known as White Mountain. Beyond that the escarpment becomes lower and loses its identify as a distinctive topographic feature in the northeastern part of the basin. Northwestward and westward across the north end of the basin, the Green River Formation makes only a low, and in places poorly defined, escarpment that faces northeastward and northward.

Along the Green River from the northwest corner of the Green River Basin as far south as LaBarge Creek, the escarpment made by the Green River and Wasatch Formations is 100–300 feet high. From LaBarge Creek south, the greater part of the western margin of the basin consists of two rather low and irregular escarpments that are roughly parallel and several miles apart. These two escarpments are formed respectively by two units of the Green River Formation, separated by a soft unit of the Wasatch Formation. South of the main line of the Union Pacific Railroad the lower escarpment vanishes, but the upper one becomes higher and forms a conspicuous bluff that rises nearly 1,000 feet above the valley to the west in the vicinity of Piedmont. Near the southwest corner of the basin, just a few miles north of the Wyoming-Utah boundary, the upper escarpment merges with the high gravel-capped erosion surface that slopes northward from Elizabeth Mountain.

From the vicinity of Elizabeth Mountain eastward across the south end of the basin nearly as far as Phil Pico Mountain, broad remnants of several gravel-capped erosion surfaces slope gently northward from the Uinta Mountains. At the Wyoming-Utah boundary these highest terraces have an altitude of about 9,500 feet above sea level. East of the remnants of this high erosion surface, beds of undifferentiated Eocene deposits, equivalent in part to the Bridger, Green River, and Wasatch Formations, make a southward-facing escarpment whose height gradually increases from less than 100 feet to 700 or 800 feet on the southwest flank of Little Mountain.

Within the Green River Basin, and in a very broad way concentric with its rim, is another escarpment that faces outward. This escarpment is formed by the Bridger Formation. In most places it is several miles from the crest line of the marginal escarpment made by the Green River Formation, and in most places it is a low, irregular, and rather inconspicuous feature. A considerable part of the basin enclosed by this secondary escarpment is nearly level or gently rolling. At various altitudes along most of the streams, terraces have been formed. Some of the lowest terraces are very broad, notably those along Big Sandy and Little Sandy Creeks in the northern part of the basin and along Blacks Fork, Smiths Fork, and other streams in the southern part of the basin. Much of this nearly level land in both parts of the basin is irrigated and under cultivation. Elsewhere, the surface of Green River Basin is either barren of vegetation or bears the usual growth of shrubs and annuals characteristic of the semiarid high plateaus.

[1] In this and subsequent reports I shall use the name Green River Basin rather than Bridger Basin on the basis of the persuasive arguments recently marshalled by J. D. Love (1961b).

Despite the large area of nearly level land in the Green River Basin, a considerable part is characterized by badlands. In general, the relief in the badlands is low, though, locally, buttes with intricately sculptured sides rise 100–200 feet above the surrounding country. But in the southern part of the basin, along the northern margins of the high gravel-capped erosion surfaces and beneath outlying remnants of these surfaces, the badlands have a relief of 1,200–1,500 feet. In this locality the badlands have a most striking aspect. (See fig. 17.)

Just east of the Green River Basin is the Rock Springs uplift, a large elliptical anticlinal uplift that exposes Upper Cretaceous rocks at the surface. Erosion has removed the somewhat resistant sandstone beds from almost all the highest part of this uplift and has cut down into the soft shale in the central part to form a large depression, known as Baxter Basin. Large parts of the floor of this basin are nearly flat and almost featureless. A few of these flats have shallow closed depressions, which in wet weather contain playa lakes. Badlands characterize the remainder of Baxter Basin and contrast sharply with the smooth level parts. Above the general altitude of the basin floor (6,300–6,600 ft above sea level), the enclosing rim of rough sandstone hogbacks rises 600–800 feet or more. Southward from Aspen Mountain, broad remnants of a high gravel-covered erosion surface rise gradually toward the Uinta Mountains. An arm of this bench extends westward into the edge of the Green River Basin on the divide north of Sage Creek.

Washakie Basin lies southeast of the Rock Springs uplift. It is somewhat smaller than the Green River Basin but is more sharply defined. Like the Green River Basin, its form is determined by the structure of the rocks. On all sides the beds dip inward toward the center. As the rocks of the Green River Formation are considerably more resistant to erosion than those of the overlying or underlying formations, their uptilted edges nearly everywhere form the crest and upper part of a bold outward-facing escarpment which encircles the basin. Along the northern margin of the basin, this rim rises 600–700 feet above the country to the north and is known as the Laney Rim. Southward the escarpment increases in height, and locally on each side of the basin its crest stands about 1,000 feet above the surrounding terrain. Along the southwestern margin of the basin, the rim is known as the Kinney Rim. The southward-facing escarpment that makes the southern margin is broken in many places and is generally lower. Near the head of Powder Wash, just south of the Wyoming-Colorado boundary, where the escarpment is low, it turns southeastward and then southward, rising in height as it does so. A few miles west of the head of Powder Wash the westward-facing escarpment that forms the western margin of Washakie Basin also is low, but from that locality it swings southwestward, and its crest rises until it reaches an altitude of 8,120 feet above sea level at Lookout Mountain.

Around most of Washakie Basin the back slopes of the outward-facing escarpments slope gently inward but are interrupted by low discontinuous escarpments and ridges made by the comparatively soft rocks in the upper part of the Green River Formation and the lower part of the Bridger Formation. The basin floor is a desolate waste of badlands and broad expanses of gravel-covered pediment that supports but a sparse growth of low vegetation. The relief in the badlands is prevailingly low, but, locally, long irregular escarpments of badlands rise several hundred feet above the general level of the basin floor. In the northern part of the basin, a large badland mountain known as Haystack Mountain rises to an altitude of more than 7,600 feet above sea level. Haystack Mountain is a conspicuous landmark visible from all parts of Washakie Basin.

The Great Divide Basin, the fourth of the major topographic units of the area, has much less clearly defined margins than the others. It lies north and northeast of Washakie Basin and is a very shallow depression nearly 100 miles long from east to west and a little more than 50 miles wide. This basin is remarkable in that it has interior drainage and is literally perched on the Continental Divide. (See fig. 2.) At Oregon Buttes, approximately 50 miles north by east from Rock Springs, the Continental Divide splits, one branch running south a little way, then irregularly southeast to the northern tip of Washakie Basin, thence generally eastward some 30 miles beyond the east edge of the geologic map (pl. 1). The other branch runs sinuously eastward from Oregon Buttes for about 70 miles and then swings southeast and south to complete the encirclement of the basin about 20 miles south by west of Rawlins.

Only the western half of the Great Divide Basin lies within the area described in this report. Its margins are defined by the divides at the heads of the streams draining into the basin. (See fig. 2.) In a rough way these divides coincide with the margins of the adjacent basins and mountain uplifts, though in some places the streams having exterior drainage have cut headward through the rims of upturned rocks that encircle the adjacent basins. Flat-lying or gently warped beds of gray and reddish-gray mudstone and sandstone belonging to the Wasatch Formation underlie much of the west end of the basin. Overlying or intertonguing with the Wasatch are buff tongues of the Green River Formation. From mudstone beds of

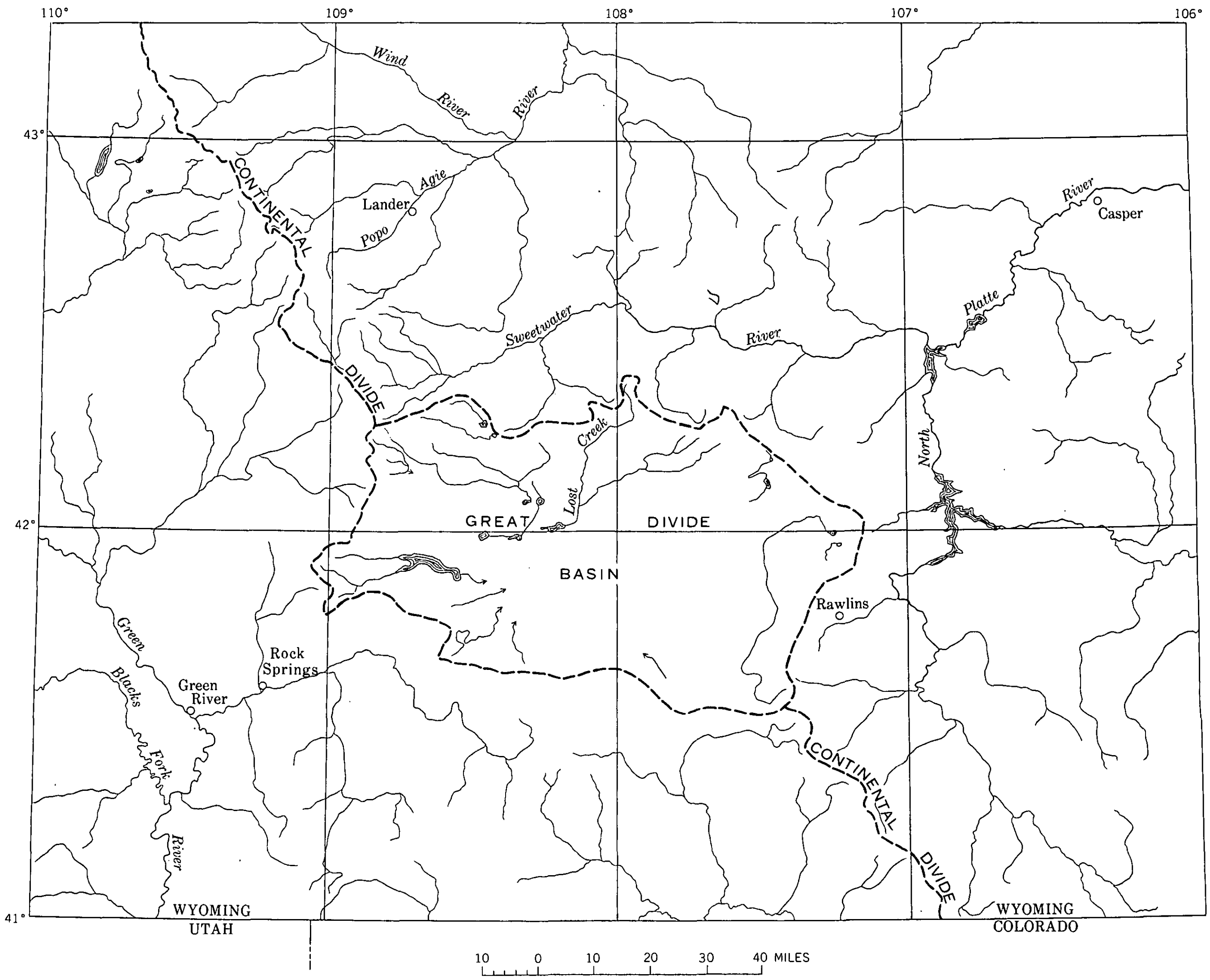

FIGURE 2.—The Great Divide Basin—a closed drainage basin perched on the Continental Divide.

the Wasatch, a thin soil cover has formed which retains the colors of the mudstone. As a consequence, large tracts of this basin are gray or drab, but a large area in the western part is dull red or reddish brown. From this prevailing red color of the soil, that area has long been known as the Red Desert. Emmons (1877) was one of the first to use this name, but he applied it also to a part of the Washakie Basin.

In general, the land surface in the Great Divide Basin, whose altitude above sea level ranges from 6,500 to 7,000 feet, is nearly flat and monotonous, though here and there isolated buttes or groups of buttes rise as conspicuous features. Shallow panlike depressions are also significant. These depressions, which are characteristic not only of this basin but of a large area in southern Wyoming, are elliptical or rounded in plan and range in size from about 100 yards to several miles across. Some of them contain playas and are nearly barren of perennial plants; others, more particularly the smaller ones, support a dense growth of greasewood.

Another conspicuous feature is the strip of large active sand dunes that extends eastward about 45 miles from the north end of the Rock Springs uplift out into the northern part of the Red Desert. Most of the dunes in the western half of the strip are compound and irregular; but, in general, they are asymmetric, and their steep faces are directed eastward. These dunes differ from one another as much in size as in form. Some of the largest are as much as 100 feet high. The dunes in the eastern half of the strip have the crescentic form typical of barchans. This strip of active dunes is superimposed on a broader strip of low dunes that are fixed by a thick growth of sage brush and rabbit brush. Less active parts of the live dunes in places support a pure stand of Indian turnip (*Psoralia* sp.). At one place—locally known as Flodden Field—near the north end of the Rock Springs uplift, numerous hollows between the sand hills contain small ponds.

North and south of the Rock Springs uplift are two small masses of high land that are somewhat isolated from the major topographic units just described. The highland north of the uplift slopes northward from Steamboat Mountain, whose highest point is a little more than 8,600 feet above sea level. A few miles north of Steamboat Mountain the high badland bluffs known as Oregon Buttes also rise to an altitude of about 8,600 feet above sea level. Between Steamboat Mountain and Oregon Buttes the northward-sloping surface is deeply dissected.

The highland south of the Rock Springs uplift is also deeply dissected. It slopes rather abruptly northeastward from three high points—Diamond Peak, Bishop Mountain, and Pine Mountain. Diamond Peak rises 9,710 feet above sea level, and Bishop and Pine Mountains are only a little lower.

The Green River and its tributaries drain all that part of the area described in this report except the Great Divide Basin and a narrow strip of country north of it which is drained by the Sweetwater River, an ultimate contributor to the Mississippi.

Most of the tributaries of the Green River that have their headwaters in the mountains bordering the Green River Basin are perennial streams. A few of these, such as New Fork River, Blacks Fork, Hams Fork, and Big Sandy River, are fairly large streams. Tributaries that do not rise in the bordering mountains are all intermittent except for a few of the longer streams such as Bitter Creek, which rises in Washakie Basin and flows across the Rock Springs uplift, and Salt Wells Creek in the Rock Springs uplift.

Nearly everywhere the courses of the rivers and large streams are unrelated to the structure of the rocks. The Green River enters Green River Basin through a canyon from the north, crosses the basin diagonally, and then leaves the basin on the south through a deep canyon cut normal to the strike of the hard rocks that make the north flank of the Uinta Mountains. Nevertheless, the westward tilt of the rocks along that reach of the river from the Union Pacific Railroad south nearly to the Wyoming-Utah boundary apparently caused the river to shift somewhat to the west as it cut downward; for, in general, the west side of the valley is precipitous, whereas the east side rises more gradually along dip slopes. Bitter Creek and some of its tributaries, notably Salt Wells Creek, cross the rim of the Rock Springs uplift nearly at right angles to the strike of the hogbacks. At each place where these streams cross the rim, they have cut deep and rather narrow canyons. Similarly, the majority of the long streams in this area have entrenched themselves more or less deeply in courses that were determined in very few places by the attitude of the rocks. On the other hand, the smaller streams throughout the area are rather well adjusted to the structure of the rocks.

The courses of Blacks Fork and its tributaries in the Green River Basin and of Bitter Creek and most of its tributaries in the Rock Springs uplift are noteworthy because they flow northward for many miles and then swing around to more southerly courses before joining the master stream, the Green River. Other smaller streams in the Green River Basin have a similar habit. A discussion of the drainage pattern and drainage changes in this part of the area has been published elsewhere (Bradley, 1936, p. 187–190, 199).

The drainage of Great Divide Basin has no outlet to the sea. Nearly all the streams in the basin are intermittent, short, and irregular and are directed toward the large playas in the center of the basin. A few streams, however, end in smaller playas that are perched on the sides of the basin remote from the center. About midway in their courses, some of the larger streams have intrenched themselves as much as 15 feet. Many of the stream courses contain small "alkali slicks" and, in places, especially near such high parts of the rim as Steamboat Mountain and Oregon Buttes, springs of good water.

North of the Great Divide Basin on the Atlantic side of the Continental Divide is a narrow strip of country drained by the Sweetwater River, a tributary of the North Platte. The Sweetwater River gets virtually all its water from a few streams that rise in the Wind River Range. The drainage basin of the Sweetwater has been so narrowed by headward erosion of the streams on either side that its lateral tributaries are all short and intermittent. Some streams end in "alkali slicks" before ever reaching the river.

GEOLOGIC STRUCTURE

MAJOR STRUCTURAL UNITS

The part of Wyoming considered in this report contains four major structural units. The first two are Green River and Washakie Basins, each of which is a large shallow synclinal basin. These are separated by the third unit, an anticlinal uplift of comparable size known as the Rock Springs uplift. The fourth unit, Great Divide Basin, lies northeast of the Rock Springs uplift.

The Green River Basin is underlain by rocks of the Wasatch, Green River, and Bridger Formations. In the central part of the basin, the rocks are virtually flat or are inclined at angles that exceed 1½° at only a few places. In a rather narrow strip around the margin of the basin, however, the beds are tilted more steeply: along the east rim they dip westward at angles ranging from 3° to 12°, along the northern margin they dip 1°–1½° southward, and on the west side they dip eastward toward the axis of the basin at angles of 2°–8°.

Along the southern margin of Green River Basin, the structure is more complex. At Little Mountain the rocks dip basinward a little more than 3°, but westward the inclination steepens, and where the basal beds of the Green River Formation cross the Green River they dip about 35° northward. A few miles farther west in the vicinity of Linwood, Utah, beds stratigraphically a little lower are overturned and dip steeply to the south. These steep dips, however, are due to drag along a large fault that trends roughly parallel to the basin rim. A few hundred yards north of this fault, which is known as the Henrys Fork fault, the structure of the Tertiary rocks is comparable with that along other parts of the basin rim, for the beds dip northward at angles ranging from 1° to 15°.

The structure of Washakie Basin is like that of the Green River Basin. Like the Green River Basin also, the Washakie Basin is underlain by rocks of the Wasatch, Green River, and Bridger Formations; beds of Uinta age overlie the Bridger, and the still younger Browns Park Formation makes up a part of the complex southern margin. In the large central area the rocks lie nearly flat, but around the edges they are tilted up. Along the north and east sides, the beds dip about 3°–5° toward the center of the basin. Along the west and southwest sides, they dip basinward at angles ranging from 8° to 15°. The southern margin of the Washakie Basin is defined by a zone of folds and faults that extends westward from the town of Baggs, Wyo., to the Kinney Rim, which forms the western boundary of the basin. Most of the folds are rather gentle, having dips that range from 3° to 7°; though locally, as in the vicinity of Baggs, the beds dip as much as 16°. Locally also along the faults, beds are flexed by drag. This faulted zone along the southern margin of the Washakie Basin has been described more fully in another paper. (Bradley, 1935.)

The Rock Springs anticlinal uplift is formed of Upper Cretaceous shale and sandstone units that belong to the Baxter Shale and the overlying Mesaverde Group. The axis of the uplift plunges northward and southward from a high central part; and, in consequence, the uplift has, in plan, a crudely elliptical outline. The arch is asymmetric toward the west, on which flank the beds dip about 12° westward. On the east flank the beds dip 5° or 6° eastward. The structure and stratigraphy of the Rock Springs uplift have been described rather fully in three other reports—Schultz (1909, 1910) and Sears (1926).

The major axes of these three major structural features—Green River Basin, Rock Springs uplift, and Washakie Basin—trend northward and are roughly parallel to the strike of the folded pre-Tertiary rocks both west and east of the area discussed in this report. West of the Green River Basin the pre-Tertiary rocks are sharply folded. Seismic surveys and drilling have shown that between these sharply folded pre-Tertiary rocks and the less steeply folded pre-Tertiary rocks in the Rock Springs uplift there are folds of intermediate form which are now concealed beneath the Tertiary beds of the Green River Basin. Presumably the axes of these folds in pre-Tertiary rocks are essentially parallel to the strike of the folded belt west of the Green River Basin and to the major axis of the Rock Springs uplift.

Pipiringos (1962, p. A41–A74, pl. 1) described in detail the structure of part of the Great Divide Basin. The structure of the remainder of the western half is well known from the development of a considerable number of oil and gas fields, notably the Patrick Draw field (Burton, 1961, p. 276–279), the Arch unit (Lawson and Crowson, 1961), the Table Rock field (Mees, Copen, and McGill, 1961), and the Desert Springs field (May, 1961). Other similar fields are the West Desert Springs and Sand Butte fields. Data from all these plus surface dips on the Wasatch Formation reveal a rather gentle eastward slope of the beds into the Great Divide Basin. The Wamsutter arch, first recognized by Schultz (1920, pl. 1) and now well known, extends westward and southwestward from the northern part of the Washakie Basin into the Rock Springs uplift and makes a structural southern boundary for the Great Divide Basin.

FAULTS

Most of the faults that cut the Tertiary rocks in this part of Wyoming are localized along the margins of major uplifts of pre-Tertiary rocks. The one notable exception is the zone of faults along the southern margin of the Washakie Basin. The largest faults are along the north flank of the Uinta Mountains and the south flank of the Wind River Mountains, though near the southeast end of the Wind River Range another large fault displaces the Tertiary beds north of Continental Peak and Oregon Buttes. This fault and associated smaller faults extend northwestward from there to Big Sandy Creek (T. 29 N., R. 106 W.).

Numerous faults cut the pre-Tertiary rocks of the Rock Springs uplift. Some of these extend out into the Tertiary rocks. At the north end of the uplift is a small group of faults in a locality where only Tertiary rocks are exposed. Along the west side of the Green River Basin, only one fault cutting the Tertiary rocks was found. It is just west of Piedmont in Uinta County.

WIND RIVER THRUST FAULT

This very large thrust fault bounds the south flank of the Wind River Mountains. The fault extends far back under the front of the range and dips at moderate angles. Although the fault is almost everywhere concealed, much is known about it from exploratory drilling and from geophysical surveys. (See Berg, 1961.) I have nothing from my own experience to add to published interpretations of this major feature.

UINTA FAULT AND UINTA FLEXURE

The Uinta fault coincides with a large and steep monoclinal flexure that defines the northern front of the Uinta range for more than 100 miles. The fault itself extends from Diamond Peak, in the extreme northwest corner of Colorado, westward along the north flank of the Uinta Mountains into Utah at least as far as Burnt Fork (south of T. 3 N., R. 16 E., S.L.M., Summit County, Utah). Westward beyond Burnt Fork the flexure apparently is not faulted, though the beds are steeply inclined and in places are nearly vertical. Lamentably little precise information is available on this structure despite its long familiarity to geologists through the stereograms and text of Powell's report (1876, p. 177–179, 205–207). In a reconnaissance survey of the Uinta Mountains, Schultz (1918, pl. 5) mapped the Uinta fault from its east end westward nearly to the west boundary of Daggett County, Utah. My own reconnaissance geologic mapping in northern Utah between the longitudes of Manila and Beaver Creek (T. 3 N., R. 15 E., S.L.M.) extended the trace of the Uinta fault and flexure and yielded the information from which the map shown on plate 1 was drawn. Westward from the vicinity of Phil Pico Mountain (T. 3 N., R. 18 E., S.L.M.), Forrester (1937, p. 645–646) evidently mapped as the westward extension of the Uinta fault a different fault from the one I mapped and refer to in this report as the Uinta fault. His mapping of the geology around Phil Pico Mountain and from there westward to Beaver Creek differs so much from mine that it is impossible to reconcile the two maps.

The trace of the Uinta fault is decidely sinuous. In many places the plane of the fault is nearly or quite vertical, but in other places it dips either southward or northward. On the basis of the limited observations now in hand, it appears that the fault plane is nearly vertical where the fault trace is essentially straight, dips northward where the fault trace makes an arc convex toward the Uinta Mountains, and dips southward where the fault trace makes an arc convex away from the mountains. Observations at additional places, however, may show that this suggested generalization is not valid.

Hansen and Bonilla (1954, p. 15–18), since my reconnaissance mapping, added substantially to our knowledge and understanding of this great fault. They discussed various aspects of the Uinta fault rather fully. One summary statement (p. 18) of theirs is quoted as particularly pertinent.

> Where Tertiary rocks are involved in the faulting (just west and east of Clay Basin) they display very little deformation despite their low competence and despite strong overturning in the immediately underlying Cretaceous rocks. It appears, therefore, that at least two distinct periods of thrusting have occurred on the Uinta fault, that the first and greatest movement followed sharp overturning and rupture before Tertiary time, and that the second movement in Tertiary time and along the already established thrust plane, simply sheared the Tertiary rocks without first flexing them or subsequently dragging them.

These same geologists (p. 14–15, 25) presented a good case for lateral displacement along the Uinta and associated faults, saying that the displacement increases eastward as the throw on the Uinta fault increases. This lateral movement offsets fold axes that are roughly normal to the trend of the Uinta fault. According to Hansen and Bonilla's map, fold axes north of the fault have been moved as much as 7 miles west of their counterparts south of the fault.

Powell (1876, p. 205) estimated the maximum displacement on the Uinta fault as about 23,000 feet. This figure apparently includes displacement due to the Uinta flexure also. According to my scattered observations along the fault, the maximum displacement on the fault itself is approximately 13,700 feet in T. 3 N., R. 23 E., S.L.M. There the stratigraphic interval between the two sides of the fault is approximately 12,300 feet.

The Uinta fault evidently cuts the Uinta flexure at least as far west as sec. 4, T. 2 N., R. 16 E., S.L.M., Summit County, Utah, for there the fault cuts off the Weber Sandstone. (See pl. 3.) It was not clear to me whether or not the fault is present a mile farther west (secs. 31 and 32, T. 3 N., R. 16 E.) where conglomeratic undifferentiated Tertiary beds (at this particular place evidently equivalent to the Bridger Formation) abut the nearly vertical wall of Carboniferous limestone. The relations are similarly obscure where the wall of Carboniferous limestone crosses the West Fork of Beaver Creek 3 miles farther west.

For reasons that are not wholly clear to me, Anderman (1955, p. 132) believed that the Uinta fault does not extend this far west. His interpretation was that the fault dies out just a few miles west of Sheep Creek (in about sec. 8, T. 2 N., R. 19 E., S.L.M., Daggett County, Utah)—that is, almost 18 miles farther east.

HENRYS FORK FAULT

The Henrys Fork fault extends from the Green River (T. 3 N., R. 21 E., S.L.M.) westward about 20 miles to Phil Pico Mountain (T. 3 N., R. 18 E., S.L.M.), where it dies out. Throughout the greater part of its length it is a steep reverse fault, and the beds on its north or downthrown side are steeply upturned or overturned in the drag zone. Near its west end, however, it becomes a normal fault.

The trace of this fault is gently curved except at two places in the valley of Henrys Fork just north of the Wyoming-Utah boundary where it makes two abrupt bends that are nearly at right angles to the general trend of the fault. At the southernmost of these bends, the strike of the fault changes within a remarkably short distance from N. 40° E. to N. 80° W. (See pl. 3.) The throw of the Henrys Fork fault can not be readily determined, but it is judged to be about 2,000 feet. Anderman (1955, p. 132), however, estimated the throw as about 12,000 feet on the east side of Phil Pico Mountain. He also said (p. 131) that on the east flank of Phil Pico Mountain there is "* * * an angular discordance of approximately 60° * * *" within the Green River Formation and in this same vicinity. He added:

> * * * a portion of the lower part of the formation is overridden along the Henrys Fork fault by the Morrison Formation, and the remainder is overlapped unconformably by the relatively gently dipping upper part of the Green River Formation. The angular discordance is present only where the Green River Formation laps highest onto the flanks of the Uinta Mountains at Phil Pico Mountain and disappears rapidly northward.

My own interpretation of the geology of Phil Pico Mountain differs somewhat from Anderman's. Although I did not recognize an unconformity within the Green River Formation, I think its presence in that area is plausible. Moreover, I think he was probably right in thinking that all or most of the conglomeratic mass of Phil Pico Mountain is a correlative of the Green River Formation. Certainly many of the finer grained beds in the lower part have a distinctly Green River aspect. However, because in my mapping of the conglomeratic facies there and farther west I was generally unable to discriminate between the Wasatch, Green River, and Bridger Formations, I prefer to use the indefinite Tertiary undifferentiated. Contrary to Anderman's interpretation, I believe that the Henrys Fork fault dies out in the conglomerates that makeup Phil Pico Mountain, because I was not able to find any displacement or distortion of the conglomeratic beds on the west side of the mountain, whereas on the east flank the upturned beds along the trace of the fault are conspicuous. (See fig. 3.) Indeed, the dip on these upturned beds decreases westward toward the top of the mountain, and there it agrees approximately with the gentle northward dip that prevails throughout

FIGURE 3.—Part of the east flank of Phil Pico Mountain showing upturned conglomeratic beds of the Tertiary undifferentiated along the trace of the Henrys Fork fault.

the conglomeratic beds of the northern part of the mountain.

An unusual feature of the geology of Phil Pico Mountain is the nearly level bench or platform of Triassic and Jurassic rocks upon which rest the northward-dipping conglomeratic Tertiary rocks that make up the mountain. (See fig. 4 and structure sections, pl. 3.) This platform apparently extends westward beyond Phil Pico Mountain; for in the valley of Birch Creek, the Nugget Sandstone (Jurassic) crops out at nearly the same altitude as it does at the east base of the mountain. (See pl. 3.) The form of this platform suggests that it may be a pre-Tertiary erosional feature, perhaps a pediment. The northern edge of the platform may be an erosional scarp or, as it apparently coincides with the trace of the Henrys Fork fault, a fault scarp. If it is a fault scarp, as Anderman (1955, p. 131 and map) believed, it probably represents pre-Green River movement along the Henrys Fork fault, because the Tertiary beds there do not appear to me to have been disturbed by faulting.

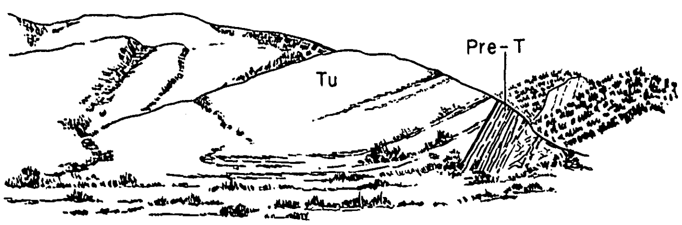

FIGURE 4.—Field sketch of the west side of Phil Pico Mountain at its south end showing the upturned Tertiary conglomeratic beds (Tu) resting with angular discordance against the steeply dipping pre-Tertiary rocks. (Pre-T).

The two structure sections in figure 4 show my concept of the structure east and west of Phil Pico Mountain. The crude notebook sketch reproduced on plate 3 shows the unconformable overlap of the Tertiary beds on the more steeply dipping Paleozoic rocks.

Powell (1876, p. 177) referred to the Henrys Fork fault as the Flaming Gorge Branch of the Uinta fault and indicated that it was an abrupt flexure between the Green River and the rivers junction with the Uinta fault a few miles east of Flaming Gorge. I was unable to find this flexure or any trace of the fault east of the Green River, where the fault apparently goes into a thick body of soft Upper Cretaceous shale.

CONTINENTAL FAULT

In the northern part of the area discussed in this report, a fault which Nace (1939, p. 45–46) called the Continental fault extends from sec. 26, T. 29 N., R. 106 W., Sublette County, southeastward nearly 55 miles. It is a normal fault whose plane is steeply inclined to the north. Along its eastern part it brings the Miocene Split Rock Formation (Love, 1961a, p. I24; written communication, May 1962) down on the north against the Wasatch Formation, but along its western part it brings the Bridger Formation down against the Wasatch and Green River Formations. In most places along the trace of this fault the rocks on both sides are flexed rather abruptly, so that close to the fault plane they dip 20°–48° northward. Nace (1939, p. 46, pl. 1), who mapped the eastern part of the fault in considerable detail, found that it was cut by many smaller cross faults and subparallel slices, especially in the vicinity of Continental Peak. At a place about 7 miles northwest of Oregon Buttes, Nace (p. 45–46) estimated that the Continental fault has a throw of 1,450–1,830 feet. Berman (McGrew and Berman, 1955) mapped the western part of the fault, between Little and Big Sandy Creeks, and found that it was offset there also by transverse faults.

In the area mapped by Berman, the Bridger contains a large amount of light-gray to white tuff and, at the top, clay that resembles altered tuff. This sequence is overlain disconformably by a coarse poorly sorted conglomerate which Berman correlated (p. 109) with Nace's Beaver Divide Conglomerate. I am not familiar with the Beaver Divide Conglomerate on Beaver Divide, but the conglomerate Berman mapped looks a good deal like a conglomerate that occurs in the upper parts of both Oregon Buttes and Continental Peak; indeed, it caps Continental Peak, which is about 200 feet lower than Oregon Buttes. In Oregon Buttes this conglomerate is about 55 feet thick and consists predominantly of schist from the east end of the Wind River Range in a matrix of coarse white sand. This conglomerate and the overlying tuffaceous beds presumably belong to the White River(?) Formation, which is of Oligocene age.

Nace (1939, p. 46) estimated the throw of the Continental fault a few miles northwest of Oregon Buttes as 1,450–1,830 feet.

South of this fault, in T. 27 N., R. 101 W., is a sharp flexure that extends northwestward from Oregon Buttes nearly to the Continental fault. It bends the beds of the Wasatch Formation down more than 250 feet on the south side. The displacement, which is opposite to that of the Continental fault, diminishes northwestward.

FAULTED ZONE SOUTH OF WASHAKIE BASIN

The faults of this belt fall into two broad groups, according to their general direction of strike. The faults of the dominant group strike generally westward; those of the other group strike more nearly northward or northwestward. The faults of the first group are apparently older, as they are cut by faults of the second group. Moreover, the faults of the second group cut beds of the Browns Park Formation, whereas the other faults in most places do not. However, some of the larger east-west faults were apparently active during the second stage of faulting, because locally they cut the Browns Park Formation. The mapping of the faults in this belt was materially improved by R. J. Hackman of the U.S. Geological Survey who remapped the whole Washakie Basin photogeologically. His photogeologic mapping is incorporated in the geologic map, plate 1.

MISCELLANEOUS FAULTS

None of the numerous faults that cut the pre-Tertiary rocks were studied as a part of this project. A small group of faults that cut the Tertiary rocks at the north end of the Rock Springs uplift were described briefly in an earlier publication (Bradley, 1926, p. 123). They are evidently related to the structure of the Rock Springs uplift.

The short normal fault near Piedmont, in Uinta County, Wyo. (Tps. 14 and 15 N., R. 117 W.), trends a little east of north and passes just west of Piedmont. It drops parts of the Wasatch and Green River Formations down on the west. The displacement, which is moderate, was not measured. Apparently most of the faults in the Wyoming Range and its southward extension are of pre-Eocene age, though Tracey, Oriel, and Rubey (1961, p. B149) mentioned post-Wasatch normal faulting. One of these large overthrust faults, the Darby fault of Schultz (1914, p. 84–85), disappears beneath the Tertiary beds in the southwest part of T. 26 N., R. 113 W., a few miles south of LaBarge Mountain.

INTERPRETATION OF THE STRUCTURE

PRE-TERTIARY DEFORMATION

The following interpretation of the structural features just described will be focused on the Tertiary history of deformation to gain a better understanding of events, particularly during the Eocene Epoch, that affected in any way the physical environment within which the Wasatch, Green River, and Bridger Formations were deposited. This is a necessary foundation to any consideration of the paleolimnology of the ancient Green River lake and to a consideration of the paleoecology of the enclosing Wasatch and Bridger Formations. Accordingly, very little attention will be given to pre-Tertiary structural features.

Essentially, what we shall be concerned with is a very large intermontane basin—one that extends roughly 150 miles eastward from the Wyoming Range and its southward extension to the flanks of the Elkhead Mountains in Colorado, the Sierra Madre, and the Rawlins uplift and its northward extension. The southern margin of this basin is defined by the Uinta Mountains and its southeastward extension. The northern margin is made up of the Gros Ventre Range, the Wind River Range, and the Granite Mountains. It is less simple to measure the north-south dimension, but it almost everywhere exceeds 100 miles. A roughly triangular extension of this basin runs far up between the Wind River and Wyoming ranges, and another rather irregular triangular extension runs equally far southeastward into northwestern Colorado. Neither of these extensions from the otherwise roughly rectangular basin are given much consideration in this report, partly because the Colorado area has been treated fully in a report by Sears (1924b, p. 292–295) and partly because my acquaintance with the area in the angle between the Wind River and Wyoming ranges is inadequate. Only the elliptical Rock Springs uplift near the center of this great intermontane basin destroys its simplicity.

All the surrounding mountain ranges and uplifts named above were in existence at the beginning of the Eocene Epoch, though the Uinta and Wind River ranges were not as high as they later became. Presumably, the floor of this great intermontane basin was not flat but had bulges and depressions. One of these was the pre-Tertiary anticline on which was later developed the Church Buttes gas field (Fidlar, 1950, p. 87). The Church Buttes anticline is in the southwestern part of the Green River Basin. According also to Fidlar (1950), seismic data indicate that one of the deep parts of the structural basin is in the southern part near the flank of the Uinta Range. The deepest part, however, now seems to be along the front of the Wind River Range not far from the great thrust fault along which the range rose. (See especially Berg, 1961.) There the celebrated Pacific Creek test well had to penetrate approximately 20,000 feet to reach either the Upper Cretaceous Frontier Sandstone (Fidlar, 1950, p. 86) or, as some think, the Lower Cretaceous Muddy Sandstone (Jenkins, 1955, p. 154).

The history and development of the basins in this large area are treated rather fully in a comprehensive paper by Love (1960) on the Cenozoic sedimentation and crustal movement in Wyoming. According to Love, the Green River, Great Divide, and Washakie Basins have been downwarp areas since long before the Cenozoic Era. In each of these basins the Precambrian surface is today more than 20,000 feet below sea level. The configuration of these deep basins is shown in a general way on the Tectonic Map of the United States (Cohee, 1962).

The Rock Springs uplift was arched up by the end of the Cretaceous into a low dome whose flanks dipped away from the axis at angles estimated to be about 1° or 2°. This dip on the flanks of the ancestral Rock Springs anticline is inferred from the fact that the lowest beds of the Wasatch exposed around the flanks of the uplift now dip only 1° or 2° less steeply than the Upper Cretacous rocks; and as the Wasatch sediments were presumably deposited as virtually horizontal beds, the Upper Cretaceous rocks must at that time have been inclined only 1° or 2°. According to these inferred dips, the dome has a structural relief of 1,000–2,500 feet, assuming its present outcrop width. It surely had a broader base than this and consequently must have stood higher. This dome persisted as a topographic feature long enough to allow all of the Lance (Laramie of Schultz, 1920), Lewis Shale, Almond coal group and Ericson Sandstone of the Mesaverde (Hale, 1950, p. 55; Hansen and Bonilla, 1954, p. 24; Roehler, 1961, p. 96) to be eroded from large areas of the steep west and southwest flanks of the dome. Much of this erosion must have occurred before the lowest part of the Wasatch Formation (of Schultz; includes the Paleocene Fort Union) was deposited, because the Wasatch overlaps the basset edges of these eroded formations and members. Probably only Fort Union is involved in this overlap, as Roehler (1961, p. 96) reported that the Wasatch and Fort Union are conformable on both flanks of the uplift and that there is an angular discordance between the Fort Union and Upper Cretaceous rocks that ranges from 3° to more than 8°.

On the other hand, Pipiringos (1962, p. A26) reported an unconformity between the Wasatch and Fort Union, at least on the southeast flank of the Rock Springs uplift near Bitter Creek station (T. 18 N., R. 99 W.). He did not say, however, whether this unconformity involves angular discordance or not. Hansen and Bonilla (1954, p. 10) reported that their Fort Union(?) Formation along the flank of the Uinta Mountains rests on the Ericson Sandstone of the Mesaverde with an unconformity that ranges "* * * from near concordance to great angularity." Nevertheless, the Rock Springs uplift persisted as a topographic feature while much of the Fort Union (though according to Roehler, 1961, p. 98, it was thinned over the arch) and much of the Wasatch Formation were deposited and while the greater part, and possibly all, of the Green River Formation was deposited. Evidence that the Rock Springs uplift existed as a topographic feature is found in the distribution of the saline facies of the Green River Formation in the eastern part of the Green River Basin. Within a few miles east of the town of Green River, this thick saline facies changes into the shoal-water nonsaline facies that makes up White Mountain, which is the escarpment facing the west flank of the Rock Springs uplift. The significance of this change in facies of the Green River Formation is discussed more fully on p. A40. The Rock Springs uplift, however, did not reach its present structural relief until somewhat later in the Tertiary, certainly not until after deposition of the Bridger Formation.

The mountain ranges and hills that resulted from these major pre-Tertiary structural changes favored sedimentation in the basins adjacent to the mountain ranges.

Apparently the downwarping of the floors of these basins, which began early in the Tertiary or before, continued more or less uniformly all through the Eocene and was primarily responsible for the continuous sedimentation of the Wasatch, Green River, Bridger, and Uinta Formations. Thus, the Tertiary deposits described in this report owe not only their beginning but their full thickness to these major structural events. The low stream gradients between this region and the ocean apparently prevented the margins of these basins from being cut downward.

EARLY EOCENE DEFORMATION

About the middle, or perhaps early, early Eocene, the forces which by the end of the Cretaceous had folded the pre-Tertiary rocks sharply in the Wyoming Range and more moderately a little way eastward acted again in essentially the same direction. This activity raised the mountains considerably, as is indicated by great masses of coarse conglomerate in the middle and upper parts of the Wasatch Formation along the north flank of the Uinta Mountains.

Subsurface data from sec. 30, T. 27 N., R. 100 W., reveal several thousand feet of conglomeratic beds in the Wasatch Formation (J. D. Love, written communication, May 1962). A comparable, though smaller, conglomeratic mass occurs in the Wasatch Formation near the Wind River Mountains (T. 27 N., R. 102 W.) and suggests that the Wind River Range was also uplifted then. Hansen and Bonilla (1954, p. 25–26) summarized briefly these events in the orogeny of the Uintas:

> Whatever the mechanics of the first uplift, it is clear that the uplift was strong and that deep erosion preceded deposition of the earliest Tertiary beds. Despite strong uplift and deep dissection, however, the height of the range at this time probably was not great; judging from the lithology of the Fort Union(?) formation and the lower part of the Wasatch formation, erosion kept pace with uplift. By Fort Union(?) time erosion had penetrated at least 8,500 feet, and possibly considerably deeper into the pre-Tertiary cover of the range. By Wasatch time the range was eroded to its pre-Cambrian core in the eastern part of the area where the Uinta Mountain group became exposed.
>
> During Wasatch time the range again began to rise. Coarse orogenic deposits about midway in the Wasatch section suggest a nearby source higher than the present Uintas.

These movements are also recorded by an angular unconformity in the Wasatch which both Powell

(1876, p. 164) and Sears (1924b, p. 305–306) described in the vicinity of Vermilion Creek, Colo. The effects of this early Tertiary deformation may have been restricted to the flanks of the mountain ranges and the margins of the adjacent basins, but they may also have included a slight deepening of the basins. Surely the increased height of the mountains had a marked effect on the characteristics of the sediments and must also have had a perceptible effect on the climate of the basin.

Evidence that compressive forces acted probably a little later in the Eocene was presented by Anderman (1955, p. 131), who noted a local angular unconformity within the Green River Formation in the vicinity of Manila, Utah. My own evidence for renewed tectonic activity at that time is restricted to a single locality on the western margin of the Green River Basin. There a narrow down fold just west of a nubbin of Jurassic rocks (T. 22 N., Rs., 114 and 115 W.) sank considerably while beds belonging to a tongue of the Wasatch Formation were being deposited. This tongue of Wasatch lithology overlies a basal tongue of the Green River Formation and underlies the main body of the Green River Formation, and as the Green River Formation is of middle Eocene age, the deformation is closely dated. The geology of this small area is discussed more fully below.

POST-EOCENE-PRE-MIOCENE(?) DEFORMATION

At some indefinite time after the Bridger Formation was deposited in the Green River Basin and before the Bishop Conglomerate (Miocene(?)) was deposited, compressive forces accentuated the Rock Springs uplift and steepened the dips locally to as much as 13°. Without departing from its original depositional dip, the Bishop Conglomerate bevels the tilted Bridger and Green River Formations and the more steeply inclined Upper Cretaceous rocks of the Rock Springs uplift.

The extensive erosion surface on which the Bishop Conglomerate was deposited indicates qualitatively that the post-Eocene deformation must have occurred appreciably earlier than the cutting of this erosion surface. In the Green River Basin this extensive surface bevels beds high in the Bridger Formation, and farther east it cuts progressively lower in the Tertiary; at Pine Mountain and Diamond Peak (near the junction of Wyoming, Colorado, and Utah) it bevels rocks that belong to a tongue of the Wasatch Formation which overlies the basal unit of the Green River Formation. These formations, therefore, must have been deformed long enough prior to the deposition of the Bishop Conglomerate to permit the removal of several thousand feet of beds over a large area and to allow for the reduction of the terrain to a remarkably smooth surface. (See Bradley, 1936, p. 170–179.) The data are inadequate, however, to evaluate this erosion interval in terms of geologic epochs; consequently, the post-Eocene deformation cannot be dated more closely than post-Eocene–pre-Miocene(?).

POST-MIOCENE DEFORMATION

Post-Browns Park (Miocene(?)) faulting and folding along the margins of Browns Park near the Utah-Colorado boundary, near Diamond Peak, and in the valley of Vermilion Creek in Moffat County, Colo., have been discussed by Sears (1924a, p. 284–304). Post-Browns Park deformation in the fault zone along the southern margin of the Washakie Basin and in other localities along the Uinta Mountain front was also discussed in my report (1936, p. 179–190) on the geomorphic history of a large part of the region considered in the present report.

The post-Miocene faulting north and northeast of the Rock Springs uplift has been mentioned by McGrew and Berman (1955, p. 109) and by Love (1961a, p. 133–134). Presumably the faulting there occurred during the same epoch as that in the southern part of the area.

