UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Summary Report of the Geology, Mineral Resources, Engineering Geology and Environmental Geochemistry of the Sweetwater-Kemmerer Area, Wyoming

PART A

Geology and Mineral Resources

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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METRIC-ENGLISH EQUIVALENTS

Metric unit			English equivalent
Length			
millimetre (mm)	=	0.03937	inch (in)
metre (m)	=	3.28	feet (ft)
kilometre (km)	=	.62	mile (mi)
Area			
square metre (m²)	=	10.76	square feet (ft²)
square kilometre (km²)	=	.386	square mile (mi²)
hectare (ha)	=	2.47	acres
Volume			
cubic centimetre (cm³)	=	0.061	cubic inch (in³)
litre (l)	=	61.03	cubic inches
cubic metre (m³)	=	35.31	cubic feet (ft³)
cubic metre	=	.00081	acre-foot (acre-ft)
cubic hectometre (hm³)	=	810.7	acre-feet
litre	=	2.113	pints (pt)
litre	=	1.06	quarts (qt)
litre	=	.26	gallon (gal)
cubic metre	=	.00026	million gallons (Mgal or 10⁶ gal)
cubic metre	=	6.290	barrels (bbl) (1 bbl = 42 gal)
Weight			
gram (g)	=	0.035	ounce, avoirdupois (oz avdp)
gram	=	.0022	pound, avoirdupois (lb avdp)
tonne (t)	=	1.1	tons, short (2,000 lb)
tonne	=	.98	ton, long (2,240 lb)
Specific combinations			
kilogram per square centimetre (kg/cm²)	=	0.96	atmosphere (atm)
kilogram per square centimetre	=	.98	bar (0.9869 atm)
cubic metre per second (m³/s)	=	35.3	cubic feet per second (ft³/s)
Specific combinations—Continued			
litre per second (l/s)	=	.0353	cubic foot per second
cubic metre per second per square kilometre [(m³/s)/km²]	=	91.47	cubic feet per second per square mile [(ft³/s)/mi²]
metre per day (m/d)	=	3.28	feet per day (hydraulic conductivity) (ft/d)
metre per kilometre (m/km)	=	5.28	feet per mile (ft/mi)
kilometre per hour (km/h)	=	.9113	foot per second (ft/s)
metre per second (m/s)	=	3.28	feet per second
metre squared per day (m²/d)	=	10.764	feet squared per day (ft²/d) (transmissivity)
cubic metre per second (m³/s)	=	22.826	million gallons per day (Mgal/d)
cubic metre per minute (m³/min)	=	264.2	gallons per minute (gal/min)
litre per second (l/s)	=	15.85	gallons per minute
litre per second per metre [(l/s)/m]	=	4.83	gallons per minute per foot [(gal/min)/ft]
kilometre per hour (km/h)	=	.62	mile per hour (mi/h)
metre per second (m/s)	=	2.237	miles per hour
gram per cubic centimetre (g/cm³)	=	62.43	pounds per cubic foot (lb/ft³)
gram per square centimetre (g/cm²)	=	2.048	pounds per square foot (lb/ft²)
gram per square centimetre	=	.0142	pound per square inch (lb/in²)
Temperature			
degree Celsius (°C)	=	1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	=	[(1.8×°C)+32]	degrees Fahrenheit

INTRODUCTION

This report summarizes the geology and mineral resources of the Sweetwater-Kemmerer coal-producing area, which includes part of the Green River Coal Region in Sweetwater County, Wyo., and part of the Hams Fork Coal Region in Lincoln and Uinta Counties, Wyo. The Sweetwater-Kemmerer area is roughly rectangular and encompasses more than 13,500 square miles in the southwest corner of the state (fig. 1). Rock Springs, Green River, Kemmerer, and Evanston are the largest cities. U.S. Interstate Highway 80 and the Union Pacific Railroad cross the area and provide access to other points within the area.

The report has been prepared by the U.S. Geological Survey for use in preparing environmental impact statements to facilitate coal leasing and mining in southwest Wyoming.

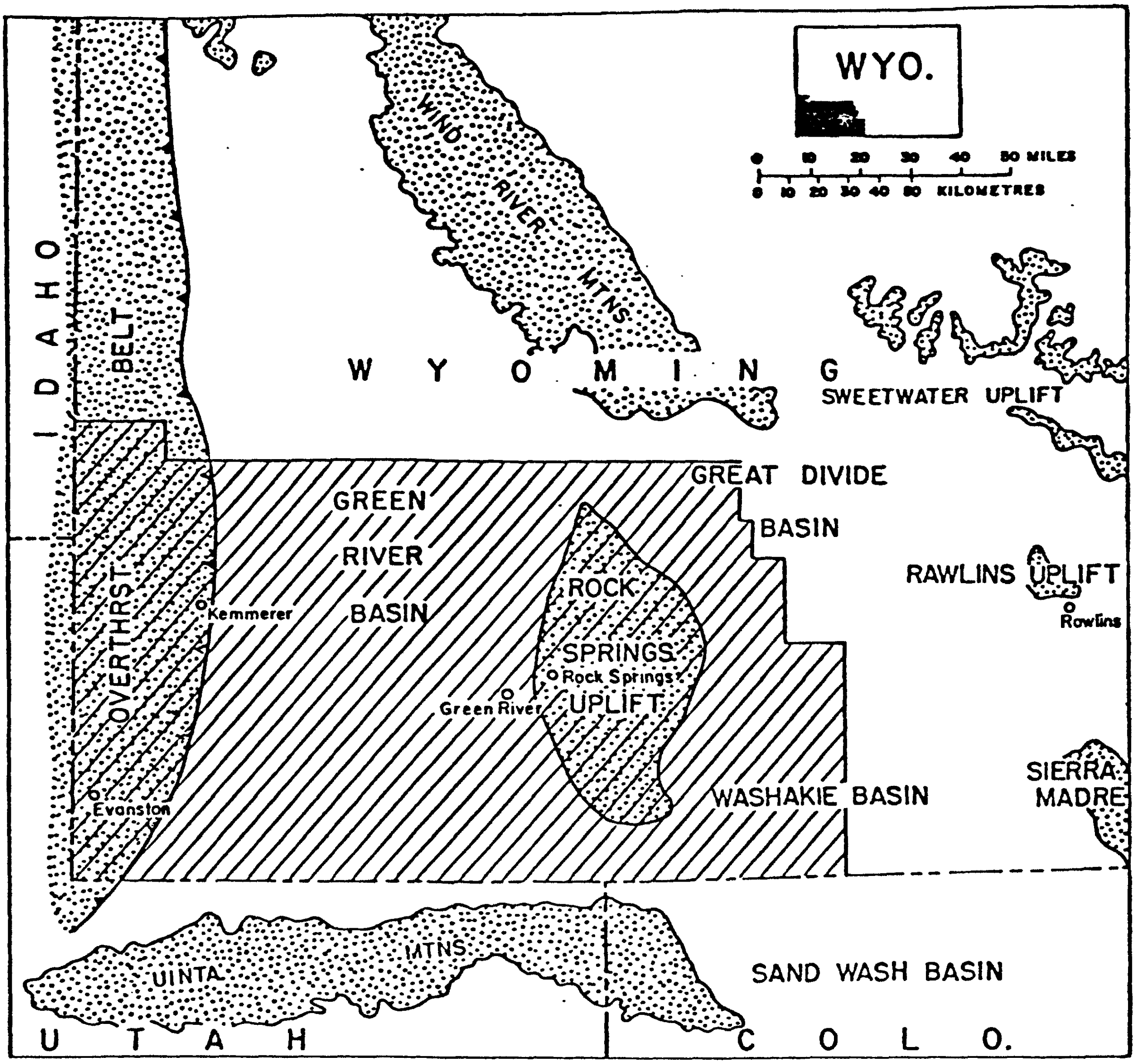


Figure 1.--Map of southwestern Wyoming and adjacent areas. (The Sweetwater-Kemmerer area is indicated by stipple pattern.)

REGIONAL GEOLOGY

Geomorphology

The Sweetwater-Kemmerer area is a region of low mountains and desert basins. It is located in the Middle Rocky Mountains and is divided geologically and geographically from west to east into the Overthrust Belt, Green River Basin, Rock Springs uplift, Great Divide Basin, and Washakie Basin (pl. 1). The topography is strongly influenced by differential erosion of folded and faulted sedimentary rocks which are mostly of Tertiary age in the Green River, Great Divide, and Washakie Basins, and of Cretaceous and older ages in the Overthrust Belt and Rock Springs Uplift (pl. 2). None of the mountains is sufficiently uplifted, faulted, or eroded to expose granitic rocks. Volcanic rocks are present only in the Leucite Hills in the northern part of the Rock Springs uplift.

Altitudes in the Sweetwater-Kemmerer area generally range from 6,000 to 9,000 feet. 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, Senate Document No. 76, p. 33). Annual temperatures usually range between -30°F and +100°F. The major drainageway is the Green River on which the Flaming Gorge and Fontenelle Reservoirs are major water storage sites. Vegetation consists mostly of pine, cedar, and aspen trees at higher altitudes and sparse sagebrush, greasewood, and desert grasses at lower altitudes. Little land is under cultivation because of a very short growing season and lack of water for irrigation. The chief industries are cattle and sheep ranching, oil and gas producing, trona mining, and coal mining. Land and mineral ownership is roughly 60 percent Federal government, 20 percent Union Pacific Railroad, 15 percent private, and 5 percent State of Wyoming.

Overthrust Belt

The Overthrust Belt is a series of north-south trending linear folds and faults that form mountains and valleys. Cenozoic, Mesozoic, and Paleozoic rocks are exposed at altitudes between 6,000 and 10,200 feet above sea level. Major mountain ranges include the Tunp Range, Sublette Range, and Commissary Ridge. The Eastern edge of the Overthrust Belt is roughly delineated by a narrow north-south trending, east-facing escarpment, Oyster Ridge. Oyster Ridge is separated from areas of higher relief to the west by a long sage- and grass-covered valley, several miles in width, called Mammoth Hollow. Situated within linear structures of the Overthrust belt is a long narrow synclinal basin, Fossil Syncline, which extends from T. 27 N., R. 117 W., southward through Fossil and east of Evanston to T. 12 N., R. 120-121 W. (pl. 1). Fossil Syncline has altitudes between 6,700 and 7,500 feet. Rougher partly forested terrain lying between Fossil Syncline on the east and the valley of Bear River on the west has altitudes generally between 7,000 and 8,000 feet.

A major drainage divide is present in the Overthrust Belt. The eastern part of the belt is drained by the headwaters of the Hams Fork and Blacks Fork Rivers that flow eastward and are part of the Green River-Colorado River drainage system. The western part of the belt is drained by the Bear River that flows northward and is part of the Columbia River drainage system.

Green River Basin

The structural and topographic basin situated between the Overthrust Belt and the Rock Springs uplift is the Green River Basin (pl. 1). Parts of the basin extend north and south of the boundaries of the Sweetwater-Kemmerer area. Altitudes in the basin range from slightly less than 6,000 feet on Flaming Gorge Reservoir in T. 12 N., R. 108 W., to more than 9,700 feet in T. 12 N., R. 116 W. The central part of the basin is a rolling grass- and sage-covered plain that is interrupted by ridges and small buttes. Altitudes of the central plain are between 6,300 feet and 6,700 feet, but they rise perceptively toward the basin margins. Badlands are present on the central plain at the Blue Rim, in T. 21-22 N., R. 108-109 W., in the area between McKinnon Junction and Lyman in T. 14-16 N., R. 109-114 W., and locally in other places. A large east-facing escarpment, White Mountain, defines the eastern edge of the basin. Pilot Butte is a small lava-capped landmark on the top of White Mountain in T. 19 N., R. 106 W. At the southern margin of the basin the landscape is broken up into a number of large buttes and mesas that include Little Mountain in T. 13 N., R. 105-106 W., Twin

Buttes in T. 13 N., R. 109-110 W., Cedar Mountain in T. 13-14 N., R. 111-113 W., and Sage Creek Mountain in T. 13-14 N., R. 114 W. Gently northward-sloping conglomerates that cap these buttes and mesas are the remnants of deposits lying on a middle Tertiary erosion surface.

The Green River Basin is drained by the Green River and a number of perennial tributary streams. The Big Sandy River flows southwestward through Farson in T. 25 N., R. 106 W., and joins the Green River in T. 22 N., R. 109 W. The Hams Fork and Blacks Fork Rivers drain the western and southwestern parts of the basin. The Hams Fork River flows eastward through Opal in T. 21 N., R. 114 W., and joins the Blacks Fork River near Granger in T. 19 N., R. 111 W. The Blacks Fork River then flows southeast from near Granger and enters the Flaming Gorge Reservoir in T. 17 N., R. 108 W. The Big Sandy, Hams Fork, and Blacks Fork Rivers provide water for irrigating farmlands near Farson and Lyman.

Rock Springs uplift

The Rock Springs uplift is a deeply eroded structural upwarp lying between the Green River Basin on the west and the Great Divide and Washakie Basins on the east. The core of the uplift is composed of soft gray shale that weathers to a depression called Baxter Basin (pl. 1). Baxter Basin has altitudes between 6,300 and 6,800 feet and low relief; it is characterized by low, rounded, sage- and grass-covered hills and valleys and by a few cliffs, ledges, and benches. A few playa lakes are present in the topographically lowest parts of the basin. The outer parts of the uplift comprise a wide oval belt of inward facing, sparsely vegetated, gray, yellow, and white sandstone escarpments that rise several hundred feet above Baxter Basin. Lava-capped buttes and mesas, cinder cones, and pipes, comprising erosional remnants of the late Tertiary Leucite Hills volcanic field, are present in the northern part of the uplift. Notable among the volcanic landforms are 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 Aspen Mountain in T. 17 N., R. 104 W. are prominent landmarks capped by hydrothermally altered sandstones. The highest altitude in the uplift is 9,680 feet on Aspen Mountain in T. 17 N., R. 104 W. Bacon Ridge, a gently north-sloping plateau in the southwest part of the uplift, is capped by a flat-lying conglomerate of middle Tertiary age that unconformably overlies older rocks of early Tertiary and Late Cretaceous age.

The major drainage in the Rock Springs uplift is Bitter Creek, which flows from east to west across the center of the uplift. Larger tributaries of Bitter Creek are Salt Wells Creek in the southern part of the uplift, and Horsethief Canyon, Deadman Wash, and Long Canyon in the northern part of the uplift.

Great Divide Basin

The Great Divide Basin is a large structural and topographic basin located northeast of the Rock Springs uplift (pl. 1). Only the western part of the basin, situated generally in T. 20-26 N., R. 94-103 W., is included in the Sweetwater-Kemmerer area. The basin is mostly an arid desert having minor topographic relief and an internal drainage system. The landscape is characterized by low rolling partly sage-covered hills that are occasionally interrupted by areas of sand dunes, badlands, alkali flats, and dry lake beds. The lowest parts of the basin have elevations between 6,500 and 7,500 feet, but several landmarks in the western parts of the basin are a few hundred feet higher. These landmarks include the lava-capped buttes, Black Rock in T. 22 N., R. 101 W., and Steamboat Butte in T. 23 N., R. 102 W., and the sandstone-capped buttes, the Pinnacles in T. 24 N., R. 100 W. and Oregon Buttes in T. 26 N., R. 101 W. A low, gently east-plunging anticline, Wamsutter arch, separates the Great Divide Basin from the Washakie Basin to the south.

Washakie Basin

The Washakie Basin is a structural and topographic basin southeast of the Rock Springs uplift (pl. 1). Altitudes range from 6,100 feet to 8,700 feet. The overall configuration of the basin is roughly a square bowl with an encircling rim that stands several hundred feet above the central part of the basin. This rim is called Laney Rim along the northern edge of the basin, Kinney Rim along the western edge of the basin, and Cherokee Ridge along the southern edge of the basin. Sand Hill and Pine Butte are landmarks on Kinney Rim in T. 15-16 N., R. 100 W. Four lesser rims rise 100 to 300 feet above the flatter terrain in the central part of the basin. Between the lesser rims the basin is largely sage- and greasewood-covered ridges and hills interrupted by areas of badlands. No perennial streams cross the basin, but in a few places springs provide enough water for the development of small grass-covered meadows. Sand dunes are present in many intermittent drainages and commonly cover large low-lying areas. The dominant feature of the landscape in the north-central part of the basin is Haystack Mountain, which trends east-west for almost 10 miles and has several hundred feet of relief. The name Adobe Town has been applied to a 40- to 50-square-mile area near the geographic center of the basin where erosion has created unusual badland configurations. Adobe Town is bounded on the west by a broad relatively undissected sand-dune- and alluvial-covered plain that is present over most of the western interior of the basin. The Washakie Basin is drained by Bitter Creek, Sand Creek, and Shell Creek, which are distant tributaries of the Green River.

Vermillion Creek Basin is small topographic basin that straddles the Colorado-Wyoming stateline southwest of the Washakie Basin (pl. 1). The northern part of Vermillion Creek Basin in Wyoming occupies about 250 square miles and has altitudes between 6,500 and 7,500 feet. The basin is bounded on the east by Kinney Rim and on the west by Pine Mountain. Exposed rocks comprise intertongued parts of the Wasatch and Green River Formations. The landscape consists of sage-covered, or barren, low ridges and valleys that are on the faulted and eroded flanks of northeast and northwest-trending minor folds. The basin is drained by Vermillion Creek, which flows southwest to the Green River.

Stratigraphy

Formation names, ages, and lithologies in the western part of the Sweetwater-Kemmerer area, shown on figure 2, differ from those used in the eastern part of the area, shown on figure 3. Much of the nomenclature is used consistently in both areas, but occasionally different names are applied to the same rock unit, or a lithologic unit may be entirely missing in one of the areas.

