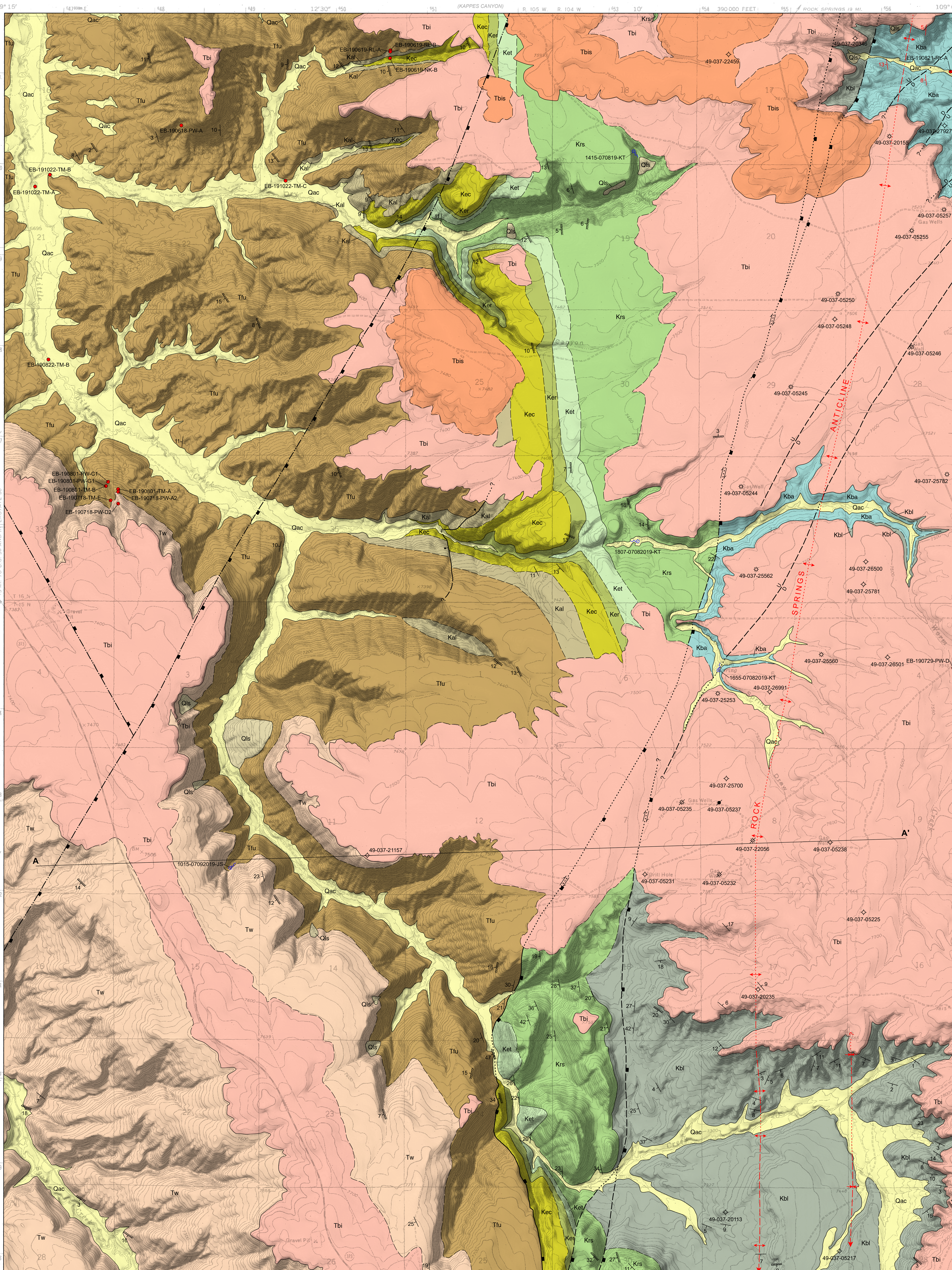
WYOMING STATE GEOLOGICAL SURVEY
Erin A. Campbell, Director and State Geologist
Laramie, Wyoming

Interpreting the past, providing for the future

OPEN FILE REPORT 2020-2
Earnest Butte 1:24,000-scale Bedrock Geologic Map



Base map from U.S. Geological Survey 1:24,000-scale topographic map of the Earnest Butte, Wyoming Quadrangle, 1968, photorevised 1978

Base hillshade derived from United States Elevation Data (NED), 10-meter Digital Elevation Model (DEM), 2019; azimuth 315º, sun angle 45º, vertical exaggeration 2.7

Projection: Polyconic
North American Datum of 1927 (NAD 27)
1,000-meter grid ticks: UTM, zone 12
10,000-foot grid ticks: Wyoming State Plane Coordinate System, west central zone

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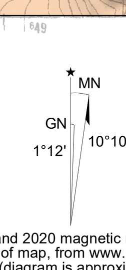
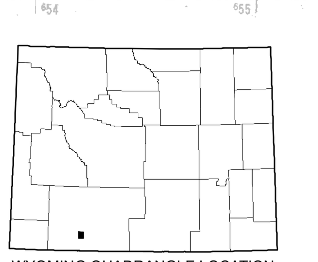


UTM grid and 2020 magnetic north declination at center of map, from www.ngdc.noaa.gov (diagram is approximate)

SCALE 1:24,000

1 — 0.5 — 0 — 1 Mile
1,000 — 0 — 1,000 — 2,000 — 3,000 — 4,000 — 5,000 — 6,000 — 7,000 Feet
1 — 0.5 — 0 — 1 Kilometer

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

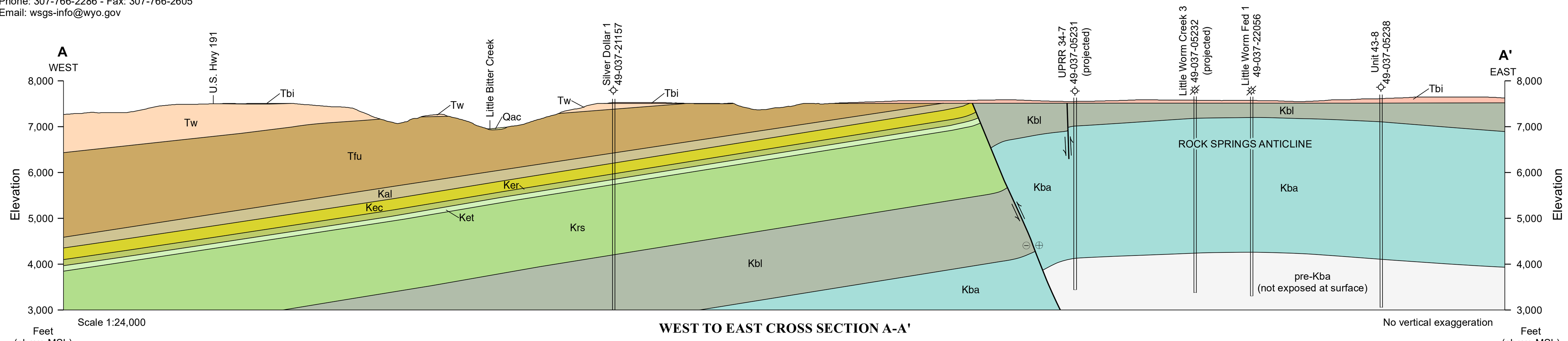


WYOMING QUADRANGLE LOCATION

Digital cartography by Ranie M. Lynds, Patricia M. Webber, and Natali A. Kragh

Map edited by Suzanne C. Luhr

Prepared in cooperation with and research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G19AC00142. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.



