Geology of the Sage and Kemmerer 15-Minute Quadrangles, Lincoln County, Wyoming

GEOLOGICAL SURVEY PROFESSIONAL PAPER 855

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SAGE AND KEMMERER
15-MINUTE QUADRANGLES,
LINCOLN COUNTY, WYOMING

FRONTISPIECE. — Absaroka thrust fault on Commissary Ridge (Absaroka Ridge of older maps); view is northward from peak in the SW¼ sec. 32, T. 23 N., R. 116 W. Rock units depicted by labels are: Hams Fork Conglomerate Member of the Evanston Formation (Keh), the Shurtliff Sandstone Member (Khs), and other units of the Hilliard Shale (Kh), the Frontier Formation (Kf), unspecified units of the Triassic System (Tʀu), the Phosphoria Formation (Pp), the Wells Formation (PIPw), colluvium, and rock debris (Qd).
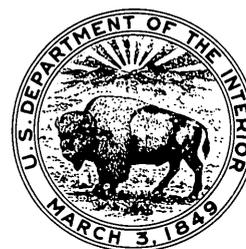
Geology of the Sage and Kemmerer 15-Minute Quadrangles, Lincoln County, Wyoming

By WILLIAM W. RUBEY, STEVEN S. ORIEL, *and* JOSHUA I. TRACEY, JR.

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Geologic map and structure sections depict
the geometry of part of the western Wyoming
thrust belt where overlapped by mainly
Tertiary strata of northern Fossil basin

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

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GEOLOGY OF THE SAGE AND KEMMERER 15-MINUTE QUADRANGLES, LINCOLN COUNTY, WYOMING

By William W. Rubey,[1] Steven S. Oriel, and Joshua I. Tracey, Jr.

ABSTRACT

West-dipping Paleozoic and Mesozoic sedimentary rocks have been thrust eastward over Cretaceous rocks along both the west-dipping Absaroka fault, exposed in the northeast along Commissary Ridge, and the Crawford fault, concealed by Quaternary sediments along Bear River Valley on the west. The thrust plates are covered extensively by continental uppermost Cretaceous and lower Tertiary strata, including the Green River Formation that forms Hams Fork Plateau; these relationships help date tectonic events. Boreholes in and north of the area document the concealed southward continuations of the Commissary and Beaver Creek thrust slices of the Absaroka plate, mapped to the north in the Cokeville quadrangle, and of other thrust slices on the west. The trace of the Tunp thrust fault is inferred to underlie Tertiary strata east of the intensely broken Dempsey Ridge. High-angle faults in the western part of the area include the conspicuous normal fault east of Rock Creek, along which there has been recent movement.

Strata of markedly contrasting facies and thickness have been juxtaposed by the thrust faults. Noteworthy is the change of Lower Cretaceous strata from dominantly gray siltstone and shale of the Bear River and Aspen Formations in the eastern plates to the sequence of equivalent variegated mudstones in the western plates. The western sequence is assigned to the new Smiths, Thomas Fork, Cokeville, and Sage Junction Formations (in ascending order). Another newly recognized unit is the Shurtliff Sandstone Member of the Hilliard Shale, a southward-extending tongue of the Upper Cretaceous Blind Bull Formation. New subdivisions are mapped for the Evanston, Wasatch, Green River, and Fowkes Formations; these strata were not affected by the thrusting.

Coal, the principal resource, is now strip mined in large pits for on-site steam-generated electric power plants and for conversion to metallurgical coke. Phosphate, oil and gas, gravel, fractured quartzite for road metal, and some building stone have also been produced; and exceptionally well preserved fossil fish have been recovered. Slumping in fine-grained Mesozoic and Tertiary strata poses a hazard to construction.

INTRODUCTION

The accompanying geologic map of the 15-minute Sage and Kemmerer quadrangles (pl. 1) is one of several maps presenting data from investigations by the U.S. Geological Survey in the central part of the thrust belt of western Wyoming. Geologic maps have been published (fig. 1) for the Bedford (Rubey, 1958), Afton (Rubey, 1973a), and Fort Hill (Oriel, 1969) quadrangles.

The Sage and Kemmerer quadrangles each cover

about 222 mi² (square miles) in Lincoln County, Wyo. They lie in the Middle Rocky Mountains physiographic province. Twin Creek drains most of the area, flowing west into Bear River of the Great Basin drainage system. Hams Fork drains the northeastern part of the area and flows southeastward into the Green River of the Colorado River system. Altitudes range from 8,889 ft (feet) along the crest of Commissary Ridge on the east to 6,160 ft along Bear River on the northwest.

Dominant landforms on the west and east are northerly to north-northeasterly trending ridges and valleys which are underlain by Paleozoic and Mesozoic strata typical of the thrust belt in southeastern Idaho and western Wyoming. In the center of the mapped area is the Hams Fork Plateau, formed by flat sedimentary rocks deposited in the Fossil sedimentary basin of early Tertiary age. On the west are the wide Bear River valley, Boulder Ridge, and Tunp Range, a southern prong of Salt River Range which splits southward into Rock Creek Ridge and Dempsey Ridge which are separated by south-flowing Rock Creek. Prominent on the east are Commissary Ridge (Absaroka Ridge on older maps), Pomeroy Basin (the middle part of the 90-mi-long Mammoth Hollow), and Oyster Ridge.

Rocks of the area were first mapped in reconnaissance in 1877 during the Hayden territorial survey (Peale, 1879). The first detailed map, prepared in 1905 by A. C. Veatch and his associates, included most of the Sage and Kemmerer quadrangles. The map and accompanying report (Veatch, 1907) were so perceptive for their time that gross geologic features have not been altered by subsequent, more detailed studies. Veatch was the first to recognize major thrust faults in western Wyoming, to describe the Absaroka thrust, and to define many important Cordilleran stratigraphic units. The northeastern part of the Kemmerer quadrangle was included in the large area mapped in 1906 by Schultz (1914) and studied in more detail by Andrews (1944).

Rubey began studies of the general geology and phosphate deposits of western Wyoming in 1931 and of

[1]Deceased April 12, 1974.

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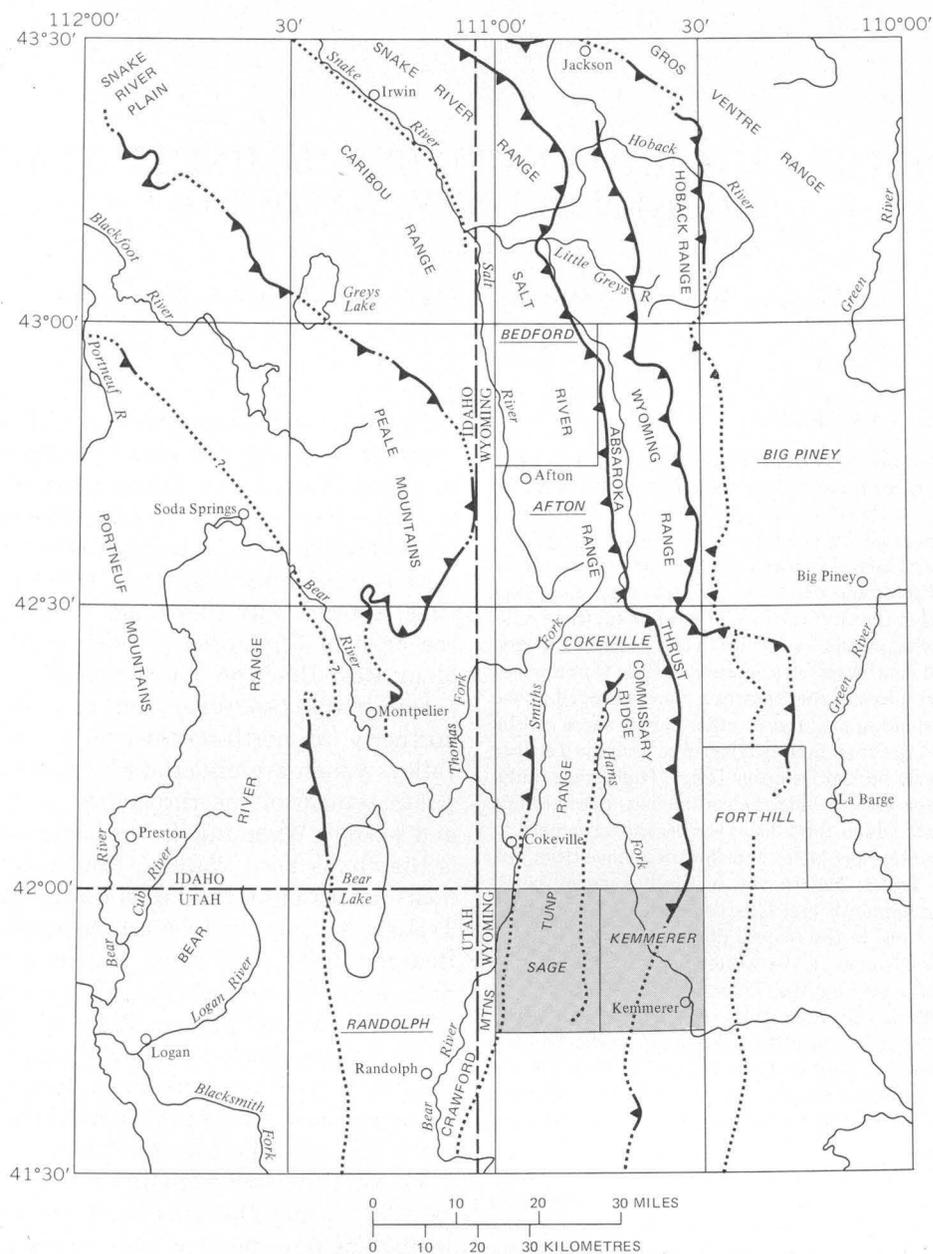
FIGURE 1. — Index map of central part of thrust belt of western Wyoming, southeastern Idaho, and northeastern Utah, showing area mapped (shaded) and nearby quadrangles discussed. Principal thrust faults are indicated by sawteeth and are dotted where concealed. Quadrangle name underscored indicates that topographic quadrangle map is out of print.

the Kemmerer and Sage quadrangles in 1947; work in the region by Oriel began in 1954 and by Tracey, in 1955; five summers were spent by all three jointly mapping the quadrangles from 1955 until 1964. Rubey concentrated on Mesozoic and older rocks, whereas Tracey and Oriel mapped uppermost Cretaceous and younger strata (described by Oriel and Tracey, 1970). Field assistants were Lucian B. Platt and Wesley E. LeMasurier in 1956, Jon L. Rau and Shield B. Montgomery in 1958, Richard L. Armstrong and Donald G. Noble in 1959, John H. Bowie in 1961, and John P. Kern in 1964. This present

report was first written in 1965 and revised in 1971 after the authors were separated by new assignments. Oriel has assumed the principal responsibility for completing the manuscript. D. L. Schleicher and K. L. Pierce improved the manuscript with helpful suggestions during critical reviews.

