# Introduction to Greater Green River Basin Geology, Physiography, and History of Investigations

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1506-A

# Introduction to Greater Green River Basin Geology, Physiography, and History of Investigations

*By* HENRY W. ROEHLER

GEOLOGY OF THE EOCENE WASATCH, GREEN RIVER, AND BRIDGER (WASHAKIE) FORMATIONS, GREATER GREEN RIVER BASIN, WYOMING, UTAH, AND COLORADO

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# CONTENTS



# ILLUSTRATIONS

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# INTRODUCTION TO GREATER GREEN RIVER BASIN GEOLOGY, PHYSIOGRAPHY, AND HISTORY OF INVESTIGATIONS

By HENRY W. ROEHLER

ABSTRACT

The greater Green River basin is an intermontane desert that occupies about 20,000 square miles of the Central Rocky Mountains in southwest Wyoming, northeast Utah, and northwest Colorado. The basin is divided by intrabasin anticlines into four structural and topographic subbasins. The largest anticline, the Rock Springs uplift, trends north-south across the center of the greater Green River basin and divides the basin into the Green River basin to the west and the Great Divide, Washakie, and Sand Wash basins to the east. Lesser east-west-trending anticlines, the Wamsutter arch and Cherokee Ridge, separate the Great Divide basin from the Washakie basin and the Washakie basin from the Sand Wash basin. The structural framework of the greater Green River basin was established during the Laramide orogeny.

Eocene rocks crop out across more than 80 percent of the greater Green River basin area, where they are as much as 10,000 ft thick and compose parts of the intertongued Wasatch, Green River, and Bridger (Washakie) Formations. The Eocene rocks are important for their energy resources, for their metallic and nonmetallic minerals, and for their abundance of fossil fauna and flora.

Geologic and geographic investigations of the greater Green River basin began in 1807. These investigations continued intermittently until about 1900, when they abruptly increased in number and scope. The author began geologic research in the basin in 1952, and this research continued until 1991. Much of this research involved the stratigraphy of Eocene rocks, from which many stratigraphic issues were resolved.

## PURPOSE AND SCOPE OF INVESTIGATION

This report series presents stratigraphic, structural, and mineral resource data compiled during investigations of Eocene rocks in the greater Green River basin. It describes nearly 10,000 ft of rocks that were deposited in the Wasatch, Green River, and Bridger (Washakie) Formations over a 15-million-year period that witnessed the terminal stages of the Laramide orogeny, great climate changes, the appearance and disappearance of large freshwater and saltwater lakes, and the introduction of enormous quantities of airfall volcanic ash. As a consequence of these events, the Green River Formation of lacustrine origin complexly intertongues with the Wasatch and Bridger (Washakie) Formations of fluvial origin. Each formation exhibits rapid lateral facies changes, abrupt thickness changes, intraformational unconformities, and in places, gradational contacts. The Eocene rocks are a vast storehouse of energy minerals, including oil, gas, oil shale, coal, and uranium, and other minerals, such as trona, zeolites, clay, placer gold, and phosphate. The abundance of fossil fauna and flora in the rocks is probably unparalleled in rocks of similar age anywhere in the world. Hayden (1869, p. 191) was prophetic when he wrote that these rocks "When carefully studied*** will form one of the most interesting groups in the West."

Specific aspects of the Eocene geology occupy separate report chapters in the series. Chapter B revises the nomenclature of the Wasatch and Green River Formations. It redefines old stratigraphic units and names new ones to establish a more accurate and acceptable stratigraphic framework for the basin. Chapter C names and describes the Godiva Rim Member, a new stratigraphic unit in the Green River Formation in the Washakie and Sand Wash basins. It provides stratigraphic evidence that Lakes Gosiute and Uinta were occasionally connected around the east end of the Uinta Mountains during the middle Eocene. Chapter D describes and correlates all the Eocene rocks present in extensive reference sections located in

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the southeastern part of the Green River basin and the southwestern part of the Washakie basin, adjacent to the Rock Springs uplift. The rocks in the Washakie basin reference section were sampled, examined petrographically, and analyzed using heavy mineral separations, X-ray techniques, and assays. Fossil palynomorphs collected from the Washakie basin reference section were used to identify five successive Eocene climates. Chapter E uses maps and cross sections to illustrate the correlation, composition, areal distribution, and thickness of Eocene stratigraphic units in the greater Green River basin. Chapter F discusses Eocene climates, depositional environments, and paleogeography. It relates observable rock cycles to the cyclicity of climates, presents models for the depositional environments, and maps the paleogeography. Further work in progress analyzes tectonic events and the structural evolution of the basin, and the origin, composition, and distribution of mineral deposits.

## LOCATION AND ACCESSIBILITY OF THE GREATER GREEN RIVER BASIN

The greater Green River basin is an irregularly shaped intermontane desert basin that comprises part of the central Rocky Mountain region. It is located between lat 40°30′ and 43°30′ N. and long 107° and 111° W. The mountains that bound the basin are the Wyoming thrust belt to the west, the Rawlins uplift and Sierra Madre to the east, the Wind River Mountains and Sweetwater arch (Granite Mountains) to the north, and the Uinta Mountains to the south (fig. 1). The basin occupies about 20,000 $mi^2$ of Sweetwater, Uinta, Lincoln, Sublette, Teton, Fremont, and Carbon Counties in southwest Wyoming, Summit and Daggett Counties in northeast Utah, and Moffat and Routt Counties in northwest Colorado. Topographic landmarks and localities, and geology of the greater Green River basin are shown on plate 1.

The greater Green River basin is accessible by Interstate Highway 80, which crosses southern Wyoming by way of the cities of Rawlins, Rock Springs, and Evanston. From I-80, other paved (numbered) Federal and State highways and unpaved (unnumbered) county roads branch in all directions as indicated on plate 1. Remote parts of the basin are accessible by ranch roads, roads to oil and gas production facilities, abandoned seismograph trails, and trails used seasonally by hunters, fishermen, and rock collectors.

## GEOLOGIC SETTING

The greater Green River basin is divided by intrabasin anticlines into four structural and topographic subbasins. The largest anticline, the north-south-trending Rock Springs uplift, occupies the center of the basin and divides the basin into nearly equal east and west halves (fig. 1). The Green River basin occupies the west half and the Great Divide, Washakie, and Sand Wash basins occupy the east half. The four subbasins are further subdivided into smaller drainage basins, such as the Red Desert basin in the Great Divide basin (pl. 1). The Great Divide basin is separated from the Washakie basin by an east-west-trending fold known as the Wamsutter arch, and the Washakie basin is separated from the Sand Wash basin by the east-west-trending Cherokee Ridge anticline (fig. 1). Red Creek syncline parallels the north flank of the Uinta Mountains.