Rocks in the Sweetwater-Kemmerer area range in age from Cambrian to Tertiary and have a cumulative thickness of nearly 19,000 feet. The succession was deposited in three stages that reflect the regional geologic history. Stage one: Rocks of Cambrian to Jurassic age thicken westward and were largely deposited in seaways that were centered in

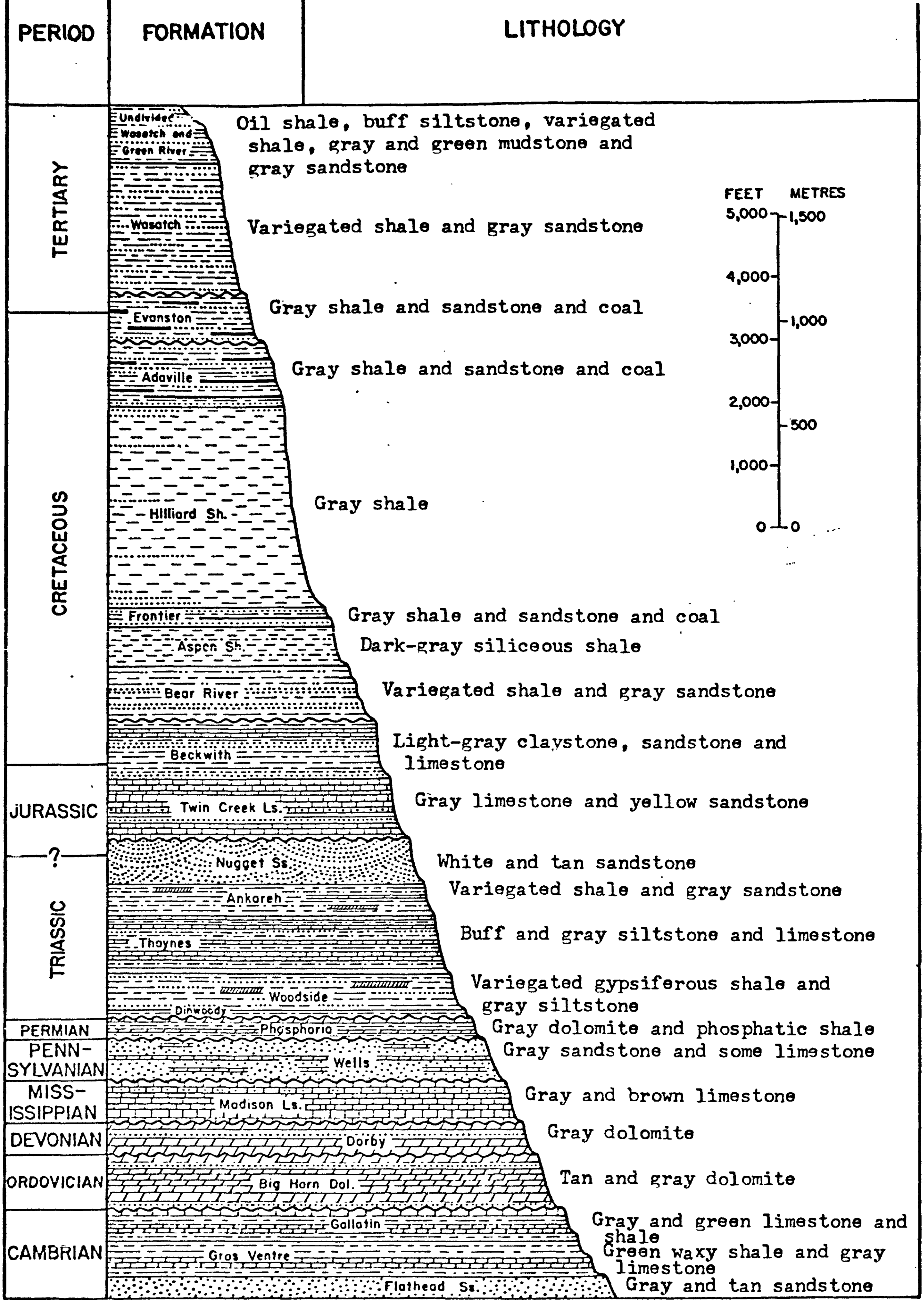


Figure 2.--Sedimentary section in the western part of the Sweetwater-Kemmerer area

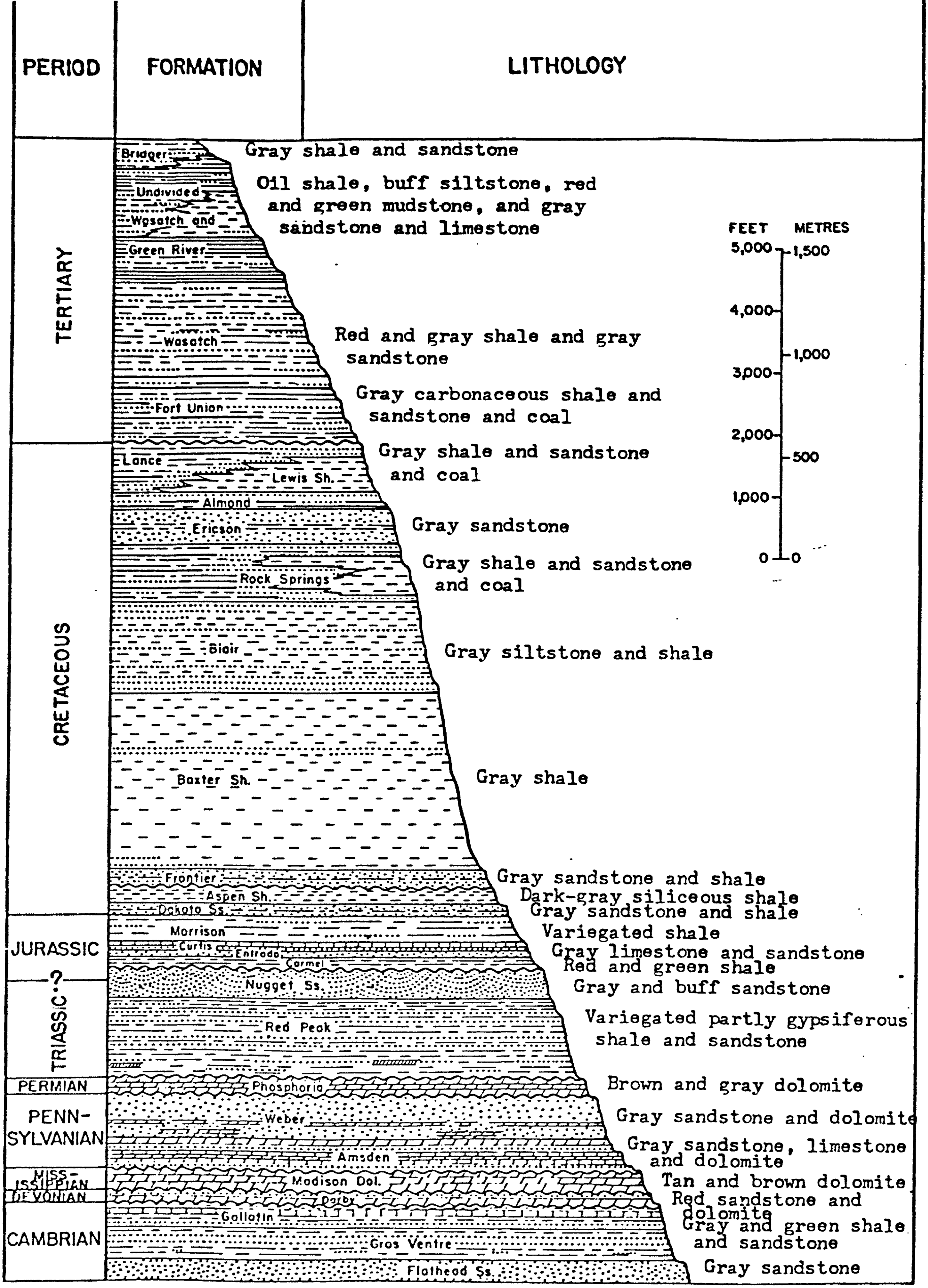


Figure 3.--Sedimentary section in the eastern part of the Sweetwater-Kemmerer area

Idaho and Utah. Limestone and dolomite deposited in marine environments in these seaways are found in the Twin Creek, Thaynes, Phosphoria, Madison, Darby, Big Horn, Gallatin, and Gros Ventre Formations. Shale and sandstone, composing marine shelf, coastal, and continental deposits are found in the Morrison, Curtis, Entrada, Carmel, Nugget, Red Peak, Weber, Amsden, and Flathead Formations. Stage two: Rocks of Cretaceous age were mostly deposited along the western edge of a broad, shallow, north-south trending seaway that crossed central North America. They are mostly marine shale, but they also include fluvial shale and sandstone and deltaic deposits including coal. These rocks are the Beckwith, Bear River, Aspen, Frontier, Hilliard, Adaville, and lower Evanston Formations in the western part of the area, and the Dakota, Aspen, Frontier, Baxter, Blair, Rock Springs, Ericson, Almond, Lewis, and Lance Formations in the eastern part of the area. Stage three: Rocks of Tertiary are are entirely continental in origin. They were deposited in intermontane basins in swamps and lakes and on floodplains during mountain-building episodes of the Middle Rocky Mountains. They are mostly fluvial sandstone and shale, but coal was locally deposited in swamps, and oil shale and evaporites (chiefly trona) were deposited in lacustrine environments. These rocks are the upper Evanston, Fort Union, Wasatch, Green River, and Bridger Formations that are preserved in Fossil Syncline and in the Green River, Great Divide, and Washakie Basins.

Surficial deposits of Quaternary alluvium are present in most of the valleys of large streams. Quarternary and Tertiary gravel and conglomerate cap pediments in scattered localities. A west-trending belt of active sand dunes 3 to 5 miles wide crosses the northern tip of the Rock Springs uplift.

Structure

The principal structures in the Sweetwater-Kemmerer area formed during the Laramide orogeny between 40 and 90 million years ago, when compressional forces acting along north- and northwest-trending alignments caused extensive folding and faulting of rock units. The overall structural relations of the area are shown on a structure contour map of the Cretaceous Dakota Formation. (pl. 3).

Overthrust Belt

The structural pattern of the Overthrust Belt is that of large, compressed, partly overturned folds that are broken into sheets by thrust faults. The direction of movement was dominantly eastward. The Absaroka thrust and the Darby thrust are major faults; the Meridian anticline and Lazeart syncline are major folds (pl. 4). According to Rubey (1954, p. 125) three principal stages of structural activity are recognizable: 1) a very long preliminary stage of geosynclinal sinking and accompanying uplift farther to the west; 2) a relatively brief climax of intensive deformation and piling up of thrust plates within the belt itself; and 3) a closing stage during which the site of crustal sinking moved eastward, and rocks in the Overthrust Belt were broken and tilted along large faults of the Basin-Range type. Rubey (1951, p. 1475) states that the Absaroka thrust, with displacement greater than 35 miles, is the largest fault within the Overthrust Belt. Blackstone (1955, p. 123) believed the Absaroka thrust sheet resulted from a series of faults with no greater lateral displacement than 4-5 miles each.

Fossil Syncline is a shallow structural depression composed of Tertiary rocks that overlie more deformed Cretaceous and older rocks (pl. 4). The syncline was formed during the Laramide orogeny following the deposition of the Cretaceous Adaville Formation, but before the Tertiary Almy Formation was deposited.

Green River Basin

The Green River Basin is the largest syncline in the Middle Rocky Mountains. The major axis trends north-south and is situated slightly east of the center of the basin. A north-trending anticline, the Church Buttes-Moxa arch, is present in Cretaceous and older rocks near the western boundary of Sweetwater County (pls. 3-4). A minor unnamed syncline is present west of the Church Buttes-Moxa arch, between the arch and Meridian anticline. Relatively undeformed Tertiary rocks that are exposed across the basin have dips as much as 8 degrees at the basin margins, but dip less than 2 degrees in central parts of the basin. Cretaceous and older rocks that crop out at the edges of the basin are more deformed and dip as much as 35 degrees. Most of the structural expression of Cretaceous and older rocks in central parts of the basin was obliterated by pre-Tertiary erosion and subsequent subsidence and deposition of Tertiary sediments.

Rock Springs uplift

The Rock Springs uplift is a doubly plunging asymmetric anticline. The steep limb is on the west, where dips are between 4 and 35 degrees; dips on the east limb are between 5 and 8 degrees (pl. 4). The irregular shape of the anticline results from a number of secondary folds on the flanks of the major structure. Notable among the secondary folds are the Wamsutter arch which causes a large convex bulge near the center of the east flank, and the Salt Wells anticline, a minor fold on the east flank near the southern tip of the uplift. Many high-angle normal and reverse faults of early Tertiary age trend generally northeast and dissect the uplift (pls. 2-3).

The Rock Springs uplift has a long structural history involving at least five periods of uplift with intervening periods of erosion. Gentle upwarping movements first took place in the Late Cretaceous Period during the deposition of the Baxter and Blair Formations. These were followed by a major uplift at the close of the Cretaceous Period after the deposition of the Lance Formation. Following a long period of erosion, renewed minor uplifting took place several times in the early Tertiary Period during the deposition of the Fort Union Formation. Another minor uplift took place during the deposition of the Green River Formation. The last and largest uplift, which resulted in present-day structural configurations, took place in the middle Tertiary Period, after deposition of the Bridger Formation, but before the deposition of the Bishop Conglomerate. The late Tertiary history of the Rock Springs uplift includes volcanic activity in the Leucite Hills and additional cycles of erosion.

Great Divide Basin

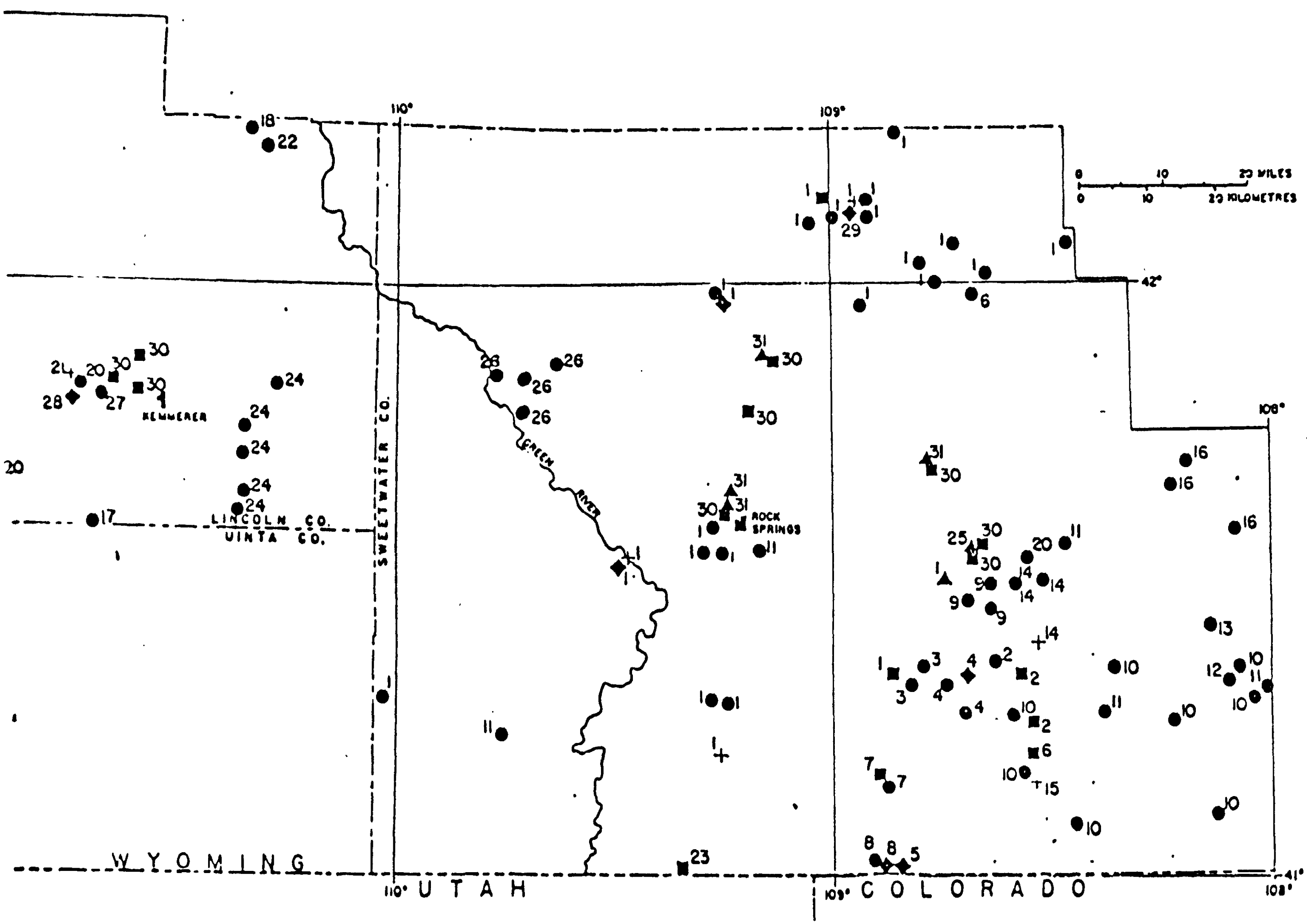
The Great Divide Basin is a shallow asymmetric syncline. The axis of the syncline trends northwestward along the eastern and northern margins of the basin, northeast of the boundaries of the Sweetwater-Kemmerer area. The southwestern part of the basin, which lies within the area of investigation, consists of rocks that dip uniformly northeast at 2 to 5 degrees (pl. 3).

Washakie Basin

The major structural axis of the Washakie Basin syncline trends southwest-northeast across the center of the basin (pl. 3). The margins of the basin are deformed by folds, the axes of which plunge at acute angles toward the major synclinal axis. The exposed rocks dip basinward 3 to 8 degrees, except in the southwestern part of the basin where the dips are locally as much as 25 degrees. Several high-angle normal faults trending northwest are present along Cherokee Ridge in the southern part of the basin.

