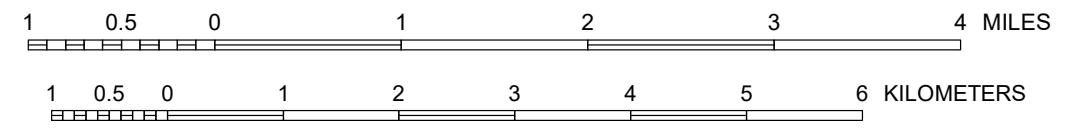
Plate 1
Utah Geological Survey Open-File Report OFR-689
Interim Geologic Map of the Duchesne 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

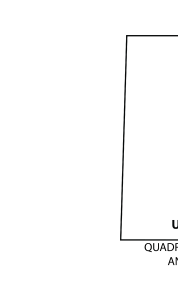
INTERIM GEOLOGIC MAP OF OF THE DUCHESNE 30' X 60' QUADRANGLE, DUCHESNE AND WASATCH COUNTIES, UTAH

by
Douglas A. Sprinkel
2018

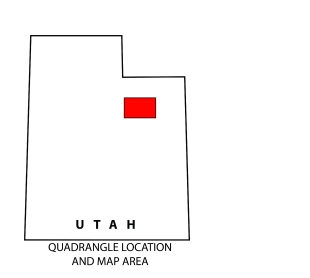
SCALE 1:62,500



CONTOUR INTERVAL 50 METERS



QUADRANGLE LOCATION AND MAP AREA



APPROXIMATE MEAN DECLINATION, 2018

This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program through U.S. Geological Survey STATEMAP Agreement Numbers G12AC20226, G13AC00169, G14AC00214, G15AC00249, and G16AC00191. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

EXPLANATION
(see Plate 2 and Booklet for Detailed Descriptions)

Unit Symbol – Unit Name

- ▨ Qh – Human disturbances, undivided
- ▨ Qhd – Earthen dams
- ▨ Qhg – Gravel pit
- ▨ Qal – River and stream alluvium
- ▨ Qat1 – Stream-terrace alluvium, level 1
- ▨ Qat2 – Stream-terrace alluvium, level 2
- ▨ Qat3 – Stream-terrace alluvium, level 3
- ▨ Qat4 – Stream-terrace alluvium, level 4
- ▨ Qat5 – Stream-terrace alluvium, level 5
- ▨ Qap2 – Piedmont alluvium, level 2
- ▨ Qap3 – Piedmont alluvium, level 3
- ▨ Qap4 – Piedmont alluvium, level 4
- ▨ Qap5 – Piedmont alluvium, level 5
- ▨ Qap6 – Piedmont alluvium, level 6
- ▨ Qafy – Alluvial-fan deposits
- ▨ Qafo – Older alluvial-fan deposits
- ▨ Qags – Glacial outwash of Smiths Fork age
- ▨ Qagb – Glacial outwash of Blacks Fork age
- ▨ Qagb? – Glacial outwash of Blacks Fork age, queried
- ▨ Qago – Glacial outwash of pre-Blacks Fork age
- ▨ Qago? – Glacial outwash of pre-Blacks Fork age, queried
- ▨ Qc – Colluvium
- ▨ Qe – Eolian deposits
- ▨ Qmf – Debris-flow deposits
- ▨ Qms – Landslide deposits
- ▨ Qms(?) – Landslide deposits, queried
- ▨ Qmt – Talus deposits
- ▨ 29 – Qgu – Glacial, periglacial, and mass-movement deposits
- ▨ 30 – Qgs – Smiths Fork till
- ▨ 31 – Qgb – Blacks Fork till
- ▨ 32 – Qgb? – Blacks Forkl till, queried
- ▨ 33 – Qgo – Pre-Blacks Fork till
- ▨ Qac – Mixed alluvium and colluvium
- ▨ Qae – Mixed alluvium and eolian deposits
- ▨ Qace – Mixed alluvium, colluvium, and eolian deposits
- ▨ Qlam – Lacustrine, alluvial, and marsh deposits
- ▨ Qmg – Mixed landslide and glacial deposits
- ▨ Qac/Tds – Alluvium and colluvium on Duchesne River Formation, Starr Flat Member
- ▨ Qac/Tdl – Mixed alluvium and colluvium on Duchesne River Formation, Lapoint Member
- ▨ Qac/Tdd – Mixed alluvium and colluvium on Duchesne River Formation, Dry Gulch Creek Member
- ▨ Qac/Tuc – Mixed alluvium and colluvium on UInta Formation, member C
- ▨ Qae/Tdd – Mixed alluvium and eolian on Duchesne River Formation, Dry Gulch Creek Member
- ▨ Qae/Tdb – Mixed alluvium and eolian on Duchesne River Formation, Brennan Basin Member
- ▨ Qae/Tuc – Mixed alluvium and eolian on Uinta Formation, member C
- ▨ Qags/Tds – Glacial outwash of Smiths Fork age on Duchesne River Formation, Starr Flat Member
- ▨ Qc/Tds – Colluvium on Duchesne River Formation, Starr Flat Member
- ▨ Qc/Tdl – Colluvium on Duchesne River Formation, Lapoint Member
- ▨ Qc/Tdd – Colluvium on Duchesne River Formation, Dry Gulch Creek Member
- ▨ Qc/Tdb – Colluvium on Duchesne River Formation, Brennan Basin Member
- ▨ Qc/Tuc – Colluvium on Uinta Formation, member C
- ▨ Qc/Tub – Colluvium on Uinta Formation, member B
- ▨ Tb – Bishop Conglomerate
- ▨ Tk – Keetley Volcanics
- ▨ Tds – Duchesne River Formation, Starr Flat Member
- ▨ Tds? – Duchesne River Formation, Starr Flat Member, queried
- ▨ Tdl – Duchesne River Formation, Lapoint Member
- ▨ Tdd – Duchesne River Formation, Dry Gulch Creek Member
- ▨ Tdb – Duchesne River Formation, Brennan Basin Member
- ▨ Tuc – Uinta Formation, member C
- ▨ Tub – Uinta Formation, member B
- ▨ Tgsl – Green River Formation, sandstone and limestone facies
- ▨ Tgss – Green River Formation, sandstone facies
- ▨ Tgs – Green River Formation, saline facies
- ▨ Tgu – Green River Formation, upper member
- ▨ Tgm – Green River Formation, middle member
- ▨ TKc – Currant Creek Formation
- ▨ 68 – Kmv – Mesaverde Group
- ▨ Km – Mancos Shale
- ▨ Kf – Frontier Formation and other units
- ▨ Kms – Mowry Shale
- ▨ Kd – Dakota Formation
- ▨ KJcm – Cedar Mountain and Morrison Formations
- ▨ Js – Stump Formation
- ▨ Jp – Preuss Formation
- ▨ Ja – Arapien Formation
- ▨ JTRn – Nugget Sandstone
- ▨ TRau – Ankareh Formation, upper member
- ▨ TRal – Ankareh Formation, lower member
- ▨ TRt – Thaynes Formation
- ▨ TRw – Woodside Formation
- ▨ Ppu – Park City-Phosphoria Formations, upper unit (Franson and Meade Peak Members, Mackentire Tongue)
- ▨ Ppg – Park City-Phosphoria Formations, lower unit (Grandeur Member)
- ▨ PIPw – Weber Sandstone
- ▨ IPm – Morgan Formation
- ▨ IPr – Round Valley Limestone
- ▨ Mdo – Doughnut Formation
- ▨ Mh – Humbug Formation
- ▨ Md – Deseret Limestone
- ▨ Mg – Gardison Limestone
- ▨ Ct – Tintic Quartzite
- ▨ W – Reservoirs, lakes, and ponds

Contacts, Faults, Scarps, and Glacial Features

- Bed, marker, Gartra Member, approximately located
- Bed, marker, Gartra Member, well located
- Bed, marker, Horse Bench Sandstone, well located
- Bed, marker, Mahogany oil-shale bed, well located
- Contact, approximately located
- Contact, gradational, approximately located
- Contact, well located
- Crest, moraine, symmetrical
- Fault, normal, approximately located
- Fault, normal, approximately located, queried
- Fault, normal, concealed
- Fault, normal, concealed, queried
- Fault, normal, well located
- Fault, oblique-slip, left-lateral, approximately located
- Fault, oblique-slip, left-lateral, concealed
- Fault, oblique-slip, left-lateral, well located
- Fault, oblique-slip, right-lateral, approximately located
- Fault, oblique-slip, right-lateral, concealed
- Fault, oblique-slip, right-lateral, well located
- Fault, thrust, approximately located
- Fault, thrust, approximately located, queried
- Fault, thrust, concealed
- Fault, thrust, concealed, queried
- Fault, thrust, well located
- Fault, thrust, with later normal offset, approximately located
- Fault, thrust, with later normal offset, concealed
- Fault, thrust, with later normal offset, well located
- Fault, offset unknown, well located
- Ice-margin channel
- Scarp, landslide, well located

Gilsonite

- Gilsonite, concealed
- Gilsonite, well located

Folds

- Anticline, upright, concealed
- Anticline, upright, well located
- Fold, monocline, concealed
- Fold, monocline, well located
- Syncline, asymmetrical, concealed, queried
- Fold, syncline, upright, well located

Point Data

- Bedding, horizontal, field measured
- Bedding, horizontal, photogrammetric (3-point)
- Bedding, inclined, field measured
- Bedding, inclined, photogrammetric (3-point)
- Fault, dip, field measured
- Paleocurrent, field measured
- Sample, isotopic with ID Number

Base from USGS Duchesne 30' x 60' Quadrangle (1982)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Jon K. King
Program Manager: Grant C. Willis
GIS and Cartography: Douglas A. Sprinkel and Kent D. Brown

Utah Geological Survey
1594 West North Temple, Suite 3110
Salt Lake City, UT 84116
(801) 537-3300
geology.utah.gov

This map was created from geographic information system (GIS) data.

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE DUCHESNE 30' X 60' QUADRANGLE, DUCHESNE AND WASATCH COUNTIES, UTAH

by

Douglas A. Sprinkel

2018

DISCLAIMER

This open-file release makes information available to the public during the review and production period necessary for a formal UGS publication. The map may be incomplete, and inconsistencies, errors, and omissions have not been resolved. While the document is in the review process, it may not conform to UGS standards; therefore, it may be premature for an individual or group to take actions based on its contents. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. Mapping intended for use at 1:62,500 scale.

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award numbers G12AC20226, G13AC00169, G14AC00214, G15AC00249, and G16AC00191. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

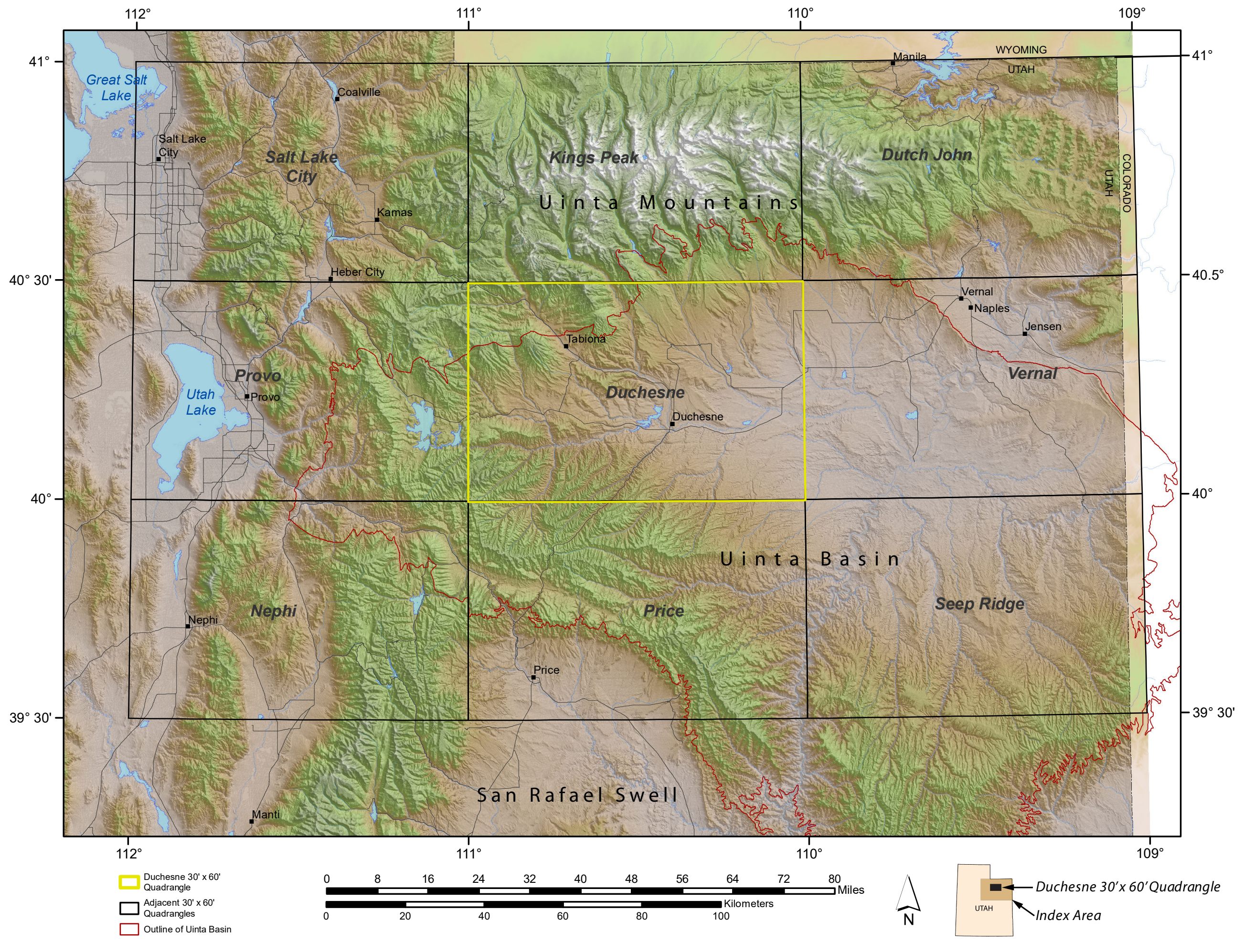
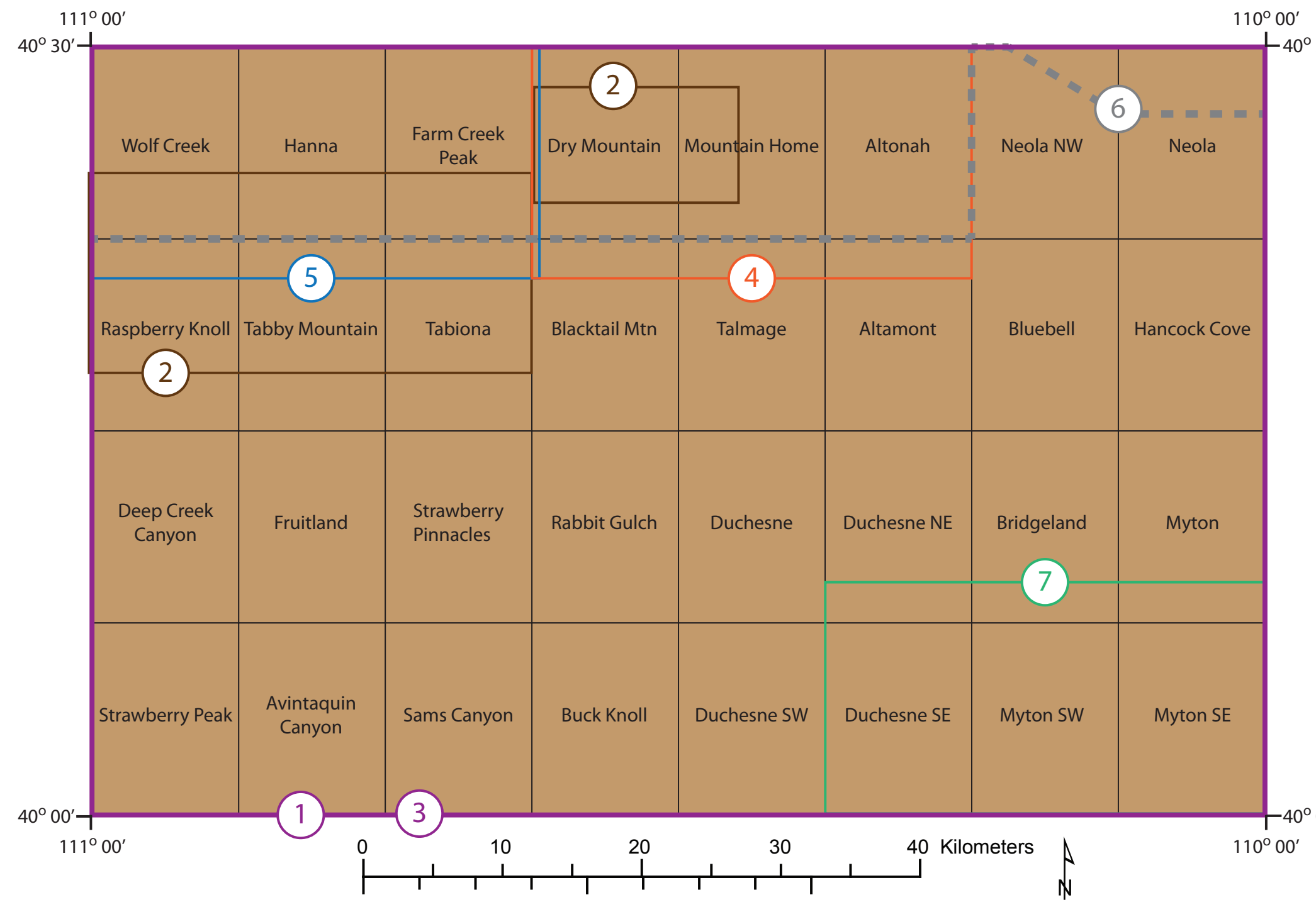


Figure 1. The Duchesne 30' x 60' quadrangle (yellow box) is located in the western part of the Uinta Basin. The northwest corner of the quadrangle extends onto the southwest flank of the Uinta Mountains.



① Bryant, B., 1992, Geologic and structure maps of the Salt Lake City 1° x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1997, 2 plates, scale 1:125,000.

② Doelling, H.H., and Graham, R.L., 1972, Eastern and northern coal fields-Vernal, Henry Mountains, Sego, La Sal-San Juan, Tabby Mountain, Coalville, Henrys Fork, Goose Creek, and Lost Creek: Utah Geological and Mineralogical Survey Monograph 2, 411 p., multiple plates, scale ~1:42,240.

③ Elliott, A.H., and Harty, K.M., 2010, Landslide maps of Utah: Utah Geological Survey Map 246DM, 14 p., plate 15 of 46, scale 1:100,000, GIS Data.

④ Huddle, J.W., Mapel, W.J., and McCann, F.T., 1951, Geology of the Moon Lake area, Duchesne County, Utah: U.S. Geological Survey Oil and Gas Investigations Map OM 115, 1 plate, scale 1:63,360.

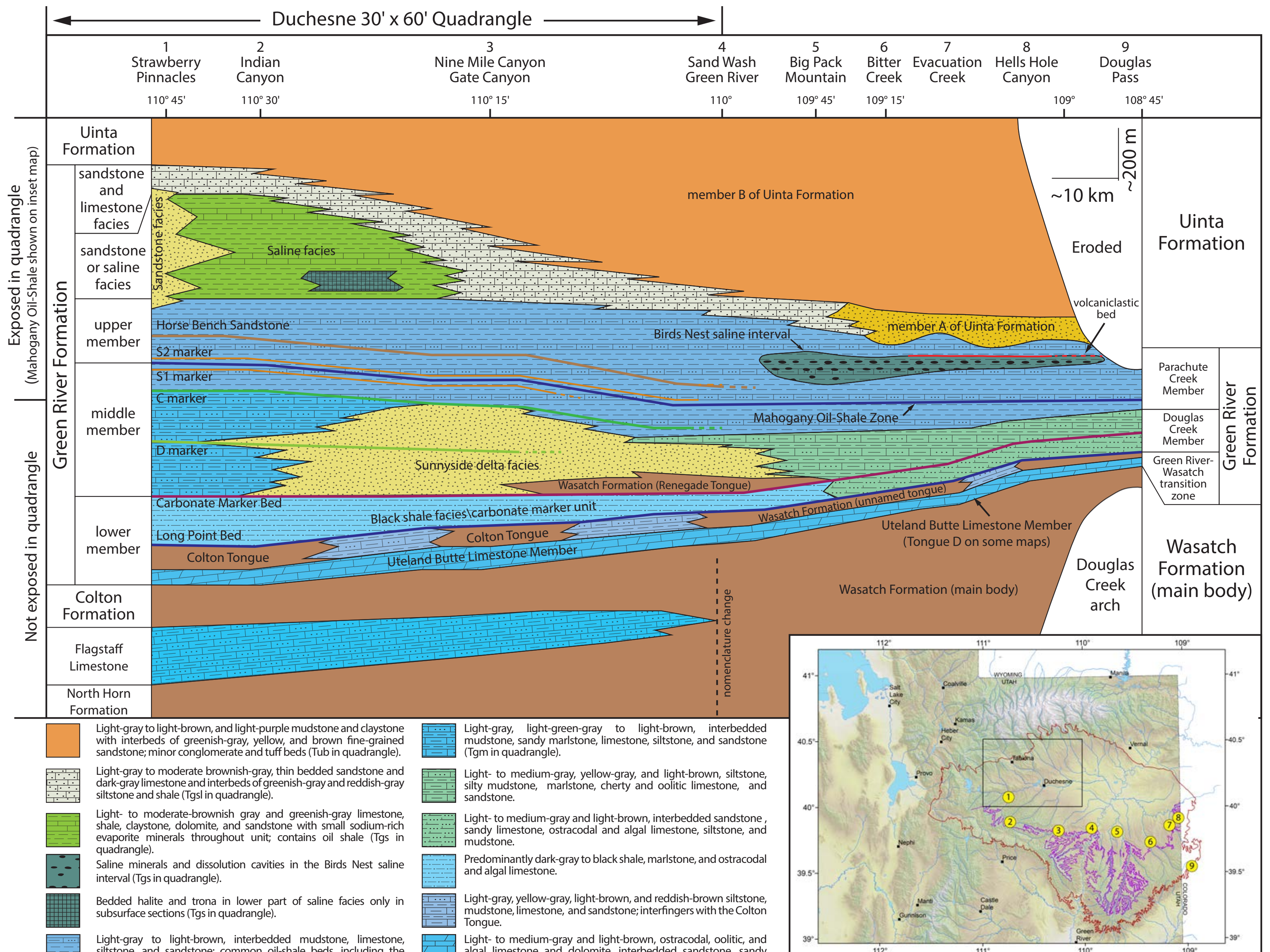
⑤ Huddle, J.W., and McCann, F.T., 1947, Geologic map of the Duchesne River area, Wasatch and Duchesne Counties, Utah: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 75, 1 plate, scale 1:63,360.

⑥ Munroe, J.S., and Laabs, B.J.C., 2009, Glacial geologic map of the Uinta Mountains area, Utah and Wyoming: Utah Geological Survey Miscellaneous Publication 09-4DM, 1 plate, scale 1:100,000.

⑦ Ray, R.G., Kent, B.H., and Dane, C.H., 1956, Stratigraphy and photogeology of the southwestern part of the Uinta Basin, Duchesne and Uintah Counties, Utah: U.S. Geological Survey Oil and Gas Investigations Map OM 171, 2 plates, scale 1:63,360.

▨ This map.

Figure 2. Index of 7.5-minute quadrangles and previous geologic maps within the Duchesne 30' x 60' quadrangle that were used to construct this geologic map.



- Light-gray to light-brown, and light-purple mudstone and claystone with interbeds of greenish-gray, yellow, and brown fine-grained sandstone; minor conglomerate and tuff beds (Tub in quadrangle).
- Light-gray to moderate brownish-gray, thin bedded sandstone and dark-gray limestone and interbeds of greenish-gray and reddish-gray siltstone and shale (Tgsl in quadrangle).
- Light- to moderate-brownish gray and greenish-gray limestone, shale, claystone, dolomite, and sandstone with small sodium-rich evaporite minerals throughout unit; contains oil shale (Tgs in quadrangle).
- Saline minerals and dissolution cavities in the Birds Nest saline interval (Tgs in quadrangle).
- Bedded halite and trona in lower part of saline facies only in subsurface sections (Tgs in quadrangle).
- Light-gray to light-brown, interbedded mudstone, limestone, siltstone, and sandstone; common oil-shale beds, including the Mahogany oil-shale zone (base of Tgu and upper Tgm in quadrangle).
- Light-brown-gray to light-green-gray sandstone (Tgss in quadrangle); Sunnyside delta facies also includes greenish-gray shale and siltstone and thin interbedded limestone.
- Light-gray, light-green-gray to light-brown, interbedded mudstone, sandy marlstone, limestone, siltstone, and sandstone (Tgm in quadrangle).
- Light- to medium-gray, yellow-gray, and light-brown, siltstone, silty mudstone, marlstone, cherty and oolitic limestone, and sandstone.
- Light- to medium-gray and light-brown, interbedded sandstone , sandy limestone, ostracodal and algal limestone, siltstone, and mudstone.
- Predominantly dark-gray to black shale, marlstone, and ostracodal and algal limestone.
- Light-gray, yellow-gray, light-brown, and reddish-brown siltstone, mudstone, limestone, and sandstone; interfingers with the Colton Tongue.
- Light- to medium-gray and light-brown, ostracodal, oolitic, and algal limestone and dolomite, interbedded sandstone, sandy limestone, siltstone, and shale.
- Variegated siltstone, mudstone, sandstone, and conglomerate beds with sparse thin limestone.

Figure 5. Correlation diagram of the Green River Formation across the southern Uinta Basin. Colors are not the same as those on map. Modified from Töro and Pratt (2015) with other sources of Cashion (1967), Johnson and others (1988), Fouch and others (1994), Morgan and others (2003), Smith and others (2008), Johnson and others (2010), Tänavsuu-Milkevicience and Sarg (2012), and Vanden Berg and others (2013).