The structural framework of the greater Green River basin formed during the Laramide orogeny that began near the close of the Cretaceous Period. The Laramide orogeny involved uplifts in the mountains bordering the basin, flank thrusting at the basin margins, local folding and normal faulting, and rapid subsidence at basin depocenters. The orogeny was not a single, long-term event; rather, tectonism occurred intermittently over a 30-million-year period, from the Late Cretaceous through the Paleocene and into the Eocene, with varying degrees of magnitude in different parts of the basin. For example, the Rock Springs uplift was folded at least five times during the Laramide orogeny—twice during the Eocene Epoch, and at least six movements took place along the Sparks Ranch thrust fault. The end of basin subsidence, near the close of the Eocene, signaled the end of the Laramide orogeny in the greater Green River basin area. The last major Laramide disturbances were a final very late Eocene upwarp of the Rock Springs uplift, and the appearance of the Wamsutter arch and Cherokee Ridge anticline. Eocene sedimentation was continuous across most of the basin during the Laramide orogeny, except for a few interruptions that occurred adjacent to thrust faults and as a result of local faulting and folding. Since the end of the Eocene Epoch, the basin has been only slightly modified by regional uplift, normal faulting, volcanism, and erosion. The Eocene structural evolution of the basin is examined in later chapters of this volume.

## GEOGRAPHIC SETTING

The greater Green River basin has surface elevations that range between about 6,000 and 9,500 ft. The topography is strongly influenced by the differential erosion of faulted and folded sedimentary rocks of Tertiary and Cretaceous ages and volcanic rocks of

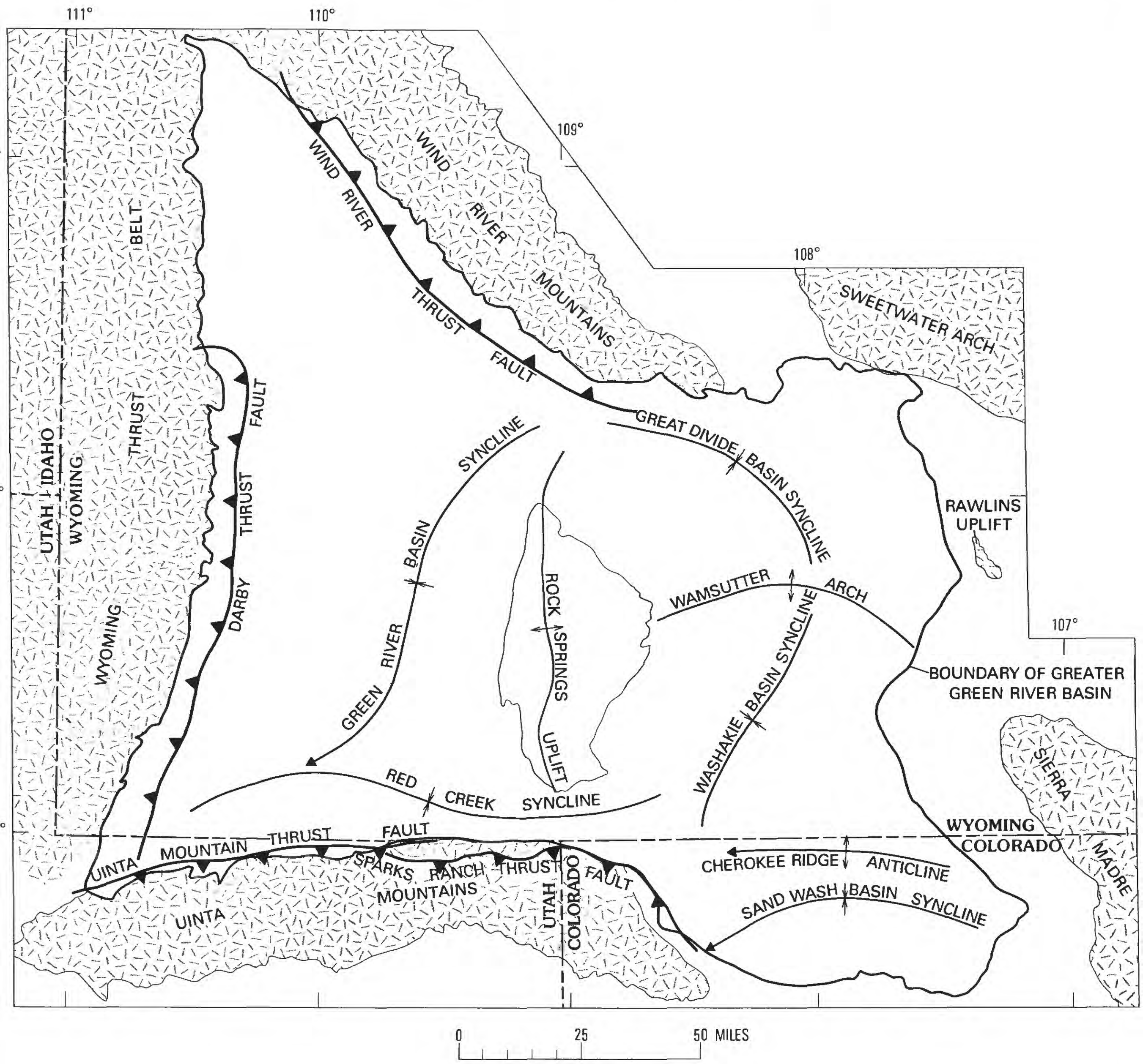



FIGURE 1.—Major structural features in greater Green River basin. Structural axes are drawn on top of the Tipton Shale Member of the Green River Formation. On thrust faults, sawteeth on overthrust block.

Quaternary age (pl. 1). A few streams are perennial, but the basin is mostly dissected by networks of dry drainages. Sand dunes and playa lakes cover large areas. The annual precipitation ranges from 7 to 15 inches (Root and others, 1973); annual runoff is between 0.5 and 10 inches (U.S. Geological Survey, 1960, p. 33); annual temperatures usually range between –30 °F and +100 °F. The vegetation consists of groves of pine, cedar, and aspen at elevations above 7,000 ft, and sagebrush, greasewood, grasses, and a variety of other small desert plants at lower elevations. Cottonwood and willow grow along perennial streams. Land and mineral ownership is roughly 60 percent Federal Government, 20 percent Union Pacific Railroad, 15 percent private, and 5 percent State of Wyoming.