STRUCTURAL EFFECT OF ORIGINAL DIP AND COMPACTION

Some part of the gentle basinward dip of the rocks that border the area considered in this report probably was caused not by the tectonic forces that deformed these older rocks but by the conbined effect of the compaction of the Tertiary deposits and their original basinward dip. This hypothesis can be tested by considering how these factors operate and then making rough quantitative estimates of their probable magnitudes. The compaction accentuates the original or depositional dip by lowering the beds in the deep parts of the basin below the level at which they were deposited The effect of the changes due to depositional dip will be considered first.

DEPOSITIONAL DIP

It is evident that the fluviatile beds had an original or depositional dip toward the center of each original structural basin which was about equal to the gradient of the streams that deposited them. But as these beds are predominantly fine grained, the original dip probably did not exceed 1 or 2 feet per mile except in a rather narrow belt adjacent to the mountains. Thus the depositional dip of the fluviatile rocks of the Green River, Great Divide, and Washakie Basins is a real but minor factor in accounting for the present basinward inclination of the beds. The depositional dip of the lacustrine beds, which are generally even finer grained, was probably negligible.

GRAVITATIONAL COMPACTION

REGIONAL EFFECT

Compaction can increase the depositional dip of sediments regionally and locally. Discussion of the effect of local differential compaction will be deferred until the probable magnitude of the regional effect is examined. Consider a column of Tertiary rocks in the central part of the Green River Basin. They are predominantly fine grained and, therefore, capable of considerable compaction. As each successive bed is deposited, those below are increasingly compacted. Actually the rate of compaction decreases as fine-grained sediments are compacted, because the original water must be squeezed out through more and more constricted pore capillaries (Terzaghi, 1925a). As the rate of accumulation of such fine-grained material is very slow, however, it is likely that compaction about keeps pace with sedimentation. In such a column of sediments where compaction has virtually ceased, both the thickness of a unit layer and its porosity decrease downward, but not at a uniform rate.

Using data published by Athy (1930) and Hedberg (1936), I made a rough analysis of the probable maximum compactibility of the column of Eocene sediments in the Green River Basin, from which it appears that differential compaction between the marginal and central parts of the Green River Basin may account for about 1° of the observed basinward dip. Depositional dip plus dip due to differential compaction might account for the observed basinward dips of 1°–1½° along the northern margin of the Green River Basin, but it is very improbable that the basinward dips of 2°–8° along the western margin and 3°–12° observed along the eastern margin of the Green River Basin could be explained in this way. Dips steeper than about 1½°, therefore, must have been produced by downwarping of the basin floors.

LOCAL EFFECTS OF GRAVITATIONAL COMPACTION

Where fine-grained sediments bury an irregular topography, the total amount of gravitational compaction is less above buried hills than above the adjacent flats or depressions where the thickness of compactible sediments is greater. Compaction is also greater in columns of fine-grained sediments containing no sand lenses than in those containing sand lenses, because the sand is much less compactible (Terzaghi, 1925b).

In places along the western margin of the Green River Basin, erosion has revealed nubbins of pre-Tertiary rocks over which the Tertiary sediments were deposited. The beds of the Green River and Wasatch Formations that now rest against the flanks of these hills dip away on all sides at angles ranging from 1° to 8° steeper than the general regional dip of that locality. Within about 1 mile east of these buried hills, the dips flatten to angles of 2° or 3°. These relations between locally steepened dips and buried hills were observed at several places along the west border of the Green River Basin, but they are particularly well shown in secs. 5, 6, 7, and 8, T. 22 N., R. 114 W., and in secs. 1, 2, 11 and 12, T. 22 N., R. 115 W.

In many places the dips of the Tertiary beds steepen markedly as they approach and overlap onto a surface of steeply dipping pre-Tertiary rock. This is especially well shown in secs. 2 and 11, T. 22 N, R. 115 W., where the Fontenelle Tongue of the Green River Formation laps up against the dip slopes of the Beckwith Formation. There the dips in the sandy beds of the Green River Formation steepen 5°–10° within a few tens of feet of the Beckwith Formation. In this little area and, indeed, in other similar overlap areas, the beds of the Green River and Wasatch Formations generally tend to blanket a steep pre-Tertiary surface and to assume its same direction of slope. Actually the angular discordance is commonly large; nevertheless, the marked steepening close to the contact is conspicuous. Whether this steepening is all due to differential compaction, I have some doubts. It seems more probable that both abnormally high initial dips and some subsequent deformation are involved.

Differential compaction and other related features are also well shown in secs. 19 and 30, T. 22 N., R. 114 W. Here, small islands in the ancient Green River lake provided local sources of sediments. As a result, the beds of the Green River Formation adjacent to the former islands are somewhat coarser grained and locally are even conglomeratic. Because these coarse-grained facies grade abruptly into fine-grained sediments and were less compactible than the fine-grained material, and as relief on some of these hills was roughly 1,000 feet in three-quarters of a mile, differential compaction seems to be an adequate explanation of some of the local basinward dips of 4°–6°.

On one of these nubbins of steeply dipping pre-Tertiary rocks that at one stage formed tiny islands in the ancient lake, shore features near the top provide us with one of the few marks made by the surface waters of the lake. (See fig. 5.)

Thick but rather short lenses of tuffaceous sandstone are locally numerous in the fine-grained marlstone and oil shale that make up the lower part of the Laney Shale Member of the Green River Formation in the

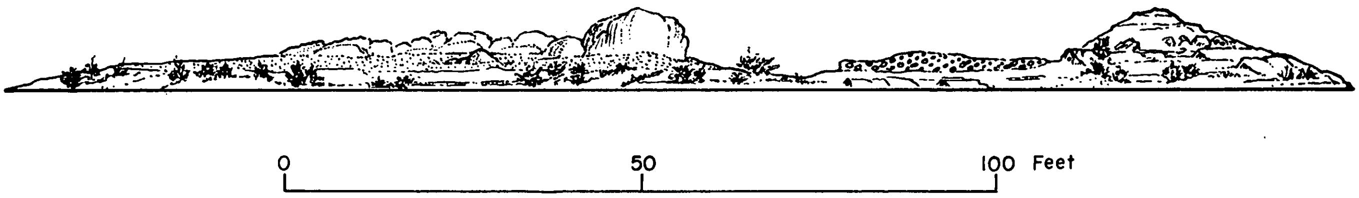

FIGURE 5.—Field sketch of shore features of Gosiute Lake on the crest of a hill of Jurassic limestone (Twin Creek Formation) in sec. 6, T. 22 N., R. 114 W., Lincoln County, Wyo. The domelike forms at the left represent an algal reef, which rests on a coarse beach sand. Right of center is a small patch of angular limestone gravel that laps up on a limestone nubbin. These beach features formed when the limestone hill was a very small island near the western margin of Gosiute Lake.

vicinity of the town of Green River. Beneath and between some of these sandstone lenses, units of fine-grained sediments have been compressed to about one-fifth of their original thickness. (See fig. 16.) Such features result in part from differential compaction and in part from differences in depth of the original tuff-filled channels and from a conspicuous feature of the landscape for many miles along the cliffs in this locality. (See figs. 11, 15.)

STRATIGRAPHY

GENERAL RELATIONS BETWEEN THE EOCENE FORMATIONS

The greater part of this report deals with three Eocene formations (Green River, Bridger, and Wasatch) which are defined wholly by their lithology. In the broadest and simplest terms, the Green River Formation is a huge lens of fine-grained generally calcareous sedimentary rock embedded in a thick body of somewhat sandy mudstone that fills a large intermontane basin (fig. 6). The body of mudstone is divided into the Wasatch Formation below the Green River and the Bridger Formation above. In most of the basin the three formations are readily separable because each has a distinctive lithology, though the boundary between the Green River and Bridger is nearly everywhere gradational and is uncertain in detail. Locally at the margin of the basin the Bridger overlies the Wasatch without a stratigraphic break. At other places along the margin, all three formations become conglomeratic and are inseparable.

During the Green River epoch, fluviatile sediments continued to accumulate around the margins of the basin in a belt that narrowed when the lake expanded and widened when the lake contracted. The lake fluctuated repeatedly, and some of the changes were large. As a result of the continual shift of the shoreline, the body of lacustrine sediments that makes up the Green River Formation interfingers or, on a larger scale, intertongues with fluviatile sediments of the same age but, by reason of its different lithology, belongs to a different formation—either the Wasatch or the Bridger. Actually, this interfingering of the two kinds of deposits is common and is on a wide range of scales—some to be measured laterally in tens of feet, others to be measured in tens of miles. Only those tongues or wedges of sediments that can be measured in miles of lateral extent have been mapped and given stratigraphic names. The stratigraphic relations between these tongues and members of the Green River and Wasatch Formations are shown schematically in figure 6. The geographic distribution of these units is indicated by their outcrop pattern on the geologic map (pls. 1, 2).

Bridger and Wasatch time, on the other hand, are defined by distinctive vertebrate faunas, and Green River time is defined by a distinctive fossil flora. Students of both the vertebrate remains and the fossil

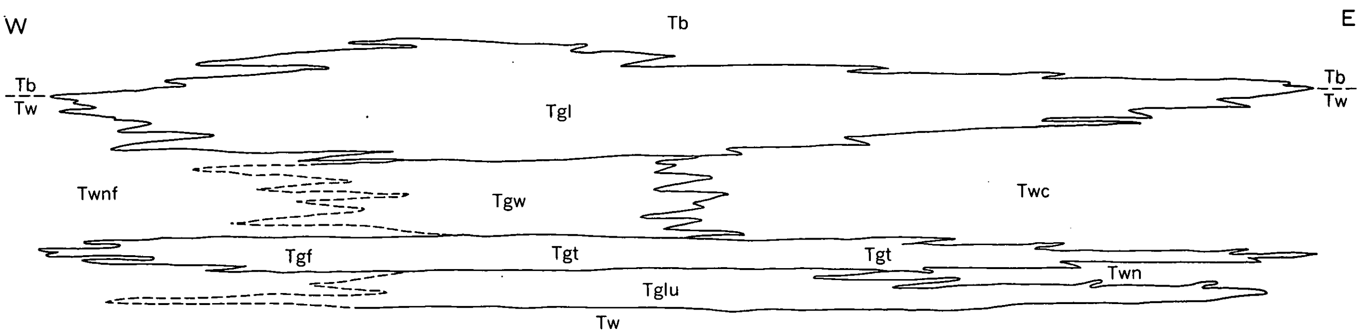

FIGURE 6.—Diagramatic section showing the relations of the members and tongues of the Green River Formation to the tongues and main bodies of the enclosing Wasatch and Bridger Formations. Tb, Bridger Formation; Tgl, Laney Shale Member of Green River Formation; Twnf, New Fork Tongue of Wasatch Formation; Tgw, Wilkins Peak Member of Green River Formation; Twc, Cathedral Bluffs Tongue of Wasatch Formation; Tgf, Fontenelle Tongue of Green River Formation; Tgt, Tipton Tongue and Tipton Shale Member of Green River Formation; Twn, Niland Tongue of Wasatch Formation; Tglu, Luman Tongue of Green River Formation; Tw, Wasatch Formation.

flora have long recognized that Green River time is in part equivalent to Bridger time and in part equivalent to Wasatch time.

This thumbnail sketch of the relations between the Eocene formations is intended only to orient the problem. The details of the stratigraphy and correlations are considered more fully in the following pages.

LITHOLOGIC TERMS USED

The descriptive terms applied to sedimentary rocks generally lack precision, and a few of them have a variety of meanings, the extremes of which differ widely. Because of this uncertainty, the terms used in an earlier report (Bradley, 1931, p. 6–8) were defined and discussed rather fully. For convenience, those definitions are summarized here and the terms are used again in this report.

Claystone and siltstone are both massive fine-grained rocks defined by the size of the predominant grains. According to Wentworth's classification (1922), which is followed for these rocks, the division between clay and silt is at 0.004 mm (millimeter) and that between silt and very fine sand, 0.0625 mm. Although the name "claystone" is not intended to imply any particular minerology, it is likely that most of the crystalline grains less than about 0.004 mm in diameter belong to the general group of clay minerals or the closely related hydromicas. But these clay minerals and hydromicas are not by any means restricted in size and may be of such dimensions as to be properly classified as silt or even as sand. The adjectives "clayey" and "silty" imply an appreciable content of either clay- or silt-sized particles.

Mudstone is also a fine-grained massive rock, but it consists of an indefinite mixture of clay-, silt-, and sand-sized grains, and therefore the term is more general than "claystone" or "siltstone." Consequently, the adjective "muddy" signifies a rock that has an admixture of enough particles smaller than fine sand to change its general aspect.

Marl and marlstone are used as defined by Rosenbusch (1923):

> Marl and dolomitic marl are intimate mixtures of crystalline calcite, occasionally of dolomite, with clayey substances whose character is not well known. In such mechanical mixtures the individual constituents vary between the widest limits, and, indeed, they show transition forms between limestone and dolomite on the one hand and clays and sandstones on the other.

The harder varieties of marl he called marlstone. Soft marlstone that has a chalky texture is referred to as chalky marlstone.

Shale is regarded as a structural term coordinate with slate, as advocated by Lewis (1924), who wrote:

> It implies no particular composition except so far as certain materials of fine texture lend themselves to the development of the characteristic structure. This structure, or fissility, may be defined as the capacity of clayey strata for splitting into somewhat uneven flakes, thin chips, and wedgelike fragments approximately parallel to the bedding. Fissility is typically developed in most of the clay rocks of finer texture and in various unsorted mixtures, such as silty clay, sandy clay, and mud, and is commonly most conspicuous on weathered surfaces.

Although the term "shale" defines the size of the constituent particles of the rock only within a general range, it must imply that a large proportion of the particles are thin and flakelike, otherwise the rock would not be fissile. These flaky particles may have been deposited in that form, or they may have grown within the sediments during compaction and solidification. The characteristic shape, therefore, may be original or secondary. Consequently, shaly is used here to modify such rock names as marlstone and mudstone to indicate that they have either a slight or apparent fissility yet lack sufficient fissility to be regarded as shale.

"Papery shale" is a term used here to designate certain shaly organic marlstones that have a marked tendency to split along organic-rich laminae.

In general, fissility becomes apparent only on weathered surfaces. Fissility may be, and commonly is, lacking or wholly obscure in the completely fresh rocks that one sees in drill cores or in mines. Judged by such fresh rocks, the Green River Formation would be regarded as predominantly massive marlstone and mudstone.

The term "tuff" is used in this report to mean any bed that consists largely of volcanic ash, whether the volcanic constituents have been much altered or not. Virtually all the tuffs in the Green River Formation were deposited in a lake. Those in the Bridger and post-Eocene formations were deposited in shallow lakes or were more or less extensively reworked by streams.

Oil shale is a fine-grained sedimentary rock containing organic matter which was derived chiefly from aquatic organisms, waxy spores, and pollen grains; which is only slightly soluble in ordinary petroleum solvents; and of which a large proportion is distillable into a liquid similar to petroleum. Despite the name, most rich beds of oil shale in the Green River Formation cannot be regarded strictly as shale. Instead, they are dolomitic marlstones rich in organic matter. Nevertheless, a few are shaly. On the other hand, many low-grade oil-shale beds are papery shale. By low grade is meant any oil shale that will yield less than 10 gallons of oil per ton of rock. This division between low- and high-grade oil shale is arbitrary and is adopted merely as a convenience in exposition. I have used it here in the same sense that I used it in earlier reports.

W. C. Culbertson of the U.S. Geological Survey, in criticizing this manuscript, reminded me that color should be mentioned as a significant criterion in recognizing oil shale in the field. All oil-shale beds of the Green River Formation are some shade of brown, though some of the richest beds are almost black; generally those that are this dark have a light-gray or even bluish-gray bloom on weathered surfaces.

WASATCH FORMATION

DEFINITION AND AGE

The Wasatch Formation of early Eocene age is a thick body of fluviatile sediments that is widely exposed in the area. It was named by Hayden (1869, p. 90) for exposures in Echo and Weber Canyons, Utah. In a later report (1871) he noted that these beds, which are conglomeratic in Echo and Weber Canyons, grade eastward into variegated sandy clays and sandstones. In the area treated in this report, variegated sandy mudstone is the predominant rock type in the Wasatch; though local facies are characterized by sandstone, carbonaceous shale, coal, or conglomerate.

STRATIGRAPHIC UNITS

The Wasatch is treated in this report as one formation, though it includes at its base the Fort Union Formation of Paleocene age. For the purposes of this report this will not make a great deal of difference, because we shall be concerned primarily with the upper half of what is here called Wasatch. Wasatch, as used here, is apparently equivalent to the main body of the Wasatch Formation as used by Oriel (1961), though his two members were not identified. Swain (1957) reported 1,530–1,750 feet of Fort Union about 10 miles north of Baggs, Wyo. The lower part of these beds contains an early Paleocene flora and a middle Paleocene fauna. Swain also reported that the Fort Union there rested conformably on the underlying Lance but was overlain along an angular discordance by the Wasatch Formation. The approximate boundary between the Wasatch and Fort Union is shown on the "Geologic Map of Wyoming" (Love, Weitz, and Hose, 1955), though the small indefinite area of Fort Union shown on the west flank of the Rock Springs uplift is probably much too short. Additional mapping of the Fort Union is much needed in that area.

According to Pipiringos (1962, p. A26),

"* * * the upper part of Schultz' 'Wasatch' is about 1,400 feet thick and is separated from the lower part by an unconformity. The beds below the unconformity (the lower part of Schultz' 'Wasatch') are about 1,100 feet thick, contain plants of Paleocene age, and rest unconformably on the Lance Formation of Late Cretaceous age."

The locality he described is along the southeast flank of the Rock Springs uplift near Bitter Creek station on the Union Pacific Railroad.

The late Roland W. Brown, of the U.S. Geological Survey, told me that he collected fossil plants and mammals of Paleocene age from a thick section of sandstone and mudstone beds just west of Rock Springs, on the south side of Bitter Creek, in the sequence of beds that Schultz included in his Wasatch.

In the upper part of the Wasatch, as here defined, are three tongues that interfinger with the lower part of the Green River Formation. These tongues have been mapped and named. Little study was given to the main body of the Wasatch Formation, but it contains at least one large sandstone unit, several conglomeratic facies, and several possible lacustrine lenses or facies that could be mapped. Separating the lower part of the Wasatch from the Fort Union is doubtless possible, but the boundary would require rather critical study.

Along the west side of the Green River Basin, I have distinguished only the main body of the Wasatch Formation and one tongue of the Wasatch, the New Fork Tongue. As in other parts of the area covered in this report, my investigation was restricted mostly to the upper parts of the main body of the Wasatch—approximately equivalent to what Veatch (1907, p. 87–96) called the Knight Formation. Steven S. Oriel, of the U.S. Geological Survey, redefined (unpub. data) and divided the Wasatch into two members and two tongues. The two members of what I have shown (pl. 1) simply as Wasatch are the Chappo Member at the base, which is of Paleocene age and perhaps in part also of Eocene age, and the unconformably overlying La Barge Member, which consists chiefly of red and variegated mudstone and muddy sandstone. The two tongues of the Wasatch are the New Fork Tongue (used in this report, pl. 1) and a higher tongue which Oriel (1961, p. B152) referred to simply as upper tongue. I think that this upper tongue probably is restricted to the northwestern part of the Green River Basin.

In the same paper Oriel (1961) listed seven genera of vertebrate fossils collected from his Chappo Member and referred by C. L. Gazin, of the U.S. National Museum, to the Paleocene. Oriel listed also a number of freshwater clams and snails and land snails collected from the Chappo Member. These were studied by D. W. Taylor, of the U.S. Geological Survey, who reported that the land snails, which in places were numerous, have Eocene affinities but that the freshwater forms have Paleocene affinities. Few new vertebrate fossils or mollusks were found in the overlying La Barge Member of the Wasatch. This member is considered as of middle(?) and late early Eocene age—that is, Lysite(?) and Lost Cabin.

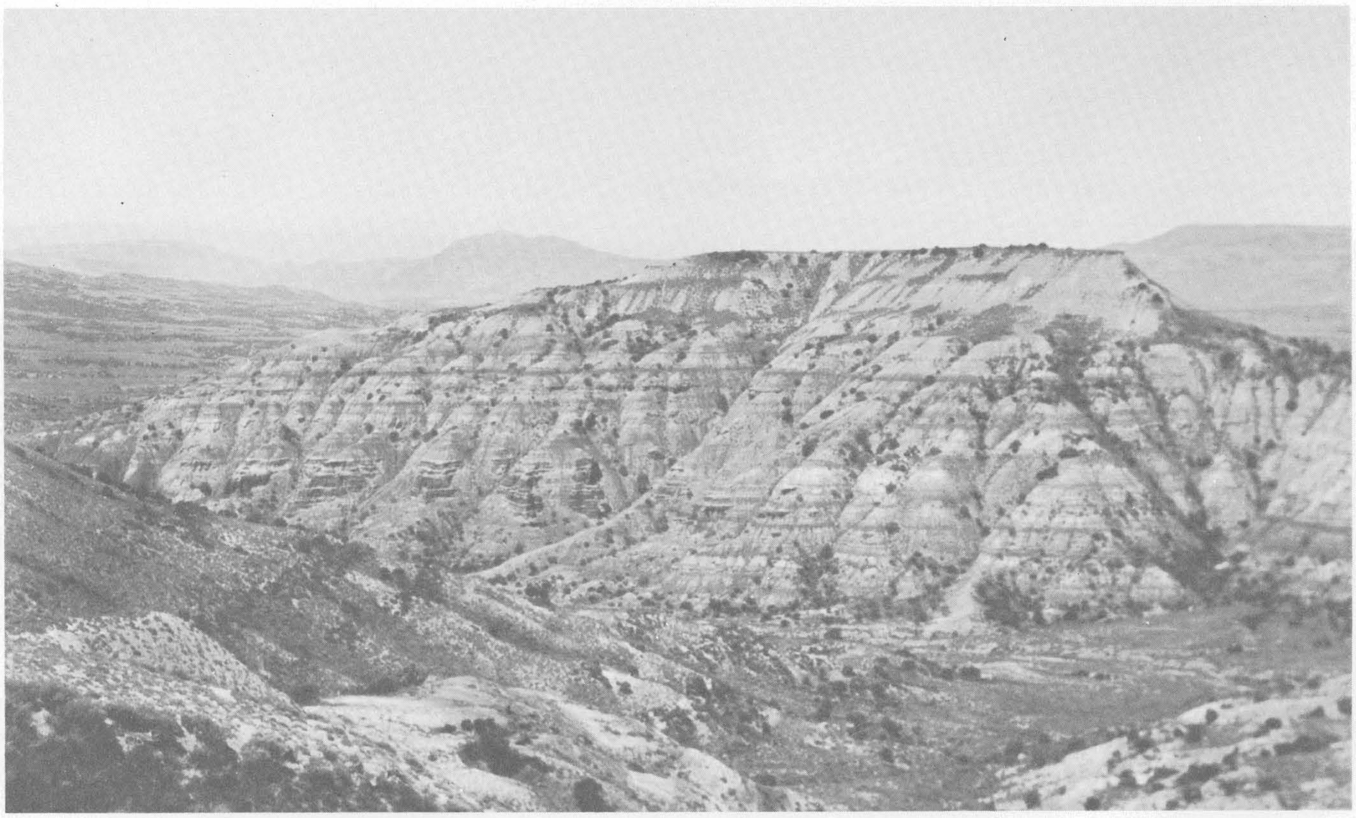

FIGURE 7.—Banded gray and red mudstone close to the top of the Wasatch Formation in the valley of Red Creek in sec. 24, T. 13 N., R. 104 W., Sweetwater County, Wyo. The flat top of Little Mountain shows on the skyline at the right and Richards Peak shows to the left of center in the distance.

Pipiringos (1962, p. A14) applied the name Red Desert Tongue to that part of the Wasatch lying between the Fort Union Formation and the base of the lowest tongue (Luman) of the Green River Formation. He reported that this part of the Wasatch is about 1,000 feet thick on the east flank of the Rock Springs uplift and there rests unconformably on the Fort Union. Vertebrate fossils he collected in sec. 12, T. 23 N., R. 100 W., indicate an earliest Eocene (Graybull and Sand Coulee) age for the beds near the base of his Red Desert Tongue. Pipiringos also listed (p. A15) other fossil vertebrates and invertebrates found near the top of the Wasatch in the Great Divide Basin which indicate an early Eocene age. The fossil plants he found were determined as of Eocene age.

McGrew and Roehler (1960), reported vertebrate fossils from the Wasatch on the west flank of the Rock Springs uplift (secs. 7, 8, and 17, T. 18 N., R. 105 W.) that also indicate a early Eocene (Graybull) age. From beds above those in which these fossils were found, they reported additional vertebrate fossils that suggest a Lysite age.

In this report I have not used the name Red Desert Tongue because over almost the whole large area covered by the map (pl. 1) the Wasatch, below the lowest Green River tongue, does not have an intertonguing relationship with adjacent formations. The Red Desert Tongue is equivalent to what I am calling the main body of the Wasatch in this report. Future work may show that the Red Desert Tongue of Pipiringos and my main body of the Wasatch are actually equivalents of Veatch's Knight formation. Gazin (1959, p. 134) indicated this correlation on the basis of his extensive studies of the Rocky Mountain Tertiary formations and their vertebrate faunas. Schultz (1920, p. 29) referred to this part of the Wasatch simply as the Wasatch Formation, inasmuch as he regarded the Cathedral Bluffs as a member of the Green River Formation. Sears and I (1924, p. 98–99) later expressed the concept that the Cathedral Bluffs should be thought of as a tongue of the Wasatch Formation.

Over the greater part of the area covered by this report, the main body of the Wasatch consists predominantly of sandy gray mudstone in which lenses and irregular beds of sandstone are fairly common and locally are plentiful. The mudstone of most parts of the area is only streaked with red bands, but, locally, layers of red mudstone and claystone are so numerous that the formation appears to be predominantly red—for example in the area southwest of the Rock Springs uplift. (See fig. 7.) Southeast of the Rock Springs uplift in the basin of Vermilion Creek, however, the

Wasatch is prevailingly gray, even including the sandstones. The name "Red Desert" as used within the Great Divide Basin, north of Washakie Basin, takes its name from the reddish soil derived from the few red mudstone layers in the Wasatch.

Carbonaceous shale and lenticular beds of subbituminous coal are rather common in the upper 3,000 feet of the main body of the Wasatch. In the basin of Vermilion Creek, southeast of the Rock Springs uplift, and in the Great Divide Basin, coal beds and carbonaceous shale are locally common. In a few places these coal beds have been mined for domestic use.

The coals in the central part of the Great Divide Basin have been studied by Pipiringos (1962, p. A41–A59), who gave analyses as well as a great deal of information on the distribution and thickness of the individual beds. Nearly all these coal beds contain from 0.001 to 0.003 percent uranium. Locally, however, parts of these beds contain no uranium, whereas in other places parts of beds contain as much as 0.026 percent.

The sandstone lenses and beds scattered through the thick body of Wasatch mudstone range widely in texture, color, and structure. Fine- to medium-grained buff massive to crossbedded sandstone lenses are rather common around the Rock Springs uplift. Gray carbonaceous medium-grained sandstone beds and rusty brown crossbedded lenses are also common in the same locality. These three types of sandstone may have been derived from Upper Cretaceous rocks eroded from the Rock Springs uplift, for they resemble the Upper Cretaceous sandstones and many of the false beds in the crossbedded Wasatch sandstones dip away from the flanks of the uplift. Sandstone beds and lenses in the main body of the Wasatch in other parts of the area range in texture from that of fine sand to conglomerate and in color from buff to dark rusty brown, from dark red through pink to white, and from light gray to nearly black, depending upon the quantities of dark minerals and carbonaceous material.

The main body of the Wasatch Formation differs in thickness from place to place because it was laid down upon an uneven surface. Along the Wyoming-Utah boundary near Richards Peak (T. 12 N., Rs. 105 and 106 W.), the Wasatch is approximately 7,000 feet thick, but how much of this should be assigned to the Fort Union is unknown. About 35 miles southeast of Richards Peak, in the vicinity of Vermilion Creek, Nightingale (1930, p. 1021) measured the thickness of the main body (his Lower Wasatch or Hiawatha Member) of the Wasatch Formation as 4,500 feet. Sections of the part of the Wasatch exposed around the Rock Springs uplift were measured at the following localities: About 3 miles north of Rock Springs (T. 19 N., R. 105 W.), where the thickness is 1,780 feet; along Salt Wells Creek (Tps. 13 and 14 N., Rs. 103 and 104 W.), where the thickness is 2,565 feet; and in the western part of T. 14 N., R. 101 W., where the thickness is 3,000 feet. All these sections, except perhaps Nightingale's, it should be understood, include an unknown amount of Paleocene rocks at the base.

Although the main body of the Wasatch is regarded as a single stratigraphic unit, significant departures from the usual lithology were observed in several parts of the area. These changes evidently reflect local environments at the time the formation was deposited, though some may reflect tectonic changes.

At several places along the north flank of the Uinta Mountains, the Wasatch contains thick units of coarse conglomerate. One of the most notable of these is the conglomerate that makes up Richards Peak, just north of the Wyoming-Utah boundary in the southern parts of T. 12 N., Rs. 105 and 106 W. This conglomerate is in the upper part of the Wasatch Formation, is approximately 2,700 feet thick, and makes a high ridge several miles long. Pebbles, cobbles, and boulders of limestone predominate, but those of red quartzite are almost equally abundant. The limestone evidently was derived from the Carboniferous limestone hogbacks along the north flank of the Uinta Range. Indeed, some of the boulders contain Pennsylvanian fossils (James S. Williams, oral communication, 1931). The red quartzite plainly came from the great mass of red quartzite that makes up the central part of the Uinta Range and that is known as the Uinta Mountain Group. Pebbles and cobbles of white quartzite and hornblende schist quite as plainly came from the Red Creek Quartzite, whose only outcrops are in that part of the Uinta Range just a few miles south and southeast of Richards Peak. All the kinds of rock found are fresh and range in shape from angular to fairly well rounded. They have an extreme range in diameter from about half an inch to more than 5 feet, but most of the conglomerate is rather well sorted and and consists of pebbles 1–2 inches in diameter. Locally, however, thick lenses consist chiefly of cobbles that are 4–8 inches across. A matrix of coarse buff sand fills the interstices of the conglomerate. The conglomerate here has been tilted, so that it dips 23° northward, and as a result of differential movement during the tilting, many of the cobbles and boulders have been sheared.

Below the conglomeratic facies, the Wasatch Formation consists of sandy mudstone that contains only a few widely spaced lenses of sandstone. Above the conglomeratic facies is a considerable thickness of red and gray banded sandy mudstone that contains many short irregular lenses of conglomeratic sandstone. This banded unit is overlain by a thinner unit of flaky carbonaceous shale that contains thin layers of lignite, shell marl, sandy gray clay, and persistent, regular thin beds of sandstone. As mentioned above, the whole formation at this place is approximately 7,000 feet thick.

A few miles east of Richards Peak is Tepee Mountain, a large sprawling feature made up of a similar conglomeratic facies of the Wasatch. This conglomeratic mass extends about 10 miles along the strike. The rocks are not well exposed, but apparently the conglomerate merges southeastward into mudstone in T. 3 N., R. 25 E., S.L.M., Daggett County, Utah.

A thin zone of coarse-grained conglomerate was found in the Wasatch a few miles northwest of Oregon Buttes (T. 27 N., R. 102 W., Fremont County, Wyo.). This conglomeratic facies makes a rather large strike ridge that extends west from the base of Oregon Buttes. The beds consist of wholly unsorted material that ranges in size from coarse sand to boulders as much as 13 feet across. Most of the large boulders are of granite and are rounded or subangular; the smaller pieces, of schist, are angular. Southward and in both directions along strike, this conglomerate grades into mudstone that is typical of most of the Wasatch exposed in this area.

Along the eastern and northeastern margins of the Great Divide Basin, Pipiringos (1962, p. A34–A35) and Masursky (1962, p. B10–B14) described a great fan of coarse-grained to pebbly arkosic sandstone (the Battle Spring Formation) that interfingers westward and southwestward with all of the subdivisions of the Wasatch and Green River Formations except the Laney Shale Member of the Green River. This great bulk of arkose was derived from the Granite Mountains, which lie northeast of the area shown on the geologic map, plate 1. (See, however, fig. 10.)

The coarse conglomerates in the main body of the Wasatch were evidently deposited by vigorous streams that emerged from either the Uinta, Wind River, or Granite Mountains onto an aggrading alluvial plain. The abundance of rather well rounded cobbles and boulders of unweathered rock suggests that the streams were actively cutting in mountains of considerable height. Furthermore, in the thick conglomerate at Richards Peak the small quantity of muddy sediment, the moderately good sorting of thick units of the conglomerate, and the matrix of coarse sand suggest that the streams, in that locality at least, had a rather uniform flow and were not subject to recurrent torrential floods. Deposits produced by torrential floods are characteristically ill-sorted mixtures of mud, sand, cobbles, and boulders.

The occurrence of these coarse conglomeratic facies along the north flank of the Uinta Mountains at approximately the same stratigraphic position in the main body of the Wasatch suggests that they were produced by tectonic changes in the regimen of the streams draining the adjacent parts of the Uinta Range. No other evidence, however, of uplift of the eastern part of the range was recognized in the Wasatch Formation of that locality.

In working out the tectonic history of the area, it is probably significant that the Wasatch along the western side of the Green River Basin does not contain these large conglomeratic facies except locally in the vicinity of La Barge and Fontenelle creeks (Steven S. Oriel, written communication, 1957). These western conglomerates, unlike those along the Uinta Mountains, are poorly sorted and have a muddy matrix.

A red sandstone facies makes up the middle part of the main body of the Wasatch Formation in the valley between the Rock Springs uplift and the escarpment of the Green River Formation that makes the eastern rim of the Green River Basin. This facies extends northwestward nearly to the Union Pacific Railroad. Where best exposed (T. 16 N., R. 105 W.), this sandstone unit is several hundred feet thick and forms a high rocky ridge whose cliffs and slopes resemble exposures of the red quartzite of the Uinta Mountain Group. The sandstone in the Wasatch, however, is softer and more friable and is more irregularly bedded. It is a coarse-grained crossbedded sandstone that ranges in color from brick red to a rather dull purplish red. Locally it is gravelly or even conglomeratic. H. W. Roehler of the Mountain States Fuel Supply Co. (oral communication, Aug. 1963) interpreted this red sandstone facies as a sand mass derived from the Upper Cretaceous sandstone formations of the Rock Springs Uplift, which were arched up along the Wamsutter Arch during middle Wasatch time. The axis of the Wamsutter Arch extends from the vicinity of Wamsutter, Wyo., southwestward diagonally across the central part of the Rock Springs Uplift, whose axis runs generally north-south. The fact that this great sandstone lens dies out into mudstone both southward and northward lends strong support to Roehler's interpretation.

NILAND TONGUE

Pipiringos (1962, p. A24–A29) separated from the lower part of what I had mapped near Wamsutter (Bradley, 1945) in 1933 as Tipton Tongue of the Green River Formation an additional tongue of the Wasatch Formation, the Niland Tongue. He mapped this tongue northward and northwestward from the north rim of the Washakie Basin out into the Great Divide Basin where it passes beneath the Tipton Tongue of the Green River Formation. (See pl. 1.) Northeastward the Niland Tongue grades laterally into the coarse-grained arkosic sandstone of the Battle Spring Formation.

At its type locality (T. 24 N., Rs. 95 and 96 W.) the Niland Tongue of the Wasatch Formation is about 400 feet thick and consists of characteristic Wasatch lithology—that is, predominantly gray mudstone and gray to nearly white lenticular sandstone beds. Interbedded with these are thinner beds of carbonaceous shale and coal beds.

Pipiringos reported fossil plants and mollusks from the middle part of the Niland which indicate an early Eocene age. McGrew and Roehler (1960, p. 158) reported finding a rather large vertebrate fauna in the Niland along the northwestern margin of Washakie Basin (sec. 8, T. 18 N., R. 98 W.). They characterized this fauna as a typical Lost Cabin fauna.

Eastward the Niland grades into the Battle Spring Formation and loses its identity. Northwestward it becomes the uppermost part of the main body of the Wasatch because the Luman Tongue of the Green River Formation disappears in that direction. In the vicinity of Steamboat Mountain, near the north end of the Rock Springs uplift, neither the Luman nor the Niland Tongue can be identified. Pipiringos and I traced the Niland and Luman Tongues 6–8 miles southward along the east side of the Washakie Basin and 10–15 miles southward along the west side of the Basin. The boundaries of these tongues are shown accurately around the north end of Washakie Basin where Pipiringos mapped them (secs. 6 and 7, T. 19 N., R. 94 W., and Tps. 19 N., Rs. 95 and 96 W.). Southwestward from there I had sketched these boundaries on aerial photographs. In 1958 J. D. Love of the Survey revised my boundaries in the field and adjusted them to the topography of the Army Map Service 1:250,000 map. Around the northeastern part of the Washakie Basin I have sketched, without control, the boundaries of the Niland and Luman Tongues southeastward until they die out. (See pl. 1.) The base of the Luman Tongue, however, was mapped by planetable and telescopic alidade in 1933, at which time I regarded it as the base of the Tipton Tongue of the Green River Formation.

In the fall of 1957, Dwight Taylor and I identified the Niland Tongue of the Wasatch and the Luman Tongue of the Green River on the west side of Washakie Basin (secs. 14, 15, 23, 24, T. 15 N., R. 101 W.) and mapped them from there southward into Colorado. This work is discussed more fully on pages A29 and A30 under the subheading "Luman Tongue."

In the basin of Vermilion Creek, southwest of Washakie Basin, the Niland is nearly everywhere less than 100 feet thick and contains several units of brown flaky shale that resembles the shale in the underlying and overlying tongues of the Green River Formation. The remainder of the Niland Tongue in that area, however, is characteristic of the Niland farther north. The most distinctive aspect of the Niland in this part of the area is a nearly white very lenticular tuff. (See fig. 8.) This is a crystal tuff that consists almost wholly of small sharply angular crystals of quartz and feldspar.

Along the southeastern edge of the basin of Vermilion Creek the Niland thickens rather rapidly and assumes a wholly Wasatch aspect. Along the west side of this basin the Niland Tongue thins to about 65 feet in sec. 4, T. 12, N., R. 101 W., and pinches out entirely between there and Canyon Creek (sec. 18, T. 12 N., R. 101 W.), about 3 miles farther southwest.

Around the northeastern margin of the Washakie Basin, the Niland contains near its top a rather remarkable canneloid subbituminous coal bed. This coal bed, which is 6 feet thick, can be traced at least 4 miles along the outcrop. Microscopic examination of thin sections of the coal shows that it contains a considerable quantity of pollen and leaf-cuticle residues, which give it a canneloid aspect. The most unusual feature, however, is the occurrence in its joint cracks and along bedding planes of the rare minerals tschermigite, an ammonium alum [$(NH_4)Al(SO_4)_2+12H_2O$], and ammoniojarosite [$NH_4Fe_3(SO_4)_2(OH)_6$]. Also present is the rare mineral melanterite [$Fe^{+2}SO_4\cdot 7H_2O$]. The tschermigite is rather plentiful, and the ammoniojarosite is common but less abundant than the tschermigite. E. T. Erickson of the U.S. Geological Survey published (1922) an analysis of the tschermigite and a description of the tschermigite and ammoniojarosite. At that time it was the first recorded occurrence of tschermigite in the United States and the first record of ammonical jarosite. Since then both tschermigite and ammoniojarosite have been reported from southern Utah (Shannon, 1927).

The canneloid coal has been mined for local use, and one tunnel about 150 feet long in sec. 7, T. 19 N., R. 94 W., has been mined out to make a rather large room. A sample taken from the working face in this room has the following analysis, which was made by the U.S. Bureau of Mines.

FIGURE 8.—White crystal tuff about 22 feet thick in the upper part of the Niland Tongue of the Wasatch Formation close to the SW cor. sec. 4, T. 12 N., R. 101 W., Sweetwater County, Wyo. The man is standing on the base of the tuff, which is lenticular along the strike. At this place the Niland is about 65 feet thick.

Analysis of canneloid coal from the Niland Tongue of the Wasatch Formation

[Data in weight percent]

	As received	*Moisture and ash free*
Moisture	9. 9	-----
Volatile matter	45. 0	52. 5
Fixed carbon	40. 7	47. 5
Ash	4. 4	-----
	100. 0	100. 0
Hydrogen	4. 5	3. 9
Carbon	51. 8	60. 4
Nitrogen	1. 9	2. 3
Oxygen	33. 8	29. 2
Sulphur	3. 6	4. 2
Ash	4. 4	-----
	100. 0	100. 0

The analysis shows that this coal has a much lower ash and moisture content than do the other Wasatch coals, analyzed for Pipiringos (1962, p. A44–A45). This coal also contains somewhat more nitrogen and sulfur than is found in most subbituminous coals. Presumably the high contents of nitrogen and sulfur are accounted for by small amounts of ammoniojarosite in the coal, as the tschermigite was rather carefully picked from the sample before analysis.

Pipiringos (1962, p. A59) mentioned that this canneloid coal bed thins rather abruptly westward along the north rim of the Washakie Basin. He discussed briefly other coals in the Niland farther north in the Great Divide Basin.

At three localities in Tps. 24 N., Rs. 95 and 96 W., Pipiringos (1962, p. A12) collected fossil plants from the Niland Tongue which Roland W. Brown of the U.S. Geological Survey identified as of Eocene age.

Pipiringos (1962, p. A12) also collected ostracodes from T. 24 N., R. 95 W., which were identified by R. E. Peck of the University of Missouri. Peck expressed the opinion that they represented a Paleocene or early Eocene age.

W. C. Culbertson, of the U.S. Geological Survey, showed in the field (Aug. 1963) that either the Niland Tongue of the Wasatch Formation, or its homotaxial equivalent, extends for several tens of miles along the east side of the Green River Basin from the east flank of Little Mountain northward almost to the south flank of Wilkins Peak. Along this escarpment the Niland Tongue, or its equivalent, is about 200 feet thick and has much the same lithology as the underlying main body of the Wasatch Formation. This tongue of the Wasatch is separated from the main body of the Wasatch by a thin tongue or, lens, of brownish-buff lacustrine beds, which is evidently the homotaxial equivalent, or perhaps was once the actual extension, of the Luman Tongue of the Green River Formation.

CATHEDRAL BLUFFS TONGUE

The Cathedral Bluffs Tongue of the Wasatch Formation encircles the greater part of Washakie Basin. Southeast (Tps. 12 and 13 N., R. 93 W., Carbon County, Wyo.) of Washakie Basin, where the Tipton Tongue of the Green River Formation dies out, the Cathedral Bluffs Tongue becomes part of the main body of the Wasatch Formation. The Cathedral Bluffs Tongue is also exposed north of the Rock Springs uplift. From that locality it has been traced eastward as far as T. 26 N., R. 95 W., where it loses its identity in the Battle Spring Formation of Pipiringos (1962, p. A32). Westward it thins and fingers out into its stratigraphic and time equivalent, the Wilkins Peak Member of the Green River Formation in T. 24 N., R. 104 W., Sweetwater County, Wyo. (Bradley, 1926, pl. 59). The relations between the Wasatch and Green River Formations and the history of the terminology have been discussed in two earlier reports (Sears and Bradley, 1924; Bradley, 1926, p. 122–125), but in those reports the Wilkins Peak Member of the Green River Formation was regarded as the Laney Shale Member.

The Cathedral Bluffs Tongue consists predominantly of gray mudstone that is banded with pink and red layers. In the steep badland slopes that characterize this unit, the red clay washes down over the gray, giving the impression that red mudstone and claystone make up the greater part of the unit. Bands of red are less numerous near the mountains in both the northern and southern parts of the area. Near the mountains also, lenses and beds of buff, brown, and greenish-gray sandstone are rather common; but farther out in the basin, sandstone layers are less numerous, and, though lenticular, they are generally somewhat thinner. Locally thin beds of algal limestone are interbedded with the sandy mudstone. To the east (T. 26 N., R. 96 W.) in the area mapped by Pipiringos, the Cathedral Bluffs Tongue becomes sandy and conglomeratic; still farther east it merges with the Battle Spring Formation.

A maximum thickness of 1,750 feet was given by Nightingale (1930, p. 1021) for the Cathedral Bluffs near its southwestern limit along Kinney Rim in northwestern Colorado, and Pipiringos (1962, p. A32) estimated the thickness west of Lost Creek as 1,100–1,300 feet. At Pine Butte (T. 16 N., R. 100 W.), Schultz gave the thickness as 740 feet. But as Love illustrated (written communication, 1964), subsurface data from only about 9 miles farther southeast (sec. 35, T. 15 N., R. 99 W.) show that the Cathedral Bluff thickens to about 2,340 feet. Indeed, Love's figure shows that in several wells within the Washakie Basin the Cathedral Bluffs is about this thick but thins markedly, both east and west, toward the outcrops around the margins. On the northeast side of Washakie Basin, east of Barrel Spring (in T. 17 N., Rs. 93 and 94 W., Carbon County, Wyo.), the Cathedral Bluffs is only 115 feet thick.