Fossils collected during the study were identified by R. W. Brown, P. E. Cloud, Jr., W. A. Cobban, D. H. Dunkle, C. L. Gazin, Estella Leopold, G. E. Lewis, H. M. Pakiser, R. E. Peck, J. B. Reeside, Jr., R. J. Ross, R. A. Scott, I. G. Sohn, D. W. Taylor, and J. A. Wolfe.

STRATIGRAPHY

The complete rock sequence has been pieced together from broken segments exposed at scattered localities. It extends from the Cambrian Gallatin Limestone to the Tertiary Fowkes Formation and younger unconsolidated sediments; Silurian rocks are absent, and Mississippian limestones are unexposed but present in subsurface.

CAMBRIAN SYSTEM
GALLATIN LIMESTONE

The oldest rocks, assigned to the Gallatin Limestone, are exposed on Eli Hill, a klippe or fossil slump block near the southwest corner of the area. The rock is yellow- and tan-mottled, thin-bedded to massive, partly dolomitic gray limestone. The unit is thicker than the observed 230 ft inasmuch as the base is not exposed. Rocks as old as Cambrian were not reported by Richardson (1941) a short distance southwest in the Crawford Mountains.

ORDOVICIAN SYSTEM
BIGHORN DOLOMITE

The Bighorn Dolomite overlies the Gallatin Limestone on Eli Hill. It consists of resistant ledges of massive dolomite, mainly light gray but partly mottled dark-gray. The formation is about 600 ft thick. An isolated block of Bighorn Dolomite 600 ft long is mapped overlying Cretaceous rocks on Boulder Ridge in the northwest corner of sec. 32, T. 22 N., R. 119 W.; the block is regarded as part of the diamictite in the Tunp Member of the Wasatch Formation.

Similar dolomite at about the same stratigraphic position in the Crawford Mountains was formerly assigned to the Silurian Laketown Dolomite (Richardson, 1941, pl. 1). Fossils collected from the unit as well as lithology, however, have led to reassignment of the rocks to the Bighorn (Berdan and Duncan, 1955).

DEVONIAN AND MISSISSIPPIAN SYSTEMS
DARBY FORMATION

The Darby Formation is incompletely represented at its one exposure on Eli Hill. The formation consists of a lower unit of mainly dark-gray massive to medium-bedded dolomite, weathering buff to dark brown and having a fetid odor on fresh fracture; and an upper unit of gray dolomite with interbeds of black, yellow, and red sandy calcareous siltstone. A borehole north of the Sage quadrangle, a few miles north of the town of Border, penetrated anhydrite in the Darby. Where complete in nearby areas, the formation is about 800 ft thick on the west, thinning eastward to about 550 ft. Although the sequence can be subdivided into several rock-stratigraphic units (Benson, 1966; Sandberg and Mapel, 1967), it is here assigned to the cartographically convenient Darby Formation, as in adjoining parts of Wyoming (Love and Keefer, 1969, p. 169).

MISSISSIPPIAN SYSTEM
MADISON LIMESTONE

Mississippian carbonate rocks, shown in the structure sections, do not crop out in the mapped area but have been penetrated by deep petroleum tests in the southeastern part of the area. They are exposed to the southwest in the Crawford Mountains in the Randolph quadrangle, where the upper part of the sequence is assigned to the now areally restricted Brazer Dolomite (Sando and others, 1959, p. 2768). Where exposed to the north in the Cokeville quadrangle, the rocks consist of thin-bedded fine-grained dark-gray to brown limestone interbedded with thick ledges of massive medium to coarsely crystalline light- to medium-gray and tan limestone. The unit is probably 1,750–1,800 ft thick on the west in subsurface and thins eastward to about 1,000 ft. Both composition and thickness are consistent with those of sequences farther north assigned by Sando (1967, p. D33) to his Mississippian Montana depositional province.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS
AMSDEN FORMATION

Only the upper part of the Amsden Formation is exposed, where Little Beaver Creek crosses Dempsey Ridge in the northeastern part of the Sage quadrangle. The unit consists of limestone like that in the upper part of the Madison Limestone; quartzite and sandstone like that in the overlying Wells Formation; red to yellow and green siltstone and claystone; red, black, and brown partly pyritic and partly cherty limestone; limestone breccia; and intraformational conglomerate. The Amsden thickens from about 150 ft on the west to 400 ft on the east; it is 650 ft thick in the Bedford quadrangle to the north (Rubey, 1958).

PENNSYLVANIAN AND PERMIAN SYSTEMS
WELLS FORMATION

The Wells Formation is well exposed along the crest of an anticline on Dempsey Ridge and near the base of the Absaroka thrust sheet on Commissary Ridge. The lower part consists dominantly of pale-buff and gray to white well-sorted fine-grained quartzite and partly calcareous sandstone; the upper part, consists of interbedded quartzite, gray finely crystalline dolomite, and siltstone. Limestone in the uppermost part may represent the Grandeur, a tongue of the Permian Park City Formation (McKelvey and others, 1959, p. 15); this limestone was mapped separately on Dempsey Ridge but not on Commissary Ridge. The Wells thickens westward within the mapped area from 600–1,000 ft. It continues to thicken outside the area both westward (Mansfield, 1927, p. 72; Cressman, 1964, p. 18; Montgomery and Cheney, 1967, p. 10) and northward (Rubey, 1958; Staatz and Albee, 1966, p. 30).

PERMIAN SYSTEM
PHOSPHORIA FORMATION AND EQUIVALENT STRATA

The heterogeneous intertonguing Permian rocks here mapped as Phosphoria Formation have been assigned to numerous stratigraphic units (McKelvey and others, 1959). Although too thin to be mapped separately, the lower part of the sequence consists of the lower chert and Meade Peak Phosphatic Shale Member of the Phosphoria; the upper part consists of the Rex Chert, Retort Phosphatic Shale, and Tosi Chert Members of the Phosphoria Formation, and the Franson Tongue of the Park City Formation (Sheldon, 1963, pl. 8). Sections in the area are probably much like those measured and chemically analyzed in detail to the north (McKelvey and others, 1953, p. 24–32). Section descriptions with accompanying analyses are also available for nearby localities west (McKelvey and others, 1953, p. 33–35), north (Sheldon and others, 1953, p. 41–45), and east (Sheldon, 1963, p. 254–258, pls. 6, 7) of the area.

The lower part of the formation consists of nonresistant dark phosphatic and partly vanadiferous siltstone, gray dolomite, dark cherty siltstone, and phosphorite. The upper part consists of resistant ledges of massive gray granular to fine-grained cherty dolomitic limestone and white to dark-gray chert, with some dark-gray siltstone, thin-bedded black chert and limestone, and a few beds of phosphate rock near the top. The Phosphoria is about 400 ft thick west of, and 325 ft east of, the trace of the Absaroka fault.

TRIASSIC SYSTEM
DINWOODY FORMATION

The Phosphoria is overlain by distinctive thinly interbedded dull greenish-gray to gray calcareous siltstone, calcareous silty claystone, and argillaceous silty to sandy limestone, all of which weather tan to buff gray and are assigned to the Lower Triassic Dinwoody Formation. The Dinwoody thickens both northward along strike and westward. Thicknesses range from 120 ft in the southeast to 525 ft in the northwest. Thicknesses increase northward to 750 ft in the Bedford quadrangle (Rubey, 1958) and westward to more than 2,400 ft in Idaho (Kummel, 1954, p. 169).

WOODSIDE RED BEDS

The nonresistant Woodside Red Beds are composed of red siltstone and claystone and some thin beds of red sandstone and gray limestone. It is one of the few units that thickens markedly eastward, ranging from 425 ft west of the Crawford fault to 650 ft east of the Absaroka fault.

THAYNES LIMESTONE

Among the most striking exposures in the mapped area are the cliffs and ledges (illustrated by Veatch, 1907, pl. 5A) of vertical to slightly overturned Thaynes Limestone along Rock Creek north of the abandoned Nugget railroad siding. The Thaynes is a resistant formation bounded by red beds of the Woodside below and of the Ankareh above, both of which thicken eastward at the expense of the Thaynes with which they intertongue (Kummel, 1954, fig. 18, pl. 34). The lower third to half of the formation consists mainly of greenish-gray calcareous siltstone with some greenish silty claystone and gray silty limestone; the rocks weather dark brown with numerous manganese oxide stains which make talus of the lower Thaynes superficially resemble that of the Nugget, with which it has been confused in such places as at Nugget. The upper part of the Thaynes contains more limestone, though much of it is also silty and sandy, and some beds of calcareous siltstone and mudstone; these rocks weather mainly pale yellowish gray. The formation thickens westward and northward in the area, from 700 ft in the southeast to 1,000 ft in the northeast and from 1,100 ft in the southwest to 1,300 ft in the northwest. Fossils from the Thaynes are assigned to the Early Triassic (Kummel, 1954, p. 182–188), but the age of the topmost part of the formation is uncertain (Oriel, in McKee and others, 1959, p. 21; Picard and others, 1969, p. 2274–2275).