The population of the basin is approximately 60,000. Rock Springs has a population of about 32,000 and Green River about 8,000; the remaining population is located in small towns and villages, oil and gas camps, and railroad stations, and on farms and ranches. The main industries are coal mining in the Rock Springs uplift and trona mining in the south-central part of the Green River basin. Oil and gas are produced from fields located throughout the basin. Large quantities of hay are grown on irrigated fields located along the valleys of perennial streams, and winter wheat is grown locally in the Sand Wash basin near Craig, Colo. Most of the greater Green River basin is rangeland for large herds of cattle and sheep, and it provides habitat for wild horses, various predators, and a variety of other non-game and game animals.

## GREEN RIVER BASIN

The Green River basin, the largest subbasin of the greater Green River basin, is about 160 mi long and 60 mi wide. It occupies about 10,500 mi$^2$. Most of the western margin of the basin is defined by a large, north-south-trending hogback ridge, known as Oyster Ridge, that is formed by resistant, west-dipping sandstone beds in the Cretaceous Frontier Formation (pl. 1). At the east edge of the basin, along the west flank of the Rock Springs uplift, is White Mountain, a large, east-facing escarpment composed mostly of middle Eocene rocks (fig. 2). Pilot Butte is a prominent lava-capped landmark on the top of White Mountain in T. 19 N., R. 106 W. (pl. 1). The northern and southern margins of the basin bordering the Wind River and Uinta Mountains are mostly formed by dissected remnants of pediment surfaces consisting of gravels and conglomerates of middle to late Tertiary age that cap large buttes, mesas, and terraces with surfaces that slope gently basinward from the mountains. Hickey Mountain in T. 13 N., R. 114 W., Cedar Mountain in Tps. 13–14 N., Rs. 111–112 W., and Little Mountain in T. 13 N., Rs. 105–106 W., are typical of these pediment surfaces.

Elevations in the Green River basin range from slightly less than 6,000 ft at Flaming Gorge Reservoir in the southeast part of the basin to nearly 9,500 ft in the foothills of mountains adjacent to the basin (pl. 1). The central part of the basin is a rolling grass- and sage-covered plain that is in places interrupted by ridges, buttes, and badlands. Eocene rocks are well exposed in the basin along ridges that extend southward from Big Piney to Carter in Tps. 17–30 N., Rs. 112–115 W. (figs. 3 and 4), and along Blue Rim in Tps. 21–22 N., Rs. 107–108 W. Eocene rocks are also well exposed in badlands that are present across the area between Wyoming Highways 530 and 414 in Tps. 13–17 N., Rs. 108–113 W., which includes Black Mountain (fig. 5), Twin Buttes, and Sage Creek Mountain.

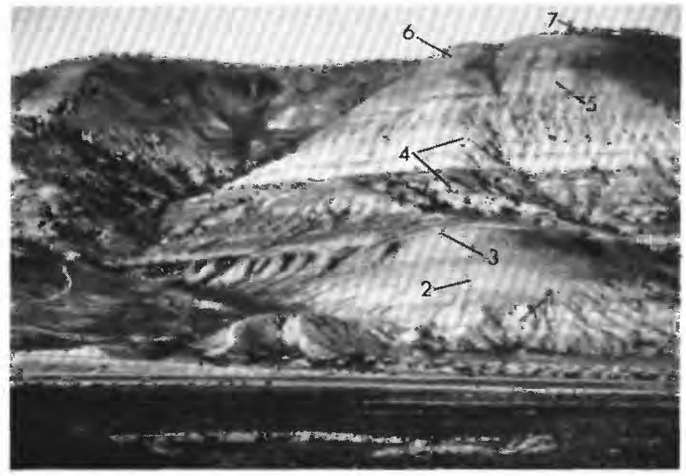


FIGURE 2.—White Mountain near intersection of Tps. 18–19 N., Rs. 105–106 W. on west flank of Rock Springs uplift. View is northwest across Bitter Creek and Interstate Highway 80, 3 mi west of Rock Springs, Wyo. 1, main body of Wasatch Formation; 2, Scheggs Bed of Tipton Shale Member; 3, Rife Bed of Tipton Shale Member; 4, Wilkins Peak Member; 5, LaClede Bed of Laney Member; 6, Sand Butte Bed of Laney Member; and 7, Hartt Cabin Bed of Laney Member, all of Green River Formation. The Eocene rocks exposed in White Mountain are nearly 1,400 ft thick.

FIGURE 3.—Eocene outcrops on north slopes of Spur Canyon in sec. 9, T. 26 N., R. 112 W., 2½ mi southeast of La Barge, Wyo. View is northwest toward the valley of Green River. 1, main body of Wasatch Formation; 2, Scheggs Bed of Tipton Shale Member of Green River Formation; 3, Farson Sandstone Member of Green River Formation; 4, Alkali Creek Tongue of Wasatch Formation; 5, Wilkins Peak Member of Green River Formation; and 6, Laney Member of Green River Formation. The exposures are about 500 ft thick.

The major drainage in the Green River basin is the Green River, which has a number of perennial tributaries. The largest of these tributaries are the New Fork and Big Sandy Rivers that flow southwestward from the Wind River Mountains, the Hams Fork River and Muddy Creek that flow eastward from the Wyoming thrust belt, and the Blacks Fork and Henrys Fork Rivers that flow northward from the Uinta Mountains. The northern tip of the Green River basin, north of T. 36 N., is drained by the Hoback River, which flows northwest through the Hoback basin and joins the Snake River a few miles east of where the Snake River enters Idaho.

## ROCK SPRINGS UPLIFT

The Rock Springs uplift is a 75-mi-long, 50-mi-wide, deeply eroded, asymmetric anticline that occupies about 1,200 mi$^2$. Dips on the east flank of the uplift range from 3° to 8°, and dips on the west flank of the uplift range from 5° to 35°. The core of the uplift is composed of soft, drab-gray-weathered shale of marine origin and Late Cretaceous age called the Baxter Shale. Across the center of the uplift, the Baxter Shale is deeply eroded to form a depression called the Baxter basin. The Baxter basin has surface elevations between 6,300 and 6,800 ft. Its relief is low and its appearance is characterized by rounded sage- and grass-covered hills and valleys and a few cliffs, ledges, and benches. Surrounding the Baxter basin is a wide belt of sparsely vegetated, gray, yellow, and white sandstone escarpments that rise several hundred feet above the floor of the basin. These escarpments comprise the Mesaverde Group of Late Cretaceous age (fig. 6). Separating the Mesaverde escarpments from an outer belt of middle and late Eocene escarpments in the Green River Formation are low ridges and valleys formed by less resistant Late Cretaceous rocks comprising the Lewis Shale, Fox Hills Sandstone, and Lance Formation; Paleocene rocks comprising the Fort Union Formation; and lower Eocene rocks comprising the main body of the Wasatch Formation. Lava-capped buttes and mesas, cinder cones, and pipes form erosional remnants of the Quaternary Leucite Hills volcanic field in the northern part of the Rock Springs uplift. Notable among the volcanic landforms there are the lava-capped South Table Mountain in T. 22 N., R. 103 W., and Spring Butte in T. 22 N., R. 101 W. Black Butte in T. 18 N., R. 101 W. and Quaking Asp Mountain in T. 17 N., R. 104 W. are prominent landmarks capped by hydrothermally altered sandstones in the Ericson Sandstone and Blair Formation of the Mesaverde Group. The highest point in the uplift is 9,680 ft on Quaking Asp Mountain. Bacon Ridge, a