WEST TO EAST CROSS SECTION A-A'

EXPLANATION

CORRELATION OF MAP UNITS

- Qac, Qls — Holocene, Pleistocene — QUATERNARY
- Unconformity
- Tbis, Tbi — Oligocene
- Unconformity
- Tw — Eocene
- Unconformity
- Tfu — Paleocene
- (Oligocene, Eocene, Paleocene: PALEOGENE — TERTIARY; QUATERNARY and TERTIARY: CENOZOIC)
- Unconformity
- Mesaverde Group: Kal, Kec
- Unconformity
- Ker, Ket
- Unconformity
- Krs, Kbl
- Kba
- (Kal through Kba: Upper Cretaceous — CRETACEOUS — MESOZOIC)

MAP SYMBOLS

Definitions: *Certain—Estimated location <25 m (82 ft)*
Approximate—Estimated location 25–100 m (82–330 ft)

Formation contact—Continuous where certain, long dash where approximate

Fault—Continuous where certain, long dash where approximate, dotted where concealed, queried where uncertain; bar and ball on downthrown block of normal fault, rectangles on upper (tectonically higher) plate of reverse fault, arrows indicate relative motion of oblique fault, upthrown (U) and downthrown (D) blocks designated when fault type is unknown

Blind fault—Concealed; rectangles on upper (tectonically higher) plate of reverse fault; mapped by Besse (1999) from seismic data

Reverse fault with oblique slip (in cross section)—Arrows indicate relative motion; circle with minus, away from observer; with plus, toward observer

Anticline—Long dash where approximate, dotted where concealed; arrow on end indicates direction of plunge

Syncline—Long dash where approximate, dotted where concealed, queried where uncertain; arrow on end indicates direction of plunge

A——A' **Line of cross section**

22 **Strike and dip of inclined bedding**

13 **Strike and dip of inclined bedding**—Derived from Sears (1926)

12 **Strike and dip of inclined bedding in cross-bedded rocks**

49-037-25782 **Gas well**—Showing API number

49-037-05235 **Gas well, plugged and abandoned**—Showing API number

49-037-05237 **Oil well, plugged and abandoned**—Showing API number

49-037-26500 **Dry hole, plugged and abandoned**—Showing API number

EB-190821-RL-A **Sample**—Showing sample number; see report for analytical results

1807-07082019-KT **Spring, sampled**—Showing sample number; see report for analytical results

DESCRIPTION OF MAP UNITS

Cenozoic

Qac — **Alluvium and colluvium (Holocene and Pleistocene)**—Unconsolidated to poorly consolidated, subangular to subrounded clay, silt, sand, gravel, cobbles, and boulders mixed with clay-rich soil; locally derived. Includes alluvium, slope wash, debris flows, and alluvial fan deposits. Thickness locally undetermined but generally less than 12 m (39 ft)

Qls — **Landslide debris (Holocene and Pleistocene)**—Blocks and slumps of locally derived detritus from steep and unstable slopes. Most common along Little Bitter Creek. Thickness undetermined

Bishop Conglomerate (Oligocene)

Tbis — **Sandstone facies**—Poorly exposed light-tan to white siltstone and fine- to coarse-grained, subrounded to subangular, poorly sorted, litharenite and tuffaceous sandstone with occasional pebble-rich layers. Iron-staining common. Basal contact gradational with underlying conglomerate facies. Approximately 0–27 m (89 ft) thick

Tbi — **Conglomerate facies**—Poorly consolidated to well-cemented, clast- to matrix-supported, poorly sorted, angular to rounded, granule to cobble and occasional boulder conglomerate composed of white, red, and green quartzite, chert, light-gray limestone, reddish sandstone and siltstone, and an array of other volcanic and metamorphic materials. Coarse to very coarse sandy matrix. Imbrication, tabular and trough cross-bedding, and channel scours common. Silicification present in northeast portion of quadrangle. Unconformably overlies all older units. Up to 38 m (120 ft) thick

Tw — **Wasatch Formation (Eocene)**—Gray and tan, very fine to medium-grained, moderately to well-sorted, angular to subrounded, thickly bedded (4 m; 13 ft), cliff-forming litharenite and red, yellow, white, and purple slope-forming mudstone. Tabular and trough cross-bedding, soft sediment deformation, and rip-up clasts common. Occasional bioturbation and plant fossils. Basal contact with underlying Fort Union Formation unconformable yet indistinct (Kirschbaum, 1987), inferred by change to steeper slope and above palynology samples in secs. 33 and 35, T. 16 N., R. 105 W. Only basal 370 m (1,210 ft) exposed

Tfu — **Fort Union Formation (Paleocene)**—Buff, tan, and red, fine- to coarse-grained, well-sorted, subrounded to subangular, resistant, thickly bedded (<5 m; 16 ft), lenticular sandstones interbedded with dark-gray, green, and yellow-brown siltstone, mudstone, carbonaceous shale, and coal. Convoluted bedding, cross-bedding, and ripples common. Subbituminous coal contains woody fragments, carbonaceous shale, rare tonsteins, gypsum crystals, and occasional resin particles. Leaf fossils locally common. Angular unconformity at the base of the formation likely represents Cretaceous-Paleogene boundary (Kirschbaum, 1986). Full thickness not exposed on quadrangle; thickens to west; only basal 40 m (130 ft) in type log

Mesozoic

Mesaverde Group (Upper Cretaceous)

Kal — **Almond Formation**—White to gray, fine-grained, well-sorted, angular to subrounded, thickly bedded, resistant sublitharenite interbedded with poorly exposed siltstone, shale, carbonaceous shale, and infrequent thin coal beds. Cross-bedding, soft sediment deformation, and bioturbation common. Shales weather to popcorn texture. Sharp and conformable basal contact. Contact with overlying Fort Union Formation is marked at the top of a 0.3–1.5 m (1–5 ft) thick, highly bioturbated, gray and brown paleosol that weathers white to light gray. Thickness in type log 64 m (210 ft)

Ericson Sandstone

Kec — **Canyon Creek Member**—Light-gray to white, salt-and-pepper, fine- to coarse-grained, moderately sorted, subrounded to angular, occasionally calcareous, friable sublitharenite with rare gray mudstone and carbonaceous shale interbeds. Cross-bedding common. Occasional soft-sediment deformation and iron-rich nodules. Basal contact sharp and unconformable. Thickness in type log 70 m (230 ft)

Ker — **Rusty zone**—Gray to orange, commonly iron-stained, medium- to coarse-grained, moderately sorted, subangular to subrounded sublitharenite intercalated with shale and carbonaceous shale. Occasional ripple marks and planar and trough cross-stratification. Shales may contain pyrite, or less frequently, dark, carbonaceous material. Iron concretions common. Basal contact gradational. Thickness in type log 40 m (130 ft)