Vertebrate fossils are rare in the Cathedral Bluffs Tongue, but Morris (1954, p. 195–199) collected a surprisingly large number of bones at four localities along the northeast side of the Washakie Basin (T. 15 N., R. 93 W. to T. 19 N., R. 95 W.). He regarded (p. 199) these as indicative of middle Eocene age ("* * * between Lost Cabin level and Bridger B, perhaps being represented by the rarely fossiliferous sediments of Bridger A * * *"). Gazin (1959) later reviewed Morris' collection and expressed the belief that it represents Lost Cabin level of the Wasatch. Morris observed that most of the fossils from the Cathedral Bluffs Tongue are smaller mammals, notably rodents and condylarths, and suggested that the biocoenose is representative of a forest environment. Gazin (1959, p. 135) revised Morris' faunal list to include the following rather diverse kinds of vertebrates:

- Marsupalia:
  - *Peratherium*, 2 sp.
- Insectivora:
  - *Notharctus*, sp.
- Tillodontia:
  - *Trogosus*? *latidens* Marsh
- Primates:
  - *Absarokius witteri* Morris
- Rodentia:
  - paramyid rodent
- Carnivora:
  - *Viverravus* cf. *V. lutosus* Gazin
  - *Didymictus* cf. *D. altidens* Cope
- Condylartha:
  - *Hyopsodus* sp.
- Perissodactyla:
  - Cf. *Hyracotherium* sp.
  - *Eotitanops* sp.
  - *Hyrachyus* cf. *H. modestus* Leidy
- Artiodactyla:
  - Cf. *Hexacodus* sp.

North of the Rock Springs uplift (sec. 21, T. 24 N., R. 101 W.) I found numerous fragments of turtle bones near the base of the Cathedral Bluffs Tongue.

McGrew and Roehler (1960, p. 158) reported further on vertebrate fossils found in the Cathedral Bluffs Tongue.

To the west of Dad, Wyo., in the upper part of the Cathedral Bluffs, a single rodent tooth was found by McGrew which was identified by R. W. Wilson (personal communication) as *Sciuravus nitidus* Marsh, a probable Bridger form. In sec. 30, T. 25 N., R. 101 W., a rodent fauna was found above the Tipton and below the Laney which H. E. Wood (personal communication) believed to be more or less intermediate between Lostcabinian and Bridgerian. From the evidence available it appears that the Cathedral Bluffs is certainly in part typical Lost Cabin (if it can be assumed that New Fork and Cathedral Bluffs are time equivalents) but that it may transgress the time boundary between Lostcabinian and Bridgerian.

The time equivalence of Cathedral Bluffs and New Fork Tongues of the Wasatch is discussed below.

NEW FORK TONGUE

Another tongue of the Wasatch Formation extends for about 100 miles along the west side of the Green River Basin. (See pl. 1.) Like the Cathedral Bluffs Tongue, it is separated from the main body of the Wasatch Formation by a thin basal tongue of the Green River Formation. Where this tongue of the Green River Formation thins and loses its identity to the north (T. 29 N., R. 110 W.) and to the south (T. 14 N., R. 118 W.), the tongue of the Wasatch Formation becomes a part of the main body of the Wasatch. Donavan (1950, p. 64) mapped this tongue for a few miles along the east side of Green River (T. 30 N., R. 109 W., southwest to the northeastern part of T. 28 N., R. 111 W.) and named it the New Fork Tongue of the Wasatch Formation from its exposures in the buttes "* * * overlooking the Green River–New Fork River junction." Donovan mapped his New Fork Tongue of the Wasatch only to the northeastern part of T. 28 N., R. 111 W. (about 14 miles northeast of La Barge), whereas, according to my interpretation, this tongue extends some 80 miles farther southwest into T. 14 N., R. 118 W. (See pl. 1.) Stephen S. Oriel, of the U.S. Geological Survey, told me (written communication, 1957) that Donavan apparently had regarded red mudstones as an essential element of the New Fork Tongue and had terminated the unit where the reds graded southeastward into greenish-gray to light-gray mudstone and gray, tan, and brown sandstone.

Through the generosity of Mr. Oriel, I am able to include on the geologic map (pl. 1) his hitherto unpublished detailed mapping of the margin of the Green River Basin (north from lat. 42° N. to La Barge Creek and thence northward along the east side of the Green River to the northern part of T. 28 N., R. 111 W.).

Throughout most of its length the New Fork Tongue consists largely of gray sandy mudstone that is banded with thin layers of pink to maroon mudstone or clay. Irregular beds and lenses of coarse-grained crossbedded gray to dark-greenish-gray sandstone, however, in places containing an abundance of well-rounded gray to black chert pebbles, make up a large percentage of the tongue. A particularly sandy facies of this unit is exposed along Hams Fork on the main road between Kemmerer and Opal. About 7 miles farther north, however, where the main road from Kemmerer north to Big Piney crosses the New Fork Tongue, the tongue contains little sandstone and is prevailingly red. Superficially the New Fork Tongue resembles the more somber phases of the Beckwith Formation of Late Jurassic and Cretaceous age, which it overlaps in many places and from which it probably was in large part derived.

The New Fork Tongue of the Wasatch Formation is 235 feet thick in sec. 31, T. 28 N., R. 112 W., and is approximately 380 feet thick along the main line of the Union Pacific Railroad just west of Carter (T. 17 N., Rs. 115 and 116 W.). Southward from the vicinity of Carter it thickens at the expense of the underlying tongue of the Green River Formation.

Gazin (1952, p. 13) suggested that the fossil vertebrates in the New Fork Tongue of the Wasatch Formation represent the upper stage of the Lost Cabin (Wasatchian) age. The fauna is characterized by *Meniscotherium chamense*, Cope, *Hyrachyus* spp., and *Bathyopsis*. *Lambdotherium popoagicum* Cope, is the most abundant species found, but the fauna also includes such typical Wasatchian forms as *Heptodon*, *Meniscotherium*, *Esthonyx*, and *Ambloctonus* cf. *A. major* Denison. Morris (1954, p. 199) observed that "* * * in spite of the relatively large number of isolated teeth found, none of the genera, with the exception of *Hyrachyus* and *Hyopsodus*, listed as occurring in the New Fork, have been identified in the Cathedral Bluffs Tongue." He then went on to make the very interesting, though tentative, suggestion that the New Fork Tongue is equivalent to at least part of the Tipton Tongue of the Green River Formation—that is, that the New Fork Tongue of the Wasatch on the west side of Green River Basin may be, in part, older than the Cathedral Bluffs Tongue of the Wasatch east of the Rock Springs uplift. Prof. Paul O. McGrew (oral communication, 1957) of the University of Wyoming, after studying the vertebrate faunas from these formations in various parts of the Green River and Washakie Basins, also believed that there is a fair basis for believing that the New Fork Tongue is somewhat older than the Cathedral Bluffs Tongue. Indeed, McGrew and Roehler (1960, p. 158)

* * * found a small but diagnostic fauna in the Tipton Tongue of the Green River Formation in sec. 30, T. 25 N., R. 101 W. The fauna is of Lost Cabin age (late early Eocene) with *Cynodontomys*, *Hyracotherium*, and *Lambdotherium*. The Tipton Tongue at this locality was described by Bradley (1926) as representing a near-shore facies.

Apart from this evidence from the vertebrate fossils, I believe that there is good reason for thinking that the New Fork and Cathedral Bluffs Tongues of the Wasatch Formation are essentially contemporaneous. Each is a wedge of fluviatile sediment that grew basinward from the mountains contemporaneously as the lake in which the Green River Formation was deposited shrank to the small size it was during the Wilkins Peak stage. If these thick and extensive wedges of fluviatile sediment were not contemporaneous, we must suppose that the floor of the lake basin was so deeply depressed that the whole lake (during its low stage) was shifted to one side of the basin while a great wedge of fluviatile sediment formed on the opposite side. Then the first wedge of fluviatile sediment must have been warped downward to become the bed of the lake while a second wedge of fluviatile sediment grew in from the opposite side of the basin. And, finally, the axis of the lake basin must have returned to its original position near the geographic center of the Green River Basin. The vertical continuity of moderately shoal-water lacustrine sediment (Wilkins Peak Member of the Green River Formation) along the east side of the Green River Basin argues against this complex interpretation.

Gazin (1959), after collecting additional fossils and studying the fossils Morris collected from the Cathedral Bluffs Tongue, concluded that the Fontenelle Tongue of the Green River Formation and the New Fork Tongue of the Wasatch Formation on the west side of the Green River Basin are equivalent, respectively, to the Tipton Tongue of the Green River and the Cathedral Bluffs of the Wasatch Formation east of the Green River Basin.

Oriel (1961) found in the Fontenelle Creek–La Barge Creek area (Fort Hill quadrangle) still another tongue of Wasatch lithology roughly 100 feet above the base of the Laney Shale Member of the Green River Formation. This tongue of the Wasatch, which he calls the upper tongue, is about 90 feet thick along Fontenelle Creek and consists largely of gray to brown muddy sandstone and greenish-gray mudstone, but it includes also a little soft platy marlstone. It grades eastward within a few miles into typical Laney Shale Member lithology.

In my reconnaissance mapping (1928) across the north end of the Green River Basin, I sketched in, very roughly, a tongue of Wasatch lithology in the lower part of the Laney Shale Member of the Green River Formation. As mapped, this Wasatch tongue extends southward from the southern part of T. 29 N., R. 108 W., to the south-central part of T. 28 N., R. 110 W. The relationship of this tongue to the upper tongue of Wasatch mapped by Oriel farther southwest can be resolved only by more detailed mapping along the northern margin of the Green River Basin.

The paleoecology of the Wasatch and Bridger Formations will be discussed in a subsequent report.

GREEN RIVER FORMATION

DEFINITION AND AGE

The Green River Formation of middle Eocene age was named by Hayden (1869, p. 90) for the exposures along Green River west of Rock Springs. In a report published 10 years earlier, Engelmann (1858, p. 70) referred to "the tertiary Green river formation" in the western part of the Green River Basin. But in an earlier part of that report (p. 46–47) it is clear from his good descriptions of the lithology that he meant to include in this term what we now think of as part of the Wasatch Formation, the Green River Formation, and the Bridger Formation. Light-gray, brown, or buff dolomitic marlstone and shale of lacustrine origin that may contain organic matter characterize the Green River Formation. Oil shale, beds of dolomitic marlstone and shale thickly studded with salt-crystal molds, oolitic limestone and bedded algal deposits, beds of volcanic ash, and limy sandstone or sandy marlstone characterize various facies of the formation. Locally, fossil fish, plants, gastropods, pelecypods, ostracodes, and fly larvae are common. Bird, mammal, and reptilian bones have been found locally in the shore facies of the formation.

STRATIGRAPHIC UNITS

LUMAN TONGUE

The Luman Tongue of the Green River Formation was named by Pipiringos (1962, p. A14–A24) for a section consisting of low-grade oil shale, fossiliferous muscovitic calcareous sandstone, siltstone, mudstone, and a few thin coal beds that is excellently exposed on the south slope of Luman Butte (sec. 34, T. 24 N., R. 97 W.). The Luman Tongue overlies the main body of the Wasatch Formation and underlies the Niland Tongue of the Wasatch Formation.

The Luman Tongue crops out in two belts; one extends from the vicinity of Luman Butte southeastward to the center of T. 22 N., R. 94 W., and the other curves around the north end and down the west side of the Washakie Basin into northwestern Colorado. As noted on page A23 of this report, Pipiringos separated the Luman Tongue of the Green River Formation and the Niland Tongue of the Wasatch from the lower part of what I had mapped (Bradley, 1945) as the Tipton Tongue along the northeastern quadrant of the Washakie Basin. Consequently, the base of the Luman has been mapped along the east side of Washakie Basin into the southwestern part of T. 17 N., R. 92 W., where it grades into lithology indistinguishable from that of the Wasatch. Pipiringos (written communication, 1958) told me that Prof. Don Blackstone of the University of Wyoming had traced the remnants of the Luman Tongue a few miles farther southeastward than I had into sec. 6, T. 16 W., R. 92 W. Also according to Pipiringos, Blackstone reported that in tracing the Niland Tongue of the Wasatch southeastward from the vicinity of Wamsutter, it gradually acquired a Green River aspect and lost its identity in sec. 10, T. 17 N., R. 93 W. The upper boundary of the Luman and Niland Tongues have been roughed in without control on my map (pl. 1) to connect these two terminal localities with the boundaries mapped by Pipiringos in the NE¼ sec. 6, T. 19 N., R. 94 W. Pipiringos (1962, pl. 1) mapped the Luman and Niland Tongues from sec. 6, T. 19 N., R. 94 W., across the northern edge of Washakie Basin to sec. 19, T. 19 N., R. 96 W. I have projected these boundaries (pl. 1) southwestward with the help of aerial photographs until they connect (in the western part of T. 17 N., R. 99 W.) with the photogeologic mapping done for me in 1957 by Robert J. Hackman. This sketching was kindly checked and revised for me by J. D. Love of the Survey while we were in the field in October 1958. Love adjusted these boundaries to the 1:250,000 topographic base of the Army Map Service.

The Luman Tongue of the Green River Formation is 180 feet thick at Luman Butte but thickens eastward to 270 feet in the eastern part of T. 23 N., R. 95 W. It also thickens eastward along the Union Pacific Railroad from about 200 feet at Tipton Station (N½ sec. 18, T. 19 N., R. 96 W.) to about 390 feet at Frewen Station, about 11 miles farther east.

In the central part of the area mapped by Pipiringos (see area 6 on index map, pl. 1), he reported (1962, p. A20) "* * * several constituent tongues of low-grade oil shale separated by sandstone and siltstone beds. The three most conspicuous and persistent tongues were mapped separately * * *." At the base of the lowest oil-shale tongue is a highly distinctive bed of nearly black concretionary limestone that weathers to pastel shades of lavender, pink, yellow, buff, and brown. This unit rests, in most of the area, directly on the highest coal bed in the main body of the Wasatch Formation and is a very useful horizon marker. The two stratigraphically higher oil-shale zones each thicken eastward and coalesce into one body of oil shale in the eastern part of T. 23 N., R. 95 W. Along the Union Pacific Railroad all three oil-shale tongues thicken eastward from Tipton Station and coalesce in the vicinity of Frewen Station to form one body of low-grade oil shale about 390 feet thick.

In the fall of 1957 Dwight Taylor, of the U.S. Geological Survey, and I identified the Luman Tongue of the Green River Formation and the Niland Tongue of the Wasatch Formation at a site about halfway down the west side of Washakie Basin (secs. 14, 15, and 23, T. 15 N., R. 101 W.). At this locality, both these tongues and the overlying Tipton Tongue of the Green River Formation are strikingly similar in lithology and thickness to what they are along Bitter Creek (T. 17 N., R. 98 W.), about 18 miles northeast around the edge of Washakie Basin, where Pipiringos and I identified them in 1956.

Taylor and I sketched the boundaries of the Luman and Niland Tongues of the Green River and Wasatch Formations, respectively, on aerial photographs at many places in and around the basin of Vermilion Creek, known as Hiawatha Basin. Subsequently, R. J. Hackman, of the U.S. Geological Survey, had diapositives made from these photographs and made a photogeologic map showing the outcrop pattern of these tongues of the Green River and Wasatch Formations in all of Hiawatha Basin and northward along the west side of Washakie Basin to the western part of T. 17 N., R. 99 W. His map has been incorporated in the geologic map (pl. 1) of this report.

Not shown on plate 1 of this report is a thin tongue, or lens, of brownish-buff lacustrine beds, which is evidently the homotaxial equivalent or perhaps was once the actual extension, of the Luman Tongue; this tongue crops out along part of the east side of the Green River Basin from the east flank of Little Mountain northward nearly to the south flank of Wilkins Peak. This unit has been mapped by W. C. Culbertson, of the U.S. Geological Survey. Culbertson called my attention to this unit in August 1963 while we were in the field together.

Both the Luman and the Niland Tongues change southward from about the midpoint of the western rim of Washakie Basin (T. 15 N., R. 101 W.). The Luman thickens to about 470 feet in the western part of T. 13 N., R. 101 W., and becomes carbonaceous and sandy; the Niland Tongue thins to less than 50 feet and becomes somewhat shaly. Westward along the north slope of Pine Mountain, where the exposures are not adequate to identify the units, the Niland extends an unknown distance. Southward along the west side of Hiawatha Basin, the Niland thins from about 65 feet thick in sec. 6, T. 12 N., R. 101 W., to 0 just a little north of Canyon Creek (sec. 18, T. 12 N., R. 101 W.). In this area the Luman Tongue is overlain by the Tipton Tongue, which it there closely resembles. Along the east side of Hiawatha Basin, the Niland thickens southward and must be several hundred feet thick east of Vermilion Creek in the southern part of T. 11 N., R. 100 W., Moffat County, Colo. The

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Luman Tongue of the Green River remains thick (400–500 ft) throughout Hiawatha Basin.

On the geologic map (pl. 1) the Luman Tongue is shown extending westward along the north flank of Pine Mountain as far as the western part of T. 13 N., R. 103 W. J. D. Love, of the U.S. Geological Survey, mapped the westernmost 6 miles of this extension and generously gave me his map to incorporate in my map, plate 1. This extension along the north flank of Pine Mountain is significant because it suggests that the Luman and Niland Tongues may once have connected with the apparent Luman and Niland Tongues that crop out of the east flank of Little Mountain and extend northward nearly to the south flank of Wilkins Peak. The gap between known Luman and Niland north of Pine Mountain and the inferred Luman and Niland on the east flank of Little Mountain is roughly 10 miles.

The Luman(?) on Little Mountain is about 40 feet thick and thins gradually northward until it disappears a little south of Wilkins Peak.

In Hiawatha Basin the Luman Tongue contains many layers of sandy shell marl, and along the east side of Vermilion Creek (T. 11 N., R. 100 W., Moffat County, Colo.) it consists predominantly of shell marl. According to Dwight Taylor, the most numerous forms are the snails *Goniobasis* sp. and *Viviparus* sp. and the freshwater clam "*Unio*" sp. These beds also contain numerous ostracodes. In most parts of Hiawatha Basin the Luman contains thin layers of subbituminous coal, and, locally, a few of these layers are thick enough to have been mined for domestic use. Along the southern edge of Hiawatha Basin the Luman grades rather rapidly into either sandstone and then conglomerate, as at Sugar Loaf Butte (sec. 15, T. 11 N., R. 101 W., Moffat County, Colo.), or into gray sandy mudstone typical of the Wasatch Formation. At irregular and rather widely spaced intervals the Luman in Hiawatha Basin and northward around the rim of Washakie Basin contains very persistent beds of sandstone that are thin bedded and ripple bedded. These beds range in thickness from a few inches to a few feet. Channel sandstone lenses occur also, but they are rare.

About 75 feet above the base of the Luman in T. 12 N., R. 101 W., the late R. W. Brown of the Survey and I collected fossil plants which he identified as *Potomageton* sp. and *Nymphaea* sp. In a zone of nearly black shale about 50 feet above the base of the Luman farther south (sec. 20, T. 11 N., R. 100 W.), Dwight Taylor and I collected shells of a minute snail, which he identified as *Valvata* sp., and a tiny clam, which he recognized as *Sphaerium* sp. These two forms, according to Taylor (oral communication, 1957), are characteristic of, but not restricted to, the muddy bottoms of lakes beyond the depth where rooted aquatic plants grow. Depths beyond rooted plants mean, according to Ruttner (1953, p. 157), depths probably greater than 25–30 feet. In samples of sandy carbonaceous shale which I collected—one (D–1178B) from about the middle of the Luman Tongue (sec. 18, T. 12 N., R. 100 W., Moffat County, Colo.) and one (D–1178A) from a bed near the top (sec. 8, T. 13 N., R. 101 W., Sweetwater County, Wyo.)—Estella B. Leopold of the Survey identified the microscopic planktonic alga *Pediastrum* sp. and the pollen grains and spores listed in table 1.

In a sample of black shale collected from a bed about 50 feet above the base of the Luman Tongue (sec. 20,

TABLE 1.—*Pollens, spores, and algae found in the Luman Tongue of the Green River Formation*

[Identified by E. B. Leopold. Numbers refer to the number of specimens found]

Flora	*USGS Loc.* D-1178B	*USGS Loc.* D-1178A
Cf. *Pinus*	1	1
Cf. *Cycas*	1	10
Ephedra cf. *torreyana* S. Watson	2	1
Cunninghamia or *Sequoia*	1	0
Total	5	12
Dicotyledons:		
Unidentified	14	37
Betulacae	3	11
Platycarya	3	15
Cf. *Engelhardtia*	0	3
Pterocarya	3	1
Juglandaceae	0	2
Velkova	0	5
Cf. *Morus*	0	1
Ulmaceae	0	1
Carya	0	1
Tilia	1	3
Cf. *Galium*	1	0
Total	25	80
Monocotyledons:		
Unidentified	0	18
Nymphaeceae	2	3
Potomogeton	0	1
Gramineae	0	4
Total	2	26
Spores:		
Unidentified	2	16
Cf. Schizaceae	0	1
Total	2	17
Algae:		
Pediastrum	4	1
Chrysophyta	1	1
Total	5	2

T. 11 N., R. 100 W., Moffat County, Colo.), Miss Leopold also found well-preserved "* * * pollen of *Platycarya* and a few structurally good remains of a *Pediastrum* of the *P. duplex* type" (written communication, 1958).

The minute planktonic fresh-water alga *Pediastrum* apparently has a remarkably resistant cell wall, for it occurs as a fossil in great abundance in certain kinds of carbonaceous sediments (Wilson and Hoffmeister, 1953; Cookson, 1953). Wilson and Hoffmeister found four clearly distinct species of *Pediastrum* in a "Paleogene" formation of Sumatra, and the individuals were incredibly well-preserved. Miss Cookson (1953) found *Pediastrum* in "Cainozoic deposits" of Australia. Professor Wilson later told me (written communication, 1953) that he had subsequently found *Pediastrum* in the Oligocene of Texas and Venezuela.

TIPTON TONGUE AND TIPTON SHALE MEMBER

The Tipton Tongue of the Green River Formation encircles the greater part of the Washakie Basin as a great horse shoe, with the open end at the south. (See pl. 1.) In this area the Tipton Tongue is entirely detached from the main body of the Green River Formation; but farther northwest, around the north end of the Rock Springs uplift where the Cathedral Bluffs Tongue of the Wasatch dies out (T. 24 N., R. 104 W.), the Tipton Tongue joins the main body of the Green River Formation and from there southward along the east side of the Green River Basin becomes the Tipton Shale Member of the Green River Formation. This intertonguing relation between the Green River and Wasatch Formations and the history of the stratigraphic nomenclature have been discussed in two earlier reports by J. D. Sears and me (Sears and Bradley, 1924; Bradley, 1926, p. 122–125).

Around the Washakie Basin the Tipton Tongue consists chiefly of rather soft brown papery organic shale and low-grade oil shale, but interbedded with the papery shale are somewhat harder beds of gray flaky marlstone and thin regular beds of brown limy sandstone. Throughout the greater part of its extent—around the Washakie Basin and through the northern part of the Great Divide Basin—the Tipton Tongue as mapped by me (pl. 1) and as mapped by Pipiringos (1962, pl. 1) includes in its upper part 100–200 feet of beds now known to belong to the Wilkins Peak Member of the Green River Formation. The recognition of these beds as Wilkins Peak rests on much detailed geologic mapping by H. W. Roehler, (unpub. data). As a consequence of having first identified the Wilkins Peak Member along the north flank of Pine Mountain and then along the west side of the Washakie Basin, and having traced it northward to and beyond Tipton Station on the Union Pacific Railroad, Roehler (unpub. data) has redefined the Tipton Tongue. As redefined, the upper body of light-colored marlstone and algal beds are excluded and are assigned to the Wilkins Peak Member. Pipiringos (1962, p. A29–A31) defined the upper part of the Tipton as that part extending upward from the base of the lowest very extensive algal-ball bed, which he mapped (1962, pl. 1). Consequently, from his map it is easy to tell the distribution of the Tipton Tongue and the Wilkins Peak Member of the Green River Formation.

That which is now defined as Tipton Tongue in the type locality, around much of Washakie Basin, and far up into the Great Divide Basin, is tan to grayish brown and is made up largely of soft papery low-grade oil shale, but it also contains a few thin brownish fine-grained limy sandstone beds and layers of concretionary sandy limestone that is either crowded with gastropod shells or is oolitic.

Southwest of Washakie Basin, where one end of the Tipton Tongue loses its identity by grading into Wasatch lithology, sandstone beds become thicker and much more plentiful in the Tipton, and beds of greenish-gray shale and gray mudstone replace much of the papery shale. Detailed sections measured along Shell Creek in secs. 27 and 28, T. 12 N., R. 99 W., Moffat County, Colo., where the Tipton is 388 feet thick, and in sec. 3, T. 10 N., R. 100 W., where it is 227 feet thick, are given in an earlier report (Sears and Bradley, 1924, p. 101–103). It should be pointed out that these two sections doubtless also contain an upper part that should be regarded as the Wilkins Peak Member. Additional fieldwork, however, will probably be needed to determine how much of each section should be regarded as belonging to the Tipton Tongue and how much to the Wilkins Peak Member.

About midway along the west side of Washakie Basin, at Pine Butte, in secs. 5 and 6, T. 15 N., R. 100 W., the Tipton is 350 feet thick (Schultz, A. R., unpub. data). Roughly the upper 200 feet of this belongs to the Wilkins Peak Member. The Tipton maintains a thickness of about 160 feet around the north end of Washakie Basin and well down the east side, but south of Dad (sec. 32, T. 16 N., R. 92 W., Carbon County, Wyo.) it thins gradually. East of Flat Top Mountain in sec. 3, T. 14 N., R. 92 W., the Tipton is between 110 and 120 feet thick. About 2½ miles northwest of Baggs the Tipton is 75 feet thick and consists almost wholly of papery shale which, near the base and top of the tongue, is somewhat carbonaceous. Much of the southward thinning of the Tipton between Dad and Baggs takes place by gradual lateral transition of the uppermost Tipton beds into lithology characteristic of the Cathedral Bluffs Tongue of the Wasatch; but the Tipton thins southward also, at least to some extent, by small-scale intertonguing with the underlying Wasatch. Westward from the vicinity of Baggs the Tipton maintains a thickness of about 75 feet, but it becomes carbonaceous, then sandy and carbonaceous, and finally loses its identity near the junction of Red and Sand Creeks in sec. 4, T. 12 N., R. 93 W.

One other distinctive detail of the Tipton on the east side of Washakie Basin is the local sandstone facies about 7 miles north of Baggs. At this place the Tipton consists predominantly of regular beds of light-gray well-sorted crossbedded sandstone. Many other sandstone beds, however, are brown and muddy. Near the top of the Tipton the sandstone beds contain an abundance of gastropod (*Viviparus*?) shell molds and a few beds of algal deposits. North and south of this locality the Tipton consists almost wholly of papery shale. Apparently this local sandstone facies represents the locus of a stream that entered the ancient Gosiute Lake basin from the east or southeast.

In the northern part of the Great Divide Basin where Pipiringos (1962, p. A29) mapped the Tipton Tongue of the Green River Formation, the Tipton has very much the same characteristics as it does around the north rim of the Washakie Basin. Pipiringos observed the same distinction between the upper and lower parts and, indeed, mapped the boundary between them using the top of the "lowest zone of algal balls" as the base of the upper part of the Tipton. He gave (p. A30) the total thickness of the Tipton as 280 feet in secs. 9 and 16, T. 24 N., R. 95 W. At that same place the lower part of the Tipton is 180 feet thick.

Eastward from Tps. 24, 25, and 26 N., R. 94 W., Pipiringos (p. A30–A31) described the lateral gradation of much of the Tipton Tongue into the coarse arkosic sandstone of his Battle Spring Formation. This gradation occurs by intertonguing and also by surprisingly rapid lateral change from brown papery low-grade oil shale into the coarse-grained pinkish gray arkose.

Westward from the western part of Piprингos's area (west edge of Tps. 24, 25, and 26 N., R. 97 W.) the Tipton Tongue maintains essentially the same characteristics as described above, though algal deposits, ostracode marl, oolite, and marlstone beds become somewhat more prevalent and the unit thins gradually.

North of the Rock Springs uplift, the Tipton is characterized by numerous beds of algal deposits, oolite, and ostracode marl. Some of the ostracode marl contains so little else besides ostracode shells that it is a coquina. These distinctive types of rock are interbedded with flaky low-grade oil shale, platy marlstone, gray mudstone, and persistent beds of gray to brown sandstone. The sandstone occurs locally as thick crossbedded lenses. Fishbone fragments are rather common in the Tipton of that locality, as are also gastropod and pelecypod shells. In this part of the area the Tipton ranges in thickness from 179 feet in T. 24 N., R. 100 W., to 87 feet in T. 24 N., R. 103 W. The various facies changes in the Tipton of this part of the area have been discussed in an earlier report (Bradley, 1926), which also contains six detailed sections of the Tipton.

The Tipton Tongue becomes the Tipton Shale Member of the Green River Formation near the north end of the Rock Springs uplift by the southward transition of the Cathedral Bluffs Tongue of the Wasatch Formation into the Wilkins Peak Member of the Green River Formation. The Tipton Shale Member crops out for more than 65 miles along the east side of the Green River Basin from T. 24, R. 104 W., to Little Mountain in T. 13 N., R. 106 W. Buff papery low-grade oil shale characterizes most of the member in this part of the area, but the lithology changes gradually from place to place and evidently reflects differences in environment determined by the topography and drainage of the low hills of the Rock Springs uplift a few miles to the east and by streams coming into the area from the northwest. In general, the deepest part of the lake persisted in that part of the basin west or southwest of Rock Springs. There the beds of the Tipton are all fine grained, and most are brown flaky shale, ostracode shale, and low-grade oil shale. Well-preserved fossil fish are fairly common in the lower part of the member, and beds of moderately rich oil shale make up a considerable thickness in the upper part. No mud cracks were observed. North and south of this locality, mud cracks and layers of ripple-bedded sandstone become increasingly plentiful; fewer of the beds are papery and they contain less organic matter. Indeed, subsurface information indicates that in a large area northwest of the town of Green River, the Tipton and its equivalent beds consist largely of a near-shore sandy facies similar to the Tipton north of the Rock Springs uplift.

Detailed stratigraphic sections of the Tipton Shale Member along the eastern margin of the Green River Basin are given later in the report under the heading, "Measured sections."

Thin regular and persistent layers of volcanic ash are fairly common in the Tipton Shale Member and in the Tipton Tongue. These range in thickness from about half an inch to about 8 inches. They range in color from light gray to brown, but most of them are buff.

A curious feature of many of these tuffs is that they have admixed with the ash such large quantities of microgranular carbonates predominantly dolomite.

From the analyses (given in table 2) of two of these carbonate-rich tuffs, the following percentages of carbonate minerals were calculated:

Minerals	Samples 1 (percent)	Samples 2 (percent)
Dolomite	66.50	72.76
Calcite	13.06	10.19
Siderite	3.11	------
Total carbonates	82.67	82.95

1. Same field No. 11-58; laboratory No. F-2399.
2. Sample field No. 12-58; laboratory No. F-2400.

According to an X-ray diffraction analysis kindly made for me by Brian Skinner of the U.S. Geological Survey, the carbonates dolomite and calcite in sample 11–58 are essentially pure species. He stated in his report that "The dolomite gives a strong X-ray pattern, and the spacing of the (112) plane is 2.892A. The best measurement for stoichiometric dolomite is 2.890A." He commented that, on the basis of one analysis, one cannot be certain that the small difference (+0.002A) is real. If real, it would correspond to approximately 1 percent mole excess $CaCO_3$ in the dolomite. "The calcite appears to be almost pure $CaCO_3$."

Inasmuch as the ferrous iron in this sample essentially balances the available CO_2 after combining all the CaO and MgO with CO_2 to form dolomite and calcite it seems reasonable to calculate the remaining CO_2 as ferrous carbonate. The small quantity of ferrous carbonate which I calculated for sample 11–58 is probably siderite. In sample 12–58 the amounts of CaO, MgO, and CO_2 are in the proper stoichiometric proportions to account for dolomite and calcite only. The amount of ferrous iron in this rock (0.09 percent) is negligible.

The carbonate grains in all these carbonate-rich tuffs appear to have accumulated rapidly. They are minute and are conspicuously lighter colored than those in the underlying and overlying rocks, which shows that they contain much less organic matter, clay, and clastic particles (presumably wind-blown dust). These carbonate-rich tuff layers (11–58 and 12–58) contain, respectively, 0.25 and 0.44 percent organic matter, whereas most of the shale and marlstone above and below contain about 6–36 times as much organic matter. Had the carbonate-rich tuff layers accumulated as slowly as the adjacent beds, they would have had comparably dark colors owing to the gradual accumulation of the same accessory constituents as are in the adjacent beds. Moreover, had the carbonate-rich tuff layers accumulated slowly, the volcanic-ash particles would have been concentrated at the bottom of the layers, but they are not; they are uniformly dispersed through the carbonate particles. These two considerations suggest that the carbonate particles precipitated out of the lake water and accumulated simultaneously with the accumulation of the ash particles on the lake bottom. In other words, there seems to have been a dependent relationship between the newly fallen volcanic ash and the precipitation of these dolomite and calcite particles. Moreover, the bottom and top surfaces of these beds are very sharply defined, which suggests also that rapid deposition of the carbonate particles began and ended abruptly, as though the rapidity of their deposition had been determined by the accumulating volcanic ash.

Throughout its extent, the base of the Tipton Shale Member is sharply defined. The basal bed, or beds, range from about 1 to about 7 feet in thickness and range from limy sandstone to oolitic limestone and, except in a very few places where the basal bed is very thin or absent (for example, see p. A65), contain a great abundance of the snail shells *Goniobasis* sp. and *Viviparus* sp. and the fresh-water clam *Unio* sp. Generally, also, the basal limestone contains numerous ostrocodes. The top of the Tipton is clearly defined for a considerable distance north and south of the main line of the Union Pacific Railroad by the overlying limy brown or buff platy sandstone and dolomitic marlstone beds in the basal part of the Wilkins Peak Member. (See fig. 9.) As the Tipton is traced northward toward the Wind River Range or southward toward the Uinta

TABLE 2.—*Chemical analyses of carbonate-rich tuffs from the Tipton Shale Member of the Green River Formation*

[Samples from sec. 31, T. 19 N., R. 105 W., Sweetwater County, Wyo. Analyst: V. C. Smith]

Constituent	1	2
SiO_2	9.92	10.42
Al_2O_3	2.18	1.03
Fe_2O_3	1.29	2.04
FeO	2.63	.09
MgO	14.54	15.91
CaO	27.54	27.83
Na_2O	.29	.22
K_2O	.47	.17
H_2O+	1.19	1.61
H_2O-	.47	.52
TiO_2	.08	.02
P_2O_5	.14	.13
MnO	.10	.07
CO_2	38.77	39.32
Organic matter [1]	.25	.44
Total	99.86	99.82
Powder density	2.83	2.78

[1] Determined by J. J. Fahey.
1. Sample field No. 11-58; laboratory No. F-2399. From bed 78 ft above base of member.
2. Sample field No. 12-58; laboratory No. F-2400. From bed 5 ft higher in member than bed of sample No. 11-58.

FIGURE 9.—Typical exposure of the Tipton Shale Member (Tgt) of the Green River Formation in the NE¼ sec. 23, T. 18 N., R. 106 W., Sweetwater County, Wyo. The base of the Tipton is marked by a thin hard bed that makes a barely discernible line in the bare slope about 25 feet below the sharp break in the shrubby vegetation. At the top of the Tipton is a rather thick ledge of oil shale, which is here capped by a few thin sandy beds. These sandy beds are the basal beds of the overlying Wilkins Peak Member (Twp). The bare slope below the Tipton is made by the uppermost part of the Wasatch Formation (Tw).

Range, its upper boundary becomes less clearly defined, particularly in the southern part of the area. Where most clearly defined, the Tipton Shale Member is about 150 feet thick; but as it approaches the shore facies near the Uinta Mountains, it gradually thickens.

FONTENELLE TONGUE

A basal tongue of the Green River Formation that is the western homolog, and probably the time equivalent, of the Tipton Shale Member and Tongue crops out for a little more than 100 miles along the west side of the Green River Basin. (See pl. 1.) Donavan (1950, p. 63–64) mapped this tongue for about 40 miles along the Green River (T. 30 N., R. 110 W., south to T. 24 N., R. 114 W.) and named it the Fontenelle Tongue of the Green River Formation. He gave as the type locality sec. 13, T. 24 N., R. 115 W., about half a mile south of Fontenelle Creek. The Fontenelle Tongue, the Tipton Shale Member, and the Tipton Tongue represent the first great expansion of Gosiute Lake—a stage exceeded in lateral extent only once, and much later, by the Laney stage, during which the Laney Shale Member was deposited.

Along Muddy Creek (T. 17 N., R. 116 W.) the Fontenelle Tongue is about 250 feet thick and consists predominantly of light-gray rather soft flaky marly shale. This lithology contrasts sharply with the red mudstone of the underlying Wasatch and with the green sandstone and mudstone of the overlying New Fork Tongue of the Wasatch Formation. About 11 miles north of Muddy Creek the Fontenelle Tongue is approximately 150 feet thick. At its base is a group of irregularly bedded hard sandy limestone or marlstone beds that contain an abundance of the snail shells *Goniobasis* and *Viviparus*. This basal unit, which resembles the basal unit of the Tipton Shale Member of the Green River on the east side of the Green River Basin, differs in sandiness from place to place along the strike and ranges in thickness from 3 to more than 30 feet. Above these sandy marlstone beds is soft flaky gray shale that is interbedded with thin but somewhat harder marlstone beds. A little of the shale is carbonaceous and papery, but most of it is poor in organic matter of any kind. Near the top of the tongue the shale grades gradually upward into sandstone, which in turn grades upward into red sandy mudstone that forms the basal part of the New Fork Tongue of the Wasatch.

Southward from Muddy Creek, however, the Fontenelle Tongue thins by progressive transition of its uppermost beds into lithology characteristic of the New Fork Tongue of the Wasatch. About 10 miles farther south, in the northern part of T. 15 N., R. 117 W., only the basal beds of the Fontenelle Tongue persist. The unit there is 5–10 feet thick and consists of marly shale, sandy marlstone, and bedded algal deposits. This thin remnant of the tongue was traced about 12 miles farther south, but it thins still more and loses its identity 5 or 6 miles southwest of Piedmont in the southern part of T. 14 N., R. 118 W.

North of Hams Fork, between Kemmerer and Opal, the Fontenelle Tongue thins gradually and becomes more sandy. In the vicinity of La Barge Creek and for several miles northward along the Green River it is about 50 feet thick, according to Steven S. Oriel (1961, p. B151). It thins rather rapidly near its northern extremity and loses its identity in the northwestern part of T. 29 N., R. 110 W., about 6 miles southeast of the town of Big Piney.

A partial section of the Fontenelle Tongue of the Green River Formation measured on Fontenelle Creek approximately 2 miles west of the junction of Fontenelle Creek and the Green River is as follows:

Top.	Ft	in
Sandstone, very fine grained, marly, buff to gray. Groups of finely laminated and banded beds alternate with beds that are massive and less limy. Top 3 ft of unit contains a few thin crossbedded layers of coarse gray sand, and uppermost layer contains abundance of mud lumps	33	0
Marlstone, silty, platy; in part coarsely varved and in part crossbedded	1	10
Sandstone, marly, light-gray; in slightly irregular beds; contains many mud lumps and a few thin lenses of crossbedded gray sandstone	9	6
Sandstone, lenticular, medium-grained, gray, crossbedded	1	0
Marlstone, buff or brownish-gray; papery at base but progressively harder, more platy, and sandy toward top	6	6
Marlstone, carbonaceous and papery at base but grades upward into sandy platy marlstone	0	4
Sandstone, soft, muddy, gray, crossbedded; base not exposed	33	0
Partial thickness, Fontenelle Tongue	85	2

WILKINS PEAK MEMBER

The Wilkins Peak Member of the Green River Formation is restricted to the Green River Basin and is the most conspicuous member in that part of Wyoming. Schultz (1920) correlated it with his Laney Shale Member, whose type locality is in the Laney Rim along the northern edge of the Washakie Basin. (See pl. 1.) All other geologists to 1959 have followed his usage. One of my reasons for giving this unit a new member name (Bradley, 1959) stems from the realization that the beds making up the bulk of the member were deposited in a lake that represented rather low stages of Gosiute Lake. Indeed, probably for a significant part of that stage the lake had only about one-third the area of its maximum extent and was essentially restricted to the Green River Basin. (See fig. 10.)

The shrinkage to this low stage gave rise to the great abundance of saline minerals that are so characteristic of this unit. Its content of saline minerals and great abundance of dolomite make it conspicuously unlike the Laney Shale Member of the Washakie Basin, unlike any other member of the Washakie Basin, and unlike any other member or tongue of the Green River Formation. My other reason for giving it a new member name is that my own studies and mapping in 1923 showed plainly that this unit was the stratigraphic and time equivalent of the Cathedral Bluffs Tongue of the Wasatch Formation (Bradley, 1926, pl. 59), which, of course, underlies the Laney Shale Member at its type locality.

At the time I defined the Wilkins Peak Member (1959, p. 1072–1075), I believed it was restricted to the Green River Basin. But in 1962 (written communication) H. W. Roehler, of the Mountain Fuel Supply Co., sent me a copy of his geologic map, which showed that the Wilkins Peak Member crops out along the north and east flanks of Pine Mountain and that in the vicinity of Canyon Creek (southern part of T. 12 N., R. 102 W., Sweetwater County, Wyo.) it grades abruptly into a sandy, crossbedded conglomerate. This conglomerate was formed by a river that must have drained a considerable part of the east end of the Uinta Range. Roehler also showed that typical Wilkins Peak is exposed along the Kinney and Laney Rims of the Washakie Basin at least as far east as sec. 14, T. 19 N., R. 95 W. (about 3 miles south of Frewen Station on the Union Pacific Railroad).

In August 1963 I had the opportunity to review much of Roehler's mapping with him in the field. During those 3 or 4 days I ate more crow than has been my lot for many years.

In both of these large areas outside of the Green River Basin, Schultz (1920, pl. 1) had included the Wilkins Peak beds with his Tipton. Unfortunately, I made the error of accepting Schultz's mapping of the Tipton–Cathedral Bluffs boundary.

As mentioned earlier, under the heading, "Tipton Tongue and Tipton Shale Member," I mentioned the fact that Pipiringos (1962, pl. 1) had mapped the lowest extensive algal-ball zone, which he quite properly used to define the base of the upper part of the Tipton Tongue. Inasmuch as Roehler's mapping now shows that the "upper part of the Tipton," as thus defined, is in fact a northeastward extension of the Wilkins Peak Member, we can use Pipiringos map (pl. 1) to see how extensive outcrops of the Wilkins Peak Member are in the central and northern parts of the Great Divide Basin.

The Wilkins Peak Member is named from almost perfect exposures of the whole unit in the north, east, and south slopes of Wilkins Peak, which is a conspicuous peak just south of Bitter Creek, on the main line of the Union Pacific Railroad, and U.S. highway 30 about 6

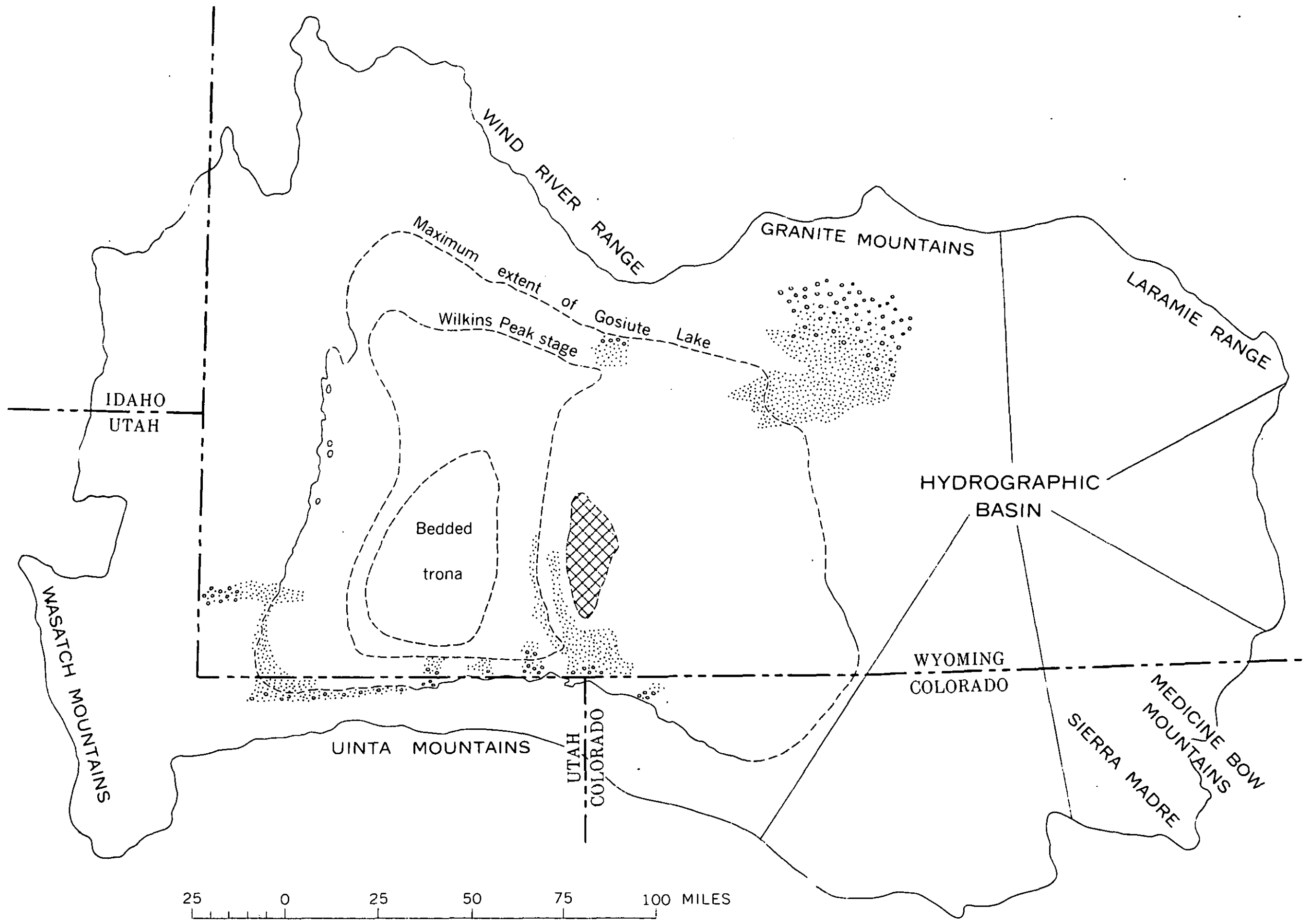

FIGURE 10.—Inferred boundary of Gosiute Lake's hydrographic basin, outline of the maximum extent of Gosiute Lake during the Laney stage, and, within that, the average extent of the lake during much of the Wilkins Peak stage. Also shown are the area below which bedded trona is known or inferred and the area (cross hatched) of the island in Gosiute Lake formed by Upper Cretaceous rocks of the ancestral Rock Springs uplift. The loci of large streams that existed during part of the time while the Wasatch and Green River Formations were accumulating are shown by the conglomerate- and sand-patterned areas.

miles southeast of the town of Green River in the southern part of T. 18 N., R. 106 W., Sweetwater County. At its type locality the member is about 900 feet thick. Culbertson (1961) discussed a number of key beds, tuffs, and sandy units in the Wilkins Peak Member and gave six columnar sections of the member.