FIGURE 4.—Bridger Formation in outcrops in sec. 29, T. 18 N., R. 111 W., 6 mi west of Little America, Wyo. View is southeast from Interstate Highway 80. Note light-colored tuff beds. Exposed interval is about 150 ft thick.

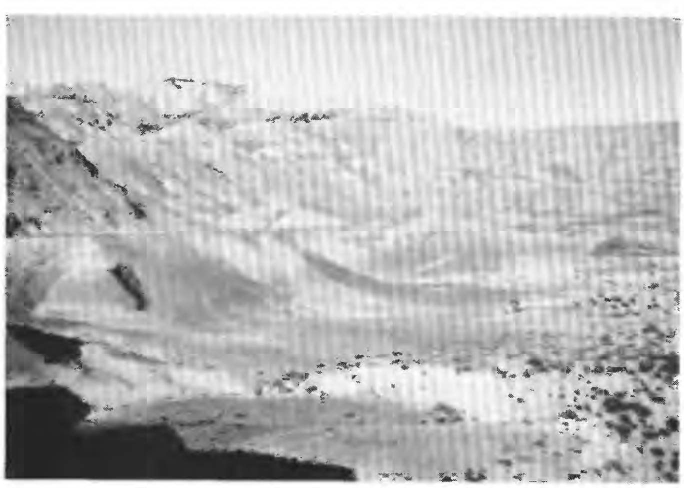


FIGURE 5.—Bridger Formation in badlands on north slopes of Black Mountain in sec. 15, T. 14 N., R. 109 W. View is northwest. Thickness of exposures about 600 ft.

FIGURE 6.—West-dipping, ridge-forming sandstone in Mesaverde Group on west flank of Rock Springs uplift in sec. 5, T. 20 N., R. 104 W. These outcrops are about 200 ft thick.

gently north sloping plateau in the southwest part of the uplift, is capped by the Bishop Conglomerate of Oligocene age that unconformably overlies folded older Tertiary and Cretaceous rocks (pl. 1). The only perennial stream in the Rock Springs uplift is Bitter Creek, which flows from east to west across the center of the uplift adjacent to the Union Pacific Railroad (pl. 1).

## GREAT DIVIDE BASIN

The Great Divide basin, about 75 mi long and 50 mi wide, is a featureless, arid desert in the northeast part of the greater Green River basin. It occupies about 3,500 mi$^2$ and is located directly on the Continental Divide—hence the name Great Divide basin. The landscape in the basin is characterized by low, rolling, partly sage covered hills and ridges interspersed with sand dunes, badlands, alkali flats, and playa lakes. The lowest parts of the basin have elevations between 6,500 and 7,500 ft, but several isolated buttes rise a few hundred feet higher. Lava-capped outliers of the Leucite Hills volcanic field include Black Rock in T. 22 N., R. 101 W. and Steamboat Mountain in T. 23 N., R. 102 W. Other prominent landmarks are Oregon Buttes in T. 26 N., R. 101 W., Continental Peak in T. 27 N., R. 100 W., The Pinnacles in T. 24 N., R. 100 W., and Cyclone Rim in T. 26 N., Rs. 96–97 W.

The Great Divide basin has an internal drainage system. A few small perennial streams flow southward from the Wind River Mountains, but they quickly evaporate and disappear within the basin. The central part of the basin is etched by numerous dry gullies that end at large playa lakes (pl. 1).

## WASHAKIE BASIN

The Washakie basin, encompassing roughly 3,000 mi$^2$, has the configuration of a very large, square bowl about 50 mi in diameter. The edges of the bowl consist of high-standing, encircling ridges. The largest of these ridges are Delaney (or Laney) Rim at the northern margin of the basin and Kinney Rim (fig. 7) at the western margin of the basin. These rims rise nearly 1,000 ft above the basin center. Sand Butte in T. 16 N., R. 100 W., and Pine Butte in T. 15 N., R. 100 W. are landmarks on Kinney Rim at elevations above 8,500 ft. Three lesser rims rise from 100 to 500 ft above the central part of the basin inside the outer encircling rims. From outermost to innermost, they are called the lower brown sandstone rim, Willow Creek Rim, and Adobe Town–Skull Creek Rim.

The basinward-sloping ridge-and-valley terrane at the outer margins of the basin is replaced at the basin center by extensive areas of badlands and inactive sand dunes. The dominant feature of the landscape in the north center of the basin is Haystack Mountain, which has an arcuate shape, open to the south. It trends east-west for nearly 10 mi across Tps. 16–17 N., Rs. 95–96 W. The slopes of Haystack Mountain rise steeply for a vertical distance of about 500 ft in steplike fashion through a maze of badlands (fig. 8) to a narrow, flat, sandstone-capped erosion surface at the top of the mountain. The badlands that form the broadly bowed south slopes of Haystack Mountain continue uninterrupted from the southwest end of the mountain to an area of small, mound-shaped badland buttes called Adobe Town (fig. 9) in T. 15 N., R. 97 W. From Adobe Town the badlands continue southward along the east face of Skull Creek Rim in Tps. 13–14 N., Rs. 96–97 W. Skull Creek Rim is triangular in shape. The upper surface is flat, and the rim narrows eastward to a high point that overlooks the central part of the Washakie basin. On the upper surface of Skull Creek Rim are numerous sage-covered, stabilized sand dunes. The southern margin of the Washakie basin is formed by Cherokee Ridge, which trends east-west parallel to the Wyoming-Colorado State line in Tps. 12–13 N., Rs. 94–97 W. Cherokee Ridge has a rounded, cedar-covered upper surface that slopes downward several hundred feet from the flanks of the ridge into the adjacent basins. Powder Mountain is a flat-topped butte on Cherokee Ridge in sec. 6, T. 12 N., R. 96 W. Flattop Mountain, a prominent butte in the southeast part of the Washakie basin, is located in sec. 2, T. 14 N., R. 93 W.