PALEONTOLOGY

The earliest known reference to fossils in the Sweetwater-Kemmerer area was in 1842 by Captain J. C. Fremont, who collected shells from the Wasatch Formation and leaves from the Frontier Formation near Cumberland Gap in T. 19 N., R. 116 W. (Veatch, 1907, p. 17). Nearly 20 years later Meek (1860, p. 311) described fossils from the Frontier and Bear River Formations in the Overthrust Belt that had been collected by Captain J. H. Simpson in 1858. Fossil mammals were first discovered in the Green River Basin by Dr. J. Van A. Carter, who accompanied the Hayden Survey parties; they were described by Dr. Joseph Leidy in 1868-1870 (Leidy, 1973). In a report dated 1871, Hayden mentions the discovery of fossil fish in a cut excavated by the Union Pacific Railroad about 2 miles west of Green River, Wyo. Fossil plants collected near Cumberland Gap were described by Lesquereux in 1872. Cope (1872, p. 481) probably collected the first dinosaur, from near Black Butte Station in T. 18 N., R. 100 W. Additional mammal collections from the Green River and Washakie Basins were described by Marsh in 1876. In the period 1877-1886 important vertebrate fossils were collected by expeditions from the Princeton and American Museums under the direction of W. B. Scott, H. F. Osborn, and J. L. Wortman (Matthew, 1909, p. 294). Since these early explorations, groups from many museums, universities, and government agencies have extensively searched the Sweetwater-Kemmerer area for fossils. The fauna and flora identified by these parties are far too extensive to list in this report, but some of the more important plant, mammal, dinosaur, bird, and fish fossil sites, and a list of references, are shown on Figure 4. Invertebrate fossils, expecially snails and clams, are so abundant that localities where they can be found were purposely omitted from Figure 4.



EXPLANATION

FOSSIL SITES

■ Plant
⊙ Mammal
▲ Dinosaur
◆ Bird
+ Fish

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Figure 4.--Fossil sites in the Sweetwater-Kemmerer area.

MINERAL DEPOSITS

Coal

Discovery and Development

Coal has been mined and used in the Sweetwater-Kemmerer coal area (pl. 5) for more than 150 years. The early fur trappers and traders knew of and used coal; this fact was recorded by General W. H. Ashley in 1825 (Rock Springs Daily Rocket-Miner, March 15, 1975). Captain B. L. E. Bonneville explored part of the area in 1834-1835, and in 1837 published the first map showing the major geographical features. Captain John C. Fremont, while exploring for the United States Army, discovered coal in the Kemmerer coal field in the Frontier Formation on Muddy Creek on August 19, 1843 (Veatch, 1907, p. 117). During these early explorations much of the Sweetwater-Kemmerer area was located within territory claimed by Mexico, and it remained so until the Mexican cession of 1848. "In August, 1852, the first mention was made of Sweetwater County coal and this was by Howard Stansbury of the topographical engineers. Stansbury mentions that Jim Bridger led him and his crew up the Green River to Bitter Creek and then east along Bitter Creek to present Rock Springs which they reached in September, 1852. Stansbury records the location of a 10-foot bed of coal on the south side of Bitter Creek and this was where Blairtown was located 16 years later" (Rock Springs Daily Rocket-Miner, March 15, 1975).

Coal mining did not commence in the Sweetwater-Kemmerer area until the Union Pacific Railroad was constructed across southwest Wyoming in 1868. The first mines in the Rock Springs coal field were opened at Rock Springs and Point of Rocks in 1868 and produced more than 21,000 tons of coal that year (Schultz, 1910, p. 250). Other mines were opened at about the same time near Evanston, Cokeville, and Almy, but most of these closed before 1901 (Veatch, 1907). The first mines in the Kemmerer coal field were opened in the region of Hodges Pass in 1876 (Hunter, 1950, p. 123). A branch line of the Union Pacific Railroad was built in 1900 to Superior in the Rock Springs coal field, and mining began there shortly thereafter. Many other mines were subsequently opened and abandoned in the Sweetwater and Kemmerer coal fields after 1900.

Underground mining reached a peak in 1945, during World War II, when the coal was used to fire steam engines on the Union Pacific Railroad and to generate electricity at small power plants. More than 6 million tons of coal were mined in 1945 (Root and others, 1973). Between 1950 and 1960 the railroad converted to diesel engines and the electric-power generating plants converted to other fuels; these events caused the collapse of the coal market and most of the mines were forced to close. Mining was reduced to 315,000 tons per year in 1960 in the Kemmerer coal field (Townsend, 1960, p. 251), and to less than 500,000 tons per year in 1972 in the Rock Springs coal field (Root and others, 1973). A resurgence of the coal industry is currently taking place following increased demands for electric power generated from low-sulfur strip-mined coals in the western United States. Two mine-mouth power plants are presently operating in the Sweetwater-Kemmerer area. In 1973 the Naughton plant of the Utah Power and Light Company in the Kemmerer field consumed 2,500,000 tons of strip-mined coal. After expansion in the late 1970's the plant is expected to consume more than 5,000,000 tons of coal per year (Rock Springs Daily Rocket-Miner, March 15, 1975). The first unit of the Jim Bridger plant in the Rock Springs coal field, owned and operated by the Idaho Power and Light Company and Pacific Power and Light Company, went on line in August, 1974. When completed in the late 1970's this plant is expected to consume 6,500,000 tons of strip-mined coal per year. The Black Butte Coal Company strip mine, scheduled to open in T. 17-19 N., R. 100-101 W. in the eastern part of the Rock Springs field, is projected to produce more than 4,000,000 tons of coal per year after 1980. The Stansbury No. 1 underground mine in T. 20 N., R. 104 W., in the western part of the Rock Springs coal field, which closed following World War II, reopened in 1975; it is expected to ultimately produce 1,400,000 tons of coal per year.

Geological Investigations

The first detailed geologic study and exploration for coal in the Sweetwater-Kemmerer area were by Veatch in 1905. In 1907 Veatch published the results of these investigations as U.S. Geological Survey Professional Paper 56. This comprehensive report has 26 plates and 9 figures that illustrate the geography and geology of the Evanston coal field and the southern part of the Kemmerer coal field in the Hams Fork Coal Region (pl. 5). Coal-bearing outcrops along the eastern margin of the Hams Fork Coal Region, north of the area covered by Veatch, were explored and mapped a few years later by Schultz (1914).

The geology and coal resources of the Rock Springs coal field in the Green River Coal Region (pl. 5) were mapped and evaluated by Schultz in 1907 and 1908. Schultz divided the field into northern and southern parts. The northern part was discussed as a chapter in U.S. Geological Survey Bulletin 341 (Schultz, 1909), and the southern part of the field was discussed as a chapter in U.S. Geological Survey Bulletin 381 (Schultz, 1910). Schultz shows the location of coal outcrops on three planimetric maps. The northern part of the field was mapped at the scale of 1:62,500, and the southern part of the field was mapped at the scale of 1:250,000. Coal outcrops for several miles in the vicinity of Rock Springs in the southern part of the field were also mapped at the scale of 1:62,500.

The geology and coal resources of the Rock Springs coal field are currently being reinvestigated by H. W. Roehler, who has mapped quadrangles at the scale of 1:24,000 in the southeast part of the field. This work has involved detailed stratigraphic correlations and computes coal resources by section and township. The quadrangles investigated to date include Titsworth Gap (1973b), Potter Mountain (1973a), Burley Draw (1974a), Sand Butte Rim NW (1976a), Cooper Ridge (1976b), Mud Springs Ranch (1977a), and Camel Rock (unpub. mapping, 1977).

A canneloid lignite in the Wasatch Formation in the Frewen field in T. 18-19 N., R. 94-95 W. was mapped by Bradley (1945). The origin and stratigraphic relations of the lignite were later discussed by him in a 1964 publication.

The thicknesses and stratigraphic positions of coal beds in the Vermillion Creek field are shown on quadrangles mapped at the scale of 1:24,000 by Roehler. These include Scrivner Butte (1974b), Chicken Creek SE (H. W. Roehler, unpub. mapping, 1977), and Chicken Creek SW (H. W. Roehler, unpub. mapping, 1977).

Coal in the Rock Springs and Frontier Formations in the Henry's Fork coal field was reported by Powell (1876), King (1878), Gale (1910), and Hansen (1965). Little detailed information has been published concerning coal in the field, but one bed in the Rock Springs Formation was mined near Linwood in T. 12 N., R. 109 W.

Stratigraphy

Hams Fork Coal Region

Coal is present in the Hams Fork Coal Region in the western part of the Sweetwater-Kemmerer area in the Evanston, Adaville, Frontier, and Bear River Formations (pls. 2,5).

Evanston Formation.--The Evanston Formation has a variable thickness because of unconformable relationships with underlying and overlying rocks. It has a maximum thickness of 1,600 feet near the SE 1/4 sec. 13, T. 16 N., R. 121 W. (Veatch, 1907, p. 80). The fossil mammal *Phenacodus* sp. collected from the upper part and the dinosaur *Triceratops* sp. collected from the lower part suggest that the Tertiary-Cretaceous time boundary lies within the formation (Tracey and Oriel, 1959, p. 128). The formation consists of yellow and brown sandstone, gray and black carbonaceous shale, coal, and conglomerate. It was deposited in a tectonically unstable area between a chain of mountains to the west in the Utah and Idaho areas and a north-trending seaway in the area of eastern Wyoming. The proximity of source areas to the west is indicated by the large number and thickness of beds of light-colored conglomerate consisting mainly of rounded quartzite boulders, derived from Mesozoic and Paleozoic formations (Oriel and Tracey, 1970, p. 9). Interbedded with lenses of conglomerate, which suggest rapid deposition by streams in well-drained areas, are finer textured clastic rocks, carbonaceous shale, and coal, which suggest long periods of floodplain, marsh, and swamp deposition in poorly drained areas.

Subbituminous coal occurs in the Evanston Formation mostly in large fault blocks north of Evanston, Wyo. It is present in an area of less than 1 square mile in and adjacent to sec. 35, T. 17 N., R. 120 W.; in a north-trending area about 6 miles long and 3 miles wide on the east side of Bear River near Almy in T. 15-16 N., R. 120 W.; and in an area 6 miles long and less than 1 mile wide that trends northeast from near Evanston toward Medicine Butte in the northwest part of T. 15 N., R. 120 W. According to Veatch (1907, pl. 4) the Evanston Formation underlies most of Fossil Syncline. Tracey and Oriel (1959, p. 128) have reported beds of coal and lignite in the Evanston Formation on the east side of Fossil Syncline for miles north and south of Hodges Pass, which is located in sec. 8, T. 21 N., R. 116 W.

Coal beds having thicknesses of as much as 28 feet are in the upper few hundred feet of the Evanston Formation near Almy, Wyo. The stratigraphic occurrence of the coal there was described by L. D. Ricketts in 1890 (in Veatch, 1907, p. 133-134) as follows:

> "There are in all at least five seams of coal, of which but one is clean enough to work. Two of them are said to be about 50 feet apart and the lower to be about 100 feet above the seam on which the mines are located. The upper is said to be 9 feet thick, the lower about 6 feet, the measurements including numerous bands of slate the seams contain. From 8 to 20 feet below the seam worked there is a small seam from 4 to 6 feet in thickness, and from 70 to 100 feet below it there is another seam from 8 to 12 feet thick. * * * The great seam from which the Almy coal is mined has been opened up and developed along the entire line of crop".

Figure 5 is a north-south section of the Almy bed in sec. 19, 30, and 31, T. 16 N., R. 120 W., and in sec. 5, 6, and 8, T. 15 N., R. 120 W.

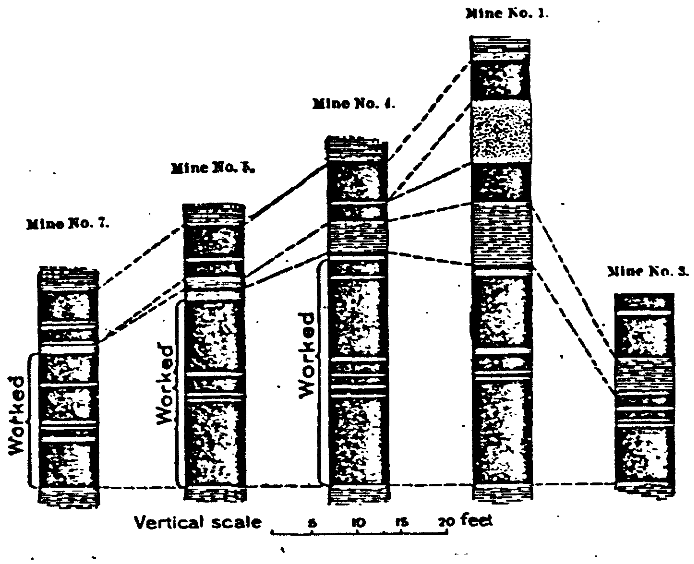


Figure 5.--Sections of the Almy coal bed in the Evanston Formation near Almy, Wyoming. (From Veatch, 1907)

Two thin coal beds are present in a mine that was opened in the Evanston Formation about 1900 in sec. 35, T. 17 N., R. 120 W. These coal beds are about 1.7 and 2.5 feet thick, dirty, and inclined to clinker (Veatch, 1907, p. 135).

Adaville Formation.--The Adaville Formation varies in thickness from a few hundred feet in local areas where it is eroded to 4,500 feet at Mammoth Hollow in T. 25 N., R. 115 W. (Schultz, 1914, p. 66) and to as much as 6,000 feet west of Kemmerer (Hunter, 1950, p. 131). It is composed mostly of gray, yellow, and black-carbonaceous shale, coal, and interbedded brown, yellow, and white sandstone. At the base of the formation is the Lazeart Sandstone Member, a white cliff-forming unit as much as 300 feet thick, that overlies the Hilliard Shale.

The Adaville Formation was deposited mostly in swamps and on floodplains along a north-trending coastal plain that covered most of the western Wyoming area. The Lazeart Sandstone Member is a beach sequence that marks a transition from marine deposition in the underlying Hilliard Shale to continental coastal plain deposition in overlying parts of the Adaville Formation.

Bituminous coal is preserved in the Adaville Formation in the Lazeart Syncline within four structural depressions along the synclinal axis. These depressions are in a small area in the north-center of T. 13 N., R. 119 W.; in an area 12 miles long and 4 miles wide that extends from the northwest part of T. 15 N., R. 118 W. northeastward to the southwest part of T. 17 N., R. 117 W.; in an area about 28 miles long and 8 miles wide that extends from the southern part of T. 19 N., R. 117 W. northwest to the northern part of T. 22 N., R. 116 W.; and in an area that includes the eastern part of T. 24 N., R. 116 W., the western part of T. 25 N., R. 115 W., and the east-center of T. 25 N., R. 116 W.

Coal in the Adaville Formation has been mined extensively in the Kemmerer field in T. 19-21 N., R. 116 W., where there are 11 coal beds, numbered consecutively from bottom to top, in the lower 1,200 feet of the formation (Glass, 1975, p. 56). The thickest coal is the Adaville No. 1 bed that overlies the Lazeart Sandstone Member in the lower part of the formation. In sec. 20, T. 21 N., R. 116 W., the Adaville No. 1 bed is 88 feet thick. About 300 feet above the Adaville No. 1 bed in the same area is the Adaville No. 3 coal bed, which is about 33 feet thick (Glass, 1975, p. 91, 101). A geologic section of the Adaville Formation showing the thickness of coals in the Kemmerer coal field in the vicinity of Elkol is shown in Figure 6.

A. C. Peale has reported (Veatch, 1907, p. 131) the presence of 29 beds of coal, ranging in thickness from 1.5 to 48 feet and having an aggregate thickness of 315 feet, in the Adaville Formation in the region of Hodges Pass in sec. 8, T. 21 N., R. 116 W.

In addition to coal mined in the vicinity of Kemmerer in the Hams Fork Region, a coal bed 5.5 to 6 feet thick has been mined at the Saley mine on LaBarge Ridge in sec. 7, T. 26 N., R. 113 W. (Schultz, 1914, p. 98). It has also been mined at the Lazeart mine in sec. 8, T. 15 N., R. 118 W., where it is 32 feet thick, and at the Carlton mine in sec. 4, T. 13 N., R. 119 W., where it is 22 feet thick (Veatch, 1907, p. 132).

Frontier Formation.--The Frontier Formation in the Hams Fork Coal Region ranges in thickness from 1,800 to 3,800 feet. It is exposed on the flanks of the Lazeart Syncline in the eastern part of the Overthrust Belt. The formation is composed mainly of gray sandstone and interbedded gray shale, mudstone, siltstone, gray and brown carbonaceous shale, and minor thin beds of gray bentonite, and limestone. The Oyster Ridge Sandstone Member, a 100- to 200-foot-thick unit containing oyster shells, is situated in the upper part of the formation. The stratigraphic succession and fossils in the formation at Cumberland Gap in sec. 31 and 32, T. 19 N., R. 116 W. were described in detail by Cobban and Reeside (1952, p. 1922).

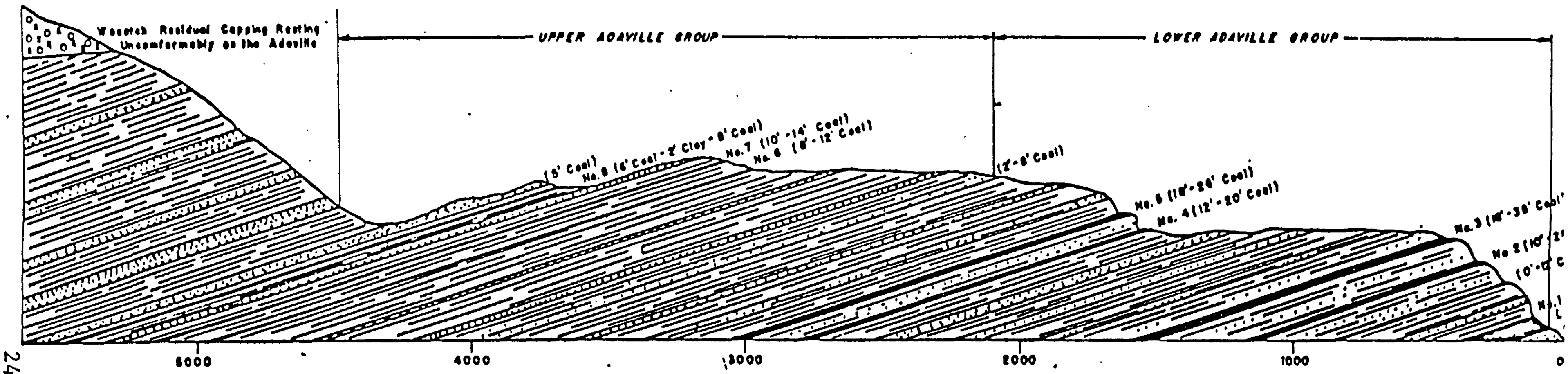


Figure 6.--Geologic section of the Adaville Formation in the vicinity of the Elkol Mine, Kemmerer coal field, in T. 20 N., R. 117 W. Vertical scale 1 inch equals 300 feet. (From Hunter, 1950)

The Frontier Formation was deposited along the western shores of a shallow Cretaceous sea. It is composed of a mixture of sediments deposited in marine, littoral, floodplain, and swamp environments. Cross-sections showing regional stratigraphic relations and depositional environments were published by Hale (1960, p. 143, 145), who believed the formation was deposited during two major transgressions and regressions of the sea across the Overthrust Belt area. The fluctuations in sea level were in response to contemporaneous orogenic uplifts to the west. Coal beds in the upper and lower parts of the formation were deposited in coastal swamps during periods when the sea had retreated to points east of the Overthrust Belt area. The Oyster Ridge Sandstone Member is a littoral deposit marking the last retreat of the sea from the area.

