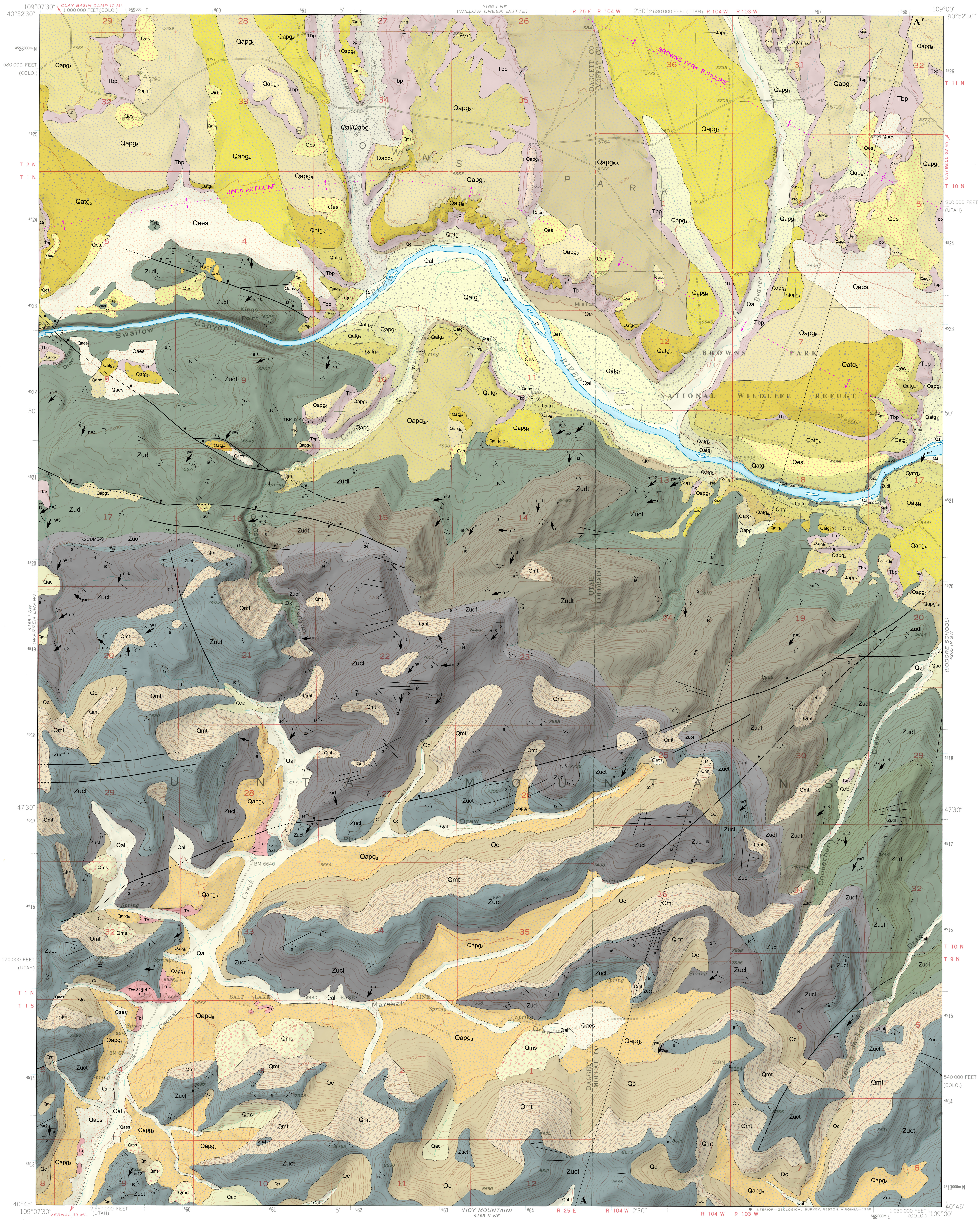

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

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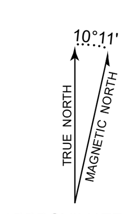

APPROXIMATE MEAN DECLINATION, 2020

GEOLOGIC MAP OF THE SWALLOW CANYON QUADRANGLE, DAGGETT COUNTY, UTAH, AND MOFFAT COUNTY, COLORADO

by

Laura D. De Grey[1], Christopher Tressler[2], Carol M. Dehler[2], Joel L. Pederson[2], and Paul K. Link[1]

2020

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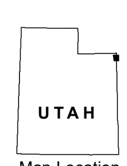

Map Location

Base from USGS Swallow Canyon 7.5' Quadrangle (1972)
Shaded relief generated from 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927

Project Manager: Douglas A. Sprinkel
GIS and Cartography: Kent D. Brown (UGS), Christopher Tressler (USU), and J. Buck Ehler (UGS)

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https://doi.org/10.34191/MP-171DM

1	2	3
4		5
6	7	8

1. Clay Basin
2. Willow Creek Butte
3. Beaver Basin
4. Warren Draw
5. Lodore School
6. Crouse Reservoir
7. Hoy Mountain
8. Canyon of Lodore North

ADJOINING 7.5' QUADRANGLE NAMES

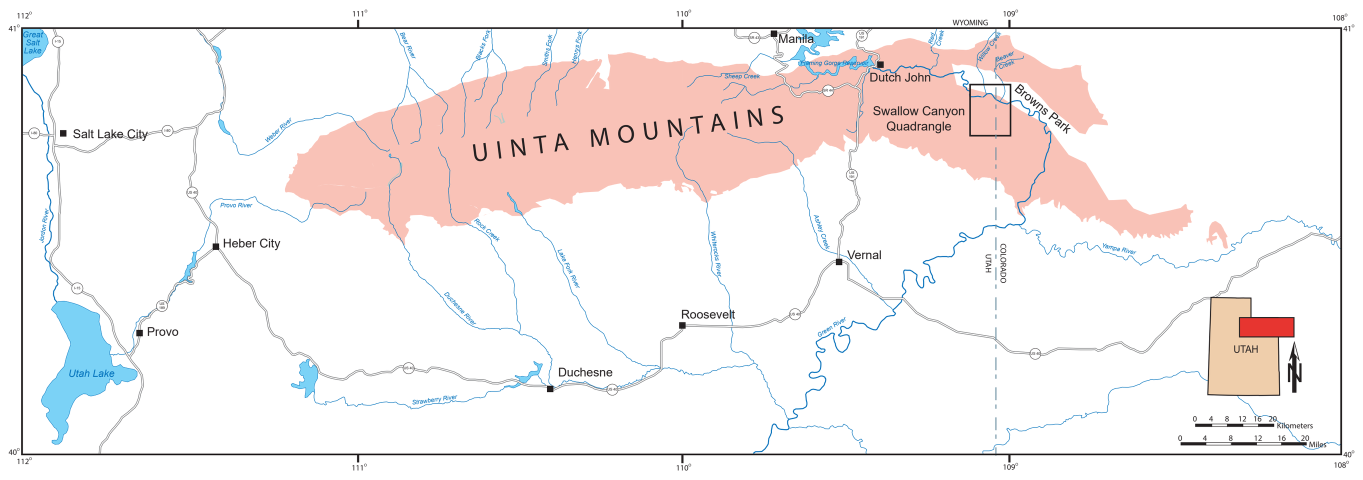


Figure 1. Index map of the Uinta Mountains showing the location of the Swallow Canyon quadrangle