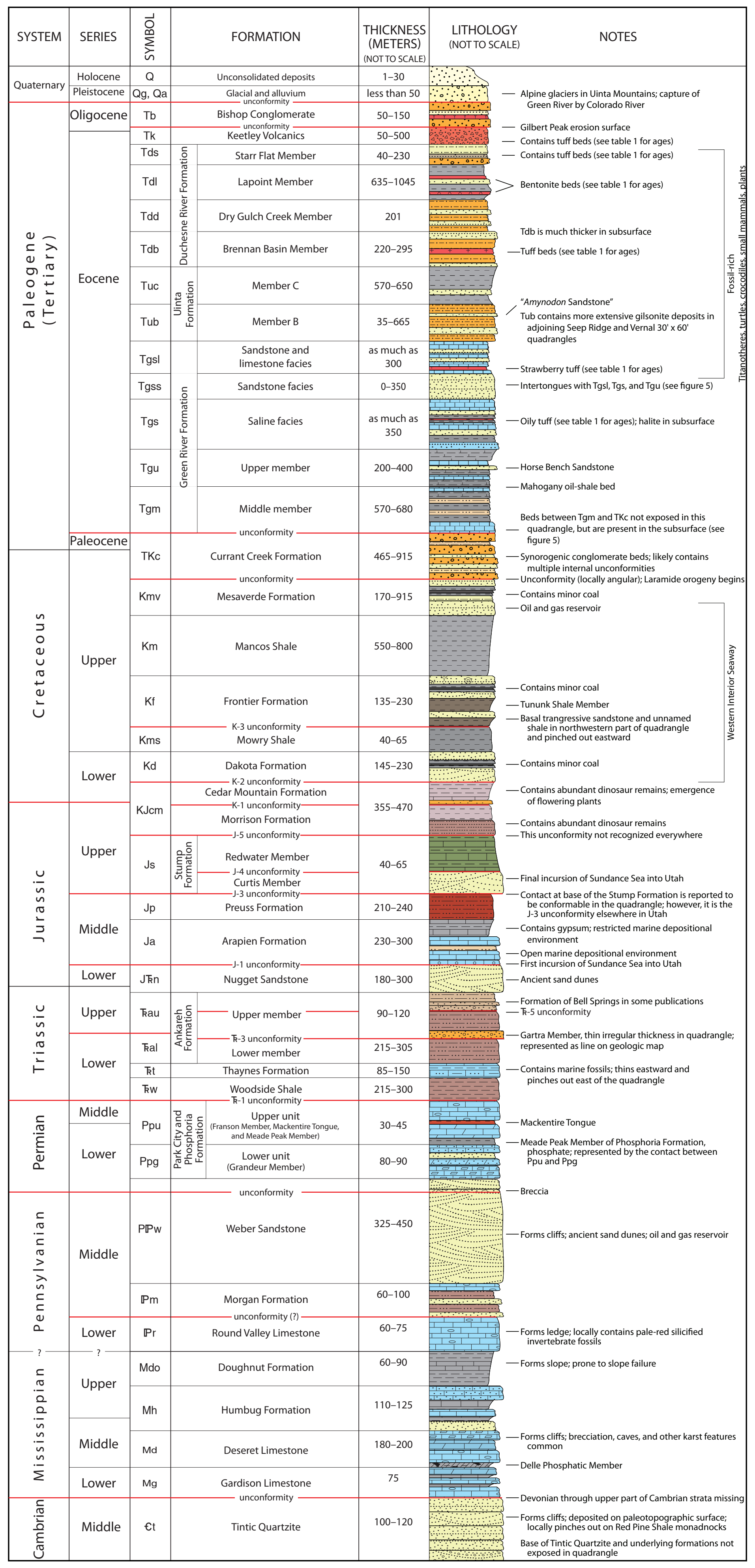


Figure 3. Stratigraphic column of bedrock units in the Duchesne 30' x 60' quadrangle. Colors in the lithologic column broadly represent typical outcrop colors and not map colors. Red lines are major unconformities.

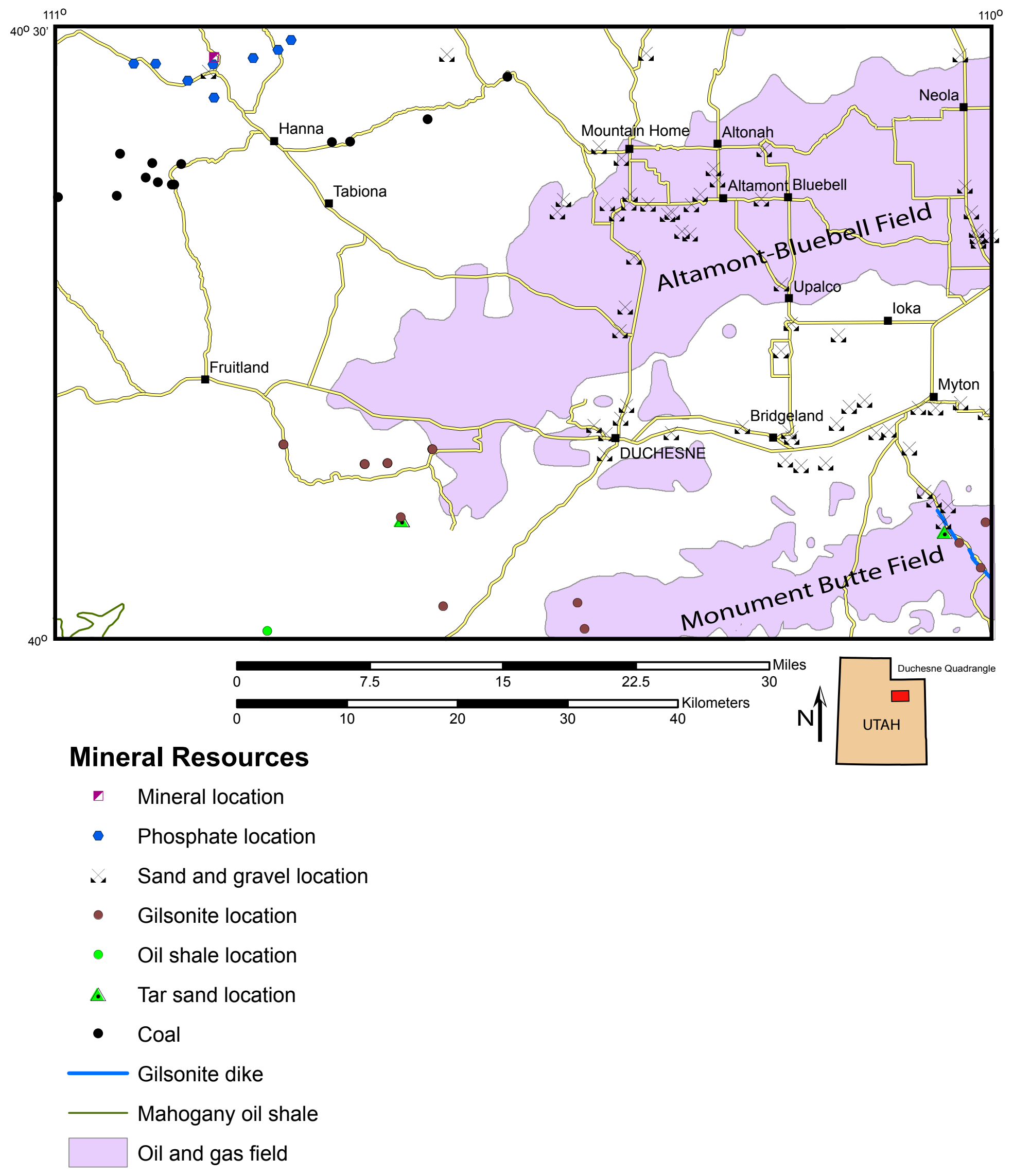
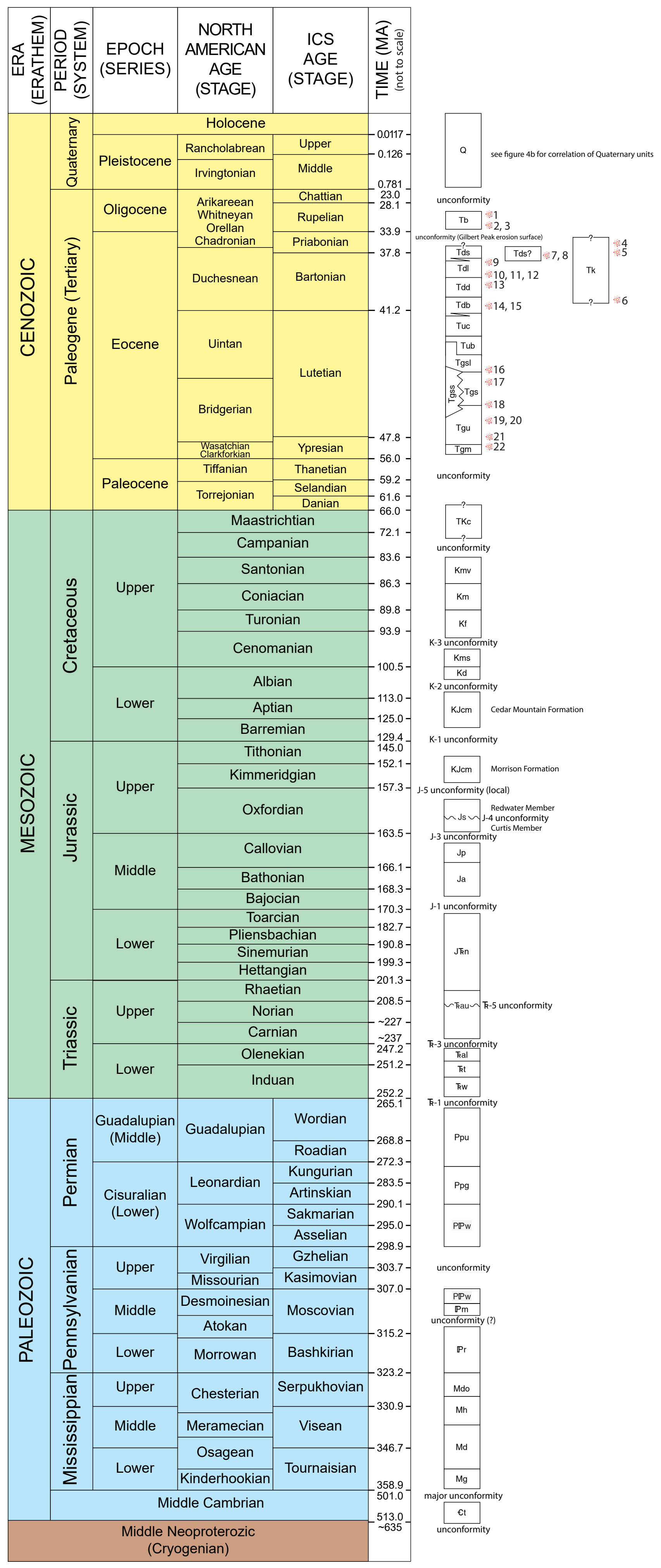
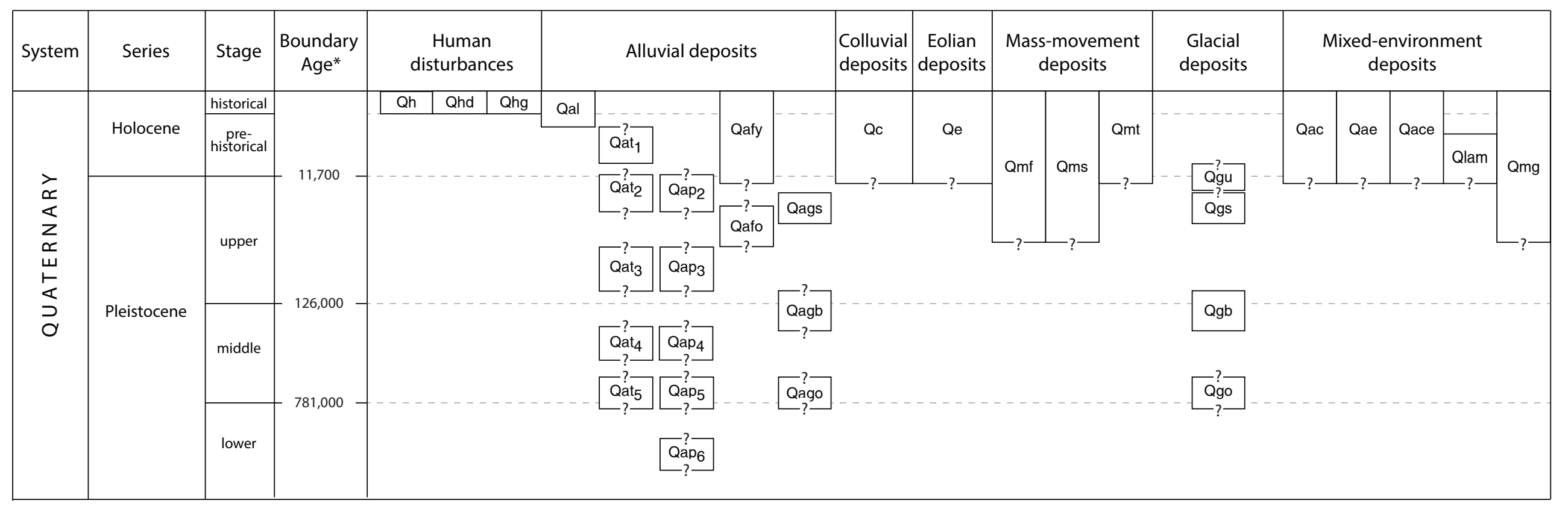


Figure 6. Location of geologic resources within the Duchesne 30' x 60' quadrangle.



* Boundary ages for series are from Cohen and others (2013); Ma=10⁶ years

Figure 4a. Correlation of bedrock map units. Red symbol and corresponding numbers represent isotopic ages found in table 1.



* Boundary age (in years B.P.) for series and stages are from Cohen and others (2013)

Figure 4b. Correlation of surficial map units.

Table 1. *Summary of isotopic age analyses of Tertiary formations in stratigraphic order from the Duchesne and surrounding 30' x 60' quadrangles.*

Figure 4a and Map ID Number	Sample Number	Map Unit	Rock Name	Formation Name	Age ± 2sd (Ma)	Analysis	Material Dated	Laboratory	Reference/Report	Latitude (N) NAD27	Longitude (W) NAD27	7.5' Quadrangle	30' x 60' Quadrangle
1	DJ-1	Tb	Altered Tuff	Bishop Conglomerate	30.54 ± 0.22	$^{40}Ar/^{39}Ar$	Sanidine	Nuclear Science Center, Texas A&M University (TAMU), College Station, TX[1]	Kowallis and others (2005)	40° 36' 10.7"	109° 18' 29.7"	Jensen Ridge	Dutch John
2	DJ-9	Tb	Altered Tuff	Bishop Conglomerate	34.03 ± 0.04	$^{40}Ar/^{39}Ar$	Sanidine	Nuclear Science Center, Texas A&M University (TAMU), College Station, TX[1]	Kowallis and others (2005)	40° 28' 35.6"	109° 05' 45.0"	Stunz Reservoir	Dutch John
3	DJ-8	Tb	Altered Tuff	Bishop Conglomerate	34.07 ± 0.04	$^{40}Ar/^{39}Ar$	Sanidine	Nuclear Science Center, Texas A&M University (TAMU), College Station, TX[1]	Kowallis and others (2005)	40° 28' 35.0"	109° 05' 44.8"	Stunz Reservoir	Dutch John
4	KNC92799-6	Tk*	Altered Tuff	Keetley Volcanics ("base")	37.25 ± 0.14	$^{40}Ar/^{39}Ar$	Hornblende	New Mexico Geochronology Research Laboratory, Socorro, NM[2]	Constenius and others (2011)	40° 22' 17.8"	111° 10' 19.8"	Co-op Creek	Provo
5	KNC6901-1	Tk*	Altered Tuff	Keetley Volcanics	38.20 ± 0.11	$^{40}Ar/^{39}Ar$	Sanidine	New Mexico Geochronology Research Laboratory, Socorro, NM[3]	Constenius and others (2011)	40° 44.483	111° 20.857"	Kamas	Salt Lake City
6	KNC92799-5	Tk*	Altered Tuff	Keetley Volcanics	40.45 ± 0.18	$^{40}Ar/^{39}Ar$	Hornblende	New Mexico Geochronology Research Laboratory, Socorro, NM[2]	Constenius and others (2011)	40° 22' 21.9"	111° 10' 19.3"	Co-op Creek	Provo
7	KNC070109-1	Tds?	Altered Tuff	Queried Duchesne River Fm, Starr Flat Member in this report**	38.90 ± 0.80	U-Pb	Zircon	Arizona LaserChron, Unversity of Arizona, Tucson, AZ[4]	Constenius and others (2011)	40° 23.240'	111° 00.908'	Wolf Creek Summit	Provo
8	KNC070109-2	Tds?	Altered Tuff	Queried Duchesne River Fm, Starr Flat Member in this report**	39.60 ± 0.70	U-Pb	Zircon	Arizona LaserChron, Unversity of Arizona, Tucson, AZ[4]	Constenius and others (2011)	40° 23.245'	111° 01.005'	Wolf Creek Summit	Provo
9	DRF-A	Tdl	Altered Tuff	Duchesne River Fm, Lapoint Member	39.47 ± 0.16	$^{40}Ar/^{39}Ar$	Plagioclase	WiscAr Lab, University of Wisconsin, Madison, WI[3]	Webb (2017); Webb and others (2017); Jensen (2017)	40° 29' 28.9"	109° 41' 28.94"	Vernal NW	Vernal
10	LP1	Tdl	Bentonite	Duchesne River Fm, Lapoint Member	39.74 ± 0.17	$^{40}Ar/^{39}Ar$	Biotite	Berkley Geochronology Center, University of California, Berkley, CA[5]	Prothero and Swisher (1992)	Not reported	Not reported	Vernal NW	Vernal
11	LP-2005-6-3-1	Tdl	Bentonite	Duchesne River Fm, Lapoint Member	41.52 ± 0.13	$^{40}Ar/^{39}Ar$	Biotite	New Mexico Geochronology Research Laboratory, Socorro, NM[6]	Kowallis and others (unpublished)/NMGRL-IR-561***	40° 25.146'	109° 45.678'	Lapoint	Vernal
12	LP-2005-6-3-3	Tdl	Bentonite	Duchesne River Fm, Lapoint Member	41.53 ± 0.61	$^{40}Ar/^{39}Ar$	Biotite	New Mexico Geochronology Research Laboratory, Socorro, NM[6]	Kowallis and others (unpublished)/NMGRL-IR-561***	40° 25.146'	109° 45.678'	Lapoint	Vernal
13	DRF-H	Tdd	Altered Tuff	Duchesne River Fm, Dry Gulch Creek Member	39.36 ± 0.15	$^{40}Ar/^{39}Ar$	Sanidine	WiscAr Lab, University of Wisconsin, Madison, WI[3]	Webb (2017); Webb and others (2017); Jensen (2017)	40° 24' 59.4"	109° 44' 47.6"	Vernal NW	Vernal
14	HC08122012-1	Tdb	Altered Tuff	Duchesne River Fm, Brennan Basin Member	40.66 ± 1.88	U-Pb	Zircon	Apatite to Zircon, Inc., Moscow, ID[7]	Utah Geological Survey and Apatite to Zircon (2014)	40° 18' 02.89"	110° 04' 58.03"	Hancock Cove	Duchesne
15	LM-2004-1	Tdb	Altered Tuff	Duchesne River Fm, Brennan Basin Member	41.10 ± 0.32	$^{40}Ar/^{39}Ar$	Biotite	New Mexico Geochronology Research Laboratory, Socorro, NM[6]	Kowallis and others (in review)/NMGRL-IR-561	40° 32' 52.68"	109° 52' 09.87"	Lake Mountain	Dutch John
16	SR-1	Tgsl	Altered Tuff	Green River Fm, sandstone-limestone facies, Strawberry tuff	44.00 ± 0.92	$^{40}Ar/^{39}Ar$	Sanidine	University of Oregon, Eugene, OR[8]	Smith and others (2008)	40° 09' 54.0"	110° 33' 5.6"	Rabbit Gulch	Duchesne
17	IC-6	Tgs	Altered Tuff	Green River Fm, saline facies, Oily tuff	45.14 ± 0.10	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[8]	Smith and others (2008)	40° 02' 56.8"	110° 31' 42.1"	Buck Knoll	Duchesne
18	IC-5	Tgu	Altered Tuff	Green River Fm, saline facies-upper member contact, Portly tuff	45.58 ± 0.14	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[8]	Smith and others (2008)	39° 50' 47.6"	110° 37' 16.3"	Minnie Maud Creek East	Price
19	IC-2	Tgu	Altered Tuff	Green River Fm, upper member, Fat tuff	46.34 ± 0.14	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[9]	Smith and others (2008)	39° 58' 46.5"	110° 37' 6.9"	Lance Canyon	Price
20	SW-1	Tgu	Altered Tuff	Green River Fm, upper member, Blind Canyon tuff	47.04 ± 0.18	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[8]	Smith and others (2008)	39° 50' 41.4"	110° 11' 11.8"	Cowboy Bench	Price
21	GC-2b	Tgu	Altered Tuff	Green River Fm, upper member, Wavy tuff	48.37 ± 0.23	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[9]	Smith and others (2008)	39° 50' 59.3"	110° 15' 17.5"	Currant Canyon	Price
22	GC-5b	Tgm	Altered Tuff	Green River Fm, upper-middle member contact, Curly tuff	49.02 ± 0.30	$^{40}Ar/^{39}Ar$	Biotite	University of Oregon, Eugene, OR[9]	Smith and others (2008)	39° 50' 33.8"	110° 15' 3.1"	Currant Canyon	Price

*Tk-Keetley Volcanics K-Ar ages summarized in Biek (2017)
**Uinta Formation, boulder conglomerate in Constenius and others (2011)
***NMGRL-New Mexico Geochronology Laboratory Report

[1] Combined single- and multi-crystal CO_2 (fusion)
[2] Furnace step-heating
[3] Single-crystal CO_2 (fusion)
[4] Not reported, but laser-ablation, inductively-coupled-plasma, mass spectrometry
[5] Single-crystal laser-fusion
[6] Furnace incremental heating
[7] Laser ablation-inductively coupled plasma-mass spectrometry
[8] Single-crystal (incremental heating) and multi-crystal CO_2 (fusion)
[9] Single-crystal (incremental heating)

Table 2. Height (meters) of major terrace and alluvial deposits above drainages and younger units. The elevation range (meters) of the drainages associated with deposits is also shown.

Unit	Qat_1	Qat_2	Qat_3	Qat_4	Qat_5	Qap_2	Qap_3	Qap_4	Qap_5	Qap_6
Minimum	3	20	50	70	100	25	50	70	120	225
Maximum	6	45	70	90	300	40	70	90	210	580
Average Height Above Drainage	5	33	60	80	200	33	60	80	165	403
Average Height Above Younger Unit		28	28	20	120		28	20	85	238
Drainage Elevation Range (north to south)	2050–1535	1820–1570	1850–1585	2065–1595	2185–1695	1920–1585	1990–1620	2045–1770	2240–1785	2750–2180

Interim Geologic Map of the Duchesne 30′ x 60′ Quadrangle, Duchesne and Wasatch Counties, Utah

by

Douglas A. Sprinkel

Disclaimer

This open-file release makes information available to the public during the review and production period necessary for a formal UGS publication. The map may be incomplete, and inconsistencies, errors, and omissions have not been resolved. While the document is in the review process, it may not conform to UGS standards; therefore, it may be premature for an individual or group to take actions based on its contents. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. Mapping intended for use at 1:62,500 scale.

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP award numbers G12AC20226, G13AC00169, G14AC00214, G15AC00249, and G16AC00191. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 689
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2018

STATE OF UTAH
Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES
Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY
Richard G. Allis, Director

PUBLICATIONS
contact
Natural Resources Map & Bookstore
1594 W. North Temple
Salt Lake City, UT 84116
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
website: mapstore.utah.gov
email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
website: geology.utah.gov

CONTENTS

ABSTRACT

This geologic map of the Duchesne 30′ x 60′ quadrangle is the result of five years of new mapping aided by previous mapping. Approximately centered on the town of Duchesne, Utah, the Duchesne County seat, the quadrangle covers most of the western Uinta Basin. Tertiary rocks of the Green River, Uinta, and Duchesne River Formations dominate the bedrock units in the quadrangle. Members of the formations are recognized and mapped throughout the Duchesne quadrangle despite the coarsening of these members in the western half of the quadrangle. In the northwest corner of the map area, Cambrian and Mississippian through Cretaceous rocks are exposed on the southwest flank of the Uinta Mountains. The map area includes a variety of Quaternary-age surficial deposits including glacial deposits from the Uinta Mountains, multiple levels of stream and fan alluvium that record downcutting in the basin, and landslides.

Major structural geologic features in the map area include (1) the Uinta Basin syncline and the related Uinta Basin-Mountain boundary fault zone, which locally offsets Quaternary deposits, (2) the Duchesne fault zone, (3) nearly conjugant normal and oblique-slip faults in the northwest part of the map area, and (4) north-trending normal faults along the western boundary of the map area. Unconformities in the Upper Cretaceous Mesaverde Formation through the Eocene Duchesne River Formation record the timing of the Laramide uplift of the Uinta Mountains and the slightly older folding and faulting of the Sevier orogeny.

The most significant geologic resources within the Duchesne 30' x 60' quadrangle are oil and gas from the prolific Altamont-Bluebell and Monument Butte fields. Other exploited and potential geologic resources include phosphate, coal, sand and gravel, gilsonite, oil shale, and tar sand.