Beds of subbituminous coal in the Frontier Formation are mostly in the lower one-third to one-half of the formation, but a few beds are also in the upper part. The beds in the Kemmerer field were mined for 20 miles along Oyster Ridge from sec. 1, T. 22 N., R. 116 W. southward through Frontier, Diamondville, and Glencoe, to Cumberland Gap in sec. 31, T. 19 N., R. 116 W. The coal beds worked above the Oyster Ridge Sandstone Member on Oyster Ridge are placed in the Upper Kemmerer group by Hunter (1950, fig. 2). Those worked below the Oyster Ridge Sandstone, in descending order, are the Willow Creek bed, the Spring Valley series, and the League of Nations bed. The thickness and distribution of coal beds in the Kemmerer coal field are shown on a map of the field, Figure 7, and on two cross-sections through Oyster Ridge, Figure 8.

The Spring Valley coal bed was mined at the Richardson mine in sec. 12, T. 15 N., R. 118 W., where the bed is 5 feet thick (Veatch, 1907, p. 136-137). Another small mine was opened in a 6-foot-thick unnamed coal bed in the formation in sec. 33, T. 34 N., R. 115 W. (Schultz, 1914, p. 96).

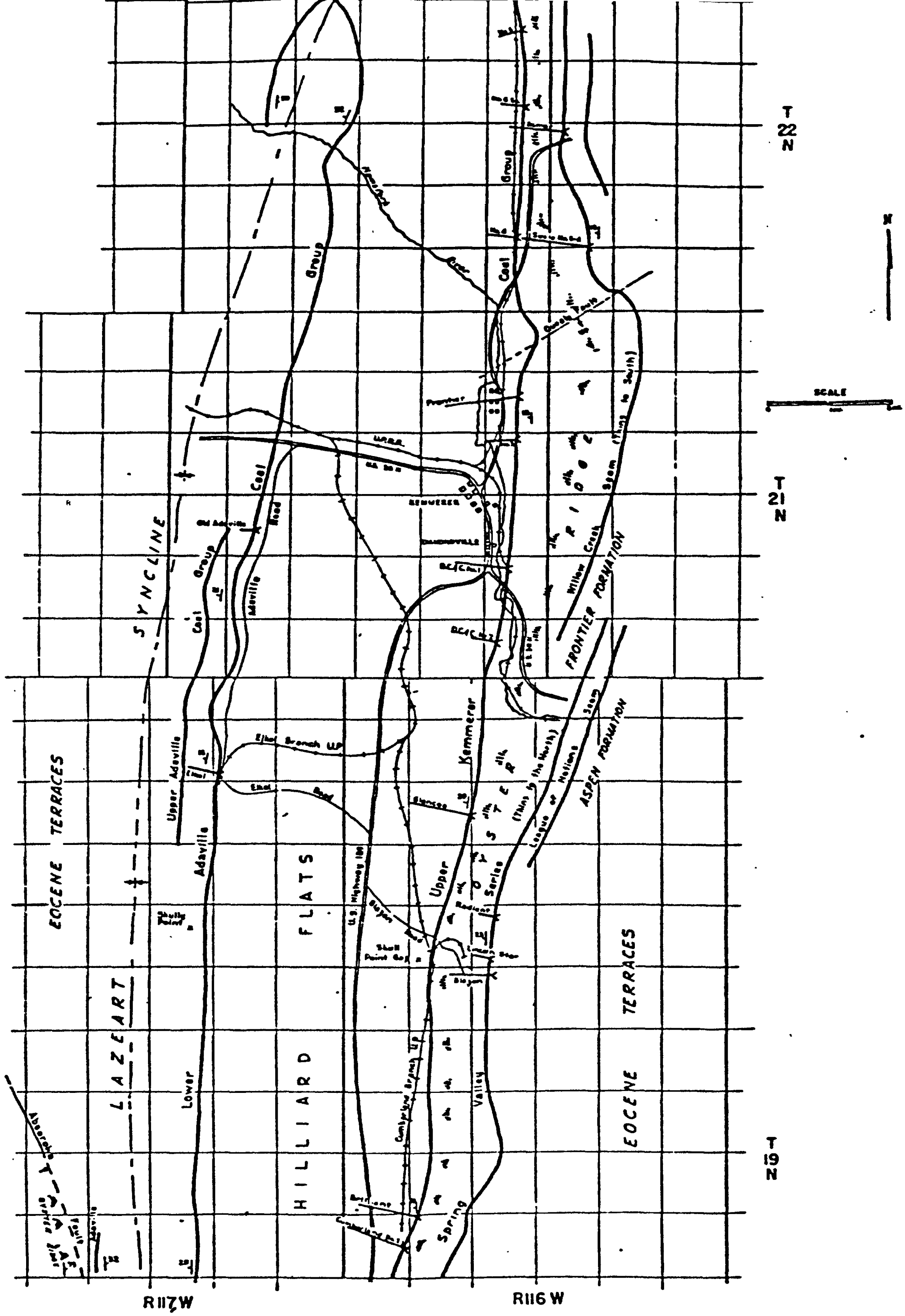


Figure 7.--Map of the Kemmerer coal field showing the locations of coal beds and mine adits. (From Hunter, 1950)

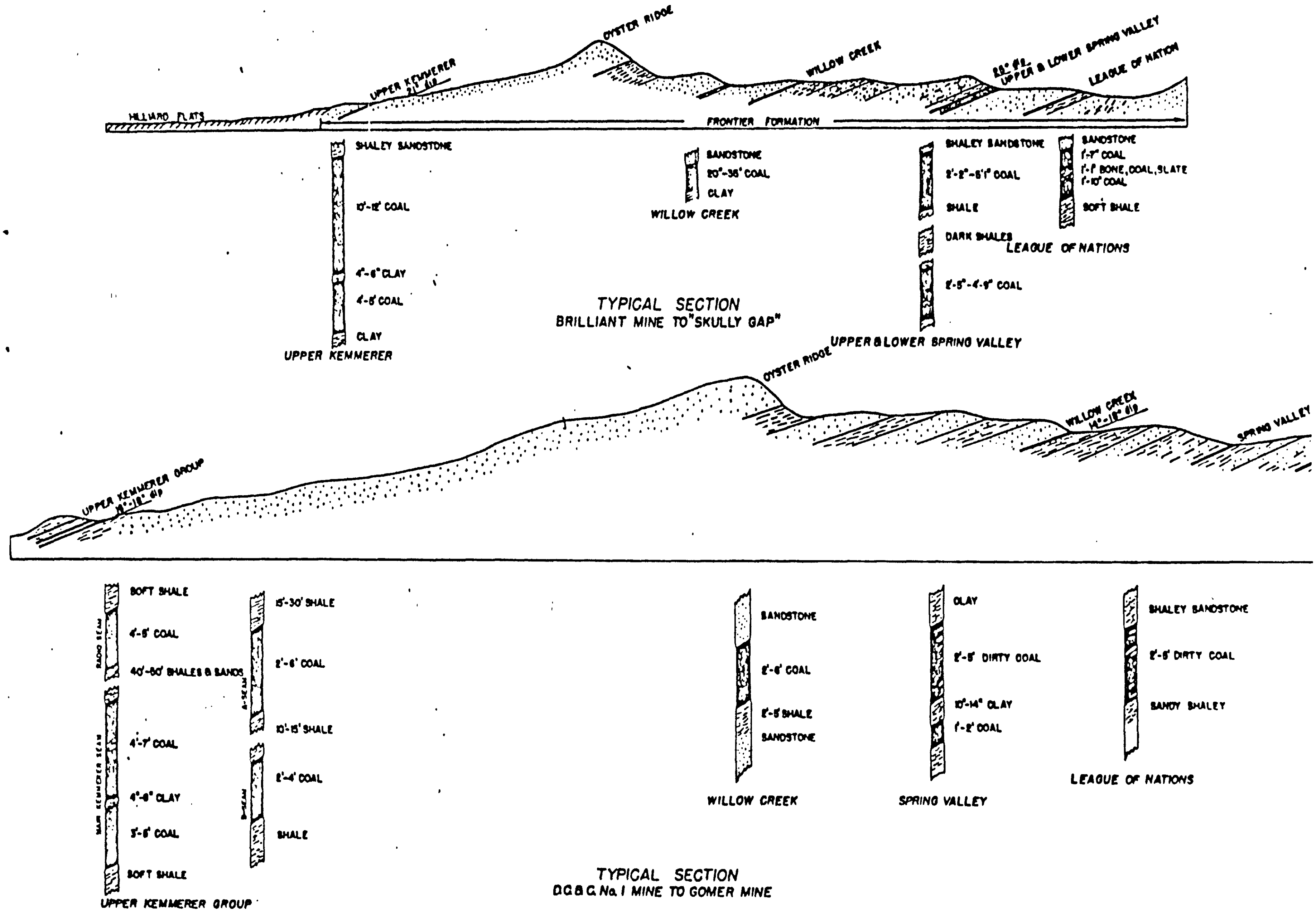


Figure 8.—Cross-sections of the Frontier Formation at the Kemmerer coal field. (From Hunter, 1950)

Bear River Formation.--The Bear River Formation is more than 5,000 feet thick in the western part of the Overthrust Belt in T. 22 N., R. 119 W., but it thins eastward and southward across the Overthrust Belt to less than 500 feet thick in T. 13 N., R. 119 W. (Veatch, 1907, p. 63). Stratigraphic equivalents of the Bear River Formation east of the Overthrust Belt in the Sweetwater-Kemmerer area include the Dakota Formation and the upper part of the Morrison Formation. The Bear River Formation is composed of gray, buff and brown sandstone, and interbedded gray limestone, shale, carbonaceous shale, and sparse beds of coal. The sediments were deposited in mixed fluvial, swamp, and marine environments. The dominantly shallow fresh-water origin of the formation has been discussed by Veatch (1907, p. 114) and Schultz (1914, p. 54-59).

Coal beds of minable thickness (as defined in this report, at least 2.5 feet thick and under less than 3,000 feet of overburden) are present in outcrops of the Bear River Formation at only a few places between T. 21 N., R. 119-120 W. and T. 28 N., R. 118-119 W. (pl. 5).

The coal is bituminous and picked samples have coking properties. Beds 3-6 feet thick were mined near Sage, Wyo. in sec. 7, T. 21 N., R. 119 W., between 1875 and 1900, and several unsuccessful attempts were made there to develop a coke industry (Veatch, 1907, p. 114). The coal deposits in the Bear River field are generally thin, dirty, and lenticular, and have doubtful economic value. However, the deposits are common enough to suggest that thicker deposits of commercial value will eventually be found.

Green River Coal Region

Coal is present in the Green River Coal Region (pl. 5) in the eastern part of the Sweetwater-Kemmerer area in the Wasatch, Fort Union, Lance, Almond, and Rock Springs Formations.

Wasatch Formation.--The Wasatch Formation ranges in thickness from 1,500 to 5,000 feet. The formation is divided into a basal member, the main body, and two overlying tongues, the Niland and Cathedral Bluffs, that are separated from the main body by tongues of the Green River Formation. The rocks of the Wasatch Formation are extremely variable, but they are mostly gray sandstone and siltstone, with interbedded gray, green, and red mudstone, gray and brown, partly carbonaceous shale, coal, and sparse thin beds of gray limestone and brown oil shale. The main body and the Niland Tongue contain coal beds.

The main body and the Niland Tongue of the Wasatch Formation were deposited in fresh-water swamps in an intermontane basin. The swamps occupied topographic depressions that trended east, north of the Uinta Mountains, and then northeast from near the southern tip of the Rock Springs uplift across the central part of the Washakie Basin. Coal beds in the Niland Tongue were deposited in swamps in this topographic depression during drying-up periods of Lake Gosiute, a lake that covered nearly all of the Sweetwater-Kemmerer area during much of Eocene time. The coals in the main body of the formation were deposited shortly before the onset of lacustrine deposition in Lake Gosiute. The coal in the Wasatch is subbituminous A to lignite and consistently has 4 to 9 percent sulfur. The environmental factors responsible for the high sulfur content are unknown.

Lignite is found in the Niland Tongue at the Frewen and Vermillion Creek coal fields (pl. 5). The Niland Tongue in the Frewen field is about 100 feet thick and is composed of soft brown oil shale, gray sandstone, brown carbonaceous shale, and a single bed of canneloid lignite. The lignite is 6 feet thick where it was mined in T. 19 N., R. 94 W., but it thins laterally and can be traced for only a few miles along outcrops. The lignite is unusual in that joints along bedding planes contain the rare sulfate minerals tschermigite, ammoniojarosite, and melanterite (Bradley, 1964, p. A24).

The Niland Tongue at the Vermillion Creek coal field is between 200 and 425 feet thick and is composed of gray sandstone and siltstone, gray and brown carbanaceous shale, brown oil shale, and a few beds of coal. Beds of subbituminous coal are present locally in the upper two-thirds of the tongue. Although the beds are lenticular, several are of minable thickness. Two beds between 2.5 and 5 feet thick are present in west-trending outcrops from sec. 12, T. 13 N., R. 102 W. to sec. 14, T. 13 N., R. 103 W. (Roehler, 1974b). A bed 5-9 feet thick, located 50-75 feet below the top of the tongue is at shallow depths in sec. 32-35, T. 13 N., R. 100 W., where it is potentially recoverable by surface mining (Roehler, 1977b). A bed 3.8 feet thick was encountered at 776 feet in the U.S. Bureau of Mines, Washakie Basin Corehole No. 1A, in sec. 24, T. 14 N., R. 100 W. (Trudell and others, 1973, p. 10). None of the beds in the Vermillion Creek field is being worked at the present time, but small mines were operated intermittently between 1900 and 1935 and supplied winter fuel for local ranches. One bed, 3.1 feet thick, was mined at the Canyon Creek Mine in sec. 17, T. 12 N., R. 101 W. (Roehler, 1974b).

The main body of the Wasatch Formation is 2,000-3,000 feet thick in the Vermillion Creek coal field. It is composed mostly of gray, green, and red mudstone and gray sandstone, except for the upper few hundred feet which has carbonaceous shale and subbituminous coal. Little is known of the coal in the subsurface, but at least one bed about 20 feet thick has been penetrated in gas wells drilled on Hiawatha Dome in T. 12 N., R. 100 W. A bed 2.4 feet thick was encountered at 1,163 feet in the U.S. Bureau of Mines, Washakie Basin Corehole No. 1A, in Sec. 24, T. 14 N., R. 100 W. (Trudell and others, 1973, p. 10). Outcrops of the upper 100 feet of the main body expose coal beds in a few places. A bed 2.8 feet thick is present in a small area on the upthrown side of a fault in sec. 19, T. 13 N., R. 99 W., at Pioneer Gas Field, and a bed 6.6 feet thick crops out in sec. 22, T. 12 N., R. 100 W. on the west slopes of Vermillion Creek at Hiawatha Dome.

Fort Union Formation.--The Fort Union Formation is about 3,000 feet thick in the subsurface in basins adjacent to the Rock Springs uplift, but it thins to between 1,000 and 1,500 feet thick in outcrops on the flanks of the uplift. The thinning is partly by intraformational erosion and partly by intervals of nondeposition across the crest of the uplift. The surfaces of erosion are easily identified in outcrops by distinctive fossil soils composed of light-gray weathering limy, siliceous siltstone containing root impressions. The dominant rock types of the formation are gray lenticular sandstone and siltstone and interbedded gray shale, gray and brown carbonaceous shale, and coal, but locally the formation has beds of green or variegated mudstone.

Coal beds in the Fort Union Formation were deposited in fresh-water swamps situated in low topographic areas of an intermontane basin during the early Tertiary Period. The great thickness and large areal extent of some of the coal beds attest to the size and longevity of some of the swamps.

The Rock Springs uplift is encircled by beds of subbituminous coal in the Fort Union Formation. The uppermost coal beds in the formation, at subsurface depths of 3,000 feet, define the outer limits of the Rock Springs coal field as illustrated on plate 5. Minable coals in the formation include the Deadman, Hail, Nuttal (Big Burn), and Leaf beds on the east flank and several unnamed beds on the west flank of the uplift. The Deadman bed, located in the lower 100 feet of the formation, is the thickest outcropping coal bed. It is 30 feet thick in a strip mine in T. 21 N., R. 100 W. that provides the fuel for the nearby Jim Bridger Power plant. The Nuttal (Big Burn) coal bed crops out for more than 20 miles on the east flank of the uplift, from T. 16 N., R. 102 W. at the south, northward to T. 18 N., R. 99-100 W.; in sec. 33, T. 18 N., R. 100 W. it is 9 feet thick. The Leaf and Hail beds thicken erratically from less than 2.5 to slightly more than 5 feet in outcrops on the southeast flank of the uplift. On the west flank of the uplift a 7.5-foot-thick unnamed bed is situated 400 feet above the base of the formation and a 2.8-foot-thick unnamed bed is situated 625 feet above the base of the formation near the city of Rock Springs (fig. 9). Another very thick unnamed bed is present on the northwest flank of the uplift northwest of Rock Springs. This bed is only 4.5 feet thick and is 700 feet above the base of the formation in outcrops in sec. 32, T. 21 N., R. 104 W. (pl. 2), but it thickens rapidly westward, downdip, in the subsurface. In three exploratory oil and gas test holes drilled by the British-American Oil Producing Company, the bed is 16 feet thick at 1,600 feet in sec. 5, T. 22 N., R. 104 W., 20 feet thick at 2,750 feet in sec. 1, T. 22 N., R. 105 W., and 20 feet thick at 4,100 feet in sec. 33, T. 21 N., R. 105 W. Basinward the bed is more than 35 feet thick at depths below 3,000 feet in several other oil and gas test holes drilled in the Green River Basin off the northwest flank of the uplift.