ANKAREH RED BEDS

The Ankareh Red Beds are more resistant than the Woodside Red Beds for they include a greater proportion of sandstone. The formation consists dominantly of well-laminated brightly colored red, maroon and purple-tinted sandy calcareous mudstone and red to tan with some purple-tinted fine-grained quartzite and partly calcareous sandstone and siltstone. Present in some places in about the middle of the formation is greenish-gray very finely crystalline limestone, as much as 8 ft thick, believed to be equivalent to the Deadman Limestone of southeastern Idaho. A distinctive purple quartzite unit, about 375 ft below the top of the formation, is useful in mapping complex structures. The Ankareh is 800–850 ft thick west of the Crawford fault and 950–1,000 ft thick east of it, and 725–750 ft thick west of the Absaroka fault and 450–700 ft thick east of it, thinning markedly northward. The formation is assigned to the Upper Triassic in western Wyoming, even though it lacks diagnostic fossils and its precise age and regional relations (High and Picard, 1969, p. 1091, fig. 2) are not established.

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

The resistant Nugget Sandstone, named for unspecified exposures near Nugget Station (Veatch, 1907, p. 56), consists almost entirely of buff to pinkish-tan, regularly bedded, partly crossbedded, and massive, fine- to medium-grained well-sorted quartzite and slightly calcareous sandstone. The lower part of the unit includes some light-gray quartzite and a few thin beds of red

mudstone. The formation thickens southward from 1,200 to 1,500 ft along the western part of the area but thins eastward to 700 ft. Because its age has not been ascertained (McKee and others, 1959, p. 22–23; Pipiringos, 1968, p. D17–D18), the formation is now assigned by the U.S. Geological Survey to the Triassic(?) and Jurassic(?) Systems.

JURASSIC SYSTEM
TWIN CREEK LIMESTONE

The distinctive *Pentacrinus*-bearing limestone (Peale, 1879, p. 623) exposed along Twin Creek and visible along U.S. Highway 30N west of Nugget was named by Veatch (1907, p. 56). Of the seven members into which the Twin Creek Limestone has been divided (Imlay, 1967, p. 17–50), only the basal unit, the Gypsum Spring Member, has been distinguished on the accompanying map. This member includes limestone breccia, believed to be a solution breccia formed by the leaching of anhydrite, and it is mainly red but contains some yellow sandy mudstone and siltstone; the member forms strike valleys and it is locally as much as 100 ft thick. Most of the formation (the upper six members undivided), however, consists of thin-bedded partly sandy, mainly argillaceous dark-gray limestone and calcareous siltstone with some units of interbedded more massive, partly coarsely bioclastic and partly oolitic medium-gray limestone. The thin-bedded argillaceous limestone and siltstone weather light gray and yellowish gray. Although the formation thickens southward within the area from 825 to 900 ft east of the Absaroka fault, westward thickening is dominant regionally and is illustrated by a thickness of about 2,900 ft west of the Crawford fault. Abundant fossils establish a Middle and Late Jurassic age for the formation.

PREUSS RED BEDS AND STUMP SANDSTONE

The Twin Creek Limestone is overlain successively, along the west flank of Rock Creek Ridge, by the Preuss Red Beds and the Stump Sandstone.

The Preuss Red Beds consist dominantly of thinly bedded dull-reddish to purplish-gray very fine grained sandstone, sandy siltstone, and silty claystone with some thin layers of greenish-gray claystone and reddish-gray argillaceous limestone. Although the formation contains salt along the Idaho-Wyoming boundary (Breger, 1910; Imlay, 1952, p. 1746), none has been reported from boreholes near the quadrangle.

The Stump Sandstone consists of 100–175 ft of alternating gray to greenish-gray fine-grained sandstone, limestone, siltstone, and claystone, with the proportions of each ranging markedly from place to place. The unit is so thin in these quadrangles that it has been mapped with the underlying Preuss.

Both formations are Upper Jurassic and together thicken westward from 600 ft on the east to about 1,700 ft west of the Crawford fault.

CRETACEOUS SYSTEM
GANNETT GROUP

Rocks in the Gannett Group were formerly (Veatch, 1907, p. 57) assigned to the Beckwith Formation for exposures on the west side of Rock Creek Ridge and were named for the Beckwith (BQ) Ranch about 3½ mi south-southwest of Beckwith Siding. The Gannett Group is also exposed in the hills east and southeast of Pixley and along the north and west flanks of Sillem Ridge.

The red Ephraim Conglomerate, at the base of the Gannett, contains brick-red to dull-maroon mudstone, sandy siltstone, and partly muddy claystone, light-gray, red, and brown crossbedded coarse-grained to gritty calcareous to quartzitic sandstone, red to brown conglomerate lentils, and light-gray to tan nodular limestone in a few places. Most pebbles in the conglomerate are gray to black chert.

The upper part of the Gannett Group consists of alternating limestone, mudstone, siltstone, and claystone which are subdivided in other parts of the region where they are thicker (Mansfield, 1927, p. 101–104; Eyer, 1969; Furer, 1970) into the Peterson Limestone, the Bechler Conglomerate, the Draney Limestone, and the recently named (Eyer, 1969, p. 1383) Smoot Formation. The Gannett is too thin to be subdivided in accompanying structure sections, although the group has been subdivided into two units on the accompanying map.

The group thickens northward, to 775 ft from 625 ft east of the Absaroka fault. It also thickens westward, attaining about 2,100 ft west of the Crawford fault. The Gannett is earliest Cretaceous in age but may include Jurassic beds at its base (Stokes, 1944, p. 969; Cobban and Reeside, 1952a, p. 1030, cols. 62–66, pl. 1; Eyer, 1969, p. 1369; Furer, 1970, p. 2286).

INTERTONGUING LOWER CRETACEOUS UNITS

Sedimentary rock sequences above the Gannett Group in the eastern part of the area differ markedly in composition and thickness from those in the west, as they do farther north in the Cokeville and Afton quadrangles. These differences are so marked that the same rock-stratigraphic designations cannot be applied to both. East of and beneath the Absaroka fault, strata assigned to the Bear River and Aspen Formations resemble those included in the units to the south and north. Parts of the western sequence resemble lithologies of the Bear River and Aspen Formations, accounting for previous use of these names west of the Absaroka fault. However, new stratigraphic assignments made during mapping of the western sequence are more expressive of significant facies relations that merit formal recognition (Rubey,

1973b). Informal brief descriptions of the new units had been published previously (as in Moritz, 1953, p. 69). In the paragraphs that follow, the rock sequence on the east is described before the new formations on the west.

BEAR RIVER FORMATION

The Bear River Formation consists of interbedded dark claystone, fine-grained sandstone, and very fossiliferous limestone. Most of the claystone is dark gray to black, fissile, and noncalcareous with thin layers of ironstone, but some is dark and porcelanitic, some light gray and bentonitic, and some brownish gray and sandy. The sandstone is well indurated, fine grained, calcareous to quartzitic, and tan and greenish gray to greenish brown. The limestone is medium to very dark gray and locally is a gastropod coquina. The formation is about 1,400 ft thick and of Early Cretaceous age; Yen (1952b, p. 761; 1954b), however, considered it to be of Late Cretaceous age.

ASPEN SHALE

Directly above the Bear River Formation, east of the Absaroka fault, is a heterogeneous unit designated the Aspen Shale. The Aspen contains light to very light gray siltstone and claystone, some of which resembles the claystone in the Bear River Formation, and gray quartzitic and virtually noncalcareous sandstone with quartz and chert grains somewhat resembling the sandstone in the overlying Frontier Formation. The formation, however, is characterized by numerous beds of very hard white to light-gray and some pink porcelanite; those in the lower part of the formation form bare silver-gray ridges and hogbacks. The porcelanite is silicified volcanic ash of approximately quartz latite composition. The upper contact is placed at the top of the highest prominent ridge-forming porcelanite bed. This horizon, a mappable contact, is higher than that selected by Cobban and Reeside (1952b, p. 1933) but follows more closely the usage of Veatch (1907, pl. 3) at the type locality near Aspen in T. 14 N., R. 118 W., and of Brown (1933) at an exposure 6 mi north of the Kemmerer quadrangle. The Aspen Shale thickens northward within the Kemmerer quadrangle from about 825 to 1,225 ft. Fossils within the formation (Reeside and Weymouth, 1931) are of latest Early Cretaceous age (Cobban and Reeside, 1951).

SMITHS FORMATION

In the northwestern part of the area, in the hills south of the mouth of Horse Creek and at scattered nearby exposures, the Gannett Group is directly overlain by the Smiths Formation (Rubey, 1973b). The lower part of the unit consists mainly of ferruginous black shale and the upper part, of tan very fine grained quartzitic sandstone; however, both rock types are interbedded and present throughout the formation. The formation is particularly

well exposed and is about 700 ft thick farther north, close to the Smiths Fork Guard Station of the U.S. Forest Service, in the NW¼ NE¼ sec. 27 of the unsurveyed T. 29 N., R. 118 W., in the Cokeville 30-minute quadrangle. The formation is thinner, only 300-400 ft, in the Sage and Kemmerer quadrangles. Whether the unit is present in the syncline beneath Tertiary strata east of Tunp Range has not been established by drilling, although it is exposed along strike farther north in the Cokeville quadrangle. Fossils collected from the formation and examined by J. B. Reeside, Jr., establish its Early Cretaceous age.