The two largest drainages in the Washakie basin are Shell Creek and Sand Creek. Shell Creek originates at Kinney Spring in sec. 8, T. 15 N., R. 98 W. Its perennial flow is maintained downstream of the spring by the waters contributed by other smaller springs located on the east slopes of Kinney Rim in Tps. 14–15 N., Rs. 99–100 W. Shell Creek drains most of the western part of the basin, flows southward, and leaves the basin at the west end of Cherokee Ridge in T. 12 N., R. 98 W. Most of the eastern part of the basin is drained by Sand Creek and its tributaries. Except for spring runoff, Sand Creek is normally a wide sand-filled valley (fig. 10) that trends southward, crosses Cherokee Ridge, and joins the Little Snake River in T. 12 N., R. 93 W. Segments of some drainages along the northern part of the Washakie basin maintain a small perennial flow of water as a result of several large springs. Water from one of these springs, Barrel Springs, in sec. 24, T. 17 N., R. 95 W., flows eastward down Barrel Springs Draw for several miles before

FIGURE 7.— Kinney Rim looking south from Pine Butte in sec. 22, T. 15 N., R. 100 W. along western margins of Washakie basin. The rim is capped by Sand Butte Bed of Laney Member of Green River Formation. Exposures in lower right slopes of rim are Cathedral Bluffs Tongue of Wasatch Formation. Relief along Kinney Rim is about 1,000 ft.

FIGURE 8.— Adobe Town Member of Washakie Formation exposed in badland slopes at east end of Haystack Mountain in sec. 30, T. 17 N., R. 95 W. in Washakie basin. Outcrops shown are 500 ft thick.

FIGURE 9.—Adobe Town Member of Washakie Formation exposed at Adobe Town in sec. 7, T. 15 N., R. 97 W. in Washakie basin. View is northeast from Adobe Town Rim. Butte near center of photograph stands about 50 ft high.

FIGURE 10.—Sand Creek in the southeastern part of Washakie basin. View is toward the south from sec. 3, T. 12 N., R. 93 W. Width of sand-filled valley is about 1,500 ft.

evaporating and seeping into alluvium. Springs at the ruins of Fort LaClede on the Overland Trail in sec. 25, T. 17 N., R. 98 W. and along Antelope Creek in secs. 2 and 3, T. 16 N., R. 99 W. create a small stream that forms Bitter Creek, which flows perennially northwest from the basin through Delaney Rim.

## SAND WASH BASIN

The Sand Wash basin, 75 mi long and 25 mi wide, is the smallest subbasin in the greater Green River basin. It occupies 2,100 mi$^2$. The basin is elongated east-west and is structurally and topographically divisible into western and eastern parts. The structurally lowest part of the basin is located in the western part near the northeast flank of the Uinta Mountains in Tps. 8–9 N., Rs. 98–99 W. The eastern part consists of a long arm of the basin that extends along the synclinal axis of the basin from the western part eastward toward the Sierra Madre (fig. 1; pl. 1). The southwest course of the Little Snake River across the basin forms a general dividing line between the two parts of the basin.

The western part of the Sand Wash basin forms a topographic depression that is roughly triangular in shape. The encircling rims of this depression, which create drainage divides, are the Vermillion Bluffs to the northwest, Sevenmile Ridge along the west slopes of the Little Snake River to the east (fig. 11), and faulted outcrops on the northeast flank of the Uinta Mountains to the southwest (pl. 1). Lookout Mountain forms a high point on the Vermillion Bluffs in sec. 35, T. 11 N., R. 99 W. Dry Mountain is a prominent landmark along the northeast flank of the Uinta Mountains in T. 9 N., R. 100 W. (pl. 1). The central part of the topographic depression is a flat-lying, arid desert consisting of minor ridges and valleys interspersed with areas of badlands. The elevation rises from less than 6,000 ft across the sage-covered central part of the depression to about 7,000 ft at cedar-covered rims at the margins of the depression. The primary drainage is Sand Wash and its tributaries that flow intermittently southward. Sand Wash leaves the basin in T. 8 N., R. 98 W. and joins the Little Snake River a few miles to the south in sec. 1, T. 7 N., R. 98 W.

The terrane along the Little Snake River in the central part of the Sand Wash basin is characterized by a number of long ridges formed by Eocene rocks that dip 3° to 8° west toward the structural center of the basin. Many of these ridges consist of long, smooth dip slopes on the west and steep outcrop slopes that form badlands on the east. One of the largest of these ridges is Godiva Rim in T. 8 N., R. 96 W. (fig. 12).

The eastern part of the Sand Wash basin is less arid than the western part. The landscape in the eastern part is mostly sage covered rolling hills and valleys. Groves of cottonwood are widely spaced along small streams. The area is drained by small west-flowing tributaries of the Little Snake River, and by Spring Creek, Big Gulch, and Fortification Creek, which flow south to the Yampa River (pl. 1).

FIGURE 11.—Northern part of Sevenmile Ridge in Sand Wash basin. View is toward the south in sec. 16, T. 11 N., R. 96 W. The rim is capped by Laney Member of Green River Formation. Slopes in foreground are in Cathedral Bluffs Tongue of Wasatch Formation. Outcrops shown are about 350 ft thick.

FIGURE 12.—Godiva Rim looking north from lower east slopes of rim in sec. 29, T. 8 N., R. 96 W., Sand Wash basin. The rim is capped by Laney Member of Green River Formation. Exposures in foreground are in Cathedral Bluffs Tongue of Wasatch Formation. Outcrops shown are about 700 ft thick.