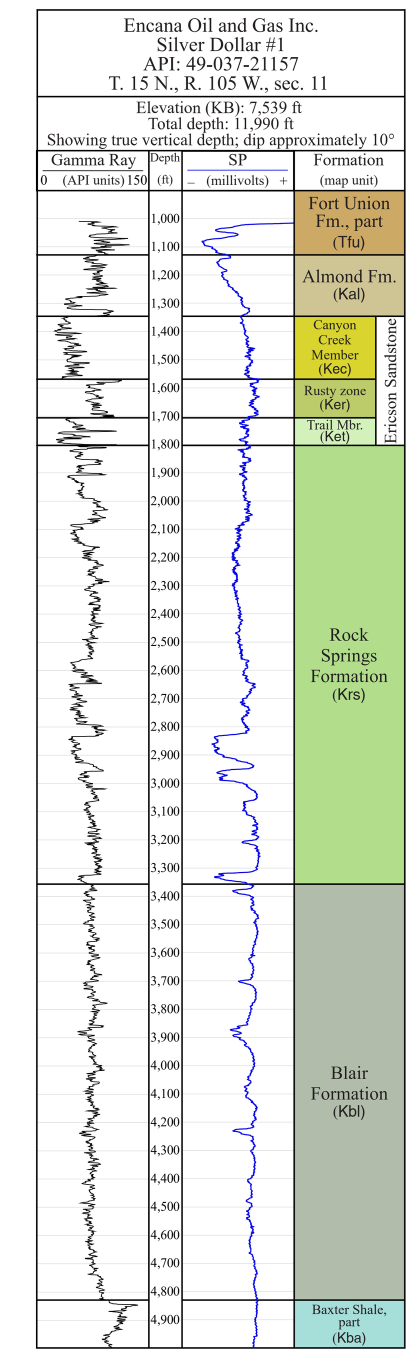
Ket — **Trail Member**—Light-gray to white, salt-and-pepper, medium- to coarse-grained, moderately sorted, subangular to angular, friable sublitharenite. Similar to the Canyon Creek Member. Trough and planar cross-bedding and soft sediment deformation common. Basal contact sharp, scoured, and unconformable. Thickness in type log 34 m (110 ft)

Krs — **Rock Springs Formation**—White, gray, and yellowish-tan, fine to coarse, poorly to well-sorted, subangular to subrounded, resistant yet friable litharenite interbedded with slope-forming shale, carbonaceous shale, and coal. Trough to planar cross-bedding, iron concretions, and trace fossils *Rhizocorallium*, *Ophiomorpa*, and *Thalassinoides* common. Basal contact gradational and not exposed. Thickness in type log 470 m (1,540 ft)

Kbl — **Blair Formation**—Lowermost formation of the Mesaverde Group. Poorly exposed, gray to brown siltstones and shales occasionally interbedded with tan, reddish-tan, and gray, thinly bedded, very fine to medium-grained, well-sorted, subangular to subrounded, quartz-rich, calcite-cemented sandstones. Current and oscillation ripples, wavy and flaser bedding, cross-bedding, and trace fossils *Thalassinoides*, *Nereites*, and *Aulichnites* common. Additional fossils include *Baculites* sp. and *Inoceramus* sp. Base of unit is sandy and mapped separately on adjacent maps (Kehoe and others, 2020; Webber and others, 2020); not observed in map area. Thickness in type log 450 m (1,480 ft)

Kba — **Baxter Shale (Upper Cretaceous)**—Very poorly exposed, blue-gray, fissile, calcareous, gypsiferous, and occasionally silty shale with popcorn weathering texture infrequently intercalated with thinly bedded, rippled sandstone, siltstone, and concretionary limestone. Occasional trace fossils *Thalassinoides* and *Aulichnites*. Only upper 61 m (200 ft) exposed; thickness in type log 900 m (2,950 ft)

TYPE LOG



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PRELIMINARY GEOLOGIC MAP OF THE EARNEST BUTTE QUADRANGLE, SWEETWATER COUNTY, WYOMING

by

Ranie M. Lynds, Patricia M. Webber, Natali A. Kragh, Thomas I. Martin, Kara L. Hoppes, and Karl G. Taboga

2020

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Preliminary Geologic Map of the Earnest Butte Quadrangle, Sweetwater County, Wyoming

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Open File Report 2020-2
May 2020

Wyoming State Geological Survey

Erin A. Campbell, Director and State Geologist

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Layout by Christina D. George

Open File Report 2020-2
Wyoming State Geological Survey
Laramie, Wyoming: 2020

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INTRODUCTION

The Earnest Butte 7.5-minute quadrangle is located in southwestern Wyoming (fig. 1) on the southwestern flank of the Rock Springs Uplift. The Rock Springs Uplift exposes Upper Cretaceous rocks at its center and progressively younger Cretaceous and Paleogene rocks dip east into the Washakie and Great Divide basins and west into the Green River Basin.