THOMAS FORK FORMATION

Also exposed in the hills south of the mouth of Horse Creek is the Thomas Fork Formation (Rubey, 1973b). The unit consists of banded and variegated red, purple, brown, and green mudstone and gray, tan, and buff sandstone which is conglomeratic in part with pebbles as much as 4 in. (inches) in diameter. The formation is characterized by pastel shades of the colors mentioned and abundant gray to brown limestone nodules to as much as several inches in diameter. The Thomas Fork is about 1,080 ft thick at the type section in sec. 25, T. 28 N., R. 119 W., in the Cokeville quadrangle (Rubey, 1973b, p. I10), but it is overlain by the Cokeville Formation, described below, which includes a 72-ft-thick tongue of the Thomas Fork 573 ft above its base. Although the Thomas Fork is about 2,000 ft thick farther north on the southwest side of Star Valley, it thins southward to 350 ft in the Sage quadrangle. Its Early Cretaceous age is established by fossils in underlying and overlying units.

COKEVILLE FORMATION

Above the red beds of the Thomas Fork Formation, and particularly well exposed in the hills in the NW¼ sec. 21, T. 23 N., R. 119 W., is the mainly gray and tan Cokeville Formation (Rubey, 1973b). The formation consists of light-gray to tan weathering medium-gray, fossiliferous sandstone and sandy siltstone, light- to dark-gray claystone and mudstone, calcareous concretions and abundantly fossiliferous tan limestone, and some beds of light-gray, tan, and pink porcelanite and bentonite. Present in the upper part of the formation are a few beds of coal which were mined half a mile west of Sage. The formation is about 1,364 ft thick at the type section in sec. 36, T. 25 N., R. 119 W., in the Cokeville area, but precise thicknesses are difficult to determine because the formation intertongues with and grades into both underlying and overlying units which thicken northward at the expense of the Cokeville. In the Sage quadrangle the formation is 1,900 ft thick west of the Stoffer Ridge fault but is 2,500 ft thick east of it. Fossils from the formation are similar to those in the Bear River Formation east and south of the quadrangles and are

assigned an Early Cretaceous age (Cobban and Reeside, 1951; but see also Yen, 1954a, p. 49-50).

SAGE JUNCTION FORMATION

The Cokeville Formation is directly overlain in the Sage quadrangle by the Sage Junction Formation, although the Quealy Formation separates the two farther north (Rubey, 1973b). The Sage Junction consists of light-gray and locally tan calcareous sandy siltstone and fine to very fine but partly medium grained, locally fossiliferous sandstone and quartzite; light-gray, tan, and grayish-red shaly mudstone and claystone; some thin beds of grit and conglomerate in the upper part; numerous thin beds of white, gray, green, and pink porcelanite throughout the formation; and a few beds of brown to gray fossiliferous limestone. A few beds of coal are present in the lower part; they have been mined at several localities along Boulder Ridge from near Sage northward to Antelope Creek. Early interest in these coal seams and in seams within the Cokeville Formation east of the town of Cokeville led to the naming of the town (Veatch, 1907, p. 113).

The type section (Rubey, 1973b) is along the south end of Boulder Ridge, in sec. 7, T. 21 N., R. 119 W., within the Sage quadrangle. Preserved unconformably beneath Tertiary strata is 2,270 ft of the formation. The Sage Junction is overlain with angular unconformity by Tertiary or Quaternary strata everywhere else that it has been examined. Total thicknesses deposited, therefore, are not known. Four miles north-northeast of the type section, along the unnamed northwest-flowing stream in sec. 20, T. 22 N., R. 119 W., about 3,375 ft is preserved, including about 1,100 ft of beds stratigraphically higher than those at the type section. Fossils indicate most of the Sage Junction Formation is Early Cretaceous in age and correlative with part of the Aspen Shale, as suggested by abundant porcelanite beds and invertebrate fossils in both the formations (Yen, 1951, 1952a).

The uppermost several hundred feet of the formation may possibly be equivalent in age to parts of the Frontier Formation which overlies the Aspen Shale farther east. At places where the greatest thicknesses of the Sage Junction are exposed, in the Sage quadrangle, the western part of the Cokeville quadrangle, and near the head of Tincup Creek in the Caribou Range of eastern Idaho, the porcelanite beds characteristic of most of the formation do not extend higher than about 2,600 ft above the base. Furthermore, layers of grit and conglomerate are more numerous in these upper beds than in the beds below, and dicotyledonous leaves were noticed at several localities, features common in the Frontier.

FRONTIER FORMATION

The town of Frontier, for which the Frontier Forma-tion was named, lies in the southeastern part of the Kemmerer quadrangle at the foot of Oyster Ridge, along which the formation is well exposed. The Frontier consists of a thick sequence of sandstone, siltstone, shaly claystone, and coal beds, some of which have been mined on a large scale in the past (Hunter, 1950; Townsend, 1960) and which continue to furnish fuel on a small scale to local residents.

The Frontier is divided into three informal map units. The lower unit consists of white and brown sandstone beds that are thinner and less resistant than those in the overlying unit; tan siltstone and dark-gray claystone; a few thin lignitic beds; and a few thin beds of gray, pink, and white porcelanite. The unit thickens northward within the area from 900 to 1,100 ft.

The middle unit is characterized by prominent hogbacks of thick-bedded sandstone. The lower half includes tan sandstone, dark shaly claystone, and the Willow Creek (No. 5) coal bed. The upper half is white to light-gray resistant sandstone which was assigned by Veatch (1907, p. 65) to the Oyster Ridge Sandstone Member, after the topographic feature that had been named by Hayden (1871, p. 149). The middle unit thins northward from 700 to 625 ft.

The upper unit consists of tan sandstone that forms small hogbacks along the west side of Oyster Ridge, lignitic claystone, and the Kemmerer (No. 1) coal bed. The upper unit, rather than the underlying beds formerly assigned to the Oyster Ridge Sandstone Member, is characterized by abundant large fossil oyster shells (*Crassostrea soleniscus*). The unit thickens northward from 450 to 750 ft.

The formation is early Late Cretaceous in age (Cobban and Reeside, 1952b, p. 1958).

HILLIARD SHALE

The Frontier is overlain by a very thick sequence of dark-gray, gray, and tan fissile marine claystone, light- to medium-gray, partly argillaceous and partly lignitic, sandy siltstone, white to dark-gray, thinly bedded, very fine grained to gritty sandstone, and white to gray bentonite. Fossil marine mollusks abound, and a few ammonites occur in some parts of the formation.

The weak, poorly exposed thin-bedded claystone and siltstone making up the bulk of the Hilliard is divided into two parts by a prominent ledge-forming tongue of mainly sandstone that thins southward. This sandstone unit was named the Shurtliff Member of the Hilliard Shale by Smith (1965, p. 14). The member is well exposed along Hams Fork where it consists of ledges of sandstone in the lower part, dark-gray shaly claystone and siltstone in the middle, and ledges of sandstone in the upper part. As the member is traced northward along

strike, the middle shale intertongues with sandstone and large fossil oyster shells increase in abundance. Shale beds above and below the member along Hams Fork also intertongue northward with sandstone beds so that increasingly greater proportions of the Hilliard are assigned to the Shurtliff Member northward. Uppermost beds of the Hilliard also intertongue northward with sandstone beds assigned to the Adaville Formation. These relations were recognized previously (Andrews, 1944; Cobban and Reeside, 1952b, p. 1934) by designation in the Bedford quadrangle (Rubey, 1958) of the "Adaville-Frontier formation," a sequence of sandstone, siltstone, claystone, and coal with no intervening Hilliard Shale recognized. This sequence is now assigned (Rubey, 1973b) to the Blind Bull Formation. Northward decrease in the abundance of claystone is accompanied by increase in the number of grit and conglomerate beds and in size of clasts composed mainly of medium- to dark-gray chert. Grit beds are present as far south as the southeastern part of the Kemmerer quadrangle.

The lower part of the Hilliard Shale beneath the Shurtliff is about 2,600 ft thick; the Shurtliff Member thickens northward from about 150 to 975 ft; and the upper part of the formation thins northward from 3,850 to about 3,000 ft. The formation is early Late Cretaceous in age.

ADAVILLE FORMATION

The Adaville Formation consists of interbedded yellow- to brown-weathering gray sandstone, siltstone, carbonaceous clay, and coal, most of which seems to be the product of cyclic deposition. The sandstone is calcareous and ranges from thin bedded to massive and from fine to coarse grained and partly conglomeratic in the upper part of the formation.

The basal part of the formation in the southeastern part of the area consists of a prominent ledge- and cliff-forming unit of light-gray to white partly gritty sandstone designated (Veatch, 1907, p. 73) the Lazeart Sandstone Member. The member is well displayed in discontinuous exposures in a band extending from sec. 4, T. 21 N., R. 116 W., to about 5 mi south of the quadrangle. It is about 400 feet thick on the south edge of the area, pinches out northward about 3 mi south of Hams Fork, and is directly overlain by the thickest and most economic coal beds present in the formation.

The Adaville is about 2,900 ft thick.

The age of the Adaville is significant because it helps date movement on the Absaroka fault. The formation is Late Cretaceous, ranging from late Colorado at its base (Cobban and Reeside, 1952a, p. 1030) into probably the middle Montana or possibly late Montana or early Lance at its top, although the precise age of the top of the formation remains in doubt.