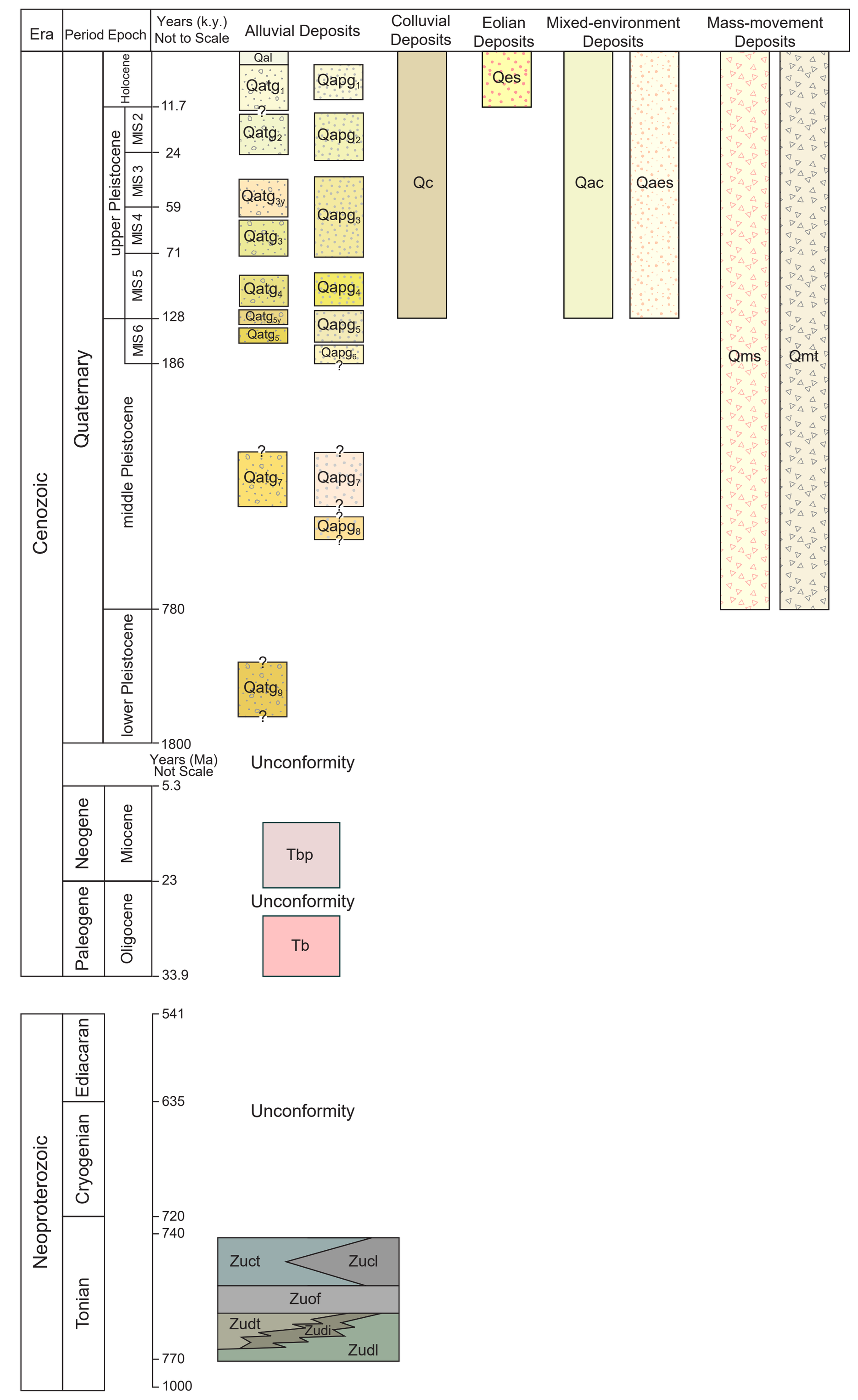


Figure 2. Correlation of map units - Swallow Canyon quadrangle

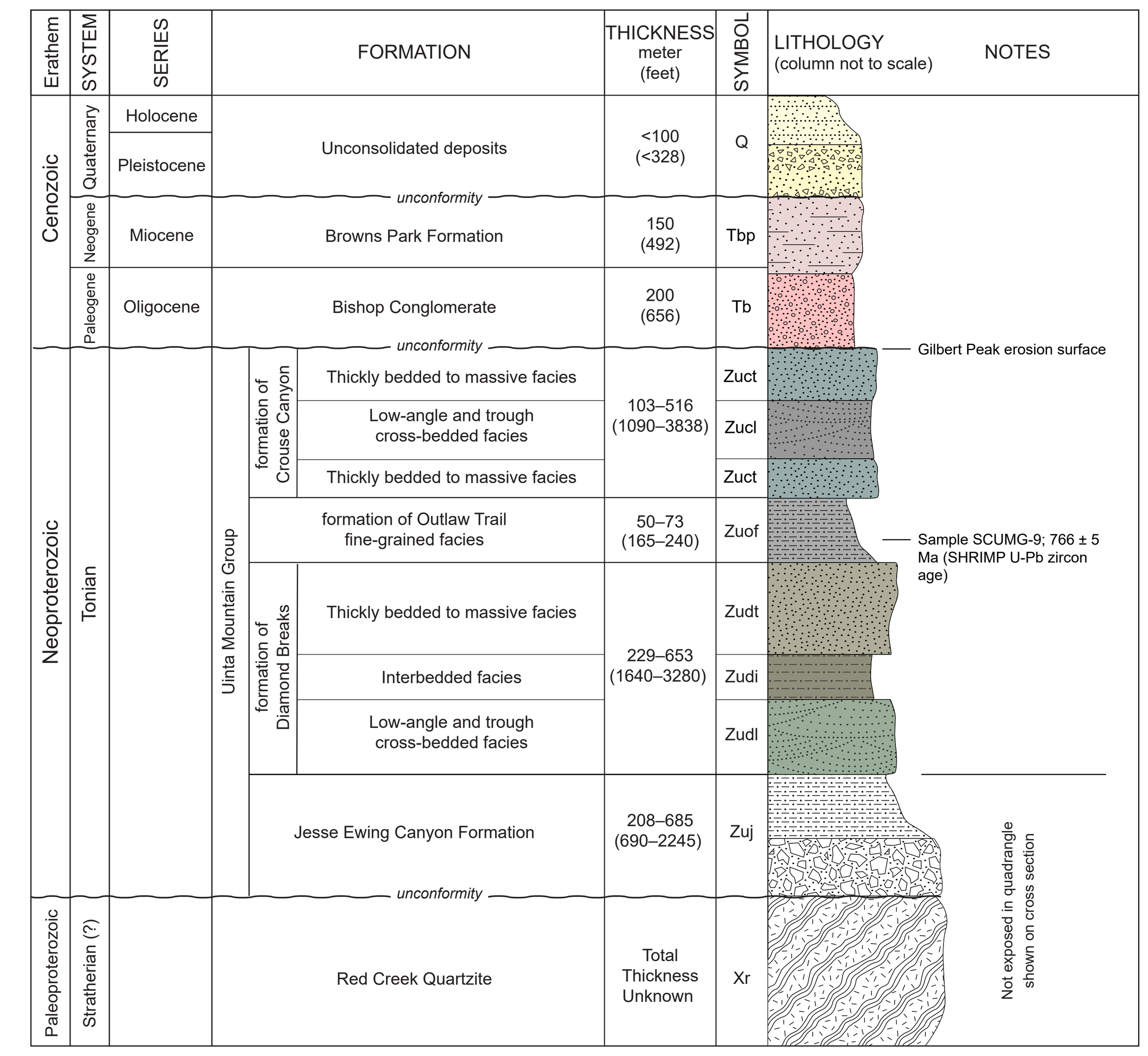


Figure 3. Lithologic column of bedrock units in the Swallow Canyon quadrangle

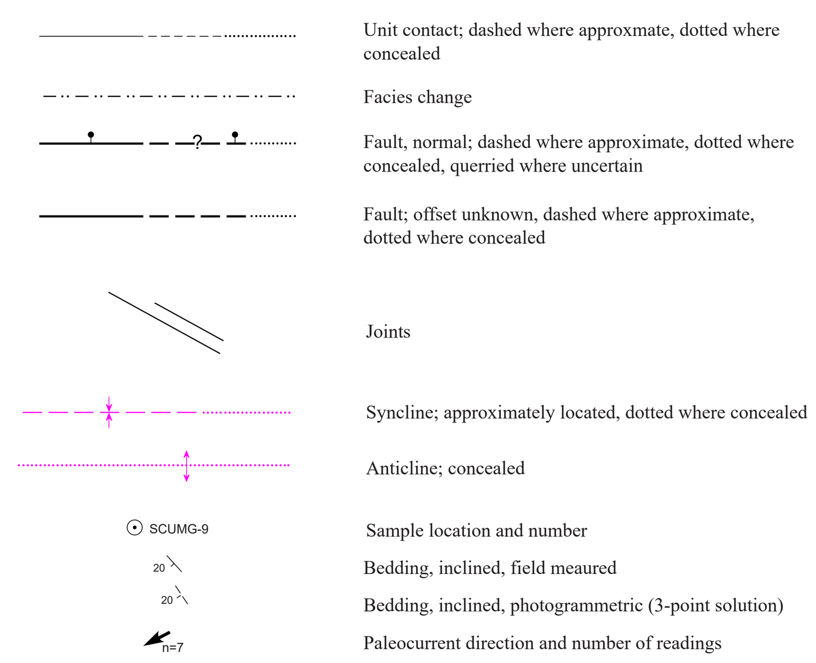
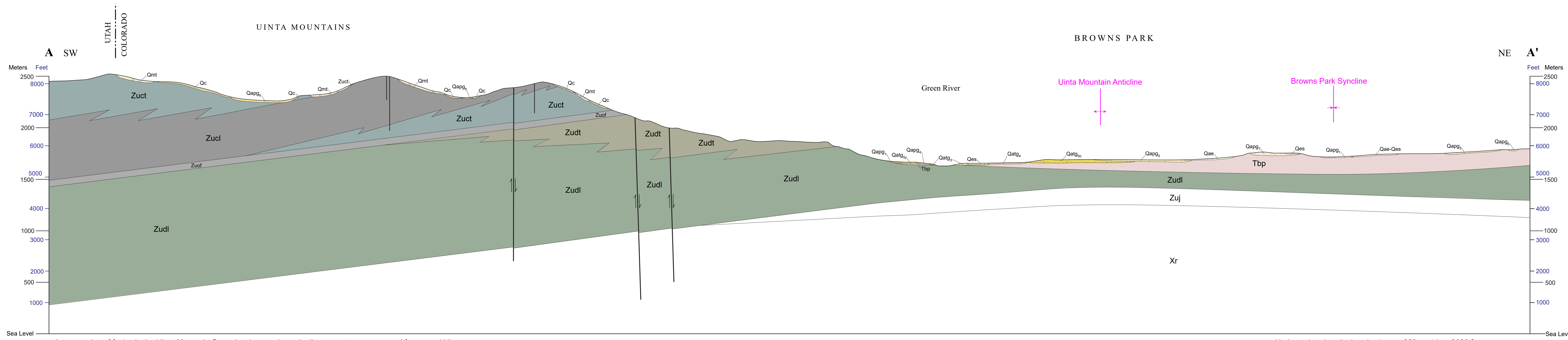


Figure 4. Geologic symbols



Intertonguing of facies in the Uinta Mountain Group is shown schematically as most tongues extend for several kilometers

Horizontal and vertical scale: 1 cm = 250 m; 1 in = 2000 ft

GEOLOGIC MAP OF THE SWALLOW CANYON QUADRANGLE, DAGGETT COUNTY, UTAH, AND MOFFAT COUNTY, COLORADO

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by Laura D. De Grey [1], Christopher Tressler [2], Carol M. Dehler [2], Joel L. Pederson [2], and Paul K. Link [1]

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Cover photo: *The Green River exits Swallow Canyon and flows eastward through Browns Park area, Utah and Colorado. Swallow Canyon is incised through a spur of quartz sandstone beds of the lower part of the Neoproterozoic (Tonian) Uinta Mountain Group. The superimposed Green River has alternately cut through the spur and flowed around it to the north over Pleistocene time—and part of this conundrum puzzled John Wesley Powell on his historic exploration of the Green and Colorado Rivers in 1869. The light-colored beds are the Miocene Browns Park Formation capped by Pleistocene Green River terrace gravels and piedmont alluvium. View to the east.*