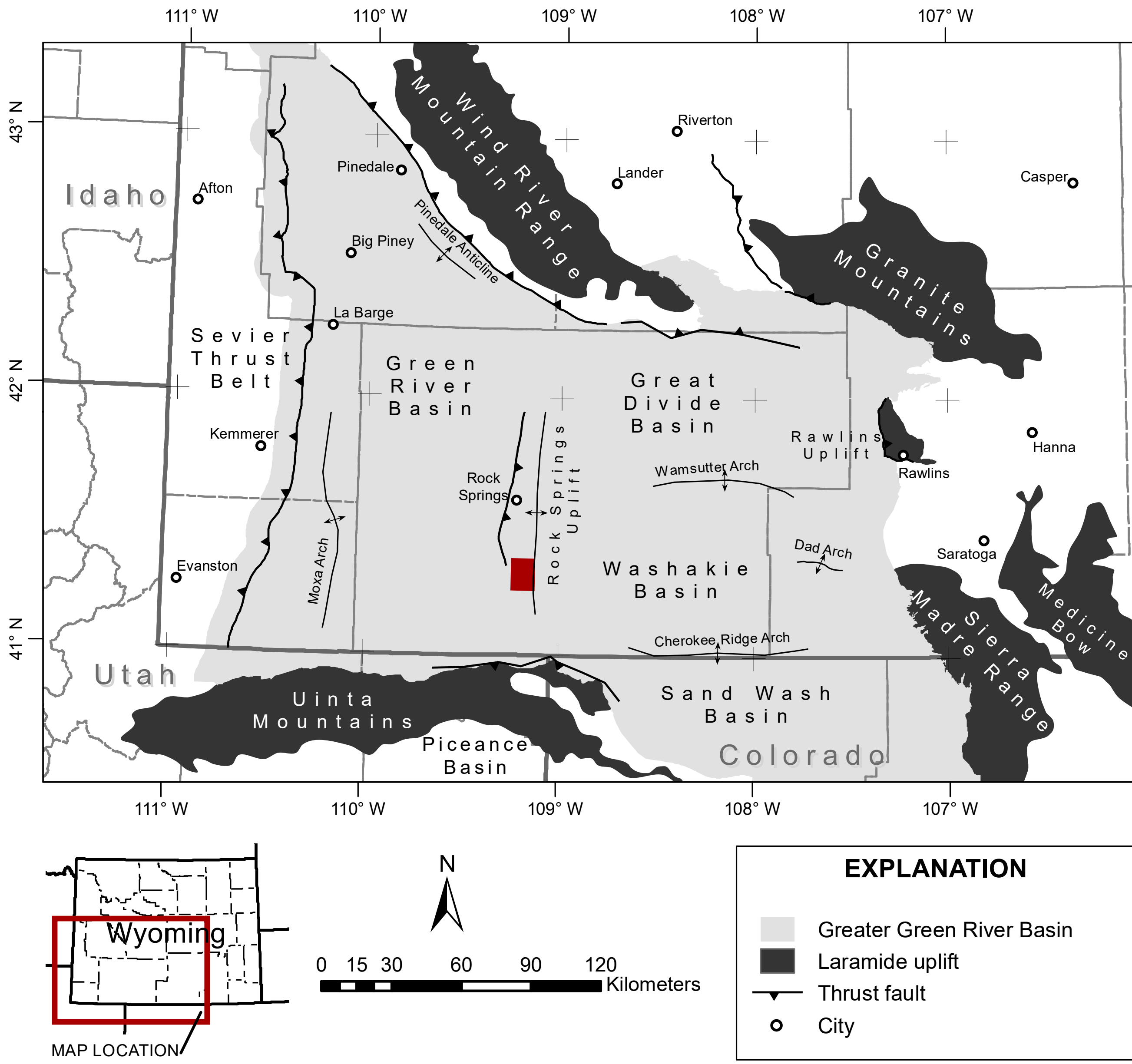

Figure 1. Map showing location of the study area in the Greater Green River Basin of south-central Wyoming. Extent of the Earnest Butte quadrangle is shown as a solid red rectangle. Counties are labeled and outlined as gray lines. Major structural features, sub-basins, and surrounding uplifts are noted.

The region was first mapped by Schultz (1920) at the 1:250,000 scale. Schultz's general map provided the basis for Sears's (1926) mapping at the 1:62,500 scale, although most of Sears's work was focused northeast of the study area. Roehler (1977) published a 1:125,000-scale map of the Rock Springs Uplift, and two years later Dames and Moore (1979) published a map of Earnest Butte quadrangle's coal resource and development potential. Kirschbaum (1987) published measured sections of the Paleocene Fort Union Formation and the Mesaverde Group on the southwest side of the Rock Springs Uplift, including three sections mapped across the Earnest Butte quadrangle. Adjacent

1:24,000-scale maps to the north and southeast include Kappes Canyon (Kirschbaum, 1986) and Titsworth Gap (Roehler, 1973), respectively.

Field mapping and sample collection occurred during June to October 2019. Sampling included whole rock and sediment samples for geochemical analysis, and detrital zircon, pollen, and fossil samples to constrain geochronology. Water from naturally occurring springs was also sampled to test local water quality.

Subsequent interpretation of field data, satellite imagery, and previous mapping aided in the final creation of the map and report. The results were completed in cooperation with the U.S. Geological Survey StateMap grant award G19AC00142.

Location

The Rock Springs Uplift of southwest Wyoming spans 96 km (60 mi) north to south and 64 km (40 mi) east to west, forming a topographical high in the center of the Greater Green River Basin. The uplift is a structural boundary between the Green River Basin to the west, the Great Divide Basin to the northeast, and the Washakie Basin to the southeast. The Earnest Butte 1:24,000-scale quadrangle (Tps. 15–16 N. and Rgs. 104–105 W.) is located toward the center of Sweetwater County, Wyoming, on the southwestern flank of the Rock Springs Uplift (fig. 1).

The northern edge of the quadrangle is about 23 km (14.3 mi) south of Rock Springs, Wyoming. The field area is easily accessible via Wyoming Route 373, which crosses through the southwestern extent of the quadrangle. Many gravel access roads also exist within the field area, including County Road (CR) 27 (Aspen Mountain Road) in the northeast, CR29 (Little Bitter Creek Road) in the northwest and center, and CR34 (Ramsey Ranch Road) and CR36 (Sage Creek Road) in the southwest. Numerous two-track roads cross the quadrangle as well.

GEOLOGY

The geology of the Earnest Butte quadrangle largely comprises Paleogene and Upper Cretaceous units that dip shallowly to the southwest along the southwestern flank of the Rock Springs Uplift. Oligocene Bishop Conglomerate caps the high plateau on the eastern side of the map, unconformably overlying Paleogene and Upper Cretaceous formations.

The oldest strata exposed within the quadrangle is the upper portion of the Baxter Shale. The formation was deposited from the Coniacian to the lower Campanian (Upper Cretaceous) and represents a deep marine depositional environment of the Western Interior Seaway (Rudolph and others, 2015). During the Cretaceous, this epicontinental sea extended longitudinally across the North American continent, submerging the majority of Wyoming (Steidtmann, 1993). The Baxter Shale preserved within the map area is compositionally dominated by shale, with minor sand content that gradually increases upward, grading into the coarser material of the overlying Mesaverde Group. This coarsening-upward sequence indicates a period of shoreline regression. Existence of the index fossil *Scaphites hippocrepis* in the upper Baxter Shale provides evidence for a minimum depositional age of lower Campanian (Cobban and others, 1994).

From the early Campanian tothe early Maastrichtian, sea level fluctuations and the initiation of the Laramide orogeny resulted in deposition of the Mesaverde Group (Roehler, 1990). Four formations of the Mesaverde Group are present within the quadrangle. In order of decreasing age, these units are the Blair Formation, Rock Springs Formation, Ericson Sandstone, and Almond Formation.

The interbedded shale and rippled sandstone of the Blair Formation highlights sediment accumulation in deltaic and shallow marine environments (fig. 2). The upper portion of the formation exhibits gradually increasing sand content that eventually intertongues with the overlying Rock Springs Formation. This coarsening upward sequence records a regression of the Western Interior Seaway (Hale, 1950; Rudolph and others, 2015). The depositional age of the Blair Formation has been constrained to the lower Campanian by the ubiquitous presence of the index fossil *Scaphites hippocrepis* (Smith, 1961).

Figure 2. Photograph of sand-rich Blair Formation. Outcrop is approximately 6 m (20 ft) high.

The Rock Springs Formation within the Earnest Butte quadrangle (fig. 3) contains repeating sequences of sandstone, shale, carbonaceous shale, and coal. These diverse rocks were deposited in a transitional environment that ranged from shallow marine to coastal swamp. Uplift of the Church Buttes anticline in western Wyoming halted deposition of the Rock Springs Formation and initiated erosion, resulting in an unconformable contact with the overlying Ericson Sandstone (Roehler, 1965). Western Interior ammonite zone correlation dates the Rock Springs Formation as the final unit deposited in the lower Campanian (Gill and others, 1970).

The Ericson Sandstone includes the Trail Member at the base, the middle rusty zone, and the overlying Canyon Creek Member (fig. 3). The Trail Member is composed of massive to cross-bedded, "salt and pepper" sandstones that were deposited in an alluvial plain setting. Alternating sandstones and occasionally carbonaceous shales of the informally named rusty zone likely accumulated across a flood plain. The Canyon Creek Member mimics the Trail Member in both lithology and depositional origin (Roehler, 1990), yet a significant unconformity of nearly 2 million years exists between the rusty zone and the Canyon Creek Member (Lynds and Slattery, 2017). A relative rise in sea level conformably transitioned the Ericson Sandstone into the shallow marine Almond Formation (Van Horn, 1979). Ammonite zone correlation restricts Ericson Sandstone deposition to the upper Campanian (Gill and others, 1970).