INTRODUCTION

The Duchesne 30′ x 60′ quadrangle is located mostly in the western Uinta Basin with the northwest corner extending onto the southwest flank of the Uinta Mountains (plate 2, figure 1). For this fifth and final year of mapping, six 7.5-minute quadrangles were mapped, which completes the mapping for all 32 quadrangles in the 30′ x 60′ quadrangle (plate 2, figure 2). The Duchesne 30′ x 60′ quadrangle includes the towns of Altamont, Altonah, Bridgeland, Duchesne (Duchesne County seat), Fruitland, Mountain Home, Tabiona, and Talmage.

Previously published geologic maps in the Duchesne 30′ x 60′ quadrangle include the geologic map of the Duchesne River area (Huddle and McCann, 1947b), the geologic map of the southwestern part of the Uinta Basin (Ray and others, 1956), geologic maps associated with a coal resources study in the northwest part of the quadrangle (Doelling and Graham, 1972), part of the geologic map of the Salt Lake City 1° x 2° quadrangle (Bryant, 1992), and landslide compilation maps (Harty, 1992; Elliott and Harty, 2010) (plate 2, figure 2). These maps were used as guides for geologic mapping in the field and compilation in the office. Regional and local field traverses were made to collect point data for bedding attitudes, contacts, rock descriptions, and samples.

All field data were collected using digital methods. Bedding attitudes were collected using the Rocklogger app on an Android device and were spot-checked using a Brunton compass. Three-point solutions were calculated using GeolMapExtractor v. 4.0 (Allmendinger and Judge, 2013) to provide bedding attitudes in key areas that lacked field measurements. The digital data were imported into ArcMap to compile and construct line, point, and polygon vector data, assisted by using high-resolution Google imagery and stereo aerial photography. The geology was mapped to fit 1:24,000-scale topographic base maps and orthophotographic images, and thus locally does not fit to the 1:100,000-scale topographic base map. Additional fieldwork was conducted to check specific areas of the completed map.

GEOLOGY OF DUCHESNE 30′ x 60′ QUADRANGLE

Stratigraphy

The exposed rock record within the map area reveals a part of the geologic history of the Uinta Mountains and Uinta Basin. Geologic map units in the quadrangle include 38 bedrock formations and members (plate 2, figures 3 and 4a), and a variety of unconsolidated to poorly consolidated surficial deposits (plate 2, figure 4b). Bedrock map units range from Cambrian through Tertiary (Oligocene) age and are interpreted as being deposited in marine, marginal marine and non-marine (synorogenic, fluvial, and lacustrine) environments (plate 2, figure 3). Several regional and local unconformities separate many of the formations and are indicated on plate 2 (figures 3 and 4a), in the description of map units, and in the following text. Surficial deposit map units are Pleistocene and Holocene (Quaternary) in age and include alluvium, colluvium, eolian, mass-movement, glacial, and mixed-environment deposits (plate 2, figure 4b). Some areas are also mapped as human disturbances where human activities, such as large gravel pits and earthen dams, and other engineered fills, have obscured the original geology.

Cambrian Stratigraphy

The oldest exposed bedrock unit in the map area is the Cambrian Tintic Quartzite, which crops out in the northwestern part of the quadrangle between forks of the Duchesne River. Williams (1953) recognized the “Pine Valley” strata of Forrester (1937) as the Tintic Quartzite; furthermore, he recognized the angular unconformity that separated the Tintic Quartzite from the underlying Red Pine Shale (not exposed in the map area). The Tintic was deposited, in part, during the first Paleozoic marine incursion into the quadrangle after a hiatus that may have lasted as much as about 230 million years. During the hiatus, the underlying strata were eroded, forming a paleotopographic surface on which the Tintic was unevenly deposited (Williams, 1953); however, elsewhere along the flanks of the Uinta Mountains, geologic units of several different ages were deposited on the paleotopographic surface where the Tintic is missing. Regional thickness of the Tintic varies because of the paleotopography as well as post-deposition erosion. In the quadrangle, the Tintic is 120 m thick, but north of the quadrangle I have observed that it pinches out on the flank of a Red Pine topographic high a few kilometers upstream along the North Fork of the Duchesne River. No fossils have been found in the Tintic in the map area, but brachiopods of Middle Cambrian age were found in the uppermost beds of the Tintic at Iron Mine Mountain, north of the quadrangle (Williams, 1953; Lochman-Balk, 1959). The Tintic and overlying Mississippian strata are separated by a major unconformity of about 140 million years; at least Upper Cambrian through Devonian rocks are missing.

Mississippian Stratigraphy

The Mississippian section includes, in ascending stratigraphic order, the Gardison Limestone, Deseret Limestone, Humbug Formation, and Doughnut Formation. The Gardison unconformably overlies the Tintic or the Red Pine Shale, depending on the presence of the Tintic, and underlies the Humbug Formation. Previous workers had mapped the Gardison and Deseret Limestones as Madison and Deseret (Huddle and McCann, 1947b) or as Madison Limestone (Bryant, 1992). I chose to extend the term Gardison Limestone into the southwest flank of the Uinta Mountains because of its similar lithology and age to the Gardison exposed in the nearby Wasatch Range (Crittenden, 1959; Morris and Lovering, 1961; Sandberg and Gutschick, 1980, 1984), and because it underlies the Delle Phosphatic Member of the Deseret Limestone. The Gardison forms steep massive-weathering cliffs of lower dark-gray, thin-bedded, cherty limestone and dolomitic limestone, with interbedded dark-gray shale, about 75 m thick. The overlying Deseret Limestone also forms steep cliffs but is light- to dark-gray limestone and dolomitic limestone. The basal Deseret exposed above the Duchesne River drainage includes a dark-gray, phosphatic shale and cherty limestone (Baker and others, 1949; Sadlick, 1957) that is likely the Delle phosphatic interval (Sandberg and Gutschick, 1980, 1984). Brecciation and karst features are common in the upper limestone of the Deseret Limestone and are quite evident in outcrop along the Duchesne River. The Deseret Limestone is about 180 to 200 m thick. An Early Mississippian (Kinderhookian) age is assigned to the Gardison Limestone (Sadlick, 1957) and an Early to Middle Mississippian (Osagean to early Meramecian) age is assigned to the Deseret based on fossils from outside of the map area (Sadlick, 1955, 1957; Sandberg and Gutschick, 1980). The Mississippian Humbug and Doughnut Formations overlie the Deseret and underlie the Pennsylvanian Round Valley Limestone. Both formations tend to be poorly exposed, although the Humbug has areas of moderately good outcrops on steep slopes because it is moderately resistant sandstone and sandy limestone. The Doughnut is characteristically poorly exposed and forms strike valleys or recessed dark-colored slopes that are prone to slope failure. Sparse fossil evidence from outside the map area indicates the age of the Humbug is Middle to Late Mississippian (middle Meramecian to Chesterian) (Sadlick, 1957; Sandberg and others, 1982). The age of the Doughnut is Late Mississippian (Chesterian) based on fossil foraminifera, brachiopods, and ammonoids in the upper Doughnut carbonates where present (Sadlick, 1955, 1957).

Pennsylvanian and Permian Stratigraphy

The Early Pennsylvanian Round Valley Limestone can be a good marker bed because of its distinctive red chert and tendency to be a resistant, ledge-forming unit sandwiched between less resistant units of the underlying slope-forming, dark-colored Doughnut and overlying reddish-colored Morgan Formations. The Round Valley is exposed in the cliffs of the Duchesne River in the northwest part of the quadrangle. Fossil mollusks, fusulinids, and conodonts indicate that the Round Valley is Early Pennsylvanian (Morrowan and Atokan) in age (Thompson, 1945; Bissell, 1950; Sadlick, 1955, 1957; Dunn, 1970). Late Mississippian (Chesterian) conodonts have been reported by Carey (1973) from the basal limestone bed of the Round Valley Limestone; however, Jon King (Utah Geological Survey, written communication, 2017) indicated that Carey misidentified the unit from which the samples were collected. The overlying Morgan Formation typically forms reddish-colored slopes because of interbedded reddish, light-brown, and grayish sandstone, siltstone, and shale. The contact between the Round Valley Limestone and Morgan Formation may be unconformable. Thompson (1945) reported that the top of the Round Valley Limestone (his Belden Formation) is irregular and is overlain by a coarse conglomerate of the basal Morgan (his Hells Canyon Formation). In addition, Thompson (1945, p. 29) reported that fossil fusulinids identified from the Hells Canyon Formation (lower Morgan) are typically Desmoinesian, suggesting that the lower Middle Pennsylvanian (Atokan) may be in part or entirely missing. Desmoinesian fusulinid fossils collected from limestone beds in the Morgan Formation near the contact with the overlying Weber Sandstone indicate the formation is Middle Pennsylvanian age (Williams, 1943; Thompson, 1945; Baker and others, 1949; Bissell, 1950; Sadlick, 1955).

The Pennsylvanian-Permian Weber Sandstone is an easily recognizable unit that generally forms steep, light-colored cliffs that exhibit large-scale cross-bedding interpreted as eolian dunes by Fryberger (1979). Large accumulations of talus are common at the base of the Weber Sandstone, obscuring the contact with the underlying Morgan. The type section of the Morgan does not intertongue with the Weber, but is instead tectonically interleaved by thrust faulting (Coogan and others, 2015). Where the contact is exposed in the Duchesne quadrangle, intertonguing relationships between the mostly reddish-colored Morgan and mostly large-scale cross-bedded Weber can be locally observed, which suggests a gradual shift in deposition from marine to coastal dune environments. The age of the Weber is Middle Pennsylvanian (Desmoinesian) and Early Permian (Wolfcampian) but Late Pennsylvanian (Missourian and Virgilian) fossils have not been recognized, suggesting that a major unconformity is within the Weber (Bissell, 1952; Bissell and Childs, 1958; Bissell, 1964).

The Permian Park City and Phosphoria Formations overlie the Weber and are mapped as the Grandeur Member of the Park City Formation (lower unit) and a combined upper unit that includes the Meade Peak Member of the Phosphoria Formation, the Franson Member of the Park City Formation, and a red bed unit previously called the "Mackentire Tongue." The Meade Peak Member forms the base of my upper map unit. It is a dark-gray phosphatic shale with interbeds of sandstone and limestone that is 10 to 15 m thick in the Duchesne River area and in the upper Rock Creek area within the quadrangle (Huddle and McCann, 1947a, 1947b). The Meade Peak is as much as 25 m thick to the northeast in the Moon Lake area of the adjoining Kings Peak 30′ x 60′ quadrangle (Huddle and others, 1951). The red bed unit (Mackentire Tongue) within the Franson Member in the map area is stratigraphically complex and its regional correlation is uncertain. The unit was named by Williams (1939) as the Mackentire "red-beds" Tongue of the Phosphoria Formation for exposures in Mackentire Draw, a tributary of the West Fork of Lake Fork River in the Kings Peak 30′ x 60′ quadrangle. Thomas and Krueger (1946) showed the Mackentire red beds as a tongue of the Woodside Shale (Triassic); however, a major unconformity, the TR-1 unconformity of Pipiringos and O'Sullivan (1978) that they labeled as TR-3, separates the Park City Formation from the overlying Woodside Formation, making an intertonguing relationship impossible. A lengthy discussion of the red bed "tongue" is presented in McKelvey and others (1959, p.34–35) with a note of Permian fossils. To the east, in and around Dinosaur National Monument, a succession of carbonate and interbedded calcareous mudstone and siltstone, referred to as the tawny beds or tawny shale, were thought to correlate with the typical Franson Member (Thomas and Krueger, 1946; McKelvey and others, 1959). Schell and Yochelson (1966) argued that the tawny beds were Permian based on the fossil assemblage recovered and identified from thin limestone beds within the section; they assigned the tawny beds to the upper Park City Formation. But Schell and Yochelson (1966) showed the Mackentire red beds are below and not correlative to the tawny beds, and pinch out near Split Mountain at Dinosaur National Monument. Farther east in northwest Colorado, Whitaker (1975) correlated the State Bridge Formation, a predominantly reddish siltstone and shale unit, to part of the Park City Formation. It is possible that a tongue of the State Bridge Formation may extend westward into the Uinta Basin and is represented by the tawny beds and underlying Mackentire red beds. The age of the Phosphoria and the Park City is Early (Leonardian) to Middle (Guadalupian) Permian based on regional fossil collections (McKelvey and others, 1959).

Triassic Stratigraphy

Triassic formations mapped in the Duchesne 30′ x 60′ quadrangle include (in ascending stratigraphic order) the Woodside, Thaynes, and Ankareh Formations. The Woodside Formation is the lowest Triassic unit in the map area but regionally it intertongues with and overlies the Dinwoody Formation (Kummel, 1954; Solien and others, 1979; Carr and Paull, 1983, see their figure 13). The Dinwoody Formation is a marine unit deposited in a basin that encompassed parts of Montana, Wyoming, Idaho, Nevada, and Utah. Where present, the Dinwoody Formation overlies the Park City Formation at the TR-1 unconformity of Pipiringos and O'Sullivan (1978); however the TR-1 unconformity is not obvious unless the Dinwoody is missing (Jon King, Utah Geological Survey, written communication, 2018). The Dinwoody is not present in the Duchesne quadrangle, which likely reflects the depositional limit of marine beds and grading into the lower red beds of the Woodside Formation. In the map area, the Woodside Formation unconformably overlies the Permian Park City Formation above the TR-1 unconformity. The age of the

Woodside is Early Triassic (Induan) based on fossils recovered from the intertonguing Dinwoody Formation in northern Utah (north of the Uinta Mountains) and southeastern Idaho (Kummel, 1954).

The Woodside and Ankareh Formations are red bed units separated by marine to marginal marine limestone, sandstone, and shale of the Thaynes Formation (Thomas and Krueger, 1946). To the east, the Thaynes thins, intertongues, and is gradational into reddish-brown, fluvial and tidal flat sandstone, siltstone, and thin gypsum beds making it difficult to impossible to distinguish the Woodside from the lower Ankareh (Thomas and Krueger, 1946; Kummel, 1954; Kinney, 1955)—this red bed interval to the east of the Duchesne quadrangle is called the Moenkopi Formation and the overlying strata (Gartra Member and upper Ankareh Formation) are called the Chinle Formation (Kummel, 1954; Kinney, 1955; Heckert and others, 2015). The Early Triassic (Induan to Olenekian) age of the Thaynes Formation is well constrained from fossil ammonite, brachiopod, conodont, and sponge biostratigraphy (Clark, 1957; Perry and Chatterton, 1979; Solien, 1979; Solien and others, 1979; Carr and Paull, 1983; Rigby and Gosney, 1983).

The Ankareh here is subdivided into two map units (lower and upper) separated by the Gartra Member, which is shown as a reddish marker line on the geologic map because it is generally too thin to show separately at the map scale. The base of the Gartra is the Ꞧ-3 unconformity (Pipiringos and O'Sullivan, 1978, labeled Tr-3 in their publication). The lower Ankareh is mostly reddish-brown sandstone, siltstone, and shale to purplish-gray siltstone and shale. It represents the Mahogany Member of Kummel (1954). The age of the lower Ankareh is considered Early Triassic by Pipiringos and O'Sullivan (1978). The upper Ankareh Formation has been called the Stanaker Formation (Thomas and Krueger, 1946), but that term has not been used by most geoscientists. The upper Ankareh consists mostly of a lower reddish-brown mudstone and siltstone interval that is gradational upward to a mostly reddish-brown, fine-grained, cross-bedded, and rippled sandstone interval. This interval is more resistant to erosion than the lower mudstone and siltstone interval and typically forms cliffs and ledges. The upper unit is lithologically like the Chinle Formation to the east (Kummel, 1954; Poole and Stewart, 1964; Irmis and others, 2015).

The upper ledge- and cliff-forming part of the upper Ankareh is like the cliff-forming part of the Chinle, which was referred to as the formation of Bell Springs (Jensen and Kowallis, 2005; Haddox and others, 2010a, 2010b) and the upper member of the Chinle Formation (Irmis and others, 2015). These beds are found in the upper part of the upper Ankareh within the map area, but I have not mapped them separately. A pebble conglomerate typically marks the base of this ledge- and cliff-forming unit at most locations; locally on the south flank of the eastern Uinta Mountains, a slight angular discordance is present between the upper Chinle (Bell Springs) and the underlying beds (High and others, 1969; Jensen and Kowallis, 2005). Taken together, some stratigraphers have considered the contact an unconformity (High and others, 1969; Lucas, 1993; Jensen and Kowallis, 2005; Jensen and others, 2016)—the Ꞧ-5 unconformity of Lucas (1993). In Wyoming, the Bell Springs is considered the basal member of the Nugget Sandstone and, at least locally, has a basal conglomerate (Pipiringos, 1968) that is thought to lie on the J-0 unconformity of Pipiringos and O'Sullivan (1978). Like in Utah, the Ꞧ-5 unconformity is within Upper Triassic beds and is a better term than J-0.

The contact between the upper Ankareh Formation and overlying Nugget Sandstone in the Duchesne 30′ x 60′ quadrangle is conformable, like the contact between the upper Chinle Formation (Bell Springs or upper member) and Nugget Sandstone in the eastern Uinta Basin (Jensen and Kowallis, 2005; Sprinkel and others, 2011b; Irmis and others, 2015), and the upper Chinle and Glen Canyon Group in the Colorado Plateau (Stewart and others, 1972b; Lucas and others, 2005; Lucas and others, 2006). In central Wyoming, the contact between the Bell Springs Member of the Nugget Sandstone and the rest of the Nugget has been interpreted as conformable (Pipiringos, 1968; Pipiringos and O'Sullivan, 1978). The contact elsewhere in northern Utah, southwestern Wyoming, and southeastern Idaho is sharp and is typically placed at the base of a thick, cliff-forming, cross-bedded sandstone (Nugget) that is on reddish-colored, poorly resistant, planar-bedded Ankareh sandstone, siltstone, and shale. I am uncertain if these beds are equivalent to the formation of Bell Springs, but the contact is also considered the Ꞧ-5 unconformity, J-0 of Pipiringos and O'Sullivan (1978, see their figure 2). More information on the Bells Springs in Wyoming is noted under the upper Ankareh Formation members in the map unit descriptions.

No definitive fossils or isotopic ages have been reported from the upper Ankareh Formation; however, it is considered Late Triassic (Carnian to Rhaetian) based on lithostratigraphic correlation with beds having isotopic ages, and paleomagnetic and biostratigraphic data from the Chinle Formation (Thomas and Krueger, 1946; Kummel, 1954; Stewart and others, 1972a; Lucas, 1993; Molina-Garza and others, 2003; Irmis and others, 2011; Ramezani and others, 2011; Atchley and others, 2013; Martz and others, 2014; Irmis and others, 2015; Martz and others, 2017).

Upper Triassic and Lower Jurassic Stratigraphy

The Nugget Sandstone is an easily recognizable unit because it is light-colored, large-scale high-angle cross-bedded sandstone sandwiched between the underlying red beds of the Ankareh Formation and the overlying medium- to greenish-gray limestone and mudstone of the Arapien Formation. The Nugget Sandstone is reportedly correlative to the Glen Canyon Group. Sprinkel and others (2011b) presented lithologic, paleontologic, and subsurface drill hole evidence showing that the Wingate, Kayenta, and Navajo (Glen Canyon Group) exposed in the Moab (Utah) area thin northward across the plunging nose of the Uncompahgre uplift and then thicken into the eastern Uinta Basin. The Wingate and Navajo continue to thicken in the subsurface at the expense of the Kayenta, which eventually pinches out or is gradational into eolian beds that form a single eolian interval in exposures on the south flank of the Uinta Mountains. I use the term Nugget instead of the Glen Canyon Sandstone of Poole and Stewart (1964) because the outcrops and associated contacts can be traced to the eastern Uinta Mountains from the western Uinta Mountains and Wasatch Range where the term Nugget was used by Thomas and Krueger (1946) and Baker (1947, 1976), and in later geologic maps (see Bryant, 1990; 1992, and his sources of geologic map data). The depositional environment of the Nugget in the Uinta Mountains is interpreted as predominantly eolian with thin fluvial beds near the base. The Nugget also locally contains thin, light-brown to very light-brown, sandy dolomite and reddish-brown siltstone of interdunal lacustrine origin as lenses in the eolian part of the formation. The age of the Nugget Sandstone on the south flank of the Uinta Mountains is Late Triassic (late Rhaetian) to Early Jurassic (Hettangian–Toarcian) based on (1) Triassic aetosaur tracks (*Brachychirotherium*) preserved in a planar-bedded, reddish-colored sandstone bed in the lower 10 m of the formation (Lockley and others, 1992; Sprinkel and others, 2011b), (2) Triassic dinosaur bones (drepanosaur and sphenosuchian) in structureless, light-gray sandstone (interdunal lacustrine origin) about 55 m above the base of the formation (Chambers and others, 2011; Engelmann and others, 2012; Britt and others, 2016), and (3) Jurassic dinosaur tracks (*Grallator* and *Eubrontes*) in lenticular planar-bedded to structureless sandstone (interdunal fluvial origin) in the upper eolian part of the formation (Hamblin and Bilbey, 1999; Hamblin and others, 2000; Sprinkel and others, 2011b).

Middle and Upper Jurassic Stratigraphy

Jurassic formations that overlie the Nugget Sandstone in the Duchesne 30′ x 60′ quadrangle include, in ascending stratigraphic order, the Arapien, Preuss, and Stump Formations. They form an outcrop belt from Rock Creek to west of the Duchesne River in the northwestern part of the map area. Unconformably overlying the Nugget Sandstone (J-1 unconformity) and underlying the Preuss Formation is an interval that was previously identified and mapped as the Twin Creek Limestone (Thomas and Krueger, 1946; Imlay, 1967, 1980; Bryant, 1992). I have applied the term Arapien Formation to this interval based on the lithofacies and the regional correlation outlined in Sprinkel and others (2011a). The Arapien Formation along the outcrop belt in the quadrangle is lithologically the same as the Arapien Formation in central Utah. In central Utah, the Arapien Formation consists of five members; they are, in ascending stratigraphic order, the Sliderock, Rich, Boundary Ridge, Watton Canyon, and Twelvemile Canyon Members (Sprinkel and others, 2011a). Three of the lower four members are composed of mostly dense, resistant, medium- to brownish-gray limestone; the Boundary Ridge Member is composed mostly of red beds. The upper member (Twelvemile Canyon) is mostly green-gray mudstone, light-gray argillaceous limestone, gypsum, and halite (Imlay, 1967; Sprinkel, 1982; Witkind, 1994; Sprinkel and others, 2011a). Sprinkel and others (2011a) argued that the Twin Creek Limestone along the southwest flank of the Uinta Mountains should be called the Arapien Formation because the upper part is lithologically similar to the Twelvemile Canyon Member of the Arapien Formation rather than the Leeds Creek and Giraffe Creek Members of the Twin Creek Limestone. They also recommended that the term Twin Creek Limestone be restricted to the region north and northwest of the Uinta Mountains. South flank strata are much thinner than the typical Twin Creek (see Imlay, 1967, p. 13). Along the south flank, the Arapien Formation grades eastward from predominantly carbonate and mudstone to predominantly sandstone and siltstone, with some carbonate beds, of the Carmel Formation. The age of the Arapien is Middle Jurassic (Bajocian to Callovian) based on invertebrate fossils in the correlative Twin Creek Limestone (Imlay, 1967), palynology, and isotopic ages that range from about 168 to 166 Ma (Imlay, 1980; Sprinkel and others, 2011a).

The Preuss Formation conformably overlies the Arapien Formation and underlies the Stump Formation. The Preuss is a reddish-brown clastic formation, ranging from fine- to medium-grained sandstone to sandy mudstone, that is interpreted as marine to evaporitic restricted marine based on having gypsum and halite and marine invertebrate (pelecypod and gastropod) fossils (Imlay, 1952). The Arapien-Preuss contact is gradational and is typically placed at the color change from greenish-gray beds (Arapien) to reddish-brown beds (Preuss), although some thin-bedded greenish-gray mudstone and limestone is present in the lower Preuss and some red beds are in the upper Twelvemile Canyon Member indicating a gradation and intertonguing stratigraphic relationship between the two formations. The age of the Preuss Sandstone is Middle Jurassic (Callovian) based on gastropod, pelecypod, and ammonite fossils in regionally bounding formations and stratigraphic relations (Imlay, 1952).

The Stump Formation was divided into the lower Curtis Member and upper Redwater Member by Pipiringos and Imlay (1979) but is mapped as a single unit (Js) in the Duchesne 30′ x 60′ quadrangle. The contact between the Middle Jurassic Preuss Formation and Upper Jurassic Stump Formation, where exposed, is sharp and appears unconformable. Thomas and Krueger (1946, p. 1279) reported that the base of the Curtis rests on an irregular surface in which the beds of the underlying Preuss Sandstone are truncated. This surface may represent the J-3 unconformity, which marks the boundary between Middle Jurassic Entrada Sandstone and Upper Jurassic Curtis Formation strata throughout most of Utah (Zuchuat and others, in press), including in the eastern Uinta Mountains and Uinta Basin where the Middle Jurassic Entrada Sandstone is unconformably overlain by the Stump Formation (Pipiringos and O'Sullivan, 1978). However, Imlay (1980) did not show an unconformity in sections at Whiterocks Canyon and Dinosaur National Monument. Pipiringos and Imlay (1979, p. C15) noted that the contact between the Preuss and Stump Formations is sharp but were uncertain about its nature; they thought it was unconformable in places in northern Utah, southeastern Idaho, and southwestern Wyoming. A hiatus represented by the J-4 unconformity is present between the Curtis and Redwater Members (Pipiringos and O'Sullivan, 1978; Pipiringos and Imlay, 1979; Imlay, 1980) based on regional stratigraphic correlation showing missing Redwater strata and irregular thickness in the Curtis Member of the Stump Formation. The J-5 unconformity separates the correlative Redwater Member of the Stump, Summerville Formation, or Romana Sandstone from the overlying Morrison Formation in most of Utah (Pipiringos and O'Sullivan, 1978; Peterson, 1988). However, some workers do not show the boundary as unconformable in the eastern Uinta Mountains and Uinta Basin (for example Currie, 1998; Bilbey and others, 2005). The age of the Stump Formation is somewhat problematic. Pipiringos and Imlay (1979) assigned a Middle Jurassic (Callovian) age to the Curtis based on (1) it appears to grade upward from the underlying Middle Jurassic (Callovian) Preuss Formation and (2) it unconformably underlies the Late Jurassic (Oxfordian) Redwater Member. Elsewhere in Utah, the Curtis Formation is considered Late Jurassic (Oxfordian) based on palynomorphs recovered from greenish-gray mudstone at the base of the Curtis Member (Wilcox and Currie, 2006; Wilcox, 2007; Wilcox and Currie, 2008) and the basal contact of the Curtis is the J-3 unconformity, which marks the boundary between Middle and Upper Jurassic strata (Pipiringos and O'Sullivan, 1978). The Redwater Member is Late Jurassic (Oxfordian) based on invertebrate fossils (Pipiringos and Imlay, 1979; Imlay, 1980). The Stump Formation is assigned to the Middle(?) and Late Jurassic because of the apparent age discrepancy and nature of the basal contact between the Curtis in the map area and the Curtis elsewhere in Utah.