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GEOLOGIC MAP OF THE SWALLOW CANYON QUADRANGLE, DAGGETT COUNTY, UTAH, AND MOFFAT COUNTY, COLORADO

by Laura D. De Grey, Christopher Tressler, Carol M. Dehler, Joel Pederson, and Paul K. Link

QUADRANGLE SUMMARY

Introduction

The Swallow Canyon 7.5-minute quadrangle is located on the north flank of the Uinta Mountains and the west part of Browns Park in northeast Utah and northwest Colorado (plates 1 and 2). The lower two-thirds of the quadrangle is occupied by mountainous terrain and the upper onethird of the quadrangle is within Browns Park, through which the Green River flows. Swallow Canyon, the quadrangle's namesake and named by John Wesley Powell during his historic 1869 expedition of the Green and Colorado Rivers, is a curious canyon that was cut by the Green River through a subtle bedrock spur that protrudes northward into Browns Park. The Swallow Canyon quadrangle contains a greater than 2-km-thick (1.2mile) exposed succession of Neoproterozoic (Tonian) Uinta Mountain Group, strata of the Oligocene Bishop Conglomerate and Miocene Browns Park Formation, and an array of Quaternary surficial deposits. This map is largely a product of bedrock mapping from De Grey (2005), which includes facies, paleocurrent, and petrographic data, with paleogeographic and paleoenvironmental interpretations of the Uinta Mountain Group, and mapping of surficial deposits from Pederson and others (in preparation).