The Wilkins Peak Member makes up much of the bare white cliffs and slopes in the vicinity of the town of Green River and along the east face of White Mountain, which marks the east rim of the Green River Basin for many miles north of the Union Pacific Railroad. (See fig. 11 and geologic map, pl. 1.) The picturesque cliffs in the canyon of Green River south of the town of Green River are made up largely of the white and greenish-gray beds of the Wilkins Peak Member, though the overlying sandstone lenses add much to the scenic splendor of that canyon.

The base of the Wilkins Peak Member is marked by a group of sandy, dolomitic, crudely bedded layers of marlstone. These marlstone beds form a bench that caps the cliff of oil shale in the uppermost part of the Tipton Shale Member. The top of the Wilkins Peak Member was taken as the change from light-gray or white dolomitic marlstone and chippy shale to chalky buff laminated and varved marlstone, because this latter represents a marked deepening and expansion of the lake. In most places this change is rather subtle.

This upper boundary is well exposed in the gulches on the north side of U.S. Highway 30 a few miles west of the town of Green River. At the mouth of the westernmost of these gulches (sec. 9, T. 18 N., R. 107 W.) the boundary is readily accessible. (See fig. 12.) There the upper part of the Wilkins Peak Member consists of more than 25 feet of gray organic marly shale that contains beds and many thin lenses of rich oil shale overlain by about 10 feet of low-grade papery oil shale and soft flaky organic marlstone. This upper unit contains several zones or layers of large calcite molds of radial aggregates of salt crystals. These

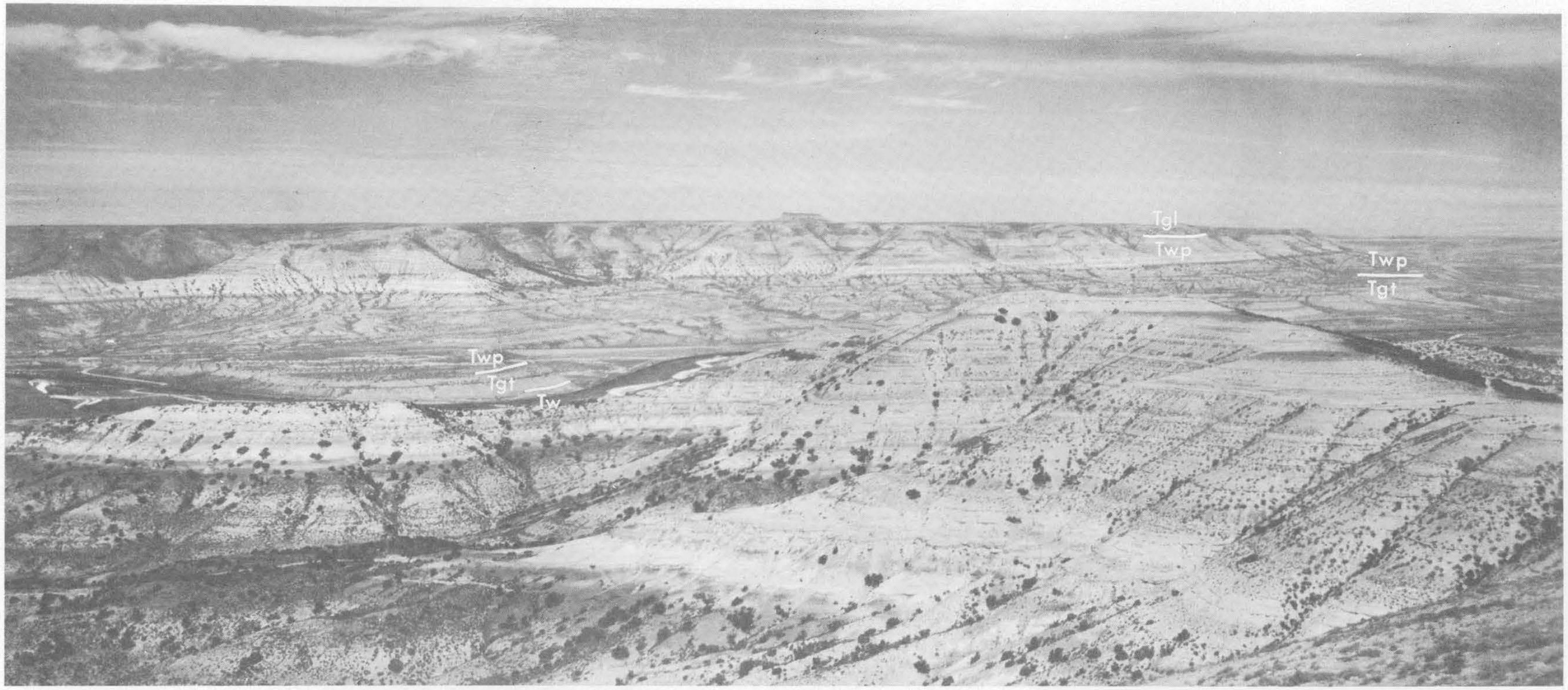

FIGURE 11.—View northward across the valley of Bitter Creek from the northwest flank of Wilkins Peak (NW¼ sec. 34, T. 18 N., R. 106 W., Sweetwater County, Wyo.) showing White Mountain in the distance and Pilot Butte on the skyline in the center. Pilot Butte is capped with wyomingite lava. In White Mountain, particularly near the right-hand margin of the photograph, the upper white and the lower dark halves of the Wilkins Peak Member of the Green River Formation show well. The Tipton Shale Member makes a light band under the Wilkins Peak Member near the upper right edge of photograph. The Laney Shale Member, showing as a dark zone overlying the Wilkins Peak Member, is truncated by an erosion surface. In the foreground are beds of the upper white half of the Wilkins Peak Member. A thick dark-olive-brown zone, which marks the top of the lower half of the Wilkins Peak Member, is conspicuous in the lower left foreground. Tw, Wasatch Formation; Tgt, Tipton Shale Member; Twp, Wilkins Peak Member; Tgl, Laney Shale Member.

FIGURE 12.—Uppermost part of the Wilkins Peak Member and basal part of the Laney Shale Member of the Green River Formation in the SW¼NW¼ sec. 9, T. 18 N., R. 107 W., Sweetwater County, Wyo. The man in the center is standing on the thin tuff bed that marks the base of the Laney. The contact selected by W. C. Culberston, of the Survey, is the lowest white band in the lower right-hand corner of the photograph. The smooth slope immediately below the tuff contains ellipsoidal molds of radial aggregates of salt crystals thought to have been nahcolite. Below the nahcolite(?) zone (about 6 ft thick) are oil shale beds that contain shortite-crystal molds. The oil-shale and organic-marlstone beds behind and above the man contain no salt-crystal molds. A channel lens of tuffaceous sandstone makes the broken cliff at the top.

strongly suggest molds of nahcolite crystals like those so common in the Green River Formation in the Uinta Basin. The beds below are characterized by an abundance of the molds of shortite. Above the zone containing the nahcolite(?) molds is a tuff bed about 8 inches thick. Resting on the tuff are the thin beds of buff laminated and varved organic marlstone that characterize the basal part of the Laney Shale Member throughout much of its great lateral extent. These buff marlstone beds contain no saline minerals. The contrast between the gray beds of the Wilkins Peak Member and the buff of the overlying Laney Shale Member is more striking from a distance than it is close to the outcrop.

W. C. Culbertson (written communication, 1962) informed me that the contact between these two members, which he mapped in detail over an extensive area south of Wilkins Peak, is about 26 feet below the one I show in figure 12. I have no quarrel with his boundary, which is more readily mappable than mine; but to be consistent with my own concept that the saline minerals are characteristic of the Wilkins Peak stage of Gosiute Lake, I prefer to place the contact above the highest salt-crystal molds.

The Wilkins Peak Member has not surely been identified on the west side of the Green River Basin, though Donovan (1950, p. 64–65) recognized a unit having a maximum thickness of 121 feet in sec. 29, T. 25 N., R. 112 W. that has "Laney lithology." He mapped this unit and called it the Laney Shale Member of the Green River Formation. He noted that south of Fontenelle Creek this unit lost its "Laney" characteristics and could not be mapped. One other, and more compelling, reason for believing that the featheredge of the Wilkins Peak Member crops out along the west side of the Green River Basin is the fact that, locally, a very few marlstone beds contain casts or molds of salt crystals. Significantly, one of these layers is close to the base of the Laney (secs. 5 and 7, T. 22 N., R. 114 W.) where one would expect the westernmost edge of the Wilkins Peak Member to crop out. The salt that gave rise to these salt-crystal casts has not been identified. (See fig. 13.)

J. D. Love, of the Survey, added (written communication, 1962) "* * * that a gastropod-bearing limy sandstone here (sec. 5) contains 0.007 percent U and 0.69 percent P_2O_5, which is par for one of the poorer uraniferous phosphate zones in the Wilkins Peak."

Along the face of White Mountain the Wilkins Peak Member is made up of two units that differ conspicuously in color. The lower part, 430–450 feet thick, is drab to light greenish gray and contains several distinctive olive-green to brown bands of muddy sandstone that can be traced for miles. The upper unit, about 400–500 feet thick, weathers almost chalky white, from which White Mountain gets its name. Why these two units should weather so differently is not clear. Both consist largely of more or less tuffaceous dolomitic mudstone that, on fresh fracture, ranges in color from neutral gray to dark greenish gray. Both units contain thin beds of volcanic ash and beds or groups of beds of marlstone that weather light gray to white, but these do not help to differentiate one unit from the other. Moreover, chemical analyses show that the content of calcium and magnesium carbonates is roughly the same throughout the whole member.

D. L. Deardorff, of the Diamond Alkali Co. (unpub. data), working with many cores from exploratory bore holes and from surface sections, divided the Wilkins Peak Member into upper, middle, and lower units, which are roughly of about the same thickness, though they differ in thickness, lithology, color, and lateral extent.

According to him, the lowest unit is composed of alternate beds of green shaly mudstone and greenish-gray dolomitic mudstone. It contains at least 17 major extensive trona beds that range in thickness from a few inches to about 38 feet. Locally, the successive trona beds have an aggregate thickness of about 150 feet. Halite occurs in some of these trona beds, but its distribution and amount differ from bed to bed and from place to place within individual beds. The halite occurs in the trona as disseminated crystals or as aggregates of crystals and even as lenses or layers. In the southern part of the Green River Basin, halite predominates over trona in most of the evaporite beds. Locally, also, wegscheiderite (Fahey and Yorks, 1963) occurs within the trona. Shortite is abundant through all this unit except for about 15 feet at the base.

Deardorff's middle unit is much more extensive areally than either the underlying or overlying unit. This unit also consists of massive to shaly gray to greenish-gray mudstone that ranges from very fine grained and dolomitic to muddy sandstone, and it contains many of the olive-green muddy crossbedded sandstone zones that are conspicuous on the outcrop. These muddy sandstone zones range in thickness from a few feet to 50 feet and have false bedding that dips generally westward at angles ranging from 10° to 18°. Characteristically, these false beds are laminated, and many are current ripple marked and rill marked. Some of the sandy mud slumped under water, so the false beds are considerably contorted. Locally these muddy sandstone units fill shallow channels scoured out of the underlying beds, and filled channels are numerous within the sandy beds. The thickest of these beds, which is roughly 400 feet about the base of the Wilkins Peak Member, ranges in thickness from 30 to a little more than 50 feet. Below this zone, about 62 feet and 152 feet, respectively, are two more similar but somewhat thinner muddy sandstone zones. The outcrops of all three of these are shown on R. J. Hackman's detailed map of the area around Wilkins Peak and the town of Green River (pl. 2). On this map these zones are lettered *A*, *B*, and *D* in ascending order to correlate with three of the nine grayish-olive-green sandy zones which William C. Culbertson (1961), of the U.S. Geological Survey, mapped in the area south of that mapped by Hackman. Culbertson lettered his zones from A to I, in ascending order. According to Culbertson, these zones can be traced as far south as Sage Creek, and they probably could be traced 12–15 miles still farther south. They thicken somewhat southward. It seems clear that most of the material in

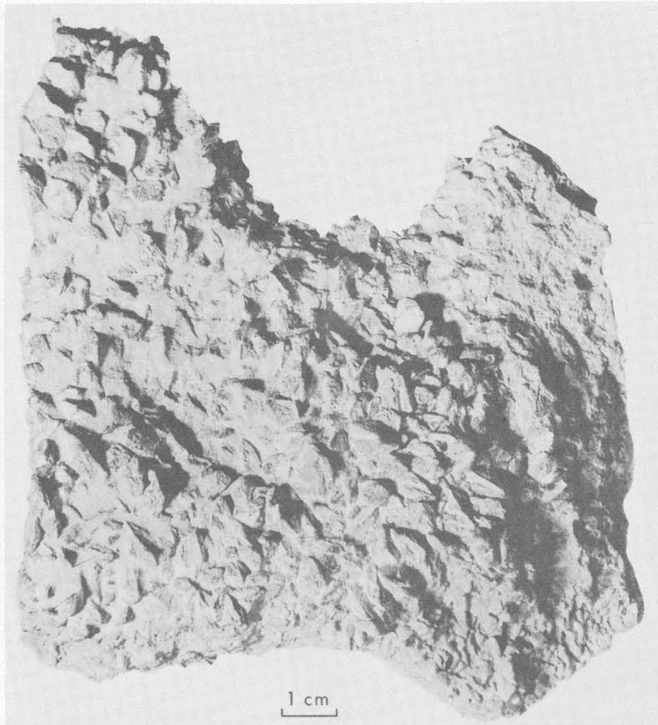

FIGURE 13.—Crystal molds of an unknown salt on the bedding plane of a sandy marlstone from the thin western edge of the Wilkins Peak Member of the Green River Formation in sec. 7, T. 22 N., R. 114 W., Lincoln County, Wyo.

them was derived from the ancestral Rock Springs uplift.

According to Deardorff, his middle unit of the Wilkins Peak Member contains beds of trona, but they are thinner and less continuous than those in the unit below. Few of these are as much as 5 feet thick. Shortite is abundant throughout this unit.

Westward and southward from the central part of the basin, this middle unit becomes sandy and carbonaceous, taking an aspect more like parts of the Fontenelle Tongue still farther west and parts of the marginal facies of the Laney Shale Member. These are evidently shallow-water and marshy facies of the Wilkins Peak Member. According to Deardorff, some of the beds of his middle unit crop out along the Green River in the vicinity of La Barge and Big Piney.

Deardorff's uppermost unit is the least extensive of the three and is restricted to a rather narrow belt along the eastern margin of the Green River Basin. Evidently that area warped downward into a troughlike depression during that last stage of Gosiute Lake. Drill holes show that all along this narrow belt the rocks of this unit grade westward into carbonaceous muddy sandstone. Like the lower two units, the upper unit consists of alternate beds of massive to shaly greenish-gray mudstone and greenish-gray to light-gray dolomitic mudstone and marlstone. Thin beds of volcanic ash are fairly common, and many of the mudstone layers are tuffaceous. Shortite is abundant. Trona beds are numerous but do not have great areal extent; they range in thickness from a few inches to about 15 feet. The Stauffer Chemical Co. recently opened a mine (sec. 15, T. 20 N., R. 109 W.) on two of these trona beds, known locally as the Upper Big Island and the Lower Big Island beds.

Deardorff's study of the Wilkins Peak Member and its trona beds is valuable for another concept. He showed that trona deposition began early in the Wilkins Peak stage in a restricted depression (roughly 287 sq mi) in the southern part of the Green River Basin and then gradually extended northward, the areal extent of trona deposition reached a maximum while the bed now being mined by the Intermountain Chemical Co. was being laid down. That bed has an estimated area of about 725 square miles. Over that extent it ranges from 2 to nearly 20 feet in thickness. The uppermost trona beds formed only in the east-central part of the Green River Basin.

Still another useful concept of the Wilkins Peak Member emerges if one thinks of the unit as a great lens of sediment laid down in a closed lake which, like all closed lakes, fluctuated greatly in area and volume during its long history. We know from the fabulous quantities of bedded trona and halite that as this lake repeatedly shrank to relatively small size, its waters became so concentrated that trona, and locally halite, precipitated out. Then it must have expanded repeatedly to considerably greater size, as is shown by the lateral extent of the beds making up this member. We find, then, as would be expected, that this great lens of lacustrine sediment has within it another comparable, but smaller, lens of saline sediment—that is, not only trona beds, but also beds of dolomitic mudstone that contain shortite [$Na_2CO_3 \cdot 2CaCO_3$], northupite [$Na_2CO_3 \cdot MgCO_3 \cdot NaCl$], halite [$NaCl$], and much smaller amounts of pirssonite [$Na_2CO_3 \cdot CaCO_3 \cdot 3H_2O$], gaylussite [$Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O$], thermonatrite [$Na_2CO_3 \cdot H_2O$], tychite [$2Na_2CO_3 \cdot 2MgCO_3 \cdot Na_2SO_4$], nahcolite [$NaHCO_3$], wegscheiderite [$Na_2CO_3 \cdot 3NaHCO_3$], and searlesite [$NaBSi_2O_6 \cdot H_2O$]. This internal lens is the saline facies of the Wilkins Peak Member.

That part of the member that encloses the saline facies can be thought of as a fresher water facies, which of course has a much greater lateral extent. It also has a greater vertical range because nonsaline beds both underlie and overlie the beds of the saline facies. One marginal part of the fresher water facies can easily be examined a little way east of Green River, Wyo. Just west of the town the Wilkins Peak Member has enormous numbers of shortite-crystal molds. These become less numerous eastward and are absent updip a few miles east of the town. This same marginal facies then extends far north along White Mountain, though here and there the outcrop cuts back into the eastern edge of the saline facies. Southward the outcrop of the Wilkins Peak Member is broader and much more dissected by canyons, so that both saline and marginal facies can be found there depending on the way the outcrop surface transects the beds.

At various levels up through this marginal facies of the Wilkins Peak Member more and less limy beds alternate with one another rhythmically. The beds in these sequences range in thickness from a few inches to several feet, but in any given sequence the pairs of beds are of roughly the same thickness. One of these sequences will illustrate the phenomenon.

Rhythmic sequence of beds from a zone 85 feet above the base of the Wilkins Peak Member in sec. 33, T. 21 N., R. 105 W.

	Ft	in
Marlstone, light-grayish-brown, platy; weathers nearly white; bedding planes mud cracked	1	0
Mudstone, greenish-drab, rather hard	3	6
Mudstone, light-greenish-gray, limy	1	0
Mudstone, greenish-drab, soft	3	6
Marlstone, light-grayish-brown, sandy; contains mud lumps	1	0
Mudstone, greenish-drab, soft	3	0

	Ft	*in*
Marlstone, light-grayish-brown; weathers nearly white		10
Mudstone, greenish-drab, soft	3	0
Marlstone, light-grayish-brown; weathers nearly white	1	0

The more limy mudcracked layers are interpreted as having formed during falling and low stages of the lake, whereas the greenish mudstone layers are interpreted as having formed during rising and higher stages. In other comparable rhythmic sequences the more limy beds contain salt-crystal molds whereas the intervening beds do not.

The saline facies of the Wilkins Peak Member can be defined as those beds lying between the stratigraphically lowest and highest occurrences of shortite crystals or their molds. Most of the beds within this bracket contain some saline minerals. The saline minerals range in abundance from sparsely scattered crystals to solid beds as much as 38 feet thick.

Although the saline facies has not been mapped, its thickness is known from numerous exploratory bore holes. (See pl. 1 and table 3.) The saline facies varies in thickness with the thickness of the Wilkins Peak Member. The saline facies, nevertheless, dies out somewhat more rapidly toward the basin margins and is considerably less extensive areally than is the Wilkins Peak.

TABLE 3.—*Boreholes in the Green River Basin drilled to explore for trona or for oil or gas*

[Holes much beyond the known or inferred possible outer limits of bedded trona are not listed]

Number on pl. 1	Company or owner and well identification	Location
1	Pan American Oil Co. Henrys Fork	sec. 10, T. 12 N., R. 110 W.
2	Northern Natural Gas Co. Great Grizzly	sec. 10, T. 13 N., R. 112 W.
3	California Co. Spring Branch	sec. 26, T. 13 N., R. 111 W.
4	----do---- Franklin Wash	sec. 33, T. 13 N., R. 109 W.
5	Barr Smedley 1	sec. 15, T. 13 N., R. 108 W.
6	Falcon Oil Co. Government	sec. 10, T. 13 N., R. 108 W.
7	William Gruenerwald Currant Creek 4	sec. 1, T. 13 N., R. 107 W.
8	Phillips Petroleum Co. Federal-Hobson	sec. 27, T. 13 N., R. 106 W.
9	Caulkins Oil Co. 2 (4-9V)	sec. 9, T. 14 N., R. 106 W.
10	California Co. Dry Creek	sec. 6, T. 14 N., R. 110 W.
11	Pure Oil Co. Butcher Knife Springs 1	sec. 21, T. 14 N., R. 113 W.
12	Mountain Fuel Supply Co. Grizzly Buttes 1.	sec. 35, T. 15 N., R. 113 W.
13	Sohio-UPRR-Uinta Development Co. UPRR 1.	sec. 13, T. 15 N., R. 113 W.
14	Park City Oil and Gas Co. 1	sec. 6, T. 15 N., R. 113 W.
15	Max Pray Government-Akridge 1	sec. 19, T. 15 N., R. 112 W.
16	Phillips Petroleum Co. Cedar Mtn. 1	sec. 28, T. 15 N., R. 111 W.
17	Marta F. Stroeck 1	sec. 14, T. 15 N., R. 111 W.
18	Perkins 2	sec. 32, T. 15 N., R. 109 W.
19	El Paso Natural Gas Co. (water well)	sec. 10, T. 15 N., R. 109 W.
20	Sinclair Oil Co. Federal 1	sec. 6, T. 15 N., R. 108 W.
21	Perkins 1	sec. 32, T. 15 N., R. 108 W.
22	Texota Oil Co. Post 1	sec. 18, T. 15 N., R. 107 W.
23	Diamond Alkali Co. Reid 1	sec. 24, T. 16 N., R. 109 W.
24	----do---- Reid 3	sec. 2, T. 16 N., R. 109 W.
25	----do---- Cockerell 2	sec. 10, T. 16 N., R. 109 W.
26	----do---- Grierson 1	sec. 4, T. 16 N., R. 109 W.
27	----do---- Cockerell 1	sec. 18, T. 16 N., R. 109 W.
28	----do---- Finley 2	sec. 26, T. 16 N., R. 110 W.
29	----do---- Grierson 2	sec. 2, T. 16 N., R. 110 W.
30	----do---- Finley 3	sec. 22, T. 16 N., R. 110 W.
31	----do---- Finley 1	sec. 8, T. 16 N., R. 110 W.
32	Mountain Fuel Supply Co. Church Buttes 5.	sec. 4, T. 16 N., R. 112 W.
33	Mountain Fuel Supply Co. Church Buttes 14.	NW¼ sec. 16, T. 16 N., R. 112 W.
34	Mountain Fuel Supply Co. Church Buttes 13.	SE¼ sec. 16, T. 16 N., R. 112 W.
35	Mountain Fuel Supply Co. Church Buttes 8.	sec. 28, T. 16 N., R. 112 W.
36	Mountain Fuel Supply Co. Church Buttes 4.	sec. 29, T. 16 N., R. 112 W.
37	Mountain Fuel Supply Co. Church Buttes 9.	sec. 20, T 16 N., R. 112 W.
38	Mountain Fuel Supply Co. Church Buttes 12.	sec. 19, T 16 N., R. 112 W.
39	Mountain Fuel Supply Co. Church Buttes 7.	sec. 17, T. 16 N., R. 112 W.
40	Mountain Fuel Supply Co. Church Buttes 1.	sec. 8, T. 16 N., R. 112 W.
41	Mountain Fuel Supply Co. Church Buttes 10.	sec. 5, T. 16 N., R. 112 W.
42	Mountain Fuel Supply Co. Church Butte 15.	sec 6, T. 16 N., R. 112 W.
43	Mountain Fuel Supply Co. Church Buttes 3.	sec 12, T. 16 N., R. 113 W.
44	Mountain Fuel Supply Co. Church Buttes 6.	sec. 13 T. 16 N., R. 113 W.
45	Mountain Fuel Supply Co. Church Buttes 11.	sec. 34, T. 17 N., R. 112 W.
46	Mountain Fuel Supply Co. Church Buttes 17.	SE¼ sec. 22, T. 17 N., R. 112 W.
47	Mountain Fuel Supply Co. Church Buttes 2.	NE¼ sec. 22, T. 17 N., R. 112 W.
48	Mountain Fuel Supply Co. Church Buttes 18.	SW¼ sec. 14, T. 17 N., R. 112 W.
49	Mountain Fuel Supply Co. Church Buttes 16.	NE¼ sec. 14, T. 17 N., R. 112 W.
50	Stauffer Chemical Co. SG 3	sec. 6, T. 17 N., R. 110 W.
51	Kern County Land Co. 2	sec. 4, T. 17 N., R. 110 W.
52	Union Pacific RR Co. 6A	sec. 15, T. 17 N., R. 110 W.
53	Diamond Alkali Co. Sturm 2	sec. 8, T. 17 N., R. 109 W.
54	----do---- Sturm 1	sec. 10, T. 17 N., R. 109 W.
55	----do---- 5	sec. 35, T. 17 N., R. 109 W.
56	Pan American Petroleum Co. Massacre Hills 1.	sec. 26, T. 17 N., R. 108 W.
57	Diamond Alkali Co. Reid 2	sec. 32, T. 17 N., R. 107 W.
58	Perkins 3	sec. 8, T. 17 N., R. 107 W.
59	Colorado Oil & Gas Rye Grass 1-26	sec. 26, T. 17 N., R. 107 W.
60	Diamond Alkali Co. McKenna 1	sec. 6, T. 18 N., R. 106 W.
61	Mountain Fuel Supply Co. Nightingale Sodium 1.	sec. 26, T. 18 N., R. 107 W.
62	Diamond Alkali Co. Butler 1	sec. 12, T. 18 N., R. 108 W.
63	----do---- 3	sec. 17, T. 18 N., R. 108 W.
64	Potash Company of America 2	sec. 12, T. 18 N., R. 109 W.
65	Allied Chemical Co. Buchanan 1	sec. 10, T. 18 N., R. 109 W.
66	----do---- Buchanan 2	sec. 4, T. 18 N., R. 109 W.
67	----do---- Spider Creek 1	sec. 19, T. 18 N., R. 109 W.
68	Potash Company of America 1	sec. 6, T. 18 N., R. 109 W.
69	J. R. Simplot Co. Ruby 1	SE¼ sec. 2, T. 18 N., R. 110 W.
70	Mountain Fuel Supply Co. John Hay Jr. 1.	NW¼ sec. 2, T. 18 N., R. 110 W.
71	Union Pacific RR Co. 1	sec. 3, T. 18 N., R. 110 W.
72	----do---- 6	sec. 15, T. 18 N., R. 110 W.
73	Humble Oil and Refining Co. Spider Creek Unit 1-B.	sec. 26, T. 18 N., R. 110 W.
74	Humble Oil and Refining Co. Spider Creek Unit 2-B.	sec. 27, T. 18 N., R. 110 W.
75	Kern County Land Co. 1	NW¼ sec. 28, T. 18 N., R. 110 W.
76	----do---- 3	SE¼ sec. 28, T. 18 N., R. 110 W.
77	----do---- 4	sec. 20, T. 18 N., R. 110 W.
78	----do---- 5	sec. 21, T. 18 N., R. 110 W.
79	Little America-Covey 1 Anderson (water well).	sec. 17, T. 18 N., R. 110 W.
80	J. R. Simplot Co. Ruby 2	sec. 4, T. 18 N., R. 110 W.
81	Union Pacific RR Co. 4	sec. 5, T. 18 N., R. 110 W.
82	Stauffer Chemical Co. SG 2	sec. 26, T. 18 N., R. 111 W.
83	----do---- SG 4	sec. 10, T. 18 N., R. 111 W.
84	Diamond Alkali Co. 1	sec. 12, T. 18 N., R. 112 W.
85	Union Oil Co. Moxa 1	sec. 30, T. 19 N., R. 112 W.
86	Texaco Inc. Moxa 1	sec. 22, T. 19 N., R. 112 W.
87	Stauffer Chemical Co. 1 SG	sec. 34, T. 19 N., R. 111 W.
88	Westvaco 4	sec. 27, T. 19 N., R. 110 W.
89	----do---- 1	sec. 26, T. 19 N., R. 110 W.
90	----do---- 8	sec. 29, T. 19 N., R. 110 W.
91	----do---- 2	SW¼ sec. 15, T. 19 N., R. 110 W.
92	Union Pacific RR Co. 2	SE¼ sec. 15, T. 19 N., R. 110 W.

TABLE 3.—*Boreholes in the Green River Basin drilled to explore for trona or for oil or gas*—Continued

Number on pl. 1	Company or owner and well identification	Location
93	Westvaco 3	center sec. 15, T. 19 N., R. 110 W.
94	Intermountain Chem. Corp. mine	SE¼ sec. 15, T. 19 N., R. 110 W.
95	Westvaco 5	sec. 11, T. 19 N., R. 110 W.
96	do 6	sec. 9, T. 19 N., R. 110 W.
97	do 9	sec. 7, T. 19 N., R. 110 W.
98	do 13	SW¼ sec. 1, T. 19 N., R. 110 W.
99	do 12	SE¼ sec. 1, T. 19 N., R. 110 W.
100	do 10	SW¼NW¼ sec. 1, T. 19 N., R. 110 W.
101	do 11	NE¼NW¼ sec. 1, T. 19 N., R. 110 W.
102	Stauffer Chemical Co. SBI-11	sec. 5, T. 19 N., R. 109 W.
103	Westvaco 7	sec. 19, T. 19 N., R. 109 W.
104	Allied Chemical 3 Buchanan	sec. 29, T. 19 N., R. 109 W.
105	Union Pacific RR Co. 3	sec. 31, T. 19 N., R. 109 W.
106	Diamond Alkali Co. 4	sec. 30, T. 19 N., R. 108 W.
107	do 2	sec. 34, T. 19 N., R. 108 W.
108	do Green 1	sec. 36, T. 19 N., R. 108 W.
109	do Mantz 1	sec. 14, T. 19 N., R. 108 W.
110	do Bennett 1	sec. 6, T. 19 N., R. 107 W.
111	P. T. Jenkins Grierson 1	sec. 4, T. 20 N., R. 107 W.
112	Diamond Alkali Co. Berger 1	sec. 28, T. 20 N., R. 108 W.
113	Stauffer Chemical Co. SBI 8	sec. 29, T. 20 N., R. 108 W.
114	do SBI 22	sec. 8, T. 20 N., R. 108 W.
115	do SBI 14	sec. 6, T. 20 N., R. 108 W.
116	do SBI 20	sec. 18, T. 20 N., R. 108 W.
117	do SBI 6	sec. 36, T. 20 N., R. 109 W.
118	do SBI 23	sec. 26, T. 20 N., R. 109 W.
119	do SBI 9	sec. 13, T. 20 N., R. 109 W.
120	do SBI 15	sec. 12, T. 20 N., R. 109 W.
121	do SBI 18	SW¼SE¼ sec. 14, T. 20 N., R. 109 W.
122	do SBI 16	NW¼SW¼ sec. 14, T. 20 N., R. 109 W.
123	do SBI 17	NW¼NE¼ sec. 14, T. 20 N., R. 109 W.
124	do SBI 10	sec. 11, T. 20 N., R. 109 W.
125	do SBI 26	sec. 10, T. 20 N., R. 109 W.
126	do SBI 25	NE¼NE¼ sec. 15, T. 20 N., R. 109 W.
127	do SBI 19	SE¼ sec. 15, T. 20 N., R. 109 W.
128	do mine shafts	NE¼ sec. 15, T. 20 N., R. 109 W.
129	do SBI 5	sec. 16, T. 20 N., R. 109 W.
130	do SBI 21	sec. 4, T. 20 N., R. 109 W.
131	do SBI 6	sec. 28, T. 20 N., R. 109 W.
132	do SBI 2	sec. 6, T. 20 N., R. 109 W.
133	do SBI 1	sec. 18, T. 20 N., R. 109 W.
134	do SBI 3	sec. 12, T. 20 N., R. 110 W.
135	do SBI 4	sec. 24, T. 20 N., R. 110 W.
136	Allied Chemical Co. Paddock 3	sec. 33, T. 20 N., R. 110 W.
137	do Paddock 1	sec. 20, T. 20 N., R. 110 W.
138	do Paddock 2	sec. 5, T. 20 N., R. 110 W.
139	do L. L. Frame 1	sec. 24, T. 20 N., R. 111 W.
140	Humble Oil and Refining Co. Blacks Draw 1-B.	sec. 24, T. 21 N., R. 110 W.
141	Union Pacific RR Co. 7	sec. 29, T. 21 N., R. 109 W.
142	Stauffer Chemical Co. SBI 13	sec. 32, T. 21 N., R. 108 W.
143	do SBI 24	sec. 28, T. 21 N., R. 108 W.
144	do SBI 12	sec. 22, T. 21 N., R. 108 W.
145	P. T. Jenkins Dymond 1	sec. 18, T. 21 N., R. 107 W.
146	do W. Reeves 1	sec. 28, T. 22 N., R. 106 W.
147	do V. Reeves 1	sec. 30, T. 22 N., R. 106 W.
148	Belco Petroleum Corp. Eden 2	sec. 17, T. 22 N., R. 106 W.
149	P. T. Jenkins Myer 1	sec. 12, T. 22 N., R. 107 W.
150	Union Pacific RR Co. 8	sec. 35, T. 22 N., R. 110 W.
151	Utah Construction and Mining Co. 1	sec. 36, T. 23 N., R. 110 W.
152	Belco Petroleum Corp. Sandy Bend 1	sec. 3, T. 23 N., R. 108 W.
153	El Paso Natural Gas Co. Simpson Gulch 1	sec. 4, T. 23 N., R. 107 W.
154	P. T. Jenkins Pittman 1	sec. 34, T. 23 N., R. 107 W.
155	P. T. Jenkins Pittman 2	sec. 34, T. 23 N., R. 107 W.
156	Wyoming Trona Corp. 5	sec. 13, T. 23 N., R. 107 W.
157	do 4	sec. 20, T. 23 N., R. 106 W.
158	do 2	sec. 6, T. 23 N., R. 106 W.
159	do 1	sec. 5, T. 23 N., R. 106 W.
160	do 3	sec. 8, T. 23 N., R. 106 W.
161	do 6	sec. 15, T. 23 N., R. 106 W.
162	P. T. Jenkins Jenkins 1	sec. 31, T. 24 N., R. 106 W.

Joseph J. Fahey, of the U.S. Geological Survey, made a very thorough study of the saline minerals in the saline facies of the John Hay Jr. 1 well (Fahey, 1962, p. 5–45). In that study Fahey estimated the abundances of several saline minerals, bed by bed, through the whole thickness of the saline zone, which is there 555 feet thick. He estimated that shortite makes up about 10 percent by volume of the whole thickness, and if that percentage holds laterally, then there is at least 125 million tons of shortite under each square mile of land in that area. He found trona at at least 22 levels (either as beds or scattered crystals) and found that trona aggregates about 6.4 percent of the saline zone. Farther south, trona makes up a much larger percentage of the saline zone; but because the saline zone itself thickens southward, the relative percentages of trona and shortite may not change much. The detailed data, however, to test this inference are not available. Fahey estimated that northupite made up about 2.2 percent of the saline zone in the John Hay Jr. 1 well.

In the saline facies in the central part of the basin, loughlinite [$Na_2O{\cdot}3MgO{\cdot}6SiO_2{\cdot}8H_2O$] (Fahey and others, 1960) is locally plentiful. This occurs as veinlets and beds and as partial replacements of minerals, especially northupite. In places the beds are more than 1 foot thick. More generally it is only one of several constituents distributed through the rock. It is fibrous, very fine grained, and has a birefringence comparable to that of several clay minerals. Its minute crystals are generally parallel and may be oriented along a bounding surface or normal to the surface. In larger veinlets its fibers are usually normal to the walls.

Only two chemical analyses of rocks in the Wilkins Peak Member are included in this report because Fahey (1962, p. 15) has already published 14 complete analyses of rocks selected at fairly regular intervals through the saline zone of the Hay well core. One of the analyses included in this report is of a tuff about 140 feet above the base of the member. The bed is light buff to brownish gray and is about 8 inches thick; it is an excellent marker bed that can be traced for many miles along the outcrop. The other analysis given in this report is of a greenish-gray muddy tuff from the uppermost part of the Wilkins Peak Member.

Culbertson (1961) described and gave accurate stratigraphic positions of six continuous tuff beds in the Wilkins Peak Member. These are very useful key beds. The tuff identified by my field number 19–58 (see table 4) is Culbertson's lowest tuff bed, which in his area is roughly 125 feet above the base of the member. This same bed has been recognized over a large area by J. D. Love, who called it the Firehole analcite bed (written communication, 1964).

Microscopic examination shows that sample 19–58

TABLE 4.—*Chemical analyses of two tuffs from the Wilkins Peak Member of the Green River Formation*

[Analyst: June Goldsmith]

Constituent	*1*	*2*
SiO_2	60.58	51.51
Al_2O_3	16.57	13.58
Fe_2O_3	2.21	5.31
FeO	.08	.05
MgO	.27	3.18
CaO	2.13	5.52
Na_2O	9.51	5.33
K_2O	.50	2.40
H_2O+	5.48	2.98
H_2O-	.28	1.06
TiO_2	.09	.18
P_2O_5	.05	.13
MnO	.02	.07
CO_2	1.58	7.75
SO_3	.06	.31
BaO	.10	.04
Total	99.51	99.40

1. Sample field No. 19–58; laboratory No. E–2382. From bed about 140 ft above base of the member in sec. 31, T. 19 N., R. 105 W., Sweetwater County, Wyo.
2. Sample field No. 23–58; laboratory No. E–2383. From bed at the top of the member in sec. 8, T. 18 N., R. 197 W., Sweetwater County, Wyo.

contains a very large amount of analcime, mostly in small euhedral crystals. Tuff sample 23–58 also contains considerable analcime, but it differs from the other tuff mostly by having a somewhat greater content of calcium and magnesium carbonates and a relatively large amount of K_2O, which is probably present as potassium feldspar. These two samples are rather typical of the altered tuffs in the Wilkins Peak Member.

J. D. Love, of the U.S. Geological Survey, made a study of about 35 thin but very extensive zones in the Wilkins Peak Member that contain detectable to significant amounts of uranium and abnormally large amounts of P_2O_5 (written communication, 1964). These zones, which range in lithology from muddy sandstone through greenish gray claystone to low-grade oil shale and marlstone, have P_2O_5 contents ranging from less than 0.05 to 18.2 percent. These same rocks contain 0.003–0.15 percent uranium.

Fossils are not common in the Wilkins Peak Member though in a few beds they are both numerous and remarkable. Locally along White Mountain, especially in sec. 9, T. 18 N., R. 106 W., a number of organic marlstone and low-grade papery oil-shale beds contain a large number of mycetophyllid fly larvae and a smaller number of oestrid and unidentified fly larvae. With some of these larvae are also adult flies and a few adult Hemiptera and Coleoptera. On the bedding planes of one of the marlstone units are many adult flies that evidently got stuck in the wet mud just after hatching, as their wings were not fully developed when they were trapped.

The other unusual fossiliferous beds are two beds of oil shale. One of these oil-shale beds is a rather rich bed that immediately underlies the trona bed being mined in the Intermountain Chemical Co.'s mine. This bed contains many microscopic aquatic animals and parts of them. These are thought to be *Cladocera* and parts of aquatic insects. They are being studied by specialists in such living organisms.

The other oil shale is a stratum about one-eighth inch thick that is very rich in organic matter and pyrite. This stratum was found in the core from the John Hay Jr. 1 well at a depth of 1646.5 feet below the surface (sec. 2, T. 18 N., R. 110 W., Sweetwater County, Wyo.) The rock contains a remarkably rich and varied microflora of algae and fungi and many pollen grains and some fragments of aquatic insects. This microflora will be described in another paper.

Both these beds of oil shale, and indeed all the beds of oil shale in the Wilkins Peak Member, are believed to represent deposits formed when Gosiute Lake was at a somewhat higher level than when any of the trona beds formed. These higher stages of the level represent fresher water stages, though none of them were high enough to overflow. While these oil-shale beds were forming, the area of the lake fluctuated between about 1,500 and 4,500 square miles. The microorganisms apparently grew in the fresher water of the epilimnion, which floated on the rather strongly saline hypolimnion. In other words, the lake was chemically stratified during those stages; and the organic matter was preserved in the stagnant, deeper, saline water.

A longer report is being prepared jointly by Prof. Hans Eugster, of Johns Hopkins University, and the U.S. Geological Survey on the conditions of deposition of the Wilkins Peak Member and the origin of its trona beds and other salts. A fuller discussion of the paleolimnology and geochemistry of Gosiute Lake during the Wilkins Peak stage will be given in that report.

LANEY SHALE MEMBER

Schultz (1920, p. 27–28) named the Laney Shale Member of the Green River Formation from exposures along the Laney Rim around the northern part of the Washakie Basin. The Laney encircles Waskakie Basin and extends southward into Moffat County, Colo., beyond the south line of the geologic map, plate 1. Along the east side of the Green River Basin the Laney makes up the buff to brownish gray hilltops out of which large lenses of tuffaceous sandstone jut boldly. Around the other side of the Green River Basin the Laney Shale Member is the thickest and most extensive member of the Green River Formation, as is shown on plate 1.

The Laney Shale member around the Washakie Basin ranges in thickness from a little less than 400 to nearly 1,900 feet and is characterized by buff, chalky to muddy marlstone and brown to light-ash-gray shale. Along the west and north sides of this basin the middle part of the Laney contains considerable amounts of low-grade oil shale and a few beds of moderately rich oil shale. Much of the low-grade oil shale is papery, and some of it contains the well-prserved remains of small fish. Most of the thin volcanic-ash layers in the Laney of this part of the area have been altered to analcime. Along the east and south sides of the Washakie Basin the shale and marlstone of the Laney are, in general, somewhat softer and muddier than they are on the west side of the basin. Also, they contain much less organic matter, although zones of chalky varved organic marlstone and low-grade oil shale make up a considerable part of the Laney, particularly along the south, faulted side of the basin.

A chemical analysis of a typical varved dolomitic organic marlstone from the lower part of the Laney Shale Member is given in table 5.

TABLE 5.—*Chemical analysis of typical dolomitic organic marlstone from the basal part of the Laney Shale Member*

[Sample collected in S½NE¼ sec. 8, T. 18 N., R. 107 W., Sweetwater County, Wyo. Sample No. 22-58c; lab. No. E-2380. Analyst: V. C. Smith]

Constituent	*Weight percent*	*Constituent*	*Weight percent*
SiO_2	43. 95	H_2O+	4. 03
Al_2O_3	11. 41	H_2O-	. 43
Fe_2O_3	1. 88	TiO_2	. 23
FeO	1. 56	P_2O_5	. 41
MgO	3. 67	MnO	. 05
CaO	11. 43	CO_2	13. 36
Na_2O	4. 25		
K_2O	2. 38	Total	99. 04

H_2O+ is abnormally high because organic matter, unfortunately, was not determined. Judging from other comparable analyses for which the organic matter was subsequently determined, the organic matter in this marlstone probably is about 4 percent. Nearly 30 percent of this rock consists of carbonates—14.3 percent dolomite, 12.63 percent calcite, and 2.45 percent siderite. It is worth noting that the amount of P_2O_5 in this rock is considerably greater than that found in most of the analyzed rocks in the Green River Formation, but it is not nearly so great as the amount Love (written communication, 1964) found in his thin uraniferous phosphate zones in the Wilkins Peak Member.