## PREVIOUS INVESTIGATIONS

### GREATER GREEN RIVER BASIN FROM 1800 TO 1900

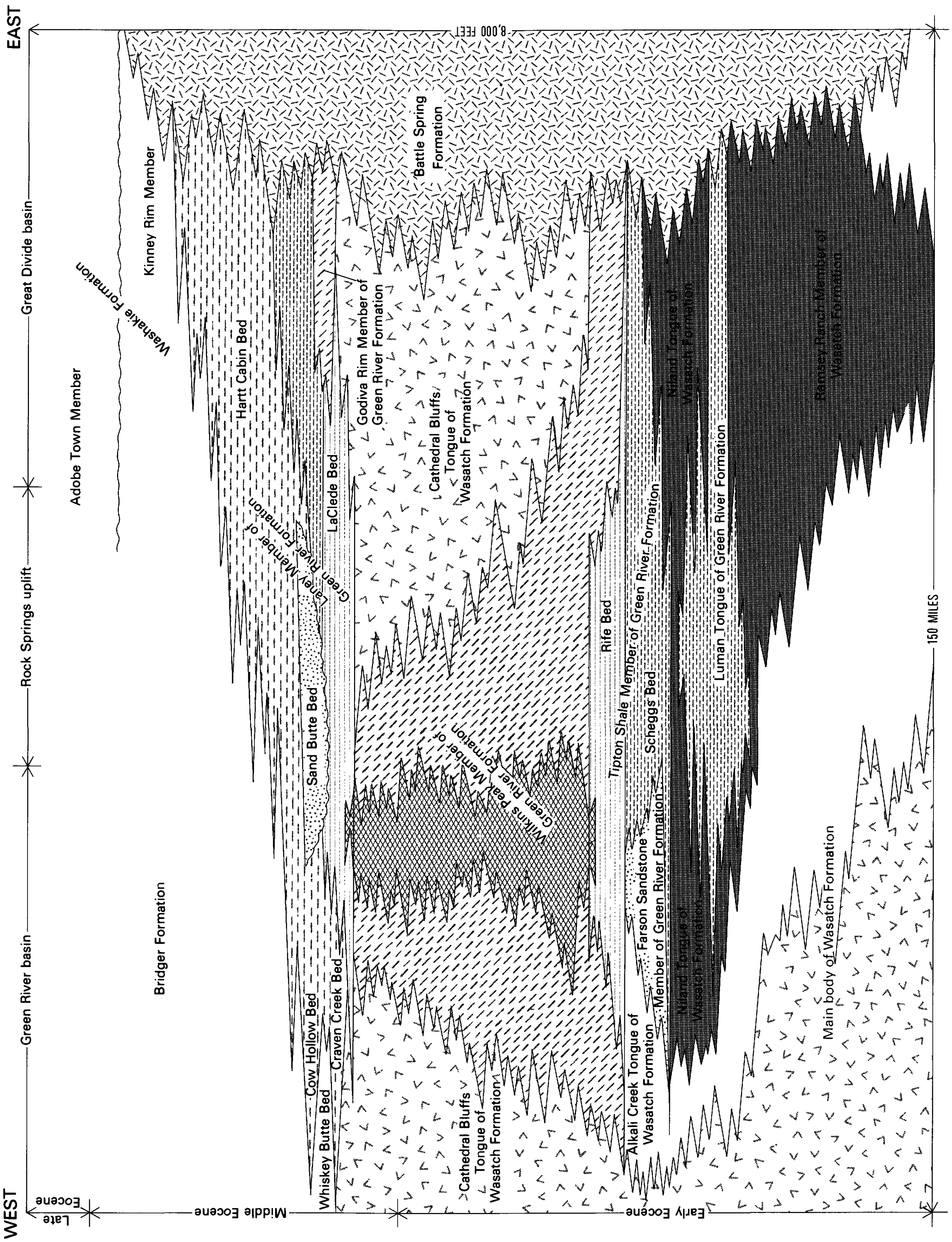
The first white man to enter the greater Green River basin was probably John Colter, who visited the headwaters of the Green River in 1807 (Chadey, 1973). He was followed a few years later by Wilson Hunt, in 1811–1812. Many of the early records of explorations in the greater Green River basin contain references to the occurrences of fossils and coal. The fur trappers and traders knew of and used coal from the basin; General W.H. Ashley recorded this fact in 1825 (Rock Springs Rocket-Miner, March 15, 1975). Captain B.L.E. Bonneville explored part of the area in 1834–1835, and published the first map showing the major geographic features (Bonneville, 1837). Captain John C. Fremont (1845), while exploring for the United States Army, collected fossil shells from the Wasatch Formation near Cumberland Gap in T. 19 N., R. 116 W. (Veatch, 1907, p. 17). During these early explorations a large part of the greater Green River basin was located within territory claimed by Mexico, and it remained so until the Mexican cession by the Treaty of Guadalupe Hidalgo in 1848. In August 1852, the first mention of coal in the Rock Springs uplift was made by Howard Stansbury of the topographical engineers (Rock Springs Rocket-Miner, March 15, 1975). Stansbury mentioned that Jim Bridger led him and his crew up the Green River to Bitter Creek and then east along Bitter Creek to the present location of the city of Rock Springs, which they reached in September 1852. Fifteen years later, in 1867, the discovery of gold started a gold rush at South Pass in T. 29 N., R. 100 W., near the east end of the Wind River Mountains (Chadey, 1973).

Fossil mammals were first discovered in the Green River basin by Dr. J. Van A. Carter; they were subsequently described by Dr. Joseph Leidy in 1868–1870 (Leidy, 1873). In 1868, and again in 1871, John Wesley Powell began his historic explorations of the West by boat trips down the Green River beginning at the present site of Green River, Wyo. (Chadey, 1973). The Eocene Wasatch, Green River, and Bridger Formations were named by Hayden (1869) during U.S. Geological Surveys of the Territories. In a later report, Hayden (1871) mentioned the discovery of fossil fish in a cut excavated by the Union Pacific Railroad about 2 mi west of Green River, Wyo. Fossil plants collected near Cumberland Gap in T. 19 N., R. 116 W. were described by Lesquereux (1872). Cope (1872, p. 481) probably discovered and collected the first dinosaur in the basin from near Black Butte Station on the Union Pacific Railroad in T. 18 N., R. 100 W. Additional fossil mammals collected in the Green River and Washakie basins were described by Marsh (1876). Early geologic maps of the southern parts of the greater Green River basin, south of lat 41°45′ N., were produced by Powell in 1876, Hague and Emmons in 1877, and King in 1878 (Bradley, 1964, p. A4). The Eocene Tower Sandstone was named by Powell (1876). In the period 1877–1886, important vertebrate fossils were collected by expeditions from the Princeton and American Museums under the directions of W.B. Scott, H.F. Osborn, and J.L. Wortman (Matthew, 1909, p. 294).

## GREATER GREEN RIVER BASIN FROM 1900 TO 1987

Since 1900, a large number of geological investigations have been undertaken in the greater Green River basin by scientists from Federal and State government agencies, universities, and private companies. The reports covering these investigations are so voluminous that only a few of those involving significant changes in stratigraphy and mapping are listed herein. Reports covering other topics are deferred to appropriate places in later chapters of this volume. Current Eocene stratigraphic nomenclature for the greater Green River basin is shown in figure 13.