Bedrock Stratigraphy

The rocks of the Neoproterozoic Uinta Mountain Group were deposited in a faulted basin by marine and non-marine processes (Dehler and others, 2005b; Rybczynski, 2009). In the east half of Uinta Mountains, the Uinta Mountain Group has been subdivided into formal and informal formations (Sanderson and Wiley, 1986; De Grey and Dehler, 2005; Dehler and Sprinkel, 2005; Sprinkel, 2006; Brehm, 2007; Dehler and others, 2007; Rybczynski, 2009; Dehler and others, 2010). They are, in ascending stratigraphic order, the basal Jesse Ewing Canyon Formation, formation of Diamond Breaks, formation of Outlaw Trail, formation of Crouse Canyon, formation of Hades Pass, and Red Pine Shale. Only the formations of Diamond Breaks, Outlaw Trail, and Crouse Canyon are exposed in the quadrangle. The Neoproterozoic Uinta Mountain Group lies unconformably on the Paleoproterozoic Red Creek Quartzite. Hansen (1965) noted that in some areas the metaquartzite of the Red Creek Quartzite grades into gneiss (gneissic quartzites) containing higher concentrations of feldspar, but did not map them separately. Sears and others (1982) named these gneissic rocks the Owiyukuts Complex, which they thought were Archean in age and underlie the Red Creek Quartzite. Nelson and others (2011) identified the rocks of the Owiyukuts Complex as quartz and potassium feldspar paragneiss and indicated that the age postdates the youngest detrital zircon of about 1740 Ma. Although the work by Nelson and others (2011) indicates that the Owiyukuts Complex is not Archean in age, the field relations precluded them from determining the relative ages and stratigraphic position between the Red Creek Quartzite and Owiyukuts Complex.

The formations of Diamond Breaks and Crouse Canyon consist predominantly of quartz arenite and the formation of Outlaw Trail consists of fine-grained quartz and subarkosic arenite, siltstone, and gray to greenish-gray shale. These formations are further subdivided into four facies associations: (1) low angle and trough cross-bedded, (2) thickly bedded to massive, (3) interbedded, and (4) fine grained. The low-angle and trough-cross-bedded facies association and the thickly bedded to massive facies association indicate braidplain and braided channels, respectively, of a braided river system; the interbedded facies association represents the mingling of these environments. The fine-grained facies association indicates a low-energy delta plain, likely formed during marine transgression.

The age of the Uinta Mountain Group ranges from about 770 to 740 Ma based on U-Pb detrital zircon analysis, palynology, and carbon and oxygen isotope analyses, and regional correlation (Dehler and others, 2005a; Nagy and Porter, 2005; Sprinkel and Waanders, 2005; Dehler and others, 2010). Sample SCUMG-9 (-109.11044, 40.77213) was collected from the fine-grained facies association (formation of Outlaw Trail) within the quadrangle for detrital zircon analysis. The analysis of four detrital grains yielded a SHRIMP U-Pb age of 766 ± 5 Ma, indicating the formation was deposited after about 770 Ma (Fanning and Dehler, 2005; Rybczynski and others, 2008; Dehler and others, 2010; Dehler and others, 2011). In addition, the complete spectra yielded age peaks of 2.7 to 2.6 Ga (Archean Wyoming Province), 1.76 to 1.65 Ga (Paleoproterozoic Yavapai and Mazatzal accretionary terrain), 1.49 to 1.3 Ga (Proterozoic transcontinental belt), and 1.2 to 1.0 Ga (Grenville Province). These age peaks are consistent with previous provenance work (Ball and Farmer, 1998; Condie and others, 2001).

The Bishop Conglomerate was deposited on the Gilbert Peak erosion surface, a broad piedmont surface that formed around the flanks of the Uinta Mountains soon after the end of the Laramide orogeny (Hansen, 1965, 1986a). Wide valleys extended into the highlands as fingers from the piedmont slope—

these paleovalleys are best preserved along the south flank of the Uinta arch in the east half of the Uinta Mountains. Crouse Canyon within the quadrangle represents the uppermost reach of one of those valleys and is where the Bishop Conglomerate is exposed. The age of the Bishop is based on radiometric dates in and outside of the quadrangle. Tuff beds preserved near the base of the Bishop Conglomerate, south of the quadrangle on the Diamond Mountain Plateau and the Yampa Plateau, have yielded $^{40}Ar/^{39}Ar$ ages (sanidine) that range from 34.03 ± 0.04 Ma to 30.54 ± 0.22 Ma (Kowallis and others, 2005). K-Ar analysis on tuff beds collected from the upper middle part of the formation, located about 24 kilometers (15 miles) southwest of quadrangle, yielded ages of 29.50 ± 1.08 Ma (biotite) and 28.58 ± 0.86 Ma (hornblende) or about 29 Ma (Hansen, 1986a). A sample of tuffaceous sandstone (Tbc-32614-1; -109.11044, 40.77213, 09) collected from the Bishop Conglomerate along Crouse Canyon in the southwest part of the quadrangle yielded a U-Pb (zircon) age of 27.0 ± 0.3 Ma (Aslan and others, 2017).

The Browns Park Formation is exposed in Browns Park valley and unconformably onlaps the formation of Diamond Breaks south of the Green River. Its age is based on paleontologic and radiometric data in and outside of the quadrangle. Fossil bones, skull fragments, and a skull from extinct fauna of camels, antelopes, horses, and dogs collected from the Browns Park Formation at sites in the Cedar Springs Draw, southwest of radiometric samples from near Maybell, Colorado, indicate an upper Miocene age (Honey and Izett, 1988).

Ash beds are preserved throughout the Browns Park Formation. An ash bed near the base of the formation along the Little Snake River (about 100 kilometers [62 miles] east of quadrangle and 23 kilometers [14 miles] northwest of Maybell, Colorado) yielded a K-Ar (biotite) age of 24.8 ± 0.8 Ma (Izett and others, 1970). Another ash bed near the base of the formation, about 13.5 kilometers (8.4 miles) south of Maybell, Colorado, yielded a fission-track (zircon) age of 23.3 ± 3.7 Ma (Izett, 1975). A fission-track (zircon) analysis of an ash near the same stratigraphic interval of the fossil mammal sites yielded an age of 11.3 ± 0.8 Ma (Honey and Izett, 1988). This ash is likely near the middle of the Browns Park Formation. Samples from near the top of the Browns Park Formation were collected from the west and east part of Browns Park valley. K-Ar analysis of glass from vitric tuff from near the top of the Browns Park Formation collected near the mouth of Jesse Ewing Canyon, about 10 kilometers (6 miles) northwest of the quadrangle, yielded an age of 11.8 ± 0.4 Ma (Damon, 1970). Another sample from near Vermillion Creek, Colorado, about 40 kilometers (25 miles) east of the quadrangle, yielded a zircon fission-track (zircon) age of 9.9 ± 0.4 Ma (Naeser and others, 1980). Recently obtained radiometric ages from tuffs and tuffaceous beds near the bottom and the top of the Browns Park Formation indicate the formation is as old as 24.5 ± 1.1 Ma (late Oligocene) in east Browns Park valley and as young as 8.4 ± 0.3 Ma (Miocene) in west Brown Park valley (Becker and others, 2013; Aslan and others, 2017). One of those samples (TBP 12-4, -109.08811, 40.83239) is within the Swallow Canyon quadrangle. The U-Pb (zircon) analysis yielded an age of 8.9 ± 0.6 Ma (Aslan and others, 2017).