The Morrison Formation is one of the most notable and studied formations in Utah and surrounding region because of its rich and diverse dinosaur assemblage and uranium deposits. The formation also has a diverse regional lithostratigraphy reflecting a complex fluvial-lacustrine depositional environment (Peterson and Turner-Peterson, 1987; Turner and Fishman, 1991; Turner and Peterson, 1999, 2004). On the south flank of the eastern Uinta Mountains, the Morrison Formation consists of as many as four members; they are, in ascending stratigraphic order, the Windy Hill, Tidwell, Salt Wash, and Brushy Basin Members (Turner and Peterson, 1999). Beds of the Salt Wash and Brushy Basin Members are represented in all areas of northeastern Utah; however, I have not observed the Windy Hill and Tidwell Members in the map area. Altered tuff and bentonite beds in the Morrison have yielded $^{40}Ar/^{39}Ar$ and U-Pb ages that range from about 157 Ma near the base to about 150 Ma near the top, indicating the Morrison is Late Jurassic (Kimmeridgian to Tithonian) in age (Trujillo and Kowallis, 2015).

The Upper Jurassic Morrison Formation is unconformably overlain by the Lower Cretaceous Cedar Mountain Formation. Picking the contact between the two formations can be difficult, despite the unconformity (K-1), because their similar lithologies are easily weathered to clay flats or clay-covered slopes. Lithostratigraphic, biostratigraphic, and chemostratigraphic criteria are emerging that will help identify the contact (see Cifelli and others, 1997; Kirkland and others, 1999; Kirkland and others, 2003; Ludvigson and others, 2003; Greenhalgh and Britt, 2007; Kirkland, 2007; Kirkland and Madsen, 2007; Kirkland and others, 2011; Sprinkel and others, 2012; Ludvigson and others, 2015; Kirkland and others, 2016). For example, the base of the Cedar Mountain Formation locally includes the Buckhorn Conglomerate, a cobble and boulder conglomerate that varies in thickness and typically forms a resistant cliff above the Morrison Formation (Stokes, 1952; Kirkland and others, 2016). Where the Buckhorn is missing, the base of the Cedar Mountain Formation is typically a chert-pebble bearing, mottled, yellow-orange mudstone that underlies the first Cedar Mountain calcrete bed (Sprinkel and others, 2012; Kirkland and others, 2016). I have combined the Upper Jurassic Morrison and Lower Cretaceous Cedar Mountain Formations as a single map unit (KJcm) for this map because I have not seen the Buckhorn or the diagnostic mudstone of the Morrison–Cedar Mountain contact.

Cretaceous Stratigraphy

Formations that represent the Cretaceous System in the map area include the Cedar Mountain, Dakota, Mowry, Frontier, Mancos, and Currant Creek Formations. As noted above, strata of the Cedar Mountain Formation are mapped with the underlying Morrison Formation. Regionally, the Cedar Mountain Formation consists of mostly varicolored mudstone and siltstone with some thin, coarse-grained sandstone beds and abundant pedogenic (calcrete) and lacustrine carbonate rocks (Kirkland and others, 2016). The carbonate rocks weather out as nodules that cover the mudstone slopes. The age of the Cedar Mountain Formation is Early Cretaceous (Albian to Aptian) based on regional stratigraphic correlation, vertebrate biostratigraphy (dinosaur), and isotopic ages obtained from outside of the map area. The reported U-Pb detrital zircon ages (maximum depositional) vary from 124.0 ± 2.9 Ma from the Yellow Cat Member to 108.6 ± 2.3 Ma from the Mussentuchit Member (Greenhalgh, 2006; Britt and others, 2007; Greenhalgh and Britt, 2007; Mori, 2009; Sprinkel and others, 2012; Kirkland and others, 2016). Older U-Pb zircon ages of 139.7 ± 2.2 to about 132 Ma from the Yellow Cat Member were reported by Hendrix and others (2015) and Kirkland and others (2016) and may represent scattered older beds.

The Lower Cretaceous Dakota Formation unconformably overlies the Cedar Mountain Formation at the K-2 unconformity. The Dakota is a three-part unit of a lower and upper light-colored sandstone separated by dark-gray, carbonaceous shale. The middle shale unit can contain thin lignitic coal beds. A thin marine mudstone and shale interval is locally preserved at the base of the Dakota Formation east of the map area near Dinosaur National Monument. Dinoflagellate cysts recovered from this interval and an isotopic age of 101.4 ± 0.4 Ma from a bentonite bed in the middle carbonaceous shale indicate a middle to late Albian age for these strata (Sprinkel and others, 2012). This thin marine interval is interpreted as the first incursion of the Cretaceous Western Interior Sea into Utah during the peak Kiowa–Skull Creek depositional cycle (Brenner and others, 2000; Sprinkel and others, 2012).

The Mowry Shale, unnamed shale, Frontier Formation, and main body of the Mancos Shale are formations of the Mancos Group on the south flank of the Uinta Mountains and in the Uinta Basin region (Molenaar and Wilson, 1990). The Mowry Shale is an easily recognizable formation because it forms silver-gray outcrops that support little vegetation. The Mowry is composed of siliceous shale that contains abundant fossilized scales and bones of teleost fish identified as belonging to the order Beryciformes and the family Aleposauridae (Bilbey and Hamblin, 1992), and shark teeth (*Carcharias amonensis*, Anderson and Kowallis, 2005). Stewart (1996) described several specimens of the sphenocephalid teleost fish *Xenyllion zonensis* from the *Neogastroplites americanus* ammonite zone from the middle of the Mowry Shale in the Steinaker Draw area (Reeside and Cobban, 1960).

The biostratigraphic age of the Mowry Shale is controversial because of a shift in the Albian-Cenomanian boundary based on ammonite zonation and radiometric ages from Japan, and the discrepancy between North American Western Interior endemic ammonite zones and cosmopolitan dinoflagellates that were used in correlations to European reference sections (Cobban and Kennedy, 1989; Obradovich, 1993; Gale and others, 1996; Obradovich and others, 2002; Oboh-Ikuenobe and others, 2007; Scott, 2007; Ogg and others, 2008). The Mowry was originally considered as Early Cretaceous (late Albian) based on a re-evaluation of regional ammonite work (Cobban and Reeside, 1951; Reeside and Cobban, 1960). However, Cobban and Kennedy (1989) recommended a downward shift of the Albian-Cenomanian boundary from the top of the five neogastroplitid (ammonite) zones to the top of the oldest zone, thus making the Mowry Late Cretaceous (Cenomanian) in age (Obradovich, 1993). Numerous researchers (Oboh-Ikuenobe and others, 2007; Scott, 2007; Scott and others, 2009) have challenged their recommendation and made a case, supported by the regional correlation of cosmopolitan dinoflagellates, for the Mowry to remain Albian in age.

The radiometric age of the Mowry Shale is well constrained from ^{40}Ar/^{39}Ar sanidine analyses on widespread bentonite beds that bracket the Mowry in northeast Wyoming. The basal Arrow Creek Bentonite is 98.5 ± 0.5 Ma and the capping Clay Spur Bentonite is 97.2 ± 0.7 Ma (Obradovich, 1993), making the Mowry Cenomanian (early Late Cretaceous) in age. I have accepted and assigned a Late Cretaceous (Cenomanian) age for the Mowry Shale in northeastern Utah based on the regional biostratigraphic and isotopic ages relative to the downward shift of the Albian-Cenomanian boundary.

An unnamed shale unconformably overlies the Mowry Shale in the northwest quarter of the map area. It is also present to the west in the Provo 30′ x 60′ quadrangle (Constenius and others, 2011), and as far north as the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016). The unnamed shale unconformably underlies a basal transgressive sandstone of the Frontier Formation of Molenaar and Wilson (1990) in the map area. The basal sandstone is about 15 m thick in the Red Creek and Farm Creek areas but thins eastward to a pinchout edge between Farm and Pigeon Water Creeks (Molenaar and Wilson, 1990). Where the basal sandstone is missing, the unnamed shale unconformably underlies the brown-weathering Tununk Shale Member of the Frontier Formation before it pinches out north and east of the map area (Molenaar and Wilson, 1990). Molenaar and Wilson (1990, their plate 1) reported a thickness range of the unnamed shale of about 65 m in Currant Creek, about 50 m in Red Creek, and about 20 m in Farm Creek, where it is best exposed. Some geologists lump the dark unnamed shale into the Mowry while others place it in the Frontier Formation; this unnamed shale unit may be a tongue of the Mancos. I have mapped the unnamed shale with the Frontier Formation in the Duchesne quadrangle. The age of the unnamed shale is Cenomanian based on fossil foraminifera (Molenaar and Wilson, 1990).

The Frontier Formation unconformably (K-3) overlies the Mowry Shale in northeastern Utah (where the unnamed shale and basal sandstone are missing) based on regional stratigraphy, molluscan biostratigraphy, and ^{40}Ar/^{39}Ar ages (Merewether and Cobban, 1986; Ryer and Lovekin, 1986; Molenaar and Wilson, 1990; M'Gonigle and others, 1995; Merewether and others, 2007). In the map area, the Frontier Formation generally includes (1) the unnamed shale and basal transgressive sandstone (where present), (2) a slope-forming, brown-weathering shale (dark- to medium-gray shale on a fresh exposure), (3) a cliff- or ledge-forming sandstone and siltstone capped by carbonaceous mudstone and coal (Vernal delta complex), and (4) an upper mudstone and capping resistant sandstone (Ashley Valley Member) (Hale and Van de Graaff, 1964; Ryer and Lovekin, 1986; Molenaar and Wilson, 1990; Kirschbaum and Mercier, 2013; Hutsky and Fielding, 2015, 2016). The brown-weathering shale is the Tununk Shale Member of the Frontier Formation of Molenaar and Wilson (1990), which correlates in part to the Tununk Member of the Mancos Shale (Molenaar and Cobban, 1991). Regionally, the age of the Frontier Formation is Turonian based on fossil ammonites, palynology, and isotopic age data (Cobban and Reeside, 1952; Nichols and Jacobson, 1982; Nichols and others, 1982; Merewether and Cobban, 1986; Molenaar and Wilson, 1990; M'Gonigle and others, 1995; Merewether and others, 2007; Hutsky and Fielding, 2015); however, the Frontier Formation map unit includes the Cenomanian unnamed shale and, thus is Cenomanian and Turonian in the Duchesne quadrangle (Molenaar and Wilson, 1990).

The Mancos Shale (main body) is characterized by thick, dark- to medium-gray shale that weathers to barren yellowish-gray slopes. It overlies and intertongues with the Frontier Formation and intertongues with the overlying Mesaverde Formation. The Mancos significantly thins with this intertonguing from the eastern part of the Uinta Basin westward into the Duchesne 30′ x 60′ quadrangle (Walton, 1944; Franczyk and others, 1992; Molenaar and Wilson, 1993). Because the Mancos Shale is thin in this quadrangle and is sandwiched between two more resistant formations, it commonly forms a strike valley. The age of the Mancos Shale is Coniacian to early Campanian based on fossil ammonites and palynology outside of the map area but is restricted to Coniacian in the western part of the Uinta Basin because of intertonguing with the Mesaverde Formation (Molenaar and Cobban, 1991; Franczyk and others, 1992; Molenaar and Wilson, 1993).

The Mesaverde Formation is exposed between Dry Mountain and the Duchesne River in the map area. The formation overlies and intertongues with the Mancos Shale and unconformably underlies the Currant Creek Formation. The Mesaverde Formation can be divided into a lower marine sandstone and an upper, mostly nonmarine sandstone, mudstone, and coal (Walton, 1944). The age of the Mesaverde Formation is Coniacian to Santonian in the western Uinta Basin but is as young as Campanian in the eastern Uinta Basin based on fossil ammonites and palynology outside the map area and regional stratigraphic correlation (Walton, 1944, 1957; Hale and Van de Graaff, 1964; Nichols and Bryant, 1986; Johnson and Johnson, 1991; Franczyk and others, 1992; Molenaar and Wilson, 1993).

The Currant Creek Formation was named and described by Walton (1944) from Currant Creek from within the map area and west of the map area. The Currant Creek Formation is a yellowish-gray to variegated synorogenic unit of mostly thick, pebble to boulder conglomerate interbedded with mudstone, siltstone, and sandstone. Clast size decreases from its type section at Currant Creek to outcrops near the Duchesne River in the map area (Isby and Picard, 1985). Clast composition is mostly quartzite derived from the Pennsylvanian-Permian Weber Sandstone and/or Oquirrh Formation, sandstone (quartz arenite) from the Neoproterozoic Uinta Mountain Group, and chert derived from Paleozoic carbonate formations (Walton, 1944, 1964; Garvin, 1969; Isby and Picard, 1985). The decreasing clast size, clast composition, and the south to southeast paleocurrent directions indicate the source for the conglomerates was from the north and northwest (Garvin, 1969; Isby and Picard, 1983, 1985).

Significant unconformities mark the lower and upper contacts of the Currant Creek Formation and the unit contains some internal unconformities. In the Currant Creek area, Walton (1964) showed that the Currant Creek Formation dips less steeply than the underlying Mesaverde Formation but is more steeply dipping than the overlying Tertiary formations. In the Tabiona area of the Duchesne 30′ x 60′ quadrangle a similar relationship is present between the Mesaverde, Currant Creek, and Uinta Formations with each unit having progressively less steeply dipping strata and bounded by angular unconformities. The synorogenic conglomerate beds within the Currant Creek Formation indicate progressive deformation and uplift of the adjacent highlands (Isby and Picard, 1983; Constenius and others, 2003)—the uplift of the Uinta Mountains to the north and northwest and possibly the Charleston-Nebo fold-and-thrust belt highlands to the west. Palynomorphs recovered from near the base of the Currant Creek Formation indicate it is latest Campanian to early Maastrichtian in age (Nichols and Bryant, 1986). No definitive age data have been published on the upper part of the Currant Creek Formation, but the regional lithostratigraphic correlation and age of the North Horn and Evanston Formations and structural studies suggest that the upper Currant Creek Formation is Paleocene in age (Walton, 1944; Newman, 1974; Fouch, 1976; Jacobson and Nichols, 1982; Isby and Picard, 1983, 1985; Franczyk and others, 1990; Constenius and others, 2003; Coogan and King, 2016).

Tertiary (Paleogene) Stratigraphy

Lower Tertiary strata of the Flagstaff and Colton Formations are between the Currant Creek and Green River Formations (plate 2, figure 5). These formations are not exposed in the Duchesne 30′ x 60′ quadrangle, but they are exposed to the west in the Provo 30′ x 60′ quadrangle and are also present in the subsurface east of the Charleston-Nebo thrust sheet (Constenius and others, 2003; 2011). The Flagstaff and Colton Formations are also exposed to the south in the Book and Roan Cliffs (Weiss and others, 1990; Morgan and others, 2003). Beds of the Flagstaff and Colton are very likely in the subsurface map area.

Tertiary formations exposed in the map area include the Eocene Green River, Uinta, and Duchesne River Formations, the Keetley Volcanics, and the Oligocene Bishop Conglomerate. The Green River Formation is subdivided into a series of formal and informal members across the Uinta Basin that reflect the varying lithofacies in a large lacustrine system called Lake Uinta (Fouch, 1975; Ryder and others, 1976; Johnson and others, 1988; Fouch and others, 1994; Johnson and others, 2010; Tänavsuu-Milkevicience and Sarg, 2012). Five informal members are mapped in the Duchesne 30′ x 60′ quadrangle. These are, in ascending stratigraphic order: (1) middle member, (2) upper member, (3) saline facies, (4) sandstone facies, and (5) sandstone and limestone facies (plate 2, figure 5). The base of the middle member and older units of the Green River Formation are exposed to the south in the Price 30′ x 60′ quadrangle (Weiss and others, 1990) and west in the Provo 30′ x 60′ quadrangle (Constenius and others, 2011).

The middle member includes abundant limestone interbedded with mudstone, siltstone, and fine-grained sandstone. The basal part of the middle member as exposed to the south in the adjoining Price 30′ x 60′ quadrangle is a cliff-forming interval of limestone, calcareous mudstone, and marlstone that Weiss and others (1990) correlated to the carbonate marker of Ryder and others (1976). The middle member is interpreted as having been deposited in a marginal lacustrine environment (Fouch, 1975; Ryder and others, 1976; Fouch and Dean, 1983). The overlying upper member is mudstone, limestone, siltstone, sandstone, and altered tuff as well as numerous oil-shale beds. The Mahogany oil-shale bed marks the base of the upper member and is also the base of the Mahogany oil-shale zone; this zone is an interval of higher grade oil-shale beds throughout the southern Uinta Basin. Near the middle to upper part of the upper member is the Horse Bench Sandstone (the brown-colored line on plate 1); a resistant fine-grained sandstone and siltstone unit that forms a topographic bench. It was first described and named by Bradley (1931) for Horse Bench, a mesa located near the junction of Nine Mile and Desolation Canyons (T. 12 S., R. 17–18 E., Salt Lake Base Line and Meridian). The topographic bench capped by the Horse Bench Sandstone is conspicuous in the Price 30′ x 60′ quadrangle and can be seen in Avintaquin Canyon in the southern part of the Duchesne 30′ x 60′ quadrangle. The Horse Bench Sandstone becomes hard to trace on the west side of Avintaquin Canyon, below Long Ridge, as the bench becomes less prominent. Eventually, I could not follow with confidence the Horse Bench Sandstone south of Finger Canyon, a side canyon of Avintaquin Canyon (T. 5 S., R. 8W., Uinta Base Line and Meridian). The Horse Bench Sandstone is generally less than 12 m thick and pinches out in places (Cashion, 1967). The upper member is interpreted as having been deposited in mostly a marginal lacustrine environment (Fouch, 1975; Fouch and Dean, 1983). The saline facies unit overlies the upper member and is light- to moderate-brownish-gray and greenish-gray limestone with some chert, shale, claystone, dolomite, sandstone (some low-angle cross-bedded), altered tuff, and some oil-shale beds. The saline facies unit also includes saline minerals in the subsurface, but exposures commonly have casts (angular dissolution molds) where the saline minerals have been dissolved (Dyni and others, 1985). The saline facies in the Duchesne quadrangle is younger than the saline interval in the eastern Uinta Basin called the Birds Nest aquifer (plate 2, figure 5) (Vanden Berg and others, 2013; Vanden Berg and Birgenheier, 2017). The saline facies is interpreted as having been deposited in an open to evaporitic marginal lacustrine environment (Fouch, 1975; Fouch and Dean, 1983; Dyni and others, 1985), but the saline interval in the Green River Formation in the Green River Basin of Wyoming was interpreted as a playa (salt pan) depositional environment (Eugster and Surdam, 1973; see also Pietras and Carroll, 2006). The sandstone facies unit is medium- to thick-bedded sandstone that forms resistant ledges and cliffs. It is exposed along the Strawberry River in the southwestern part of the quadrangle and forms the Strawberry Pinnacles at the mouth of Avintaquin Canyon. The sandstone facies intertongues with the top of the upper member, the saline facies, and much of the sandstone and limestone facies. The intertonguing stratigraphic relationships are mapped in the Timber Canyon and western Strawberry River areas. The sandstone facies is interpreted as a delta deposited into a fluctuating but ultimately shallowing Lake Uinta (Fouch and Dean, 1983). The capping sandstone and limestone facies unit is mostly light-colored, interbedded sandstone and limestone (as the name implies), but also contains interbeds of greenish-gray and grayish-red siltstone and shale and some altered tuff beds. This facies is interpreted as having been deposited in a marginal lacustrine environment (Picard, 1955; Fouch, 1975). This capping member intertongues with and is gradational into most of member B of the Uinta Formation in the south-central part of the map area near Coyote and Cottonwood Canyons (see also plate 2, figure 5). The contact on plate 1 is shown as gradational to reflect the intertonguing and gradational relationship.

The lower to middle Eocene age of the Green River Formation is constrained by the isotopic ages of several altered tuff beds (plate 2, table 1); 49.02 ± 0.30 Ma (^{40}Ar/^{39}Ar biotite) from the Curly tuff (ID #22) in the upper member, 48.37 ± 0.23 Ma (^{40}Ar/^{39}Ar biotite) from the Wavy tuff (ID #21) in the upper member, 47.04 ± 0.18 Ma (^{40}Ar/^{39}Ar biotite) from the Blind Canyon tuff (ID #20) in the upper member, 46.34 ± 0.13 Ma (^{40}Ar/^{39}Ar biotite) from the Fat tuff (ID #19) in the saline facies, 45.58 ± 0.14 Ma (^{40}Ar/^{39}Ar biotite) from the Portly tuff (ID #18) in the saline facies, 45.14 ± 0.10 Ma (^{40}Ar/^{39}Ar biotite) from the Oily tuff (ID #17) near the upper part of the saline facies, and 44.0 ± 0.92 Ma (^{40}Ar/^{39}Ar sanidine) from the Strawberry tuff (ID #16) near the base of the sandstone and limestone facies (Smith and others, 2008). The Oily and Strawberry tuff samples are from Indian Canyon in the Duchesne 30′ x 60′ quadrangle (plate 1), whereas all other tuff samples were collected from the Price 30′ x 60′ quadrangle.

The Eocene Uinta Formation is composed of three informal members. They were called Horizon A, Horizon B, and Horizon C by Peterson in Osborn (1895) based on the characteristic species of titanotheres in each interval. Subsequently, workers used Horizon A, B, and C of the Uinta Formation interchangeably with Uinta A, B, and C (Peterson, 1931; Peterson and Kay, 1931; Peterson, 1932). Wood (1934) proposed the formal member names, the Wagonhound Member (for Horizons A and B), and the Myton Member (for Horizon C). The names Wagonhound and Myton continue to be used by some workers (Townsend and others, 2006; Townsend and others, 2010), but the informal names Horizon A (Uinta A or member A), Horizon B (Uinta B or member B), and Horizon C (Uinta C or member C) have been used or referred to more often by others (Stagner, 1941; Cashion, 1967, 1974; Cashion and Donnell, 1974; Cashion, 1982; Sprinkel, 2007, 2009). For now, I have used the informal names, member A, member B, and member C to reflect the more common usage.

Only two of the three members are present (members B and C) in the Duchesne 30′ x 60′ quadrangle. Member A is a thick-bedded, cliff-forming sandstone unit that exhibits large-scale soft-sediment deformation in the eastern Uinta Basin; however, member A is not present in the map area because it intertongues with and is gradational into the lower part of the sandstone and limestone facies of Green River Formation to the southeast in the Seep Ridge 30′ x 60′ quadrangle (Sprinkel, 2009; Töro and Pratt, 2015) (see also plate 2, figure 5). Member B is composed of light-colored, interbedded mudstone, claystone, and sandstone with minor altered tuffaceous beds, but becomes predominantly sandstone with minor conglomerate beds in the western part of the Uinta Basin. The unit transitions to the sandier lithofacies a few kilometers west of Starvation Reservoir. Member C is typically slope-forming, light-colored mudstone, claystone, and some sandstone with thin beds of limestone with local altered tuffaceous beds. It also becomes sandier to the west of Starvation Reservoir, although it maintains its fine-grained and slope-forming character to Red Creek in the westernmost part of the quadrangle. Conglomerate beds are common in the upper part of Member C in the Red Creek drainage and in the Currant Creek drainage, the next major drainage to the west, and is shown as mostly conglomerate in the adjoining Provo 30′ x 60′ quadrangle (Constenius and others, 2011). However, some of what has been shown as Uinta Formation conglomerate (Tucb) in the Provo quadrangle is probably younger than the Uinta Formation (plate 2, table 1), and is mapped as Starr Flat Member of the Duchesne River Formation in the Duchesne 30′ x 60′ quadrangle.

The Uinta Formation is generally interpreted as the transition from predominantly lacustrine deposition of the underlying and intertonguing Green River Formation to fluvial deposition of the Duchesne River Formation (Fouch, 1975; Bryant and others, 1989; Sandau, 2005). Within the map area, the contact between the Uinta and Duchesne River Formations is placed at the top of slope-forming siltstone and mudstone of member C of the Uinta Formation and at the base of the first cliff-forming sandstone of the Brennan Basin Member of the Duchesne River Formation; regionally the contact is problematic because it is gradational, the formations intertongue, and conglomerates overwhelm the typical lithologies of both formations to the west. The Uinta Formation is Uintan (middle Eocene) based on a rich assemblage of fossil mammals (Osborn, 1895; Riggs, 1912; Osborn, 1929; Murphey and others, 2017), magnetostratigraphic studies (Prothero, 1990; Prothero and Swisher, 1992), and isotopic ages of laterally equivalent altered tuff beds in the upper Green River Formation (Dane, 1954, 1955; Smith and others, 2008).