The first definitive geologic investigations of Eocene rocks in the greater Green River basin were undertaken by Schultz (1920). Schultz (1920, p. 27–30) named and described the Tipton Shale, Cathedral Bluffs, and Laney Members and assigned them to the Green River Formation along outcrops in the northern part of the Washakie basin. (The Cathedral Bluffs Member was later correctly redefined as a tongue of the Wasatch Formation by Sears and Bradley, 1924.) Schultz (1920, pl. 1) also published the first detailed geologic map of the central and eastern parts of the greater Green River basin that included the Rock Springs uplift and most of the Great Divide, Washakie, and Sand Wash basins. Bradley (1926) made a detailed study of the biological and environmental conditions that were present along the northern margins of the Eocene Green River Lakes (Lake Gosiute). During these studies, he made several important discoveries concerning the origin and composition of oil shale, and he applied the name Morrow Creek Member to the uppermost beds of the Green River Formation (Bradley, 1926, p. 123). Bradley also mapped Eocene outcrops in the Washakie and Sand Wash basins (Bradley, 1945). The New Fork Tongue of the Wasatch Formation and the Fontenelle Tongue of the Green River Formation were named and mapped by Donavan (1950) for exposures of Eocene rocks along the western margins of the Green River basin. Pipiringos (1955) evaluated uranium-bearing coal beds in the Wasatch Formation in the central part of the Great Divide basin, where he named, described, and mapped the Luman Tongue, the lowermost stratigraphic unit in the Green River Formation. To the fluvial, lacustrine, and paludal rocks situated between the Luman Tongue and the overlying Tipton Shale Member of the Green River Formation, Pipiringos (1955) applied the name Niland Tongue of the Wasatch Formation. Pipiringos (1955) also named the Battle Spring Formation for the arkosic sandstone that intertongues with and replaces most of the Wasatch and Green River Formations along the northeastern margins of the greater Green River basin. A major revision of the Eocene stratigraphy was made by Bradley in 1959, when he named the Wilkins Peak Member of the Green River Formation and abandoned the name Morrow Creek Member of the Green River Formation. These nomenclature changes were made because he believed that the previously named Laney Shale Member in the Washakie basin was equivalent to the Morrow Creek Member in the Green River basin (fig. 13). A preliminary geologic map of the Fort Hill Quadrangle in the western part of the Green River basin was published by Oriel (1963). The geology of the Big Piney area in the Green River basin was mapped and described by Privrasky (1963). Extensive areas in the northwestern part of the Great Divide basin and northeastern part of the Green River basin were mapped by Zeller and


EAST
WEST
8,000 FEET
150 MILES
Great Divide basin
Rock Springs uplift
Green River basin
Late Eocene
Middle Eocene
Early Eocene
Washakie Formation
Kinney Rim Member
Adobe Town Member
Bridger Formation
Hartt Cabin Bed
Laney Member of Green River Formation
Sand Butte Bed
LaClede Bed
Cow Hollow Bed
Whiskey Butte Bed
Craven Creek Bed
Godiva Rim Member of Green River Formation
Battle Spring Formation
Cathedral Bluffs Tongue of Wasatch Formation
Wilkins Peak Member of Green River Formation
Cathedral Bluffs Tongue of Wasatch Formation
Rife Bed
Tipton Shale Member of Green River Formation
Scheggs Bed
Farson Sandstone Member of Green River Formation
Alkali Creek Tongue of Wasatch Formation
Niland Tongue of Wasatch Formation
Niland Tongue of Wasatch Formation
Luman Tongue of Green River Formation
Ramsey Ranch Member of Wasatch Formation
Main body of Wasatch Formation

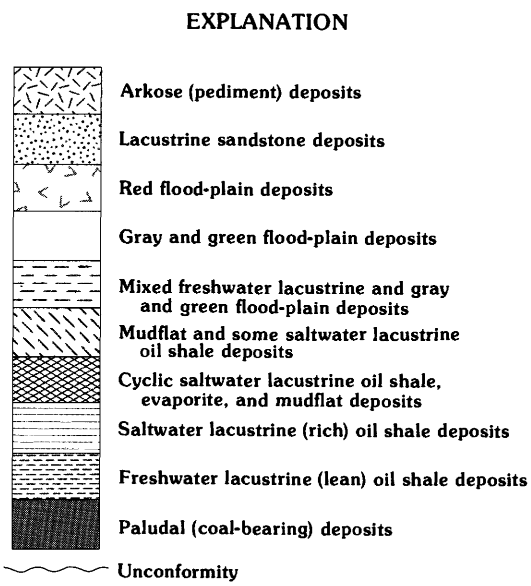



FIGURE 13 (above and facing page).—Generalized stratigraphic correlation of Eocene rocks across central part of greater Green River basin. Not to scale.

Stephens (1964a–1964e). The name Tower Sandstone Lentil of the Green River Formation (Sand Butte Bed of this report) was abandoned by Culbertson (1962, p. C54), because he did not recognize the unconformity identified by Schultz (1920, p. 26) and Bradley (1969, p. B6) that separates the sandstone from underlying parts of the Laney Member that are composed mostly of oil shale. While mapping Eocene rocks adjacent to the Rock Springs uplift, Roehler (1968) discovered that most of the type Tipton Shale Member of Schultz (1920) in the Washakie basin was equivalent to the lower part of the type Wilkins Peak Member of Bradley (1959) in the Green River basin. To correct this discrepancy, the type Tipton Shale Member was redefined and the Wilkins Peak equivalents were excluded (Roehler, 1968, p. 2249). A geologic map of Eocene rocks in the greater Green River basin was compiled by Bradley in 1964, using data from U.S. Geological Survey publications, graduate theses, and other sources. Revisions of the nomenclature of middle and upper Eocene rocks in the Washakie basin were made by Roehler (1973a and 1973b). The Laney Member was divided into three stratigraphic units consisting of a base lacustrine oil shale named the LaClede Bed, a middle lacustrine sandstone named the Sand Butte Bed, and an upper intertongued lacustrine and fluvial mudstone, sandstone, and limestone unit named the Hartt Cabin Bed (Roehler, 1973a). The name Washakie Formation was reintroduced the same year for rocks of mostly late Eocene age (Roehler, 1973b). The Washakie Formation has different lithologies and is somewhat younger in age than the Bridger Formation in the Green River basin, although both formations are primarily of fluvial origin. Two parts of the Washakie Formation, which are separated by an unconformity, were named the Kinney Rim and Adobe Town Members (Roehler, 1973b). Tongues of the Laney Member along the western margins of the Green River basin were given the names Cow Hollow Bed and Craven Creek Bed by Sullivan (1980). Between the Cow Hollow and Craven Creek Beds is a tongue of the Bridger Formation that Sullivan (1980) named the Whiskey Butte Bed. Sullivan (1980) also named the Desertion Point Tongue of the Wasatch Formation. A geologic map of the Kinney Rim 30×60-minute quadrangle, which includes the southeast flank of the Rock Springs uplift and most of the Washakie basin, was published by Roehler (1985). The names Alkali Creek Tongue of the Wasatch Formation and Farson Sandstone Member of the Green River Formation are introduced, and the Tipton Shale Member of the Green River Formation is divided into the Rife and Scheggs Beds in Chapter B of this volume (fig. 13). The name Godiva Rim Member of the Green River Formation is introduced in Chapter C of this volume.