Structural Geology

The structural geology of the Swallow Canyon quadrangle is relatively simple. Strata of the Uinta Mountains generally dip about 5° to 15° south to southwest reflecting dip on the south flank of the Uinta anticline. The exposed axis of the anticline is west of the quadrangle but projects under the Tertiary and Quaternary units within Browns Park. The projected east-west axis is thought to lie along the south side of the valley (see plate 1 and cross section on plate 2). Browns Park valley is a half-graben with the controlling fault (Mountain Home fault) located north of the quadrangle along the base of Mountain Home, Bender Mountain, and the O-Wi-Yu-Cuts Mountains (Hansen, 1965; Stone, 1993; Sprinkel, 2006). The Miocene Browns Park Formation, which is mostly restricted to the Browns Park valley, is deposited on the eroded crest of the buried Uinta anticline (Sears, 1924; Hansen, 1965). The Browns Park Formation is also folded into a gentle syncline the axis of which trends the length of Browns Park valley (Sears, 1924; Hansen, 1965). Beds of Browns Park Formation that form the limbs of the syncline typically dip less than 10°. The north limb, however, has steeper dips of 30° to 60° south where the Browns Park Formation is near the faults along the north margin of the valley (Sears, 1924; Hansen, 1965, 1986b, 1986a). The axial trace of the syncline generally lies north of the Green River and just north of the crest of the Uinta anticline (plates 1 and 2). The syncline is thought to have formed by a combination of depositional dip, differential compaction of the thickest part of the section, and down-to-the-south movement of faults along the north margin of the valley (Sears, 1924; Hansen, 1965, 1986a).

DESCRIPTION OF FACIES ASSOCIATIONS FOR THE FORMATIONS OF THE NEOPROTEROZOIC UINTA MOUNTAIN GROUP

Low-Angle and Trough Cross-Bedded Facies Association

The low-angle and trough cross-bedded facies association consists of moderate reddish-brown to very pale orange, fine- to coarse-grained quartz arenite (granules and pebbles with an average of medium sand-sized). The grains are well to poorly sorted and subangular to well-rounded. This facies association is medium-bedded with common lenticular and planar-tabular beds having internal cross-bedding. The lenticular beds are troughs of 0.5- to 1-meter (1.6 to 3 ft) scale. Lithofacies types include planar cross-beds (Sp), trough cross-beds (St), low-angle cross-beds (Sl), erosional scours (Se), large scours (Ss), and soft sediment deformation (Sss), with St and Sl most common (table 1; after Miall, 1978). Co-

Table 1. Lithofacies classification scheme used in the descriptions of facies associations for the formations of the Uinta Mountain Group. Modified from Miall (1978)

Lithofacies	Description	Sedimentary Structures	Grain Size	Dimensions	Interpretation
Sp	planar-tabular cross-bedded sandstone; may be grouped or solitary	internally massive or cross-bedded with high angle (>10°, average 15° to 20°), often planar-tabular internal cross-beds	fine- to coarse-grained sandstone	thinly to medium to thickly bedded foresets; cm-scale (inch-scale) internal cross-beds	straight-crested transverse bars
St	trough cross-bedded sandstone; may be grouped or solitary	internally cross-bedded with tangential and planar-tabular high angle (>10°, average 15° to 20°), cross-beds, graded bedding and alternating coarse and fine layers, troughs often cut each other	fine-grained sandstone to pebble; average grain size is medium to coarse	thinly to medium to thickly bedded; average width as much as 0.5 m (2 feet)	thin to medium-bedded troughs = migrating dunes; thickly bedded troughs = troughs within channels
Sl	low-angle cross-beds (<10°)	low-angle cross-beds, internally cross-bedded or massive, most internal cross-beds are higher angle planar-tabular cross-beds	fine- to coarse-grained sandstone; mostly granules and pebbles	thinly to medium-bedded, laterally continuous	bar?
Se	erosional scours	internally massive to crudely cross-bedded, often grouped and amalgamated, intraclasts	fine- to coarse-grained sandstone; mostly granules and pebbles	thinly to medium-bedded, average width is 0.5m to 2 m (2–7 feet)	possible cut and fill structures
Ss	broad, shallow erosional scours with common concave to undulose bases	massive to internally cross-bedded with high-angle (>10°) cross-beds	fine- to coarse-grained sandstone; mostly granules and pebbles	m-scale (feet-scale) width; as much as 0.5 m (2 feet) thick	possible channel
Sss	soft-sediment deformation	convolute bedding, recumbent folds, load structures, water escape structures	fine- to coarse-grained sandstone; average grain size is medium to coarse	dimensions vary	loading, water escape
Fl	finely laminated and fine-grained sedimentary rocks	laminae, small ripples, minor soft-sediment deformation	very fine sand, silt, and mud	laterally continuous beds; usually less than 1 cm (0.4 inches) thick	waning flow deposit
Fm	massive, very fine grained sandstone, siltstone, and mudstone	mud cracks	very fine sand, silt, and mud	laminated to thinly bedded, laterally continuous	waning flow deposit with some subaerial exposure

sets often contain interbedded lithofacies Sp, St, and Sl within a fining upward sequence. Channels and scours are common. Other sedimentary structures include slump folds and climbing ripples. Pebble lag deposits are common with pebbles up to 4 centimeters (1.6 in) diameter of quartzite and chert, likely from the Red Creek Quartzite and the Uinta Mountain Group. Outcrops form patterns of moderately steep slopes and discontinuous small ledges (10-meter [33 ft] scale). Float forms pancake-shaped disks and flaggy textured boulders.

Thickly Bedded to Massive Facies Association

The thickly bedded to massive facies association consists of moderate orange-pink, moderate red, and moderate orange-pink, medium- to very coarse, quartz arenite to pebble conglomerate. Grains in this facies association are moderately to poorly sorted and rounded to angular with the average being subrounded to subangular. It also contains rip-up mud chip clasts and the bottom contact is sharp with a large scour or channel. The common lithofacies types include simple and composite sets of planar beds (Sp) and low-angle cross-beds (Sl) (table 1; after Miall, 1978). Bedding thickness of the facies association ranges from thickly bedded to massive (0.5- to 1-meter [1.6 to 3 ft] scale). This facies association forms persistent cliffs, which extend laterally for tens of kilometers across the entire quadrangle and beyond. It often weathers into large meter-scale blocks that form block fields that are usually within the talus.

Interbedded Facies Association

This facies association contains interbedded vertical changes between the low-angle (Sl) and trough cross-bedded (St) facies association and the thickly bedded to massive facies association, making it difficult to map the separate facies associations at this scale. Overall, the low-angle (Sl) and trough cross-bedded (St) facies association composes about 65% and the thickly bedded to massive facies association composed about 35% of the map unit. The thickly bedded to massive facies association builds laterally extensive steep cliffs, which are sandwiched between thick intervals of the low-angle and trough cross-bedded facies association. This association is located only along the east edge of the map area, below the formation of the Outlaw Trail.

Fine-Grained Facies Association

The fine-grained facies association is moderate yellow-green, moderate orange-pink, moderate red, and moderate reddish-brown, fine-grained sandstone to mudstone. It is moderately to poorly sorted with subrounded to angular clasts. Bedding within this facies association include laminae to thin beds with symmetric ripples, interference ripples, mudcracks, possible gypsum crystal casts and molds, and soft sediment deformation. Planar-tabular cross-beds are found in medium beds. Outcrops are uncommon; facies association Fl and Fm are usually identified by pieces in float in the slope forming topography.

DESCRIPTION OF MAP UNITS

Quaternary Surficial Map Units

Alluvial Deposits

Qal **River and stream alluvium** (Historical and Holocene) – Unconsolidated pebble and cobble gravel, sand, and silt underlying the present channel and floodplain of the Green River and Crouse Creek and their tributaries; gravels are clast-supported, imbricated, and are primarily pebble-to-cobble clasts of Uinta Mountain Group sandstone with minor Phanerozoic limestone and sandstone, well sorted and well rounded; grasses, willow trees, and cottonwood trees mark the floodplain and tributary valley bottoms; mapping Qal was partly guided by previous, detailed mapping of Grams (1997); Qal here generally matches the distribution of Grams' intermediate bench, post-dam floodplain and active map units; less than 2 meters (6.5 ft) exposed, total thickness unknown.