Lance Formation.--The Lance Formation ranges in thickness from 0 to about 725 feet on the east flank of the Rock Springs uplift. The formation is exposed as a crescent-shaped belt of outcrops 35 miles long and as much as 6 miles wide that wedges out to the south in T. 17 N., R. 101 W. and to the north in T. 22 N., R. 102 W. (pl. 2). The dominant rock types are gray sandstone and siltstone and interbedded gray shale, gray and brown carbonaceous shale, and coal.

The Lance Formation was deposited on the landward side of shorelines of the Late Cretaceous Lewis sea while the sea was retreating from west to east across the area of the Rock Springs uplift. Coal beds in the formation are commonly interbedded with sandstone and shale that contain oyster shells and other brackish-water mollusks. This association suggests that the coals were deposited in swampy lagoons that formed behind barrier bars of sand.

Beds of subbituminous coal in the Lance Formation are lenticular. They frequently split or are channeled out, and they are difficult to correlate. The coal beds in the vicinity of Black Butte in the northwest part of T. 18 N., R. 100 W. are named in descending order the Overland, Gibralter, Black Butte, Maxwell, and Hall beds (fig. 9). The Hall, Maxwell, and Gibralter are the most persistent of these beds in outcrops.

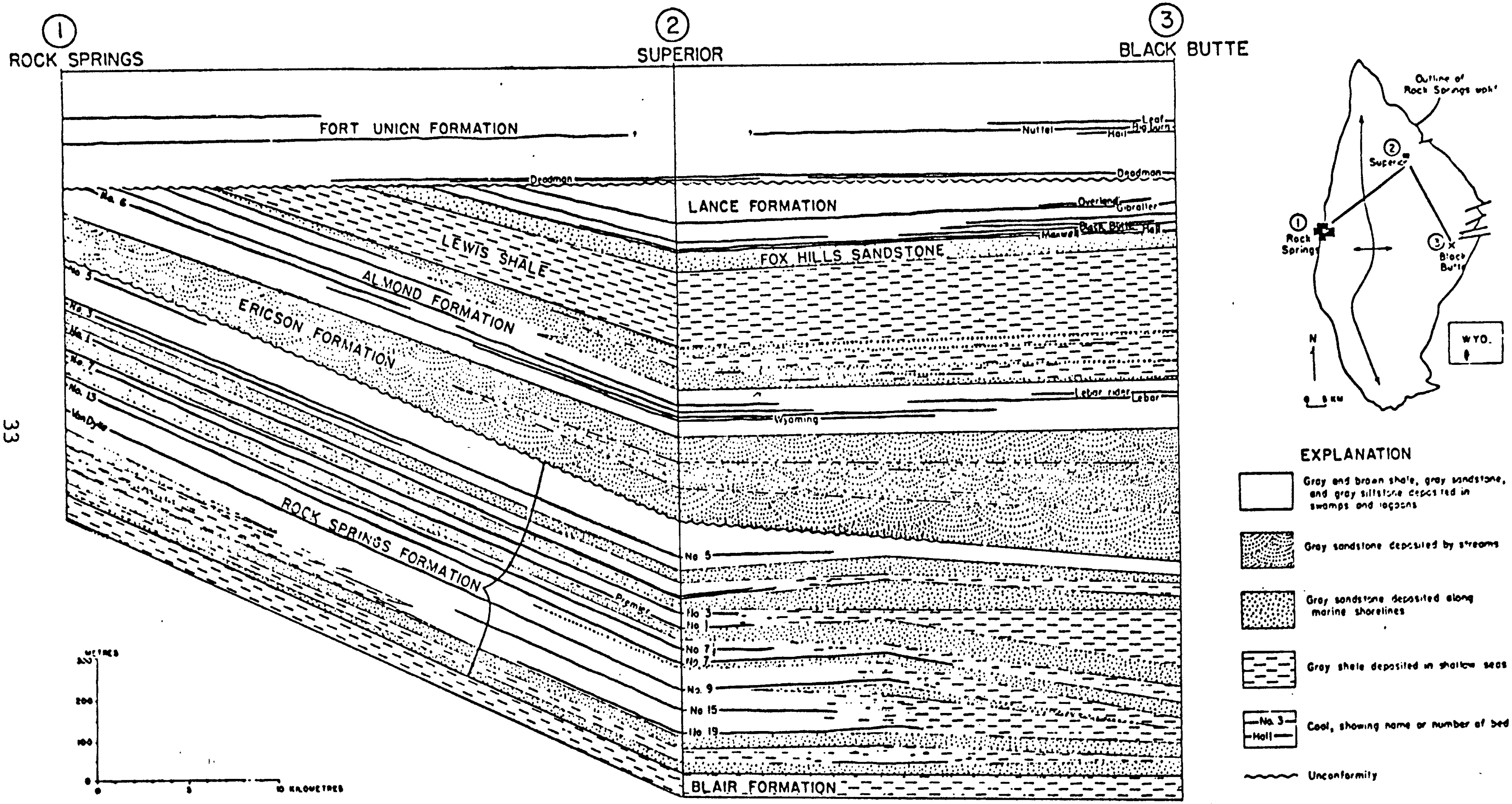


Figure 9.--Correlations of coal-producing formations in the Rock Springs uplift.

The Hall bed at the base of the Lance Formation is about 8 feet thick in sec. 4, T. 18 N., R. 100 W. at Black Butte. It thins irregularly and splits in places along outcrops south of Black Butte, but is 6 feet thick in sec. 22, T. 17 N., R. 101 W., where it wedges out below the Fort Union Formation. North of Black Butte the Hall bed is 9.8 feet thick in sec. 29, T. 19 N., R. 100 W., and 4.9 feet thick in sec. 15, T. 21 N., R. 101 W.

The Maxwell bed, situated 75 feet above the base of the Lance Formation, varies in thickness from 2.5 to nearly 6 feet between Black Butte in sec. 6, T. 18 N., R. 100 W. and sec. 15, T. 21 N., R. 101 W., 15 miles to the north. The bed thins irregularly in outcrops south of Black Butte, but is 4.7 feet thick in sec. 22, T. 17 N., R. 101 W. where it wedges out below the Fort Union Formation.

The Gibralter bed, situated about 175 feet above the base of the Lance Formation, is 6.7 feet thick at the abandoned Gibralter mine in sec. 20, T. 18 N., R. 100 W. In outcrops north of the Gibralter mine it is 3.5 to 9 feet thick to near the northern boundary of T. 21 N., R.101 W. It wedges out and is missing in outcrops 2 miles southwest of the Gibralter mine in sec. 20, T. 18 N., R. 100 W.

Almond Formation.--The Almond Formation has an average thickness of 725 feet on the east flank of the Rock Springs uplift. It thins irregularly and is missing by Late Cretaceous-Tertiary erosion in places on the west flank of the uplift. It is 590 feet thick at the northern tip of the uplift in T. 23 N., R. 103 W. Southward, along the northwest flank, it is 855 feet thick in sec. 26, T. 22 N., R. 104 W., 625 feet thick in sec. 32-33, T. 21 N., R. 104 W., and 205 feet thick in sec. 10, T. 18 N., R. 105 W. The formation is missing in outcrops for more than 4 miles in sec. 21, 28, and 33, T. 18 N., R. 105 W., and sec. 4 and 9, T. 17 N., R. 105 W., on part of the southwest flank. It is 105 feet thick in sec. 21, T. 17 N., R. 105 W., but is again missing by erosion for several miles in T. 15-16 N., R. 104-105 W. It is 665 feet thick near the southern tip of the uplift in sec. 18, 19, and 30, T. 14 N., R. 103 W. The formation is composed of gray sandstone and interbedded gray shale, gray and brown carbonaceous shale, coal, and minor thin beds of gray siltstone and dolomite.

The Almond Formation was deposited in coastal swamps, in lagoons, and along shorelines during westward transgressions of the Lewis sea in Late Cretaceous time (Roehler, 1976a, 1976b). The lower 100-250 feet of the formation, which is generally not coal bearing, was deposited in coastal swamps. The middle 200- to 350-foot-thick coal-bearing part of the formation was deposited in swampy lagoons that developed west of north-trending barrier bars. The evidence for lagoonal origins for the coals are (1) the intertonguing and juxtaposition of the coal beds with barrier bars, and, (2) the presence of fossil oyster beds within coal-bearing sequences (Roehler, 1976a). The sediments in the upper 250 to 350 feet of the formation were deposited as barrier bars and in shallow seas.

Beds of subbituminous coal of minable thickness are present in the Almond Formation in the interval from 150 to 500 feet above the base of the formation on the east and northwest flanks of the Rock Springs uplift. A few beds of minable thickness are also present in the interval from 500 feet above the base to the top of the formation in the southern and southeastern parts of the uplift. Approximately 20 coal beds have been named and mapped, mostly by Roehler (1976a, 1976b) the southeast part of the field. The coal beds named there in descending order are the Falcon, Goldeneye, Teal, Waxwing, Pintail, Finch, Gull, Sparrow, Coot, Buzzard, Shrike, Eagle, Mallard, Robin, Meadow Lark, Magpie, Mourning Dove, and Starling beds. The thickest beds in outcrops are the Gull bed, 12.2 feet thick, situated 400 feet above the base of the formation in sec. 19, T. 14 N., R. 103 W.; the Mallard bed, 10.2 feet thick, 360 feet above the base in sec. 15, T. 16 N., R. 102 W.; the Robin bed, 15.8 feet thick, 340 feet above the base in sec. 10, T. 16 N., R. 102 W.; the Magpie bed, 11.6 to 12.0 feet thick, 330 feet above the base in sec. 33-34, T. 18 N., R. 101 W. and sec. 3-4, T. 17 N., R. 101 W.; the Mourning Dove bed, 16.6 feet thick, 325 feet above the base in sec. 32-33, T. 16 N., R. 102 W.; and the Starling bed, 11.6 feet thick, 175 feet above the base in sec. 21, T. 16 N., R. 102 W.

The Lebar bed, recently named by the Black Butte Coal Company, is 7.7 to 8.7 feet thick in outcrops near Black Butte in T. 18-19 N., R. 100-101 W. (fig. 9). At Point of Rocks in sec. 27, T. 20 N., R. 101 W., the Lebar bed is 6.2 feet thick. A 4.8- to 5.0-foot-thick bed 15-20 feet above the Lebar bed in the vicinity of Black Butte has been designated the Lebar rider.

The Wyoming bed is 5.7 feet thick and is situated 100 feet above the base of the formation. It was mined near Point of Rocks in sec. 27, T. 20 N., R. 101 W. (fig. 9).

Coal beds in the Almond Formation have not beed adequately mapped in the northern part of the Rock Springs uplift. For that reason a number of minable beds there remain unnamed and uncorrelated. On the northeast flank of the uplift four unnamed beds have an aggregate thickness of 15.2 feet along Potash Wash in the southern part of T. 21 N., R. 101 W. On the northwest flank of the uplift three coal beds have an aggregate thickness of 10.5 feet on the north slopes of Pine Canyon in sec. 6, T. 22 N., R. 104 W., five beds have an aggregate thickness of 27.1 feet in sec. 26, T. 22 N., R. 104 W., and four beds west of Winton in sec. 32-33, T. 21 N., R. 104 W. have an aggregate thickness of 21.3 feet.

Rock Springs Formation.--The Rock Springs Formation is nearly 2,000 feet thick in the northwest part of the Rock Springs uplift, but it thins to less than 1,000 feet in the southeast part of the uplift. The thinning is due partly to erosion on the top of the formation and partly to a facies change of continental to marine rocks in a southeast direction. The erosion on the top of the formation reflects the paleogeographical location of the Rock Springs uplift area on the eroded east flank of the Church Buttes-Moxa arch, a fold that developed prior to the structural expression of uplift (pl. 4). The Rock Springs Formation is composed of gray sandstone and siltstone, and interbedded gray shale, gray and brown carbonaceous shale, and coal in the northwest one-half of the Rock Springs uplift, where the formation was deposited mostly in coastal swamps. Rocks deposited in coastal swamps are replaced southeastward by gray beach and shoreline sandstone and farther southeastward by dark-gray marine shale. Coal beds in the formation are restricted to the areas of coastal swamp deposition in the northwest part of the uplift (fig. 9).

Coal beds in the Rock Springs Formation in the Rock Springs coal field have been given local names and numbers, but a number system adopted by the Union Pacific Railroad is most commonly used (Schultz, 1908, p. 253-256). The beds worked in the field are numbered, in descending order, 5, 3, 1, 7 1/2, 7, 8, 9, 10, 11, and 19. At Rock Springs the lowest bed is named Van Dyke (fig. 9). The same nomenclature is used across the field, although recent stratigraphic investigations suggest that the beds commonly have been miscorrelated.

Minable beds of bituminous coal occur in the Rock Springs Formation in an irregularly semicircular belt of outcrops 6-10 miles wide from T. 16 N., R. 105 W., on the west flank of the uplift, northward through Rock Springs, Reliance, and Winton to Long Canyon and Cedar Canyon, and then southeastward on the northeastern flank of the uplift through Superior to the vicinity of Point of Rocks in T. 20 N., R. 101 W. The minable beds are widely spaced in an interval hundreds of feet thick from about 200 feet above the base to about 50 feet below the top of the formation. The mined coal beds are generally 6-8 feet thick, but coal 14 feet thick has been mined at Stansbury (Yourston, 1955, p. 202). The number of coal beds (in parentheses) and the aggregate thickness of minable coal are (12) 49 feet at Rock Springs, (14) 67 feet at Winton, and (18) 96 feet at Superior.

Coal beds outcrop in the Rock Springs Formation in the Henrys Fork coal field in T. 12 N., R. 108-110 W. W. C. Culbertson (oral comm., 1976) has mapped the field in Wyoming and reports that the Rock Springs Formation there is about 1,250 feet thick. It is composed of gray sandstone and shale with interbedded gray and brown carbonaceous shale and coal. A 5-foot-thick bed of coal, situated 370 feet below the top of the formation, was mined at two places in the early 1900's near Wyoming Highway 530, a short distance north of the Wyoming-Utah Stateline. One of the mine workings is now partly obliterated by the bed of a highway that was constructed in the early 1960's from Highway 530 to the Lucerne Valley campground on Flaming Gorge Reservoir. Coal in this mine was afire and the roof caved in 1950; apparently the coal had been burning for more than 40 years (Hansen, 1965, p. 100).

Structure

Little is known of the detailed structural relationships of coal-bearing sequences in the Evanston and Bear River Formations in the Hams Fork Coal Region. Veatch (1907, p. 114, 133) reported that coal beds in the Evanston Formation near Almy dip from 5 to 13 degrees east, and that those in the Bear River Formation near Sage dip 35 to 45 degrees west. Coal beds in the Adaville and Frontier Formations in the Kemmerer coal field dip 16 to 25 degrees west. Primary joint orientations in the Adaville Formation at the Kemmerer field are N. 65° E. and N. 20° W. (Glass, 1975, p. 58-102). No major faults were mapped in coal fields in the Hams Fork Coal Region by Veatch (1907, pl. 23). A few faults have subsequently been mapped, however, such as the Quealy fault, which trends southwest near the common corner of T. 21-22 N., R. 115-116 W. in the Kemmerer field (fig. 7).

Coal beds in the Henrys Fork coal field in the Green River Coal Region are unfaulted but dip 60 to 65 degrees north. A bed of canneloid lignite at the Frewen field is unfaulted and dips 3 to 4 degrees southeast. In the Vermillion Creek field coal beds dip 1 to 4 degrees on the flanks of minor folds; the beds are locally cut by high-angle normal faults.

The coal beds worked in the Rock Springs coal field are cut at many places by northeast-trending high-angle normal and reverse faults having displacements generally less than 200 feet (pl. 2). Faults in the vicinity of Rock Springs are shown on a map published by Schultz (1910, pl. 15). Faults in the northeastern part of the Rock Springs coal field in the vicinity of Superior are shown on an unpublished geologic map prepared on a planimetric base at the scale of 1:24,000 by C. E. Dobbin in 1941. Dips along the eastern part of the Rock Springs coal field are consistently between 3 and 6 degrees east; those along the western part of the field are mostly between 6 and 32 degrees west. The orientation of primary joints is about N. 75° E. and N. 30° W. in areas where coal has been mined in the northern part of the Rock Springs field (fig. 10).

Coal quality and composition

Coal beds in southwestern Wyoming contain appreciable coal resources in nine different formations ranging in age from Late Cretaceous to Eocene. The coal generally ranks from subbituminous C to high volatile B bituminous, though there are a few thin beds of lignite in the Wasatch Formation. In general, the older Rock Springs and Frontier Formations contain bituminous coal, and the younger Almond, Lance, Evanston, and Fort Union Formations contain subbituminous coal. The heat values of these coals, on an as-received basis, range from 8,000 Btu per pound for the lower grades of subbituminous coal, to 12,250 Btu per pound for the better grades of bituminous coal. No large resources of naturally occuring coking coal (medium- and low-volatile bituminous coal) have been identified in southwestern Wyoming.

Most of the coal has a low- to medium-ash content and is classified as low-sulfur coal; it contains 5 to 10 percent ash and 0.5 to 1.0 percent sulfur. The butiminous coal in the Rock Springs Formation has a slightly higher sulfur content averaging 0.8 to 1.2 percent, and some samples may contain as much as 3.5 percent.