## FIELD WORK BY THE AUTHOR

My investigations of Eocene rocks in the greater Green River basin began in 1952, while I was an undergraduate student at the University of Wyoming. During June of 1952, about 10 days were spent in the field in the Washakie basin collecting vertebrate fossils under the direction of Professor P.O. McGrew. Professor McGrew was an energetic fossil collector and one of the first to identify and classify depositional environments in continental Tertiary rocks. In June of 1953, I returned with Professor McGrew to the Washakie basin as part of a university field party that again collected vertebrate fossils. From 1954 to 1965, I was intermittently employed as a petroleum geologist by Mountain Fuel Supply Company in Rock Springs, Wyo. Work with the company included geologic mapping of Eocene rocks in the southeastern part of the Washakie basin in 1954–1956, in the northwestern part of the Great Divide basin in 1958, on the west flank of the Rock Springs uplift in 1959, and along the western and northern parts of the Washakie basin in 1960. Oil-shale beds were studied along the western margins of the Washakie basin in 1964 and 1965.

After joining the U.S. Geological Survey in 1966, I was assigned the task of investigating the oil-shale resources of the Washakie and Sand Wash basins. From June through September of 1968, Eocene rocks in the Washakie and Sand Wash basins were mapped on aerial photomosaics at the scale of 1 inch equals 1 mile. During this mapping, numerous stratigraphic sections were measured, key marker beds were identified, and a stratigraphic framework for Eocene rocks was developed. The same year a composite reference section of the lower, middle, and upper Eocene rocks, 7,939 ft thick, was measured, sampled, and described in the Washakie basin (Chapter D, this volume). From 1969 to 1971, eleven 7½-minute geologic quadrangles were mapped along the western margins of the Washakie basin. In 1972, I was reassigned by the U.S. Geological Survey to investigate the coal resources of the Rock Springs coal field. Valuable coal deposits were subsequently discovered in Eocene rocks in the southern part of the field, where seven additional 7½-minute geologic quadrangles were mapped along the southern margins of the Rock Springs uplift. In 1984, I was authorized by the U.S. Geological Survey to establish a stratigraphic framework for Cretaceous and Tertiary rocks across the greater Green River basin. From 1984 to 1987, numerous sections were measured in Eocene rocks along the western margins of the Green River basin, across the northern part of the Great Divide basin, and in the southern and central parts of the Sand Wash basin (Chapter E, this volume). The upper part of a composite reference section of Eocene rocks in the southeast part of the Green River basin was measured and described in 1985 (Chapter D, this volume). During my investigations in the greater Green River basin encompassing a period of nearly 40 years, I have mapped more than 60 percent of the basin and have described more than 500,000 ft of Eocene rocks.

## ACKNOWLEDGMENTS

I appreciatively acknowledge the advice and assistance given me over the years by several now deceased friends and colleagues, who at various times accompanied me in the field. P.O. "Doc" McGrew at the University of Wyoming introduced me to Eocene stratigraphy, sedimentology, and vertebrate paleontology. W.H. "Bill" Bradley with the U.S. Geological Survey had amazing knowledge of the fossils and mineralogy of the Green River Formation. H.D. "Mac" MacGinitie at the University of California identified plant fossils and deciphered changes in the Eocene climate. John H. Hanley with the U.S. Geological Survey classified mollusks and determined their habitats. From S.S. "Steve" Oriel I learned the tenets of U.S. Geological Survey stratigraphic nomenclature.

## UNRESOLVED ISSUES OF STRATIGRAPHIC NOMENCLATURE

In 1964, after spending several years investigating the stratigraphy of Eocene rocks in southwest Wyoming, I proposed that the Green River and Wasatch Formations should be elevated to group status. This change would allow the former tongues and members of the Green River and Wasatch Formations to be elevated to formations, so that, in turn, thick and lithologically distinct subdivisions of these formations could be formally recognized as tongues and members. The resulting nomenclature changes would allow for greater flexibility in defining new subordinate stratigraphic units. But, a number of colleagues disagreed with this idea. Among them was W.H. Bradley, who stated (written commun., 1965):

> I do not see the compelling necessity for raising the Green River Formation to Group and I do not like it because it would tend to fragment the concept of continued deposition of lake beds continuously all through some 4 million years. This body of lacustrine beds fits the Code's definition of one lithologic unit, hence formation. If we call it a group the group name gradually falls into disuse and the several constituent formations, none of which can have the name Green River, take over.

As a result of Bradley's opposition, the idea of elevating the rank of the Wasatch and Green River Formations to group status was dropped.

I am aware of the unequal rank assigned to lithostratigraphic units of the Green River Formation in this professional paper. All of the units defined by me as "beds" (for example, Scheggs Bed and Rife Bed of the Tipton Shale Member, and LaClede Bed, Sand Butte Bed, and Hartt Cabin Bed of the Laney Member) fully qualify as formal "members," equal in rank to other members of the formation, such as the Godiva Rim Member and Farson Sandstone Member. Article 26(a) of the North American Stratigraphic Code (1983) states that units designated as beds should be limited to certain distinctive beds whose recognition is particularly useful. The beds that I have named are not necessarily distinctive, and they are very thick. The type section of the Hartt Cabin Bed, for instance, is composed of interbedded sandstone, siltstone, mudstone, shale, oil shale, dolomite, algal limestone, and tuff, and is 625 ft thick (Roehler, 1973a, p. E24–E27). In revising the stratigraphic nomenclature of the Green River Formation in Chapter B (this volume), it was my intention to give the units named as beds the rank of formal members of the formation, but this proposal was rejected by the Geologic Names Unit of the U.S. Geological Survey. The reason given for rejecting my proposal was that the names Laney and Tipton Shale Members are firmly entrenched in the literature and that additional redefinitions or the abandonment of the names would be confusing to readers of this and other reports and would render previous studies of these members obsolete. As an alternative, it was recommended that the units be designated beds. The argument for use of the stratigraphic rank of bed is certainly valid, but it does not resolve the problem of the unequal rank of the units. The major stratigraphic units are nevertheless identified, named, and described in this volume, and their appropriate ranks can be assigned at some future date.

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