$Qatg_1$ **Green River gravelly alluvium, terrace level 1** (Holocene and latest Pleistocene[?]) – Unconsolidated sand with lenses of clast-supported, well-rounded, imbricated pebbles and cobbles; clasts are sandstone, carbonates (limestone and dolomite), and minor granitic rocks; map unit includes terrace treads; higher terrace tread up to about 4 meters (13 ft) above the modern Green River; the predominant lower tread of this unit lies 2 to 3 meters (6.5–10 ft) above the modern Green River; vegetated with sagebrush, juniper, and Ponderosa pine, and may have been inundated by the largest historical flooding prior to Flaming Gorge dam; may include thin stream alluvium and colluvium in drainages developed on $Qatg_1$ deposits; thickness unknown.

$Qatg_2$ **Green River gravelly alluvium, terrace level 2** (upper Pleistocene) – Clast-supported and locally matrix-supported, rounded, moderately sorted, imbricated, pebble-cobble gravel with a sandy matrix and lenses of pebbly silty sand; clast types are diverse and include quartzite, chert, sandstone, carbonates, traces of basalt, and epidote-rich granitic rocks from the Wind River Mountains; $Qatg_2$ is relatively poorly preserved terrace deposit, likely recording localized deposition during overall incision of the Green River after abandonment of the $Qatg_3$ fill terrace; the terrace tread lies ~9 meters (30 ft) above the Green River, and its basal strath is mostly obscured beneath the floodplain, and so the total thickness is unknown.

$Qatg_3$ **Green River gravelly alluvium, terrace level 3** (upper Pleistocene) – Clast-supported and locally matrix-supported, rounded, moderately sorted, imbricated, pebble-cobble gravel with a sandy matrix and lenses of pebbly silty sand; clast types are diverse and include quartzite, chert, sandstone, carbonates, traces of basalt, and epidote-rich granitic rocks from the Wind River Mountains; in Browns Park, $Qatg_3$ deposits are 3- to 10-meters-thick (10–33 ft) with treads about 26 meters (85 ft) or ~20 meters (65 ft) above modern floodplain, for 3 and the 3y fill-cut terrace, respectively; soils are typified by stage II-III carbonate development.

$Qatg_4$ **Green River gravelly alluvium, terrace level 4** (upper Pleistocene) – Clast-supported and locally matrix-supported, rounded, moderately sorted, imbricated, pebble-cobble gravel with a sandy matrix and lenses of pebbly silty sand; clast types are diverse and include quartzite, chert, sandstone, carbonates, traces of basalt(?), and epidote-rich granite from the Wind River Mountains; in Browns Park, the $Qatg_4$ deposit is 3- to 10-meter-thick with a tread ~30 meters (130 ft) above modern floodplain; soils are typified by stage II-III carbonate development; $Qatg_4$ underlies a notable Green River paleovalley that skirts immediately north of Swallow Canyon.

$Qatg_5$ **Green River gravelly alluvium, terrace level 5** (upper to middle Pleistocene) – Unit is distinctly different in Little Hole-Red Canyon reach versus the west part of Browns Park; in the Little Hole-Red Canyon reach, $Qatg_5$ is typical Pleistocene gravelly terrace alluvium (see $Qatg_2$–$Qatg_4$ descriptions), 5 to 10 meters (16–33 ft) thick, with a tread about 45 meters (148 ft) above floodplain; in Browns Park, the $Qatg_5$ deposit has a fan-shaped geometry that spreads across much of the west part of the valley floor; the fill has lower and upper sedimentary units with distinct texture and composition and a sharp but conformable transition; the lower fill is a very poorly sorted, sub-angular, boulder gravel dominated by clasts of Uinta Mountain Group sandstone and having a matrix of rounded pebbles, cobbles, and sand between the boulder framework; the caliber and prevalence of Uinta Mountain Group clasts in the basal unit decreases strongly downstream, from boulders as much as 5 meters (16 ft) in intermediate diameter at the mouth of Red Canyon to a maximum of 0.5 meter (2 ft) in the Swallow Canyon area; lower unit also thins strongly downstream from more than 25 meters (82 ft) at the mouth of Red Canyon to less than 10 meters (33 ft) thick in central Browns Park; the hypothesized origin for the lower sedimentary unit is an outburst flood from the failure of a landslide-dam that impounded the Green River in lowest Red Canyon; upper sedimentary unit of $Qatg_5$ is clast-supported, moderately sorted, imbricated, sandy pebble-to-cobble gravel of typical Green River polymictic clasts; upper unit is 3 to 8 meters thick, making the full $Qatg_5$ about 30 m thick in the west to 15 m thick in central Browns Park; $Qatg_5$ is underlain by a planar strath cut into the Browns Park Formation 40 to 50 meters (131–164 ft) above grade; the $Qatg_5$ deposit locally has a fill-cut erosional terrace expressed in western Browns Park ($Qatg_{5y}$) with a tread ~10 m (35 ft) lower than the deposit top.

$Qatg_7$ **Green River alluvium, terrace level 7** (middle Pleistocene) – In western Browns Park, this is clast-supported, rounded, well-sorted, imbricated, cobble-pebble gravel; contains relatively few Uinta Mountain Group clasts; deposit is 5 to 12 meters (16–39 ft) thick with tread ~105 meters (340 feet) above grade. $Qatg^7$ upstream in the Little Hole-Devils Hole reach is distinctly different sand-dominated deposit that was previously mapped as Tertiary Browns Park Formation by Hansen (1965); the deposit overall coarsens upward and is cross-bedded, pebbly sand with clast-supported, relatively immature, pebble-boulder gravel lenses of locally derived Uinta Mountain Group clasts; it has a few faintly reddened horizons interpreted as hiatuses in fluvial deposition marked by soil-profile alteration; pebbles and cobbles of brown and tan, undifferentiated, quartzite clasts, typical of mainstem Green River deposits, appear and become more prevalent near the top; at both Little Hole and Devils Hole, thin- to medium-scale, lenticular beds of fine-grained, reworked tephra crops out 15 to 20 meters (49–66 ft) below the preserved top of the deposit; glass shards geochemically correlate to the 640 ka Lava Creek B and A ashes; at least 70 meters (230 ft) thick (the base of the deposit is below grade). In the Little Hole-Devils Hole reach, the thick $Qatg_7$ is interpreted as a fill deposit impounded behind a landslide dam evident in the downstream, bedrock reach.

$Qatg_9$ **Green River gravelly alluvium, terrace level 9** (lower Pleistocene) – Clast-supported, rounded, well-sorted, imbricated, cobble-pebble gravel; poorly exposed, single remnant lies within a perched, former bedrock canyon of the Green River, currently a wind gap, cut in Uinta Mountain Group bedrock ridge south of Swallow Canyon; it is about 265 meters (875 ft) above the Green River; thickness unknown.

$Qapg_1$ **Piedmont-tributary gravelly alluvium, level 1** (Holocene and upper Pleistocene[?]) – Clast-supported and minor matrix-supported, poorly to moderately sorted, subangular to subrounded, pebble-cobble gravel and sand; clasts are derived from local Uinta Mountain Group, Red Creek Quartzite, and minor other units; grades to a higher surface of $Qatg_1$, frequently appears on map as 2 to 4 meters (7–13 feet) above the grade of typical $Qatg_1$ map units; may include thin stream alluvium and colluvium in drainages developed on $Qapg_1$ deposits; as much as 5 meters (16 ft) thickness exposed in lowest tributary terraces; total thickness unknown.