The Laney Shale Member in and around the Green River Basin is characterized by brown and buff-colored rocks that include marlstone, tuff, sandstone, shale, and limestone. Buff coarsely chippy to platy marlstone and tuff, and brown iron-stained muddy sandstone make up the greater part of the unit though locally soft chalky varved organic marlstone and low-grade papery oil shale are rather plentiful, especially in the lower part of the member. Plant remains, particularly palms, and silicified wood are locally common in the platy marlstone. Thin algal-limestone beds and nodular masses occur near the margins of the depositional basin. Near the center of the basin the rocks in the lower part of the member contain more low-grade oil shale than do those in the marginal facies. Locally, oil-shale beds of fair quality are found in lenses of soft fine-grained muddy tuff. Most of the sandy tuff occurs as thick lenses which grade laterally into sandy shale or soft sandy marlstone. In the Green River Basin the Laney Shale Member is well exposed in the cliffs along the north banks of Big Sandy Creek (T. 23 N., R. 109 W.) and in cliffs along a tributary to Blacks Fork in the northwestern part of T. 16 N., R. 108 W. (see fig. 14) and the northeastern part of T. 16 N., R. 109 W., though at neither locality is either the base or the top exposed. In the vicinity of the town of Green River the Laney is more than 600 feet thick.

A nearly complete section of the Laney Shale Member was measured about 23 miles south of the town of Green River near Twin Buttes (sec. 8, T. 14 N., R. 108 W.). The lithologic details of this section are given later in the report under the heading, "Measured sections."

North of the Rock Springs uplift and along the north side of the Green River Basin the Laney extends beyond the feather edge of the Wilkins Peak Member and rests either upon the Cathedral Bluffs Tongue, the New Fork Tongue, or the main body of the Wasatch Formation. (See pl. 1.)

Along the north and west sides of the Green River Basin the Laney Shale Member contains a considerably greater proportion of soft shale and mudstone than it does elsewhere. The rocks are consistently poor in organic matter and locally along the western side of the basin soft muddy sandstone beds and lenses are rather numerous. Comparatively hard marlstone and limy shale is interbedded with these soft muddy rocks. Near the southwest corner of the Green River Basin where the Laney is only 284 feet thick the following section was measured:

Laney Shale Member of the Green River Formation measured east of Piedmont in the northern part of T. 14 N., R. 117 W., Uinta County, Wyo.

	Ft	*in*
Mudstone of the Bridger Formation.		
Marlstone, hard, white; makes a broad bench	2	0
Volcanic ash, pure white, chalky	2	0
Shale, soft, gray; contains a few layers of less fissile mudstone and a few thin layers of hard marlstone	24	0

	Ft	in
Marlstone, hard, thin-bedded, platy, light-gray; contains an abundance of ostracodes	0	6
Mudstone, soft, gray, sandy	13	0
Marlstone, hard, very limy, almost white; contains shells	1	0
Sandstone, soft, muddy, dark-olive-gray; bottom part consists of very coarse sand grains embedded in greenish-gray waxy clay matrix; becomes fine grained and fissile toward top	16	0
Marlstone, gray, flecked with white; apparently tuffaceous	1	0
Mudstone, pale-greenish-gray	2	0
Marlstone, rather hard and crudely chippy	0	6
Mudstone, soft, pale-greenish-gray	12	0
Sandstone, massive, medium- to fine-grained, dark-gray	2	0
Marlstone, hard, clayey, dense, light-grayish-buff, very crudely chippy	2	0
Mudstone, soft, gray, crudely fissile	6	0
Mudstone, soft, gray, massive; contains one or more thin bands of pink mudstone	25	0
Marlstone, dense, nearly white, chippy; makes conspicuous bench	5	0
Limestone, dense, gray; weathers nearly white	1	0
Mudstone, soft, gray; crudely fissile at base but grades upward into limy shale	3	6
Limestone, gray, regularly bedded	0	6
Shale, soft, very limy, light-gray; weathers nearly white	2	0
Marlstone, alternate dense and chalky layers	1	0
Mudstone, soft, gray, crudely fissile; contains few thin layers of dense marlstone	4	0
Marlstone, rather chalky, pale-grayish-buff; in part massive, in part crudely chippy	2	0
Shale, soft, gray; rather poorly developed fissility	45	0
Mudstone and limy shale; unit poorly exposed; soft gray mudstone grades into pale-buff limy shale that contains a few thin mud-cracked marlstone layers	110	0
Thickness, Laney Shale Member	283	0

A section of the Laney Shale Member measured on the west slope of Steamboat Mountain (sec. 17, T. 23 N., R. 102 W.) was published in an earlier report (Bradley, 1926, p. 131), though, of course, it was there designated as Morrow Creek Member of the Green River Formation.

Northeastward from the north end of the Rock Springs uplift the member thins, and on the northeastern slope of Oregon Buttes (sec. 2 T. 26 N., R. 101 W.), where the following section was measured, it is only a little more than 20 feet thick:

Section of the Laney Shale Member of the Green River Formation measured in sec. 2, T. 26 N., R. 101 W., Sweetwater County, Wyo.

	Ft	in
Algal and oolitic limestone, in part silicified; contains abundance of ostracode shells	1	0
Marlstone, shaly; has rather thick but regular laminae	0	6
Mudstone, brown, soft, massive	3	0
Shale, papery, very soft, chocolate-brown; contains small quantity of organic matter except in uppermost 6 in. which is barren clay	14	0
Marlstone, nearly white, sandy, massive; contains clay pellets	2	0
Thickness, Laney Shale Member	20	6

Approximately 2½ miles northwest of this locality the Laney is represented by only two beds, as follows:

	Thickness (feet)
Oolite, brown, sandy, platy-bedded; contains many ostracodes	2
Sandstone, coarse-grained, muddy ocherous	5
Thickness, Laney Shale Member	7

The Laney Shale Member continues to thin northwestward and is absent from Tps. 28 and 29 N., Rs. 103–105 W., according to Berman's mapping. (See McGrew, and Berman, 1955.) There, north of the Continental fault, the Bridger Formation rests directly on the Wasatch Formation.

Prof. Paul O. McGrew, of the University of Wyoming, showed me (August 1963) a considerable thickness of the Green River Formation (apparently Laney) along the Big Sandy River north of the area shown on plate 1. The Green River Formation at that locality was faulted down on the north side of an unmapped fault that strikes northwest-southeast.

Locally in shore phases, generally but not everywhere near the mountains, the Laney Shale Member contains massive green mudstone beds, thinner zones of carbonaceous shale, and beds and lenses of carbonaceous sandstone. In these beds, particularly the greenish-gray mudstone, crocodile and turtle bones and gar-pike scales are abundant. Silicified wood is also common in such associations. In the buff chippy marlstone beds that characterize this member, impressions of leaves are common and, locally, plentiful. Leaves and fragments of palms (*Sabalites* sp.) are by far the most numerous, though leaves of deciduous trees are common in the limy shale and marlstone of the Laney.

McGrew (McGrew and Berman 1955, p. 110) reported finding abundant crocodile, turtle, and gar-pike remains and also the small fish *Knightia* in the Laney Shale (then Morrow Creek) Member in Tps. 26 and 27 N., R. 105 W. More significantly, however, McGrew also found (McGrew and others, 1959, p. 125–127) an important collection of mammalian remains in this shore facies. Of these remains he says, "* * * none was larger than *Hyopsodus lepidus* Mathew except for *Hyrachyus*, of which an astragalus was

732-765 O—64——4

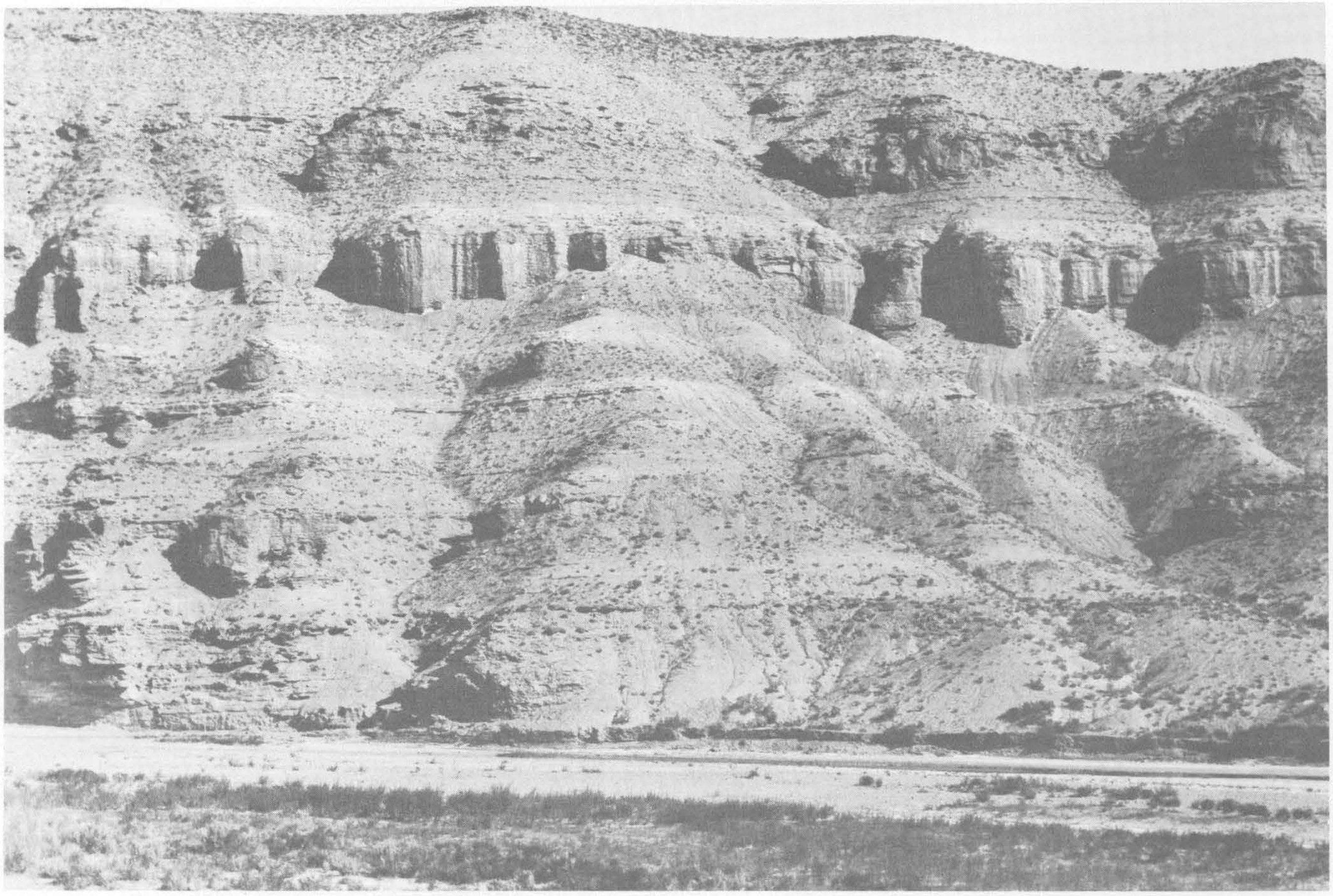

FIGURE 14.—Characteristic exposure of the Laney Shale Member of the Green River Formation in the north bank of a tributary to Blacks Fork in sec. 7, T. 16 N., R. 108 W., Sweetwater County, Wyo. The member here consists predominantly of brownish buff sandy marlstone. Typical sandstone lenses are visible in the upper part of this exposure.

found. Insectivores, primates, rodents, and *Hyopsodus* make up the great bulk of the fauna." The list follows:

Leptotomus parvus n. sp. McGrew	*Thisbemys* sp.
Diacodon edenensis McGrew	*Sciuravus nitidus* Marsh
Notharctus gracilis Marsh	*Hyrachyus* sp.
Omomys carteri Leidy	*Hyopsodus lepidus* Matthew
Shoshonius? *laurae* McGrew	*Melanosaurus* sp.
Paramys delicatus Leidy	

These mammals, he believed, indicate early Bridgerian age. He wrote by way of interpretation (McGrew and others, 1959, p. 127) of the ecology: "Altogether the evidence suggests a rather extensive, heavily forested swampland, with numerous braided waterways. The occasional beds of calcareous shale containing abundant impressions of the fish *Knightia* indicate periodic, perhaps widespread submergence." With this interpretation I fully agree. The geology indicates that Gosiute Lake was shallow and that small fluctuations of level produced large lateral shifts of the shoreline.

On the basis of a recent study of the Green River Formation by W. C. Culbertson (1962, p. C54–C57), of the Geological Survey, the formal stratigraphic name Tower Sandstone Lentil has been abandoned. He showed that the Tower is not a single sandstone lens as the name suggested but a complex and extensive system of sand-filled channels and beds. Most of these channel sandstones, which are near or at the base of the Laney Shale Member, are 50–75 feet thick and 150–300 feet wide. (See fig. 15.) In the vicinity of the town of Green River, the sandstones cap towers which gave rise to the name Tower Sandstone Lentil (Bradley, 1926, p. 123). Locally, however, the sandstones are scattered through the lower 400 feet of the Laney. These channel sandstones are common as far south as Sage Creek (T. 15 N., R. 106 W.), but south of that they are less conspicuous, though sandstone beds become progressively more numerous still farther south near the Uinta Mountains. Northward from the Union Pacific Railroad the channel sandstones become thinner and less numerous and within 10 or 12 miles lose their identity, though they may be present as softer sandstone beds. Sandstone lenses and beds that may be correlative with some of those in the Green River Basin occur along the western rim of Washakie Basin and are responsible for

FIGURE 15.—Tuffaceous sandstone lens close to the base of the Laney Shale Member of the Green River Formation. Scour into the underlying oil-shale and marlstone beds and differential compaction beneath the sandstone lens are visible in the central part of the photograph. This sandstone lens is one of many exposed along U.S. Highway 30 a few miles west of the town of Green River (sec. 9, T. 18 N., R. 107 W.). This group of sandstone lenses and beds was formerly known as the Tower Sandstone Lentil.

the topographic relief of Pine and Sand Buttes (T. 15 N., R. 100 W.).

Because the channels in which these sandstones were deposited were cut in fine-grained highly compactible sediment, differential compaction has considerably distorted both the original form of the sandstone bodies and the enclosing sediments. (See figs. 15, 16.)

The actual channels cut in the Laney Shale Member have gently sloping sides. Moreover, the part of the sand that filled these channels evidently mixed gradually with the marly mud, for in many places the base of the sandstone lens is silty or slightly sandy regularly laminated more or less organic marlstone. In addition, it contains fish remains and locally shows subaqueous slumping. This marlstone grows more sandy upward to 10–15 feet above the base where it grades into the typical massive or finely banded sandstone.

Much of the sand that makes up these lenses and beds is of volcanic origin. The sandstone lenses apparently represent concentrations of the crystal and lithic grains from blankets of volcanic ash. In thin sections the volcanic aspect is as apparent as it is obscure in the outcrop or even in a hand specimen. Almost without exception the grains are sharply angular, muscovite is absent but a phologopitelike biotite is common, and the quartz grains are nearly all clear and unstrained. The phologopitelike biotite and the hornblende suggest an alkalic source, which is not surprising; many of the tuffs in the Green River Formation of Wyoming have the same kind of biotite, and the hornblende is commonly riebeckite. The nearest vents containing this kind of volcanic material are in the Rattlesnake Hills, Tps. 32 and 33 N., Rs. 87 and 88 W., Natrona County, Wyo. (Carey, 1954). But as J. D. Love (written communication, May 1962) pointed out, ash from that source probably would have had to oppose the prevailing winds. Accordingly, a source in the volcanic center of the Absaroka Range of northwestern Wyoming is perhaps more reasonable. The volcanoes of that area also are known to have been active during the middle and late Eocene (Love, 1939, p. 109–110).

Presumably the finer particles of this ash fall were washed or blown farther southward away from the volcanoes and incorporated in the sediments that make up the lower part of the Laney Shale Member of the Green River Formation.

Volcanic ash, as has been noted, is abundant in the upper part of the Laney Shale Member. Most of this ash has been considerably altered, but some beds are comparatively little altered. Two of these were selected for chemical analysis (table 6).

TABLE 6.—*Chemical analyses of a rhyolitic and an andesitic tuff from the upper and middle parts of the Laney Shale Member and, for comparison, Daly's average compositions of rhyolite and andesite*

[Analyst: D. F. Powers]

	1	2	3	4
SiO_2	76.56	72.77	58.59	59.59
Al_2O_3	9.39	13.33	15.58	17.31
Fe_2O_3	2.15	1.40	5.06	3.33
FeO	.18	1.02	.62	3.13
MgO	.53	.38	3.36	2.75
CaO	1.36	1.22	3.87	5.80
Na_2O	1.02	3.34	4.54	3.58
K_2O	4.52	4.58	2.01	2.04
H_2O+	1.98	1.50	2.23	1.26
H_2O-	.88	--------	2.00	--------
TiO_2	.36	.29	.66	.77
P_2O_5	.09	.10	.22	.26
MnO	.02	.07	.03	.18
CO_2	.05	--------	.38	--------
SO_3	.63	--------	.28	--------
Cl	.01	--------	.06	--------
F	.03	--------	.06	--------
S	.01	--------	.00	--------
BaO	.03	--------	.09	--------
Subtotal	99.80	--------	99.64	--------
Less O_2 correction for S and Cl	.02	--------	.03	--------
Total	99.78	--------	99.61	--------

1. Field No. 26-58, lab. No. F-2798; rhyolite from sec. 9, T. 15 N., R. 100 W., Sweetwater County, Wyo.
2. Daly's average rhyolite (Daly, 1933, p. 9).
3. Field No. 36-58, lab. No. F-2799; andesite from sec. 27, T. 23 N., R. 109 W., Sweetwater County, Wyo.
4. Daly's average andesite (Daly, 1933, p. 16).

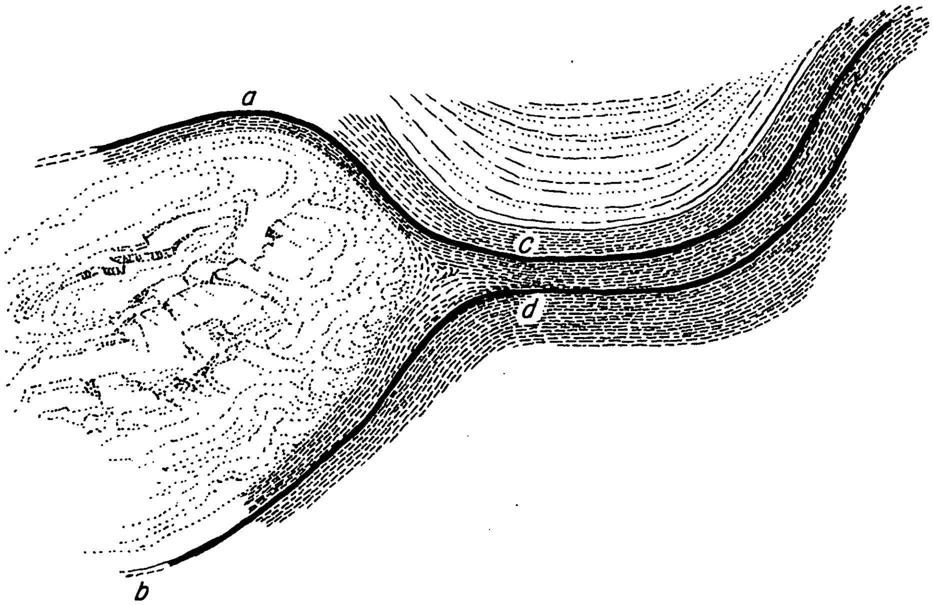

FIGURE 16.—Field sketch (simplified) to show extent of differential compaction around and between tuffaceous sandstone lenses in the lower part of the Laney Shale Member. The interval between two rich oil-shale beds at *a* and *b* is 61.5 feet, whereas the interval between them at *c* and *d* is only 12.4 feet. The beds enclosing these two oil-shale layers consist of papery oil shale. A lens of sandy marlstone fills the depression above *c–d*. Exposed in the north wall of a small gulch in the SE¼ sec. 21, T. 18. N., R. 107 W.

Sample 26–58 is exceedingly fine grained and consists mostly of partly devitrified shards that are sharp and almost needlelike. Its composition is similar to the average composition of 102 rhyolites given by Daly (1933, p. 9). It differs from the average composition most notably by having higher a SiO_2 content and lower Al_2O_3 and Na_2O contents. The total iron is nearly the same; though, as might be expected, much more of the iron in the Green River ash is in the ferric state.

Sample 36–58 is a medium-grained crystal-lithic tuff whose micas are somewhat chloritized. Its composition is closely similar to the average composition of 87 andesites given by Daly (1933, p. 16). It differs from the average most by having less Al_2O_3 and more Na_2O and by having somewhat more MgO and less CaO.

Tuffs more or less similar to these are fairly common in the Laney Shale Member, but variants of the andesitic tuffs make up a greater volume than do the rhyolitic tuffs.

BATTLE SPRING FORMATION

Pipiringos (1962, p. A34–A35) gave the name Battle Spring Formation to a thick sequence of arkosic sandstone in the eastern part of the Great Divide Basin, taking the name "* * * from typical exposures southwest of Battle Spring Flat * * *" (T. 23 N., R 94 W.) and "* * * southeast of Lost Creek Butte * * *" (eastern part of T. 23 N., R. 95 W.). The Battle Spring Formation, of early and middle Eocene age, intertongues with all the subdivisions of the Wasatch and Green River Formations already described except the Laney Shale Member of the Green River Formation. Pipiringos inferred that the Battle Spring Formation is about 3,300 feet thick but that it may be even thicker. His description (1962, p. A34–A35) of the formation follows:

The base of the Battle Spring formation is exposed on the north slope of Flattop Buttes [northern part of T. 26 N., R. 95 W.] and at a point about 10 miles west of Rawlins, Wyoming, in the northwest part of T. 21 N., R. 89 W.; at both localities the Battle Spring formation overlies the Fort Union formation unconformably.

The Battle Spring formation consists of very coarse-grained to pebbly arkosic sandstone with less amounts of bright green claystone that contains abundant large grains of clear angular quartz. Locally the beds form low rounded bluffs in which the cross-bedded nature of the sandstone is clearly visible, elsewhere the sandstone weathers into soft slopes littered with spheriodal sandstone concretions that are moderately calcareous and often contain limonitic centers. The sediments that make up this formation appear to have been deposited in deltaic sheets, the source of which appears to have been the Granite Mountains north and northeast of the map area. [See fig. 10.]

Where the rivers that carried the sediments spilled out into one of the ancient Green River lakes, extensive areas of foreset beds were formed, which today exhibit dips up to 15 degrees.

No fossils were found in the Battle Spring formation, but the formations with which it intertongues range in age from earliest Eocene through early middle Eocene. The Battle Spring formation seemingly represents a period of continuous deposition during this time.

BRIDGER FORMATION

DEFINITION AND AGE

The Bridger Formation, of middle and upper(?) Eocene age, was named by F. V. Hayden (1873) for badland exposures in the central part of the Green River Basin along the main line of the Union Pacific Railroad.

The Bridger Formation occupies large areas in the central parts of the Green River and Washakie Basins where it makes a picturesque badland terrain. Outliers of the Bridger Formation were mapped northeast of the Rock Springs uplift. Pipiringos (1962, pl. 1) and Nace (1939, pl. 1) mapped other outliers of the Bridger along the northern part of the central Great Divide Basin (Tp. 26 N., R. 94–97 W.), and Sears (1924b) mapped rather large areas of Bridger in Moffat County, Colo. The Bridger outliers mapped by Pipiringos and Sears (in part) are shown on plate 1 of this report.

CLASTIC SEDIMENT

The Bridger Formation resembles in many respects the Wasatch Formation, but it contains fewer red beds and much more volcanic ash. It consists predominantly of sandy tuffaceous mudstone that ranges in color from light neutral gray to rather dark greenish drab and grayish chocolate brown. Locally some of the gray mudstone in the uppermost parts of the formation in the Green River Basin is banded with pink, dull red, or mauve. Interbedded with the mudstone are beds and lenses of crossbedded gray to brownish-gray medium-grained tuffaceous muddy sandstone. Volcanic-ash beds that contain little clastic material are numerous in the Bridger and locally make up as much as 15–20 percent of the formation. Widely separated thin limestone and marlstone layers make extensive and conspicuous benches in the Bridger badland terrain. (See fig. 17.) Locally these thin layers are silicified. Carbonaceous sandstone, shale, and clay layers are rare but apparently are significant, as they represent swamp sites and a few of them may represent fossil soils. In an excellent description of the Bridger Formation in the southern part of the Green River Basin, Koenig (1960, p. 165–168) reported also thin lignitic and coaly layers in several parts of the formation. Koenig (p. 168) proposed a volcanic source for virtually all the sediments of the Bridger Formation except the thin calcareous layers of lacustrine origin. In this, he agrees with Sinclair (1906, p. 273). My impression is that most of the beds in the Bridger are tuffaceous but also contain a significant percentage of clastic material.

PYROCLASTIC SEDIMENT

One of the most distinctive features of the Bridger Formation in the Green River Basin is its andesite tuff, most of which occurs in irregular beds that consist of continguous or overlapping thick crossbedded lenses. The tuff has been altered, and the alteration minerals have given it surprisingly vivid colors. Because these colors are so exceptional as rock colors and because they make such conspicuous bands in the gray badland terrain, it seems worthwhile to define two of the commonest colors with some precision. One of these colors matches Ridgway's (1912) "deep bluish glaucous," which is a mixture of 93 percent primary green and 7 percent primary blue subdued by the addition of

FIGURE 17.—Characteristic exposure of the Bridger Formation in the northeast slope of Twin Buttes in the southeastern part of the Green River Basin. About 1,400 feet of Bridger is exposed here. The three highest points, all of small area, are each capped by about 50 feet of Bishop Conglomerate. The apparent highest point, near the center of the photograph, is in sec. 21, T. 14 N., R. 109 W., Sweetwater County, Wyo. The Buckboard Crossing topographic quadrangle map, published in 1959, shows this mass as Black Mountain, a name I never heard used in that locality. According to that map the name Twin Buttes is restricted to two much smaller, but slightly higher, buttes in secs. 6 and 7, T. 13 N., R. 109 W.

considerable neutral gray and lightened in tint by the addition of a moderate amount of white. The other common andesite tuff color is a strong green, although Ridgway gave this particular color the name "deep dull yellow-green (1)." This is a mixture of equal amounts of primary yellow and green subdued by a moderate amount of black. The colors of these particular tuffs, of course, change with changing light and with the moisture content of the rock. Although these are the prevailing hues of the altered andesite tuffs, other more sombre hues that grade into dull olive brown are common.

The bluish-gray andesite tuff is a medium-grained sandy rock consisting of angular to subrounded grains of more or less devitrified glassy volcanic rock that contains an abundance of plagioclase laths and sand-size crystals of calcic plagioclase, green to brown hornblende, biotite, augite, and a few grains of potash feldspar and quartz. Much of the hornblende and some of the plagioclase is idiomorphic. Some of the glassy fragments are fairly fresh and contain minute spherical bubbles, whereas other fragments have been altered to a felt of clay-mineral laths. Most of the biotite has been bleached or converted to a chloritelike mineral. Pore spaces are filled in part with calcite but mostly with a bright-bluish-green fibrous and flaky clay mineral that is probably nontronite.

The deep-green andesite tuff is closely similar to the light-bluish tuff just described, but it contains considerably more of the green alteration mineral that is inferred to be nontronite and a much larger quantity of hydrated iron oxide. The green alteration mineral forms a tightly adhering film on each crystal or lithic grain and also fills the pore spaces. Much of this alteration mineral is brilliant emerald green and appears to be made up either of felts of flakelike particles or of closely spaced fibres. Some of this material, however, makes clusters of radiating needles that line cavities. In plain light this material is bright bluish green parallel to the elongation and greenish yellow at right angles to the elongation. C. S. Ross of the Geological Survey suggested (oral communication, 1931) that this may be the bluish-green variety of glauconite known as celadonite. Attempts to isolate this mineral for further tests were unsuccessful.

The crossbedding and lenticularity of these strongly colored tuffs shows that they were reworked by streams; but apparently the reworking was not extensive, for the tuffs contain only a small percentage of clastic grains such as quartz and rounded grains of calcite and limestone. The large areal extent and the continuity of crossbedded lenses of these andesite tuffs suggest that the ash falls choked the drainage channels and caused the overloaded streams to wander widely in the newly fallen ash until their former gradients were reestablished. Other andesitic ash falls, however, were reworked considerably more, as is shown by the greater admixture of clastic material. In fact, all gradations are found between the nearly pure strongly colored andesite tuff and gray muddy sandstone whose pyroclastic constituents are obscure or absent.

Tuffs more alkalic than andesite make up a greater percentage of the Bridger Formation than do the andesite tuffs. Most of these alkalic tuffs are evidently rhyolitic, but some appear to represent rocks intermediate between rhyolite and andesite. Johannsen (1914, p. 220–221) studied samples collected from bone-bearing beds in the Bridger Formation and reported most of them as dacite, dacite?, and tuffs but called one "glass tuff." Possibly, chemical analyses of a series of these tuffs would show a rather complete gradation between the dacite and glassy tuff. The rhyolitic tuffs range in color from dull greenish gray to white (fig. 18) and in texture from that of fine-grained sandstone to clay depending upon the content and size of crystal fragments and the degree of alteration.

The commonest rhyolitic tuffs consist of a mixture of lumps and shards of pumiceous glass and angular fragments of quartz and potash feldspar. In addition to the quartz and potassic feldspar, at least some of which is sanidine, are lesser amounts of biotite, green hornblende, and plagioclase (oligoclase and andesine). Zircon and apatite are rare. In some of the tuffs richest in crystal constitutents, biotite is abundant and hornblende is common. Unaltered glass in these tuffs has a refractive index close to 1.52.

Most of the rhyolitic tuffs are altered; the glass has been devitrified or, in some, altered to a felt of clay-mineral flakes. The shard and pumiceous textures, however, are clearly visible. A few of the rhyolitic tuffs that apparently were originally made up mainly of minute and delicate glass shards have been altered to a bentonitic clay. These tuffs contain only a small quantity of very small angular grains of quartz, sanidine, and sodic plagioclase but have an abundance of dark-brown to black biotite flakes and a moderate amount of dark-green hornblende. All these crystal constituents are remarkably fresh. One of these tuff layers, which weathers to a distinctive pale lavender, contains an abundance of well-preserved vertebrate remains.

A likely source for most of this volcanic material is the great volcanic center in the Absaroka Range in northwestern Wyoming (Love, 1939, p. 109–110).

STRATIGRAPHIC UNITS

WHITE LAYERS

In the southern half of the Green River Basin, a number of rather widely spaced white layers make

FIGURE 18.—White layers of altered tuff that make persistent benches in gray and greenish-gray mudstone of the Bridger Formation. View southward from sec. 11, T. 16 N., R. 113 W., Sweetwater County, Wyo.

conspicuous features in the landscape and are used by vertebrate paleontologists as key beds to identify the boundaries of faunal zones. (See fig. 6.) One of the most extensive of these white layers is the one Matthew (1909) called the Sage Creek white layer. This unit was mapped over much of the southern Green River Basin, and its outcrop is shown on plate 1. Near the headwaters of Little Dry Creek (sec. 27, T. 14 N., R. 115 W.) the Sage Creek white layer consists of two beds.

	Thickness (feet)
Marlstone, white, hard, platy; some bedding planes have numerous long stem impressions and a few leaf fragments; locally contains thin lenses of carbonaceous shale	4
Marlstone, light-brown, hard, platy; has irregular bands of brown and black chert	5
Total	9

A nearly identical but more detailed description of the Sage Creek white layer was given by Sinclair (1906, p. 280) for the type locality of the Sage Creek white layer on Sage Creek. But farther east this white layer loses its whiteness and in the vicinity of Twin Buttes becomes a group of thin platy brown marlstone beds that contain an abundance of flat-coiled snail shells.

The Lonetree white layer of Matthew is 440 feet stratigraphically higher than the Sage Creek white layer in the Bridger and crops out in the badlands a few miles north of Lonetree, Uinta County, Wyo. The outcrops of the Lonetree white layer and another, 390 feet still higher, which Matthew called the Upper white layer are shown in figure 19. Partial sections of the beds that include the Lonetree white layer and the Upper white layer measured on the southwest slope of Sage Creek Butte a few miles north of Lonetree are as follows:

Partial section of the Bridger Formation that includes the Lonetree white layer of Matthew. (Sec. 8, T. 13 N., R. 113 W.)

	Thickness (feet)
Mudstone, pale-greenish-gray	14
Sandstone, light-gray, medium-grained, muddy, cross-bedded	2
Mudstone, light-gray, and sand	3
Claystone, brown, soft, waxy	1
Marlstone; contains flat-coiled snail shells, gar-pike scales, and crocodile and turtle bones	1
Mudstone, light-gray	1
Lonetree white layer: Marlstone, white, chalky, alternate hard and soft layers	6

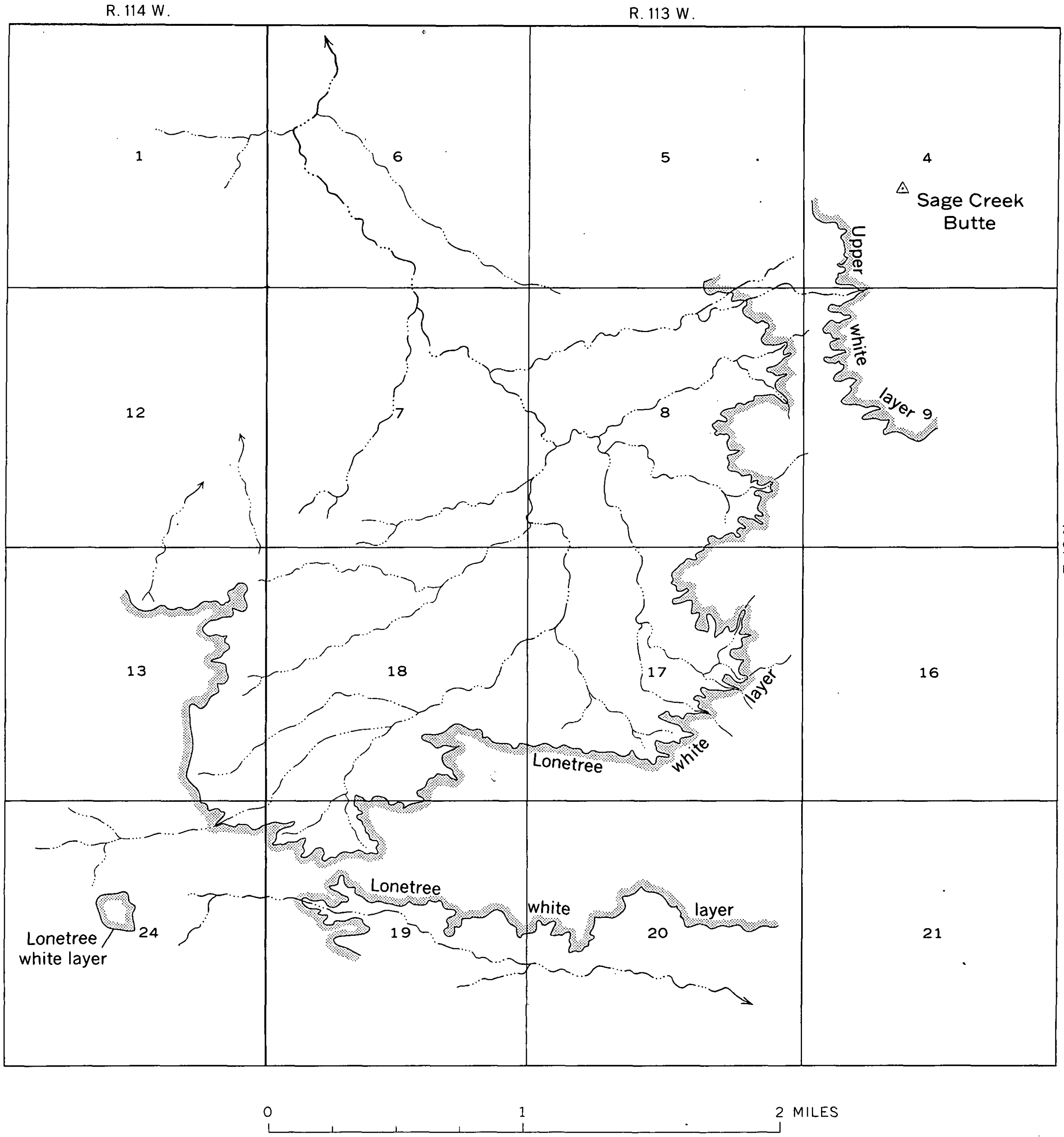

FIGURE 19.—Map shows outcrops (shaded) of two of the white layers in the Bridger Formation in the southwestern part of the Green River Basin.

	Thickness (feet)
Rhyolitic tuff, soft, medium-grained; rich in biotite; lenticular but continuous	3
Mudstone, tuffaceous, biotitic; contains brown clay pellets	5
Andesite tuff, light-bluish-green, sandy, crossbedded, lenticular but persistent	23

Partial section of the Bridger Formation that includes the Upper white layer of Matthew. (*Sec. 9, T. 13 N., R. 113 W.*)

	Thickness (feet)
Mudstone, soft, brownish-gray	61
Mudstone, dark-brown, and sandy	½
Mudstone, soft, brown, clayey; contains fresh-water-pelecypod shells	3

	Thickness (feet)
Upper white layer: Marlstone, brownish gray on fresh fracture but weathers stark white; contains an abundance of flat-coiled snail shells	1
Mudstone, brownish-gray; contains lenses of granular gray tuff	8
Marlstone, white; contains *Viviparus* and flat-coiled snail shells	½
Mudstone, soft, brown	12
Tuff, buff, muddy	10

These partial sections were taken from a much longer section of the Bridger measured on the southwest flank of Sage Creek Butte in T. 13 N., R. 113 W. The details of this section are given later in the report under the heading, "Measured sections."

Although the white layers closely resemble some of the white rhyolitic glass tuffs of the Bridger, they consist dominantly of microgranular carbonates and clay. The Lonetree white layer contains 66 percent calcite, about 32 percent minute clay flakes, and about 1 percent small angular grains of quartz and potassium feldspar. Small brownish-gray pellets of clay are common in the Lonetree white layer. The abundance of carbonates and the presence of fresh-water-gastropod shells indicate that these white layers were probably deposited in extensive but shallow lakes. Carbonaceous lenses either within or adjacent to the white layers indicate that swampy areas bordered the lakes or at times replaced them. For some reason these white layers, particularly the Lonetree and Upper white layers, contain numerous remains of small animals. Teeth and jaws are particularly common.

No study was made of either the Burnt Fork or Cottonwood white layers of Matthew.

At many places, petrified wood is common in the Bridger Formation, particularly around Oregon Buttes (T. 26 N., R. 101 W.) (See fig. 20.) In that area much of the wood is encrusted with silicified algal deposits.

Near the mountains, particularly near the Uinta and Wind River Mountains, the Bridger becomes coarse grained and locally conglomeratic. Along the Uinta Mountains the conglomeratic facies of the Bridger are characterized by pebbles and cobbles of Carboniferous limestone and, near the Wind River Mountains, by cobbles of hornblende schist and granite. Along the north flank of the Uinta Mountains, not only the Bridger but also the underlying Green River and Wasatch Formations become so conglomeratic that they lose their identity. On the geologic map (pl. 1) these conglomeratic Eocene rocks are shown as Tertiary undifferentiated. This facies of the Eocene rocks is discussed later in this report.

Nearly everywhere the base of the Bridger Formation is uncertain because it grades downward into the top of the Laney Shale Member of the Green River Formation. This gradation takes place by extensive interfingering of the two lithologies from the central parts of the Green River Basin marginward in all directions. In other words, the Green River Formation is appreciably thicker in the central part of the Green River Basin and grades laterally outward into successively lower units of the Bridger Formation. (See fig. 6.)

FIGURE 20.—Petrified log with the bark well preserved. Found in the lower part of the Bridger Formation in sec. 3, T. 26 N., R. 101 W., approximately on the boundary between Sweetwater and Fremont Counties, Wyo.

The top of the formation in the Green River Basin is unknown because even where it is thickest (Twin Buttes) it is truncated by the younger Bishop Conglomerate.

The maximum thickness of the Bridger Formation is in the southern part of the Green River Basin. In Twin Buttes, shown on some maps as Black Mountain (T. 14 N., Rs. 109 and 110 W.), the Bridger is about 1,560 feet thick; westward it thickens about 725 feet so that in the area west of Sage Creek Butte (north of Lonetree, Wyo.) it must be about 2,285 feet thick. This 725 feet of westward thickening replaces an equivalent amount of the upper part of the Laney Shale Member of the Green River Formation in the vicinity of Twin Buttes. At the north end of the Rock Springs uplift, in Oregon Buttes (T. 26 N., R. 101 W.), the Bridger is about 480 feet thick. Detailed sections of the

Bridger measured at these two localities are given later in the report under the heading "Measured sections."

FAUNAL ZONES

For convenience in locating the numerous collections of vertebrate fossils stratigraphically, Matthew (1909) divided the Bridger into five zones, beginning with A at the base. Simpson (1933) pointed out that these subdivisions of the Bridger do not correspond to major faunal divisions; zones A and B are each distinctive faunal units, C and D together make a distinctive faunal unit, and E contains no identifiable fossils.

Wood (1934) grouped zones A and B together to make his Black's Fork Member of the Bridger and zones C and D to make his Twin Buttes Member. Zone E of Matthew he regarded as Uinta A of the vertebrate paleontologists. These members are defined as faunal units analogous to Lysite and Lost Cabin and were intended to obviate the need for such cumbersome terms as Bridger C and D. The two members proposed by Wood are not distinguishable lithologic units though they are separable and mappable in part of the area, by means of the Sage Creek and Lonetree white layers. Beyond the limits of these white layers the members are recognizable only by means of their contained faunas.

The large vertebrate fauna collected by C. W. Gilmore of the U.S. National Museum in the summer of 1930 will be listed in another report in which the paleocology of the Wasatch and Bridger Formation will be discussed.

WASHAKIE BASIN

The Bridger Formation in the Washakie Basin is much like that in the Green River Basin except that the tuff is less conspicuous, probably because it is mixed with more clastic sediment, and the upper part is more conspicuously banded with pink. This pink banding is also characteristic of the Bridger Formation farther south in Moffat County, Colo.

Gray mudstone and drab grayish-brown lenticular sandstone beds that weather into badlands or extensive almost featureless benches are characteristic of the Bridger Formation in the Washakie Basin. Some of the mudstone, however, is pale sage green and, where banded with pink or mauve, makes a colorful landscape. More of the sandstones, especially in the northern part of the Washakie Basin, are coarser grained than those in the Green River Basin; indeed, gravel lenses are common in the Bridger of Haystack Mountain. There, some of the coarse gravelly sandstones are nearly white and have false beds that dip steeply southeast, indicating a source to the northwest. Many of the details of the Bridger and overlying Uinta formation are given later in the report under the heading "Measured sections."

In the Washakie Basin the base of the Bridger Formation is marked by a rather conspicuous change from buff tuffaceous marlstone of the Green River Formation to greenish-brown crossbedded medium- to coarse-grained lenticular sandstone and greenish-gray mudstone characteristic of the Bridger Formation. The boundary between the Bridger and Green River in the Washakie Basin was located on aerial photographs in the field by J. D. Love and me along the east slope of the Kinny Rim. Subsequently, R. J. Hackman, of the Survey traced this boundary all around the Washakie Basin photogrammetrically. (See pl. 1.)

UINTA FORMATION

Vertebrate paleontologists report (Wood, 1934) younger faunas in the uppermost parts of the Bridger-like beds in the Washakie Basin and therefore assign those beds to the Uinta Formation of late Eocene age. Also, according to Simpson (1933), the Bridger Formation in the Washakie Basin is younger than the Bridger in the Green River Basin. The vertebrate paleontologists refer to the lower (perhaps a little less than half) beds in the Washakie Basin that have general Bridger-like lithology as Washakie A and the upper part as Washakie B. According to McGrew (1951, p. 54), "The fauna from Washakie A is adequate to prove approximate contemporaneity with the upper faunal horizon (Bridger D) of the Green River Basin. The fauna of Washakie B is like that of the lowest faunal horizon (Uinta B) of the Uinta formation." He listed (p. 54) 20 genera of vertebrates from Washakie A and 10 genera from Washakie B. Because of these age relations and because the Uinta Formation was not mapped, the rocks above the Green River Formation in the Washakie Basin are grouped as Bridger and Uinta Formations and are so shown on plate 1.

The thickest section of the Bridger and Uinta Formations in the Washakie Basin is exposed on the flanks of Haystack Mountain (T. 16 N., R. 95 W.). There the basal 50–75 feet of the Bridger is not well exposed, but above that about 780 feet of the two formations is perfectly exposed. A section measured there is given later in the report under the heading, "Measured sections."

UNDIFFERENTIATED EOCENE FORMATIONS

Along the north flank of the Uinta Mountains from a place a few miles west of Manila, Utah (T. 3 N., R. 19 E.), to the vicinity of Elizabeth Mountain (T. 3 N., R. 10 E.), the Wasatch, Green River, and Bridger Formations are all so conglomeratic that they cannot be distinguished from one another. Moreover, in this belt, which is about 50 miles long and almost entirely in Utah, the exposures are generally poor. Cobbles and boulders of cherty limestone, mostly from the Madison Limestone, make up the greater part of this conglomeratic facies, though red quartzite from the Uinta Mountain Group is locally plentiful. White quartzite is next most abundant, and pebbles of black chert are common.

On the southwest side of Phil Pico Mountain (T. 3 N., R. 17 E., Dagget County, Utah) is exposed a facies of this undifferentiated Eocene sequence, all of which Anderman (1955, p. 131) assigned to the Green River Formation, that resembles in lithology the Green River Formation 17 or 18 miles farther east in the canyon of the Green River (T. 12 N., R. 108 W., Sweetwater County, Wyo.). This possible tongue of the Green River Formation is thin (not measured) and consists of very fine grained buff soft limy sandstone in thin regular beds. It is interbedded with gray sandy gravel and conglomerate, some of which contains well-rounded limestone boulders as much as 18 inches in diameter, and is underlain by even coarser bouldery conglomerate. Along the south end of Phil Pico Mountain, these and the overlying beds are turned up so that they dip about 23° northward.