In the map area, the Almond Formation (fig. 4) is composed of shale, sandstone, and minor amounts of coal, recording a transitional depositional environment between lagoonal and shallow marine (Hale, 1955). Cretaceous rocks deposited after the Almond Formation were removed by erosion associated with Laramide folding and faulting of the Rock Springs Uplift. The unconformity between the Almond Formation and overlying Paleocene rocks is intermittently marked by the presence of a white, bioturbated and heavily rooted paleosol (Roehler, 1961; Kirschbaum, 1986; fig. 5). Correlation of ammonite zones within the Western Interior Seaway dates the Almond Formation as upper Campanian (Lynds and Slattery, 2017).

The Paleocene Fort Union Formation is the oldest Cenozoic unit present within the Earnest Butte quadrangle (fig. 4). The sandstone, mudstone, and coal seams of the unit record terrestrial depositional environments ranging from fluvial and flood plain, to organic-rich swamps (Winterfeld, 1979). The formation is unconformably overlain by

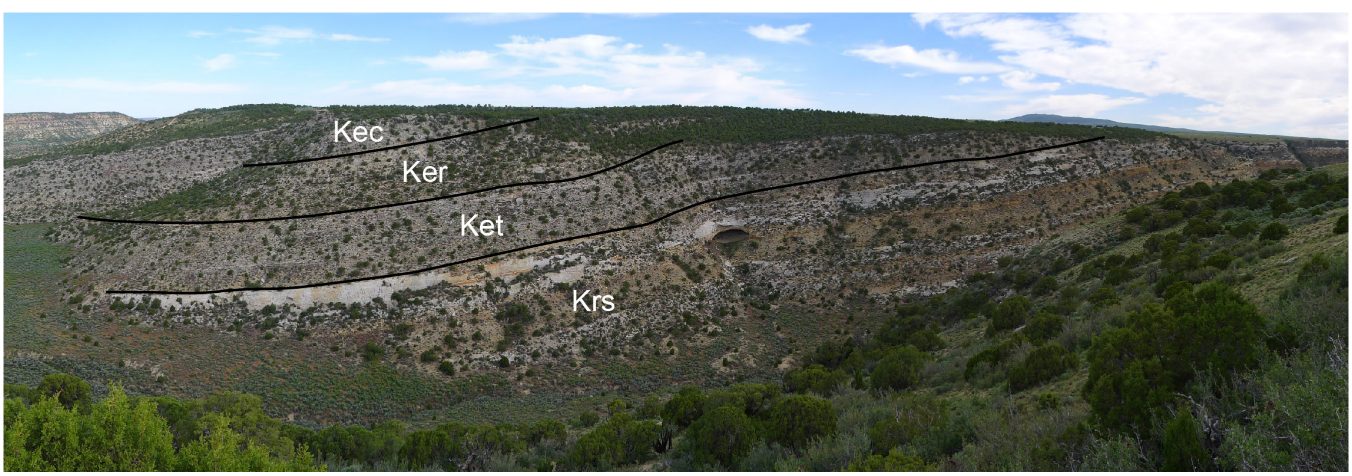

Figure 3. Photograph looking north across Dry Canyon, highlighting contacts between the Rock Springs Formation (Krs) and the Trail Member (Ket), rusty zone (Ker), and Canyon Creek Member (Kec) of the Ericson Sandstone.

Figure 4. Photograph looking north across the northern tributary to Dry Canyon, highlighting contacts between the Canyon Creek Member of the Ericson Sandstone (Kec), the Almond Formation (Kal), and the Fort Union Formation (Tfu).

the Eocene Wasatch Formation (Kirschbaum, 1987). Grab samples were collected from the upper part of the Fort Union and analyzed for palynology, yielding Paleocene and older flora (Appendix 4). Detrital zircon geochronology samples were also collected from the base and top of the Fort Union Formation, with results summarized in Appendix 3.

Figure 5. Photograph of the paleosol at the contact between the Cretaceous Almond Formation and Paleocene Fort Union Formation. Field notebook is 19 cm (7.5 in) high

In the vicinity of the Rock Springs Uplift, the Wasatch Formation (fig. 6) is similar to the Fort Union Formation in both depositional environment and lithology, rendering the two units difficult to differentiate in the field, despite the unconformity. Often, the only distinguishing characteristics of the Wasatch Formation compared to the Fort Union are a decrease in organic matter and an increase in the number of red-colored sandstone beds (Kirschbaum and Nelson, 1988). Vertebrate fossil assemblages throughout the Wasatch Formation constrain the depositional age to lower Eocene (McGrew and Roehler, 1960).

During the Oligocene, a period of crustal stability allowed erosive processes to carve the Gilbert Peak erosional surface (fig. 7). Colluvium and alluvium collected atop this pediment and eventually lithified to form the Bishop Conglomerate (Bradley, 1936; Hansen, 1986), in both a conglomeratic (fig. 8) and sandy facies (Kirschbaum, 1986; Aslan and others, 2017). On the Earnest Butte quadrangle, the majority of Bishop Conglomerate clasts were sourced from the Uinta Mountains (Hansen, 1986; Aslan, and others, 2017). This unit can be observed capping plateaus of older Paleogene and Upper Cretaceous rock within the map area. Near Diamond Mountain Plateau, Utah, biotite within Bishop

Figure 6. Photograph of typical outcrop of Wasatch Formation.

Figure 7. Photograph of Gilbert Peak erosion surface capped by poorly exposed Bishop Conglomerate.

Conglomerate tuff beds was dated using K-Ar to be 29.50 ± 1.08 Ma to 26.2 ± 0.7 Ma (Winkler, 1970; Hansen, 1986). U-Pb detrital zircon geochronology for Bishop Conglomerates samples collected from the larger Firehole Canyon area yielded maximum depositional ages ranging from 35.5 ± 0.6 to 31.2 ± 0.6 Ma (weighted mean age at 95 percent confidence; Aslan and others, 2017). More recently, the bedrock units of the Earnest Butte quadrangle have been eroded, reworked, and deposited as alluvium, colluvium, and landslide debris.

Figure 8. Photograph of poorly sorted Bishop Conglomerate outcrop from the southeastern part of the map area. Hammer is 40.6 cm (16 in) long.

Structure

The Earnest Butte quadrangle is positioned along the southern end of the Rock Springs Uplift, which is a basement-cored, doubly-plunging, asymmetrical, low-amplitude anticline that trends generally north–south. The anticlinal axis intersects the study area in the eastern third of the quadrangle.

Structural deformation in the southern Rock Springs Uplift is primarily controlled by a series of laterally continuous, steeply dipping, north–northeast-trending, west–southwest-vergent reverse faults with significant right-lateral oblique motion. The major axis of the Rock Springs Uplift lies within the hanging wall of the easternmost of these faults, which is the primary structure exposed within the map area. This oblique reverse fault is verified from seismic data (Besse, 1999) and geophysical-log correlation (see cross section on map), with more than 1,219 m (4,000 ft) of vertical displacement within the Paleozoic and much deeper Madison Limestone. However, the fault trace is difficult to interpret at the surface, where it either offsets poorly exposed, indeterminate shales and often silicified sands of the Baxter Shale, Blair Formation, and Rock Springs Formation, or is covered by the Bishop Conglomerate. Numerous smaller faults occur within the hanging wall in the northeastern part of the map area, which are typically conjugate to the main fault, but vary in lateral extent as well as amount and orientation of displacement.