Proximate and/or ultimate analyses of about 130 samples of coal from mines in southwestern Wyoming are listed by Fieldner, Cooper, and Osgood (1931, p. 35-77). Most of these samples were collected and analyzed before 1913. Recent representative analyses of coal from southwestern Wyoming are recorded in tables 1-6. The data are generally representative of coal in the different geologic units and areas. Table 1 is an analysis of a high volatile C bituminous coal from the Rock Springs Formation of Late Cretaceous age near Rock Springs. Tables 2 and 3

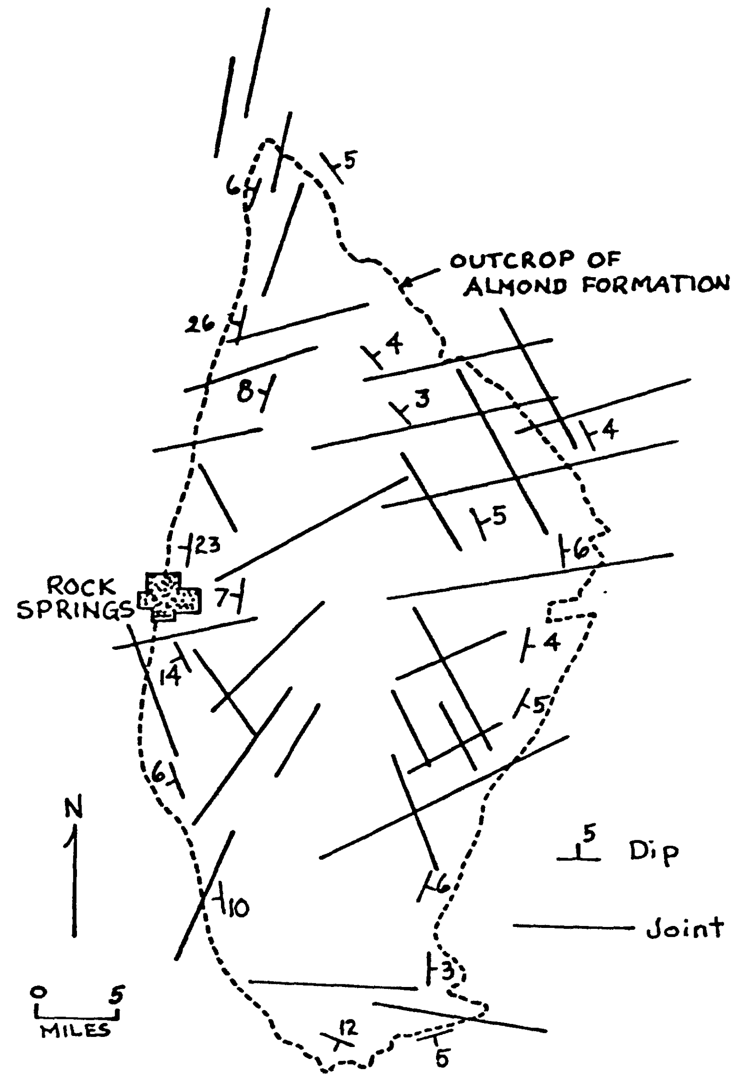


Figure 10.--Map of the Rock Springs coal field showing the dip of strata and the orientation of primary joints.

Table 1.--Analysis of bituminous coal sample from the Rock Springs Formation of Late Cretaceous age, from Rainbow No. 8 Mine near Rock Springs Wyo.

[Data from Glass, 1975, sample no. 74-22. Proximate and ultimate analysis on as-received basis; sample ashed at 525° C; L indicates less than value shown.]

Proximate and ultimate analysis (percent)	
Moisture	10.4
Vol Matter	38.1
Fixed C	46.1
Ash	5.4
Carbon	66.1
Hydrogen	5.8
Nitrogen	1.6
Oxygen	20.2
Sulfur	.9
Sulfate	.04
Pyritic	.40
Organic	.49
Btu/lb	11,720

Major and minor oxides in ash (percent)			
SiO_2	51.	Fe_2O_3	11.
Al_2O_3	25.	MnO	.02L
CaO	4.8	TiO_2	.86
MgO	.73	P_2O_5	1.70
Na_2O	.22	SO_3	1.8
K_2O	1.20		

Trace elements in whole coal (ppm)	
As	2
F	100
Hg	.08
Sb	1.1
Se	1.2
Th	2.0 L
U	1.5

Trace elements in ash (ppm)			
B	2,000	Nb	20
Ba	2,000	Ni	30
Be	15	Pb	70
Cd	2.0	Sc	30
Co	15	Sr	3,000
Cr	70	V	150
Cu	82	Y	70
Ga	30	Yb	7
Li	206	Zn	84
Mo	10	Zr	300

Table 2.--Composition of coal in the Adaville Formation, Lincoln County, Wyo., based on standard coal analyses of 19 samples, reported in percent on as-received basis (modified from Glass, 1975). Analyses by Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pa.

	Average (arithmetic mean)	Range
Moisture	20.3	15.4-27.5
Vol. matter	34.1	31.1-37.1
Fixed C	40.7	33.5-44.7
Ash	4.9	3.2- 8.9
Hydrogen	6.1	5.9- 6.4
Carbon	55.4	48.8-60.1
Nitrogen	1.3	.8- 1.5
Oxygen	31.6	27.5-39.4
Sulfur	.7	.3- 1.8
Btu/lb	9,600	7,920-10,530
Sulfate S	0.04	0.00- .28
Pyritic S	.31	.03-1.25
Organic S	.33	.14-1.11

Table 3.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 14 coal samples from the Adaville Formation, Lincoln County, Wyo. (modified from Glass, 1975)

[All samples were ashed at 525°C; L after a value means less than the value shown]

Major and Minor Oxides in Ash (percent)

Oxide	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
Ash	6.4	4.4	11.6
Si_02	53.	38.	70.
$Al_2 0_3$	12.	4.3	19.
Ca0	5.7	3.8	8.6
Mg0	2.95	1.20	5.15
$Na_2 0$	.12	.08	.19
$K_2 0$	.58	.14	1.30
$Fe_2 0_3$	9.5	3.2	26.
Mn0	.11	.02L	.55
$Ti0_2$	.50	.24	.67
$P_2 0_5$	.22	.10L	.50
$S0_3$	8.4	1.3	15.

Trace Elements in Ash (ppm)

Element	Average (arithmetic mean)	Observed Range	
		Minimum	Maximum
B	1,500	500	2,000
Ba	2,000	1,000	5,000
Be	10	2	30
Cd	1.1	1.0L	2.0
Co	15	7L	30
Cr	50	20	200
Cu	39	30	52
Ga	30	20	70
Li	38	27	56
Mo	5L	5L	10
Nb	10	10L	20
Ni	50	20	100
Pb	25L	25L	30
Sc	10	7	30
Sr	700	200	2,000
V	100	50	150
Y	30	20	70
Yb	2	2	5
Zn	117	40	274
Zr	150	50	200

Table 3.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 14 coal samples from the Adaville Formation, Lincoln County, Wyo. (modified from Glass, 1975).--Continued

Trace Elements in Whole Coal (ppm)

Element	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
As	1.0L	1.0L	2.
F	55.	25.	95.
Hg	.05	.02	.13
Sb	.2	.1L	.5
Se	.4	.1L	1.0
Th	2.0L	2.0L	3.0
U	.3	.2L	1.0

Table 4.--Composition of coal in the Deadman bed (local usage), Jim Bridger Mine, Sweetwater County, Wyo., based on standard coal analysis of five composite samples reported in percent on as-received basis. Analyses by Coal Analysis Section, U.S. Bureau of Mines, Pittsburg, Pa.

	Average (arithmetic mean)	Range
Moisture	19.2	16.5-21.9
Vol. matter	32.9	29.9-34.9
Fixed C	40.4	37.8-45.2
Ash	7.5	4.9-12.0
Hydrogen	5.4	5.3- 5.7
Carbon	52.8	50.0-57.6
Nitrogen	1.2	1.1- 1.6
Oxygen	32.6	27.8-35.2
Sulfur	.5	.4- .6
Btu/lb	8,740	8,070-9,570
Sulfate S	0.13	0.07-.18
Pyritic S	.10	.03-.18
Organic S	.31	.22-.38

Table 5.—Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 12 coal samples, Deadman bed, Jim Bridger Mine, Sweetwater County, Wyo.

[All samples were ashed at 525°; L after a value means less than the value shown]

Major and Minor Oxides in Ash (percent)

Oxide	Average (arithmetic mean)	Observed range Minimum	Observed range Maximum
Ash	8.3	5.5	14.8
SiO_2	46.	35.	57.
Al_2O_3	23.	14.	32.
CaO	7.0	2.9	12.
MgO	1.88	1.08	2.82
Na_2O	.21	.09	.42
K_2O	.45	.053	1.5
Fe_2O_3	6.0	2.2	12.
MnO	.028	.020L	.094
TiO_2	.72	.39	1.0
P_2O_5	.20	.10L	.81
SO_3	11.	6.7	17.

Element	Average (arithmetic mean)	Observed range Minimum	Observed range Maximum
B	1,500	1,000	2,000
Ba	5,000	3,000	7,000
Be	3	3L	5
Cd	1.0L	1.0L	3.0
Co	15	10	20
Cr	70	70	70
Cu	137	96	302
Ga	30	15	50
La	70	70	100
Li	149	96	216
Mo	10	7	20
Nb	10L	10L	10L
Ni	30	15	50
Pb	40	25L	65
Sc	15	10	30
Sr	1,000	300	1,500
V	100	70	150
Y	20	20	30
Yb	3	2	3
Zn	72	36	242
Zr	200	100	300

Table 5.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 12 coal samples, Deadman bed, Jim Bridger Mine, Sweetwater County, Wyo.--Continued

Trace Elements in Whole Coal (ppm)

Element	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
As	3	1.0L	15
F	45	30	90
Hg	.15	.04	.69
Sb	.4	.2	.8
Se	2.0	1.1	3.5
Th	3.7	2.0	7.2
U	1.2	.2L	2.3

Table 6.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 295 Rocky Mountain province coal samples

[All samples were ashed at 525°C; L after a value means less than the value shown]

Major and Minor Oxides in Ash (percent)

Oxide	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
Ash	13.3	1.8	88.2
$Si_0 2$	46	15	79
$Al_2 0_3$	21	4.3	35
Ca0	8.9	.21	35
Mg0	1.63	.22	7.1
$Na_2 0$	1.39	.08	8.6
$K_2 0$	.65	.05	3.0
$Fe_2 0_3$	7.6	1.1	26
Mn0	.049	.004	.55
$Ti0_2$	.89	.02 L	1.8
$S0_3$	8.4	.10 L	29

Trace Elements in Ash (ppm)

Element	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
B	500	70	3,000
Ba	2,000	70	10,000
Be	5	.1L	15
Cd	.7	.5L	4.0
Co	15	10 L	50
Cr	30	10	150
Cu	87	22	1,260
Ga	30	10	50
Li	88	10 L	328
Mo	15	5 L	70
Nb	7	20 L	50
Ni	20	10 L	70
Pb	45	20 L	195
Sc	15	7	30
Sr	700	150	3,000
V	100	50	300
Y	50	20	150
Yb	5	2	15
Zn	77	13	1,820
Zr	200	50	500

Table 6.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of seven additional trace elements in 295 Rocky Mountain province coal samples.--Continued

Trace Elements in Whole Coal (ppm)

Element	Average (arithmetic mean)	Observed range	
		Minimum	Maximum
As	2	1 L	50
F	95	20 L	920
Hg	.08	.01	1.48
Sb	.4	.05L	5.2
Se	1.6	.1 L	5.7
Th	4.2	1.7	34.8
U	1.9	.1	23.8

summarize analyses of the subbituminous B coal from the Adaville Formation of Late Cretaceous age near Kemmerer (See table 2, Swanson, 1972, for similar data on five coal samples from the Adaville Formation). Tables 4 and 5 summarize analyses of the subbituminous B and C coal from the Fort Union Formation of Tertiary (Paleocene) age about 30 miles east-northeast of Rock Springs.

Table 6 gives the average composition and range of values for the major and minor oxides and 27 trace elements in 295 Rocky Mountain province coal samples, which provides a basis for comparison of similar data on southwestern Wyoming coal. The most notable differences between southwestern Wyoming coal and the average Rocky Mountain coal are: southwestern Wyoming coal contains 6 to 10 times less Na_2O slightly less CaO, about 3 times more B, and 2-5 times more Be in the ash of the coal. Coal from the Adaville and Fort Union Formations in southwestern Wyoming contains about one-half the amount of F as the average Rocky Mountain coal.

Detailed chemical data are not available for the coal in the Upper Cretaceous Bear River, Frontier, and Evanston Formations in Lincoln and Uinta Counties. Such data are available, however, on some 75 coal samples that were collected from outcrops of the Upper Cretaceous Almond and Lance Formations, and the Tertiary Fort Union and Wasatch Formations in Sweetwater County (H. W. Roehler, unpub. data, 1976). From all of the geologic and geochemical data available, it can be concluded that, except for local variations in a particular bed or differences between single samples, only the general differences in coal composition cited above will prove to be significant. None of the analyzed coal samples from southwestern Wyoming showed evidence of mineralization or high metal contents that would indicate potentially economic byproduct materials in the coal, or that would produce abnormally high levels of pollutants during utilization of the coal.

Resources

More than 3,100 square miles of the Sweetwater-Kemmerer area is underlain by minable coal deposits (pl. 5). Total identified original resources [1/], in all categories, are 20,853,000,000 short tons, based largely on extrapolation of information from surface mapping. This amount is believed a conservative estimate. Published data on coal resources are listed on Table 7.

Original resources of the Kemmerer field are 2,284,000,000 tons of bituminous coal and 1,362,000,000 tons of subbituminous coal. As of 1960, 62,370,000 tons of coal had been produced, which is less than 2 percent of the total identified resources of the field (Townsend, 1960, p. 251.

Original resources of the Rock Springs coal field are 12,993,000,000 tons of bituminous and 3,830,000,000 tons of subbituminous coal. Nearly 30,000 acres has been worked through more than 40 openings along the west flank, and nearly 5,000 acres has been worked through more than 25 openings on the east flank of the Rock Springs uplift. The total production from the field to January 1955, was about 192,000,000 tons (Yourston, 1955, p. 202). These figures represent about 3 percent of the geographical area and less than 1.5 percent of the total identified resources of the field.

Coal production in the Sweetwater-Kemmerer area will reach 20 million tons annually during the next decade. More than 80 percent of this amount will be recovered by surface mining.

[1/] Resources are defined as coal in beds thick enough that economic extraction is currently or may become feasible. This term should not be confused with reserves of coal, which is defined as those parts of the resource that can be economically mined today.

Table 7.--Identified original coal resources in the Sweetwater-Kemmerer area (in millions of short tons).

[---, indicates no data]

	Bituminous	Subbituminous	Lignite	Strippable Resources
Hams Fork Region:				
Evanston field	0	[1] 314	0	---
Kemmerer field	[1] 2,284	[1] 1,362	0	[2] 1,000
LaBarge field	0	1	0	---
Bear River field	---	---	---	---
Green River Region:				
Rock Springs field	[4] 12,933	[4] 3,830	0	[3] 250
Henry's Fork field	0	[1] <1	0	0
Frewen field	0	---	---	0
Vermillion Creek field	0	[5] 130	0	[5] 130

[1] Berryhill and others, 1950--bituminous coal>14 inches; subbituminous coal>2.5 feet; under less than 3,000 feet overburden.

[2] Smith and others, 1972--200 feet of bituminous coal under less than 1,400 feet overburden

[3] Smith and others, 1972--30-40 feet of subbituminous coal under less than 200 feet overburden.

[4] Root and others, 1973--bituminous coal>14 inches; subbituminous coal>2.5 feet; under less than 3,000 feet overburden.

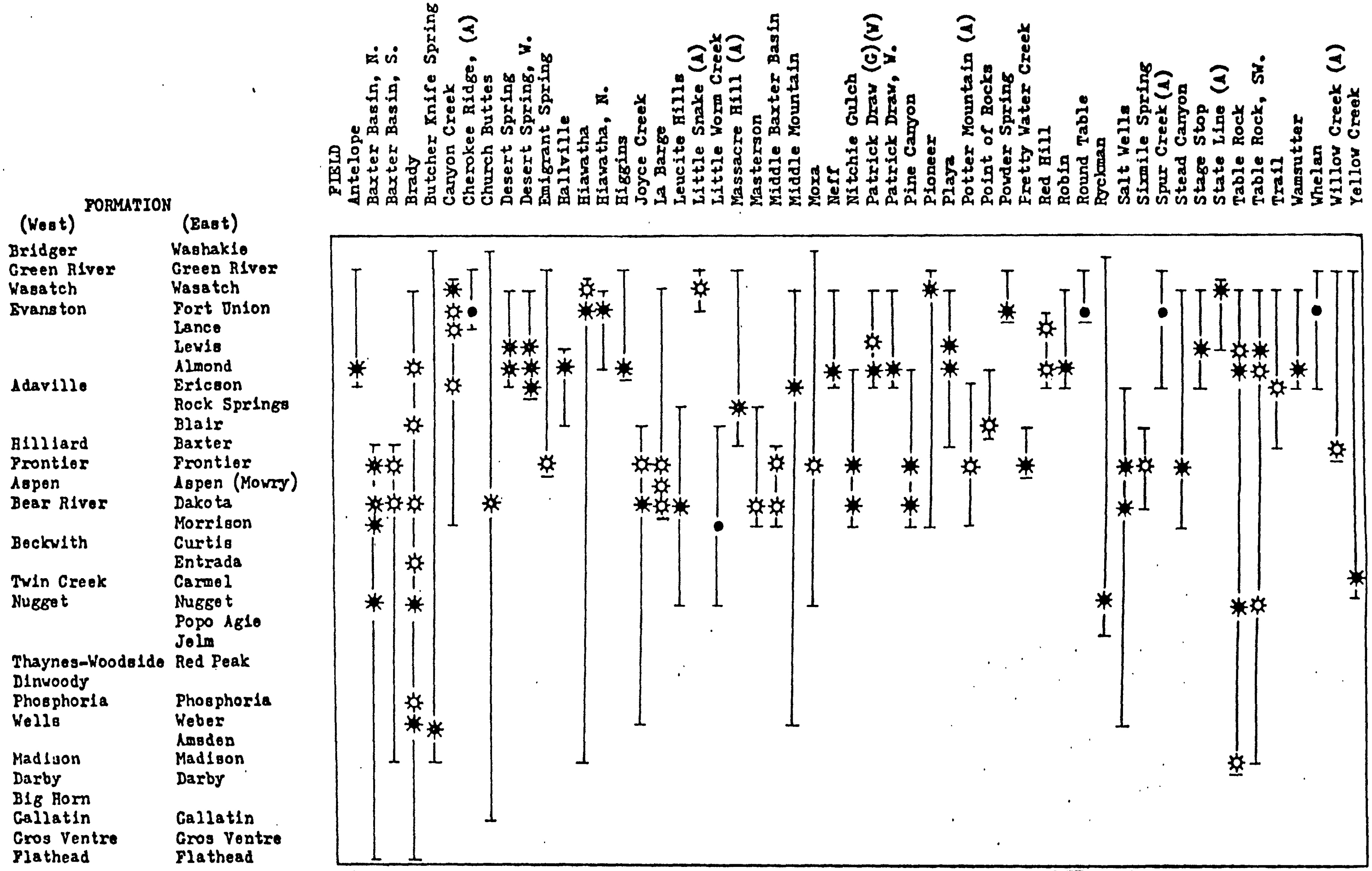
[5] Roehler, Coal resources of the Chicken Creek SW quadrangle, (H. W. Roehler, unpub. data, 1977), high sulfur subbituminous coal <10 feet; under less than 200 feet overburden.