The Duchesne River Formation is composed of four formal members defined by Andersen and Picard (1972). In ascending stratigraphic order, they are the Brennan Basin, Dry Gulch Creek, Lapoint, and Starr Flat Members. Each member is composed of varying amounts of reddish-brown sandstone, siltstone, and mudstone. The ratio of sandstone to mudstone decreases upward from the Brennan Basin Member through the Lapoint Member, exhibiting a generally fining-upward stratigraphic succession (Sato, 2014; Sato and Chan, 2015a; Sato and Chan, 2015b). However, the uppermost Starr Flat Member is coarse-grained to conglomeratic sandstone and conglomerate with some interbedded siltstone, mudstone, and vitric tuff beds. The Duchesne River Formation was deposited in a fluvial to fluvial-lacustrine environment capped by the mostly fluvial Starr Flat Member (Andersen, 1972; Andersen and Picard, 1972, 1974; Bruhn and others, 1986; Sato, 2014; Sato and Chan, 2015a). Like the Uinta Formation, the Duchesne River Formation becomes sandier west of Starvation Reservoir, closer to areas of active uplift in the rising Uinta Mountains and highlands of the inactive Sevier fold-and-thrust belt (Bruhn and others, 1986; Sato, 2014; Sato and Chan, 2015a).

The stratigraphic relationships of the Starr Flat Member with the underlying Lapoint Member and the overlying Bishop Conglomerate are complicated by limited outcrop areas, poorly exposed contacts, and the previous mapping of Bryant (1992). Andersen and Picard (1972) defined the Starr Flat Member as conglomeratic beds that conformably overlie and intertongue with the Lapoint Member on John Starr Flat in the Duchesne 30′ x 60′ quadrangle. They did not discuss the stratigraphic relationship with the overlying Bishop Conglomerate (Andersen and Picard, 1972, 1974). The Starr Flat Member conformably overlies the Lapoint Member in the eastern part of the Duchesne 30′ x 60′ quadrangle, but it was mapped as unconformably overlying older members of the Duchesne River Formation and older formations (Mesozoic through Neoproterozoic) in the western part of the Duchesne quadrangle (Bryant and others, 1989; Bryant, 1992). Thus, Bryant's (1992) Starr Flat in the western part of the quadrangle may or may not be the Starr Flat (see the discussion of the Bishop Conglomerate below).

The age of the Duchesne River Formation ranges from about 41 to 39 Ma based on a diverse assemblage of vertebrate fossils of Duchesnean (middle Eocene) age (see Andersen and Picard, 1972; Kelly and others, 2012; Murphey and others, 2017) and isotopic data (McDowell and others, 1973; Prothero and Swisher, 1992; Utah Geological Survey and Apatite to Zircon Inc., 2014; Jensen and others, 2017; Webb and others, 2017) (plate 2, table 1). The Brennan Basin Member has a thin (about 15 cm thick), purplish-gray, biotite-rich altered tuff (ID #14) that was collected near the middle of the member and yielded a weighted mean U-Pb zircon age of 40.66 ± 1.88 Ma (Utah Geological Survey and Apatite to Zircon Inc., 2014). The large margin of error suggests some detrital reworking. East of the Duchesne 30′ x 60′ quadrangle in the Lake Mountain 7.5-minute quadrangle, an altered tuff (ID #15) in the Brennan Basin Member yielded an ^{40}Ar/^{39}Ar biotite age of 41.1 ± 0.32 Ma (Kowallis and others, in review; New Mexico Geochronology Research Laboratory and Utah Geological Survey, unpublished report NMGRL-IR-561). An air-fall vitric tuff bed (ID #13, plate 2, table 1) in the Dry Gulch Creek Member, but within 2 m of the Dry Gulch-Lapoint contact, yielded an ^{40}Ar/^{39}Ar plagioclase age of 39.36 ± 0.15 (Jensen and others, 2017; Webb and others, 2017). Several isotopic ages have been reported from the basal Lapoint Member. McDowell and others (1973) reported a K-Ar biotite age of 39.3 ± 0.8 Ma from an tuffaceous siltstone bed at the Lapoint-Dry Gulch contact and Prothero and Swisher (1992) reported a mean ^{40}Ar/^{39}Ar biotite age of 39.74 ± 0.17 Ma from the bentonitic bed (ID # 10, plate 2, table 1) at the base of the Lapoint Member; both reported ages were from the Vernal 30′ x 60′ quadrangle. Bart Kowallis (Brigham Young University) and I sampled bentonitic beds (ID #11 and #12, plate 2, table 1) near the base of the Lapoint Member, also from the adjoining Vernal 30′ x 60′ quadrangle, that yielded ^{40}Ar/^{39}Ar biotite ages of 41.52 ± 0.13 Ma and 41.53 ± 0.61 Ma (New Mexico Geochronology Research Laboratory and Utah Geological Survey, unpublished report NMGRL-IR-561). An altered tuff (ID #9, plate 2, table 1) in the upper part of the Lapoint Member yielded an ^{40}Ar/^{39}Ar sanidine age of 39.47 ± 0.16 Ma (Jensen and others, 2017; Webb and others, 2017). This tuff bed was in the lower part of the Lapoint and within the lowest intertonguing interval with the Starr Flat Member. The apparent older age (39.47 ± 0.16 Ma) from the Lapoint Member compared to the age (39.36 ± 0.15) from near the top of the underlying Dry Gulch Creek Member seems stratigraphically inverted. However, the margin of error of the two ages overlap, which suggests that the Dry Gulch Creek and Lapoint Members are essentially the same age.

A boulder conglomerate mapped as queried Starr Flat (Tds?) caps Red Creek Mountain in the Duchesne quadrangle. The unit has been more widely mapped in the northeastern part of the adjoining Provo quadrangle as a boulder conglomerate in the Uinta Formation (Tucb) with reported U-Pb (zircon) ages of 38.9 ± 0.8 and 39.6 ± 0.7 Ma (Constenius and others, 2011). These ages are comparable to ^{40}Ar/^{39}Ar (plagioclase and sanidine) ages of 39.47 ± 0.16 and 39.36 ± 0.15 Ma obtained from altered tuff beds in the upper part of the Dry Gulch Creek and overlying Lapoint Members of the Duchesne River Formation (Jensen and others, 2017; Webb and others, 2017). The Lapoint sample (table 1, ID #9) is within the intertonguing interval with the Starr Flat Member. Thus, the boulder conglomerate (Tucb) is younger than the Uinta Formation and is about the same isotopic age as the Dry Gulch and Lapoint-Starr Flat Members of the Duchesne River Formation.

The Bishop Conglomerate was mapped (with a query) in the western part of the Duchesne 30′ x 60′ quadrangle by previous geologists (Huddle and McCann, 1947b; Huddle and others, 1951). With the contradictory mapping by Bryant (1992), who mapped it as Starr Flat Member of the Duchesne River Formation, there is a question as to the age and identity of the gently dipping conglomerate beds that overlie more steeply dipping beds on the higher terrain in the western part of the Duchesne quadrangle. Unfortunately, there is no place in the Duchesne 30′ x 60′ quadrangle where the unequivocal Bishop Conglomerate directly overlies the Starr Flat Member. The Bishop Conglomerate overlies the Starr Flat Member in the southeastern part of the north-adjoining Kings Peak 30′ x 60′ quadrangle (Bryant, 1992) and the east-adjoining Vernal 30' x 60' quadrangle (Sprinkel, 2007). In most places along the south flank of the Uinta Mountains, the Bishop Conglomerate unconformably overlies a variety of more steeply dipping formations, including the Duchesne River Formation (see plate 1). The unconformity at the base of the Bishop Conglomerate is the Gilbert Peak erosion surface that cut older bedrock formations on the flanks of the Uinta Mountains, and that Hansen (1965, 1986) had interpreted as evidence for the end of the Laramide uplift of the Uinta Mountains. The Laramide orogeny ended by the middle Eocene (pre-Bridgerian) in Wyoming and late Eocene in Colorado and New Mexico (Snoke, 1993).

On the south side of Little Mountain (in the Vernal 30′ x 60′ quadrangle), I mapped both the Bishop Conglomerate and the underlying Starr Flat Member (Sprinkel, 2007). The Starr Flat Member seemed to dip more steeply west than the overlying Bishop Conglomerate; however, the contact (Gilbert Peak erosion surface) was obscured. I revisited exposures of the Duchesne River Formation on Little Mountain with Takashi Sato (University of Utah masters student studying the Duchesne River Formation) in August 2013, and we observed that most of the Starr Flat Member of the Duchesne River Formation conformably overlies the Lapoint Member of the Duchesne River Formation, but that tongues of conglomerate beds of Starr Flat Member extend into the Lapoint Member. These conglomerate tongues eventually pinch out to the south (basinward) into the finer-grained Lapoint

Member. The contact between the Starr Flat Member and overlying Bishop Conglomerate is mostly obscured (as I originally observed), but it is clear that the Starr Flat Member dips more steeply than the nearly flat-lying Bishop Conglomerate, indicating an angular unconformity separates the Starr Flat Member and Bishop Conglomerate at Little Mountain. Recent stratigraphic studies, isotopic dating, and geologic mapping of the Duchesne River Formation in the Vernal NW 7.5-minute quadrangle confirms that the Bishop and Starr Flat contact is an angular unconformity (Jensen and others, 2017; Webb, 2017; Webb and others, 2017). It now seems evident to me that beds mapped by Bryant (1992) as Starr Flat Member at its type section on John Starr Flat are correctly identified, but other beds mapped by Bryant (1992) as Starr Flat on Dry Mountain, Farm Creek Peak, Tabby Mountain, and Raspberry Knoll are Bishop Conglomerate and are mapped as such in this report (plate 1).

Kowallis and others (2005) reported ^{40}Ar/^{39}Ar (sanidine) ages from near the base of the Bishop Conglomerate on the Diamond Mountain Plateau (Dutch John 30′ x 60′ quadrangles) and the Yampa Plateau (Vernal 30′ x 60′ quadrangle) that range from 30.54 ± 0.22 Ma to 34.03 ± 0.04 Ma. The age of the underlying Duchesne River Formation is about 39 Ma, indicating the unconformity (Gilbert Peak erosion surface) that separates the Duchesne River Formation from the Bishop Conglomerate is less than 5 Ma.

The Keetley Volcanics cap a few high mountainous areas above the upper Duchesne River, upper Wolf Creek, and east flank of Wolf Creek Pass in the northwest corner of the quadrangle. The Keetley rocks are altered tuff, tuffaceous sandstone, volcanic breccia, and pebble to boulder conglomerate composed of volcanic (andesite and rhyolite) and sedimentary clasts (Paleozoic orthoquartzite, sandstone, and limestone). In the Provo quadrangle, light-gray tuffaceous sandstone has yielded ^{40}Ar/^{39}Ar (sanidine and hornblende) ages of 38.20 ± 0.11 Ma and 40.46 ± 0.18 Ma (respectively) with a suspect hornblende age of 37.25 ± 0.14 (Constenius and others, 2011). Other isotopic ages reported from Keetley rocks and associated intrusions range from ~40 to 32 Ma (Crittenden and others, 1973; John and others, 1997, their table 2; Vogel and others, 1997; Biek, 2017). The Keetley rocks, therefore, are generally time equivalent to the upper part of the Duchesne River Formation and older than the Bishop Conglomerate; however, they are not in contact anywhere to confirm this and no volcanic clasts have been found in the Duchesne River Formation.

Quaternary Stratigraphy

The map area includes a variety of surficial deposits of early Pleistocene to historical age (plate 2, figure 4b). Multiple levels of alluvium are on piedmont slopes ($\mathrm{Qap}_{2–6}$) of the Uinta Mountains and in strath terraces ($\mathrm{Qat}_{1–5}$) that are closely associated with and located above stream drainages (plate 2, table 2). Piedmont alluvium was deposited primarily by coalescing debris flows and ephemeral streams on broad pediment-like bedrock benches that formed broad sub-planar mantle deposits. Stream-terrace alluvium was deposited as floodplain deposits associated with stream drainages. The piedmont and stream-terrace alluvial deposits have not been dated. The relative ages are based on heights above drainages and stratigraphic relationships with glacial deposits, which are mostly middle to upper Pleistocene. These deposits provide clues to the Quaternary history of the Uinta Basin and the mountain-front retreat along the south flank of the Uinta Mountains.

The glacial deposits (till and outwash) are from three glacial events and include, in ascending stratigraphic order, the pre-Blacks Fork, Blacks Fork, and Smiths Fork glaciations (Atwood, 1909; Munroe, 2001; Laabs and Carson, 2005; Laabs and others, 2009; Munroe and Laabs, 2009). The Blacks Fork (186 to 127 ka) and Smiths Fork (32 to 14 ka) events are well documented (Laabs and Carson, 2005; Laabs and others, 2007; Refsnider and others, 2008; Laabs and others, 2009; Munroe and Laabs, 2009) and are roughly coeval with the Middle Rocky Mountain (Wind River, Wyoming) Bull Lake and Pinedale glaciations, respectively (Chadwick and others, 1997; Phillips and others, 1997). An older event, pre-Blacks Fork (> 245 ka; Laabs and Carson, 2005), is likely coeval with one of the pre-Bull Lake glaciations in Wyoming (Chadwick and others, 1997; Laabs and Carson, 2005). The glacial till and outwash and associated features (moraines, moraine crests, and ice-margin channels) are in the Wolf Creek, Lake Fork, and Yellowstone drainages on the south flank of the Uinta Mountains in the northern part of the map area. Outwash deposits are on successively lower topographic surfaces with the oldest deposit on the highest surface. A comparison between the north and south flank outwash terrace heights above nearby active drainages, where outwash deposits from all three glaciations are present, show little difference in the Smiths Fork and Blacks Fork terraces (Sprinkel, unpublished data). However, a difference exists in terrace heights of the pre-Blacks Fork outwash (Sprinkel, unpublished data). This suggests that downcutting and erosion between pre-Blacks Fork and Blacks Fork glacial events were greater in the Uinta Basin (along the south flank) than in the Green River Basin (along the north flank) but were relatively the same on both flanks among Blacks Fork and Smiths Fork and post-Smiths Fork glacial events (Sprinkel, unpublished data).

Other surficial deposits include alluvium in floodplains of the Duchesne River and its tributaries, two ages of alluvial-fan deposits (late Pleistocene and Holocene), colluvial deposits, eolian (wind-blown) deposits, mass-movement deposits (landslides, debris flows, and talus), and a variety of mixed-environment deposits. Most deposits are late Pleistocene to Holocene with the exception of the mass-movement deposits, which are Pleistocene to historical.

Structural Geology

The geology of the Duchesne 30′ x 60′ quadrangle offers a glimpse into the complex interaction between foreland uplifts (Laramide-age Uinta Mountains) and fold-and-thrust belt structures (Sevier age), as well as Tertiary extension. Structural features in the map area include the basin-mountain boundary fault zone, the south limb of the Uinta Mountain uplift, the hinge zone of the Uinta Basin syncline and associated folds, a series of northeast-trending and northwest-trending faults in the northwest quadrant of the map, north-trending faults along the west side of the map area, and the Duchesne fault zone. The Uinta Basin and the syncline are asymmetric with a steep north limb and a gently dipping south limb. The syncline hinge zone is located near the north margin of the basin, as is the related Uinta Basin-Uinta Mountain boundary fault zone, which I refer to as the basin boundary fault zone.

The basin boundary fault zone is generally poorly exposed along its trace and is inferred from exposed fault segments mapped within the Uinta and Duchesne River Formations. The location of the covered portions of the basin boundary fault is not precisely shown on the map because my study of subsurface data (well data and seismic reflection profiles) and cross sections will be done after this mapping is released, but it generally follows the trace of Bryant (1992). A reactivated normal-faulted part of the fault zone may be exposed on the slopes of John Starr Flat in the northeastern part of the map area where beds of the upper two members of the Duchesne River Formation (Tdl, Tds) are offset down to the south, and between Bald and Twin Knolls (west of Towanta Flat) where the Brennan Basin and Dry Gulch Creek Members of the Duchesne Formation (Tdb, Tdd) are offset down to the south. In the western part of the map area, beds of the Uinta Formation (Tub, Tuc), the Brennan Basin Member of the Duchesne River Formation (Tdb), and the Bishop Conglomerate (Tb) are offset both down to the south and north, so the fault name is queried on the map. To the east, the basin boundary fault zone is mostly a blind thrust fault, but published seismic-reflection data indicate that the thrust fault cuts rocks as young as middle Eocene Green River Formation (Stone, 1993). Sprinkel (2007) mapped two short fault segments that cut beds of the Brennan Basin Member of the Duchesne River Formation along U.S. Highway 40 that corresponds to the approximate location of the basin boundary fault. At the time I was uncertain as to the sense of movement; however, since the release of the map (Sprinkel, 2007), U.S. Highway 40 has been expanded and a new road cut has better exposed the fault trace; the fault dips between 45° and 55° north and beds of the Brennan Basin Member are offset down to the north. Prolonged movement along the basin boundary fault zone occurred during the latest Cretaceous to middle Eocene Laramide uplift as shown by conglomerate beds containing clasts from the Uinta Mountains in the Currant Creek through Duchesne River Formations and Bishop Conglomerate.

A series of northeast- and northwest-trending faults are exposed in the north part of the quadrangle. These faults cut Paleozoic and Mesozoic rocks. The northeast-trending faults are steeply dipping normal faults that generally appear to have down-to-the-northwest offset. These faults generally parallel the trend of the basin boundary fault zone and may be related to Laramide uplift of the Uinta Mountains; however, the normal sense of offset suggests normal movement was during Tertiary extension. The northwest-trending faults are also steeply dipping but with apparent down-to-the-northeast offset. However, kinematic indicators found on one of these faults show right-lateral oblique- to strike-slip movement. Kinematic indicators were not observed on the other similarly trending faults in the area, but folds associated with the faults suggest strike-slip movement and these northwest-trending faults are mapped as such. The northwest-trending strike-slip faults may be related to complex interaction of the late stages of Sevier thrusting and Laramide uplift in the southwest part of the Uinta Mountains. The apparent conjugate northeast-trending faults may have the same origin, but the strike-slip indicators may be obscured by later normal offset.

The generally north-trending faults along the west boundary of the Duchesne 30′ x 60′ quadrangle are like faults in the adjoining 30′ x 60′ quadrangles. These faults are steeply dipping, have a normal sense of offset, and some form horst and graben structures. These faults appear to be related to Tertiary extension, either Paleogene, called extensional collapse (Constenius, 1996; Constenius and others, 2003; Schelling and others, 2007), and/or Neogene basin-and-range extension. With either age, the normal faults may “sole” into and reverse movement on Sevier-age thrust faults.

The Duchesne fault zone is a series of east-west-trending faults that form a discontinuous graben and cut beds of the Green River Formation (Tgs and Tgsl) and Uinta Formation (Tub) in the southern part of the map area. Although displacement on the faults forms scarp-like topographic linear embankments that can be seen on the ground, aerial photographs, and satellite imagery, no surficial deposits appear to be displaced. Thus, the age of the faulting is no better defined than post-Eocene Uinta Formation. In some areas, graben-bounding faults are not shown on my map because some are too close together to be shown separately at map scale and poor exposures make it difficult to recognize bed offset. Groeger and Bruhn (2001) indicate the master fault in the fault zone has 200 m of slip and terminates downward by a depth of 1400 m or flattens into a north-dipping, low-angle to bedding-plane fault at about 1000 m. Several fault surfaces with kinematic indicators are exposed on closely spaced strands of the Duchesne fault zone about 500 m east of Coyote Canyon (SE¼SE¼ section 17, T. 4 S., R. 4. W., Uinta Base Line and Meridian). There, the faults cut beds of the sandstone and limestone facies of the Eocene Green River Formation and the indicators are found on carbonate beds. The kinematic indicators show normal movement that is down to the north. The dip direction was measured on three fault surfaces; 339°, 349°, and 354° with an average of about 347°, with dips of 29°, 53°, and 67°, with an average of 50°.

A series of fault scarps cut glacial outwash of pre-Blacks Fork age (middle to early[?] Pleistocene) on Towanta Flat, northwest of Mountain Home along the west side of Lake Fork, and generally align with other normal faults that I believe are related to the basin boundary fault system. Hansen (1969) first described the graben, noting that the scarps cut Pleistocene glacial outwash. Later, a trench study by Nelson and Weisser (1985) showed that the fault scarps are 15 m high, with at least three faulting events of 2 to 3 m of stratigraphic displacement per event, and were in glacial outwash they interpreted to be of pre-Blacks Fork age (their pre-Bull Lake age). This graben, with displacement of Pleistocene deposits, shows segments of the normal fault system have been active in the Quaternary.

Geologic Resources

The Duchesne 30′ x 60′ quadrangle contains an array of geologic resources (plate 2, figure 6). Energy resources are the most important, but other resources include phosphate, sand and gravel, and gilsonite (for more information see Doelling and Graham, 1972; Verbeek and Grout, 1993; Longman and Morgan, 2008; Boden and Tripp, 2012; Logan and others, 2016; Utah Geological Survey website at https://geology.utah.gov). Energy resources include oil and gas, oil shale, some tar sand, and coal. The giant Altamont-Bluebell and Monument Butte oil fields are the largest in the quadrangle and are among the most productive in the Uinta Basin and the state of Utah (for more information see Fouch and others, 1992; Longman and Morgan, 2008; Utah Division of Oil, Gas and Mining website at https://oilgas.ogm.utah.gov). The reservoir rocks in these fields are the Green River Formation and what has been called the Wasatch Formation, but may be too old (early to middle Paleocene) to be the latest Paleocene to early Eocene Wasatch.

Geologic Hazards

Landslides dominate the geologic hazards in the quadrangle. They range from small (less than 1400 m^2) to as large as nearly 20 km^2 (Harty, 1992; plate 1). Two of the largest landslides (Tabby Mountain area and south of Fruita, Utah) have been developed for cabin sites where many cabins and associated infrastructure are built. These areas were developed for the scenic views and easy access provided by landslides that have modified the steep terrain. Landslides are more common in formations that have fine-grained, clay-rich shale and mudstone and are on steep slopes (generally greater than 30 percent). The geologic units in the Duchesne 30′ x 60′ quadrangle that have failed or have high potential to fail include the Mississippian Doughnut Formation, Triassic Woodside (Ŧw) and upper Ankareh (Ŧau) Formations, Jurassic Morrison and Cretaceous Cedar Mountain Formations (KJcm), and the sandstone and limestone facies of the Tertiary Green River Formation (Tgsl), member C of the Uinta Formation (Tuc), Bishop Conglomerate (Tb), and several unconsolidated surficial deposits. According to Ashland (Ashland, 2003), landslides are commonly triggered by increased (often rapid) soil moisture caused by high-intensity rainfall events, above-normal precipitation, rapid snowmelt, excessive irrigation, or by natural or human-caused undercutting. The relative ages of mass-movement deposits are not differentiated because even landslides that may be considered old and inactive may continue to move by slow creep and “old” landslides are capable of renewed movement, and in either case pose a risk (Ashland, 2003).

Other geologic hazards include stream and fan flooding and debris flows triggered by high-intensity rainfall events or rapid snowmelt during the spring. An under-appreciated geologic hazard is earthquakes that can rupture the ground surface and generate strong ground shaking. Small-magnitude earthquakes have occurred in the area but are rarely felt (Bowman and Arabasz, 2017; see the University of Utah Seismograph Stations website at http://quake.utah.edu/). An exception was a magnitude 5.3 earthquake in 1950 that was 4.5 km northwest of the Towanta Flat graben (Bowman and Arabasz, 2017). However, fault scarps that form the Towanta Flat graben cut Pleistocene deposits and indicate that larger magnitude earthquakes have occurred in the Quaternary and may still be possible. Earthquakes are associated with some fault zones in the Uinta Mountains, along the south flank of the Uinta Mountains west of the Lake Fork River, and within the Uinta Basin (Sprinkel, 2014).

DESCRIPTION OF MAP UNITS

Quaternary Map Units

Human Disturbances

Qh Human disturbances, undivided (Historical) – Engineered fill or disturbed areas resulting from construction, such as sewage lagoons, that obscures the original geology; variable thickness.

Qhd Earthen dams (Historical) – Materials used in these structures may include clay, sand, gravel, and boulders derived from local sources; variable thickness.

Qhg Gravel pit (Historical) – Disturbed areas left after extracting borrow materials, mostly for dams, roads, and building pads; gravel pits are in the various levels of the Quaternary Duchesne River deposits (Qat$_2$, Qat$_3$, and Qat$_4$) and older level-3 alluvium (Qap$_3$); only the larger gravel pits are mapped; pit depth varies depending on thickness of the gravel deposit, which may be as much as 10 m.

Alluvial Deposits

Qal River and stream alluvium (upper Holocene) – Unconsolidated mud, silt, sand, and gravel (pebble-size to small boulder-size clasts) in floodplains of the Duchesne River, Cottonwood Creek, Dry Gulch Creek, and other perennial creeks and in drainages that are downstream of large springs; locally gradational into Qac, Qae, and Qace; estimated 1 to 30 m thick.

Qat$_1$ Stream-terrace alluvium, level 1 (Holocene) – Unconsolidated to locally cemented mud, silt, sand, and gravel (pebbles, cobbles, and boulders); moderately sorted mixed-clast deposits that are remnants of stream and fan alluvium 3 to 6 m (average 5 m) above Red, Zimmerman, Dry Gulch, and Cottonwood Creeks, and in Big Draw (table 1); located along drainages at elevations of about 1535 to 2050 m; less than a few tens of meters thick.

Qat$_2$ Stream-terrace alluvium, level 2 (Holocene[?] to upper Pleistocene) – Unconsolidated mud, silt, sand, and gravel (pebble-size to small boulder-size clasts); finer grained compared to level-2 piedmont alluvial deposits; clasts (estimate 10% Mesozoic, 60% Paleozoic, and 30% Neoproterozoic clasts) were derived from Mesozoic sandstone units (Nugget Sandstone and Gartra Member of Chinle Formation), Paleozoic carbonate and sandstone units (Weber Sandstone, Round Valley Limestone, Deseret Limestone, and Gardison Limestone), and Neoproterozoic sandstone units (Uinta Mountain Group); forms prominent gravel-capped benches 20 to 45 m above drainages at elevations of about 1570 to 1820 m (plate 2, table 2); source of gravel deposits mapped as Qhg; 1 to 10 m thick.