Two additional reverse faults, located in the western portion of the map, were interpreted from seismic data to not break the surface (Besse, 1999). Outcrop observations suggest that gentle folding associated with these faults affects at least the Upper Cretaceous units exposed near the headwaters of Dry Canyon.

ECONOMICS

Oil and Gas

Two oil and gas fields overlap the Earnest Butte quadrangle: Baxter Basin South, discovered in 1922, and Little Worm Creek, discovered in 1957 (WOGCC, 2020). Until its closure in 1989, the Little Worm Creek field produced 113,922 barrels of oil and 4,360,382 thousand cubic feet of natural gas. Baxter Basin South remains active, producing 1,143 barrels of oil and 183,088,494 thousand cubic feet of gas through 2019 (WOGCC, 2020).

Thirty-one wells have been drilled within the quadrangle (table 1). The locations of most well sites were confirmed through either satellite imagery or physical location in the field. Physically located sites were recorded with handheld GPS. The confirmed positions were subsequently compared to well-site locations reported by the Wyoming Oil and Gas Conservation Commission (WOGCC, 2020) and corrected on the final map when necessary.

Coal

Industrial coal mining in Sweetwater County began in 1868 (Schultz, 1920). Around the Rock Springs Uplift, significant coal reserves were discovered in Upper Cretaceous (Rock Springs and Almond formations) and Paleogene

Table 1. Records and field-verified locations and status for wells within the Earnest Butte quadrangle (WOGCC, 2020).

API Number	Well Name	Company	Latitude (NAD27)	Longitude (NAD27)	Year	Status	Total depth (ft)	Gas produced (Mcf)	Oil produced (Bbl)	Water produced (Bbl)	Producing or target formation
49-037-05217	UPRR 1	Wexpro Company	41.25222	-109.14019	1937	PA	3,330	-	-	-	UNKNOWN
49-037-20113	MAGGIES CABIN 1	Wexpro Company	41.25606	-109.15516	1968	PA	5,000	-	-	-	UNKNOWN
49-037-20235	FRIZZELL-GOVT 1	Shenandoah Energy Inc	41.27816	-109.15086	1970	PA	4,904	-	-	-	UNKNOWN
49-037-05225	STATE 1-16	Caulkins Oil Company	41.28581	-109.13698	1952	PA	5,215	-	-	-	UNKNOWN
49-037-05231	UPRR 34-7	Caulkins Oil Company	41.28957	-109.16573	1958	PA	4,103	-	-	-	UNKNOWN
49-037-05232	LITTLE WORM CREEK 3	TXO Production Corporation	41.28958	-109.15595	1957	PA	4,227	44,003	-	-	LAKOTA
49-037-05238	UNIT 43-8	Caulkins Oil Company	41.29275	-109.14137	1960	PA	4,567	-	-	-	UNKNOWN
49-037-22056	LITTLE WORM FED 1	TXO Production Corporation	41.29295	-109.15156	1982	PA	4,225	28,250	-	-	DAKOTA
49-037-05237	GOVT 2-8	TXO Production Corporation	41.29671	-109.15601	1958	PA	4,768	52,292	6,574	499	MORRISON
49-037-05235	UPRR 42-7	Robert Hawkins Inc	41.29674	-109.16087	1959	PA	4,406	75	-	-	LAKOTA
49-037-25700	FULLERTON FEDERAL 11-8	True Oil LLC	41.29908	-109.15504	2003	PA	4,053	-	-	-	FORT UNION
49-037-25253	SOUTH BAXTER UNIT 22	North Shore Exploration & Prod LLC	41.30745	-109.15613	2003	PG	4,010	2,141,752	657	546	DAKOTA/MORRISON
49-037-26991	SOUTH BAXTER 32	Wexpro Company	41.30768	-109.14932	2006	PA	3,819	-	-	-	DAKOTA
49-037-25560	SOUTH BAXTER UNIT 24	North Shore Exploration & Prod LLC	41.31136	-109.14252	2003	PG	3,825	1,388,728	329	1,910	DAKOTA/MORRISON
49-037-26501	SOUTH BAXTER UNIT 28	Wexpro Company	41.31109	-109.13380	2005	PA	3,891	-	-	-	FRONTIER/DAKOTA/MORRISON
49-037-25781	SOUTH BAXTER UNIT 25	Wexpro Company	41.31834	-109.13698	2004	PA	3,819	-	-	-	FRONTIER/MORRISON
49-037-26500	SOUTH BAXTER UNIT 27	Wexpro Company	41.32059	-109.13667	2005	PA	3,670	-	-	-	FRONTIER/DAKOTA/MORRISON
49-037-25562	SOUTH BAXTER UNIT 23	North Shore Exploration & Prod LLC	41.31981	-109.15109	2003	PG	3,665	77,424	5	85	FRONTIER/MORRISON
49-037-05244	W T NIGHTINGALE A 1	North Shore Exploration & Prod LLC	41.32801	-109.15308	1936	PG	2,752	813,678	-	305	FRONTIER
49-037-25782	SOUTH BAXTER UNIT 26	North Shore Exploration & Prod LLC	41.32923	-109.12597	2004	PG	3,750	660,772	152	318	FRONTIER/MORRISON
49-037-21157	SILVER DOLLAR 1	Encana Oil and Gas USA Inc	41.29147	-109.20222	1978	PA	11,990	-	-	-	UNKNOWN
49-037-05245	UNIT UPRR 2	North Shore Exploration & Prod LLC	41.33792	-109.14652	1943	PG	2,749	456,483	-	146	FRONTIER
49-037-05246	UNIT E-08341-B 3	Wexpro Company	41.34188	-109.13062	1943	PA	2,694	138,040	-	-	FRONTIER
49-037-05248	UNIT UPRR 5	Wexpro Company	41.34463	-109.14072	1944	PA	3,066	-	-	-	DAKOTA
49-037-05250	MF WHELAN 1	North Shore Exploration & Prod LLC	41.34715	-109.14032	1934	PG	2,565	899,979	-	403	FRONTIER
49-037-05255	UP 21-16-104 2	North Shore Exploration & Prod LLC	41.35341	-109.13059	1933	PG	2,447	976,208	-	246	FRONTIER
49-037-05257	UNIT PATENTED 1	North Shore Exploration & Prod LLC	41.35549	-109.12634	1943	PG	7,172	1,566,370	-	353	DAKOTA
49-037-20155	BAXTER BASIN SO UNIT 12	North Shore Exploration & Prod LLC	41.36276	-109.13353	1969	PG	3,042	444,098	0	41	DAKOTA
49-037-27927	SOUTH BAXTER UNIT 33	Wexpro Company	41.36382	-109.12627	2009	PA	2,407	-	-	-	FRONTIER/MORRISON
49-037-22459	KAPPES CANYON 10-17	Pacific Enterprises Oil Co USA	41.37089	-109.15470	1987	PA	6,025	-	-	-	DAKOTA
49-037-20346	SO BAXTER UNIT 14	Wexpro Company	41.37248	-109.13802	1972	PA	3,550	-	-	-	UNKNOWN

(Fort Union and Wasatch formations) strata. Within the county, coal is currently mined from these units, but not from within the quadrangle.