$Qapg_2$ **Piedmont-tributary gravelly alluvium, level 2** (upper Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units; units represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; typical exposed thickness ranges from 3 to 8 meters (10–26 ft); full thicknesses rare.

$Qapg_3$ **Piedmont-tributary gravelly alluvium, level 3** (upper Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units; units represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; $Qapg_3$ deposits are particularly well developed and preserved in the west part of Browns Park landscape; thickness varies up to 10 m (33 ft).

$Qapg_4$ **Piedmont-tributary gravelly alluvium, level 4** (upper Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units; units represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; thickness varies up to 10 m (33 ft).

$Qapg_5$ **Piedmont-tributary gravelly alluvium, level 5** (upper to middle Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units; units represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; $Qapg_5$ deposits are particularly well developed and preserved in the west part of the Browns Park landscape; thickness varies up to 10 m (33 ft).

$Qapg_6$ **Piedmont-tributary gravelly alluvium, level 6** (middle Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units; units represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; thickness varies up to 10 m (33 ft).

$Qapg_7$ **Piedmont-tributary gravelly alluvium, level 7** (middle Pleistocene) – Clast- to matrix-supported, angular to subrounded, poorly to moderately sorted, sandy pebble to boulder gravel and gravelly sand; clasts are reworked from local bedrock units that represent alluvium of tributary streams and washes and dissected alluvial fans that grade to mainstem deposits of the same number designation; $Qapg_7$ deposits are preserved in two places—one is the Little Hole area in the west part of the map, where the deposit thins and grades downslope to the $Qatg_7$ fill deposit; it is also preserved in the east part of the map, north of the Green River along the divide between George and Beaver Creeks; thicknesses in Browns Park is up to 10 m (33 ft).

$Qapg_8$ **Piedmont gravel of Diamond Mountain Plateau, level 8** (middle Pleistocene) – Light-brown to reddish-brown, unconsolidated gravel in a sand matrix. This unit contains rounded boulders, cobbles, and pebbles of Uinta Mountain Group (up to 20 cm diameter [8 inches]) and basal rip-up clasts of Bishop Conglomerate in a fine- to coarse-grained sand matrix; clasts are poorly sorted and angular to rounded; commonly covered with vegetation; commonly overlies the Bishop Conglomerate in south- and west-draining valleys of the Diamond Plateau in south part of field area; less than 5 meters (16 ft) thick.

Colluvial Deposits

Qc **Colluvium** (Holocene and Pleistocene) – Poorly sorted, angular gravel derived by mass wasting of Uinta Mountain Group and Browns Park Formation bedrock slopes; typically, clast-supported, open-framework cobble-boulder talus that grades to surfaces of varying age and landscape position; variable thickness.

Eolian Deposits

Qes **Eolian deposits** (Holocene) – Stabilized or locally active sand sheet and coppice dune sand; well-sorted, very fine to fine-grained sand and silt;

deposits are typically located immediately downwind of the Green River floodplain and are broadly distributed as thin cover on higher terraces and piedmonts or as falling dunes on the east flank of hillslopes; as much as 8 meters (26 ft) thick.

Mass-movement Deposits

Qms **Landslide deposits** (Holocene to Pleistocene) – Slumps and slide blocks of Browns Park Formation and Uinta Mountain Group, or derived diamicton, associated with slopes undercut by trunk drainages; notable is complex of large landslides on south slope of lower Red Canyon below confluence of Red Creek, which appears to have failed along the incised formation of Outlaw Trail of the Uinta Mountain Group near river level; relative ages of mass-movement deposits were not differentiated due to reactivation of older landslides, which continue to move by slow creep, are capable of renewed movement, and pose a risk (Ashland, 2003); variable thickness.

Qmt **Talus** (Holocene to Pleistocene) – Unconsolidated deposit of purple- and mauve-colored to reddish-pink-colored boulders (up to 2 meter [6.5 ft] diameter and larger) of Uinta Mountain Group sandstone; boulders are generally well sorted and very angular; most common on steep north-facing slopes, grading downslope into Qc; bedrock outcrops of Uinta Mountain Group common within talus fields; about 10 meters (33 ft) thick.

Mixed-environment Deposits

Qac **Mixed alluvium and colluvium** (Holocene to Pleistocene) – Unconsolidated mud, silt, sand, and gravel (pebble to cobble clasts) deposited by streams, sheet wash, and slope creep; bedded to nonstratified; moderately sorted to unsorted with angular to subrounded clasts; typically mapped in broad drainages that lack a flat bottom like Qal; locally derived from bedrock units or reworked from other unconsolidated deposits; about 1 to at least 2 meters (6.5 ft) thick.

Qaes **Mixed alluvium and eolian deposits** (Holocene to Pleistocene) – Unconsolidated alluvial clay, silt, and sand mixed with windblown sand and silt; many of these deposits are on broad flat surfaces, next to drainages, and locally gradational into other surficial deposits; generally less than 10 meters (33 ft) thick.

Undivided Deposits

$Qal/Qapg_1$

(Holocene to Pleistocene) – Thin Qal that covers $Qapg_1$; see description of individual units above; Qal is less than 1 meter (3 ft) thick.

$Qapg_{3/4}$

(upper to middle Pleistocene) – Undivided $Qapg_3$ on $Qapg_4$ piedmont-tributary gravelly alluvium; see individual units above for detailed descriptions; thickness unknown.

$Qapg_{5/6}$

(upper to middle Pleistocene) – Undivided $Qapg_5$ on $Qapg_6$ piedmont-tributary gravelly alluvium; see individual units above for detailed descriptions; thickness unknown.

Bedrock Units

Tertiary

Tbp **Browns Park Formation** (Miocene to late Oligocene) – Very light gray to light-brown, fine-grained, tuffaceous, poorly to moderately consolidated sandstone; contains glass shards and rhyolite ash with local intraclastic breccias (clasts up to 5 centimeters [2 inches] diameter) in carbonate cement; well sorted with angular clasts; outcrops are generally finely laminated to thinly bedded and sometimes appear massive; sedimentary structures include low-angle tangential and planar cross-beds, soft-sediment deformation, and ripple-cross laminae; forms gentle slopes in the north part of the map area; extensive in the Browns Park area, filling most of the basin north of the Diamond Breaks; onlaps the Uinta Mountain Group along the base of the Diamond Breaks; sample TBP 12-4, (109°05'17.2" W, 40°49'56.6" N) yielded a U-Pb (zircon) age of 8.9 ± 0.6 Ma (Aslan and others, 2017); about 150 meters (492 ft) thick.

Tb **Bishop Conglomerate** (Oligocene) – Light-tan and medium- to light-gray, tuffaceous sandstone; fine- to medium-grained; poorly to moderately consolidated with grains of quartz, muscovite, and biotite; calcite cement; grains are moderately to well sorted and subangular to angular; bedding thickness is thin to medium (as much as 0.5 meter [2 feet] thick); contains low-angle cross-beds and internally cross-bedded planar bed-sets and cut-and-fill structures; sample Tbc-32614-1 (109°06'37.6" W, 40°46'19.7" N) yielded a U-Pb (zircon) age of 27.0 ± 0.3 Ma (Aslan and others, 2017); about 200 meters (656 ft) thick.