Leaves collected from 50 and 100 ft below the top of the formation about 1 mi west of the Elkol strip mine have been identified as *"Myrica" torreyi* Lesquereux, *"Dryophyllum" subfalcatum* Lesquereux, *"Vitis" stantoni* (Knowlton) Brown, and *Grewiopsis saportana* Lesquereux, and have been assigned a Lance or latest Cretaceous age by J. A. Wolfe (written commun., Dec. 22, 1959). This determination agrees with the conclusion of Dorf (1955, p. 99), based on the study of plant remains, that at least part of the Adaville is of Lance age; some of his collections, however, may have been from the basal part of the overlying Evanston Formation.

Samples collected from the very top of the Adaville 2.3 mi west-northwest of Moyer were found to yield the following pollen and spores (Estella Leopold, written commun., Mar. 19, 1965): abundant *Proteacidites thalmanii* and *Proteacidites* sp., *Cupanieidites, Plicapollis, Quercoidites henrici, Tricolpopollenites parmularius, Eucommiidites troedssonii, Classopollis torosus, Araucariacites, Hymenzonotriletes reticulatus, Cyathidites, Podocarpidites biformis, Phyllocladidites, Sporopollis laqueaeformis, Quedlinburgipollis, Tricolpopollenites* C3rt-8, *T. retiformis* C3rt-6, *Aquilapollenites calvus,* and *Salicoidites.* "The burst of *Proteacidites,* both in species and in numbers, in the upper Adaville is a feature that is of Montana age," stated Leopold. Leopold concluded from her study of several collections "that the upper Adaville Formation is of late Campanian (late but not latest Montana) age and that the base of the formation may be as old as late Colorado or early Montana."

The highest horizon in which invertebrates have been found in the Adaville is about 2,100 ft above the base and 800 ft below the top of the formation about 3 mi south of the quadrangle, in sec. 21, T. 20 N., R. 117 W. The fossils were identified by W. A. Cobban (written commun., Dec. 22, 1958) as *Crassostrea* cf. *C. glabra* (Meek and Hayden), *Anomia* cf. *A. micronema* Meek, *Brachidontes* sp., *Corbicula?* sp., *Corbula* aff. *C. perundata* Meek. "This brackish-water fauna is undescribed," according to Cobban. "The general aspect suggests an early or possibly a middle Montana age."

Arenaceous foraminifera from the Adaville Formation identified by Martin (1954) are also consistent with a Campanian or Maestrichtian (middle or late Montana) age, according to James Mello (oral commun., March 1965), and tend to support the age inferred from palynology.

CRETACEOUS SYSTEM AND PALEOCENE SERIES
EVANSTON FORMATION

Resting unconformably above the thrust plates both east and west of the Absaroka fault are rocks here assigned to the Evanston Formation although they were previously mapped as the Almy Formation (Veatch, 1907, pl. 3). The formation is also present on the south

end of Dempsey Ridge and in the low hills along the east fork of Collett Creek. The formation consists of dominantly gray conglomerate, sandstone, siltstone, mudstone, claystone, lignite, and ironstone in proportions that vary both laterally and vertically.

The lowest Evanston beds, exposed only on the northeast along the east fork of Trail Creek, are assigned to an unnamed lower member consisting of about 400 ft of dominantly dark-gray partly carbonaceous mudstone and siltstone with layers of carbonaceous sandstone. Above the lower member along Trail Creek but at the base of the formation along most of the east side of the Fossil basin is the recently defined (Oriel and Tracey, 1970, p. 6) Hams Fork Conglomerate Member, which may be as thick as 1,000 ft; well-rounded, subspherical pebbles, cobbles, and boulders, including clasts from such distinctive formations as the Worm Creek Quartzite Member of the St. Charles Limestone (Cambrian) and the Brigham Quartzite (Cambrian and Precambrian) of southeastern Idaho (Bear River Range), weather from a brown sandstone matrix which is winnowed to form pavements and boulder trains. The Hams Fork Member is overlain by mainly light- and medium-gray carbonaceous sandy to clayey and partly quartzitic siltstone with layers of sandstone, claystone, ironstone, lignite, and coal assigned to the main body of the Evanston Formation, which may be more than 1,000 ft thick locally. Members of the Evanston Formation were mapped separately only in the Kemmerer quadrangle.

The unnamed lower and Hams Fork Conglomerate Members are of latest Cretaceous (Lance) age (Rubey and others, 1961; Oriel and Tracey, 1970, p. 11-12); the main body may include beds of Cretaceous age but most fossils found are of middle Paleocene (Gazin, 1969, p. 1) and late Paleocene (Gazin, 1956; Oriel and Tracey, 1970, p. 13) age.

EOCENE SERIES

WASATCH FORMATION

The Wasatch Formation is a heterogeneous continental unit composed overwhelmingly of red detrital strata with a large range in grain size. The coarsest parts of the unit lie along the periphery of the Fossil depositional basin; the finest, near the middle. The middle and upper parts of the formation intertongue in the central part of the basin with units of the Green River Formation.

Subdivisions of the formation are described in moderate detail elsewhere (Oriel and Tracey, 1970, p. 17-27) and are summarized here. The basal conglomerate member, from a few to 200 ft thick on Dempsey Ridge and on the hills to the south, consists chiefly of tan to buff mainly sandstone pebbles, cobbles and boulders in a sandstone matrix, all derived chiefly from the Nugget Sandstone. The lower member, as much as 300 ft thick on Dempsey Ridge, includes dark-gray claystone, drab

and variegated mudstone, brown, buff, and red sandstone and conglomerate, and dark-brown limestone and pisolitic limestone. The main body, which includes most of the formation beneath the lowest Green River beds and is as much as 1,700 ft thick in the Fossil basin, consists mainly of variegated and banded red, maroon, gray, and yellow mudstone with layers and lenses of sandstone and well-sorted conglomerate. The sandstone tongue, 50 ft thick in the southern part of the area and pinching out northward within the Fossil Butte Member of the Green River Formation, consists of brown-weathering gray crossbedded fine- to coarse-grained sandstone with thin layers of green mudstone. The mudstone tongue, pinching out southward from a thickness of about 60 ft, separates the Fossil Butte Member from the Angelo Member of the Green River Formation and consists of red and green mudstone, brown-weathering gray sandstone, and thin beds of limestone. The Bullpen Member, as thick as 320 ft where most completely preserved above the Green River Formation, consists of red, gray, and green mudstone, tan, brown, and gray sandstone, and tan to brown limestone like that in the Green River Formation, several beds of which are mapped locally. The Tunp Member, at least several hundred feet thick though poorly exposed, consists of unoriented angular blocks (some are hundreds of feet long) and boulders in unsorted pebbly to sandy dark-red to maroon mudstone, termed diamictite (Tracey and others, 1961; Oriel and Tracey, 1970, p. 23), and conglomerate in a mappable band around the periphery of the Fossil basin; some tongues of diamictite extend into the very fine grained strata of the Green River Formation; others grade laterally into the mudstone tongue and the Bullpen Member of the Wasatch.

The Wasatch Formation is assigned an early Eocene age even though the basal conglomerate may be partly older and the Bullpen Member partly younger (Oriel and Tracey, 1970, p. 27-28).

GREEN RIVER FORMATION

The heterogeneous Green River Formation is composed mainly of very well laminated limestone, siltstone, marlstone, and claystone with layers of oil shale, deposited principally in a lacustrine environment. Deposition of the formation was uninterrupted in the middle of the Fossil basin but the unit intertongues with parts of the Wasatch Formation in all directions toward the periphery of the basin.

The lower part, the Fossil Butte Member (Oriel and Tracey, 1970, p. 30), overlaps the underlying main body of the Wasatch Formation in a few places along the periphery of the Fossil basin; it is overlain in most places by the mudstone tongue of the Wasatch. The Fossil Butte Member consists mainly of tan and brown-weathering buff laminated limestone and marlstone,

bluish-gray to bluish-white-weathering brown to black oil shale, and light-gray siltstone, mudstone, and claystone with some thin beds of brown-weathering tuffaceous ash. These rocks grade laterally into algal, ostracodal, and gastropodal limestones that were deposited in shallow water near the shore of the ancient Fossil Lake. In a few places Green River limestone cements angular pieces of older rock interpreted as talus of Eocene age. Fossils are moderately abundant in the member particularly in the upper part, and they include spectacularly preserved fish, leaves, and insects, as well as rare birds, reptiles, bats, and other forms. Exposures on Fossil Butte and on Fossil Ridge have supplied museums throughout the world with well-preserved fossils for about a century (Peale, 1879, p. 535). The Fossil Butte Member is 200–280 ft thick where best developed. Its age may be middle to late early Eocene.

The upper part of the Green River Formation is assigned to the Angelo Member (Oriel and Tracey, 1970, p. 31). The member is characterized by bluish-white- and white-weathering calcareous shaly claystone, siltstone, and siliceous limestone but includes tan laminated limestone, brown algal, ostracodal, and gastropodal limestone, a few poorly developed oil-shale beds, and a few thin beds of tuffaceous ash. Maximum thickness of the member in the area is about 200 ft. Its age has not been determined but may be late early or middle Eocene.

FOWKES FORMATION

Both the Wasatch and the Green River Formations are overlain by the light-gray tuffaceous Fowkes Formation which was erroneously considered a unit within the Wasatch by Veatch (1907, p. 90–92). Despite the incorrect stratigraphic assignment, the Fowkes is a valid mappable unit based on Veatch's accurate lithologic description. The formation consists mainly of very pale gray, green, and pink tuffaceous mudstone, sandstone, siltstone, conglomerate, and some claystone and limestone. The formation has been divided into three mappable members by Oriel and Tracey (1970, p. 34–35).