Qat$_3$ Stream-terrace alluvium, level 3 (upper Pleistocene) – Unconsolidated silt, sand, and gravel (pebble-size to small boulder-size clasts); sorting, clast size, and clast composition are similar to Qat$_2$ with a minor increase in Paleozoic clasts at the expense of Neoproterozoic clasts; forms prominent gravel-capped benches 50 to 70 m above drainages, including South Myton Bench, at elevations of about 1585 to 1850 m (plate 2, table 2); source of gravel deposits mapped as Qhg; 1 to 10 m thick.

Qat$_4$ Stream-terrace alluvium, level 4 (middle Pleistocene) – Unconsolidated silt, sand, and gravel (pebble-size to small boulder-size clasts); sorting, clast size, and clast composition are similar to Qat$_2$ and Qat$_3$ with a minor increase in Paleozoic clasts at the expense of Neoproterozoic clasts; forms prominent gravel-capped benches 70 to 90 m above drainages, including South Myton Bench, at elevations of about 1595 to 2065 m (plate 2, table 2); source of gravel pits mapped as Qhg; 1 to 10 m thick.

Qat$_5$ Stream-terrace alluvium, level 5 (middle to lower[?] Pleistocene) – Unconsolidated silt, sand, and gravel (pebble-size to small boulder-size clasts); forms prominent gravel-capped benches 100 to 300 m above drainages, including Blue Bench, at elevations of about 1695 to 2185 m in map area (plate 2, table 2).

Qap$_2$ Piedmont alluvium, level 2 (Holocene[?] to upper Pleistocene) – Unconsolidated to consolidated pebble to boulder clast-supported gravel in a sand matrix; calcium carbonate coats the underside of some clasts in top 3 m; calcium carbonate coating becomes more pervasive in the underlying 3 m and interval is more consolidated; well-rounded and moderately sorted; deposit has more Neoproterozoic and less Mesozoic and Paleozoic clasts (estimated 5% Mesozoic, 40% Paleozoic, and 55% Neoproterozoic clasts) and is coarser grained than level 2 stream-terrace deposits (Qat_2); clasts were derived from Mesozoic sandstone units (Nugget Sandstone and Gartra Member of Chinle Formation), Paleozoic carbonate and sandstone units (Weber Sandstone, Round Valley Limestone, Deseret Limestone, and Gardison Limestone), and Neoproterozoic sandstone units (Uinta Mountain Group); forms the lowest prominent gravel-capped benches (like Myton Bench) that generally slope south from 1920 to 1585 m elevation and 25 to 40 m (average 33 m) above the lower Duchesne River and Cottonwood Creek in map area (plate 2, table 2); forms broad alluvial surfaces that have been dissected; despite clast compositional differences, Qap_2 may be gradational downslope into finer grained Qat_2; 6 to 6.5 m thick.

Qap_3 Piedmont alluvium, level 3 (upper Pleistocene) – Unconsolidated to poorly consolidated pebble to boulder clast-supported gravel in a sand matrix; calcium carbonate coatings on the underside of clasts; sorting and clast size are similar to Qap_2, but clasts are predominately derived from the Uinta Mountain Group (estimated at about 30% Paleozoic clasts and 70% Uinta Mountain Group clasts); forms prominent gravel-capped benches that generally slope gently southward from 1990 to 1620 m elevation and 50 to 70 m (average 53 m) mostly above Cottonwood Creek in map area (plate 2, table 2); forms broad alluvial surfaces that have been dissected; Qap_3 may be gradational downslope into finer grained Qat_3; 1 to 3 m thick.

Qap_4 Piedmont alluvium, level 4 (middle Pleistocene) – Poorly to moderately consolidated pebble to boulder gravel in a sand matrix; calcium carbonate coatings on the underside of clasts; sorting, clast size, and clast composition are similar to Qap_3; forms gravel-capped bench of Pine Ridge (section 36, T. 1 S., R. 3 W., UBLM), an unnamed bench southeast of Monarch Ridge (sections 6, 7, 18, 19, T. 1 S., R. 3 W., UBLM), and Flat Top (section 13, T. 2 S., R. 3 W., UBLM) above Dry Gulch and Cottonwood Creeks; generally slopes gently southward from 2045 to 1770 m elevation and 70 to 90 m (averages about 80 m) above drainages in map area (plate 2, table 2); forms broad alluvial surfaces that have been dissected; Qap_4 may be gradational downslope into finer grained Qat_4; 1 to 3 m thick.

Qap_5 Piedmont alluvium, level 5 (middle to lower[?] Pleistocene) – Poorly to moderately consolidated pebble to boulder gravel in a sand matrix; sorting, clast size, and clast composition are similar to Qap_3 and are differentiated based on elevation above the drainage; forms the gravel-capped bench of La Mink (section 30, T. 1 S., R. 2 W., UBLM); forms gravel-capped benches that generally slope gently southward from 2240 to 1785 m elevation and 120 to 210 (averages 165 m) above Dry Gulch Creek and the upper Duchesne River (plate 2, table 2); 1 to 3 m thick.

Qap_6 Piedmont alluvium, level 6 (lower Pleistocene) – Poorly to moderately consolidated pebble to boulder gravel in a sand matrix; sorting, clast size, and clast composition are similar to Qap_4 and are differentiated based on elevation above the drainage; forms small gravel-capped surfaces that generally slope gently southward from 2750 to 2180 m elevation and 225 to 580 m (averages 403 m) above the upper Duchesne River and Rock Creek (plate 2, table 2); 1 to 3 m thick.

Qafy Alluvial-fan deposits (Holocene and uppermost Pleistocene[?]) – Unconsolidated mud, silt, sand, and gravel (cobbles to few boulders); poorly sorted; gradational into stream and river alluvial deposits (Qal), a variety of mixed deposits (Qac, Qace, Qae), and colluvial deposits (Qc); some small alluvial fans are mapped with Qac and Qc; forms fan-shape deposit at the mouths of drainages and coalescing deposits where the fans from several drainages overlap; overlies Smiths Fork-age glacial outwash (12 to 17.6 ka); less than 10 m thick.

Qafo Older alluvial-fan deposits (upper Pleistocene) – Unconsolidated mud, silt, sand, and gravel (cobbles to few boulders); poorly sorted; older alluvial fans are dissected and tend to be larger in area than younger alluvial fans; older fan surfaces are generally several meters above younger alluvial fans and about 12 m below older alluvial deposits (Qap_3); mapped above the lower part of Spring Branch Creek (W/2, T. 1 N., R. 2 W., UBLM) to its confluence with Cottonwood Creek; 10 m thick.

Qags Glacial outwash of Smiths Fork age (upper Pleistocene) – Unconsolidated, clast-supported, well-rounded, mostly red sandstone and quartzite (Uinta Mountain Group) boulders to pebbles and sand deposited by meltwaters of the Smiths Fork-age glaciers on the south flank of the Uinta Mountains approximately 12,000 to 17,600 (calendar) years ago (Laabs and Carson, 2005; Munroe and others, 2006; Laabs and others, 2007; Laabs and others, 2009; Munroe and Laabs, 2009); Smiths Fork outwash is about 15 to 20 m above the Lake Fork and Duchesne Rivers; 1 to 20 m thick.

Qagb Glacial outwash of Blacks Fork age (upper to middle Pleistocene) – Unconsolidated, clast-supported, well-rounded, mostly red sandstone and quartzite (Uinta Mountain Group) boulders to pebbles and sand deposited by meltwaters of the Blacks Fork-age glaciers; timing of deglaciation has not been directly determined in the Uinta Mountains but is thought to be roughly correlative with and to follow Bull Lake Glaciation ages (Munroe, 2001; Laabs and Carson, 2005; Munroe and Laabs, 2009), which range from 95,000 to 130,000 years as dated by several methods in the Wind River Range, Wyoming, in the Middle Rocky Mountains (see Chadwick and others, 1997; Phillips and others, 1997); preserved on high benches (in map area) and upper reaches of drainages (north of map area) along the south flank of the Uinta Mountains; deposits are about 30 to 45 m above the Lake Fork and Duchesne Rivers and about 10 to 30 m above Smiths Fork outwash deposits (Qgas); less than 1 to 20 m thick.

Qago Glacial outwash of pre-Blacks Fork age (middle to lower[?] Pleistocene) – Unconsolidated, clast-supported, well-rounded, mostly red sandstone and quartzite (Uinta Mountain Group) boulders to pebbles and sand deposited by meltwaters of glaciers older than the Blacks Fork glaciation (Munroe, 2001; Munroe and Laabs, 2009); see Chadwick and others (1997), Phillips and others (1997), Oviatt and others (1999), and Coogan and King (2016) for possible correlation ages; preserved on high benches in map area; deposits are about 115 to 120 m above the Lake Fork River and about 95 to 105 m above the Smiths Fork outwash deposits (Qgas); less than 1 to 20 m thick.

Colluvial Deposits

Qc Colluvium (Holocene to Pleistocene) – Heterogeneous mixture of mud, silt, sand, and pebble to boulder gravel that is transported downslope mostly by soil creep and slope wash; locally gradational into talus (Qmt), landslide (Qms), alluvial fan (Qaf), stream alluvium (Qal), and mixed deposits (Qac, Qae, Qace); thin on steep slopes and ridge tops to a few meters thick on gentle slopes; mapped as stacked units (Qc/Tdl, for example) where colluvial deposits thinly (less than 1 m thick) cover bedrock; stacked unit present south of Currant Creek on gently north-dipping slope.

Eolian Deposits

Qe Eolian deposits (Holocene to Pleistocene) – Unconsolidated, well-sorted, fine-grained, windblown sand and silt; mostly accumulated on or near outcrops of the Brennan Basin Member (Tdb) of the Duchesne River Formation in broad low-lying areas; generally stabilized by vegetation; gradational into mixed alluvial and eolian deposits (Qae); less than 10 m thick.

Mass-Movement Deposits

Qmf Debris-flow deposits (Historical to Pleistocene) – Locally derived, poorly sorted, matrix-supported clay to boulders; generally confined to drainages but can spread at the drainage mouth; even where not mapped, debris-flow deposits are likely present in and at the mouths of any drainage where alluvial fans are mapped; according to Ashland (2003), a high-intensity rainfall or snowmelt event can trigger a debris flow or a landslide, which can mobilize into a debris flow; debris flows are dangerous events because they are fast moving mixtures of thick mud and large debris (boulders, trees, etc.) that can cause significant damage, injuries, and fatalities; as much as 10 m thick.

Qms Landslide deposits (Historical to Pleistocene) – Locally derived, very poorly sorted, mixed clay to boulders and blocks of bedrock that result in rotational slumps, translational slides, and earth and debris flows (larger flows are mapped separately as Qmf); commonly forms hummocky and irregular topography that includes closed depressions and sag ponds, internal scarps, and chaotic bedding attitudes; commonly formed in fine-grained and clay-rich bedrock units.

Qmt Talus (Holocene to Pleistocene) – Subangular cobble- to boulder-size material that accumulates on and at the base of steeper slopes; may locally include colluvial deposits (Qc) and gradational into mixed alluvium and colluvium (Qac); as much as 5 m thick.

Glacial Deposits

Qgu Glacial, periglacial, and mass movement deposits, undivided (Holocene[?] and upper Pleistocene) – Unconsolidated, poorly sorted, matrix supported, angular to rounded boulders, cobbles, and pebbles of carbonate and reddish-brown sandstone (diamicton) that is similar to Smiths Fork till, but ages uncertain; present in cirque and nivation basins and at least locally modified by slope failure; downslope may include moraines and landslides; smooth to hummocky surface with thin soils; mapped east of Big Ridge and in Rhoades Canyon; less than 50 m thick.

Qgs Smiths Fork till (upper Pleistocene) – Unconsolidated, poorly sorted, matrix supported, angular to rounded boulders, cobbles, and pebbles mostly of red sandstone and quartzite (Uinta Mountain Group) in silt, clay, and sand matrix; generally forms lateral and terminal moraines with steep crests, knolls, and kettles with a smooth to hummocky surface and thin soils; lateral moraines and till deposits on steeper bedrock slopes are prone to mass wasting, especially when water-saturated; Smiths Fork till was deposited ca. 14,000 to 32,000 years B.P. but cosmogenic ^{10}Be surface-exposure dating reveal that terminal moraines were abandoned by retreating glaciers before 16,000 years B.P. (Laabs and others, 2009); outside of map area the ice reached its maximum extent (terminal moraine) during the last glacial maximum between 14,000 ± 500 and 17,400 ± 500 years ago based on ^{26}Al/^{10}Be ages from striated bedrock on Bald Mountain and cosmogenic ^{10}Be surface-exposure ages on terminal moraine boulders in the North Fork of the Provo River, respectively (Refsnider and others, 2008); considered correlative to the Pinedale glaciation (Douglass, 2000; Munroe, 2001; Munroe and others, 2006; Laabs and others, 2007; Refsnider and others, 2008); 1 to 50 m thick.

Qgb Blacks Fork till (upper to middle Pleistocene) – Unconsolidated, matrix-supported, poorly sorted, angular to subrounded boulders, cobbles, and pebbles mostly of red sandstone and quartzite (Uinta Mountain Group) in a sand matrix; generally forms moderately steep moraine crests, ridges, knolls, and kettles with a smooth to hummocky surface and thin soils; mapped along Yellowstone, Lake Fork, and Dry Gulch Creek drainages; age of Blacks Fork glaciation has not been directly determined in the Uinta Mountains but is thought to range from 127,000 to 186,000 years (Munroe, 2001; Pierce, 2003; Laabs and Carson, 2005; Munroe and Laabs, 2009) based on the age of marine oxygen isotope stage 6 (see Coogan and King, 2016, table 3), which roughly correlates with Bull Lake glaciation in the Wind River Range, Wyoming (130–190 ka) (Fournier and others, 1994; Chadwick and others, 1997; Phillips and others, 1997; Pierce, 2003); less than 50 m thick.

Qgo Pre-Blacks Fork till (middle to lower[?] Pleistocene) – Similar in physical properties and composition to Smiths Fork till but beyond the glacial limits of the Smiths and Blacks Fork tills; age >245,000 years as dated in the Wind River Range in the Rocky Mountains (Phillips and others, 1997); moraines and till mapped above the Yellowstone and Lake Fork drainages; generally not as thick as Smith Fork or Blacks Fork till but may be as much as 100 m 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 narrow 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 m thick.

Qae 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 and next to drainages on or near outcrops of the Dry Gulch Creek (Tdd) and Brennan Basin (Tdb) Members of Duchesne River Formation; locally gradational into other mixed deposits (Qac, Qace), eolian deposits (Qes), and colluvial deposits (Qc); mapped as stacked units (Qae/Tdb, for example) where deposits thinly (less than 1 m) cover bedrock; generally less than 10 m thick.

Qace Mixed alluvium, colluvium, and eolian deposits (Holocene to Pleistocene) – Unconsolidated clay, silt, sand, and some gravel deposited by streams, sheet wash, slope creep, and wind; covers large hollows where it is difficult to map deposits from each process separately; as much as 3 m thick.

Qlam Lacustrine, alluvial, and marsh deposits (Holocene to Pleistocene) – Unconsolidated clay, silt, fine-grained sand, and some gravel in floodplain, oxbow lakes, and marshes associated with abandoned meanders of the Duchesne and Strawberry Rivers; marsh deposits are also mapped in low-lying areas of Rock Creek, Lake, Sams, and Right Fork Indian Canyons, and where streams and rivers flow into Starvation Reservoir and in low-lying areas along the shoreline of Starvation Reservoir, which may reflect the reservoir's maximum fill elevation and changing water levels; estimated 1 to 30 m thick.

Qmg Mass-movement and glacial deposits, undivided (Holocene and Pleistocene) – Unsorted and nonstratified clay, silt, sand, and gravel; mapped where glacial deposits lack typical moraine morphology and appear to have failed or moved down slope; mapped south of Red Creek in the northwest corner of the map and part of Big Ridge; likely less than 30 feet (9 m) thick.

Stacked Units

Qac/Tds, Qac/Tdl, Qac/Tdd, Qac/Tuc, Qae/Tdd, Qae/Tdb, Qae/Tuc, Qc/Tds, Qc/Tdl, Qc/Tdd, Qc/Tdb, Qc/Tuc, Qgas/Tds (Holocene to Pleistocene) – Thin, unconsolidated surficial deposits that cover bedrock; small outcrops of bedrock are common within these stacked map units; thickness of surficial deposits is less than 1 m.

Bedrock Map Units

Tertiary Rock Units

Tb Bishop Conglomerate (Oligocene, Rupelian [Arikareean(?) to Orellan]) – Reddish-brown to yellow-gray, cobble and boulder conglomerate and sandstone with some greenish-gray claystone interbeds mapped in the northwest part of the quadrangle; clast composition dominated by reddish-purple-brown quartz arenite and arkosic sandstone of the Neoproterozoic Uinta Mountain Group with some Mississippian Gardison Limestone, Pennsylvanian Round Valley Limestone, Pennsylvanian-Permian Weber Sandstone, and some Mesozoic sandstone formations; clast-composition changes upward exhibiting an inverted stratigraphy, and may indicate unroofing of the Uinta Mountains; gently dipping Bishop conglomeratic beds unconformably overlie and truncate more steeply dipping beds of the Duchesne River Formation and older formations; the Bishop is separated from older strata by the Gilbert Peak erosion surface; see the Tertiary (Paleogene) Stratigraphy section for a discussion of previous mapping of the Bishop Conglomerate and its age; 50 to 150 m thick.

Unconformity

Tk Keetley Volcanics (Oligocene to middle Eocene, Priabonian to Bartonian [Chadronian to Duchesnean]) – Volcanic breccia and conglomerate (lahar deposits), tuffaceous sandstone, and tuff; breccia and conglomerate in upper part and interbedded volcanic conglomerate and minor light-gray tuffaceous sandstone in lower 300 feet (90 m); volcanic clasts are andesite to rhyodacite; conglomerate has light-orange and gray, coarse sandstone matrix and locally contains orthoquartzite, sandstone, and limestone boulders to pebbles; tuffaceous sandstone is light gray, coarse grained to pebbly, and trough cross-bedded; includes beds of non-volcanic sandstone and conglomerate; 50 to 500 m thick.

Duchesne River Formation: Thick reddish-brown to light-gray sandstone to mudstone; descriptions and thicknesses of four formal members given below; combined exposed thickness about 1096 to 1590 m; members defined by Andersen and Picard (1972). Detailed regional setting and sequence stratigraphy of the Duchesne River Formation is discussed by Sato (2014). See plate 2, table 1 for isotopic ages.

Tds Starr Flat Member (middle Eocene, Bartonian [Duchesnean]) – Reddish-brown, reddish-purple, yellowish-gray, and greenish-gray sandstone (73% at type section), siltstone and mudstone (15% at type section), and conglomerate (12% at type section); sandstone is fine to coarse grained, well to poorly sorted, horizontally to cross-stratified, and very thin to thick bedded (thick beds are generally coarse grained and resistant, and thin beds are generally fine grained); sandstone and fine-grained beds dominate the member and coarsen upward; contact is sharp with underlying Lapoint Member (Sato, 2014) and appears conformable at John Starr Flat (Andersen and Picard, 1974); the type section is at John Starr Flat in the Duchesne and Kings Peak 30′ x 60′ quadrangles (from section 22, T. 1 N., R. 2 W. [Neola 7.5-minute quadrangle] to boundary of sections 34 and 35, T. 2 N., R. 2 W. [Pole Creek Cave 7.5-minute quadrangle], Uinta Base Line and Meridian); 40 to 230 m thick.

Tds? Starr Flat Member, queried (middle Eocene, Bartonian [Duchesnean]) – Boulder conglomerate that caps Red Creek Mountain on the west margin of the map area; it is more widely mapped in the northeastern part of the adjoining Provo 30′ x 60′ quadrangle as a boulder conglomerate in the Uinta Formation (Tucb) with reported U-Pb (zircon) ages of 38.9 ± 0.8 and 39.6 ± 0.7 Ma (Constenius and others, 2011), but these ages are like those of the Duchesne River Formation (see plate 2, table 1, and discussion in geology section); as much as 150 m thick in map area.

Tdl Lapoint Member (middle Eocene, Bartonian [Duchesnean]) – Light-reddish-brown and yellowish-gray, fine-grained sandstone, siltstone, and mudstone; contains abundant light-greenish-gray bentonite beds; mostly nonresistant and thin- to very thin bedded; mostly reddish in color in the adjoining Vernal 30′ x 60′ quadrangle but becomes predominately light gray in the map area possibly due to reduction of iron-rich minerals from microseepage of hydrocarbons from the Altamont-Bluebell field or a gradation to more lacustrine lithofacies; 635 to 1045 m thick.

Tdd Dry Gulch Creek Member (middle Eocene, Bartonian [Duchesnean]) – Medium-reddish-brown and purplish-gray siltstone, mudstone, fine-grained sandstone, and conglomerate; dominated by slope-forming siltstone and mudstone with ledge-forming thin-bedded sandstone; generally fining upward; the type section, designated by Andersen and Picard (1972), was measured east of Dry Gulch Creek in the Duchesne 30′ x 60′ quadrangle (from section 7, T. 2 S., R. 2 W. to NW corner, section 32, T. 1 S., R. 2 W., Uinta Base Line and Meridian; Bluebell 7.5-minute quadrangle); 201 m thick at the type section to about 150 m thick to the east in the Vernal 30′ x 60′ quadrangle (Andersen and Picard, 1972; Sprinkel, 2007).

Tdb Brennan Basin Member (middle Eocene, Bartonian [Duchesnean]) – Light- to medium-red, light-reddish-brown, and yellowish-gray, fine- to medium-grained lithic sandstone and siltstone with minor amounts of mudstone and conglomerate; contains well-developed paleosols; the exposed basal part of the Brennan Basin Member intertongues with the underlying Uinta Formation in the adjoining Vernal 30′ x 60′ quadrangle (Sprinkel, 2007). The interval of intertonguing in the Vernal 30′ x 60′ quadrangle is as much as 60 m thick but is minimal in the map area; the contact is placed at the base of a resistant reddish-brown sandstone bed that lies on the uppermost variegated mudstone bed of the Uinta Formation; exposed thickness 220 to 295 m, but is as much as 1040 m thick in the subsurface of Uinta Basin.

Uinta Formation: Light-colored mix of mudstone, claystone, and sandstone with local altered tuffaceous beds. Only the upper two of the three members (C and B) are exposed in the Duchesne 30′ x 60′ quadrangle; member A (the lowest unit) is not present in this quadrangle as discussed in the Tertiary (Paleogene) Stratigraphy section. Combined exposed thickness is less than 1100 m.

Tuc Member C (middle Eocene, Lutetian [Uintan]) – Light-gray, greenish-gray, white, grayish-purple, red, and pale-yellow shale, mudstone, claystone, and minor sandstone with local altered tuffaceous interbeds generally east of Starvation Reservoir and Duchesne River and gradational into more sandy lithologies in the western part of the Duchesne quadrangle; the base of member C has been placed on the top of the "*Amynodon* Sandstone" of Riggs (1912), but Townsend and others (2006) have shown that the contact is transitional and is about 73 m above the "*Amynodon* Sandstone" in the eastern Uinta Basin; forms badlands topography characteristic of Fantasy Canyon (section 12, T. 9 S., R. 22 E., Salt Lake Base Line and Meridian); generally 570 to 650 m thick but may be as much as 1100 m thick in the eastern part of the quadrangle.

Tub Member B (middle Eocene, Lutetian [Uintan]) – Light-gray, light-greenish-gray, light-brown, and light-purple mudstone and claystone with interbeds of greenish-gray, yellow, and brown fine-grained sandstone; contains minor conglomerate and altered tuffaceous beds; forms nonresistant slopes and thin resistant ledges; source of gravel in pits mapped as Qhg; most of the unit intertongues with and gradational into the sandstone and limestone facies of the Green River Formation (Tgsl) (see plate 2, figure 5); thickness varies from about 300 m east of Duchesne to about 35 m near Starvation Reservoir dam because of intertonguing and grading into Tgsl, but thickens to the west and northwest of Starvation Reservoir to about 665 m.

Green River Formation: Light- to medium-colored shale, mudstone, claystone, sandstone, and carbonate beds with oil-shale and altered tuff beds. The Green River Formation consists of a series of informal members within the Duchesne 30′ x 60′ quadrangle. They include the sandstone and limestone facies, sandstone facies, saline facies, middle member, and upper member (plate 2, figure 5).

Tgsl Sandstone and limestone facies (middle Eocene, Lutetian [Uintan]) – Interbedded light-gray to moderate brownish-gray, thin bedded sandstone and dark-gray limestone with beds of greenish-gray and grayish-red siltstone and shale; contains fossil ostracods, fossil gar pike scales, and fossil plants; also contains organic-rich mudstone to thin coaly beds, as well as a few thin beds of oil shale; contains altered tuff beds including the Strawberry tuff, located near the base of the unit (see plate 2, table 1 for age); as much as 300 m thick.

Tgss Sandstone facies (middle Eocene, Lutetian [Uintan to Bridgerian]) – Light-gray, light-brown-gray to light-green-gray sandstone; fine grained, well sorted and calcareous; forms ledges and cliffs; composed of medium to thin tabular beds; contains some laminated bedding to small-scale cross-bedding; intertongues with Tgsl, Tgs, and upper part of Tgu (see plate 2, figure 5); exposed along the Strawberry River and forms the Strawberry Pinnacles at the mouth of Avintaquin Canyon; 0 to 275 m.

Tgs Saline facies (middle Eocene, Lutetian [Uintan to Bridgerian]) – Light- to moderate-brownish gray and greenish-gray limestone with some chert, shale, claystone, dolomite, and sandstone with some low-angle cross-bedding; mud cracks are common in fine-grained rocks; also contains some oil shale beds; saline minerals are reported in subsurface, but in outcrop beds have angular molds where saline minerals have been dissolved (Dyni and others, 1985); contains altered tuff beds including the Oily, Portly, and Fat tuffs (see plate 2, table 1 for isotopic age); the saline facies is gradational upward and laterally eastward into the sandstone and limestone facies (Tgsl) (see plate 2, figure 5); as much as 350 m thick.