Neoproterozoic

The formations of Crouse Canyon and Diamond Breaks are divided into map units based on facies associations rather than as traditional members. The intertonguing and lateral changes of the facies associations are depicted schematically on cross section A-A′ on plate 2.

Zuct **Formation of Crouse Canyon, thickly bedded to massive facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Moderate-red, moderate reddish-brown, and moderate orange-pink quartz arenite; medium to coarse grained; grains are predominantly quartz (85% to 99%) with lesser amounts of feldspar (<5%), lithic quartzite fragments (<5%), and minor amounts (<1%) of iron oxide minerals and zircon; matrix ranges from 0.6% to 14% and contains micaceous clay minerals; cement is hematite and silica; unit is well-consolidated; thickly bedded to massive facies association dominates formation of Crouse Canyon (see Description of Facies Associations and table 1 for details); overlies the formation of Outlaw Trail with a seemingly sharp contact where exposed; contact with the overlying formation of Hades Pass is south of the quadrangle but is generally poorly exposed throughout most of the region; unit dominates the bedrock in the south part of the map area; top is not exposed in the quadrangle; about 103 to 516 meters (1090–1693 ft) thick.

Zucl **Formation of Crouse Canyon, low-angle and trough cross-bedded facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Moderate-red, moderate reddish-brown, and moderate orange-pink quartz arenite; medium to coarse grained; grains are predominantly quartz (85% to 99%) with lesser amounts of feldspar (<5%), lithic quartzite fragments (<5%), and minor amounts (<1%) of iron oxide minerals and zircon; matrix ranges from 0.6% to 14% and contains micaceous clay minerals; cement is hematite and silica; unit is well consolidated; percentage of low-angle and trough cross-bedded facies association (Zucl) is subordinate compared to the thickly bedded to massive facies association (Zuct) within the formation of Crouse Canyon (see Description of Facies Associations and table 1 for details); overlies formation of Outlaw Trail with a seemingly sharp contact where exposed; contact with the overlying formation of Hades Pass is south of the quadrangle but is generally poorly exposed throughout most of the region; 229 to 653 meters (750–2145 ft) thick.

Zuof **Formation of Outlaw Trail, fine-grained facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Pale-green, moderate yellow-green, moderate orange-pink, moderate red, moderate reddish-brown sandstone to mudstone; fine-grained; sandstone consists of quartz (78% to 86%), feldspar (12% to 19%), lithic fragments of mostly chert (0.8% to 3%), muscovite (2.2% to 10.4%), and minor amounts of hematite and biotite, hematite and silica cement; matrix consists of clay-forming minerals, mostly altered sericite, muscovite, biotite, and chlorite; unit is moderately to well consolidated; bedding is characterized by laminae to thin beds with symmetric ripples, interference ripples, mudcracks, and soft sediment deformation; characterized as the fine-grained facies association (see Description of Facies Associations and table 1 for details); formation is poorly exposed but is identified by a laterally continuous bench on aerial photographs that trends northwest to southeast across entire middle part of quadrangle, and by pieces of characteristic lithologies of float in the slope-forming topography; overlies formation of Diamond Breaks; contacts are poorly exposed, but appear abrupt; sample SCUMG-9 (-109.11044, 40.77213) yielded a SHRIMP U-Pb age of 766 ± 5 Ma (Dehler and others, 2010); 50 to 73 meters (165–240 ft) thick.

Zudt **Formation of Diamond Breaks, thickly bedded to massive facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Moderate orange-pink, very pale orange, and moderate reddish-brown quartz arenite; fine- to very coarse grained; grains are predominantly quartz (88% to 98%) with lesser amounts of feldspar (0 to 6%) and quartzite lithic fragments (0 to 6%); matrix (2.6% to 19.2%) contains clay-forming minerals (very fine grained micas); unit is well consolidated; thickly bedded to massive facies (Zudt) association grades laterally and vertically into Zudl and Zudi (see Description of Facies Associations and table 1 for details); base of the formation not exposed in quadrangle; formation of Diamond Breaks forms belt of ledgy outcrops north of formation of Outlaw Trail and south of Browns Park; about 365 to 650 meters (1200-2133 ft) thick.

Zudi **Formation of Diamond Breaks, interbedded facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Moderate orange-pink, very pale orange, and moderate reddish-brown quartz arenite; fine- to very coarse grained; grains are predominantly quartz (88% to 98%) with lesser amounts of feldspar (0 to 6%) and quartzite lithic fragments (0 to 6%); matrix (2.6% to 19.2%) contains clay-forming minerals (very fine grained micas); unit is well consolidated; interbedded facies association (Zudi) grades laterally and vertically into Zudt and Zudl (see Description of Facies Associations and table 1 for details); base of the formation not exposed in quadrangle; formation of Diamond Breaks forms belt of ledgy outcrops north of formation of Outlaw Trail and south of Browns Park; about 0 to 133 meters (0–435 ft) thick.

Zudl **Formation of Diamond Breaks, low-angle to trough cross-bedded facies, Uinta Mountain Group** (Neoproterozoic [Tonian]) – Moderate orange-pink, very pale orange, and moderate reddish-brown quartz arenite; fine- to very coarse grained; grains are predominantly quartz (88% to 98%) with lesser amounts of feldspar (0 to 6%) and quartzite lithic fragments (0 to 6%); matrix (2.6% to 19.2%) contains clay-forming minerals (very fine grained micas); unit is well consolidated; the low-angle and trough cross-bedded facies association (Zudl) grades laterally and vertically into Zudt and Zudi (see Description of Facies Associations and table 1 for details); base of formation not exposed in the quadrangle; formation of Diamond Breaks forms belt of ledgy outcrops north of formation of Outlaw Trail and south of Browns Park; about 134 to 1170 meters (440–3838 ft) thick.

Zuj **Jesse Ewing Canyon Formation** (Neoproterozoic [Tonian]) – In subsurface only within the quadrangle (see cross section on plate 2) but exposed north of Browns Park in north-adjoining quadrangle; consists of upper and lower units; upper unit is dark-gray shale (on fresh surface) interbedded with light- to medium-red-brown quartzose and lithic sandstone; medium to thick bedded; few conglomerate beds similar to conglomerate in lower unit are present but pinch out southward into shale; age based on palynomorphs recovered from dark-gray shale bed (Sprinkel and Waanders, 2005) preserved in a down-faulted block defined as basal Jesse Ewing Canyon Formation by Sanderson and Wiley (1986); 150 to 440 meters (500–1445 ft) thick; lower unit is dark- to light-red, brown, and reddish-purple, pebble to boulder conglomerate; interbedded with quartzose and lithic sandstone and some shale; clasts are subrounded to subangular, white, pale green, and pink quartzite (from Red Creek Quartzite); thick to medium bedded; fining upward in individual beds as well as in formation as a whole; 58 to 245 meters (190–800 ft) thick.

Xr **Red Creek Quartzite** (Paleoproterozoic) – In subsurface only within the quadrangle (see cross section on plate 2) but exposed north of Browns Park in north-adjoining quadrangle; contains three main rock types: metaquartzite (with some gneissic quartzite), mica schist, and amphibolite with minor amounts of epidiorite, pegmatite, and metacarbonate (marble); estimated as much as 6100 meters thick (Hansen, 1965; Sears and others, 1982).

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