The basal Sillem Member is exposed on Sillem Ridge where it consists of light-gray and pale-pinkish-gray sparingly tuffaceous mudstone, fine-grained sandstone, siltstone, and conglomerate beds, particularly in the lower part. Pebbles and cobbles in the conglomerate are very well rounded and consist predominantly of light- to dark-gray and tan pebbles of quartzite and chert; Paleozoic limestone pebbles are not uncommon, as well as distinctive pebbles of dark-gray to black quartzitic conglomerate with pebbles and granules of dark-gray quartzite which may have been derived from the Brigham Quartzite now exposed to the west in Idaho. Conglomerate pebbles are particularly well displayed on the crest of Sillem Ridge where fines have been win-

nowed to form a gravel pavement. The member ranges in thickness from less than 100 ft to at least 400 ft. Its age, despite the absence of diagnostic fossils, is probably middle Eocene.

The Bulldog Hollow Member in the middle of the Fowkes is exposed in streamcuts along Bulldog Hollow south of Sage. It consists of light-gray and green to white tuff and moderately to dominantly tuffaceous and ashy rhyolitic sandstone, siltstone, mudstone, and claystone, with thin lenses of very light gray conglomerate composed of sandy limestone matrix or opaline cement. Biotite and magnetite are fairly to moderately abundant heavy minerals, particularly in the darker green fine- to medium-grained tuffaceous sandstone beds. The member is more than 200 ft thick near Sage but thickens greatly southward, possibly to several thousand feet. Fresh-water mollusks in the member are of middle or late Eocene age. The middle Eocene age assigned by R. L. Armstrong (Oriel and Tracey, 1970, p. 37) on the basis of potassium-argon analysis of hornblende from tuff in this member has recently been confirmed by vertebrates found farther south by Nelson (1972; 1973).

The highest unit tentatively included in the Fowkes Formation is the Gooseberry Member (Oriel and Tracey, 1970, p. 35) exposed near Gooseberry Spring about 4 mi northeast of Sage. The Gooseberry consists mainly of indurated puddingstone and conglomerate with well-rounded pebbles and cobbles of Paleozoic quartzite, chert, and limestone and volcanic rocks of unknown derivation ranging in composition from rhyolite to vesicular basalt. The pebbles are cemented by white sandy to silty tuffaceous limestone. Packing of rounded coarse clasts is poor (puddingstone) to good (conglomerate). Granules or pebbles are concentrated in lenses and are sparsely scattered in other places. Most clasts are 6 in. or less in diameter, but a few are as much as 1 ft. No stratigraphic top is known for the Gooseberry, but the unit is as much as 200 ft thick. Fossils have not been found in the member within the area; its similarity to conglomerate lenses in the underlying Bulldog Hollow Member suggests it may be of Eocene age. However, rocks apparently identical in composition 20 mi to the northwest on the Bear Lake Plateau yielded fossil teeth of Miocene or Pliocene age. Thus, Gooseberry puddingstone may represent an isolated easternmost exposure of the Salt Lake Formation (Oriel and Tracey, 1970, p. 37).

UPPER CENOZOIC DEPOSITS

Poorly dated Pleistocene and Holocene deposits are broadly categorized as alluvium, slumps, landslides, and rockslides, hillwash and talus, gravel deposits, terrace deposits, and loess. High terrace gravels, several hundred feet above the present bed of Hams Fork, as at the airport 1 mile northwest of Kemmerer, may be as old as early Pleistocene or possibly late Pliocene. Elevations of

350 ft and more above present drainage suggest an age well back in the pre-Wisconsin Rocky Mountain pediment and terrace sequence (Richmond, 1948; Scott, 1965); the elevations above drainage are close to those of surfaces interpreted by Hansen (1969, p. 97–99) to predate diversion of the ancestral Green River to its present course. One terrace gravel remnant in the southern part of sec. 19, T. 22 N., R. 115 W., slopes away from a modern main stream, suggesting tilting by downdropping along the fault 1 mi east-southeast.

In the western part of the area, as on Boulder and Sillem Ridges, we map a smaller total area as Quaternary gravel deposits than Veatch (1907, pl. 3), because we believe that many of the cobble and boulder deposits there are lag pavements formed by both wind and water winnowing from Tertiary conglomerates.

Slumps are far more extensive in the central and north-central parts of the area than shown on the map. Their extents have been minimized to avoid concealing Tertiary rock relations. Clays in the main body of the Wasatch are impermeable, whereas partly jointed limestone in the overlying Green River Formation is relatively permeable. As a result, the contact between the two formations is marked by springs and bands of vegetation (Oriel and Tracey, 1970, frontispiece). In many places water seeping from the contact wets and lubricates the montmorillonitic muds in the Wasatch slopes below, resulting in hummocky landslide topography, ponding, and local downsliding of large blocks of the more competent Green River Formation.

STRUCTURE

The structure of the area is interpreted in the seven equally spaced structure sections (pl. 2). The degree of complexity partly reflects the availability of data; comparatively simple parts of the sections may require modification when more boreholes are drilled.

Dominant structural features, from west to east, are the Crawford thrust fault, the Stoffer Ridge reverse fault, the Tunp thrust fault, the Absaroka thrust fault (see frontispiece) and associated thrust slices concealed beneath flat-lying Tertiary strata of the Hams Fork Plateau, and the Lazeart syncline. Most of these features were recognized by Veatch (1907, pls. 3, 4).

CRAWFORD FAULT

Although concealed by Quaternary deposits (not shown on cross sections) in the map area, the Crawford thrust fault is exposed to the north in the Cokeville quadrangle and to the southwest in the Randolph quadrangle (Richardson, 1941, pl. 1). Its buried trace lies between exposures of the Wells Formation around Big Knob in Bear River valley and Cretaceous units along Boulder Ridge. The half-mile-long block of lower Paleozoic rocks that form Eli Hill may represent an

eastern prong or klippe of the Crawford thrust sheet, or the block may, instead, have slumped to its present position after thrusting but before downdrop of the Bear River valley, possibly in early Eocene time. Stratigraphic throw along the Crawford fault ranges from 18,000 to 22,000 ft, decreasing northward. The fault probably dips west 30° to 70°, averaging 40°, and probably flattens at depth. Lateral displacement along the fault was a minimum of 5 mi and may have been considerably more; northward decrease of stratigraphic throw suggests that the displacement decreased in that direction.

STOFFER RIDGE FAULT

A steeply dipping reverse fault in the northwestern part of the Sage quadrangle places rocks ranging from the Preuss Red Beds to the Cokeville Formation in contact with the Sage Junction Formation. The fault is well exposed west of Stoffer Ridge. Stratigraphic throw is about 9,000 ft on the north but diminishes southward. The fault continues northward for at least 8 mi in the Cokeville quadrangle.

TUNP FAULT

The Tunp thrust fault, though not exposed within the area nor demanded by local data, is inferred to underlie Tertiary strata on the basis of regional observations and thrust relations mapped northward along strike in the Cokeville quadrangle. Nearly all the subparallel mountain ranges in the thrust belt are bounded on the east by major westerly dipping thrust faults and on the west by younger high-angle faults downthrown to the west. Unusually great deformation including thrust slices and overturning of the rocks along Dempsey Ridge, as well as the presence of the ridge, suggests a significant thrust fault. Moreover, contrasts in thicknesses and facies between upper Paleozoic and Mesozoic units exposed from Tunp Range west and those exposed and drilled to the east are also best explained by telescoping along a thrust fault. Thrust relations are exposed in the Cokeville quadrangle along the West Branch of Hams Fork and east and northeast of Big Park. For these reasons, a thrust fault is probably present on the east side of Dempsey Ridge; such a fault seems to be supported by unpublished company geophysical data.

The inferred Tunp fault probably parallels overlying strata which dip gently to the west. Stratigraphic throw may be 6,000 ft or more, but information is inadequate to demonstrate the throw or the order of magnitude of lateral displacement, for which a minimum of 1–2 mi seems reasonable.

THRUST SLICES

Several thrust faults beneath Tertiary strata making up the Hams Fork Plateau are documented by drilling and by exposures to the northeast in the Cokeville quad-

rangle. These faults are interpreted as upward slices or branches from the Absaroka sole fault at depth.

The concealed Commissary and Beaver Creek thrust faults shown in the structure sections are named for topographic features in the Cokeville quadrangle. The eastern or Commissary fault is exposed along the east side of Commissary Ridge from Clear Creek in T. 29 N., R. 116 W., to the South Fork of Fontenelle Creek, in T. 26 N., R. 116 W., where Pennsylvanian and Permian strata overlie Jurassic and Triassic strata, and as far south as the NE¼ sec. 6, T. 24 N., R. 116 W., where Triassic red beds overlie the Lower Cretaceous Gannett Group. Interpretation of the Commissary fault as a slice of the Absaroka is supported by the merging of the traces of the Commissary and Absaroka faults in the northern part of the Cokeville quadrangle.

The Beaver Creek fault is exposed in the Cokeville quadrangle along the Middle Fork of Beaver Creek in the NE¼ sec. 8, and SE¼ sec. 5, T. 25 N., R. 116 W., where the Amsden Formation overlies Ankareh Red Beds. This fault was drilled through by the National Cooperative Refinery Assoc. on the Government-Larsen lease in CE½E½ sec. 33, T. 24 N., R. 117 W., just north of the Kemmerer quadrangle: Mississippian limestone directly overlies Jurassic Stump sandstone in this hole at a depth of 4,335 ft.

Unnamed fault slices west of the Beaver Creek fault were drilled by the Amerada Petroleum Corp. in the Chicken Creek unit No. 1 (Goering and Smith, 1960) on the north side of Fossil Butte in the SW¼ SW¼ sec. 30, T. 22 N., R. 117 W. Permian and Triassic strata are repeated by several faults, as shown in the structure sections.

An unnamed thrust fault is exposed on Commissary Ridge, where the Triassic Dinwoody, Woodside, and Thaynes Formations are repeated. The fault trace is subparallel to that of the Absaroka, and the fault parallels overlying strata.