A mile or two farther west (secs. 34 and 35, T. 3 N., R. 17 E.), the undifferentiated Eocene has an unusual and local aspect. There the Weber Sandstone of Pennsylvanian and Permian age makes a prominent hogback that dips about 60° northward. The Weber is a soft friable very fine grained and well-sorted white sandstone. It is also markedly crossbedded. The undifferentiated Eocene laps up against the Weber with approximately a 30° angular discordance—that is, the Eocene rocks dip about 30° N. The Eocene rocks consist of this same white fine-grained sandstone but contain stringers of rather angular limestone and white sandstone pebbles. Mixed in with these pebbles and distributed through the mass of white sandstone are a large number of boulders and blocks of Weber Sandstone that are as much as 10 feet across. Some are sharply angular and obviously could have moved but a few feet from the parent Weber cliff. Others are rounded, but this is expectable for such soft sandstone. A subordinate number of hard well-rounded limestone boulders are also found.

Another, but much smaller, strip of undifferentiated Tertiary rocks was mapped in the vicinity of Vermilion Creek (Tps. 10 and 11 N., Rs. 100 and 101 W., Moffat County, Colo.). In this area the Tertiary rocks consist mostly of sandy and pebbly gray mudstone and represent only part of the Wasatch and Green River Formations.

I did not measure the thickness of the undifferentiated Eocene formations, but along the Uinta Mountain flank they must aggregate several thousand feet. They represent a piedmont facies that probably does not extend more than a few miles out into the Green River Basin.

BISHOP CONGLOMERATE

The Bishop Conglomerate caps several large erosion benches or pediments that slope away from the Uinta Mountains. The largest area of Bishop Conglomerate extends over a large area in the southwest quadrant of the Rock Springs uplift. Other extensive benches capped by this conglomerate are distributed across the southern margin of the Green River Basin. Isolated remnants are found on high points south of the Rock Springs uplift and as far east as Flat Top Mountain on the eastern rim of the Washakie Basin (T. 14 N., R. 93 W.).

The Bishop Conglomerate consists almost wholly of well-rounded cobbles and boulders. Inasmuch as the formation in this area was derived from the high part of the Uinta Mountains, boulders and cobbles of red quartzite from the Uinta Mountain Group are predominant. Boulders and cobbles of limestone and metamorphic rock, however, are locally common.

Local sources also contributed material to the Bishop Conglomerate, as around the flanks of Aspen Mountain in T. 17 N., R. 104 W. There the Bishop Conglomerate consists chiefly of angular fragments of brown sandstone and quartzite derived from nearby outcrops of the Upper Cretaceous Blair Formation. This local facies interfingers with the better rounded material derived from the Uinta Mountains.

The origin, geomorphic history, and stratigraphic position of the Bishop Conglomerate have been discussed at some length in another report (Bradley, 1936, p. 172–174). Perhaps all that need be added here is that, as I interpret the geology and geomorphology of the north flank of the Uinta Mountains, the Bishop Conglomerate is older than the Browns Park Formation and is not to be confused with the basal conglomerate of the Browns Park Formation, which it closely resembles. Recent studies by Hansen, Kinney, and Good (1960, p. B257–B259) cast doubt on this conclusion and show that the geologic history in critical areas along the north flank of the Uinta Mountains is complex and not yet fully understood.

The age of the Bishop Conglomerate is given tentatively as Miocene(?), but it may prove to be Oligocene. The key to its age may be contained in the thick section of white or light gray biotitic tuff, white sand stone, and quartzite that rests on the Bishop Conglomerate and is thick enough to cap the western part of Aspen Mountain in the southern part of T. 17 N., R. 104 W. Southwest of Aspen Mountain the white tuff makes a small conical butte known as Antelope Butte. Near the top of this butte is a bed of soft greenish-gray muddy sandstone in which I found bones of vertebrates, but the bones were so badly leached and so fragile that I could not collect them. A significant gap in our knowledge of the geologic history of this part of Wyoming might be filled if some vertebrate paleontologist could find identifiable and datable fossils in these tuffaceous beds.

OLIGOCENE, MIOCENE, AND PLIOCENE FORMATIONS

Much geologic work has been done on these younger Tertiary rocks by different geologists in different parts of the area shown on the geologic map (pl. 1). Because these rocks are prevailingly white or very light colored, because they are all more or less tuffaceous and sandy, and because diagnostic fossils are difficult to find in them, a variety of opinions about their identity, geologic age, and correlations have grown up. Moreover, many uncertainties persist. The following discussion represents the state of our knowledge as of mid-1962. No attempt to exhaust the subject seems appropriate now.

UNDIFFERENTIATED OLIGOCENE AND MIOCENE

Nace (1939, p. 31–35) mapped beds in the upper parts of Oregon Buttes and Continental Peak and north of the Continental fault as Oligocene (Chadron). Many years later J. D. Love, of the U.S. Geological Survey, and Paul O. McGrew, of the University of Wyoming, reported to me (oral communication, May 1957) that vertebrate fossils of Oligocene age have been found north of Oregon Buttes and Continental Peak in beds that underlie the Miocene Split Rock Formation (Love, 1961a). The lithology of both these formations resembles that of the Browns Park Formation. The beds of Oligocene and Miocene age were not mapped separately but are included in the northern part of the band in that area shown on plate 1 as Miocene and Oligocene undifferentiated. No post-Bridger beds are shown in Oregon Buttes and Continental Peak on my map (pl. 1), but they are, in fact, present. (See section of Bridger Formation in Oregon Buttes in the part of this report titled, "Measured sections.")

In 1958 Love and I found a thick section (roughly 1,200 ft) of white tuff, tuffaceous sandstone, and quartzite on and around Aspen Mountain (T. 17 N., R. 104 W.). The beds on the south flank of Aspen Mountain and those that cap the mountain are an upward extension of the white beds that make up Antelope Butte (just described) and that blanket a considerable area around Aspen Mountain proper. The age of these beds is unknown, but I have shown them on the map (pl. 1) as Miocene and Oligocene undifferentiated on the assumption that they represent the same series of beds as those that crop out in a belt north of Oregon Buttes and Continental Peak. Love (1960, p. 209) suggested that these beds might be of Oligocene age, but he was more inclined (oral communication, May 1961) to think that they may be late Miocene or Pliocene.

Most of the sandstone and quartzite beds in the upper part of this formation weather dark brown, but on fresh fracture they are white. They are remarkable in that they consist almost wholly of rounded quartz grains, though some thin sections show a considerable number of plagioclase grains. Dark minerals of any kind are exceedingly rare. In this they resemble the quartzite beds in the Browns Park Formation, which I mapped along the southern, faulted margin of the Washakie Basin. This absence of dark minerals in an otherwise tuffaceous formation is puzzling.

A few days after Love and I found these beds on and around Aspen Mountain, he climbed Black Butte (sec. 9, T. 18 N., R. 101 W.) and found that it also was capped by about 200 feet of the same kind of white sandstone and also quartzite beds. I have shown these rocks on the map (pl. 1) as undifferentiated Miocene and Oligocene.

BROWNS PARK FORMATION

The Browns Park Formation, whose type locality, Browns Park, is shown in the extreme southern part of plate 1, consists predominantly of white sandy tuff and white or light-gray tuffaceous sandstone, clean sandstone, and sandy mudstone. Locally it contains thin layers and lenses of greenish-gray clayey mudstone, and in some rather extensive areas the sandstone is conspicuously crossbedded. Much of this crossbedding apparently resulted from wind action, as the false beds are curved and tangential. At the base of the formation is a coarse conglomerate that in many places resembles the Bishop Conglomerate except that it is generally thinner. In some places, beds of the Browns Park Formation above the basal conglomerate overlap older rocks, and in such places there is no basal conglomerate or even coarse-grained sandstone. Sears (1924b, p. 286) reported a maximum thickness of 1,200 feet for the Browns Park in Moffat County, Colo. (T. 9 N., R. 100 W.).

The Browns Park, of Miocene(?) age, extends as an irregular, discontinuous band from the type locality eastward across the southern part of the geologic map, plate 1.

The characteristics, distribution, origin, and stratigraphic relations of the Browns Park Formation in the area covered by this report have been discussed rather fully in several reports (Sears, 1924a, p. 295–296; Sears, 1924b, p. 284–287; Bradley, 1936, p. 182–184; and

Pipiringos, 1962, p. A35–A37). Nevertheless, a significant addition to our knowledge of the history and distribution of the Browns Park Formation was published in 1960 by Hansen, Kinney, and Good (1960).

Deposits of uranium of commercial size and grade have been discovered within the past few years in the Browns Park Formation west of Baggs, Wyo., and in the area around the towns of Lay and Maybell in Moffat County, Colo.

McGrew (1951, p. 54–55) reviewed the vertebrate faunas already collected from the Browns Park Formation and collected still others. He concluded that a middle Miocene age is very probable. Because the Wyoming Geological Association Guide Books, in which he published the results of his study, are not everywhere available, it seems desirable to quote pertinent parts (p. 56) of his report:

The only faunal element that suggests a later age, i.e. post middle Miocene, is the mastodon, *Trilophodon fricki*, found in the Browns Park of Colorado. Osborn (1936) considered this one of the most primitive proboscidians known from North America and in the light of the other mammals it must be considered a middle Miocene form. Of other forms from the Browns Park all are known from middle Miocene rocks of other areas and one, *Moropus*, is not known from post middle Miocene rocks.

The known mammalian fauna from the Browns Park is as follows:

From the Browns Park of Colorado

Procyonid	Camelid
Bassariscops	Gen. undet.
Mastodont	Oreodont
Trilophodon	Gen. undet.
Chalicotherid	Antilocaprid
Moropus	Gen. undet.
Rhinocerotid	
Aphelops	

From Saratoga Basin

Mustelid	Camelid
Gen. nov.	*Gentilocamelus*

In a written communication (May 1962) J. D. Love told me, however, that the age of the Browns Park Formation in the type locality itself may be in doubt, and that there may, in fact, be two formations there instead of one. In the first place, he recalled the fact that there is an angular unconformity of about 16° within the Browns Park Formation (Sears, 1924a, p. 296); and, in the second place, samples from the type locality collected by W. R. Hansen of the Survey contain diatoms determined by K. E. Lohman, also of the Survey, to be of Pliocene age (unpub. data). Plainly more study is needed in the type locality.

SPLIT ROCK FORMATION

The white, tuffaceous, and sandy beds, which resemble the Browns Fork Formation and which Pipiringos (1962, p. A35–A37) called Browns Park(?) in the northern part of his area (from the east side of T. 26 N., R. 95 W. to the NW. cor. T. 26 N., R. 97 W.), have subsequently been redefined by J. D. Love (1961a, I5–I8) as the Split Rock Formation. Most of the area shown along the northeast edge of the geologic map (pl. 1) as undifferentiated Oligocene and Miocene belongs, in fact, to the Split Rock Formation.

On the basis of vertebrate fossils found in this formation, it is of early and middle Miocene age (Love, 1961a, p. I24). Indeed, the uppermost part of the Split Rock Formation may possibly be of late Miocene age. The Split Rock Formation, therefore, is in part at least correlative with the Browns Park Formation farther south.

IGNEOUS ROCKS

At the north end of the Rock Springs uplift is a rather widely scattered group of buttes capped by one or more flows of the leucite-rich lava, wyomingite. In addition to the buttes are a few spines of the same kind of rock that obviously are remnants of feeder pipes. Similar feeders doubtless exist under several of the buttes. Two low pumice cones on Steamboat Mountain (T. 23 N., R. 102 W.) indicate that it surely was the site of a vent.

Pilot Butte (T. 19 N., R. 106 W.) is an isolated small butte, also capped by wyomingite, that is 20 miles southwest of the other plugs and lava-capped hills. The lava here contains throughout a great number of fragments and blocks of shale from the underlying Green River Formation. These range from half-inch flakes to blocks 2½ feet long. All are baked to a greenish or yellowish gray, some appear to be sintered, and others are rounded and contain fused vesicular masses. Nevertheless, most of them retain their original bedding. These inclusions of the underlying bedrock are so numerous and so uniformly distributed through the flow that a feeder pipe must make up the core of the butte.

According to Kemp and Knight (1903), these lavas consist principally of leucite and phlogopite, together with a small amount of diopside and hornblende, in a gray-green glass. The accessory minerals are rutile and apatite. Schultz and Cross (1912) made a study of of these lavas as a possible source of potash.

These lavas postdate the Bridger epoch and, as they rest on erosion surfaces not far above the present general terrain and are not known to be overlain by such formations as the Browns Park, are inferred to be of late Tertiary age.

This inference was verified by Prof. S. S. Goldich, then of the University of Minnesota, now with the Geological Survey, who made a potassium-argon age determination on the phlogopite mica from two samples of the lava collected in 1958 on Zirkle Butte by Richard Johnston, then a graduate student at the University of Wyoming, now with the Geological Survey. The samples came, respectively, from SE¼SE¼NW¼ sec. 1, T. 22 N., R. 103 W., and NE¼SE¼SE¼ sec. 15, T. 21 N., R. 102 W., Sweetwater County, Wyo. Goldich found that the argon contents of these samples are so low that he was unable to make a satisfactory determination. He expressed the opinion (written communication, July 15, 1959) that the rocks were, however, probably less than 5 million years old. As a further check on this he sent the samples to Dr. Oliver Schaeffer at the Brookhaven National Laboratory, whose argon apparatus was geared to the determination of small quantities of argon. Dr. W. A. Bassett, then of that Laboratory, determined the age as about 1.25×10^6 years. This makes the wyomingite lavas of latest Pliocene age.

MEASURED SECTIONS OF THE GREEN RIVER, WASATCH, AND BRIDGER FORMATIONS

The following abbreviations are used in the measured sections given here:

- c, Unit contains mud cracks;
- f, Unit contains fossil fish;
- s, Unit contains salt crystal molds.

Brackets indicate Culbertson's (1961, p. D172, fig. 348.2) key sandy-mudstone units.

Boldface indicates beds in rhythmic sequence.

Section of the Laney, Wilkins Peak, and Tipton Shale Members of the Green River Formation and part of the Wasatch Formation in sec. 1, T. 18 N., R. 106 W.

Key unit		Ft	in
	Green River Formation:		
	Laney Shale Member:		
	Marlstone, buff, chalky to hard, chippy to platy; interbedded with gray silty shale, a few beds of rich oil shale, and buff even-grained crossbedded to massive crystal tuff in lenses and irregular beds near the base; these tuffs are poorly exposed here	500+	
	Marlstone, buff, soft, papery; interbedded with sandy shale layers	25	0
	Marlstone, buff, chalky, platy	2	6
	Oil shale, low-grade, flaky to papery; grades upward into organic-poor buff papery marlstone that contains many paper-thin laminae of rich oil shale	24	0
	Thickness, Laney Shale Member	551+	
	Wilkins Peak Member:		
	Marlstone, buff, soft, papery; poor in organic matter	9	0
	Organic marlstone, buff to gray	1	0
	Sandstone, limy, muddy, fine-grained, platy, ripple-bedded	2	6
	Oil shale, low-grade, papery	1	0
	Sandstone, limy, muddy, fine-grained, ripple-bedded	2	6
	Shale, flaky; in part thin-bedded organic marlstone	7	0
	Green River Formation—Continued		
	Wilkins Peak Member—Continued		
	Oil shale, low-grade, flaky	2	0
	Sandstone, limy, muddy, fine-grained, ripple-bedded	2	0
	Shale, flaky; contains layer of papery oil shale about 1 ft thick in middle	5	0
	Sandstone, limy, muddy, fine-grained, platy ripple-bedded	2	6
	Shale, light-gray, sandy, flaky	3	0
	Oil shale, low-grade, papery to flaky	2	0
	Shale, light-brown, flaky	2	6
	Sandstone, medium-grained		10
	Shale, grayish-brown, soft, flaky; contains groups of thin sandstone beds	15	0
	Sandstone, gray, limy, muddy, fine-grained, ripple-bedded	2	6
	Oil shale, low-grade, soft, papery	1	6
	Sandstone, limy, muddy, fine-grained, ripple-bedded	2	4
	Shale, sandy, platy, thinly laminated	1	6
	Oil shale, low-grade, bluish-gray, flaky	2	0
	Sandstone, very limy, muddy, hard, platy, ripple-bedded	2	6
	Oil shale, very low-grade, brownish-buff, soft, papery; contains a few thin laminae of purplish-gray rich oil shale	1	4
Unit I	Mudstone, greenish-drab, soft; unit also contains some greenish-gray flaky shale	24	0
Unit I	Sandstone, very limy, muddy, fine-grained, in part shaly	1	0
	Oil shale, low-grade, papery; contains thin layers of rich oil shale	1	6
	Shale, light-brown, flaky	4	0
	Oil shale, very low-grade, papery		6
	Shale, gray, soft, flaky	4	0
	Shale, sandy, and thin sandstone beds	1	6
	Oil shale, low-grade, buff, papery	1	0
	Oil shale, massive; estimated 25 gallons per ton		8
	Shale, brownish-gray, soft, flaky; contains thin group of thin limy tuff beds near base, Big Island tuff	22	6
	Oil shale, medium-grade, papery	1	0
	c Sandstone, limy, fine-grained, platy; interbedded with sandy shale; all ripple bedded; many surfaces mud cracked; mud lumps common	14	0
	Shale, drab to brownish gray, flaky	4	0
	Oil shale, low-grade, bluish-gray, papery	2	6
	Shale, light-brown to drab, flaky	19	0
	c Sandstone, very limy, hard, platy; a few bedding planes mud cracked	1	5
	Shale, brown, soft, flaky; contains considerable organic matter at base but progressively less upward	5	6
	Oil shale, medium-grade, papery	2	0
	Shale, greenish-gray, very soft, papery	2	0
	Shale, very sandy; alternates with beds of very limy sandstone and sandy limestone; contains a few mud lumps	8	0
	Oil shale, low-grade, flaky to papery		8

Green River Formation—Continued

Wilkins Peak Member—Continued

			Ft	in
		Mudstone, greenish-drab, soft	9	0
		Shale, papery; contains considerable organic matter	1	0
		Shale, gray, sandy, soft, flaky	2	0
	c	Limestone, sandy, ripple-bedded and mud-cracked		5
		Sandstone, very limy, moderately fine grained, massive but lenticular		8
		Shale, light-brown, flaky; considerable organic matter at base but decreases upward; unit grades upward into barren sandy shale	3	6
		Oil shale; lower third low grade and papery; middle third rich and massive; top third less rich and flaky but contains a few thin lenses of rich oil shale	3	5
		Shale, drab, soft; poorly developed fissility	3	0
		Sandstone, very limy, fine-grained, ripple-bedded		2
		Shale, flaky		6
	c	Sandstone, very limy, fine-grained, ripple-bedded and mud-cracked		2
		Marlstone, organic, chocolate-brown, platy to chippy	2	0
		Sandstone, very limy, fine-grained, ripple-bedded		3
Unit H		Shale, drab, soft, flaky	12	0
Unit H	c	Marlstone, sandy, platy, mud-cracked		2
Unit H		Oil shale, low-grade, papery; contains thin lenses of massive rich oil shale	1	6
Unit H		Sandstone, very limy, fine-grained, ripple-bedded		4
Unit H		Mudstone, greenish-gray, soft	7	6
		Oil shale, rich; weathers blue; fairly short lens		1½
		Oil shale, low-grade, flaky; weathers blue gray	1	0
	c	Sandstone, very limy, fine-grained, ripple-bedded and mud-cracked		6
		Shale, greenish-drab, soft, flaky	3	6
	c	Sandstone, muddy; alternates with thin sandy shale layers; one layer of sandy edgewise conglomerate; mud cracks and ripple marks plentiful	1	6
		Shale, sandy and limy, soft, flaky	1	6
		Edgewise conglomerate in limestone matrix, very sandy		1
		Limestone, sandy, dense; contains mud lumps		2
		Shale, flaky	1	0
Unit G		Mudstone, drab, soft	6	0
Unit G	c	Limestone, white, sandy, hard; weathers brown; contains many shale fragments and mud lumps; ripple bedded and remarkably persistent		8
Unit G		Marlstone, brownish-buff, rather soft, laminated; weathers white; contains many carbonaceous fragments; alternates with a few thin limy ripple-bedded sandstone beds	1	6

Green River Formation—Continued

Wilkins Peak Member—Continued

			Ft	in
Unit G		Mudstone, light-gray; contains greenish-gray lumps; poor fissility	5	0
Unit G	c	Marlstone, sandy, platy, ripple-bedded and mud-cracked		10
Unit G		Shale, light-grayish-brown; massive but laminae visible; soft; becomes sandy upward	2	6
Unit G		Mudstone, so carbonaceous that it is nearly black; rich in iron oxide		6
Unit G		Mudstone, greenish-gray, sandy, hard	2	6
Unit G	c	Sandstone, very limy, muddy, platy, ripple-bedded and mud-cracked		6
Unit G		Mudstone, drab to greenish-gray, soft; contains streaks of iron oxides	7	0
		Shale, light-chocolate-brown, flaky	2	0
	c	Sandstone, light-gray, very limy, medium-grained, iron-stained, ripple-bedded and mud-cracked	1	0
		Shale, light-grayish-brown, soft, flaky		8
		Sandstone, very limy, fine-grained, ripple-bedded		11
		Shale, light-brown, soft, flaky		4
		Limestone, sandy, hard, platy, ripple-bedded		10
		Shale, light-brown, soft, flaky	2	0
		Mudstone, drab, limy, very soft	4	0
	c	Marlstone, light-grayish-brown; contains many thin siliceous layers that are mud cracked	9	0
		Oil shale, flaky to papery; weathers white; apparent slight gas brecciation; grades upward into buff varved organic marlstone	1	6
		Marlstone, sandy; contains many large mud lumps		3
		Marlstone, light-grayish-brown; alternates with thin beds of siliceous limestone	1	3
		Marlstone, light - brownish - gray; weathers white; soft, almost flaky	3	0
		Marlstone, light - brownish - gray; weathers white; contains many thin siliceous limestone beds	9	0
Unit F	c	Marlstone, sandy; alternates with muddy marlstone layers; some edgewise conglomerate; harder layers are ripple bedded and mud cracked; 1-inch volcanic ash layer in middle	4	6
Unit F		Marlstone, drab or gray, silty, massive	3	0
Unit F		Shale, light-chocolate-brown, flaky to papery; contains five thin siliceous ripple-bedded limestone beds	2	6
Unit F		Mudstone, grayish-green, much iron oxide stain; locally contains much carbonaceous stuff	2	0
		Marlstone, light-grayish-brown, chippy, ripple-bedded	3	0
		Sandstone, very limy, fine-grained, ripple-bedded		2
		Marlstone, light - grayish - brown, coarsely chippy	8	0
	c	Marlstone, very sandy; ripple marked at top; several layers mud cracked	1	3

Green River Formation—Continued

Wilkins Peak Member—Continued

Unit		Ft	in
	Marlstone, light-yellowish-brown, chalky		3
	Marlstone, sandy, hard		6
	Marlstone, light-yellowish-brown, chalky		5
	Marlstone, sandy, hard		5
	Marlstone, light-yellowish-brown, chalky		11
	Marlstone, sandy, hard		2
	Marlstone, light-yellowish-brown, chalky		6
	Oil shale, low-grade, papery, gas-brecciated		10
Unit E	Mudstone, grayish-drab, sandy, hard	6	0
Unit E	Sandstone, limy, fine-grained; alternates with sandy platy mudstone	4	0
Unit E	Mudstone, greenish-drab, sandy, rather hard; slightly carbonaceous and flecked with iron oxide	7	6
Unit E	Shale, drab, limy, coarsely chippy; small quantity of organic matter	4	0
Unit E	Mudstone, very dark gray, carbonaceous and iron-stained; weathers rusty lavender		6
Unit E	Mudstone, greenish-drab	7	6
	Marlstone, light-gray, very clayey; becomes more limy upward	4	0
	Oil shale, medium-grade, papery, gas-brecciated		6
	Marlstone, sandy, hard; full of mud lumps; gently crossbedded		1
	Marlstone, light-gray, very clayey; becomes more limy upward	5	0
	c Marlstone, silty, hard; many bedding planes mud cracked; alternates with softer more muddy layers; all weathers nearly white	9	0
	Shale, light-gray, soft, flaky	6	6
	Sandstone, very muddy, fine-grained; beds thin and lenticular; alternate with sandy platy layers of mudstone	1	6
Unit D	Mudstone, greenish-drab, hard; weathers ash gray	5	6
Unit D	Shale, sandy, greenish-drab, hard, platy		8
Unit D	Shale, sandy, greenish-drab, hard, flaky	4	0
Unit D	Shale, light-greenish-brown, flaky	3	0
Unit D	Shale, greenish-gray, very soft; poor fissility	4	0
Unit D	c Sandstone, muddy; brownish buff on on fresh surface; weathers dark reddish brown; fine grained; very micaceous; ripple bedded and crossbedded; some bedding planes mud cracked; along strike and downdip such sandstone lenses grade into sandy greenish-drab mudstone	20	0

Green River Formation—Continued

Wilkins Peak Member—Continued

Unit		Ft	in
Unit D	Mudstone, greenish-gray, sandy. This unit, together with overlying sandstone, makes up Principal Olive zone (D bed of detailed geologic map, pl. 2)	11	0
	Sandstone, light-gray, very limy, moderately fine grained, ripple-bedded and ripple-marked	1	0
	Mudstone, greenish-gray; nearly pure clay	12	0
	Sandstone, light-gray, very limy, ripple-bedded and ripple-marked; makes persistent bench	6	0
	Mudstone, greenish-gray; not well exposed	9	0
	Sandstone, light-gray, very limy, laminated, ripple-bedded and ripple-marked	1	6
Unit C	Mudstone, greenish-gray to nearly black with carbonaceous matter, soft; well exposed only near top	17	0
Unit C	Sandstone, nearly white, very limy, fine-grained, ripple-bedded		10
Unit C	c Marlstone, sandy, laminated; many layers mud cracked	1	0
Unit C	Sandstone, very muddy, fine-grained; alternates with thin beds of sandy limy mudstone	1	0
	Oil shale, low-grade, coarsely flaky	1	3
	Mudstone, greenish-gray, soft	2	0
	Oil shale, low-grade, papery	1	0
	Mudstone, greenish-gray, soft	2	0
	Shale, flaky to almost papery; contains considerable organic matter	2	0
	c Marlstone, nearly white, sandy; platy bedding; numerous mud-cracked bedding planes	1	6
	Mudstone, greenish-gray, very soft	5	0
	Oil shale, low-grade, papery	2	0
	Sandstone, very limy, fine-grained, platy; doubtful mudcracks		4
	Shale, flaky to almost papery; considerable organic matter	9	6
	Marlstone, light chocolate-brown, coarsely chippy; considerable organic matter	7	0
Unit B	c Sandstone, very muddy, very fine-grained, limy, platy; many bedding planes mud cracked	5	0
Unit B	Shale, greenish-brown, silty, soft	6	6
Unit B	Sandstone, gray, iron-stained, fine-grained, well-sorted, very micaceous, thinly and smoothly bedded or laminated; thin beds are ripple-bedded and whole is crossbedded	6	0
Unit B	Mudstone, greenish-gray; grades upward into muddy fine-grained sandstone	7	0
	Shale, chocolate-brown, coarsely chippy	1	6

Green River Formation—Continued

Wilkins Peak Member—Continued

Unit		Ft	in
	c Sandstone, limy and muddy, very fine-grained; many bedding planes mud cracked	1	0
	Mudstone, greenish-gray; grades from sandy at base to nearly pure clay at top	4	6
	Limestone, massive, crystalline		½
	Oil shale, low-grade, papery	2	0
	c Marlstone, sandy, crudely platy, mud cracked		8
	Oil shale, low-grade, papery; becomes less rich in organic matter upward	5	0
	c Marlstone, sandy, crudely platy; many bedding planes mud cracked	3	2
	Shale, flaky to almost papery; organic matter moderately abundant at base but decreases upward	5	6
	c Marlstone; dense and massive at base, grades upward into platy marlstone; several bedding planes mud cracked	1	6
	Mudstone, greenish-gray, soft	7	0
	Shale, light-chocolate-brown, coarsely flaky; much organic matter	2	6
Unit A	c Sandstone, muddy, fine-grained, ripple-bedded; many bedding planes mud cracked	2	0
Unit A	Shale, sandy, flaky; very little lime or organic matter	6	0
Unit A	Sandstone, greenish-gray, muddy, very fine grained, ripple-bedded and crossbedded	2	6
Unit A	Sandstone, light-gray, fine- to coarse-grained, micaceous, ripple-bedded and crossbedded	6	0
Unit A	Shale, sandy soft	11	6
Unit A	Tuff, No. 2 of Culbertson, very sandy, fine-grained		8
Unit A	Mudstone, greenish-gray	11	0
	Shale, flaky; contains some organic matter	2	6
	Marlstone, gray, sandy, very fine grained, platy		6
	Mudstone, greenish-gray, soft	4	0
	Marlstone, gray, sandy, very fine grained, platy	1	6
	Marlstone, light-brown, clayey, soft, flaky to blocky	7	6
	c Sandstone, light-gray, limy; many beds ripple bedded and mud cracked; some bedding planes contain numerous mud flakes and lumps	3	0
	Shale, brown, soft, clayey, flaky; becomes more sandy toward top	7	0
	Sandstone, light-gray to buff, iron-stained, fine-grained; bedding suggested by color banding		4
	Shale, brown, soft, flaky to blocky	7	0
	Marlstone, light-gray, sandy; thinly laminated to platy; locally crossbedded	7	0

Green River Formation—Continued

Wilkins Peak Member—Continued

	Ft	in
Shale, grayish- to greenish-brown, soft, flaky	19	0
Marlstone, silty, hard, platy		8
Shale, grayish- to greenish-brown, soft, flaky	32	0
Tuff, No. 1 of Culbertson, Firehole analcite of Love; light-gray; strongly stained with iron oxides; weathers reddish brown and makes small but easily traceable bench; consists very largely of analcite crystals		4
Shale, brown, soft, flaky	23	0
Marlstone, sandy, platy	1	0
Shale, soft, flaky; contains considerable organic matter	12	6
Marlstone, sandy, platy	4	0
Mudstone, grayish-brown, blocky, soft	7	0
Marlstone, sandy, platy		6
Marlstone, organic, chocolate-brown; weathers gray, soft chippy; makes earthy slope	5	0
c Marlstone, sandy; irregular platy bedding; many bedding planes mud cracked	1	0
Marlstone, organic, and low-grade oil shale; oil-shale zones papery; organic marlstone massive to chippy	16	6
Marlstone, light-gray to ocherous buff, shaly; unit contains two thin zones of papery low-grade oil shale	13	0
Marlstone, light-gray to buff, silty to sandy; rather regular platy bedding	8	0
Shale, chocolate-brown; weathers gray, flaky to chippy	2	0
Marlstone, buff, sandy; platy bedding	2	0
Marlstone, organic; contains thin siltstone layers	11	0
c Sandstone, very limy, light-gray to ocherous buff, platy; wavy bedding, in part crossbedded; some beds mudcracked; some beds thinly laminated	8	0
Thickness, Wilkins Peak Member	833	

Tipton Shale Member:

	Ft	in
Shale, gray, flaky; nearly free of organic matter	4	0
Oil shale, low-grade, flaky; contains several thin short lenses of rich oil shale near base; upper half less rich in organic matter and grades upward into chippy marlstone	18	0
Oil shale, rich, lenticular; contains abundance of pyrrhotite		3
Oil shale, low-grade, gray, flaky to almost papery; contains thin pancake-shaped dolomitic limestone concretions that are poor in organic matter	11	0
Tuff, gray, micaceous, very fine grained		1

Green River Formation—Continued

Tipton Shale Member—Continued

	Ft	in
Oil shale; many thin rich beds separated by lower-grade flaky oil shale; unit contains thin discoid limestone concretions; thin rich oil-shale beds contain abundant pyrrhotite crystal aggregates	3	0
Tuff, reddish-brown, earthy, very fine grained		5
Oil shale, low-grade, flaky; contains several thin (1–3 in.) layers of rich oil shale	1	0
Oil shale, rich, reddish-brown; massive with papery phases; contains many thin limy concretions	2	2
Tuff, soft, sandy		1
Shale, hard, lumpy and chippy, poor in organic matter		3
Marlstone, dense, platy; wavy bedding		4
Shale, gray, hard, lumpy to chippy; poor in organic matter; contains many limy lenses	9	0
Oil shale, low-grade, papery to flaky; contains many short irregular lenses of silty marlstone	3	6
Oil shale, medium-grade, black, massive to papery; weathers gray		6
Shale, light-chocolate-brown, soft, papery	4	6
Tuff, white, powdery		2
Shale, light-chocolate-brown, papery to flaky, soft	53	0
Shale, chocolate-brown, rather hard and limy, coarsely chippy	2	0
f Shale, light-chocolate-brown, papery; contains bones and scales of small fish	13	0
Limestone, sandy, irregular; platy bedding; almost a coquina of ostracod valves		5
f Shale, chocolate-brown, slightly carbonaceous, soft, papery; many bedding surfaces contain bones and scales of small fish	9	0
Limestone, gray, dense, sandy; contains fine tubules		6
Shale, gray, flaky	4	0
Limestone, sandy; rich in ostracodes		1
Shale, blocky to chippy		6
Limestone, brown, sandy persistent; rich in ostracodes		2
Shale, chocolate-brown, soft, flaky	9	6
Shell marl, muddy, gray, hard, crudely bedded; contains great abundance of *Goniobasis* and *Unio* shells	1	0
Shale, chocolate-brown, soft, papery	2	0
Shell marl, black, dense; considerable organic matter; contains abundance of broken shells of *Goniobasis* and *Unio*		2
Thickness, Tipton Shale Member	153	7

Wasatch Formation:

	Ft	in
Shale, greenish-gray, very soft, crudely fissile; contains dense limestone concretions and zones of very fine grained carbonaceous sandstone; top few inches more sandy, carbonaceous, and iron stained	15	0
Mudstone, drab; contains zones of very fine grained greenish-gray sandstone that is nearly unconsolidated	18	0
Sandstone, gray, virtually unconsolidated; contains many muscovite flakes; sand grains in lower part are $1/10$–$1/2$ mm in diameter; grades gradually upward through finer and finer sand into soft clayey mudstone at top	17	0
Mudstone, greenish-drab	35	0
Mudstone, brownish-maroon; weathers pink	53	0
Partial section, Wasatch Formation	138	

Section of the Green River Formation (Tipton Shale, Wilkins Peak and Laney Shale Members) and the uppermost part of the Wasatch Formation in sec. 33, T. 21 N., R. 105 W.

Green River Formation:

Laney Shale Member:

	Ft	in
Marlstone and limy shale, brownish to yellowish-buff, soft, chippy to flaky; at intervals of a few tens of feet are thin irregular medium- to coarse-grained dark-brown sandstone beds; unit also contains occasional thin hard layers of white porcelanous marlstone which are probably tuffaceous; whole unit poorly exposed	300	0
Tuff, white; fine nodular structure; thin bedded at base, massive in upper part	1	1
Shale, brown, soft, papery; weathers brownish-lavender; contains considerable organic matter—some is medium-grade oil shale; unit contains many thin platy sandstone beds near the base, but top 30 ft is virtually unbroken shale; shale laminated, and much of it is varved; one-quarter-inch bed of analcitized tuff near top	43	0
Shale, light-chocolate-brown, flaky to papery	2	6
Oil shale, low-grade, chocolate-brown, flaky to papery; weathers bluish gray	1	3
Thickness, Laney Shale Member	348	

Wilkins Peak Member:

	Ft	in
Sandstone and sandy shale	5	0
Shale, gray, sandy; very little organic matter	1	0

Green River Formation—Continued

Wilkins Peak Member—Continued

		Ft	in
	Sandstone, limy, medium-grained, and sandy shale	4	6
	Shale, greenish-brown; weathers light bluish gray; lower part contains considerable organic matter but grades upward into barren sandy shale	14	0
	Tuff, buff, soft, earthy	1	0
	Sandstone, limy, medium-grained, platy; muddy at base	1	0
	Shale, chocolate-brown, flaky; considerable organic matter	1	6
s	Shale, chocolate-brown flaky, contains great abundance of shortite molds	2	0
	Shale, chocolate-brown, flaky: considerable organic matter	1	0
	Shale, greenish-brown, soft, flaky	3	6
	Sandstone, white, medium-grained, sugary-textured; crudely platy and ripple bedded; muddy at base	2	0
	Shale, greenish-gray, sandy, crudely flaky; contains one 8-inch zone that contains considerable organic matter	8	0
	Oil shale, rich, bluish-black, massive		6
	Shale, greenish-brown, very soft, flaky	6	4
	Marlstone, brown, soft		8
	Sandstone, limy, and sandy marlstone; in alternate beds ½ to 2 in. thick; medium fine grained	3	6
	Marlstone, organic, brown, platy	1	0
Unit I	Mudstone, greenish-gray, soft; contains a few sandy layers	14	6
	Oil shale, low-grade, light-bluish-gray, papery to massive		3
	Marlstone, chocolate-brown, laminated	1	0
	Mudstone, greenish-drab, clayey, soft	15	0
	Marlstone, sandy, platy		2
	Shale, buff, soft, papery; considerable organic matter	1	6
	Oil shale, medium-grade, massive to nearly papery		4
	Marlstone, light-brown, silty, platy	1	0
	Shale, chocolate-brown, soft, flaky to chippy	1	0
	Sandstone, very limy, muddy, fine-grained, platy		10
	Shale, chocolate-brown, soft, flaky to chippy	2	6
	Marlstone, sandy, platy		6
	Mudstone, greenish-brown, soft, lumpy	1	8
	Sandstone, nearly white, very limy and muddy, fine-grained, platy	1	6
	Mudstone, greenish-drab, very soft; contains a few harder sandier layers	18	0
	Shale, chocolate-brown, soft, flaky to chippy; contains thin groups of platy sandy marlstone layers; some shale zones contain nearly enough organic matter to be classed as low-grade oil shale	36	0

Green River Formation—Continued

Wilkins Peak Member—Continued

		Ft	in
	Marlstone, organic, gray, chippy	1	0
	Shale, greenish-gray, soft, flaky	2	0
	Sandstone, limy, muddy, platy	1	0
	Shale, greenish-gray, soft flaky	1	6
	Sandstone, limy, muddy, platy		5
	Shale, greenish-gray, soft, flaky	4	0
	Sandstone, limy, muddy, platy		3
	Shale, greenish-gray, soft, flaky	10	0
c	Sandstone, limy, muddy, platy, mud-cracked		6
	Shale, gray, flaky; virtually no organic matter	1	6
	Oil shale, medium-grade		1
	Shale, light-brown, flaky to chippy	1	0
	Oil shale, rich; weathers nearly papery		4
	Shale, gray, soft, flaky	1	0
	Sandstone, very limy, platy, ripple-bedded		3
	Shale, gray, soft, flaky	1	0
	Sandstone, very limy, platy, ripple-bedded		3
	Shale, gray, soft, flaky		8
	Sandstone, very limy, platy, ripple-bedded		3
	Shale, light-chocolate-brown, flaky	1	0
	Mudstone, greenish-drab, soft	7	0
	Shale, soft, flaky; considerable organic matter; somewhat carbonaceous		3
	Mudstone, greenish-buff, soft, blocky to flaky	4	0
	Marlstone, silty, coarsely chippy to platy	2	0
	Sandstone, very limy, muddy, fine-grained, hard		3
	Mudstone, greenish-gray, sandy; weathers to puffy soil	6	0
	Sandstone, limy, fine-grained, ripple-bedded with oscillation ripples		3
	Mudstone, greenish-gray, sandy, hard, blocky	5	0
	Marlstone, nearly white, dense, platy	1	5
	Shale, chocolate-brown, soft, chippy		10
c	Sandstone, limy and muddy, fine-grained; wavy bedding; mud cracked	1	0
	Shale, light-brownish-gray, soft, flaky		6
	Sandstone, limy and muddy, fine-grained; crudely bedded		2
	Shale, sage-gray, soft, flaky		3
	Sandstone, limy and muddy, fine-grained; wavy bedding		2
	Shale, sage-gray, soft, flaky		3
	Sandstone, limy and muddy, fine-grained; wavy bedding		2
	Shale, sage-gray, soft, flaky		4
	Sandstone, limy; contains mud lumps		2
	Shale, sage-gray, soft, flaky	1	6
c	Marlstone, light-greenish-gray, silty and muddy, platy; bedding planes mud cracked		2
	Mudstone, drab, blocky; weathers to smooth slope	5	0

	Ft	in
Green River Formation—Continued		
Wilkins Peak Member—Continued		
c Marlstone, nearly white; contains layers of sage-green clayey marlstone; many bedding planes mud cracked	2	3
Shale, greenish-gray, clayey, very soft, flaky	9	0
Marlstone, light-gray, clayey, hard, massive	8	0
Marlstone, light-grayish-brown, very soft	11	0
Mudstone, grayish-brown, very soft	3	6
Marlstone, light-grayish-brown; weathers light ash gray, as coarse chips or plates	1	0
Mudstone, greenish-gray, sandy, hard	10	6
Tuff, white, limy, friable, sandy-textured, regularly laminated; contains great abundance of biotite; makes very persistent ledge	5	0
Shale, very limy, light-grayish-brown; poor in organic matter	28	0
Shale, grayish-buff, soft, flaky	3	0
Mudstone, greenish-drab, sandy, hard	7	0
Marlstone, light-chocolate-brown, coarsely chippy	1	6
Mudstone, greenish-drab, sandy, hard	8	0
c Limestone, silty, platy, mud-cracked		3
Mudstone, greenish-gray; grades upward into shale	5	5
Sandstone, limy, hard, fine-grained, ripple-bedded	3	0
Marlstone, light-chocolate-brown, crudely chippy; weathers ash gray	2	0
Limestone, sandy, fine-grained		3
Marlstone, light-chocolate-brown, crudely chippy; contains thin sandy layers		8
Limestone, sandy, fine-grained		1
Marlstone, light-chocolate-brown, crudely chippy; weathers ash gray	4	6
Shale, very clayey; poor fissility	2	6
c Sandstone, very limy, platy-bedded to ripple-bedded; uppermost surface mudcracked		10
Mudstone, sandy	3	0
Marlstone, light-grayish-brown, crudely platy or chippy; weathers gray	2	0
Oil shale, low-grade, papery; weathers lavender	2	0
Marlstone, light-grayish-brown; crudely platy or chippy	1	0
Mudstone, chocolate-brown	2	0
Oil shale, low-grade, papery; weathers lavender	1	5
Marlstone, light-grayish-brown; crudely platy or chippy; weathers light ash gray	5	8
Oil shale, low-grade; papery	2	2
Mudstone, greenish-gray, hard	7	5
Marlstone, light-grayish-brown, platy to chippy; weathers light gray	1	6
Mudstone, greenish-gray; contains few thin marlstone layers	15	0
Marlstone, light-grayish-brown, platy to chippy; weathers light gray	2	6

	Ft	in
Green River Formation—Continued		
Wilkins Peak Member—Continued		
Oil shale, low-grade, papery	1	0
Marlstone, light-grayish-brown, platy to chippy; weathers light gray	1	2
Mudstone, greenish-gray, hard	5	6
c **Marlstone**, light-grayish-brown, platy; weathers nearly white; bedding planes mud cracked	1	0
Mudstone, greenish-drab, rather hard	3	6
Mudstone, greenish-drab, spheroidal to platy	1	0
Mudstone, greenish-drab, soft	3	6
Marlstone, light-grayish-brown, sandy; contains mud lumps	1	0
Mudstone, greenish-drab, soft	3	0
Marlstone, light-grayish-brown; weathers nearly white		10
Mudstone, greenish-drab, soft	3	0
Marlstone, light-grayish-brown; weathers nearly white	1	0
Tuff; consists almost wholly of analcite crystals		1
Marlstone, light-chocolate-brown, hard, massive to platy	15	3
Mudstone, light-grayish-drab, clayey	4	6
Marlstone, light-chocolate-brown, hard, massive to platy	7	0
Mudstone, greenish-drab, clayey, soft	5	0
Marlstone, light-gray; ranges from massive through coarsely chippy to flaky	20	0
Sandstone, limy and muddy, fine-grained, platy		1
Marlstone, brownish-gray, sandy, coarsely chippy to platy; weathers ash gray	15	6
Oil shale, low-grade, papery		6
Marlstone, brownish-gray, sandy, coarsely chippy to platy	10	6
Oil shale, low-grade, papery	1	0
Marlstone, brownish-gray, sandy, coarsely chippy to platy	6	0
Thickness, Wilkins Peak Member	498	
Tipton Shale Member:		
c Oil shale, low-grade; contains many closely spaced thin layers of hard mud-cracked marlstone	14	0
c Marlstone, organic; many bedding planes mud cracked, especially near top of unit; interbedded with thin layers of papery low-grade oil shale	3	0
Oil shale, medium-grade, bluish-gray, papery	5	4
Tuff; made up mostly of small analcite crystals but also contains biotite, hornblende, quartz and feldspar		1½
Oil shale, medium-grade, bluish-gray, papery		5
Limestone, granular; in thin beds		6
Oil shale, medium-grade, bluish-gray, papery		10

Green River Formation—Continued Tipton Shale Member—Continued	Ft	in
Tuff; made up mostly of small analcite crystals but also contains biotite, hornblende, quartz, and feldspar		1
Oil shale, medium-grade, bluish-gray, papery		11
Tuff, white, chalky; probably rich in carbonates		5
Oil shale, low-grade; contains thin marlstone layers		10
Tuff, largely analcite; overlain by brecciated chert		2
c Marlstone, sandy, platy; nearly every thin bed mud-cracked; intervening beds are low-grade papery oil shale	1	0
Oil shale, medium-grade, bluish-gray, papery; contains lenses of massive rich oil shale	2	0
Tuff, soft, powdery; consists largely of very minute analcite crystals		1
Limestone		½
Marlstone, buff, soft, almost papery	1	0
Tuff; largely analcite; iron stained		2
c,f Marlstone, organic, buff, hard, banded; contains a few fishbone fragments; top surface mud cracked	1	0
Shale, buff, soft, papery; contains many ostracodes	2	0
Ostracode limestone, hard; contains many mud lumps		3
Marlstone, buff, soft, papery	2	6
Tuff; lower part analcitized		2
Marlstone, buff, soft, papery	1	0
Tuff; mostly analcite		1
Marlstone, buff, shaly, soft, papery; contains some thin harder marlstone layers	4	0
Tuff, mostly analcite crystals; some crystals as much as 2 mm across; upper part of bed dense		2
Shale, buff, papery	1	0
Tuff, almost wholly analcite crystals; resembles coarse sandstone		5
Marlstone, buff, very soft; weathers papery; contains ostracodes	2	8
Tuff; mostly analcite but contains much biotite		5
f Marlstone, soft; very regular laminations; bedding planes contain many large thin-shelled ostracodes, a few plant stems, and fishbone fragments	3	6
c Sandstone, ocherous, muddy, medium-grained, crudely bedded; contains many thin beds of flaky sandy shale that is ripple bedded; top surface mud cracked	13	0
f Shale, soft, flaky; contains a few thin sandy shale layers and fishbone fragments	5	0
f Sandstone, limy, muddy, very fine grained, ripple-bedded; contains great many fishbone fragments		6
Shale, brown, sandy, soft, flaky	4	0
c,f Sandstone, limy, platy; contains fishbone fragments and rests on mud-cracked surface		3
Shale, light-brown, very soft, papery; contains a few thin harder marlstone layers; weathers buffish lavender	16	0
Tuff; almost wholly analcite crystals; lenticular		1
Marlstone, chocolate-brown; in beds ½ to 2 in. thick that contain a few thin layers of gravelly limy sandstone that contains ostracodes and mud lumps	5	6
Oil shale, low-grade; contains bone fragments and mud lumps		1
Oil shale, low-grade, bluish-gray, papery; contains lenses of medium-grade massive oil shale	3	0
Note: The characteristic fossiliferous basal bed is either so thin that it was missed or it is absent at this place.		
Thickness, Tipton Shale Member	98	

Wasatch Formation:	Ft	in
Mudstone, drab; lower part very sandy	25	0
Sandstone, light-gray, medium-grained, massive to crudely bedded; contains much biotite, suggesting tuff	1	0
Mudstone; sandy at base but becomes less so upward	18	0
Mudstone, brick-red, clayey	2	0
Mudstone, drab, clayey	1	0
Sandstone, light-gray, muddy; virtually unconsolidated	15	0
Mudstone, drab, sandy	11	0
Sandstone, gray, medium-grained; in beds about 1 ft thick; this is a stubby lens, evidently a stream-channel deposit	6	0
Mudstone, drab, sandy	4	0
Sandstone, soft, micaceous, medium-grained	1	0
Mudstone, drab; has few thin maroon layers	10	0
Partial section, Wasatch Formation	94	

Section of the Green River Formation (Tipton Shale, Wilkins Peak, and Laney Shale Members) in sec. 14, T. 23 N., R. 105 W.