Dames and Moore (1979) surveyed coal on Federal Known Recoverable Coal Resource Areas (KRCRAs), which constitutes approximately a quarter of the Earnest Butte quadrangle. None of the coal seams, all from the Fort Union Formation, qualify as reserve base coal beds, which require a minimum thickness of 1.5 m (4.9 ft) and a maximum overburden of 914 m (3,000 ft), despite a few locally thick beds (fig. 9). These coal beds are thought to be subbituminous.

Figure 9. Photograph of thick coal within the Fort Union Formation. Coal is laterally extensive but rapidly thins to less than 1 m (3 ft). Note geologist for scale.

Uranium

There are no historical or active uranium mines in the Earnest Butte quadrangle. However, numerous uranium and thorium prospect pits and sample sites exist just to the west and northwest of the quadrangle boundary. Two Wasatch Formation samples collected from these prospects, less than a kilometer west of the quadrangle, contain both uranium and thorium (Sutherland and others, 2018). The Wilkins Peak Member of the Green River Formation, mapped just to the west of the Earnest Butte quadrangle, is also reported to contain 0.003–0.15 percent uranium (Bradley, 1964).

In the late 1970s through the early 1980s, the National Uranium Resource Evaluation (NURE) program sampled stream water and sediment in order to discern uranium occurrences. The Earnest Butte quadrangle hosts 21 sites where NURE collected data (U.S. Geological Survey, 2004). Five of these sites were resampled by WSGS geologists in 2019. Results from the geochemical analysis of these samples are reported in Appendix 2.

Industrial Materials

Aggregate

The Earnest Butte quadrangle has moderate potential for gravel and aggregate development. Weathered Bishop Conglomerate occasionally leaves poorly consolidated cobble and gravel deposits capping high plateaus within the map area. Though the thicknesses of these deposits are most commonly around 0.6 m (2 ft), surface area coverages can be quite extensive.

Historically, one gravel pit existed where Wyoming Route 373 enters the west-central edge of Earnest Butte quadrangle. Four other gravel pits follow Wyoming Route 373 just to the west of the map area. Proximity of the quadrangle to this major roadway may increase the economic viability of resource recovery at this location.

HYDROLOGY

Surface Hydrology

The Earnest Butte quadrangle contains one perennial and three named intermittent streams, as well as numerous unnamed ephemeral streams. The perennial stream, Sage Creek, flows northwesterly across the southwestern corner of the map to where it enters the Upper Green River arm of Flaming Gorge Reservoir 19 km (12 mi) west of the quadrangle. The intermittent stream system formed by Little Bitter Creek and its tributary, Worm Creek, drain most of the land encompassed by the quadrangle, flowing to the north and west before joining the Green River at the city of Green River, Wyoming. Lastly, Circle Creek flows east across the northeast corner of the quadrangle to Pretty Water Creek and on to Salt Wells Creek, a tributary of Bitter Creek to the north.

The streams within the Earnest Butte quadrangle have carved steeply incised canyons through the Oligocene Bishop Conglomerate into Paleogene and Upper Cretaceous formations. In fact, all but the uppermost reaches of the Little Bitter Creek watershed can be delineated by exposures of the Paleogene Wasatch and Fort Union formations

Streamflows in the quadrangle are driven mostly by spring runoff from snowmelt and by periodic downpours from summer convective thunderstorms. By June 2019, Worm Creek was dry, but both Sage Creek and Little Bitter Creek were at bankfull flow. At the same time, Circle Creek contained sporadic pools of standing water separated by intermittent dry sections, tens of meters in length. In addition to runoff, these streams receive small flows from widely scattered in-channel and near-channel springs and seeps (low magnitude discharge springs), discussed in the following section.

Hydrogeology

The U.S. Geological Survey mapped four springs in the Earnest Butte quadrangle. During July 2019, water samples were collected from the four springs for water quality analyses. Field measurements indicated that all four springs discharged cold (44–55 °F; 7–13 °C), fresh water (total dissolved solids, TDS<1,000 mg/L) to Little Bitter Creek and its tributaries. Although three of the four springs discharge less than 0.03 m^3/s (1.0 ft^3/s), animal tracks indicate that all of these springs serve as important water sources for livestock and wildlife in this semi-arid environment. Results from these samples are reported in Appendix 5.

Three of the four mapped springs are rheocrene springs (Springer and Stevens, 2008), flowing springs that discharge into a stream channel. These springs frequently discharge where a small ephemeral first-order drainage enters the main streambed. One limnocrene spring (Springer and Stevens, 2008) discharges into a wetland shared with the main channel of Worm Creek. Limnocrene springs discharge into standing (lentic) pools of water, which may then discharge into nearby streambeds.

Dry Canyon spring (sample 1415-070819-KT): A rheocrene spring that discharges at several points from a layer of tan fractured sandstone in the Rock Springs Formation (fig. 10). The spring discharges from the base of a 15-degree hillslope and flows downslope for approximately 30 m (100 ft) into the Dry Canyon stream channel. Discharge is estimated at 0.02 m^3/s (0.7 ft^3/s).

Figure 10. Photograph of Dry Canyon spring, taken July 8, 2019, sample 1415-070819-KT.

South spring (sample 1655-07082019-KT): A rheocrene spring that discharges from a gravel layer in alluvium (fig. 11). The spring discharges from the base of a 5-degree hillslope and flows approximately 45 m (150 ft) through a marshy area into the South Spring Draw stream channel. Discharge is estimated at 0.01–0.03 m^3/s (0.5–1.0 ft^3/s).

Worm Creek spring (sample 1807-07082019-KT): A circular limnocrene spring about 6.4 m (21 ft) in diameter located 12 m (40 ft) north of the channel of Worm Creek (fig. 12). This spring discharges at about 0.08–0.1 m^3/s (3–4 ft^3/s) by vertical upwelling on its western edge. It was not possible to determine spring depth, but the bottom was not visible. The spring contained many algae. The spring is located at the confluence of Worm Creek and an unnamed first order tributary that is approximately 5 km (3 mi) long.

Little Bitter Creek spring near Sally Draw (sample 1015-07092019-JS): A low (0.003 m^3/s, 0.1 ft^3/s) discharging rheocrene spring that feeds a deeply incised first order tributary near the contact of the Wasatch and Fort Union formations (fig. 13). This spring discharges from the base of a 23-degree hillslope. Flows increase substantially down-channel, likely fed by baseflow inputs.

Figure 11. Photograph of South spring, taken July 8, 2019, sample 1655-07082019-KT.