Stratigraphic throws along these fault slices are as much as 10,000 ft, and lateral displacements must have been at least several miles. The minimum possible displacement along the Beaver Creek fault is 7 mi.

ABSAROKA FAULT

The Absaroka fault, one of the eastern Cordillera's great thrust faults, was first understood and named by Veatch (1907, p. 109), although the presence of a major fault had been noted by Peale (1879, pls. 51, 53, 55). The fault trace parallels the strikes of overlying strata and the dip of the fault is inferred to parallel overlying strata. The fault has been mapped for a linear distance of 205 mi in Wyoming and Idaho. Relatively steep fault dips, ranging from about 35° on the north to 70° on the south, probably decrease considerably westward with depth (Rubey and Hubbert, 1959, p. 187), as for other major

faults nearby (Oriel, 1969, p. M24). Stratigraphic throw ranges from 10,000 ft in the northeastern part of the area to about 15,000 ft to the south. Structure sections suggest that eastward movement along the fault was at least 3 mi within the Kemmerer quadrangle, although considerably more is required if the fault flattens at depth as inferred. Farther north, lateral displacement of from 10–15 mi (with an uncertainty factor of about two either way) is based on conservative interpretations of observed field evidence (Rubey, 1958; Rubey and Hubbert, 1959, p. 187). Marked contrasts in thicknesses and lithologies of involved strata require telescoping of contrasting facies by the fault.

LAZEART SYNCLINE

The asymmetric Lazeart syncline is easily defined in the field and on air photographs (fig. 2) by sharply folded Cretaceous sandstone and siltstone beds. The gently inclined eastern limb dips about 30°, in marked contrast to the western limb where beds are vertical and overturned as much as 35° past vertical, or to 55° westward dips. Exposures along the south end of Commissary Ridge and subsurface data indicate that the Absaroka fault truncates the west limb of the syncline. The axial trace of the syncline nearly parallels that of the Absaroka fault (Veatch, 1907, pls. 3, 4,; Schultz, 1914, pl. 1). An intervening anticline, between the syncline and the fault, has been mapped just north in the Cokeville quadrangle.

OTHER FOLDS

Other prominent broken folds, evident on map and (or) sections, include the striking tightly folded asymmetric south-plunging anticline southeast of Pixley just east of Bear River; the axial plane dips steeply west and the east limb is cut by the Stoffer Ridge fault. In the northwestern part of the area, two large asymmetric synclines with rocks as young as the Sage Junction Formation are partially overridden by the Crawford and Stoffer Ridge faults. The well-exposed anticline on the north end of Dempsey Ridge was named the Rock Creek anticline and was considered by Veatch (1907, pl. 4) to extend to considerable depth, but we regard it as a minor flexure just behind the leading edge of the inferred Tunp thrust fault. Structural features beneath Tertiary strata of the Hams Fork Plateau may be more complex than the broad open simple folds inferred from the sparse data available for sections A–A', B–B', and G–G'.

Geometric relations suggest that all the folds were formed during the deformation that produced the thrusts, although the precise sequence of development has not been established (Dahlstrom, 1970, p. 358).

HIGH-ANGLE FAULTS

Steeply dipping faults are common in the area, particularly on the west. Most are normal faults downdropped to the west, but a few are reverse faults bound-

FIGURE 2. — The Lazeart syncline on a high-altitude vertical air photograph of the northeastern part of the Kemmerer quadrangle. The area shown also includes part of the trace of the Absaroka thrust fault. Scale is approximately 1 : 80,000. Among the units present are the Wells Formation (PIPw), the Phosphoria Formation (Pp), the Dinwoody Formation (TR d), the Woodside Red Beds (TR w), the Thaynes Limestone (TR t), the Frontier Formation (Kf), the Hilliard Shale (Kh) with its included Shurtliff Sandstone Member (Khs), the Adaville Formation (Kav), the Hams Fork Conglomerate Member of the Evanston Formation (Keh), and the Tunp Member of the Wasatch Formation (Twt). Compare with plate 1. (Photograph, taken in 1953, is AMS Strip 48, Frame 406.)

ing horsts and grabens. Stratigraphic throw ranges from a few hundred to several thousand feet. Many of the faults cut young Tertiary strata. And many faults lie in north- to northeast-trending sets that apparently con-tinue southward and help explain some of the anomalous structural relations mapped by Veatch (1907, pl. 3) along the western flank of the Fossil basin, particularly the curious wedge-shaped junction (in plan) of his

Acocks and Medicine Butte faults. A north- to northeast-trending fault set has also been observed west of the quadrangle along Boundary Ridge west of Bear River valley. The fault sets and faceted spurs along the west front of the Crawford Mountains to the southwest and of the Sublette Range to the north suggest that much of Bear River and Thomas Fork valleys may occupy a graben.

The normal fault east of Rock Creek is especially conspicuous. Stratigraphic throw of upper Paleozoic, Mesozoic, and Eocene strata ranges from 1,000 to 1,500 ft. But the fault also offsets alluvial fans and gravel deposits as much as 50 ft, indicating very recent minor movement. Efforts to date this movement have not succeeded; trees more than 60 years old have grown both on the fault scarp and on rock slides which were probably triggered by the movement.

Northward-trending reverse faults on the west flank of Rock Creek Ridge and on the east side of Bear River valley bear on the composition of some of the Wasatch Formation. Topographically high exposures of the formation, particularly the Tunp Member, consist of diamictite that contains blocks and cobbles from formations now exposed 1,000–1,600 ft lower to the west. Paleozoic formations west of Boulder Ridge and Ephraim Conglomerate west of Rock Creek Ridge clearly must formerly have been higher than the Eocene Wasatch sediments derived from them.

Reverse faults in the Nugget Sandstone south of Twin Creek, in the south-central part of the area, are required because measured dips make the apparent thickness of the Nugget excessive; but because the faults are bounded by similar rocks, the displacements cannot be demonstrated. The fault traces have been placed along zones of brecciated rock recognized in the field and along lineations recognized on air photographs.

The Fowkes Formation is restricted areally to a narrow south-trending belt that extends beyond Evanston (Veatch, 1907, pl. 3). Faults along this belt cut not only the Wasatch and Green River Formations but also the Fowkes. Moreover, the Fowkes does not contain detritus that would have been derived from adjoining formations had it formed in a fault trough. Thus, the linear belt probably reflects down-faulting and local preservation of a widespread sheet deposit rather than a depositional trough.

Data are insufficient to determine the dips of the high-angle faults or whether the dips diminish with depth, as they do for listric faults (Bally and others, 1966, p. 355; Dahlstrom, 1970, p. 379). Nor can it be established whether the faults cut only sedimentary strata or the underlying basement as well. Movement occurred on some faults well after the thrusting because they cut rocks as young as middle Eocene; these faults probably reflect Cenozoic regional extension accompanying formation of

basins and ranges farther west. However, a few faults moved before deposition of overlying Wasatch strata.

AGES OF DEFORMATION

Movement along the Crawford fault cannot be dated closely; the fault cuts the Sage Junction Formation of late Early Cretaceous age and is unconformably overlain to the southwest (Richardson, 1941, pl. 1) by the Wasatch Formation, which incorporates debris from the Crawford sheet. Movement, therefore, occurred between the late Early Cretaceous and early Eocene. If very coarse conglomerate beds dated as early Late Cretaceous (Niobrara) at Echo Canyon (Williams and Madsen, 1959, p. 125) and elsewhere are the synorogenic products of this deformation, then much of the movement may have been early in Late Cretaceous time.

If the inferred Tunp thrust fault is correctly depicted on the structure sections, then major movement along this fault must have occurred in post-Sage Junction and pre-Evanston time, probably during the Late Cretaceous. Data are inadequate either to prove this or to suggest a more precise date.

Major movement along the Absaroka fault a few miles northwest of Kemmerer was very late in Cretaceous time (Campanian or Maestrichtian), although there was probably a late minor movement in the Paleocene (Oriel and Armstrong, 1966, p. 2616–2617; Oriel and Tracey 1970, p. 14).

The Commissary and Beaver Creek faults cut Lower Cretaceous rocks and the faults are presumably overlain by the Evanston Formation, but whether the fault traces are directly overlain by or cut the Hams Fork Conglomerate Member has not been ascertained. These faults could have moved before, after, or during the Absaroka fault movement.

The data are consistent with the conclusion that major thrust faults in the region are successively younger eastward (Rubey and Hubbert, 1959, p. 190; Armstrong and Oriel, 1965, p. 1855–1860), although the sequence of minor thrust slice movements may be reversed (Douglas, 1950, p. 93–95).

The western side of the ridge formed by the Absaroka thrust plate is not marked by large normal faults common elsewhere in the thrust belt. Instead, gentle regional sagging produced the Fossil basin early during deposition of the Evanston Formation. Upwardly decreasing dips in Evanston strata suggest that the basin was taking shape in latest Cretaceous time (Oriel and Tracey, 1970, p. 14) and that it continued to receive sediments through Paleocene and into Eocene time, when the Green River lacustrine sediments were formed.

ECONOMIC GEOLOGY
COAL

The towns of Kemmerer, Frontier, and Diamondville were founded late in the 19th century at least partly to

mine abundant coal in the upper part of the Frontier Formation and in the lower part of the Adaville Formation. Coal continues to be a major resource despite the shutdown of underground operations at the Brilliant No. 5 mine in the Frontier Formation south of the area. The strip mines at Elkol, operated by the Kemmerer Coal Co., produce more coal annually than was produced earlier at all the nearby mines together.

About 1 million tons of coal is stripped annually at the Elkol pits from thick beds in the Adaville Formation by draglines and bulldozers (Consalus, 1967). The coal is moved to a long conveyor belt that leads directly into the automated Utah Power Co. steam generating plant. Electric transmission lines from the plant supply power to parts of northern Utah and southeastern Idaho.