Green River Formation: Laney Shale Member:	Ft	in
Marlstone and shale, buff; range from very soft and flaky to hard and crudely platy; unit contains sandstone lenses at 30 and 50 ft above base; upper part consists mostly of grayish-buff hard chippy to platy marlstone that locally contains plant stems and, especially, palm leaves	200	0
Marlstone, buff, muddy, massive; contains many mud lumps	1	0

Green River Formation—Continued

Laney Shale Member—Continued

	Ft	in
Shale, buff, soft, papery; contains a few thin hard layers of marlstone and a few beds of papery low-grade oil shale	30	0
Tuff, ocherous, soft, fine-grained, massive	1	0
Shale, buff, papery; contains a few thin hard layers of marlstone at rather regular intervals	69	0
Marlstone, organic, flaky to massive	1	0
Shale, greenish-gray, soft, flaky; contains layers of low-grade papery oil shale at intervals of 5–6 ft in lower part	29	0
Thickness, Laney Shale Member	331	

Wilkins Peak Member:

	Ft	in
Shale, greenish-gray, soft, flaky	11	0
c Sandstone, limy, very fine grained, platy, mud-cracked		6
Marlstone, flaky	2	3
Mudstone, greenish-gray	1	0
Marlstone, white, hard, lumpy	1	0
Sandstone, limy, muddy, very fine grained, platy	1	0
Shale, grayish-brown, soft, flaky	1	3
Mudstone, carbonaceous and iron-stained		2
Mudstone, greenish-gray, soft	13	0
Marlstone, ash-gray, coarsely lumpy and chippy	4	0
c Marlstone, light-gray, muddy and sandy, mud-cracked		6
c Marlstone, nearly white, hard, chippy; top mudcracked	2	6
Mudstone, dark-greenish-gray, soft	1	0
Marlstone, nearly white, hard, chippy	1	0
Shale, light-chocolate-brown, soft, papery	2	0
Mudstone, greenish-gray, sandy, hard	8	0
Marlstone, nearly white, hard, massive	1	0
Mudstone, greenish-gray, sandy, hard	8	0
Sandstone, buff, medium-grained; contains mud lumps		3
c Marlstone, buff, flaky to coarsely chippy; makes conspicuous band in nearly white marlstone; mud cracked at top	9	0
Mudstone, greenish-gray, soft	5	0
Marlstone, organic, buff, papery	1	0
Shale, greenish-gray, soft	2	0
Oil shale, low-grade, flaky to papery	2	6
Shale, greenish-gray, soft	2	6
Shale, marly and organic; weathers bluish gray	1	6
Shale, greenish-gray, soft	2	6
Shale, marly and organic; weathers bluish gray	5	0
Shale, greenish-gray, soft	3	0
Marlstone, organic, papery	2	0

Green River Formation—Continued

Wilkins Peak Member—Continued

	Ft	in
Shale, greenish-gray, soft	5	0
Marlstone, organic, platy to papery	1	0
Shale, drab, soft, flaky	9	0
Marlstone, organic, papery	3	0
Mudstone, greenish- to brownish-gray, very soft	2	6
Marlstone, organic, flaky to chippy	1	0
Mudstone, greenish-gray to brown, very soft	10	0
Marlstone, organic, coarsely chippy	1	0
Ostracode limestone, sandy; contains many mud lumps and pebbles		4
Ostracode limestone, nearly white and platy		2
Oolite, nearly white		2
Algal reef, laminated		2
Shale, greenish-gray to brown	2	6
c Oolite, platy; contains mud lumps and is mud cracked		6
Sandstone, limy, medium-grained, platy		1
Shale, greenish-gray to brown, soft, flaky	2	6
Shale, greenish-gray, very sandy, micaceous	3	5
Shale, gray, papery to flaky; considerable organic matter	2	6
Sandstone, medium- to coarse-grained; gravel streaks	1	3
Gravel, limy; contains many mud lumps and bone fragments; some of the bone fragments are probably avian		2
Shale, sandy, contorted		8
Oil shale, rich, dark bluish-gray, massive to papery		1
Shale, gray, sandy, micaceous, flaky	2	3
Sandstone, buff, micaceous, massive; contains many mud lumps	3	0
Thickness, Wilkins Peak Member	148	

Tipton Shale Member (location of contact uncertain):

	Ft	in
Algal reef, penicillate	1	2
Sandstone, medium-grained, massive; lenses of gravel	1	0
Shale, sandy, soft, flaky	13	0
Sandstone, dark-brown, coarse-grained, crossbedded		2
Shale, sandy, soft, flaky	1	6
Sandstone, limy; contains mud lumps		1
Shale, muddy, flaky to almost papery	1	0
Sandstone, limy, fine-grained, micaceous, platy		3
Shale, sandy, soft, flaky	3	6
Sandstone, buff, medium-grained, soft, massive	3	0
Shale, sandy, soft, flaky	1	0
Sandstone, very limy, dark-brown, medium-grained		3

Green River Formation—Continued

Tipton Shale Member—Continued

		Ft	*in*
	Shale, sandy, soft, flaky	1	0
	Sandstone, dark-brown, hard, platy		6
	Sandstone, buff, medium-grained, massive to crossbedded	15	0
	Shale, sandy, soft, flaky	3	0
	Sandstone, buff, medium-grained, massive	3	0
	Shale, sandy, soft, flaky	6	0
	Sandstone, dark-brown, strongly iron stained; may be tuff	1	0
	Shale, sandy, very soft, flaky; contains a few harder platy sandstone beds; locally this unit contains much regularly bedded sandstone	29	0
	Sandstone, dark-brown, iron-stained; almost certainly a tuff		2
	Shale, very sandy, flaky; thin platy beds of hard medium-grained sandstone at intervals of a few feet	50	0
	Sandstone, buff, medium-grained, friable, crossbedded	2	6
	Shale, sandy, soft, flaky	3	0
	Sandstone, buff, micaceous, massive, lenticular	1	0
	Shale, sandy, flaky, somewhat limy	20	0
	Sandstone, dark-brown, muddy, fine-grained	1	5
	Shale, sandy, soft, flaky	3	0
	Sandstone, dark-brown, muddy, soft, lenticular		6
	Shale, very sandy, crudely fissile	6	0
	Sandstone, dark-brown, muddy, well-bedded	1	0
	Interval concealed	8	0
	Sandstone, dark-brown, muddy, fine-grained, platy		4
	Interval concealed, probably soft sandy shale	50	0
c	Sandstone, very limy, strongly iron stained, mud-cracked; probably a tuff		2
	Shale, soft, papery	5	0
	Oolite, sandy; contains mud lumps		3
	Shale, soft, flaky	6	0
	Oolite, sandy, fine-grained; contains mud lumps		3
	Shale, soft, flaky; contains some papery low-grade oil shale	5	0
	Marlstone, muddy, dense		6
	Oil shale, low-grade, papery	1	6
	Marlstone, grayish-buff, massive	3	6
	Ostracode limestone, sandy		6
	Sandstone, buff, limy; contains ostracodes		8
	Ostracode limestone, sandy, lenticular		5
	Thickness, Tipton shale member	255	

Underlain by mudstone of the Wasatch Formation.

Section of Green River Formation (Tipton Shale, Wilkins Peak, and Laney Shale Members) and the uppermost part of the Wasatch Formation measured along Sage Creek in the northern part of T. 15 N., R. 106 W.

Green River Formation:

Laney Shale Member:

		Ft	*in*
	Tuff, crystal and lithic, buff, muddy, ocherous, medium- to fine-grained, ripple bedded and crossbedded	50	0
	Marlstone, light-gray, chippy; alternates with beds of soft ocherous sandstone (or crystal tuff?); unit contains some beds of algal deposits that have turbinate heads about 1 ft high	160	0
	Sandstone, very limy, buff, medium-grained		6
	Algal bed, nodular, discontinuous		6
	Shale, buff, soft; alternates with buff sandy marlstone and sandstone layers	55	0
	Partial section, Laney Shale Member	266	

Wilkins Peak Member:

		Ft	*in*
c	Shale, light-gray, soft, flaky; contains many platy layers of sandy marlstone, some of which are mudcracked	25	0
c	Limestone, sandy, platy, mud-cracked	4	0
	Shale, soft; poor fissility	4	6
c	Marlstone, light-gray, sandy, hard, platy, mudcracked	1	0
	Oil shale, low-grade, gray, flaky	17	0
c, s	Marlstone, platy; salt-crystal molds and mudcracks		6
	Shale, light-gray, soft, flaky	10	0
s	Marlstone, organic, gray, platy; a few layers of salt-crystal molds	11	0
	Oil shale, rich		1
	Limestone, light-gray, sandy; banded with dense white porcellanous layers	2	5
c	Marlstone, white, platy; contains many thin sandstone layers and several shaly zones; shaly zones contain a few thin lenses of rich oil shale; mudcracked marlstone layers	21	0
Unit I	Sandstone, limy and muddy, gray, crudely platy	2	0
Unit I	Mudstone and muddy sandstone; greenish-gray platy	5	0
c	Marlstone, sandy; alternates with layers of mudstone that contains many mud lumps; unit contains several thin lenses of rich oil shale; mud-cracked marlstone	5	0
	Shale, greenish-gray, soft, flaky; few thin marlstone layers	22	0
s	**Shale,** brown, soft, flaky; shortite molds	5	0
	Tuff, No. 3(?) of Culbertson, buff, fine-grained, earthy		4

Green River Formation—Continued

Wilkins Peak Member—Continued

			Ft	in
	s	**Marlstone,** shaly, soft; a few large shortite molds	1	0
		Mudstone, limy, rather hard and lumpy	8	0
	s	**Marlstone,** shaly, soft; many shortite molds and molds of interlocking platy crystals	5	0
	s	**Marlstone,** gray, platy; shortite molds	3	6
		Shale, gray, flaky to platy	2	6
	s	**Marlstone,** gray, platy; abundance of shortite molds	1	0
		Shale, soft; with limy concretionary layers	3	0
	s	**Marlstone,** gray, hard, platy; small shortite molds		1
		Interval concealed; apparently soft shale or mudstone containing a few thin marlstone layers	17	0
		Sandstone, gray, limy, medium-grained, platy	1	0
		Interval concealed; apparently soft flaky gray shale and few thin layers of marlstone	30	0
Unit H		Sandstone, gray to buff, ripple-bedded and crossbedded; channels into underlying unit about 2 ft	30	0
Unit H	c	**Marlstone,** sandy, platy, thin-bedded and laminated; many bedding planes have thin films of mud which are mud cracked; some thin layers of flaky mudstone	3	0
Unit H		**Mudstone,** gray, very sandy, fine-grained, ripple-bedded	3	0
Unit H		**Sandstone,** very limy and muddy, ripple-bedded	3	6
	s	**Limestone,** sandy; many layers of interlocking bladed salt-crystal molds	1	0
		Marlstone; bedding planes coated with sand grains	2	0
		Mudstone, light-brown, soft	2	0
	c	**Limestone,** sandy; banded with dense white cellular layers that may represent salt crusts; mud cracked	3	6
Unit G		**Mudstone,** light-brown, soft; contains lenses of olive-brown sandstone	18	0
Unit G		**Sandstone,** gray, limy, hard, fine-grained, regularly-bedded	1	2
Unit G		**Mudstone,** greenish-gray, sandy; contains lenses of ripple-bedded and crossbedded sandstone	18	0
	c, s	**Limestone,** sandy; small quantity of bladed salt-crystal molds; mud cracked	1	0
		Marlstone, sandy, flaky; contains thin sandstone laminae	4	0
		Mudstone, light-brown, soft	2	6
	s	**Limestone,** brownish-buff, sandy, ripple-bedded and irregularly bedded; contains cyclic recurrence of platy salt-crystal molds at 3–3.5-in intervals near middle	6	0

Green River Formation—Continued

Wilkins Peak Member—Continued

			Ft	in
		Marlstone, brown, flaky; weathers gray	1	6
		Mudstone, light-brown, soft	2	0
		Limestone, white, sandy, thin-bedded and ripple-bedded	1	0
		Mudstone, brownish-gray, limy, hard, spheroidal	5	0
	c, s	**Limestone,** sandy, ripple-bedded; contains many mud balls; some bedding surfaces mud cracked and some have bladed salt-crystal molds	1	6
		Algal bed, layered		2
		Sandstone and clay-gall layer; Sandstone is limy; clay galls fill shallow hollows at base of bed		1
		Shale, dark-greenish-gray, clayey, soft; layers of carbonaceous clay	3	0
		Limestone, white, sandy, thin-bedded; interlaminated with dense translucent carbonate layers; contains many mud lumps and is, in part, ripple bedded	2	6
Unit F		**Mudstone,** gray, sandy; contains a few platy ripple-bedded sandstone layers	29	6
		Marlstone, brown; weathers gray; in part ripple bedded; possibly mud cracked	3	0
		Limestone, very sandy; contains many small mud flakes		6
		Mudstone, gray, sandy	2	0
	c	**Marlstone,** gray; contains more organic matter upward; contains sandy layers; many bedding planes mud cracked	7	0
		Limestone; banded with dense white carbonate layers; some beds show oscillation ripple marks, others show feeble current ripples; apparent raindrop impressions	4	0
		Tuff, white, soft, sugary		4
Unit E		**Mudstone,** greenish-gray; contains thin sandstone lenses	38	0
		Limestone, silty; weathers reddish-gray; probably tuff		4
		Mudstone, greenish-gray	2	0
		Marlstone, light-gray, muddy, lumpy	3	0
	c	**Limestone,** white, sugary, layered, mud-cracked	4	0
		Marlstone, gray, muddy, lumpy	4	0
		Tuff, grayish-brown, limy, fine-grained, dense		6
Unit D		Sandstone, micaceous, medium-grained, ripple-bedded and crossbedded	22	0
Unit D		Mudstone, slate-gray, very sandy	2	0
Unit D		Sandstone. limy, ripple-bedded; contains buff limy layers that contain mud lumps	2	0
Unit D		Mudstone, slate-gray, very sandy; contains lenses of sandstone	22	0

Green River Formation—Continued

Wilkins Peak Member—Continued

			Ft	in
Unit D		Limestone, white, crystalline, granular, platy		8
Unit D		Sandstone, muddy, micaceous, fine-grained, ripple-bedded; contains zones of sandy greenish-gray mudstone	9	0
Unit D		Mudstone, greenish-gray, sandy	3	0
Unit D	s	Sandstone, very limy, ripple-bedded; contains small salt-crystal molds	6	0
	c,s	Marlstone, light-gray, sandy; thin regular beds whose upper surfaces are mud cracked and are covered with molds of bladed salt crystals; between these thin marlstone beds are layers of unidentified white powdery material, possibly tuff	11	0
		Algal bed, buff, coarsely laminated		4
Unit C		Mudstone, brownish-drab	3	0
Unit C		Sandstone, white, extremely limy, ripple-bedded; bedding surfaces pitted as though salt crystals had once been there	1	6
Unit C		Algal bed, buff, coarsely lamiuated		5
Unit C		Shale, sandy, soft, palty		8
Unit C		Mudstone, greenish-gray, sandy, rather hard; thin beds of greenish-gray muddy sandstone make up about 5 percent of unit; mud lumps and plant fragments at top	34	0
Unit C		Sandstone, light-gray, very limy, medium-grained, ripple-bedded	1	0
		Marlstone shaly, soft; interlaminated with sandy zones	2	8
		Mudstone, greenish-gray, sandy	4	0
		Marlstone organic, sandy, hard, platy		6
		Mudstone, greenish-gray, sandy	4	0
		Marlstone, organic, sandy, hard, platy	1	0
		Mudstone, greenish-gray, sandy	5	0
		Sandstone, light-gray, limy, platy, ripple-bedded	2	0
		Shale, gray, limy, soft, flaky	7	0
		Mudstone, greenish-gray, sandy	2	6
	c	**Sandstone**, buff, very limy, ripple-bedded; contains mud lumps and is mud cracked	2	6
Unit B		Mudstone, greenish-gray, sandy; contains two zones of platy sandstone lenses	33	0
Unit B	c	Marlstone, organic, hard, platy; top surface mud cracked	1	6
Unit B		Oil shale, low-grade, brownish-gray, papery	1	0
Unit B		Mudstone, greenish-gray, sandy	3	0
	c	Marlstone, sandy, crudely platy; bedding planes mud cracked	1	0
		Shale, brown, soft, flaky to papery	2	6
		Shale, gray, flaky to chippy, hard	7	6
	c	Shale, gray, sandy, interbedded with gray shale; sandy layers mud cracked; thin layer of edgewise conglomerate at top	1	0
Unit A		Mudstone, greenish-drab, sandy, soft; contains lenses of platy sandstone	8	0
Unit A		Sandstone, gray, muddy, fine-grained, thin-bedded, ripple-bedded and crossbedded; weathers brown; grades upward into coarser grained sandstone; unit contains lenses of gray sandy mudstone	25	0
Unit A		Mudstone, drab		10
Unit A		Sandstone, muddy, shaly	2	0
Unit A	s	Marlstone, light-brown, dense; contains salt-crystal pseudomorphs	1	10
Unit A		Tuff, No. 2 of Culbertson, silty		6
Unit A		Oil shale, low-grade, laminated; contains plant fragments		6
Unit A		Sandstone, drab, very muddy, shaly	16	0
Unit A		Mudstone, greenish-gray, sandy	3	0
		Marlstone, light-chocolate-brown, flaky to chippy	3	0
	c	Sandstone, limy, hard, platy, ripple-bedded and mud cracked	3	0
		Shale, grayish-green, sandy, soft	7	0
		Marlstone, organic, light-chocolate-brown, coarsely laminated; weathers gray; a few carbonized plant stems	7	6
		Mudstone; poorly exposed	15	0
		Shale, limy and sandy; alternates with beds of platy organic marlstone	8	0
		Mudstone; contains at least one thin sandy layer	15	0
		Marlstone, sandy, hard, platy	1	0
		Shale, brown, soft, papery	2	6
		Marlstone, gray, sandy, platy	1	6
		Mudstone, greenish-gray, soft	10	6
		Marlstone, organic, sandy, hard, platy to papery	2	0
		Mudstone, greenish-gray, soft	10	0
		Marlstone, dark-gray, silty, hard, crudely bedded	1	0
		Shale, grayish-brown, soft, flaky	8	6
	c	Sandstone, very muddy and limy, shaly to platy; in part ripple bedded; many bedding planes mud cracked	7	0
		Shale, ash-gray, soft, flaky	3	6
		Mudstone, sage-gray, hard, spheroidal	6	0
	c	**Sandstone**, limy and muddy, very fine grained, platy; bedding surfaces mud cracked	6	0
		Mudstone, greenish-gray, clayey	2	0
		Marlstone, gray, platy	1	0
		Mudstone, greenish-gray, clayey	3	6
		Marlstone, gray, sandy, hard, platy	3	0
		Mudstone, greenish-gray, clayey	10	0
	c	**Marlstone**, sandy, hard, platy; a few mud cracks	2	0
		Mudstone, greenish-gray, clayey	12	0
		Marlstone, buff, silty, hard, platy	2	0
		Mudstone, greenish-gray, clayey	12	0

Green River Formation—Continued		
Wilkins Peak Member—Continued	*Ft*	*in*
c Marlstone, light-brownish-buff, coarsely chippy, platy; weathers gray; contains numerous thin sandy layers that are mud cracked; the mud cracks are filled with coarse sand	40	0
Sandstone, yellowish-brown, fine-grained, ripple-bedded	3	0
Clay, pinkish-gray, soft, chalky	2	0
Mudstone, reddish-gray; about 10 percent of unit consists of fine-grained muddy sandstone beds 2–8 in. thick; locally unit is more sandy and dark brick red; probably baked by underground burning of underlying oil shale	15	0
Sandstone, grayish-brown, limy, fine-grained, ripple-bedded	1	0
Mudstone, gray	1	6
Marlstone, sage-gray, hard, coarsely laminated	20	0
Mudstone, greenish-gray	33	0
Sandstone, limy, hard, fine-grained, platy	1	0
Mudstone, greenish-gray, rather hard	30	0
Sandstone, shaly, muddy, platy, ripple-bedded	4	0
Thickness, Wilkins Peak Member	1,000	
Tipton Shale Member:		
c Marlstone, shaly; many mud-cracked bedding planes; makes persistent cliff	45	0
Shale, soft; poorly exposed	14	0
Marlstone, shaly; contains interbedded papery low-grade oil shale; grades upward into nearly barren marlstone	23	0
Oil shale, medium-grade, papery	2	0
c Marlstone, shaly; hundreds of bedding planes mud cracked; cracks filled with sand	22	0
c Sandstone, limy and muddy, fine-grained; bedding planes mud cracked	3	0
Mudstone, hard, massive	4	0
c Sandstone, fine-grained, limy, ripple-bedded; alternates with hard mudstone layers; many bedding planes mud cracked	6	6
Marlstone, shaly; thin layers of rich oil shale	3	6
Marlstone, organic, hard, coarsely laminated	3	0
Sandstone, gray, limy, fine-grained; contains lumps of underlying chalky marlstone; subaqueous deformation; mud cracked at top of unit	2	0
Marlstone, ocherous, chalky, ripple-bedded; contains many claystone layers that are wrinkled; mud cracks at top	4	2

Green River Formation—Continued		
Tipton Shale Member—Continued	*Ft*	*in*
Oil shale, black, somewhat carbonaceous; weathers bluish gray; massive in lower part; becomes papery in upper part	10	6
Marlstone, soft, shaly, laminated	1	0
Marlstone, light-buff, chalky, laminated	1	0
Marlstone, organic, light-chocolate-brown, massive to flaky; weathers grayish buff	4	0
Note: Culbertson reports (written communication) having found the basal *Goniobasis* bed here.		
Thickness, Tipton Shale Member	149	
Wasatch Formation:		
Interval concealed by talus	50	0
Mudstone, predominantly gray; contains a few thin bands of red sandy mudstone and a few lenses of soft buff sandstone	175	0
Sandstone, buff; an elongate lens	6	0
Mudstone, gray, sandy; reddish brown sandy layers	17	0
Sandstone, buff, massive, medium-grained; a lens	2	0
Shale, gray, sandy, flaky	3	0
Carbonaceous shale, black, flaky	1	0
Mudstone, gray; banded with red	12	0
Sandstone, reddish-buff, muddy, medium-grained; contains many mud lumps; a large lens that channels into underlying beds as much as 8 ft; contains large limy concretions near top	40	0
Marlstone, grayish-buff; mottled with reddish stain; irregularly bedded	1	0
Shale, gray, very sandy, coarsely fissile	4	0
Mudstone, sage-gray, very sandy, very soft; contains dull-purplish sandy zones that are harder	48	0
Sandstone, reddish-gray, medium-grained, massive; lens	2	0
Mudstone, gray; banded with red	15	0
Marlstone, sandy; contains great number of mud lumps	2	0
Sandstone, grayish-brick-red, muddy, fine-grained, massive	3	0
Mudstone, gray and reddish-gray; contains several small lenses of deep-red sandstone	4	0
Sandstone, grayish-brick-red, fine-grained, massive; a lens	5	0
Mudstone, gray, soft	5	0
Sandstone, deep-red, muddy, very soft, fine-grained; gray and limy in top 1 ft	6	6
Mudstone, gray, soft	4	0
Sandstone, gray, very muddy, soft, fine-grained	2	0
Mudstone, variegated; contains thin lenses of deep-red sandstone	11	0

Wasatch Formation—Continued

	Ft	in
Sandstone, maroon, medium-grained, massive; mottled light yellow and grayish vermilion where lenticular; sandy marlstone concretions at top	7	0
Marlstone, gray, dense; weathers buff	1	0
Mudstone; banded light gray and light brick red; clayey	13	0
Sandstone; mottled light buff and dark brick red; muddy; soft; lenticular	7	0
Shale, greenish-gray, sandy, soft, flaky	1	0
Mudstone; banded buff, gray, and reddish-gray; sandy	5	0
Sandstone, bright-red; grades up into gray medium- to fine-grained material; a lens	3	0
Mudstone; mottled sage gray and dark brick red; sandy; soft; contains a few short lenses of buff or reddish-brown medium-grained sandstone	27	0
Sandstone, deep-red, soft, medium-grained, massive to crudely bedded; locally crossbedded	5	0
Sandstone, very muddy; ocherous at base, vermilion at top; possibly tuff		3
Mudstone, gray, soft	5	0
Sandstone, red, muddy, shaly		8
Shale, sandy, soft, flaky	2	0
Shale, nearly black, carbonaceous, flaky	1	0
Mudstone, gray, soft	3	0
Sandstone, reddish-gray, muddy, very soft, shaly	1	0
Mudstone, gray, soft	5	0
Sandstone, reddish-gray, soft, medium-grained; upper part limy and ripple-bedded	10	0
Shale, gray, soft, flaky	6	0
Sandstone, reddish-brown, soft, medium-grained, crossbedded and current-ripple-bedded	12	0
Sandstone, reddish-gray, very muddy, regularly bedded and ripple-bedded	6	0
Mudstone, very sandy, crudely fissile; alternates with beds of gray ripple-bedded sandstone	10	0
Partial section, Wasatch Formation	549	

Partial section of the Wilkins Peak Member of the Green River Formation in secs. 23, 5, and 8 T. 18 N., R. 107 W.

Green River Formation:

Wilkins Peak Member:

			Ft	in
		Tuff, dark-gray, medium-grained		4
		Marlstone, chalky, soft, massive to platy, finely banded	5	0
		Marlstone, light-gray, massive to thinly bedded; contains thin layers of greenish-gray mudstone	3	0
		Tuff, No. 6 of Culbertson, white, very fine grained		6
		Marlstone, light-gray, massive to shaly	1	0
		Tuff, dense		2
		Marlstone, light-gray, massive to thin-bedded	10	0
		Marlstone, tuffaceous, micaceous	1	4
	s	Marlstone, somewhat shaly; contains great abundance of shortite molds, especially in upper 6 ft where salt-crystal molds exceed marlstone in volume	17	0
		Marlstone, slate-gray to cream-colored, shaly	14	0
	s	Shale, gray, soft, flaky; contains great abundance of salt-crystal molds in layers and lenses	4	0
	s	Marlstone, organic, thin-bedded to flaky; contains lenses of rich oil shale, especially at top; shortite molds throughout	4	0
	s	Mudstone, gray; great many shortite molds at base but these decrease to essentially zero at top	15	0
	s	Tuff, marly; contains layers and dispersed molds of shortite	2	3
		Marlstone, light-gray, massive, probably tuffaceous	2	0
	s	Tuff, white; contains shortite molds at top		3
	s	Shale, gray and buff, limy; contains thin lenses of rich oil shale and dispersed and layered shortite molds	15	0
		Oil shale, low-grade, brown; contains lenses of rich oil shale	2	0
		Tuff, No. 5 of Culbertson, white to pinkish-buff; contains marlstone layers		10
	c, s	Marlstone, massive; contains shortite molds and is mud cracked	1	10
		Shale, gray, sandy, flaky to platy	5	0
		Oil shale, low-grade, brown; contains thin stubby lenses of rich oil shale	1	10
		Edgewise conglomerate composed of slightly rounded mudstone pieces in marlstone matrix		2
		Shale, greenish-gray, sandy, soft, flaky to massive	4	10
		Tuff, pinkish-gray, chalky, soft		3
		Oil shale, medium-grade, laminated to massive		7
Unit I	s	Mudstone, sage-green; contains abundant shortite molds; contains 1-in. carbonaceous layer about in middle	7	3
Unit I		Mudstone, light-brownish-buff, limy	2	3
Unit I		Marlstone, gray; contains layers of white tuff	1	5
Unit I		Mudstone, sage-gray, massive to shaly	10	2
Unit I	s	Mudstone, greenish-brown, very sandy, ripple-bedded; shortite molds sparsely distributed in top 2 ft	11	2
	c, s	Oil shale, rich; thin discontinuous lenses alternate with layers of shortite molds and pseudomorphs; mud cracked; contains some thin micaceous tuff layers	2	8

Green River Formation—Continued

Wilkins Peak Member—Continued

	Ft	in
s Marlstone, shaly; contains shortite molds	3	10
Tuff, sandy and micaceous		1½
s Marlstone, massive to shaly; scattered shortite molds and layers of shortite pseudomorphs	5	9
Tuff, white, micaceous; contains coarser crystal-tuff laminae		8
s Marlstone, gray, thin, obscure bedding; alternate layers contain many shortite molds; contains a few thin lenses of rich oil shale which are studded with shortite pseudomorphs	6	0
Tuff, white		1
s Marlstone, gray, massive; shortite molds	1	4
Tuff and marlstone, in alternate thin beds; shortite molds	2	0
Tuff, No. 4 of Culbertson or Big Island tuff, white	1	2
s Marlstone, light-gray, massive though regularly banded; shortite molds abundant	3	4
Tuff		2
s Marlstone, brownish-gray to sage-green; shortite molds abundant	5	10
Tuff, No. 3 of Culbertson, white		6
s Shale, light-gray, limy; contains few thin beds of low-grade oil shale; shortite and possibly northupite molds and pseudomorphs abundant throughout unit; some crystal molds large and others unusually fine; layers 3 in. thick of loose salt pseudomorphs at several levels	61	0
s Oil shale, rich; weathers blue; bedding planes covered with shortite-crystal molds; gas brecciated	1	3
c,s Shale, light-gray; contains thin layers of low-grade oil shale; all except bottom 1 ft contains abundance of salt-crystal molds; mud cracks very common	6	6
s Oil shale, low-grade, massive to flaky; many shortite molds	2	6
Interval concealed	4	0
s Oil shale, medium-grade, dark-brown; weathers bluish gray; shortite molds abundant; gas brecciated	3	0
s Mudstone, light-gray, soft, limy; great abundance of salt-crystal molds and and pseudomorphs, dispersed and in layers	7	4
s Oil shale, medium-grade, brown; weathers bluish gray; numerous large shortite molds; gas brecciated	3	0
s Oil shale, low-grade, papery; more than half of volume made up of shortite molds and pseudomorphs		7
c,s Shale, soft, flaky; shortite molds abundant; mud cracked	1	2
Analcite layer		½

Green River Formation—Continued

Wilkins Peak Member—Continued

		Ft	in
	c,s Shale, soft, flaky; great abundance of shortite molds; mud cracked	1	4
	s Oil shale, medium-grade, dark-brown, massive to flaky; weathers bluish gray; shortite molds and pseudomorphs abundant; mud cracks very numerous	3	2
	s Marlstone, light-gray, rather coarsely laminated; shortite molds sparse; unit grades upward into greenish-gray sandy mudstone	6	7
	s Marlstone, light-gray, coarsely laminated; contains many crudely lenticular layers of salt-crystal molds that resemble aggregates of northupite and shortite	2	4
	s Oil shale, rich, dark-brown, varved; regularly spaced thin layers of shortite pseudomorphs; bedding distorted by subaqueous slumping	1	1
	Marlstone, light-gray, rather coarsely laminated		8
Unit H	Mudstone, sage-green, sandy, soft	14	0
	Section continued about 3 miles east in sec. 23		
	Sandstone, fine-grained, platy		6
	Shale, grayish-buff, coarsely chippy	6	6
	s Marlstone, light-brown, hard, platy; shortite pseudomorphs	2	6
	s Marlstone, silty; contains molds of bladed salt crystals		10
	s Marlstone, light-brown, chippy; shortite pseudomorphs	6	0
	Sandstone, gray limy, fine-grained, platy		3
	Marlstone, light-grayish-buff, chippy	3	0
	Oil shale, medium-grade, papery; weathers bluish gray		4
	Sandstone, gray, medium-grained, crudely bedded	3	0
	Marlstone, organic, chocolate-brown; weathers gray, chippy	2	0
	Shale, light-brown, soft, flaky	2	0
Unit G	Mudstone, sage-green, sandy	15	0
Unit G	Marlstone, light-buff, sandy, hard, platy		8
Unit G	Mudstone, sage-green, sandy	5	0
	c Shale, light-buff, soft, flaky; contains a few thin sandy marlstone layers that are mud cracked	3	0
	c Marlstone, silty, platy to chippy; many bedding planes mud cracked	1	0
	Shale, drab, soft, flaky	7	0
	Sandstone, rather coarse grained; full of mud lumps and flakes		½
	Shale, limy, sandy, flaky		3
	Sandstone, coarse-grained; full of mud lumps and flakes		2
	Shale, gray, soft; contains thin sandy marlstone layers	1	0
	Edgewise conglomerate; angular and subangular pieces of marlstone in marlstone matrix		1

Green River Formation—Continued

Wilkins Peak Member—Continued

Unit		Description	Ft	in
	c	Marlstone, light-buff, very sandy, mud cracked		1
	c, s	Shale, marly, hard, platy; contains salt-crystal molds; many layers mud cracked	1	2
	c	Marlstone, very sandy; thin regular beds; mud cracked		2
	s	Shale, light-brown, soft, flaky; shortite pseudomorphs abundant	1	3
	s	Limestone, buff, sandy; alternates with thin layers of soft limy flaky shale; limestone layers contain salt-crystal molds that suggest northupite and molds of interlocking platy salt crystals; makes persistent bench	5	6
	s	Clay, buff; contains many salt-crystal molds		10
		Oil shale, low-grade, light-chocolate-brown, massive; weathers gray; contains a few coarse stem impressions		10
		Sandstone, light-gray, very limy, fine-grained, ripple-bedded; has mud lumps in lower part		8
		Shale, buff, soft, papery	3	0
	s	Limestone, light-gray, platy; in thin beds that alternate with buff limy shale; shortite pseudomorphs	2	0
		Shale, buff, soft, papery	4	0
	s	Clay, buff; a soft earthy mixture of pseudomorphs of coarse platy bladed salt crystals and sandy and limy clay; may represent salt bed	2	0
	s	Sandstone, gray; contains flat shale lumps and salt-crystal molds		2
		Oil shale, medium-grade; alternates with thin rich oil-shale laminae; somewhat carbonaceous		2
		Edgewise conglomerate; angular and subangular clay fragments and clay pellets randomly oriented	1	0
	s	Shale, drab to buff, flaky; contains salt crystal molds	7	0
		Limestone, white, sandy, fine-grained, platy	1	0
		Mudstone, drab, limy, chippy	3	6
		Shale, buff, soft, papery; contains several thin hard sandy marlstone layers	3	6
		Sandstone, very limy, light-gray, fine-grained, platy	1	7
Unit F		Mudstone, olive-drab, sandy, soft	22	9
		Marlstone, gray, sandy, hard, platy	1	0
	s	Shale, chocolate-brown, soft, flaky; full of shortite pseudomorphs	2	10
		Marlstone, light-gray, sandy, platy		6
		Shale, light-chocolate-brown, flaky; a few thin fine-grained sandstone layers	9	6
	c,s	Marlstone, light-gray, very sandy, hard, platy; in thin beds that alternate with coarser sandy layers which contain sandy pseudomorphs of bladed salt crystals; includes also ellipsoidal cavities that suggest northupite; many bedding planes mud cracked	2	8
		Tuff, ocherous, sandy		2
		Oil shale, low-grade, gray, hard, somewhat carbonaceous; contains many coarse plant stems or leaves that look like rushes; gas brecciated		6
		Edgewise conglomerate; clay pebbles rounded; matrix very limy		2
Unit E		Mudstone; olive-drab, sandy, soft	8	5
Unit E		Limestone, white, sandy, hard, platy		6
Unit E		Edgewise conglomerate; sandy mudstone pebbles in limestone matrix; platy bedding		4
Unit E		Marlstone, organic; wavy laminations		4
Unit E		Mudstone, sage-green, sandy, soft	8	9
Unit E		Shale, olive-drab, flaky	1	2
Unit E		Marlstone, light-gray, platy		7
Unit E		Mudstone, greenish-buff, soft	12	0
		Shale, greenish-drab, soft, flaky; contains thin marlstone layers	1	9
		Oil shale, low-grade, carbonaceous, gas-brecciated		10
		Marlstone; contains abundance of buff mudstone pellets		2
		Shale, light-brown, flaky	1	2
		Clay, brownish-drab; probably bentonitic, as it contains laminae rich in biotite		8
		Tuff, dark-gray, sandy; contains much biotite		1½
	c	Mudstone, olive-drab, clayey, soft; mud cracked at top	6	6
		Shale, light-chocolate-brown, soft, flaky to papery	4	0
		Marlstone, grayish-buff, sandy		3
	c	Shale, light-chocolate-brown, crudely flaky; lamination becomes more regular and better defined upward; slightly carbonaceous; mud cracked	8	0
Unit D		Mudstone, sage-green; buff sandy mudstone lumps throughout		2
Unit D		Mudstone, drab, soft	16	0
Unit D		Shale, light-brown, soft, papery	1	6
Unit D		Marlstone, sandy, platy; laminated algal bed in middle	1	0
Unit D		Mudstone, greenish-gray to brown, sandy, micaceous; contains lenses and beds of ripple-bedded and cross-bedded gray to greenish-brown muddy sandstone; unit is Principal Olive zone mentioned in text and D bed shown on geologic map (pl. 2)	34	0
		Partial section, Wilkins Peak Member	545	

Partial section of the Wilkins Peak Member of the Green River Formation in sec. 9, T. 18 N., R. 106 W.

	Ft	in
Green River Formation:		
Wilkins Peak Member:		
s Marlstone, buff, papery; contains layers and modules of molds of bladed salt crystals that suggest nahcolite	3	0
Marlstone, buff, soft, papery; contains several nearly black volcanic-ash layers	37	0
Tuff, No. 6 of Culbertson, andesitic; in part analcitized		5
Marlstone, buff, soft, papery; contains a few thin layers of low-grade oil shale	19	0
Tuff, light-grayish-buff, rather coarse grained		10
Marlstone, light-gray, flaky to papery; contains thin layers of low-grade oil shale and some analcitized volcanic ash	19	0
c Tuff, white, limy, platy, mud-cracked		4
c Marlstone, light-gray, coarsely chippy, mud-cracked	6	0
Tuff, white to buff; mottled		8
Sandstone, white, fine-grained; undulating bedding	2	6
Marlstone, organic, shaly to platy	6	0
Limestone, white, sandy, platy		6
Marlstone, hard and platy, to papery low-grade oil shale	2	6
Tuff, yellowish-buff		2
c Marlstone, hard chippy to platy; interbedded with layers of low-grade papery oil shale; lower part mud cracked	6	0
Tuff, white, very limy, massive		2
Marlstone, gray, hard, coarsely fissile or chippy; upper part contains many thin crystalline white limestone layers	5	0
Sandstone, very limy, light-gray, platy	1	6
Marlstone, sandy; grades upward into sandy shale	4	0
Tuff, No. 5 of Culbertson, yellowish-buff, soft, very fine grained		3
Marlstone, white, sandy, platy	4	0
Marlstone, organic; contains lenses of papery low-grade oil shale	2	0
c Limestone, white, sandy, ripple-marked and mud-cracked	3	0
Marlstone, organic, massive but finely banded; bedding planes have a few mycetophyllid fly larvae and a few seeds	3	6
c Limestone, light-gray, sandy, ripple-marked and mud-cracked	1	10
Marlstone, buff, papery; contains lenses and films of rich oil shale	1	0
Shale, light-grayish-brown, clayey, soft, almost waxy; grades upward into about 3 ft of greenish-gray mudstone	14	0
c Mudstone, greenish-gray, sandy; contains lenses and beds of ripple-bedded micaceous sandstone; mud cracked near top	24	0

Green River Formation—Continued		
Wilkins Peak Member—Continued	Ft	in
Marlstone, light-gray, chalky; perfect lamination; may be carbonate-rich tuff	1	0
Oil shale, low-grade, gray; contains lenses of richer oil shale	1	0
Shale, light-brown to gray, soft, flaky	13	0
Tuff, cream-colored, soft, micaceous; a glassy tuff containing many crystal fragments		8
Mudstone, sage-gray, soft	5	0
Marlstone, gray, sandy, soft	6	0
c Sandstone, white, very limy, platy, mud cracked; may be tuff		6
Shale, greenish-gray, soft	2	6
c Sandstone, white, very limy, ripple-bedded and mud-cracked	1	10
Mudstone, greenish-gray, soft	6	0
s Marlstone, light-gray, soft, shaly; salt-crystal molds	4	0
s Shale, rather coarsely fissile; scattered shortite pseudomorphs	1	8
Mudstone, greenish-gray to brownish-gray; contains a few thin sandy layers that may be analcitized tuffs	20	6
c Sandstone, white, very limy, ripple-bedded and mud-cracked	1	8
Marlstone, organic, light-chocolate-brown; has fine banding that suggests varves; many bedding planes have an abundance of oestrid fly larvae and other smaller fly larvae; also, many adult flies that appear to have gotten caught in mud before their wings fully developed	6	0
c Sandstone, very limy, platy; mud cracked	4	6
Mudstone, greenish-gray, sandy, soft; contains also some muddy sandstone beds	3	6
Sandstone, very limy; in beds 1–1½ in. thick; muddy at base; clean at top	2	0
Shale, sage-green, soft	12	6
Oil shale, low-grade, papery; bedding planes have an abundance of mycetophyllid fly larvae, a few oestrid fly larvae, and a few unidentified larvae of medium size; Coleoptera and Hemiptera also present but not numerous	1	8
Limestone, nearly white, sandy, ripple-bedded	1	11
Mudstone, sage-green, soft	3	0
Oil shale, low-grade, gray, flaky		5
Shale, gray, flaky	2	0
Oil shale, low-grade, dark-brown, flaky; weathers gray		11
Mudstone, light-greenish-gray; a few beds muddy sandstone	2	8
Marlstone, slightly organic; in thin beds that alternate with thin beds of white sandy limestone that has characteristic undulant bedding	2	0

Green River Formation—Continued
Wilkins Peak Member—Continued

		Ft	in
	Marlstone, organic, shaly		10
	Sandstone, limy, fine-grained; may be tuff		3
Unit H	Mudstone, greenish-gray, sandy	7	0
Unit H	Limestone, nearly white, sandy, ripple-bedded		6
Unit H	Mudstone, gray	5	0
	Oil shale, medium-grade, papery; lenses of rich oil shale	1	0
	Mudstone, greenish-gray, clayey, very soft	8	0
	Sandstone, very limy; in beds 2 in. thick, ripple bedded		8
	Mudstone, sage-green, soft, almost fissile	3	0
	c Limestone, nearly white, sandy, ripple-bedded; contains some layers that look like analcitized tuff; mud cracked	2	0
Unit G	Mudstone, greenish-gray, sandy	10	0
Unit G	c Limestone, nearly white, sandy, gently ripple bedded, mud-cracked; some cracks filled with fine sand	1	3
Unit G	Marlstone, sandy; contains many mud lumps		1
Unit G	Mudstone, greenish-gray, sandy	14	0
Unit G	c Sandstone, very limy, micaceous, muddy; locally mud cracked and locally ripple bedded		10
Unit G	Mudstone, greenish-gray, sandy	11	0
	c Shale, limy, sandy; contains many thin layers of sandstone, some of which are mud cracked	2	6
	Sandstone, very limy, fine-grained; thin regular beds, some of which are gently rippled; few layers contain mud lumps	3	0
	Shale, gray, soft, crudely fissile; contains moderate number of hard sandy marlstone layers	15	0
	c Oil shale, low-grade, light-brown, somewhat carbonaceous; grades upward into platy marlstone that is sparsely mud cracked	1	2
	Marlstone, sandy; contains many rounded mud lumps and pieces of shale		3
Unit F	Mudstone, sage-gray; contains one group of sandy shale beds	13	0
Unit F	Shale, light-grayish-cream-colored, sandy, limy; contains thin shaly sandstone layers	5	0
Unit F	Mudstone, sage-gray, sandy; contains greenish-gray layers	10	0
Unit F	Shale, gray, sandy, micaceous, contains thin platy marlstone layers	3	0
	c Marlstone; weathers white, sandy, fissile to chippy; many bedding planes mud cracked	10	0
	c Sandstone, limy, fine-grained, gently ripple bedded; has partings of clay that are mud cracked, as are some sandstone beds		3

Green River Formation—Continued
Wilkins Peak Member—Continued

		Ft	in
	c Marlstone, white, sandy, crudely platy; some layers contain mud lumps; many layers mud cracked; cracks commonly filled with sand	3	0
	Oil shale, low-grade, carbonaceous, coarsely fissile	1	0
	Marlstone; contains mud lumps		½
Unit E	Mudstone, sage-gray, soft	6	0
Unit E	Limestone, white, sandy, platy		10
Unit E	Oil shale, low-grade, brown, coarsely fissile, carbonaceous	1	0
Unit E	Sandstone, limy, fine-grained, platy	1	3
Unit E	Mudstone, greenish-gray, soft	20	0
	Shale, grayish-buff; grades upward into mudstone	5	0
	Oil shale, very low grade, carbonaceous, papery		3
	Marlstone, sandy; full of rounded and angular mud lumps and curled mud flakes		3
	c Marlstone, light-grayish-cream-colored, clayey, crudely chippy to massive; weathers stark white; contains in upper half many thin platy sandy marlstone layers that are mud cracked; unit typical of much of white lower half of Wilkins Peak Member	25	6
	c Sandstone, limy, muddy, micaceous; in thin regular platy beds that are mud cracked	1	6
	Edgewise conglomerate; clay balls and shale flakes in limy, sandy matrix		1
Unit D	Mudstone, greenish-gray, sandy, micaceous; contains a few widely spaced muddy ripple-bedded sandstone layers; unit is Principal Olive zone mentioned in text and D bed of detailed geologic map (pl. 2) of area around town of Green River	51	0
	Partial section, Wilkins Peak Member	523	

Partial section of Laney Shale Member in sec. 8, T. 14 N., R. 108 W.