Oil and Gas

The first oil or gas reported in the Sweetwater-Kemmerer area was in 1847 in the Overthrust Belt in sec. 4, T. 13 N., R. 119 W. at an "oil spring" discovered by Mormon pioneers during their trek to the Great Salt Lake in Utah (Veatch, 1907, p. 139-140). A similar spring was discovered in the Overthrust Belt about 20 years later by C. M. White in NW 1/4 sec. 33, T. 14 N., R. 119 W. The earliest record of oil drilling was at this spring in 1868, when White drilled a hole to 480 feet. The oil from the well was skimmed and sold to tanners in Salt Lake City. The first economically significant oil discovery was at 491 feet in a water well drilled by the Union Pacific Railroad in 1900 near Spring Valley in T. 15 N., R. 118 W. (Veatch, 1907, p. 141).

The first natural gas discovery was in the Rock Springs uplift by the Ohio Oil Company in 1922 in sec. 16, T. 16 N., R. 104 W. in the southern part of the Baxter Basin. The discovery well produced 36 million cubic feet of gas per day from the Dakota Formation at 2,475 feet. In 1929 a pipeline was built by the Ohio Oil Company and the gas was marketed in the Great Salt Lake valley (Andrews, 1965, p. 232).

Drilling activity in the Sweetwater-Kemmerer area intensified after the discovery of oil at LaBarge field in 1924, of oil and gas at Hiawatha Dome in 1928, and of additional gas at Baxter Basin field in the 1930's. There are currently about 50 oil and gas fields in the area that produce more than 60 billion cubic feet of natural gas annually (Crews and others, 1973, p. 105-107), and more than 3 million barrels of oil annually (Wyo. Geol. Assoc., 1973, p. 14-18). The locations of oil and gas fields are shown on Plate 6, producing formations are shown on Figure 11, and production statistics and oil characteristics are shown on Table 8.



Production or important show of oil ● or gas ☼, or both ✱. Abandoned oil or gas field (A), Waterflood project (W), Gas injection project (G).

Figure 11.--Penetration chart of oil and gas fields in the Sweetwater-Kemmerer area.

Table 8.--Production statistics for oil and gas for 1972 and oil characteristics in the Sweetwater-Kemmerer area

[Date from Wyo. Geol. Assoc., 1973]

Field	Disc.	Form	Wells	Oil Prod.	Cum. Oil (BBL)	Gravity API°	Vis. @ 100°F	Sulf. % Wt.	Carb. Res. %	Nitro % Wt.	Gas Prod.(MCF)	Cum. Gas (MCF)
Antelope	1970	Kal	8	1,470	1,470	41.7					2,542,417	2,542,417
Baxter Basin, N	1926	Kf, Kd, Jm, Us, Jn, Pw	13	786	2,541	39.4-41.1	32.0-37.0	<0.1-0.63	0.002-1.7	0.0	1,507,764	65,431,573
Baxter Basin, S	1922	Kf, Kd	26	0	0						1,656,787	144,643,204
Brady	1960	Kmv, Kd, Jn, Pw	2	312	312	52.0					310,804	310,804
Butcher Knife Spring	1971	Pm	0	0	0						0	0
Canyon Creek	1941	Kmv, Kd	25	47,113	763,957	46.6					15,524,165	127,485,872
Cherokee Ridge												
Church Buttes	1946	Kd, Pm	11	0	0	47.6	30.0	<.01	0.0	0.0	7,437,066	236,012,758
Desert Spring	1958	Kls, Kmv	30	93,632	680,382	45.5-61.5	31.4	.03	.04		12,916,197	81,401,295
Desert Spring, W	1959	Kfh, Kle, Kal	22	64,672	316,744						1,656,569	5,521,754
Emigrant Spring	1958	Kf	0	0	0						0	11,964
Hallville	1962	Kal	1	501	23,536	41.0					0	2,737
Hiawatha	1928	Tw	12	0	0	40.6	36.0	.12	.6	.015	2,202,594	53,163,932
Hiawatha, N												
Higgins	1969	Kal	1	64	2,167						158,641	955,379
Joyce Creek	1958	Kf, Kd	4	1,183	53,097	34.2	57.0	.42	1.0		48,224	4,641,218
LaBarge	1924	Ta, Kmv, Kf, Kmv	98	272,433	17,238,553	43.4	34.0	<.1	.32		3,483,820	26,337,691
Leucite Hills	1969	Kd	1	0	0						129,547	342,584
Little Worm Creek	1957	Kd	0	0	107,348						0	4,082,907
Massacre Hill	1962	Krs	0	0	759						0	0
Masterson	1970	Kd	1	0	0						192,674	192,674
Middle Baxter Basin	1938	Kf, Kd	4	0	0						214,413	14,957,575
Middle Mounbarn	1952	Kmv	1	0	56,062	46.0	30.8	.05	.17		263,502	8,372,031
Noxa	1961	Kf	1	0	0						147,129	903,280
Naff	1968	Ka	0	0	255						0	32,795
Nitchie Gulch	1962	Kf, Kd	10	7,056	115,778	48.0					4,012,569	33,509,947
Patrick Draw	1959	Kal	110	2,518,967	45,501,039	44.0	31.7	.04	.09		7,698,432	161,734,483
Patrick Draw, W	1959	Kal	3	10,749	743,892	42.0					204,125	2,400,111
Pine Canyon	1964	Kf	1	661	13,015	58.9					135,304	1,809,019
Pioneer	1959	Kmv	2	1,146	15,661						795,900	9,754,600
Playa	1958	Kal	7	17,661	255,627	45.0					2,372,858	12,725,523
Potter Mountain	1956	Kf	0	0	0						0	391,660
Point of Rocks	1963	Kbl	1	0	0						108,219	645,664
Powder Spring	1970	Tfu	1	6,077	32,861	78.1					447,401	1,654,546
Pretty Water Creek	1962	Kf	0	0	184						0	829,072
Ted Hill	1962	Kal	0	0	0	21.5	88.0	.20	.7		0	14,913
Robin	1971	Kal	2	1,970	16,221	39.1					27,378	38,197
Round Table	1967	Tfu	0	0	9,224	40.0					0	0
Ryckman	1975											
Salt Wells	1949	Kf, Kd	1	0	316,565	42.6					376,826	10,379,810
Sixmile Spring	1962	Kf	0	0	0						0	249,105
Spur Creek												
Stud Canyon		Ta				44.0	33.8	.03	.18			
Stage Stop	1966	Kle	5	52,327	302,535	45.1	32.9	.11	.70		401,667	1,450,160
State Line	1959	Tw	0	0	14,625	38.0					0	493,100
Table Rock	1946	Tw, Kla, Kal, Ja	5	55,573	890,104	40.4	35.8	.04	.12		1,232,384	13,804,977
Table Rock, SW	1955	Kal	1	0	0						87,008	657,215
Trail	1952	Ks	7	10,426	213,874						2,213,674	35,093,597
Wamsutter	1958	Kal	8	35,045	225,985	54.0					2,937,109	16,504,603
Whelan	1970	Ts	2	13,095	40,458	40.0					11,572	24,483
Willow Creek	1957	Ta	0	0	0						0	8,020
Yellow Creek	1975											

Phosphate

Deposits of phosphate rock are present in the Phosphoria Formation in the Overthrust Belt. The formation crops out locally in T. 19 N., R. 117 W., T. 21-22 N., R. 121 W., T. 27 N., R. 119 W., and in elongate north-trending areas as much as 2 miles wide in T. 22-28 N., R. 116-118 W. (pl. 6). The occurrence of the phosphate was first described by F. B. Weeks and W. F. Ferrier in 1907 (Schultz, 1914, p. 131). The origin and the stratigraphic and geographic distribution of the deposits have been discussed by McKelvey and others (1959) and Sheldon (1955; 1964). The phosphate is in beds as much as several feet thick that contain 30 percent or more P_2O_5. They formed by divergence upwelling of sea waters during the Permian Period (Cathcart and Gulbrandsen, 1973, p. 518-519). The principal chemical constitutents, in order of abundance, are lime, phosphate, silica, carbon dioxide, organic matter, magnesia, alumina, iron oxide, and flourine (Cochran, 1950, p. 133). The Phosphoria Formation also contains small quantities of vanadium, uranium, selenium, molybdenum, zinc, titanium, nickel, chromium, and cadmium (Love, 1961, p. C282).

The phosphate deposits in the Overthrust Belt have been mined by the San Francisco Chemical Company near Leefe, Wyo., in T. 21 N., R. 121 W., and by Phosphate Mines, Inc., in T. 23-24 N., R. 116 W. Precise resource estimates are not available, but the deposits underlie hundreds of square miles, and there may be as much as 250 million short tons in the Sweetwater-Kemmerer area.

The United States produced 5,605,000 tons of phosphate rocks in 1968, which was 45 percent of the total world output that year (Lewis, 1970b, p. 1143). About 70 percent of the domestic consumption of phosphate rocks is in fertilizer. Other uses include animal feed supplement, detergent, electroplating, and incendiary bombs (Cathcart and Gulbrandsen, 1973, p. 516). Mining of phosphate rock in the Sweetwater-Kemmerer area is from open pits, making reclamation programs necessary for mined-out areas. Flourine, a dangerous gas, is given off during the processing of phosphate rock to make fertilizer (Lewis, 1970, p. 1149), but is now adequately controlled by precipitators in the stacks of the phosphate plants.

Trona

Trona, a complex sodium carbonate mineral, was discovered in the Green River Basin in 1938 in an oil and gas test well drilled in sec. 2, T. 18 N., R. 110 W., by Mountain Fuel Supply Company (Brown, 1950, p. 136). In 1946, following several years of exploratory drilling, Westvaco Company sank a 12-foot circular concrete-lined shaft to a depth of 1,500 feet in T. 19 N., R. 110 W. A processing plant was simultaneously constructed at the mine mouth, and ore was marketed for the first time in 1947 (Jacobucci, 1955, p. 203).

Trona is present in the Wilkins Peak Member of the Green River Formation in at least 42 beds in an area of about 1,300 square miles (pl. 6). Eleven of these beds are at subsurface depths of 400–3,500 feet, are more than 6 feet thick, and are potentially minable (Deardorff and Mannion, 1971, p. 15). Trona has the formula $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$ in relative proportions 46.90 percent sodium carbonate, 37.17 percent sodium bicarbonate, and 15.93 percent water. The mineral has a tabular or fibrous habit and a dull, vitreous, or silky luster. It is associated with other saline minerals such as shortite, halite, and nahcolite, and is interbedded with dolomitic mudstone, oil shale, sandstone, siltstone, and tuff. The trona-bearing part of the Green River Formation was deposited by evaporation of saline waters from the previously mentioned Lake Gosiute.

Trona is extracted by underground mining at the Food Machinery Corporation (Westvaco) Mine in T. 19 N., R. 110 W., at the Allied Chemical Company Mine in T. 19 N., R. 109 W., at the Stauffer Mine in T. 20 N., R. 109 W., and at the Texas Gulf Sulfur Mine in T. 20 N., R. 111 W. Culbertson (1966, p. B161) has estimated that there are 67 billion tons of trona in the Green River Basin in beds thicker than 3 feet. This is the largest deposit of naturally occuring sodium carbonate in the world. Mined trona is normally converted thermally to soda ash at the mine-mine mouth plants, a process that upgrades the ore by removing carbon dioxide, water, and insolubles.

In 1970 the United States produced 6.8 million tons and exported 0.3 million tons of sodium carbonate. Identified resources in the United States, at current rates of consumption, will last at least 5,000 years (Smith and others, 1973, p. 213). About 50 percent of the soda ash is consumed for the manufacture of glass, 40 percent for making other chemicals, 8 percent in the paper industry, and 2 percent is used for miscellaneous uses such as manufacturing soap, detergents, and water softeners (Smith and others, 1973, p. 206). An important potential use for sodium bicarbonate, derived from soda ash, is as a cleanser of sulfur dioxide from stack gases in coal-fired electric-power-generating plants.

Trona mining is not considered harmful to the environment, but during its conversion to soda ash fine particulates are released to the atmosphere and form a thin fog-like haze in dominantly eastward, downwind directions from plant sites. Minor subsidence of surface rocks resulting from trona mining is discussed in the section on engineering geology.

Halite

Halite, or rock salt (NaCl), was found in disseminated crystals and in beds a few feet thick interbedded with trona in the southern part of the Green River Basin in exploratory core holes drilled in the 1940's and 1950's by the Union Pacific Railroad and several chemical companies (pl. 6). When certain naturally occurring sodium brines are evaporated in the laboratory or in processing plants, precipitation takes place in stages, with trona coming out of solution before halite. Apparently this happened during extremely arid periods of time when the confined saline waters of Lake Gosiute were reduced in size to supersaline ponds from which, first trona, and then trona and halite, were precipitated.

Halite is not presently economically extractable and none is mined in the Green River Basin, but Culbertson (1966, p. B161) estimates there are 35.6 billion tons of mixed trona and halite in beds more than 3 feet thick. Halite is considered an impurity in trona mining, and hence at least one-third of the total trona resources of the area contain sufficient sodium chloride to make these mixed salts undesirable as a source of sodium carbonate (Deardorff and Mannion, 1971, p. 28).

Halite is used principally as a control agent for ice on highways, where it has a deleterious effect on vegetation bordering the treated areas (MacMillan, 1971, p. 1211). If halite, or trona and halite, are mined in the Green River Basin, contamination of surface waters could result from the leaching of spoil piles.

Minerals of Potential Economic Value

Oil shale

Oil shale is a tan, brown, to nearly black, very finely textured, usually laminated rock containing kerogen. The rock matrix can be either mostly a carbonate (dolomite) or mostly a silicate (shale), so that the term "oil shale" is ambiguous and has more economic significance than lighologic meaning. Kerogen is a naturally occurring solid material derived from organic matter, that is a precursor of crude oil and coal. applying heat to oil shale much of the kerogen is converted synthetically to crude oil.

Many companies, universities, and government agencies have investigated oil shale for more than 100 years. The earliest mention of oil shale in the area was in 1871, when Hayden (p. 142) stated that near the town of Green River, Wyo. dark-colored rock containing an "oily substance" was used as stove fuel; it burned well, but the ash was as great as the original mass of rock. The geology of oil shale in the area has been studied by Lesquereux (1872), Schultz (1920), Winchester (1923), Bradley (1926; 1929; 1964), Culbertson (1971), Roehler (1969; 1973c), and Trudell and others (1973). The origin of oil shale was discussed by Smith and Stanfield (1965). Current investigations of oil shale by ERDA (formerly the U.S. Bureau of Mines) at a field site in T. 19 N., R. 106 W. include experiments on oil recovery by in-situ retorting.

Oil shale is found in the lacustrine Green River Formation, which underlies more than 8,000 square miles of the Sweetwater-Kemmerer area (pl. 7). The formation has a maximum thickness of about 3,000 feet. In Fossil Syncline it is divided into two parts, a lower Fossil Butte member and an upper Angelo Member. In the remaining parts of the

Sweetwater-Kemmerer area, it is divided, in descending order, into the Laney Member, Wilkins Peak Member, Tipton Shale Member, and Luman Tongue. All of these stratigraphic units contain oil shale, but only the basal parts of the Wilkins Peak and Laney Members in local areas have beds of oil shale that are more than 10 feet thick that will yield more than 25 gallons of oil per ton of rock when assayed. The richer beds are located in the eastern part of the Green River Basin in T. 14-24 N., R. 105-111 W., and in the western part of the Washakie Basin in T. 13-16 N., R. 97-100 W., (Root and others, 1973).

It is estimated that the total amount of oil equivalent in place in oil-shale beds in the Sweetwater-Kemmerer area is more than 1 trillion barrels. Of this amount, however, not more than 50 billion barrels, or 5 percent, are in beds more than 10 feet thick that will yield more than 25 gallons of oil per ton of rock when assayed. There is no record that oil shale has been mined in the Sweetwater-Kemmerer area. Two tracts of land containing high-quality oil shale in T. 13-14 N., R. 99 W., in the Washakie Basin were opened for competitive bidding for oil-shale leases by the Federal Government in 1973. No bids were received, which suggests that there presently is not sufficient economic incentive to justify a shale-oil industry in the Sweetwater-Kemmerer area.