More than a dozen beds have been explored by the Kemmerer Coal Co., and several are now being mined. The thickest, directly above the basal Lazeart Sandstone Member, is locally more than 85 ft thick but splits and thins laterally by intertonguing with sandstone and mudstone. The coal is mainly subbituminous although some seams are bituminous (Townsend, 1960, p. 254), and the coal is high in moisture, low in ash and sulphur, and waxy in luster (Hunter, 1950, p. 132). Dips average about 18° west, limiting the volume that may be stripped before overburden becomes excessive; local relief is also a factor, for a ridge rises several hundred feet westward from the base of the west-dipping Adaville Formation.

Coal from the Adaville Formation is also being mined on a smaller scale to produce metallurgical coke from subbituminous coal in a joint venture undertaken by FMC, Inc., and U.S. Steel Corp. (Townsend, 1960, p. 251). The coke plant is in sec. 12, T. 20 N., R. 117 W.

Formations other than the Frontier and Adaville have been prospected for coal. Cokeville Formation coal was discovered near Sage in 1875 and was mined in limited quantity by 1877 (Peale, 1879, p. 575) with the belief it might prove of coking quality. Subbitminuous coal occurs in several thin beds in the upper part of the Cokeville Formation. A few thin coal beds are also present in the lower part of the overlying Sage Junction Formation. The coal is not known to have been mined since 1900, and Veatch's (1907, p. 114) evaluation of the deposits seems as valid now as when it was written.

The Evanston Formation has also been prospected for coal about 1 mile northeast of Nugget station and also on Collett Creek. The coal beds in this unit are too thin, too poor in quality, and too limited areally to be economic, although they were formerly mined near Evanston.

OIL AND GAS

Oil and gas were produced in small quantities at about the turn of the century from springs and shallow wells in the upper part of the Evanston Formation just east of the South Fork of Twin Creek (Veatch, 1907, p. 140, 144-145). Despite the drilling of several deep tests during the past decade, no oil or gas is now produced in the area. The closest significant production is near La Barge, about 25 mi north-northeast of Kemmerer.

The boreholes drilled thus far have not, in our opinion, exhausted the possibilities for hydrocarbon concentrations in the region. Drill sites were selected largely on the basis of geophysical surveys, which were difficult to interpret because of gravels and conglomerate beds covering older rock units of interest. Moreover, stratigraphic information is still inadequate to delimit potential subsurface traps in Cretaceous sandstone tongues that pinch out eastward. Probable facies changes in older formations are also inadequately known.

PHOSPHATE

A small tonnage of phosphate was mined in 1948–49 by Phosphate Mines, Inc., at the Top of the World Mine on Commissary Ridge, in the SE¼ sec. 9, T. 23 N., R. 116 W. About 4½ feet of beds averaging about 31 percent P_2O_5 (Cochran, 1950, p. 135) was mined, although thinner layers contain as much as 34 percent P_2O_5 (Sheldon, 1963, p. 258). Strata here are moderately contorted and broken, for they are not far above the Absaroka fault. Ore transportation by truck over steep mountain road to the Susie (later renamed Phosphate) railroad siding on Willow Creek proved uneconomic.

Published detailed sections and analyses of the Phosphoria Formation (referred to on p. 4) indicate significant tonnages of high-grade phosphate close to the Oregon Short Line of the Union Pacific Railroad. The structural relations along Rock Creek may make both strip operations and underground mining feasible. The Meade Peak Phosphatic Shale Member is exposed near the crest and on the west flank of Dempsey Ridge in secs. 9, 16 and 21, T. 23 N., R. 118 W.; it is also present beneath a thin cover farther south along the ridge. Topography is favorable for both stripping and gravity feed of ore to Rock Creek valley for processing and shipment. Hills farther south contain additional reserves, although exposures of Triassic rocks indicate a greater volume of overburden.

Underground operations may be feasible beneath Rock Creek valley and westward. The formation is believed to be fairly unbroken west of the Rock Creek fault and to dip gently from 8° to 18° westward. Phosphate beds may lie as close to the surface as about 1,000 ft near the north end of the quadrangle, but they deepen southward to nearly 2,000 ft. Possibly the advantages of year-round underground mining of a very large ore body close to a railroad may offset economic advantages of stripping.

VANADIFEROUS SHALE

Several beds of carbonaceous shale in the Meade Peak Member of the Phosphoria Formation in west-central Wyoming and southeastern Idaho contain a small amount of vanadium (Rubey, 1943). These beds were prospected extensively during World War II by the U.S. Geological Survey and the Homestake Mining Co. On the basis of both grade and thickness, the most highly vanadiferous material found in the Sage and Kemmerer quadrangles at that time was considered to be in a layer 3.3 ft thick, 18.9 ft below the top of the member, in the SW¼ sec. 21, T. 22 N., R. 118 W.; the layer contains 0.59 percent V_2O_5.

OIL SHALE

Thin beds of oil shale were measured (Oriel and Tracey, 1970, p. 44–46) in both members of the Green River Formation in the central part of the Fossil basin. Organic-rich shale and limestone within the basin grade laterally through ostracodal and gastropodal limestone to algal limestone and increasingly detrital rocks that mark the shorelines of the Eocene lake in which the sediments formed. The small size of the Fossil basin and moderate tectonism limited the extents and thicknesses of oil shales deposited; far greater volumes are known in the Uinta and Green River Basins.

Analyses of two 10-ft-thick stratal intervals sampled southwest of Fossil by Winchester (1923, p. 126) yielded 37 and 15 gallons of oil per ton. We have not determined if oil-shale beds of sufficient thickness and yield to be of potential value are present in the central part of the Fossil basin; they are not in most of the basin. Fossil basin oil shale is unlikely to be exploited until the far greater reserves in the larger basins are exhausted.

FOSSIL FISH

Well-preserved fossil fish and associated forms have been a source of revenue to families in the Kemmerer area as well as a local tourist attraction. The extraordinary preservation has resulted in the sale of better specimens to museums and other scientific organizations throughout the world for almost a century; remaining specimens have commonly been sold to tourists. A national monument has been established for Fossil Butte to preserve and exhibit the fossils in situ.

COPPER AND ASSOCIATED METALS

Mineral claims have been staked and prospect pits dug along Rock Creek on the basis of limonitic, malachitic, and azuritic stains on quartzite, apparently at the same locality noted by Veatch (1907, p. 163). The claims and pits are in fractured Wells quartzite, which is 20–30 ft stratigraphically below the limestone of the Grandeur Member of the Park City Formation, on the steep hill north of Watercress Canyon in about the center of the SE¼ NW¼ sec. 4, T. 22 N., R. 118 W. They lie along the west limb of a north-trending anticline just

east of the normal fault east of Rock Creek. The degree of alteration of the quartzite, which includes an unidentified fine-grained black mineral in pores and fractures, seems to be related to distance from the fault. Partial results of analyses of samples collected in the pits are shown in table 1. The claims have not been evaluated. Copper and associated metals have been reported previously (Love and Antweiler, 1973) in quartzites of the Nugget Sandstone (some prospects are present about 25 mi north of the area along Hobble Creek) and in other rocks (Mansfield, 1927, p. 344; Schultz, 1914, p. 130).

TABLE 1. — *Analyses (in parts per million) of mineralized quartzite, Wells Formation, in the SE¼ NW¼ sec. 4, T. 22 N., R. 118 W., north of Watercress Canyon*

Semiquantitative spectrographic analyses by C. L. Forn, Dec. 4, 1967; atomic absorption analyses (') by Zelia Stephenson, Sept. 1, 1967; and colorimetric analysis (²) by S. Hoffman, Sept. 1, 1967

Sample _____ Distance east of fault (ft)_	1 50	2 100	3 200	4 400
Fe _____	10,000	30,000	30,000	2,000
Mn _____	30	50	30	50
Ag' _____	.6	2.7	1.1	2.4
Au' _____	<.02	<.02	<.02	.03
As _____	200	700	700	200
Cu' _____	1,500	5,000	75,000	1,000
Mo² _____	8	150	80	16
Ni _____	20	50	30	5
Pb _____	30	200	150	700
V _____	10	15	20	10
Zn' _____	360	360	130	70

ENGINEERING GEOLOGY

Terrace gravels, especially the high-terrace gravels along Hams Fork, and lag concentrates from conglomerate beds in the lower part of the Evanston Formation have furnished road metal for highway construction in the area. Well-rounded pebbles and boulders of quartzite and chert are abundant enough to meet all projected local needs.

Fractured Nugget quartzite about three-fourths of a mile east-northeast of Nugget station has also been quarried in limited quantity for use as road metal.

Sandstone beds in the Frontier and Adaville Formations and limestone beds in the Green River Formation were formerly quarried for local use as building stone.

Failure of roadcuts made during construction in 1956 of a new right-of-way for the Union Pacific Railroad emphasizes the need for engineering geologic advice for major construction in the area. Wet, saturated gray claystones slid when they were undercut in construction of the new roadbed. Moreover, bentonitic mudstones of the Wasatch Formation removed in large volume from cuts proved less than satisfactory for nearby fills. Exposure to weathering resulted in uneven compaction and in gullying that required bolstering of the larger fills by additional material.

Landslides of Wasatch material from both valley walls are possible near the reservoirs in Hams Fork valley. Abundant water at the Wasatch–Green River contact and hummocky typography beneath the contact clearly indicate that the mudstones have slid in the past.

Relatively recent movement along the Rock Creek fault, with accompanying rock slides, indicates potential earthquake hazards in the area. Minor earthquake shocks have affected the region during recorded history. The great number of faults provides many surfaces for release of strains within the crust.

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