	Ft	in
Bridger Formation:		
Mudstone, gray; grades up into grayish brown; becomes more sandy upward	85	0
Green River Formation:		
Laney Shale Member:		
Marlstone, white, chippy, porcellaneous, locally carbonaceous; contains leaf and stem impressions	1	0
Mudstone, brown, soft, very sandy	5	0
Marlstone, light-gray, chippy		3
Shale, light-brown, soft, sandy	1	0
Marlstone, white, hard		3
Shale, brown, soft, sandy	1	1
Marlstone, brown; contains *Goniobasis* and *Unio*? shells	1	2
Marlstone, dark-brownish-gray, hard chippy	2	0

Green River Formation—Continued
Laney Shale Member—Continued

	Ft	in
Marlstone, dark-brown, sandy; contains abundant shells of *Goniobasis* and *Unio*?	1	0
Tuff, light-gray, silty, hard		3
Marlstone, buff; banded with many 2–5-in.-thick gray tuff layers and a few muddy sandstone layers	16	0
Tuff, in thin beds that alternate with equally thin claystone layers	8	0
Tuff, gray, silty; in beds about 6 in. thick that alternate with coarse sandy tuff beds 1–2 ft thick	10	0
Tuff, light-gray, banded; mixed with a considerable amount of mud and sand	25	0
Tuff, light-gray, chippy to platy, hard; fine-grained glassy tuff	3	0
Sandstone, grayish-brown, shaly; contains a few thin platy layers of cleanly sorted reddish-brown sandstone	19	0
Marlstone, buff; almost a coquina of ostracode shells but contains also some *Unio*? shells		8
Sandstone, buff to dark-reddish-brown, medium-grained, platy, more or less crossbedded	12	6
Marlstone, light-grayish-buff, shaly to almost papery; many layers hard	5	6
Sandstone, buff to dark-grayish-brown, very fine grained; in beds ½–2½ ft thick separated by thin carbonaceous claystone layers	26	0
Sandstone, grayish-brown; poorly exposed but contains some lenses of dark-gray biotitic sandy tuff	60	0
Claystone, dark-gray, very carbonaceous, hard, brittle	1	6
Sandstone, white through buff to dark-gray, medium- to coarse-grained, soft; beds range from a few inches to several feet in thickness	35	0
Marlstone, gray, shaly to platy, sandy		10
Shale, ocherous-brown to gray; alternate sandy and very fine grained earthy carbonaceous layers	7	0
Marlstone, dark-gray, hard, massive to crudely fissile, carbonaceous, locally sandy	5	0
Sandstone, dark-gray, fine-grained; almost unconsolidated but contains a few thin hard layers	12	0
Marlstone, buff; alternate thin soft shaly layers and harder sandy layers; contains several thin layers of tuff	10	0
Tuff, buff, soft; consists largely of analcite		4
Marlstone, light-gray to buff, laminated; contains a few thin sandy layers	8	0
Shale, dark-brown, soft, sandy, carbonaceous	5	0
Sandstone, dark-gray, shaly, carbonaceous, ripple-bedded	1	6
f Oil shale, black, rich, papery; contains skeletons of many small fish		3
Oil shale, brown, low-grade, papery to massive	3	0
Marlstone, buff to light-brown; alternates with thinner beds of papery low-grade oil shale	5	6
Shale, sandy, carbonaceous	2	0
Mudstone, chocolate-brown, very soft; slightly carbonaceous at top	4	0
Mudstone, dark-grayish-brown, soft, sandy	16	0
Marlstone, dark- to light-gray, thickly laminated; not well exposed	4	0
Oil shale, black papery, rich		10
Section incomplete; estimated to be perhaps 50 ft more of well-bedded marlstone and oil shale.		
Approximate thickness, Laney Shale Member	370	

Partial section of Laney Shale Member of the Green River Formation in sections 8, 17, and 18, T. 14 N., R. 99 W.

Green River Formation:
Laney Shale Member:

	Ft	in
Tuff, medium-gray to buff; a muddy crystal tuff containing considerable microgranular calcite in lenticular beds which alternate with buff chalky marlstone and sandy shale (overlying this unit is an estimated 300–400 ft of similar buff marlstone and a few algal beds)	100+	
Sandstone, fine-grained, shaly; alternates with beds of hard shaly marlstone	9	0
Tuff, gray, massive	1	0
Marlstone, buff, soft, shaly; poorly exposed	117	0
Shale, gray-buff, soft, flaky; alternates with similar shale that contains somewhat more organic matter; not well exposed	128	0
Tuff; bed consists almost wholly of clear analcite crystals		4
Shale, papery; contains some organic matter	10	0
Oil shale, low-grade, papery; top 1–6 in. rich oil shale	6	6
Marlstone, buff, sandy, soft	11	0
Tuff, rusty, analcitized		6
Sandstone, limy, sandy, platy; alternates with beds of sandy shale	14	0
Marlstone, buff, sandy, flaky to coarsely chippy; contains several harder more sandy beds	25	0
Oil shale, low-grade, light-gray, flaky; contains lenses of rich oil shale; also contains several thin beds of analcitized tuff	12	0

Green River Formation—Continued

Laney Shale Member—Continued	Ft	in
Shale, papery, soft; some organic matter	5	0
Tuff, black, bituminous, fine-grained; mostly analcite		1
Oil shale, low-grade, papery; contains progressively more numerous thin lenses of rich oil shale upward	11	6
Oil shale, rich, black; groups of thin lenses		6
f Marlstone, buff, varved; contains rather numerous small fossil fish and vertebrae of larger fish; unit contains also several one-fourth-inch beds of analcitized tuff	17	0
Marlstone, sandy, coarsely chippy	3	0
Shale, papery	1	6
c Algal bed, platy; mud on upper surface mud cracked		3
Marlstone, buff, papery, soft; contains one-half-inch bed of analcitized tuff	5	0
Algal bed		5
Shale, marly, papery	6	0
Algal bed; algal rubble at base; laminated above		3
Limestone, concretionary, dense		4
Mudstone, buff, marly, soft	2	0
Marlstone, sandy, concretionary, brecciated		6
Shale, low-grade oil shale, papery; grades upward into harder organic marlstone	7	0
Oolite, coarse-grained; locally an algal deposit		3
Marlstone, buff, varved; papery at base to massive at top	11	6
Oil shale, rich, papery to massive		3
Marlstone, varved, hard, platy	1	0
Tuff, mostly analcite but in part coarse-grained ash		3
Shale, marly, papery	5	0
Oil shale, rich, papery to massive		4
Algal bed; changes laterally from algal deposit to limy rubble and back to algal deposit again		3
Sandstone, brown, muddy, fine-grained	2	0
Mudstone, gray, sandy	1	0
Marlstone; full of mud lumps; contains some oolite		10
Shale, sandy and marly	1	0
Marlstone; contains mud lumps and oolite		3
Shale, marly, sandy, organic, papery	2	0
Algal bed		2
Shale, gray, flaky		1
Oolite, very fine grained		4
Mudstone, gray, sandy		6
Sandstone, medium- to fine-grained, iron-stained, poorly bedded; contains mud lumps		5
Mudstone, gray, flaky		3
Sandstone, medium- to fine-grained, iron-stained; contains mud lumps	1	0

Green River Formation—Continued

Laney Shale Member—Continued	Ft	in
Mudstone, gray, sandy; shaly at top		10
Sandstone, muddy, fine-grained, cross-bedded		4
Mudstone, gray, sandy		6
Sandstone, muddy, fine-grained, cross-bedded	2	0
Mudstone, light-gray, sandy; locally replaced by overlying sandstone	1	9
Sandstone, muddy, shaly	1	0
Shale, gray, very soft, flaky	2	0
Sandstone, muddy, carbonaceous, iron-stained	2	0
Shale, gray, very soft, flaky	3	0
Algal bed; large well-formed heads that grew around flat nuclei	2	0
Marlstone, light-brown, varved, papery; contains two thin dense massive marlstone beds	12	0
c Marlstone, buff, hard, sandy, platy, mud-cracked, in part oolitic		6
Marlstone, buff, coarsely varved, soft, papery	7	6
Algal bed, hard; made up of low, flattened heads		3
Marlstone, light-brown, hard, platy; alternates with softer shaly marlstone beds		11
Marlstone, buff, soft, papery, varved; somewhat richer in organic matter at top	5	6
c Limestone, brown, sandy; contains dark-gray limy sandstone layers that are mud cracked	1	0
Shale, slightly organic, flaky		8
Partial section, Laney Shale Member	567+	
Underlain by gray clayey mudstone of the Cathedral Bluffs Tongue of the Wasatch Formation.		

Partial section of the upper part of the Laney Shale Member of the Green River Formation measured on Big Sandy Creek in sec. 24, T. 23 N., R. 109 W.

Green River Formation:

Laney Shale Member, upper part:	Ft	in
Mudstone, olive-drab to brownish-drab, and soft chippy marlstone; (top of unit not more than a few tens of feet below base of Bridger Formation, which is not exposed here)	10	0
Tuff, light-gray, platy; weathers brown		1
Mudstone, olive-drab, very soft; has platy rusty-brown sandstone bed at top	9	0
Marlstone, platy, sandy; alternates with thin beds of limy sandstone	1	0
Tuff, white to light-gray		1½
Marlstone, buff, platy, sandy; alternates with thin beds of limy sandstone	9	0
Tuff, white		8

Green River Formation—Continued

Laney Shale Member, upper part—Con.

	Ft	*in*
Marlstone, light-buff, platy to flaky	2	3
Mudstone, olive-drab, massive	2	6
Sandstone, buff, limy, platy		6
Tuff, white		1½
Tuff; altered to coarse-grained analcite		4
Mudstone, greenish-brown; contains harder crossbedded sandstone layers	10	6
Marlstone, gray to buff, hard, platy to chippy; contains two 1-in. layers of pure white tuff	3	0
Mudstone, olive-drab, sandy, coarse-grained	2	4
Mudstone, olive-drab; alternates in thin beds with buff to grayish-gray muddy marlstone	1	6
Sandstone, gray, irregularly platy; weathers brown		6
Tuff, gray, platy		3
Marlstone, buff; alternates in thin beds with limy mudstone	1	3
Tuff, light-gray to buff		3½
Sandstone, buff, medium-grained, lenticular; alternates in thin layers with olive-drab mudstone	1	4
Marlstone, buff, flaky; in beds ½–4 in. thick	4	0
Marlstone, buff, soft, papery to laminated; some laminae very rich in ostracodes	2	1
Ostracode limestone; essentially coquina		2
Sandstone, buff, very marly, soft, platy		5
Marlstone, buff, laminated	2	0
Tuff, light-gray, dense; ranges in thickness from 2 to 10 in		6
Marlstone, buff, massive to flaky	3	0
Tuff, light-gray		5
Mudstone, greenish-drab, sandy	4	0
Marlstone, buff, massive to flaky, lenticular	2	0
Tuff, gray; mixed with considerable mud and sand		8
Mudstone, olive-drab, sandy	4	0
Tuff, gray; mostly coarse-grained analcite crystals	1	3
Marlstone, buff, massive	2	8
Tuff, light-gray, micaceous		4
Mudstone, olive-drab	2	4
Tuff; lenticular bed ranging in thickness from 4 to 14 in		8
Mudstone, olive-drab, flaky; ranges in thickness from 8 to 18 in	1	0
Tuff, gray, micaceous		3
Sandstone, greenish-gray to brown, muddy; probably tuffaceous	2	7
Mudstone, light-gray, muddy, tuffaceous, soft	3	6
Sandstone, olive-drab, very muddy, probably tuffaceous, massive to crossbedded	10	6
Tuff; mostly coarse-grained analcite		2
Tuff, dark-gray, dense		4
Limestone, buff, sandy, iron-stained		5
Mudstone, olive-drab, sandy	3	0
Marlstone, buff; beds 1½–5 in. thick that are themselves laminated and that alternate with somewhat thicker beds of papery marly shale	6	0
Mudstone, greenish-buff, sandy	4	0
Marlstone, buff, thinly laminated	5	0
Sandstone, reddish-brown, limy; thin irregular beds		3½
Marlstone, buff, laminated; mostly silicified tuff	2	7
Tuff, light-gray; has rusty tubules; glass shards very little devitrified		9
Tuff, andesitic, greenish-drab, muddy, massive; contains many irregular zones of well-rounded mud lumps that range in size from tiny pellets to about 2 in. in diameter; makes cliff	36	0
Partial section, Laney Shale Member	163	

NOTE.—Only two of the mudstone beds in this partial section were examined under the microscope; but because both proved to be tuffs containing only minor amounts of mud, it is quite possible that many of the "olive-drab mudstone" beds in this part of the Green River Formation are also tuffs or, at least, tuffaceous mudstone.

Section of the Bridger Formation and overlying White River(?) Formation at Oregon Buttes in sec. 3, T. 26 N., R. 101 W.

White River(?) Formation:

	Ft	*in*
Tuff, light-gray, massive to crossbedded, nodular; composed of glassy shards with small percentage of crystal fragments except near base where it is darker and much coarser grained; predominantly crystal and lithic tuff. (On middle butte of group is roughly 125 feet more of this same kind of tuff.)	75	0
Tuff, white, lenticular; ranges in thickness from about 1 in. to more than 3½ ft; averages about		6
Tuff, light-gray, banded, massive; (weathers light orange brown)	24	0
Gravel; pebbles subangular to rounded, black and green, and range from less than ⅛ in. to 1½ in.; matrix white, tuffaceous	17	0
Conglomerate; presumably Beaver Divide Conglomerate of Nace (1939, p. 32–34); matrix white sand (probably tuff); pebbles and cobbles predominantly angular and consist of black schist (from vicinity of Atlantic City, Wyo.) mixed with some quartz and chlorite schist; locally predominantly granitic pebbles and matrix; predominant size of material is about ½–4 in. but boulders as much as 1 ft in diameter are found; locally, parts of conglomerate resemble volcanic-ash mud flow	55	0

White River(?) Formation—Continued	Ft	in
Sandstone, purplish-brown; rather coarse grained at base where it channels underlying bed; fine grained at top where it contains many mud lumps	11	0
Thickness, White River(?) Formation	182	
Bridger Formation:		
Marlstone, cream-color, dense	3	0
Mudstone, sage-gray, soft	15	0
Sandstone, light-brownish-gray, fine-grained, massive	2	0
Mudstone, gray to brownish-gray, clayey, soft	21	0
Sandstone, buff, medium-grained, massive	9	0
Mudstone, gray, clayey, soft	7	0
Sandstone, light-gray, muddy, limy, fine-grained, massive	11	0
Sandstone, yellowish-brown, medium-grained, crossbedded; lower 5 ft contains great many shale and mud lumps and channels into underlying beds of shale; 25 ft above base is another zone of mud lumps; upper part massive and less cross-bedded	51	0
Sandstone, marly, muddy, fine-grained; banded with very thin alternate brownish-buff and ash-gray laminae: locally, laminae contorted by subaqueous slumping	19	0
Marlstone, white, silty, laminated	6	0
Shale, thinly laminated, papery; rich in ostracode valves; becomes sandy and platy at top	6	6
Sandstone, white, marly, fine-grained, massive	1	6
Mudstone, gray, drab, and rusty-buff; clayey but contains some zones of fairly clean fine sand; unit contains many fossil turtles	40	0
Sandstone, gray, very muddy; contains rows of small brown sandy concretions	22	0
Mudstone, gray, clayey, soft; fossil turtles in place	8	0
Sandstone, brownish-gray, muddy, fine-grained; brown sandy concretions near top	12	6
Sandstone, gray, limy, muddy, fine-grained; contains many large gastropod shells		6
Tuff, yellowish-drab, muddy, fine-grained; much biotite	10	0
Mudstone, gray, sandy; a few thin platy sandstone beds near base	12	0
Marlstone, buff to light-gray, sandy, platy; contains oolites and ostracodes	3	0
Mudstone, greenish-gray, sandy	15	0
Mudstone, gray, sandy; contains lens of strongly iron stained medium-grained sandstone near top	45	0
Sandstone, gray, medium- to coarse-grained, soft, massive	3	6
Mudstone, gray, sandy, soft	47	0
Algal bed and coarse-grained oolite, dark-brown, silicified		10
Bridger Formation—Continued		
Mudstone, marly; contains much petrified wood	1	6
Oolite, buff, very fine grained, crudely bedded	2	0
Marlstone, gray, sandy, thin-bedded		6
Shale, gray, soft, flaky	4	0
Marlstone, gray, sandy, platy		6
Mudstone, gray, sandy; locally buff muddy sandstone	28	0
Mudstone, light-brown, soft; lower one-third shaly; upper part massive	12	0
Marlstone, buff, soft, thinly laminated	6	0
Sandstone, very muddy, fine-grained, almost unconsolidated; contains many petrified logs, many of which are encrusted with algal deposits as much as 4 in. thick	1	6
Mudstone, greenish-gray, soft	2	0
Marlstone, nearly white; contains many ostracodes		4
Mudstoné, gray to grayish-buff, clayey to sandy	27	0
Tuff, greenish-gray, silty; contains great many petrified logs, some of which must have been originally 1–2 ft in diameter	2	0
Sandstone, dark-brown, medium-grained, limy; locally contains many small turtle bones		6
Mudstone, gray to brownish-gray; contains several very sandy zones; also contains considerable petrified wood near base	22	0
Thickness, Bridger Formation	482	

Section of the Bridger Formation measured on the east slope of Twin Buttes (Black Mountain of some maps) in sections 21, 22, 23 and 24, T. 14 N., R. 109 W.

Bridger Formation:	Ft	in
Overlain by 75–100 ft of Bishop Conglomerate.		
Mudstone, sage-gray, clayey to sandy and even gravelly; in uppermost part, banded dark-greenish-gray tuffaceous beds alternate with gray mudstone beds; greenish bands range in thickness from one-half in. to 8 in.; upper part also contains sandstone lenses and beds that are locally gravelly and as much as 15 ft thick; pebbles are well-rounded black chert and jasper and some white quartzite and hard limestone	225	0
Mudstone, gray to greenish-gray, sandy; contains some tuffaceous mudstone; fossil turtles common throughout unit; some large turtles are in place and have been virtually undisturbed since death	130	0
Mudstone, ash-gray; probably in large part tuff; contains many fossil turtles	15	0
Mudstone, sage-gray to greenish-gray; alternates with hard muddy sandstone beds 6 in. to 4 ft thick and spaced 5–15 ft apart	105	0
Mudstone, grayish-lavender		6

Bridger Formation—Continued	Ft	in
Mudstone, light-greenish-gray		8
Mudstone, light-brick-red	1	0
Mudstone, light-greenish-gray	2	0
Mudstone, dull-red	12	0
Mudstone, light-brick-red; banded with some gray	5	0
Mudstone, light-gray; stained pinkish	8	0
Mudstone, light-gray; a few beds of alternate greenish-gray claystone and dull-reddish-gray mudstone near top	40	0
Tuff, greenish-gray, very sandy, biotitic, fine-grained	10	0
Tuff, dark-gray, sandy, biotitic	10	0
Sand, unconsolidated, medium- to coarse-grained; petrified logs common locally; smoothly rounded black chert pebbles as much as 1 in. in diameter rather generally distributed through this sand; no other kind of pebble found	25	0
Marlstone, hard, chippy	1	6
Soil?, dark-reddish-brown, carbonaceous, soft, earthy		6
Oil shale, very low grade, laminated	1	0
Tuff, yellowish-buff, powdery		3
Mudstone, dull-brick-red, carbonaceous, earthy	1	0
Claystone, brownish-drab; grades upward to dark gray; very soft	15	0
Marlstone, brownish-buff, silty; makes bench	3	0
Claystone, light-grayish-green, very soft; contains several thin ocherous tuff layers; contains fossil turtles and carbonized logs	26	0
Tuff, dark-greenish-gray, biotitic, fine-grained	3	0
Mudstone, sage-gray; contains 3-ft layer of soft pale-grayish-green claystone; contains many fossil turtles	21	0
Tuff, light-yellowish-brown, gritty, biotitic	2	0
Tuff, dark-grayish-drab, muddy, biotitic	16	6
c Marlstone, light-gray to light-yellowish-brown, thin; platy bedding; some bedding planes mud cracked; some have plant-stem impressions	1	6
Mudstone, brownish-gray, soft; not well exposed	15	0
Marlstone, brownish-gray, dense, regularly bedded	2	6
Mudstone, gray, clayey, very soft	60	0
Mudstone, tuffaceous, and tuff; tuffaceous mudstone is dark gray with occasional pistacio-green clay layers; interbedded with tuffaceous mudstone are rough lenses of coarse-grained, greenish-brown andesitic tuff	130	0
Mudstone, pale-greenish-gray; fossil turtles very numerous	10	0
Marlstone, grayish-brown, hard, chippy to platy	2	6
Mudstone, sage-gray, sandy; contains a few sandy concretionary masses	88	0
Chert, dark-brown; weathers yellowish-brown; contains many stems and fruiting bodies? of *Chara*		6

Bridger Formation—Continued		Ft	in
	Claystone, gray, rather hard	11	0
	Tuff, light-gray, marly, massive	1	0
	Claystone, gray, rather hard; probably tuffaceous	12	0
Sage Creek white layer	Marlstone, yellowish-gray, hard; lower part full of clay flakes and mud lumps; makes the extensive broad bench at the top of the Sage Creek white layer of Matthew	2	0
	Tuff, dark-gray, biotitic, massive	23	0
	Mudstone, light-gray; locally contains lenses of medium-grained sandstone; tuffaceous and biotitic in upper part	86	0
	Mudstone, pistacio-green, clayey; contains great number of fossil turtles; also contains remains of gar pike and crocodiles	10	0
	Tuff, marly, hard; makes extensive bench	1	0
	Mudstone, sage-gray, sandy; turtle carapace fragments	16	0
	Tuff, dark-greenish-drab, medium-grained, muddy; andesitic volcanic ash reworked with mud	15	0
	Marlstone, tuffaceous	2	0
	Mudstone, brownish-gray, sandy, soft	15	0
	Marlstone, light-gray to buff, sandy; makes narrow bench	3	0
	Sandstone, drab, tuffaceous, muddy, biotitic, fine-grained	15	0
	Sandstone, dark-gray to greenish-brown, biotitic, crossbedded, concretionary; mostly andesitic volcanic ash	6	0
	Mudstone, cream-colored, clayey, soft	3	0
	Tuff, greenish-gray, muddy; largely basic volcanic ash	4	0
	Claystone, light-pinkish-buff, waxy; probably derived from glassy volcanic ash	7	0
	Chert, dark-brown, almost black; makes extensive bench		3
	Mudstone, gray, clayey, very soft	4	0
	Tuff, andesitic, gray, gritty	2	0
	Mudstone, brownish-gray, sandy, soft	12	0
	Algal bed, finely laminated, in part silicified; mixed with hard cream-colored dense marlstone that is coarsely chippy or massive; these two rocks together make a broad and extensive bench near base of Twin Buttes	1	6
	Mudstone, tuffaceous, gray, biotitic; contains irregular lenses of coarse-grained greenish-gray andesitic crystal tuff	28	0
	Marlstone, greenish-gray, hard, platy; weathers yellowish brown; makes persistent bench	3	6
	Mudstone, gray, clayey; contains many lenses of greenish-gray, crossbedded sandstone which is largely andesitic crystal tuff	20	10
	Marlstone, light-gray, sandy, thin-bedded; contains a few small plant fragments		2
	Mudstone, gray, very sandy; contains yellowish-brown limy concretions	18	0
	Tuff, andesitic, dark-greenish-gray, fine-grained, muddy; contains lumps of underlying greenish-gray mudstone	5	0

Bridger Formation—Continued

	Ft	in
Mudstone, greenish-gray, sandy, massive; contains irregular masses and lenses of sandy andesitic volcanic ash	4	0
Mudstone, sage-green, in part clayey; contains beds of fine-grained dark-gray muddy sandstone that locally contains botryoidal limy concretions which weather rusty buff	15	0
Thickness, Bridger Formation	1, 336	

Underlain by Laney Shale Member of Green River Formation.

Section of the Uinta and Bridger Formations (undifferentiated) on the east end of Haystack Mountain in sections 5 and 6, T. 16 N., R. 95 W.

Uinta and Bridger Formations (undifferentiated):

	Ft	in
Sandstone, brown, very coarse grained, gravelly, crossbedded, lenticular; caps high, eastern end of Haystack Mountain	9	0
Mudstone, gray, sandy; contains gravelly lenses	23	0
Sandstone, nearly white, very coarse grained, gravelly, crossbedded; contains pebbles as much as one-half inch in diameter; a lens that ranges in thickness from about 5 to 18 ft	5	0
Mudstone, brownish-gray, soft	7	0
Sandstone, gray, coarse-grained, gravelly, crossbedded; a lens	10	0
Mudstone, drab to light-gray, sandy; contains a few poorly defined sandy lenses and one pink layer	83	0
Gravel, gray, muddy and sandy; banded with pink	12	0
Mudstone, greenish-gray; several pink layers; contains lenses of fine-grained muddy sandstone	23	0
Gravel, gray, muddy, soft	11	0
Mudstone, gray; pink bands; contains sandy layers	17	0
Mudstone, pink or reddish-gray; has barite and limy concretions	3	0
Mudstone, sage-green; gravelly and sandy at base but grades upward into silty claystone	30	0
Sandstone, gray, muddy, thin-bedded to massive; has some iron-stained concretions	10	0
Mudstone, gray, sandy	4	0
Sandstone, coarse-grained, crossbedded; a lens	8	0
Mudstone, grayish-drab; contains pale-green and pink layers in upper part; very sandy; makes steep slope	90	0
Tuff, andesitic, greenish-brown, coarse-grained, crossbedded; contains lenses of gravel, largely of greenish-gray chert	18	0
Sandstone, dark-brown, very carbonaceous, fine-grained, muddy; grades upward into gray mudstone	4	0

Uinta and Bridger Formations—Continued

	Ft	in
Tuff, nearly white, limy; supports low heads of algal limestone that apparently formed around coarse plant stems; centers now filled with clear chalcedony stained chrysocollalike blue	1	0
Mudstone, drab, rather hard	11	0
Sandstone, buff, moderately coarse grained, muddy	7	0
Mudstone, light-sage-gray, soft	4	0
Mudstone, gray, sandy	6	0
Sandstone, greenish-buff, rather coarse-grained, muddy; weathers dark gray; probably in large part tuff	24	0
Mudstone, pinkish-gray, sandy; grades upward into gray	5	0
Tuff, dark-gray, sandy, coarse-grained; grades upward into muddy sandstone	12	0
Marlstone, nearly white; weathers gray to brown; in part algal; heads extend up into overlying tuff	4	6
Mudstone, gray, sandy	23	0
Mudstone, pinkish-gray; limy concretions	2	0
Mudstone, light-gray to greenish-gray, locally sandy	58	0
Mudstone, brownish-gray; makes conspicuous band in landscape	5	0
c Sandstone, limy, mud-cracked		3
Mudstone, ash-gray, very clayey; probably derived from glassy volcanic ash	20	0
Mudstone, gray, soft; many limy concretions	15	0
c Sandstone, dark-gray, hard, medium-grained; weathers brownish-gray; makes conspicuous and extensive bench	3	0
Mudstone, gray, sandy; several sandstone lenses	42	0
Sandstone, gray to brown, muddy, laminated, rippled	2	6
Mudstone, gray to drab; a few thin pink and mauve bands; becomes more sandy upward; locally unit contains great massive lenses of dark-brown muddy sandstone	115	0
Sandstone, gray to brown, iron-stained, muddy, lenticular	8	0
Mudstone, pale-greenish-gray, locally sandy	23	0
Sandstone, gray, muddy; contains iron-stained concretions	20	0
Thickness, Uinta and Bridger Formations	778	

Base concealed by sand dunes; estimated to be 50–75 ft lower.

REFERENCES

Anderman, G. S., 1955, Tertiary deformational history of a portion of the north flank of the Uinta Mountains in the vicinity of Manila, Utah, *in* Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf., Green River Basin, 1955: p. 130–134, and map.

Athy, L. F., 1930, Density, porosity, and compaction of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 13–14.

Berg, Robert R., 1961, Laramide tectonics of the Wind River Mountains, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas, 1961: p. 70–80.

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, pl. 58.

——— 1931, Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168, p. 1–58.

——— 1935, Anticlines between Hiawatha gas field and Baggs, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 537–543, figs. 1, 2.

——— 1936, Geomorphology of the north flank of the Uinta Mountains: U.S. Geol. Survey Prof. Paper 185–I, p. 163–199, pl. 34.

——— 1945, Geology of the Washakie Basin, Sweetwater and Carbon Counties, Wyoming, and Moffat County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 32.

——— 1959, Revision of stratigraphic nomenclature of Green River formation of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1072–1075.

Burton, Guy, 1961, Patrick Draw area, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas, 1961: p. 276–279.

Carey, Byrl D., Jr., 1954, A brief sketch of the geology of the Rattlesnake Hills, *in* Wyoming Geol. Assoc. Guidebook, 9th Ann. Field Conf., Casper area, Wyoming, 1954: p. 32–34.

Cohee, G. V., Chairman, 1962, Tectonic map of the United States, exclusive of Alaska and Hawaii; prepared by a joint committee of the U.S. Geological Survey and the American Association of Petroleum Geologists: scale 1:2,500,000.

Cookson, Isabel C., 1953, Records of the occurrence of *Botryococcus braunii, Pediastrum* and the Hystrichosphaerideae in Cainozoic deposits of Australia: Natl. Museum Melbourne Mem. 18, p. 107–123.

Culbertson, W. C., 1961, Stratigraphy of the Wilkins Peak Member of the Green River formation, Firehole Basin quadrangle, Wyoming: Art. 348, *in* Geol. Survey Prof. Paper 424–D, p. D170–D173, fig. 348.2.

——— 1962, Tower Sandstone Lentil and Laney Shale Member of the Green River formation, Green River area, Wyoming: Art. 78, *in* U.S. Geol. Survey Prof. Paper 450–C, p. C54–C57.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., p. 9, 16.

Donovan, 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., Southwest Wyoming, 1950: p. 59–67.

Emmons, S. F., 1877, *in* King, Clarence, Report of the geological exploration of the 40th Parallel: Prof. Papers of the Engineer Department, U.S. Army, no. 18, v. 2, p. 211.

Engelmann, Henry, 1858, Preliminary report on the geology of the country between Fort Bridger and Camp Floyd, Utah Territory, and southwest of the latter place, along Captain J. H. Simpson's routes, 1858: U.S. 35th Cong., 2d sess., Senate Ex. Doc. 40, p. 45–75.

Erickson, E. T., 1922, Tschermigite (ammonium alum) from Wyoming: Washington Acad. Sci. Jour., v. 12, p. 49–54.

Fahey, Joseph J., 1962, Saline minerals of the Green River Formation, *with section on* X-ray powder data for saline minerals of the Green River Formation, by Mary E. Mrose: U.S. Geol. Survey Prof. Paper 405, 50 p.

Fahey, Joseph J., Ross, Macolm, and Axelrod, Joseph M., 1960, Loughlinite, a new hydrous sodium magnesium silicate: Am. Mineralogist, v. 45, p. 270–281.

Fahey, Joseph J., and Yorks, K. P., 1963, Wegscheiderite, a new saline mineral from the Green River Formation, Wyoming: Am. Mineralogist, v. 48, p. 400–403.

Fidlar, M. M., 1950, Structural features of the Green River Basin, *in* Wyoming Geol. Assoc. Guidebook, 5th Ann. Field Conf., Southwest Wyoming, 1950: p. 86–87.

Forrester, J. D., 1937, Structure of the Uinta Mountains: Geol. Soc. America Bull., v. 48, p. 631–666, pl. 3–4.

Gale, H. S., 1907, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geol. Survey Bull. 341–C, p. 310–314.

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

——— 1959, Paleontological exploration and dating of the early Tertiary deposits in basins adjacent to the Uinta Mountains, *in* Intermountain Assoc. Petroleum Geologists Guidebook to the geology of the Wasatch and Uinta Mountains transition area, 10th Ann. Field Conf., 1959: p. 133–135.

Hague, Arnold, and Emmons, S. F., 1877, Descriptive geology: U.S. Geol. Explor. 40th Parallel (King), v. 2, p. 181–310.

Hale, Lyle A., 1950, Stratigraphy of the Upper Cretaceous Montana group in the Rock Springs uplift, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 5th Ann. Field Conf., Southwest Wyoming, 1950: p. 48–58.

Hansen, W. R., 1961a, Geologic map of the Willow Creek Butte quadrangle, Utah-Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–322.

——— 1961b, Geologic map of the Dutch John Mountain and Goslin Mountain quadrangle, Utah-Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–324.

Hansen, W. R., and Bonilla, M. G., 1954, Laramide faulting and orogeny on the north flank of the Uinta Mountains in eastern Dagget County, Utah: Colorado Sci. Soc. Proc., v. 17, no. 1, p. 1–29.

——— 1956, Geology of the Manila quadrangle, Utah-Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–156.

Hansen, W. R., Kinney, D. M., and Good, J. M., 1960. Distribution and physiographic significance of the Browns Park Formation, Flaming Gorge and Red Canyon areas, Utah-Colorado: Art. 115, *in* U.S. Geol. Survey Prof. Paper 400–B, p. B257–B259.

Hayden, F. V., 1869, U.S. Geol. and Geog. Survey Terr., 3d Ann. Rept., p. 90.

——— 1871, U.S. Geol. and Geog. Survey Terr., 4th Ann. Rept., p. 155–156.

——— 1873 ed., U.S. Geol. and Geog. Survey Terr., 3d Ann. Rept., p. 191.

Hedberg, H. D., 1936, Gravitational compaction of clays and shales: Am. Jour. Sci., 5th ser., v. 31, p. 262–268.

Jenkins, Carl E., 1955, The Pacific Creek deep test, Superior Oil Company No. 1 Unit, sec. 27, T. 27 N., R. 103 W., Sublette County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf., Green River Basin, 1955: p. 153–154.

Johannsen, Albert, 1914, Petrographic analysis of the Bridger, Washakie, and other Eocene formations of the Rocky Mountains: Am. Mus. Nat. History Bull., v. 33, p. 209–222.

Kemp, J. R., and Knight, W. C., 1903, Leucite Hills of Wyoming: Geol. Soc. America Bull., v. 14, p. 326.

King, Clarence, 1878, U.S. Geol. Explor. 40th Parallel: v. 1, p. 444–449, Atlas (folio) maps II and III, 1876.

Koenig, Karl J., 1960, Bridger Formation in the Bridger Basin, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 15th Ann. Field Conf., Overthrust belt of southwestern Wyoming and adjacent areas, 1960: p. 163–168.

Lawson, Don E., and Crowson, C. W., 1961, Geology of the Arch unit and adjacent areas, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on late Cretaceous rocks, Wyoming and adjacent areas, 1961: p. 280–289.

Lewis, J. V., 1924, Fissility of shale and its relationship to petroleum: Geol. Soc. America Bull., v. 35, p. 568.

Love, J. D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geol. Soc. America Spec. Paper 20, p. 1–134.

——— 1960, Cenozoic sedimentation and crustal movement in Wyoming: Am. Jour. Sci., v. 258–A, p. 204–214.

——— 1961a, Split Rock Formation (Miocene) and Moonstone Formation (Pliocene) in central Wyoming: U.S. Geol. Survey Bull. 1121–I, p. I1–I34.

——— 1961b, Definition of Green River, Great Divide, and Washakie Basins, southwestern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 1749–1755.

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

McGrew, Paul O., 1951, Tertiary stratigraphy and paleontology of south-central Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 6th Ann. Field Conf., South-Central Wyoming, 1951: p. 54–57.

McGrew, Paul O., and Berman, Jack E., 1955, Geology of the Tabernacle Butte area, Sublette County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf., Green River Basin, 1955: p. 108–111.

McGrew, Paul O., with the collaboration of Jack E. Berman, Max K. Hecht, John M. Hummel, George Gaylord Simpson, and Albert E. Wood, 1959, The geology and paleontology of the Elk Mountain and Tabernacle Butte area, Wyoming: Am. Mus. Nat. History Bull., v. 117, p. 121–176.

McGrew, P. O., and Roehler, H. W., 1960, Correlation of Tertiary units in southwestern Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 15th Ann. Field Conf., Overthrust belt of southwestern Wyoming and adjacent areas, 1960: p. 158.

Masursky, Harold, 1962, Uranium-bearing coal in the eastern part of the Red Desert area: U.S. Geol. Survey Bull. 1099–B, p. B1–B19, pl. 1.

Matthew, W. D., 1909, The carnivora and insectivore of the Bridger Basin, middle Eocene: Am. Mus. Nat. History Mem. 9, pt. 6, p. 296.

May, B. E., 1961, The desert springs field, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas, 1961: p. 290–293.

Mees, E. C., Copen, J. D., and McGee, J. C., 1961, Table rock field, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, Wyoming and adjacent areas, 1961: p. 294–300.

Morris, W. J., 1954, An Eocene fauna from the Cathedral Bluffs tongue of the Washakie Basin, Wyoming: Jour. Paleontology, v. 28, p. 195–203.

Nace, R. L., 1939, Geology of the northwest part of the Red Desert, Sweetwater and Fremont Counties, Wyoming: Wyoming Geol. Survey Bull. 27, p. 1–48, pl. 1.

Nightingale, W. T., 1930, Geology of Vermilion Creek gas area in southwest Wyoming and northwest Colorado: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 1013–1040.

Oriel, S. S., 1961, Tongues of the Wasatch and Green River Formations, Fort Hill area, Wyoming: Art. 63 in U.S. Geol. Survey Prof. Paper 424–B, p. B151–B152.

Osborn, H. F., 1936, Proboscidea; a monograph of the discovery, evolution, migration, and extinction of the mastodonts and elephants of the world, v. I, Moeritheroidea, Deinotherioidea, Mastodontoidea; edited by Mabel Rice Percy: New York Am. Mus. Press, p. 312–315.

Peale, A. C., and Endlich, F. M., 1879, Eleventh Ann. Rept., for 1877: U.S. Geol. and Geog. Survey Terr., p. 64–154, 511–643.

Pipiringos, G. N., 1962, Uranium-bearing coal in the central part of the Great Divide Basin: U.S. Geol. Survey Bull. 1099–A, p. A1–A103, pl. I.

Powell, J. W., 1876, Report on the geology of the eastern portion of the Uinta Mountains: U.S. Geol. and Geog. Survey Terr., 2nd div., p. 161–171, 204–210, atlas (folio) map B.

Ridgway, Robert, 1912, Color standards and color nomenclature: Washington, D.C., published by the author.

Roehler, H. W., 1961, The late Cretaceous-Tertiary boundary in the Rock Springs uplift, Sweetwater County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 16th Ann. Field Conf., Symposium on Late Cretaceous rocks, Wyoming and adjacent area, 1961, p. 96–100.

Rosenbusch, Harry, 1923, Elements der Gesteinslehre, 4th ed., revised by A. Osann: Stuttgart, E. Schweizerbart schen-Verlagsbuchandlung, p. 561, 563.

Ruttner, Franz, 1953, Fundamentals of limnology, *translated by* D. G. Frey and F. E. J. Fry: Toronto Univ. Press, 242 p.

Schultz, A. R., 1909, The northern part of the Rock Springs coal field, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 341, p. 256–282, pl. 14.

——— 1910, The southern part of the Rock Springs coal field, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 381, p. 214–281, pl. 14.

——— 1914, Geology and geography of a portion of Lincoln County, Wyoming: U.S. Geol. Survey Bull. 543, p. 71–89, pl. 1.

——— 1918, A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U.S. Geol. Survey Bull. 690, pl. 5.

——— 1920, Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 702, p. 24–29, pl. 1.

Schultz, A. R., and Cross, Whitman, 1912, Potash-bearing rocks of the Leucite Hills, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 512, p. 5–39.

Sears, J. D., 1924a, Relations of the Browns Park Formation and the Bishop Conglomerate, and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., v. 35, p. 279–304.

——— 1924b, Geology and oil and gas prospects of a part of Moffat County, Colorado, and southern Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 751–G, p. 269–319, pl. 35.

——— 1926, Geology of the Baxter Basin gas field, Sweetwater County, Wyoming: U.S. Geol. Survey Bull. 781, p. 13–27.

Sears, J. D., and Bradley, W. H., 1924, Relations of the Wasatch and Green River Formations in northwestern Colorado and southern Wyoming: U.S. Geol. Survey Prof. Paper 132–F, p. 97–103.

Shannon, E. V., 1927, Ammoniojarosite, a new mineral of the jarosite group from Utah: Am. Mineralogist, v. 12, p. 424–426.

Simpson, G. G., 1933, Glossary and correlation charts of North American Tertiary mammal-bearing formations: Am. Mus. Nat. History Bull., v. 47, p. 91.

Sinclair, W. J., 1906, Volcanic ash in the Bridger beds of Wyoming: Am. Mus. Nat. History Bull., v. 22, p. 273–280, pl. 38.

Swain, Barbara W., 1957, Fort Union Formation, west flank of the Sierra Madre, Carbon County, Wyoming: Geol. Soc. America Bull., v. 68, p. 1874.

Terzaghi, Charles, 1925a, Principles of Soil mechanics: Settlement and consolidation of clay: Eng. News-Rec., v. 95, p. 874–876.

——— 1925b, Principles of soil mechanics: Physical differences between sand and clay: Eng. News-Rec., v. 95, p. 912–915.

Tracey, J. I., Jr., Oriel, S. S. and Rubey, W. W., 1961, Diamictite facies of the Wasatch Formation in the Fossil basin, southwestern Wyoming: Art. 62, *in* U.S. Geol. Survey Prof. Paper 424–B, p. B149–B150.

Veatch, A. C. 1907, Geography and geology of a portion of southwestern Wyoming: U.S. Geol. Survey Prof. Paper 56, p. 75–105, pl. 3.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 380–389.

Wilson, L. R., and Hoffmeister, W. S., 1953, Four new species of fossil *Pediastrum:* Am. Jour. Sci., v. 251, p. 753–760.

Winchester, D. E., 1923, Oil shale of the Rocky Mountain region: U.S. Geol. Survey Bull. 729, p. 1–204, pl. 18.

Wood, H. E., 2d, 1934, Revision of the Hyrachyidae: Am. Mus. Nat. History Bull., v. 67, p. 241–242.

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