The effect of oil-shale mining on the natural environment includes deterioration of water and air quality, disturbance of land, destruction of vegetation, and dispersion of animal life.

Uranium

Uranium is present in the Sweetwater-Kemmerer area associated with phosphates in the Wasatch, Green River, and Phosphoria Formations, and as oxides in the Ericson Formation. Traces of uranium have been detected by radioactive anomalies in the Almond and Browns Park Formations.

Uraniferous phosphate of unknown origin occurs northeast of Pine Mountain in T. 13-14 N., R. 102-103 W. (pl. 7). The mineralized rocks are variegated tuffaceous mudstone and siltstone in the lower 300 feet of the Cathedral Bluffs Tongue of the Wasatch Formation. Love (1964, p. E37) believed that the mineralized zone, which contains as much as 0.3 percent uranium and 19 percent phosphate, would contain 1,470 tons of uranium and 146,000 tons of phosphate per square mile.

Love (1964, p. E19-E30) also identified 25 uraniferous phosphate zones in the Wilkins Peak Member of the Green River Formation in scattered outcrops in the southeast part of the Green River Basin in T. 14-19 N., R. 105-107 W. (pl. 7), and in a number of holes cored for trona mostly in T. 15-23 N., R. 106-109 W. The Wilkins Peak Member is about 1,000 feet thick and is composed of gray and green dolomitic mudstone and claystone, and interbedded gray sandstone and siltstone, brown oil shale, and evaporites. The mineralized zones are 3-6 feet thick, have variable lithologies, and are spaced throughout the member. The maximum uranium content is 0.15 percent and the maximum phosphate content is 18.2 percent; the average for 25 sampled zones is about 0.05 percent uranium and 2.2 percent phosphate (Love, 1964, p. E1). None of the deposits has been mined, but they have been extensively prospected since their discovery in the early 1950's.

The middle and lower parts of the Phosphoria Formation in the Overthrust Belt also contain minor quantities of uraniferous phosphate. Love (1961, p. C282) reported that the uranium content in the richer zones ranges from 0.01 to 0.02 percent.

Oxides of uranium are present locally in outcrops of the Ericson Formation on the southeast flank of the Rock Springs uplift in T. 16-19 N., R. 101-102 W. The Ericson Formation is about 800 feet thick and is mostly gray medium- to coarse-grained crossbedded sandstone. A horizontal tunnel, about 50 feet long, was opened in the upper part of the formation in the SW 1/4 sec. 28, T. 18 N., R. 101 W. in the late 1950's. Yellow uranium mineralization was visible in places in the walls of the tunnel, but the prospect was never a commercial venture and has since been abandoned.

Dozens of uranium claims have been staked in the Almond Formation on the east flank of the Rock Springs uplift and in the Browns Park Formation on Cherokee Ridge at the southern edge of the Washakie Basin. The amount of uranium in these formations is unknown, but none of the claims has been worked.

Uranium is used mostly to produce nuclear explosives and to generate electric power, and to lesser extent in the chemical and plastic industries (DeCarlo and Shortt, 1970, p. 234-238).

Titanium

Littoral sandstone units in the upper part of the Rock Springs Formation contain titanium in natural placer deposits of heavy minerals in local areas in T. 14 N., R. 103 W., T. 16 N., R. 102 W., T. 17 N., R. 102 W., and T. 18 N., R. 101-102 W. The occurrence of these and similar sedimentary deposits was discussed by Murphy and Houston (1955). Several of the deposits on the southeast flank of the Rock Springs uplift have been mapped by Roehler (Cooper Ridge NE quad, 1977c and Camel Rock quad. unpub. mapping, 1977).

The titanium-bearing sandstone beds are dark gray, but on exposure they weather dark reddish brown. The grain-size distribution is about 15 percent coarse, 30 percent medium, 20 percent fine, and 20 percent very fine sand, and 15 percent silt and clay. Magnetic heavy-mineral fractions, consisting mainly of ilmenite and magnetite, compose 50 to 55 percent of the sandstone. The nonmagnetic heavy-mineral fraction is more than 95 percent zircon and minor garnet and rutile. The titanium is found mainly in ilmenite, which is composed of 52 to 68 percent titanium dioxide (Murphy and Houston, 1955, p. 193). The only evidence of mining these deposits are several pits, 50-100 feet in diameter, that were excavated years ago in the SW 1/4 sec. 19, T. 19 N., R. 101 W.

Titanium is used in industry as an alloy to produce corrosion-resistant metals, as paint pigment, and in plastics. The deposits in the Sweetwater-Kemmerer area are small, low-grade, and presently uneconomical to mine.

Potash

Lavas in the Leucite Hills are rich in the mineral leucite, which has an especially high concentration of potassium. Potassium ore is referred to as its oxide, "potash" (K_20). The Leucite Hills were named by S. F. Emmons, who discovered the leucite during exploration of the area in 1871 (Carey, 1955, p. 112).

Leucite is a light-colored potassium aluminum silicate, having the formula $K_20 \cdot Al_20_3 \cdot 4Si0_2$ in the proportion of 21.52 percent K_20, 23.33 percent Al_20_3, and 55.15 percent $Si0_2$ (Ladoo and Myers, 1951, p. 278). Schultz and Cross (1912) have calculated that there are approximately 2 billion tons of rock in the Leucite Hills that contain 200 million tons of potash. At present no commercial method is known for extracting the potash from the silicates in the rocks. Concerning the economic potential of the deposits, Carey (1955, p. 113) wrote:

> ".....considerable effort has gone into a search for a commercial method of combining the potash in the leucite-bearing rocks and the phosphorus in the phosphatic shales of the Phorphoria formation to form a fertilizer containing both of these elements in available form. The economic success of such a process appears to depend mainly upon obtaining a local source of large quantities of inexpensive ammonia."

About 95 percent of the potassium produced in the United States is used as fertilizers, and about 5 percent in the manufacture of drugs, dyes, and chemical reagents (Lewis, 1970, p. 1163). The Leucite Hills potash deposits probably will not be utilized for many decades because of the abundance of more economically recoverable deposits elsewhere in the United States and Canada.

Zeolites

The zeolite minerals analcime, clinoptilolite, and mordenite are widely distributed in a 6,000-foot-thick section of Eocene rocks comprising the Washakie, Green River, and Wasatch Formations. They have been identified and studied in the Sweetwater-Kemmerer area by Johannsen (1914), Bradley (1928; 1945), Parker and Surdam (1971), and Roehler (1972c).

The zeolite minerals are aluminosilicates formed by the diagenetic alteration of volcanic glass in air-laid andesitic tuff. Time and depth of burial are important factors, but the alteration is specifically related to pH, salinity, and cation content of overlying and interstitial waters. Zeolite minerals are especially abundant in the Green River Formation, because the waters of Lake Gosiute were saline, were high in sodium carbonate, and were at times chemically stratified.

A minable zeolite deposit is the "robins-egg-blue tuff, which encircles the central part of the Washakie Basin (pl. 7) and is composed of more than 50 percent clinoptilolite (Roehler, 1973c, p. 54-55). The bed ranges in thickness from slightly less than 10 feet to more than 100 feet and has a distinctive blue-green color. R. A. Sheppard of the U.S. Geological Survey (oral comm., 1972) has estimated the bed contains at least 5 billion tons of clinoptilolite. Similar zeolite tuffs are present in the Green River Basin, but they have not been mapped.

Zeolites are used in industry as agents for moisture absorption and for deodorization, as an additive to aid in retention of fertilizer on agricultural lands, and, in the form of clays, for papermaking (Minato and Utada,1969, p. 132-133). Clinoptilolite, as an agent for the removal of ammonia nitrate from waste waters, is expected to have its major use in the control of water pollution (Mercer, 1969, p. 209).

Alunite and Clay

Potentially economic deposits of alunite and clay were discovered in 1958 in the Bishop Conglomerate on Aspen Mountain in T. 17 N., R. 104 W. by E. R. Keller of Mountain Fuel Supply Company. The locality was later investigated by Love and Blackmon (1962, p. D11-D15).

The Bishop Conglomerate is generally 10-50 feet thick and is composed mostly of rounded cobbles and pebbles of red, white, gray, and tan quartzite and sparse hornblende gneiss, granite and chert, with interbedded gray, green, and red sandstone, siltstone, and mudstone. A few beds of alunite-bearing claystone, as much as 12 feet thick, are present within the interbedded sequence. The analyses,in percent, of two samples from a trench dug in the north-center of sec. 26, T. 17 N., R. 104 W., are as follows (Love and Blackmon, 1962, p. D13):

	Sample A	Sample B
SiO_2	8.0	16.0
Al_2O_3	32.0	29.5
Fe_2O_3	1.5	.4
MgO	.5	1.0
CaO	.1	.1
K_2O	6.8	5.8
TiO_2	.1	.1
SO_3	37.0	33.0
Li_2O	.01	.01
Na_2O	.58	.49
H_2O	>10.0	>10.0

Associated with the alunite are as much as 25 percent clay minerals consisting of kaolinite, montmorillonite, and halloysite. The deposit probably formed during early Tertiary hydrothermal activity, when ascending hot solutions dissolved country rock and precipitated alunite and clay.

Alunite, $KAl_3(SO_4)_2(OH)_6$, is a white mineral that has value as a source of aluminum and potash. Kaolinite, montmorillonite, and halloysite are white or light-gray fine-textured minerals composed of hydrous aluminum (or magnesium) silicates. Clays have a variety of uses in fired materials, paper, chemicals, rubber, paint, and fillers. The deposits on Aspen Mountain are small, but they are minable.

Helium

Helium is a minor constituent of natural gas at South Baxter Basin Gas Field in the Rock Springs uplift in T. 16-17 N., R. 103-104 W. Helium is a lightweight inert gas that is an end product of the radioactive decay of uranium and thorium. Its origin at the South Baxter Basin Gas Field is unknown, but its distribution there suggests that it may be associated with hydrothermal activity at Aspen Mountain.

The highest concentration of helium is in gas from the Dakota Formation. Natural gas in the Dakota Formation is composed of 76.6 percent methane, 0.6 percent ethane, 20.6 percent nitrogen, 0.72 percent helium, and 2.2 percent carbon dioxide; the gas has a heating value of 787 Btu/cu ft. It also contains 65 to 85 grains of hydrogen sulfide per 100 cu ft of gas (Biggs and Espach, 1960, p. 23, 287). Natural gas in the Frontier Formation is composed of 92.4 percent methane, 3.5 percent ethane, 1.2 percent nitrogen, 0.4 percent oxygen, 0.09 percent helium, and 2.5 percent carbon dioxide; it has a heating value of 999 Btu/cu ft (Biggs and Espach, 1960, p. 287).

The original helium reserves of the field have not been estimated and no attempt has been made to recover the helium during the marketing of natural gas. Since 1929, about 150 billion cu ft of natural gas have been produced at the field, and the natural gas (and helium) reserves are now nearly depleted.

Sulfur

Natural gas containing hydrogen sulfide (H_2S) is a potential source for large quantities of sulfur in the Sweetwater-Kemmerer area. Hydrogen sulfide is in natural gases in the Nugget, Phosphoria, Weber, and Madison Formations at the North Baxter Basin Gas Field in T. 19-20 N., R. 104 W., in the Amsden and Madison Formations at the Church Buttes-Butcherknife Springs Gas Fields in T. 15-17 N., R. 112 W., and in the Phosphoria and Weber Formations at Brady Field in T. 16-17 N., R. 100-101 W. The gas from the Phosphoria Formation at Brady Field contains more than 30 percent hydrogen sulfide. The origin of Hydrogen sulfide in natural gases can be explained by several theories: (1) simultaneous hydrogen sulfide and methane generation in freshwater swamps; (2) sulfate in ground water coming in contact with petroleum, which activates anerobic, sulfur-reducing bacteria; and (3) petroleum entrapment in beds of anhydrite (Bodenlos, 1973, p. 612).

Hydrogen sulfide can be extracted from natural gas, and elemental sulfur recovered from the hydrogen sulfide by a number of patented processes (Lewis, 1970a, p. 1251-1252). As a byproduct of the natural-gas industry it provides 7 percent of the total production in the United States. Sulfur is used mainly in the manufacture of sulphuric acid. It is used in the manufacture of soluble fertilizer, synthetic fibers, plastics, papers, pigments, explosives, petroleum products, drugs, and insecticides (Bodenlos, 1973, p. 606.

Hydrogen sulfide gas is extremely poisonous. Where it is produced with methane, it is extracted and burned to upgrade the gas to pipeline quality. At Brady Field, and for miles around the field, a strong sulfurous odor is present in the atmosphere as a result of the production and extraction of hydrogen sulfide.

Copper, silver and zinc

Copper, silver, and zinc occur in the Nugget sandstone in the Lake Alice District in T. 27-28 N., R. 117-118 W. in the Overthrust Belt. In a historical sketch of the district, Lloyd (1970, p. 131-134) stated that the first attempt to mine the deposits was in 1895 by the Collett Mining Company. Mining activity continued there intermittently through 1920, but was then discontinued because of mining and transportation problems. Love and Antweiler (1973, p. 141) reported that another unsuccessful attempt was made to mine the deposits during World War II.

The Nugget Sandstone in the Lake Alice District is 500-700 feet thick and consists of dull-red, mostly fine grained sandstone. Copper, silver, and zinc minerals occur as carbonates and sulfides in scattered gray, brown, black, and green altered zones mostly in the upper 50 feet of the sandstone. Chemical analyses of samples from several mines in the district indicate that the ore contains 180-67,000 ppm copper, 1-1,200 ppm silver, and 18-31,000 ppm zinc (Love and Antweiler, 1973, p. 143). Several theories have been advanced concerning the origin of the Lake Alice deposits. Love and Antweiler (1973, p. 146) believed that the deposits could have resulted from the ionic exchange of sulfate ions from anhydrite in beds overlying the Nugget Sandstone, followed by bacterial action that reduced sulfate to sulfide ions, and then the combining of metals derived from residual oils in the Nugget Sandstone and sulfide ions to precipitate insoluble metallic sulfides.

Copper mineralization has been reported in red beds in the Beckwith Formation at a locality at the Rock Creek-Needles anticline in T. 18 N., R. 120 W. Veatch (1907, p. 163) described the deposit as follows:

> "The red beds are here involved in an overturned anticline, and at three places along the axis of this anticline copper carbonates have been found in a gray sandstone containing considerable vegetable matter. The prospects are all shallow surface pits, and there is no evidence that surface work will yield returns. Deep prospecting alone might yield value....."

Copper mineralization was also reported by Veatch (1907, p. 163) in a small area in the valley of Rock Creek, 6 miles north of Nugget, in T. 22 N., R. 118 W. Copper carbonates were found there in horizontal tunnels opened in the Ankareh Formation along a small, faulted, compressed anticline. There is no indication that this deposit has commercial value.

Black Water

Black water was discovered in the Wilkins Peak Member of the Green River Formation by J. R. McDermott of Wyoming Trona Company in an exploratory hole drilled for trona in sec. 5, T. 23 N., R. 106 W. (Dana and Smith, 1976, p. 9). Black water has since been found in 23 other holes drilled in a 75- to 100-square-mile area of the Green River Basin near Farson in T. 23-25 N., R. 106-108 W. (pl. 7). Black water consists of organic acids dissolved in sodium carbonate brines. The pH of the water is between 9.9 and 11.2; the maximum content of organic acids is about 20 weight percent, and the maximum CO_2 content is about 2.4 weight percent (Dana and Smith, 1973, p. 155). The origin of the black water is unknown, but it is certainly genetically related to oil shale and evaporites found in the Wilkins Peak Member in most parts of the Green River Basin. Black water is a potential source of soda ash and oil. Dana and Smith (1976, p. 12) have demonstrated that a black-water flow of 200 gallons per minute could produce 62 tons of soda ash and 130 tons of organic matter daily. The organic matter would yield 73.3 weight percent oil when heated in an inert atmosphere.

Construction Materials

Construction materials in the form of sand, gravel, and crushable aggregate rock are abundant in the Sweetwater-Kemmerer area (pl. 8). The materials are contained in valley alluvium, sand dunes, glacial outwash, terrace gravels, and volcanic rock of Tertiary and Quaternary ages. Sands and gravels in the Sweetwater-Kemmerer area are composed mostly of quartz, quartzite, and chert, and lesser amounts of limestone, sandstone and siltstone.

Sand resources are mostly in a west-trending dune field at the northern tip of the Rock Springs uplift in T. 23-24 N., R. 97-107 W., and in scattered dune fields in the Washakie Basin in T. 13-16 N., R. 95-98 W. The dunes that cross the northern tip of the Rock Springs uplift are actively migrating eastward; those in the Washakie Basin have been mostly stabilized by vegetation. The sand in these dune fields is composed of 60 to 90 percent quartz.

Tertiary terrace deposits consisting of clay, sand, pebbles, cobbles, and boulders compose the Bishop Conglomerate on Aspen Mountain and Bacon Ridge, and cap numerous small buttes and mesas in other parts of the Rock Springs uplift and in the southern part of the Green River Basin. The Bishop Conglomerate is consolidated, but the area also has many small terraces capped by unconsolidated gravels.

Glacial outwash consisting of clay, silt, sand, pebbles, cobbles, and boulders occupies floodplains of the Big Sandy River and its tributaries in the vicinity of Farson in T. 24-26 N., R. 105-106 W. This material was derived from Pleistocene alpine glaciers in the Wind River Mountains to the north. Glacial outwash also composes parts of the floodplain of the Blacks Fork River in the vicinity of Mountain View in T. 13-16 N., R. 114-116 W. This material originated from Pleistocene alpine glaciers in the Uinta Mountains to the south.

The principal gravel deposits in the Sweetwater-Kemmerer area are in valley alluvium along major drainageways. Large deposits of this type are located along the Green, Hams Fork, and Bear Rivers (pl. 8).

The Leucite Hills volcanic field has benches composed of lava that can be crushed and used for aggregate or as decorative building stone (Root and others, 1973). Cinder cones on Zirkle Butte in T. 21 N., R. 102 W., and on Steamboat Butte in T. 23 N., R. 102 W. contain pumice, which can be utilized as a light-weight aggregate for concretes or cinder blocks.

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