Tgu Upper member (middle to lower(?) Eocene, Lutetian to Ypresian(?) [Bridgerian]) – Light-gray to light-brown, interbedded, calcareous mudstone, limestone, siltstone, and sandstone; includes numerous oil shale and altered tuff beds; Mahogany oil-shale zone (3 to 4 m thick), which has higher-grade oil-shale beds throughout the southern Uinta Basin, marks the base of this unit and includes the Mahogany oil-shale bed (less than about 1 m thick); oil-shale beds above the Mahogany oil-shale ledge are generally thin and organically lean; light-gray to very light-gray, resistant altered tuff beds, including the Blind Canyon and Wavy tuffs (see plate 2, table 1 for age); also includes Horse Bench Sandstone (mapped in Avintaquin Canyon) that is light-brown, fine-grained sandstone, thin bedded and rippled, and siltstone with some greenish-gray micaceous mudstone; Horse Bench can include tuffaceous sandstone with muscovite and biotite, and forms conspicuous bench in most places; Horse Bench Sandstone is 0 to 12 m thick; Tgu is 200 to 400 m thick.

Tgm Middle Member (lower Eocene, Ypresian [Wasatchian]) – Light-gray limestone interbedded with light-gray to dark-brown mudstone and siltstone, light-green-gray sandy marlstone, and dark-yellowish-brown to greenish-brown, fine-grained sandstone; contains sparse oil-shale beds generally restricted to the upper part of the member, and thin very light-gray to white altered tuff beds; the Curly tuff is in the uppermost part of the member and very near the contact with the overlying upper member (see plate 2, table 1 for isotopic age); base of middle member is not exposed in this quadrangle; only the upper 70 to 85 m of the middle member is exposed in the Duchesne quadrangle; regionally 570 to 680 m thick.

Unconformity

Tertiary-Cretaceous Rock Units

TKc Currant Creek Formation (Lower Tertiary(?) and Upper Cretaceous, lower Paleocene(?) and Maastrichtian and Campanian[?]) – Gray to yellowish-gray cobble and boulder conglomerate, yellow-gray to light-gray, medium- to coarse-grained sandstone, reddish-gray to variegated siltstone and silty mudstone, and thin bentonitic claystone; conglomerate clasts dominated by quartzite (Weber Sandstone and/or Oquirrh Formation), reddish-gray quartz arenite (Uinta Mountain Group), and black chert (Paleozoic) clasts (Walton, 1964; Garvin, 1969); exposed east and west of the Duchesne River near Hanna; 465 to 915 m thick.

Unconformity

Cretaceous Rock Units

Kmv Mesaverde Group (Upper Cretaceous, Santonian to Coniacian) – Light-gray to light-yellowish-gray, fine- to medium-grained, low-angle cross-bedded sandstone, medium- to dark-gray siltstone and carbonaceous shale, and some coal; can be subdivided into named formal formations but I have mapped it as a single unit; exposed east of the Duchesne River between Tabiona and Hanna, Utah, in the map area; thickens westward; 170 to 915 m thick.

Km Mancos Shale (Upper Cretaceous, Coniacian) – Dark- to medium-gray, soft (slope-forming) calcareous shale that weathers to barren yellowish-gray slopes; contains beds of siltstone and bentonitic clay; poorly exposed and generally forms strike valleys; 1035 to 1645 m thick in eastern Uinta Basin and 550 to 800 m thick in this quadrangle.

Kf Frontier Formation and other units (Upper Cretaceous, Turonian and Cenomanian) – Includes (in descending stratigraphic order) an upper and lower sandstone with middle shale and coal beds, the Tununk Shale, a basal transgressive sandstone, and an unnamed shale; upper and lower ledge- to cliff-forming sandstone separated by shale; upper sandstone is light to moderate yellow brown, medium to coarse grained, thin bedded to very thick bedded, and low-angle cross-bedded; middle shale is medium- to dark-gray and carbonaceous; lower sandstone is similar to the upper sandstone; coal beds occur in the upper part of the Frontier; coal beds are dark gray to black, low-grade (subbituminous) and 0.2 to 1.5 m thick (Doelling and Graham, 1972); underlying the lower sandstone is Tununk Shale Member of Molenaar and Wilson (1990), which is brown-weathering shale that is dark to medium gray on fresh exposures; a basal transgressive sandstone (marine), fine to very fine grained with fossil oysters common to abundant; lower unnamed shale of Molenaar and Wilson (1990); dark-gray, non-fissile shale or silty claystone, lignitic in the upper part, and moderately soft; the basal sandstone and unnamed shale are found in the northwest part of the quadrangle and pinchout eastward; the typical Frontier stratigraphy of an upper sandstone, middle shale, lower sandstone, and Tununk Shale in subsurface in the eastern part of the quadrangle 135 to 230 m thick.

Unconformity

Kms Mowry Shale (Upper Cretaceous, Cenomanian) – Dark-gray siliceous shale, with thin bentonitic beds; weathers characteristically into silver-gray outcrops that support little vegetation and are strewn with centimeter-sized, hard fragments; contains abundant fossil teleost fish scales and bones, shark teeth, and coprolites (Anderson and Kowallis, 2005); marine origin based on fossils; 40 to 65 m thick.

Kd Dakota Formation (Lower Cretaceous, Albian) – Upper and lower sandstone and shale; sandstone beds are light brown to yellowish gray, coarse grained with some pebble conglomerate lenses, limonite stained, and ledge to cliff forming; shale is dark gray, carbonaceous to locally lignitic; forms slopes; upper and lower sandstone separated by carbonaceous shale; 145 to 230 m thick.

K-2 Unconformity

Cretaceous and Jurassic Rock Units

KJcm Cedar Mountain and Morrison Formations, undivided (Lower Cretaceous and Upper Jurassic) – The Cedar Mountain Formation and underlying Morrison Formation are mapped as a single slope-forming unit because the contact between the two formations has not been resolved in the map area, despite being an unconformity; regionally the contact can be marked by a resistant conglomerate at the base of the Cedar Mountain called the Buckhorn Conglomerate Member or a chert-pebble bearing, mottled, yellow-orange mudstone (see the Middle and Upper Jurassic Stratigraphy section for details about the contact); combined thickness of map unit is 355 to 470 m.

<u>Cedar Mountain Formation</u> (Lower Cretaceous, Aptian to Albian) – Purple, purplish-gray, and greenish-gray mudstone and siltstone and minor light-gray sandstone; contains calcrete and minor limestone beds that weather out as carbonate-coated fragments and carbonate nodules.

K-1 Unconformity

Jurassic Rock Units

<u>Morrison Formation</u> (Upper Jurassic, Tithonian to Kimmeridgian) – Color-banded, variegated (light-gray, olive-gray, red, and light-purple) shale, bentonitic claystone, and siltstone; light-gray, low-angle cross-bedded sandstone, and some pebble-conglomerate beds.

J-5 Unconformity

Js Stump Formation (Upper and Middle[?] Jurassic, Oxfordian and Callovian[?]) – Sandstone and limestone interbedded with lesser shale; upper part (Redwater Member) is ledge-forming, light-brown, sandy, oolitic, fossiliferous, cross-bedded limestone, and underlying slope-forming olive-brown, glauconitic shale; locally contains gypsum and belemnite fossils; basal part of formation (Curtis Member) is very light-gray, coarse-grained, cross-bedded, glauconitic, friable sandstone that can form resistant ledge; regionally the Redwater Member is mostly red shale with glauconitic beds in the underlying Curtis Member (Pipiringos and Imlay, 1979); 40 to 65 m thick.

J-3 Unconformity

Jp Preuss Formation (Middle Jurassic, Callovian) – Dark-reddish-brown to reddish-gray, fine- to medium-grained sandstone (quartz arenite and some feldspathic) with low-angle cross-bedding, ripple marks, and some salt casts; dark-reddish-brown sandy siltstone and sandy mudstone; some thin greenish-gray to light-gray sandstone; may include salt beds, especially in subsurface; slope forming; gradational eastward into the eolian sandstone beds of the Entrada Sandstone; 210–240 m thick.

Ja Arapien Formation (Middle Jurassic, Callovian to Bajocian) – Upper part is medium-gray to greenish-gray, slope-forming mudstone and siltstone with anhydrite and equivalent to the Twelvemile Canyon Member (Sprinkel and others, 2011a); lower part is predominately medium-gray to light-gray and light-brownish-gray micritic to oolitic limestone; limestone beds are well cemented but highly fractured; contains marine invertebrate fossils; includes strata equivalent to the Watton Canyon, Boundary Ridge, Rich, and Sliderock Members of the Twin Creek Limestone (Sprinkel and others, 2011a); 230 to 300 m thick.

J-1 Unconformity

Jurassic and Triassic Rocks

JTRn Nugget Sandstone (Lower Jurassic to Upper Triassic, Hettangian–Toarcian to Rhaetian) – Light-brown to light-reddish-gray, medium- to fine-grained, massive weathering, quartz sandstone with large-scale, high-angle cross-beds; forms cliffs, ledges, monoliths, arches, and spires; commonly jointed; gently dipping surfaces weather into loose sand commonly reworked by wind; locally contains thin, light-brown to very light-brown sandy dolomite and reddish-brown siltstone (interdunal lacustrine origin) in high-angle cross-bedded sandstone in upper part of the formation (Haddox and others, 2010a); at base contains reddish-colored planar-bedded sandstone and siltstone interbedded with high-angle cross-bedded sandstone (Jensen, 2005; Sprinkel and others, 2011b); 180 to 300 m thick.

Triassic Rock Units

TRau Ankareh Formation, upper members (Upper Triassic, Rhaetian to Carnian) – Variegated (reddish-brown, grayish-brown, greenish-gray, and yellowish-gray) siltstone and mudstone; light-brown to light-gray, fine-grained, ripple-marked and ripple-laminated sandstone; contains two thin greenish-gray silty and argillaceous limestone beds near top of unit (Huddle and McCann, 1947b); contains some mudcracks and salt casts; uppermost part includes a more resistant sandstone and overlying slope-forming, fine-grained beds that are similar to the formation of Bell Springs of Sprinkel and others (2011b; see also Jensen and others, 2016); base includes 5 to 15 m of light-gray to purplish-gray, coarse-grained sandstone and pebble conglomerate beds of the Gartra Member of the Ankareh Formation, shown as a red marker bed that separates the upper and lower Ankareh Formation on the geologic map; upper map unit unconformably overlies lower map unit; 90 to 120 m thick.

TR-3 Unconformity

TRal Ankareh Formation, lower member (Lower Triassic, Olenekian) – Purplish-gray and reddish-brown, fine-grained sandstone, siltstone, and mudstone; slope forming with thin ledges of resistant beds; thins to east; 215 to 305 m thick.

TRt Thaynes Formation (Lower Triassic, Olenekian and Induan) – Light-gray to light-brownish-gray, thick- to thin-bedded limestone, brownish-gray siltstone, and some light-gray, fine-grained sandstone; resistant and cliff forming; intertongues and is gradational eastward and southeastward into variegated siltstone and mudstone beds of part of the Moenkopi Formation; thins eastward; 85 to 150 m thick.

TRw Woodside Formation (Lower Triassic, Induan) – Grayish-red and reddish-brown shale, moderate-red siltstone, and very fine-grained sandstone; slope forming; 215 to 300 m thick.

T̵R-1 Unconformity

Permian Rock Units

Park City and Phosphoria Formations: Mapped as an upper and lower unit. The upper unit includes the Franson Member of the Park City Formation, Mackentire Tongue, and the Meade Peak Member of the Phosphoria Formation. The Mackentire Tongue red beds have been called a tongue of the Phosphoria (Williams, 1939) and a tongue of the Woodside Shale (Thomas, 1939; Thomas and Krueger, 1946) and may be related to the State Bridge Formation of Colorado (see Pennsylvanian and Permian Stratigraphy section for details). The lower unit is the Grandeur Member of the Park City Formation. The combined thickness of map units is 110 to 135 m.

Ppu Upper unit – Franson Member of Park City Formation, Mackentire Tongue, and Meade Peak Member (Middle to Lower Permian, Wordian to Kungurian [Guadalupian to Leonardian])

Franson Member – Light- to medium-gray, brownish-gray, and dark-greenish-gray cherty limestone, dolomitic limestone, and dolomitic sandstone; glauconitic in part; vugs and calcite-filled vugs in lower part of member; fossiliferous in the lower part of the member, and forms prominent ledges; 30 to 45 m thick.

Mackentire Tongue – Moderate red shale, siltstone and very fine grained sandstone; forms slope; 17 m thick at Lake Fork measured section (Thomas and Krueger, 1946); thins to the east, west, and north of the type locality (McKelvey and others, 1959).

Meade Peak Member of Phosphoria Formation – Forms base of unit; slope-forming, dark-gray phosphatic shale with interbeds of sandstone and limestone; 10 to 15 m thick.

Ppg Lower unit – Grandeur Member of Park City Formation, (Lower Permian, Kungurian to Artinskian [Leonardian]) – Light-gray to light-brownish-gray sandstone, limestone, and dolomitic limestone; local low-angle cross-bedding; contains large vugs in the lower part of member; fossiliferous; forms prominent cliff; 80 to 90 m.

Permian and Pennsylvanian Rocks

Pℙw Weber Sandstone (Lower Permian and Middle Pennsylvanian, Sakmarian to Asselian and Moscovian [Wolfcampian and Desmoinesian]) – Light-gray to light-brown, fine- to medium-grained; generally forms steep, light-colored cliffs with large-scale cross-bedding (see Fryberger, 1979, on eolian origin); large talus accumulations common at base of cliffs; light-gray, thin-bedded, cherty limestone and dolomite beds are present in the upper part; locally contains large-scale fluid-escape structures; may or may not contain Upper Pennsylvanian strata; 325 to 450 m thick.

Pennsylvanian Rock Units

ℙm Morgan Formation (Middle Pennsylvanian, Moscovian [Desmoinesian]) – Light to medium reddish-brown and reddish-gray siltstone and shale; light-gray to light yellowish-brown with some mottled brownish and purplish, very fine grained, cross-bedded sandstone; and some conglomeratic sandstone (pebble-sized limestone clasts); light-gray, medium crystalline, cherty (pink), and thin-bedded limestone; forms reddish-colored ledges and slopes; 60 to 100 m thick.

Unconformity (?)

ℙr Round Valley Limestone (Lower Pennsylvanian, Bashkirian [Atokan and Morrowan]) – Gray to dark-gray, thin- to thick-bedded, cherty (medium red and gray) limestone; weathers light gray; pale-red to orangish-gray silicified invertebrate fossils are common; forms ledges; 60 to 75 m thick.

Mississippian Rock Units

Mdo	Doughnut Formation (Upper Mississippian, Serpukhovian [Chesterian]) – Dark-gray, organic- and clay-rich shale with beds of light yellow-gray, coarse-grained sandstone and dark-gray, thin-bedded limestone; mostly poorly exposed forming strike valleys and dark recessed slopes and is prone to slope failure; upper Doughnut carbonate beds have not been identified in the map area; 60 to 90 m thick.
Mh	Humbug Formation (Upper to Middle Mississippian, Serpukhovian to Visean [Chesterian to Meramecian]) – Light-gray to reddish-gray, fine-grained sandstone; reddish-colored and hematitic near the top; interbedded with light-gray limestone and reddish- to dark-gray mudstone; 110 to 125 m thick.
Md	Deseret Limestone (Middle to Lower Mississippian, Visean to Tournaisian [Meramecian to Osagean]) – Upper dark- and light-gray, thick-bedded, dense and cherty limestone and dolomitic limestone that forms steep cliffs; zones of brecciated limestone, abundant caves, and other karst features; lower dark-gray phosphatic shale and thin-bedded, cherty limestone approximately 5 to 10 m thick (Delle Phosphatic Member); generally poorly exposed and slope forming; 180 to 200 m total thickness.
Mg	Gardison Limestone (Lower Mississippian, lower Tournaisian [Kinderhookian]) – Dark-gray, fossiliferous and cherty limestone and dolomitic limestone with minor interbedded dark-gray shale; limestone and dolomitic limestone are thin- to medium-bedded but generally form massive-weathering cliff; 75 m thick.

Major Unconformity (Devonian to Upper Cambrian is missing)

Cambrian Rock Units

Ꞓt	Tintic Quartzite (Middle Cambrian) – Very light brown to light yellow-brown, medium- to coarse-grained, cross-bedded, quartz sandstone, with some conglomerate beds of pebble- to cobble-sized bull quartz; 100 to 120 m thick.

ACKNOWLEDGMENTS

The Duchesne 30′ x 60′ geologic map has benefitted greatly from discussions about the regional geology with Jon King (Utah Geological Survey) and Steve Schamel (GeoX Consulting, Inc.), and from reviews by Jon King and Grant Willis (Utah Geological Survey). I thank Tom Fouch (TFGS LLC, formerly U.S. Geological Survey, retired), Ron Johnson (U.S. Geological Survey), and Michael Vanden Berg (Utah Geological Survey) for reviewing the Green River Formation correlation diagram (plate 2, figure 5). The review and technical editing by Kimm Harty (Utah Geological Survey) is greatly appreciated. I thank Scott Wilson (formerly Duchesne County Water Conservancy District) for his past support of my fieldwork in the quadrangle, Kevin Duncan of Roosevelt for granting me access to his property, and Gibson Peters (Governor's Office of Energy Development) for arranging a meeting with the Energy and Minerals Department of the Ute Indian Tribe to discuss geologic mapping on and energy development of Tribal Lands. I gratefully acknowledge and thank the Ute Indian Tribe, especially Manuel Myore (deceased, Director, Energy and Minerals Department), Bruce Pargeets (Director, Energy and Minerals Department), Steve Nelson (Minerals Revenue Director, Energy and Minerals Department), Lauren Lomahaftewa (Office Coordinator, Energy and Minerals Department), and Marie Kaufusi (Emissions Specialist for the Ute Indian Tribe Air Quality Department), for discussing the geology and geologic mapping of Ute Tribal Lands and helping with access to Tribal Lands. Finally, I thank Tom Giles (Sand Creek Ranch) and Casey Cardwell (Moon Ranch) for access to those areas.

REFERENCES

Allmendinger, R.W., and Judge, P., 2013, Stratigraphic uncertainty and errors in shortening from balanced sections in the North American Cordillera: Geological Society of America Bulletin, v. 125, no. 9–10, p. 1569–1579.

Andersen, D.W., 1972, Stratigraphy of the Duchesne River Formation (Eocene-Oligocene), northern Uinta Basin, northeastern Utah: Salt lake City, University of Utah, M.S. thesis, 84 p.

Andersen, D.W., and Picard, M.D., 1972, Stratigraphy of the Duchesne River Formation (Eocene-Oligocene?), northern Uinta Basin, northeastern Utah: Utah Geological and Mineral Survey Bulletin 97, 29 p.

Andersen, D.W., and Picard, M.D., 1974, Evolution of synorogenic clastic deposits in the intermontane Uinta Basin of Utah, *in* Dickinson, W.R., editor, Tectonics and sedimentation: SEPM (Society for Sedimentary Geology) Special Publication 22, p. 167–189.

Anderson, A.D., and Kowallis, B.J., 2005, Storm deposited fish debris in the Cretaceous Mowry Shale near Vernal, Utah, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 125–130.

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Atchley, S.C., Nordt, L.C., Dworkin, S.I., Ramezani, J., Parker, W.G., Ash, S.R., and Bowring, S.A., 2013, A linkage among Pangean tectonism, cyclic alluviation, climate change, and biological turnover in the Late Triassic—the record from the Chinle Formation, southwestern United States: Journal of Sedimentary Research, v. 83, p. 1147–1161.

Atwood, W.W., 1909, Glaciation of the Uinta and Wasatch Mountains: U.S. Geological Survey Professional Paper 61, 96 p., 1 plate, scale 1:1,250,000.

Baker, A.A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC-30, 1 plate, scale 1:316,800.

Baker, A.A., 1976, Geologic map of the Strawberry Valley quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Series I-931, scale 1:62,500.

Baker, A.A., Huddle, J.W., and Kinney, D.M., 1949, Paleozoic geology of the north and west sides of Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 33, no. 7, p. 1161–1197.

Biek, R.F., 2017, Interim geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: Utah Geological Survey Open-File Report OFR-677, 19 p., 2 plates, scale 1:24,000.

Bilbey, S.A., and Hamblin, A.H., 1992, Roadlog—Vernal to Manila, Utah, *in* Wilson, J.R., editor, Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publication 92-3, p. 363–367.

Bilbey, S.A., Mickelson, D.L., Hall, E.J., Kirkland, J.I., Madsen, S.K., Blackshear, B., and Todd, C., 2005, Vertebrate ichnofossils from the Upper Jurassic Stump to Morrison transition—Flaming Gorge Reservoir, Utah, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 111–123.

Bissell, H.J., 1950, Carboniferous and Permian stratigraphy of the Uinta Basin, *in* Eardley, A.J., editor, Petroleum geology of the Uintah Basin: Intermountain Association of Petroleum Geologists Guidebook to the Geology of Utah 5, p. 71–96.

Bissell, H.J., 1952, Stratigraphy and structure of northeast Strawberry Valley quadrangle, Utah: American Association of Petroleum Geologists Bulletin, v. 36, no. 4, p. 575–634.

Bissell, H.J., 1964, Lithology and petrography of the Weber Formation, in Utah and Colorado, *in* Sabatka, E.F., editor, Guidebook to the geology and mineral resources of the Uinta Basin, Utah's hydrocarbon storehouse: Intermountain Association of Petroleum Geologists 13th Annual Field Conference Guidebook, p. 67–91.

Bissell, H.J., and Childs, O.E., 1958, The Weber Formation of Utah and Colorado, *in* Curtis, B., and Warner, H.L., editors, Symposium on Pennsylvanian rocks of Colorado and adjacent areas: Rocky Mountain Association of Geologists, p. 26–30.

Boden, T., and Tripp, B.T., 2012, Gilsonite veins of the Uinta Basin: Utah Geological Survey Special Studies 141, 50 p., 1 plate, scale 1:100,000.

Bowman, S.D., and Arabasz, W.J., 2017, Utah earthquakes (1850–2016) and Quaternary faults: Utah Geological Survey Map 277, 1 plate, scale 1:500,000.

Bradley, W.H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geological Survey Professional Paper 168, 58 p.

Brenner, R.L., Ludvigson, G.A., Witzke, B.J., Zawistoki, A.N., Kvale, E.P., Ravn, R.L., and Joeckel, R.M., 2000, Late Albian Kiowa-Skull Creek marine transgression, lower Dakota Formation, eastern margin of Western Interior Seaway, U.S.A.: Journal of Sedimentary Research, v. 70, no. 4, p. 868–878.

Britt, B.B., Burton, D., Greenhalgh, B.W., Kowallis, B.J., and Christiansen, E.H., 2007, Detrital zircon ages for the basal Cedar Mountain Formation (Early Cretaceous) near Moab, and Dinosaur National Monument, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 39, no. 5, p. 16.

Britt, B.B., Chure, D.J., Engelmann, G.F., and Shumway, J.D., 2016, Rise of the erg—paleontology and paleoenvironments of the Triassic-Jurassic transition in northeastern Utah: Geology of the Intermountain West, v. 3, p. 1–32.

Bruhn, R.L., Picard, M.D., and Isby, J.S., 1986, Tectonics and sedimentology of Uinta Arch, western Uinta Mountains and Uinta Basin, *in* Peterson, J.A., editor, Paleotectonics and sedimentation: American Association of Petroleum Geologists Memoir 41, p. 333–352.

Bryant, B., 1990, Geologic map of the Salt Lake City 30′ x 60′ quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, 3 plates, scale 1:100,000.

Bryant, B., 1992, Geologic and structure maps of the Salt Lake City 1° x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1997, 2 plates, scale 1:125,000.

Bryant, B., Naeser, C.W., Marvin, R.F., and Mehnert, H.H., 1989, Upper Cretaceous and Paleogene sedimentary rocks and isotopic ages of Paleogene tuffs, Uinta Basin, Utah: U.S. Geological Survey Bulletin 1787-J, p. J1-J22, 1 plate, scale 1:500,000.

Carey, M.A., 1973, Chesterian-Morrowan conodont biostratigraphy from northeastern Utah: Salt Lake City, University of Utah, M.S. thesis, 83 p.

Carr, T.R., and Paull, R.K., 1983, Early Triassic stratigraphy and paleogeography of the Cordilleran miogeocline, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of west-central United States Rocky Mountain, Denver: Rocky Mountain Section SEPM (Society for Sedimentary Geology) Paleogeography Symposium 2, p. 39–55.

Cashion, W.B., 1967, Geology and fuel resources of the Green River Formation southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Professional Paper 548, 48 p.

Cashion, W.B., 1974, Geologic map of the Southam Canyon quadrangle, Uintah County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-579, 1 plate, scale 1:24,000.

Cashion, W.B., 1982, Descriptions of four stratigraphic sections of parts of the Green River and Uinta Formations in the eastern Uinta Basin, Uintah County, Utah, and Rio Blanco County, Colorado: U.S. Geological Survey Open-File Report 83-17, 42 p.

Cashion, W.B., and Donnell, J.R., 1974, Revision of nomenclature of the upper part of the Green River Formation, Piceance Creek basin, Colorado, and eastern Uinta Basin, Utah: U.S. Geological Survey Bulletin 1394-G, 9 p.

Chadwick, O.A., Hall, R.D., and Phillips, F.M., 1997, Chronology of Pleistocene glacial advances in the central Rocky Mountains: Geological Society of America Bulletin, v. 109, no. 11, p. 1443–1452.

Chambers, M., Hales, K., Britt, B.B., Chure, D.J., Engelmann, G.F., and Scheetz, R., 2011, Preliminary taphonomic analysis of a *coelophysoid* theropod dinosaur bonebed in the Early Jurassic Nugget Sandstone of Utah [abs.]: Geological Society of America Abstracts with Programs, v. 43, no. 4, p. 16.