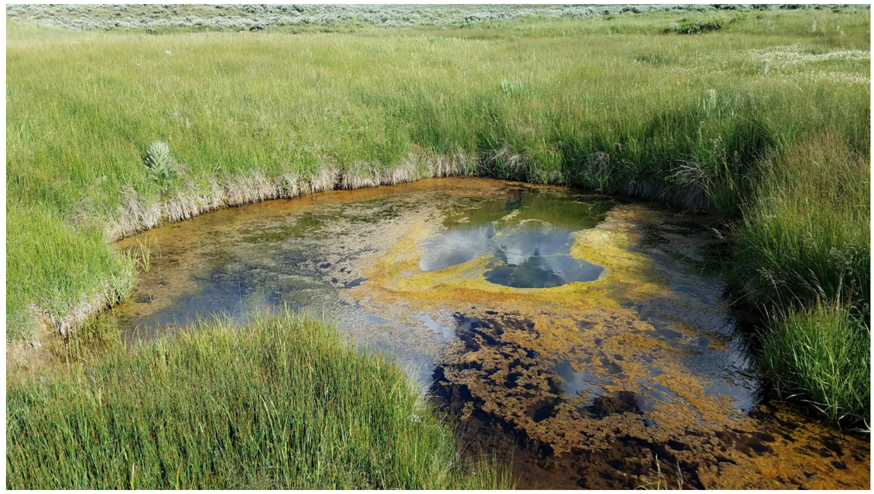

Figure 12. Photograph of Worm Creek spring, taken July 8, 2019, sample 1807-07082019-KT.

Figure 13. Photograph of Little Bitter Creek spring, taken July 9, 2019, sample 1015-07092019-JS.

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Appendices

APPENDIX 1: GEOCHEMICAL ANALYSES—ROCK SAMPLES

ALS Chemex, in Reno, Nevada, analyzed four samples from the Earnest Butte quadrangle using complete elemental characterization package CCP-PCK01 for whole rock, trace elements, rare earths, and base metals. Analyses were conducted using inductively coupled plasma (ICP) atomic emission spectrometry, ICP mass spectrometry, and by infrared spectroscopy via induction furnace. Samples submitted for geochemical analysis were selected to collect baseline data and evaluate alteration associated with silicification. Data table A1 shows sample name, sampled formation, location, and elemental results as reported by ALS Chemex. All sample locations are shown on the map.

APPENDIX 2: GEOCHEMICAL ANALYSES—STREAM-SEDIMENT SAMPLES

Stream-sediment samples were collected from the Earnest Butte quadrangle to test the reproducibility of geochemical results obtained from sediment samples collected in the late 1970s as part of the National Uranium Resource Evaluation (NURE) program (Smith, 1997). Sample locations were chosen to mimic those of the original NURE dataset. AGAT Laboratories, from Mississauga, Ontario, analyzed six stream-sediment samples for 58 elements using sodium peroxide fusion followed by ICP-OES and ICP-MS finish (AGAT method code: 201 378; AGAT SOP: MIN-200-12001). Data table A2 shows sample name, location, and elemental results as reported by AGAT Laboratories. All sample locations are shown on the map.

APPENDIX 3: DETRITAL ZIRCON GEOCHRONOLOGY

U-Pb Methodology

Detrital zircon geochronology analyses were carried out at the Arizona LaserChron Center at the University of Arizona, and the following text is modified from Pecha (2019). Zircon grains were extracted from bulk sample, including density separation using a Wilfley table and heavy liquids (methylene i). The resulting heavy mineral fraction then underwent separation using a Frantz LB-1 magnetic barrier separator to isolate the zircons. A representative split of the entire zircon yield of each sample was incorporated into a 1-inch epoxy mount along with multiple fragments of each of the three zircon standards (FC1, SL-mix, and R33). The mounts were sanded down approximately 20 microns, polished progressively using a 9-, 5-, 3-, and 1-micron polishing pads, and backscatter electron (BSE) imaged using a Hitachi S-3400N scanning electron microscope (SEM) equipped with a Gatan Chroma CL2 detector. Prior to isotopic analysis, the mounts were cleaned in an ultrasound bath of one percent HNO3 and one percent HCl in order to remove any residual common Pb from the surface of the mount.

U-Pb geochronology of individual zircon crystals was conducted by laser ablation multicollector inductively coupled mass spectrometry (LA-ICPMS) at the Arizona LaserChron Center (Gehrels and others, 2006, 2008). The isotopic analyses involved ablation of zircon using a Photon Machines Analyte G2 excimer laser coupled to a Thermo Element 2 single-collector-ICPMS. Drill rate is approximately one micron per second, resulting in a final ablation pit depth of about 12 microns.

The errors in determining the $^{206}Pb/^{238}U$ and $^{206}Pb/^{204}Pb$ result in a final measurement error of approximately 1–2 percent (at 2σ level) in the $^{206}Pb/^{238}U$ age for each analysis. The errors in determining $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{204}Pb$ also result in approximately 1–2 percent (at 2σ level) uncertainty in age for grains that are older than 900 Ma, however, they are substantially larger for younger grains due to the low intensity of the ^{207}Pb signal.

The common Pb correction is accomplished by using the Hg-corrected ^{204}Pb and assuming an initial Pb composition from Stacey and Kramers (1975). Uncertainties of 1.5 for $^{206}Pb/^{204}Pb$ and 0.3 for $^{207}Pb/^{204}Pb$ are applied to these compositional values based on the variation in Pb isotopic composition in modern crystalline rocks. Interference of ^{204}Hg with ^{204}Pb is accounted for measurement of ^{202}Hg during laser ablation and subtraction of ^{204}Hg, according to the natural $^{202}Hg/^{204}Hg$ of 4.35.

U-Pb Results

Samples were collected for detrital zircon geochronology from the Wasatch and Fort Union formations. The locations of all four samples are shown on the map, and all sample locations are summarized in data table A3.

For each sample, maximum depositional age was calculated by multiple methods following Dickinson and Gehrels (2009), with results summarized in data table A3. Youngest single grain (YSG) is the absolute youngest age measured in a sample. The probability density peak (PDP) age was calculated from the crest of the youngest discrete age peak on a probability density plot. Final age (FA), or age incorporating both internal analytical error accounted for with the weighted mean age and external systematic error, was calculated using the DZ Age Pick Program (version of September 1, 2009) of the Arizona LaserChron Center (www.geo.arizona.edu/alc). The weighted mean age at 2σ was determined from the youngest cluster of three or more grain ages ($i \geq 3$) overlapping in age by weighting each measurement by the square of its uncertainty. This method assumes the grains are cogenetic and is valid if the mean square weighted deviation (MSWD) of the set of grains is near one.

Compiled single zircon age results for all four samples are also reported in data table A3. Uncertainties shown in these results are at the 1σ level and include only measurement errors. Complete digital analytical data are available from the Wyoming State Geological Survey (www.wsgs.wyo.gov/).

APPENDIX 4: PALYNOLOGY

Carbonaceous shales and an interpreted paleosol were sampled from the Fort Union Formation and the Fort Union/Almond contact. Four samples were sent to Biostratigraphy.com for processing and analysis. Sample locations and interpreted results are detailed in data table A4; sample locations are identified on the map.

APPENDIX 5: GEOCHEMICAL ANALYSES—SPRING WATER

Water samples were collected at four springs with visible water flow. Two samples were taken from each flowing spring in bottles provided by the Wyoming Department of Agriculture. One water sample for major ion analysis was collected in a rinsed 800-mL plastic bottle; a second water sample for metals analysis was collected in a 200-mL plastic bottle containing nitric acid. Water samples were analyzed by the Wyoming Department of Agriculture in Laramie, Wyoming. Results are reported in data table A5. All sample locations are shown on the map.