Cifelli, R.L., Kirkland, J.I., Weil, A., Deino, A.L., and Kowallis, B.J., 1997, High precision ^{40}Ar/^{39}Ar geochronology and the advent of North America's Late Cretaceous terrestrial fauna: Proceedings of the National Academy of Sciences, v. 94, p. 11,163–11,167.

Clark, D.L., 1957, Marine Triassic stratigraphy in eastern Great Basin: American Association of Petroleum Geologists Bulletin, v. 41, no. 10, p. 2192–2222.

Cobban, W.A., and Kennedy, W.J., 1989, The ammonite *Metengonoceras* Hyatt, 1903, from the Mowry Shale (Cretaceous) of Montana and Wyoming: U.S. Geological Survey Bulletin 1787-L, 11 p.

Cobban, W.A., and Reeside, J.B., Jr., 1951, Lower Cretaceous ammonites in Colorado, Wyoming, and Montana: American Association of Petroleum Geologists Bulletin, v. 35, no. 8, p. 1892–1893.

Cobban, W.A., and Reeside, J.B., Jr., 1952, Frontier Formation, Wyoming and adjacent areas: American Association of Petroleum Geologists Bulletin, v. 36, no. 10, p. 1913–1961.

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, no. 1, p. 20–39.

Constenius, K.N., Clark, D.L., King, J.K., and Ehler, J.B., 2011, Interim geologic map of the Provo 30′ x 60′ quadrangle, Salt Lake, Utah, and Wasatch Counties, Utah: Utah Geological Survey Open-File Report 586, 42 p., 2 plates, scale 1:62,500.

Constenius, K.N., Esser, R.P., and Layer, P.W., 2003, Extensional collapse of the Charleston-Nebo salient and its relationship to space-time variations in Cordilleran orogenic belt tectonism and continental stratigraphy, *in* Raynolds, R.G., and Flores, R.M., editors, Cenozoic systems of the Rocky Mountain Region, Denver: Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 303–353.

Coogan, J.C., and King, J.K., 2016, Interim geologic map of the Ogden 30′ x 60′ quadrangle, Box Elder, Cache, Davis, Morgan, Rich, and Summit Counties, Utah, and Uinta County, Wyoming: Utah Geological Survey Open-File Report 653, 112 p., 3 plates, scale 1:62,500.

Coogan, J.C., King, J.K., and McDonald, G.N., 2015, Interim geologic map of the Morgan quadrangle, Morgan County, Utah: Utah Geological Survey Open-File Report 643, 30 p., 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1959, Mississippian stratigraphy of the central Wasatch and western Uinta Mountains, Utah, *in* Williams, N.C., editor, Guidebook to the geology of the Wasatch and Uinta Mountains transition area: Intermountain Association of Petroleum Geologist 10th Annual Field Conference, p. 63–74.

Crittenden, M.D., Jr., Stuckless, J.S., Kistler, R.W., and Stern, T.W., 1973, Radiometric dating of intrusive rocks in the Cottonwood area, Utah: U.S. Geological Survey Journal of Research, v. 1, no. 2, p. 173–178.

Currie, B.S., 1998, Upper Jurassic-Lower Cretaceous Morrison and Cedar Mountain Formations, NE Utah-NW Colorado—relationships between nonmarine deposition and early Cordilleran foreland basin development: Journal of Sedimentary Research, v. 68, no. 4, p. 632–652.

Dane, C.H., 1954, Stratigraphic and facies relationships of upper part of Green River Formation and lower part of Uinta Formation in Duchesne, Uintah, and Wasatch Counties, Utah: American Association of Petroleum Geologists Bulletin, v. 38, no. 9, p. 405–425.

Dane, C.H., 1955, Stratigraphic and facies relationships of the upper part of the Green River Formation and the lower part of the Uinta Formation in Duchesne, Uintah, and Wasatch Counties, Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC-52, 2 plates.

Doelling, H.H., and Graham, R.L., 1972, Eastern and northern coal fields-Vernal, Henry Mountains, Sego, La Sal-San Juan, Tabby Mountain, Coalville, Henrys Fork, Goose Creek, and Lost Creek: Utah Geological and Mineralogical Survey Monograph 2, 411 p., multiple plates, various scales.

Douglass, D.C., 2000, Glacial history of the West Fork of Beaver Creek, Uinta Mountains, Utah: Madison, University of Wisconsin, M.S. thesis, 49 p.

Dunn, D.L., 1970, Middle Carboniferous conodonts from western United States and phylogeny of the platform group: Journal of Paleontology, v. 44, no. 2, p. 312–342.

Dyni, J.R., Milton, C., and Cashion, W.B., 1985, The saline facies of the upper part of the Green River Formation near Duchesne, Utah, *in* Picard, M.D., editor, Geology and energy resources, Uinta Basin: Utah Geological Association Publication 12, p. 51–60.

Elliott, A.H., and Harty, K.M., 2010, Landslide maps of Utah: Utah Geological Survey Map 246DM, 14 p., plate 15 of 46 plates, scale 1:100,000, GIS Data.

Engelmann, G.F., Chure, D.J., Britt, B.B., and Andrus, A., 2012, The biostratigraphic and paleoecological significance of a new Drepanosaur from the Triassic-?Jurassic Nugget Sandstone of northeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 44, no. 7, p. 604.

Eugster, H.P., and Surdam, R.C., 1973, Depositional environment of the Green River Formation of Wyoming—a preliminary report: Geological Society of America Bulletin, v. 84, no. 4, p. 1115–1120.

Forrester, J.D., 1937, Structure of the Uinta Mountains: Geological Society of America Bulletin, v. 48, no. 5, p. 631–666.

Fouch, T.D., 1975, Lithofacies and related hydrocarbon accumulations in Tertiary strata of the western and central Uinta Basin, *in* Boylard, D.W., editor, Symposium on deep drilling frontiers in the central Rocky Mountains, Denver: Rocky Mountain Association of Geologists, p. 163–173.

Fouch, T.D., 1976, Revision of the lower part of the Tertiary system in the central and western Uinta Basin, Utah: U.S. Geological Survey Bulletin 1405-C, p. C1–C7.

Fouch, T.D., and Dean, W.E., 1983, Lacustrine and associated clastic depositional environments, *in* Scholle, P.A., Debout, D.G., and Moore, C.H., editors, Carbonate depositional environments: American Association of Petroleum Geologists Memoir 33, p. 87–114.

Fouch, T.D., Nuccio, V.F., Anders, D.E., Rice, D.D., Pitman, J.K., and Mast, R.F., 1994, Green River(!) petroleum system, Uinta Basin, Utah, U.S.A., *in* Magoon, L.B., and Dow, W.G., editors, The petroleum system—from source to trap: American Association of Petroleum Geologists Memoir 60, p. 399–421.

Fouch, T.D., Nuccio, V.F., and Chidsey, T.C., Jr., editors, 1992, Hydrocarbon and mineral resources of the Uinta Basin, Utah and Colorado, Utah Geological Association, 366 p.

Fournier, R.O., Christiansen, R.L., Hutchinson, R.A., and Pierce, K.L., 1994, A field guide to Yellowstone National Park, Wyoming, Montana, and Idaho—volcanic hydrothermal, and glacial activity in the region: U.S. Geological Survey Bulletin 2099, 46 p., 2 appendices.

Franczyk, K.J., Fouch, T.D., Johnson, R.C., Molenaar, C.M., and Cobban, W.A., 1992, Cretaceous and Tertiary paleogeographic reconstructions from the Uinta-Piceance basin study area, Colorado and Utah: U.S. Geological Survey Bulletin 1787-Q, 37 p.

Franczyk, K.J., Pitman, J.K., and Nichols, D.J., 1990, Sedimentology, mineralogy, palynology, and depositional history of the uppermost Cretaceous and lowermost Tertiary rocks along the Book and Roan Cliffs east of the Green River: U.S. Geological Survey Bulletin 1787-N, 27 p., 2 plates.

Fryberger, S.G., 1979, Eolian-fluviatile (continental) origin of ancient stratigraphic trap for petroleum in Weber Sandstone, Rangely oil field, Colorado: The Mountain Geologist, v. 16, p. 1–36.

Gale, A.S., Kennedy, W.J., Burnett, J.A., Caron, M., and Kidd, B.E., 1996, The Late Albian to Early Cenomanian succession at Mount Risou near Rosans (Drôme, SE France)—an integrated study (ammonites, inoceramids, planktonic foraminifera, nannofossils, oxygen and carbon isotopes): Cretaceous Research, v. 17, p. 515–606.

Garvin, R.F., 1969, Stratigraphy and economic significance, Currant Creek Formation, northwest Uinta Basin, Utah: Utah Geological Survey Special Studies 27, 62 p., 2 plates, multiple scales.

Greenhalgh, B.W., 2006, A stratigraphic and geochronological analysis of the Morrison Formation/Cedar Mountain Formation boundary, Utah: Provo, Brigham Young University, M.S. thesis, 61 p.

Greenhalgh, B.W., and Britt, B.B., 2007, Stratigraphy and sedimentology of the Morrison-Cedar Mountain Formation boundary, east-central Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 81–100.

Groeger, A., and Bruhn, R.L., 2001, Structure and geomorphology of the Duchesne graben, Uinta basin, Utah, and its enhancement of a hydrocarbon reservoir: American Association of Petroleum Geologists Bulletin, v. 85, no. 9, p. 1661–1678.

Haddox, D.A., Kowallis, B.J., and Sprinkel, D.A., 2010a, Geologic map of the Steinaker Reservoir quadrangle, Uintah County, Utah: Utah Geological Survey Miscellaneous Publication 10-3, 2 plates, scale 1:24,000.

Haddox, D.A., Kowallis, B.J., and Sprinkel, D.A., 2010b, Geologic map of the Dry Fork quadrangle, Uintah County, Utah: Utah Geological Survey Miscellaneous Publication 10-4, 2 plates, scale 1:24,000.

Hale, L.A., and Van de Graaff, F.R., 1964, Cretaceous stratigraphy and facies patterns—northeastern Utah and adjacent areas, *in* Sabatka, E.F., editor, Guidebook to the geology and mineral resources of the Uinta Basin—Utah's hydrocarbon storehouse: Intermountain Association of Petroleum Geologists Thirteenth Annual Field Conference, p. 115–138.

Hamblin, A.H., and Bilbey, S.A., 1999, A dinosaur track site in the Navajo-Nugget Sandstone, Red Fleet Reservoir, Uintah County, Utah, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 51–57.

Hamblin, A.H., Bilbey, S.A., and Hall, J.E., 2000, Prehistoric animal tracks at Red Fleet State Park, northeastern Utah, *in* Sprinkel, D.A., Anderson, P.B., and Chidsey, T.C., Jr., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 569–578.

Hansen, W.R., 1965, Geology of the Flaming Gorge area Utah-Colorado-Wyoming: U.S. Geological Survey Professional Paper 490, 196 p., 3 plates, scale 1:48,000.

Hansen, W.R., 1969, Quaternary faulting at Towanta Flat, on the south flank of the Uinta Mountains, Duchesne County, Utah, *in* Lindsay, J.B., editor, Geologic guidebook of the Uinta Mountains-Utah's maverick range: Intermountain Association of Geologists and Utah Geological Society 16th Annual Field Conference, p. 91–92.

Hansen, W.R., 1986, Neogene tectonics and geomorphology of the eastern Uinta Mountains in Utah, Colorado, and Wyoming: U.S. Geological Survey Professional Paper 1356, 78 p.

Harty, K.M., 1992, Landslide map of the Duchesne 30′ x 60′ quadrangle, Utah: Utah Geological Survey Open-File Report 257, 11 p., 1 plate, scale 1:100,000.

Heckert, A.B., Chure, D.J., Voris, J.T., Harrison, A.A., and Thomson, T.J., 2015, Stratigraphy, correlation, and age of the Moenkopi Formation in the vicinity of Dinosaur National Monument, eastern Uinta Basin, Utah and Colorado, USA, *in* Vanden Berg, M.D., Ressetar, R.R., and Birgenheier, L.P., editors, Geology of Utah's Uinta Basin and Uinta Mountains: Utah Geological Association Publication 44, p. 1–12.

Hendrix, B., Moeller, A., Ludvigson, G.A., Joeckel, R.M., and Kirkland, J.I., 2015, A new approach to date paleosols in terrestrial strata—a case study using U-Pb zircon ages for the Yellow Cat Member of the Cedar Mountain Formation of eastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 47, no. 7, p. 597.

High, L.R., Jr., Hepp, D.M., Clark, T., and Picard, M.D., 1969, Stratigraphy of Popo Agie Formation (Late Triassic), Uinta Mountain area, Utah and Colorado, *in* Lindsay, J.B., editor, Geologic guidebook of the Uinta Mountains - Utah's maverick range: Intermountain Association of Geologists 16th Annual Field Conference, p. 181–192.

Huddle, J.W., Mapel, W.J., and McCann, F.T., 1951, Geology of the Moon Lake area, Duchesne County, Utah: U.S. Geological Survey Oil and Gas Investigations Map OM 115, 1 plate, scale 1:63,360.

Huddle, J.W., and McCann, F.T., 1947a, Late Paleozoic rocks exposed in the Duchesne River area, Duchesne County, Utah: U.S. Geological Survey Circular 16, 21 p.

Huddle, J.W., and McCann, F.T., 1947b, Geologic map of the Duchesne River area, Wasatch and Duchesne Counties, Utah: U.S. Geological Survey Oil and Gas Investigations Preliminary Map OM 75, 1 plate, scale 1:63,360.

Hutsky, A.J., and Fielding, C.R., 2015, A field guide to the middle to upper Turonian Frontier Formation, "Vernal delta complex", northern Uinta Basin, Utah and Colorado, *in* Birgenheier, L.P., Ressetar, R., and Vanden Berg, M.D., editors, The Uinta Basin: Utah Geological Association Publication 44, p. 13–48.

Hutsky, A.J., and Fielding, C.R., 2016, The offshore bar revisited—a new depositional model for isolated shallow marine sandstone in the Cretaceous Frontier Formation of the northern Uinta Basin, Utah, U.S.A.: Journal of Sedimentary Research, v. 86, p. 38–58.

Imlay, R.W., 1952, Marine origin of Preuss Sandstone of Idaho, Wyoming , and Utah: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1735–1753.

Imlay, R.W., 1967, Twin Creek Limestone (Jurassic) in the western interior of the United States: U.S. Geological Survey Professional Paper 540, 105 p.

Imlay, R.W., 1980, Jurassic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Irmis, R.B., Chure, D.J., Engelmann, G.F., Wiersma, J.P., and Lindström, S., 2015, The alluvial to eolian transition of the Chinle and Nugget Formations in the southern Uinta Mountains, northeastern Utah, *in* Vanden Berg, M.D., Ressetar, R., and Birgenheier, L.P., editors, The Uinta Basin and Uinta Mountains: Utah Geological Association Publication 44, p. 13–48.

Irmis, R.B., Mundil, R., Martz, J.W., and Parker, W.G., 2011, High-resolution U-Pb ages from the Upper Triassic Chinle Formation (New Mexico, USA) support a diachronous rise of dinosaurs: Earth and Planetary Science Letters, v. 309, p. 258–267.

Isby, J.S., and Picard, M.D., 1983, Currant Creek Formation—record of tectonism in Sevier-Laramide orogenic belt, north-central Utah: Rocky Mountain Geology, v. 22, no. 2, p. 91–108.

Isby, J.S., and Picard, M.D., 1985, Depositional setting of Upper Cretaceous-lower Tertiary Currant Creek Formation, *in* Picard, M.D., editor, Geology and energy resources, Uinta Basin of Utah: Utah Geological Association Publication 39, p. 39–49.

Jacobson, S.R., and Nichols, D.J., 1982, Palynological dating of syntectonic units in the Utah-Wyoming thrust belt—the Evanston Formation, Echo Canyon Conglomerate, and Little Muddy Creek Conglomerate, *in* Powers, R.B., editor, Geologic Studies of the Cordilleran thrust belt, volume II: Rocky Mountain Association of Geologists, p. 735–750.

Jensen, M., Webb, C., Kowallis, B.J., Christiansen, E.H., and Sprinkel, D.A., 2017, 40Ar/39Ar ages, composition, and likely source of fallout tuffs in the Duchesne River Formation, northeastern Utah [abs.]: Geological Society of America Abstracts with Program, v. 49, no. 5.

Jensen, P.H., 2005, Mapping and piecing together the Triassic/Jurassic stratigraphy along the south flank of the Uinta Mountains, northeastern Utah: a stratigraphic analysis of the Bell Springs Member of the Nugget Formation: Provo, Brigham Young University, M.S. thesis, 59 p.

Jensen, P.H., and Kowallis, B.J., 2005, Piecing together the Triassic/Jurassic stratigraphy along the south flank of the Uinta Mountains, northeast Utah–a preliminary analysis, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 99–109.

Jensen, P.H., Sprinkel, D.A., Kowallis, B.J., and Brown, K.D., 2016, Geologic map of the Donkey Flat quadrangle, Uintah County, Utah: Utah Geological Survey Miscellaneous Publication 16-2DM, 8 p., 2 plates, scale 1:24,000.

John, D.A., Turrin, B.D., and Miller, R.J., 1997, New K-Ar and ages of plutonism, hydrothermal alteration, and mineralization in the central Wasatch Mountains, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains: Society of Economic Geologists Guidebook Series 29, second edition, p. 47–57.

Johnson, R.C., and Johnson, S.Y., 1991, Stratigraphic and time-stratigraphic cross sections of Phanerozoic rocks along line B-B*'*, Uinta and Piceance Basin area, west-central Uinta Basin, Utah to eastern Piceance Basin, Colorado: U.S. Geological Survey Miscellaneous Investigation Series Map I-2184-B, 2 plates, scale 1:500,000.

Johnson, R.C., Mercier, T.J., Brownfield, M.E., and Self, J.G., 2010, Assessment if on-place oil shale resources in the Eocene Green River Formation, Uinta Basin, Utah and Colorado: U.S. Geological Survey Digital Data Series DDS-69-BB, chapter 1, compact disc, 153 p.

Johnson, R.C., Nichols, D.J., and Hanley, J.H., 1988, Stratigraphic sections lower Tertiary strata and charts showing palynomorphs and mollusk assemblages, Douglas Creek arch area, Colorado and Utah: U.S. Geological Survey Miscellaneous Field Studies MF-1997, 2 plates, scale 1:125,000.

Kelly, T.S., Murphey, P.C., and Walsh, S.L., 2012, New record of small mammals from the middle Eocene Duchesne River Formation, Utah, and their implications for the Uintan-Duchesnean North American land mammal age transition: Paludicola, v. 8, no. 4, p. 208–251.

Kinney, D.M., 1955, Geology of the Uinta River–Brush Creek area, Duchesne and Uintah Counties, Utah: U.S. Geological Survey Bulletin 1007, 185 p., 6 plates, scale 1:63,360.

Kirkland, J.I., 2007, Redefining the Jurassic-Cretaceous contact in east-central Utah [abs.]: Geological Society of America Abstracts with Programs, v. 39, no. 5, p. 16.

Kirkland, J.I., Cifelli, R.L., Britt, B.B., Burge, D.L., DeCourten, F., Eaton, J.G., and Parrish, J.M., 1999, Distribution of vertebrate faunas in the Cedar Mountain Formation, east-central Utah, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 201–218.

Kirkland, J.I., Ludvigson, G.A., Gonzalez, L., Joeckel, R.M., and Madsen, S.K., 2003, Correlating Early Cretaceous dinosaur sites using stratigraphic trends in ^{13}C from pedogenic carbonates—an example from the Cedar Mountain Formation [abs.]: Journal of Vertebrate Paleontology, v. 23, no. 3, p. 67A.

Kirkland, J.I., and Madsen, S.K., 2007, The Lower Cretaceous Cedar Mountain Formation, eastern Utah: the view up an always interesting learning curve, *in* Lund, W.R., editor, Field guide to excursions in southern Utah: Utah Geological Association Publication 35, p. 1–108.

Kirkland, J.I., Madsen, S.K., Hunt, G.J., Waanders, G., and Sprinkel, D.A., 2011, Contact, ages, and correlation of Lower Cretaceous strata on the north side of the Uinta Basin, northeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 43, no. 4, p. 2.

Kirkland, J.I., Suarez, M., Suarez, C., and Hunt-Foster, R.K., 2016, The Lower Cretaceous in east-central Utah—the Cedar Mountain Formation and its bounding strata: Geology of the Intermountain West, v. 3, no. 101–228.

Kirschbaum, M.A., and Mercier, T.J., 2013, Controls on the deposition and preservation of the Cretaceous Mowry Shale and Frontier Formation and equivalents, Rocky Mountain region, Colorado, Utah, and Wyoming: American Association of Petroleum Geologists Bulletin, v. 97, no. 6, p. 899–921.

Kowallis, B.J., Christiansen, E.H., Balls, E., Heizler, M.T., and Sprinkel, D.A., 2005, The Bishop Conglomerate ash beds, south flank of the Uinta Mountains—are they pyroclastic fall beds from the Oligocene ignimbrites of western Utah and eastern Nevada?, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 131–145.

Kowallis, B.J., Hunt, J.E., Sprinkel, D.A., May, S.B., and Bradfield, T.D., in review, Geologic map of the Lake Mountain quadrangle, Uintah County, Utah: Utah Geological Survey Miscellaneous Publication, 2 plates, scale 24,000.

Kummel, B., 1954, Triassic Stratigraphy of southeastern Idaho and adjacent areas: U.S. Geological Survey Professional Paper 254-H, 165–194 p., 7 plates, various scales.

Laabs, B.J.C., and Carson, E.C., 2005, Glacial geology of the southern Uinta Mountains, *in* Dehler, C.M., Pederson, J.L., Sprinkel, D.A., and Kowallis, B.J., editors, Uinta Mountain geology: Utah Geological Association Publication 33, p. 235–253.

Laabs, B.J.C., Munroe, J.S., Rosenbaum, J.G., Refsnider, K.A., and Mickelson, D.M., 2007, Chronology of the Last Glacial Maximum in the upper Bear River basin, Utah: Arctic, Antarctic, and Alpine Research, v. 39, no. 4, p. 537–548.

Laabs, B.J.C., Refsnider, K.A., Munroe, J.S., Mickelson, D.M., Applegate, P.J., Singer, B.S., and Caffee, M.W., 2009, Latest Pleistocene glacial chronology of the Uinta Mountains—support for moisture-driven asynchrony of the last deglaciation: Quaternary Science Review, v. 28, p. 1171–1187.

Lochman-Balk, C., 1959, The Cambrian section in the central and southern Wasatch Mountains, *in* Williams, N.C., editor, Guidebook to the geology of the Wasatch and Uinta Mountains transition area: Intermountain Association of Petroleum Geologist Tenth Annual Field Conference, p. 40–45.

Lockley, M.G., Conrad, K., Paquette, M., and Hamblin, A.H., 1992, Late Triassic vertebrate tracks in the Dinosaur National Monument area, *in* Wilson, J.R., editor, Field guide to geologic excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming: Utah Geological and Mineral Survey Miscellaneous Publication 92-3, p. 383–391.

Logan, S.K., Sarg, J.F., and Vanden Berg, M.D., 2016, Lithofacies, deposition, early diagenesis, and porosity of the Uteland Butte Member, Green River Formation, eastern Uinta Basin, Utah and Colorado: Utah Geological Survey Open-File Report 652, p. 32.

Longman, M.W., and Morgan, C.D., editors, 2008, Hydrocarbon systems and production in the Uinta Basin, Utah, Rocky Mountain Association of Geologists and Utah Geological Association Publication 37, 468 p.

Lucas, S.G., 1993, The Chinle Group—revised stratigraphy and biochronology of Upper Triassic nonmarine strata in the western United States, *in* Morales, M., editor, Aspects of Mesozoic geology and paleontology of the Colorado Plateau: Museum of Northern Arizona Bulletin 59, p. 27–50.

Lucas, S.G., Heckert, A.B., and Tanner, L.H., 2005, Arizona's Jurassic vertebrates and the age of the Glen Canyon Group, *in* Heckert, A.B., and Lucas, S.G., editors, Vertebrate paleontology in Arizona: New Mexico Museum of Natural History and Science Bulletin 29, p. 94–103.

Lucas, S.G., Lockley, M.G., Hunt, A.P., and Tanner, L.H., 2006, Biostratigraphic significance of tetropod footprints from the Triassic-Jurassic Wingate Sandstone on the Colorado Plateau, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 109–117.

Ludvigson, G.A., Gonzalez, L.A., Kirkland, J.I., and Joeckel, R.M., 2003, A mid-Cretaceous record of carbon isotope excursions in palustrine carbonates of the Cedar Mountain Formation of Utah—marine-terrestrial correlation of Aptian-Albian oceanic anoxic events 1a, 1b, and 1d 9 [abs.]: The 3rd International Limnogeology Congress Abstract Volume, p. 169.

Ludvigson, G.A., Joeckel, R.M., Murphy, L.R., Stockli, D.F., González, L.A., Suarez, C.A., Kirkland, J.I., and Al-Suwaidi, A., 2015, The emerging terrestrial record of Aptian-Albian global change: Cretaceous Research, v. 56, p. 1–24.

M'Gonigle, J.W., Dalrymple, G.B., and Holmes, C.A., 1995, Single-crystal ^{40}Ar/^{39}Ar ages for rocks in the lower part of the Frontier Formation (Upper Cretaceous), southwest Wyoming: The Mountain Geologist, v. 32, p. 47–53.

Martz, J.W., Irmis, R.B., and Milner, A.R.C., 2014, Lithostratigraphy and biostratigraphy of the Chinle Formation (Upper Triassic) in southern Lisbon Valley, southeastern Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 397–448.

Martz, J.W., Kirkland, J.I., Milner, A.R.C., Parker, J.W., and Santucci, V.L., 2017, Upper Triassic lithostratigraphy, depositional systems, and vertebrate paleontology across southern Utah: Geology of the Intermountain West, v. 4, p. 99–180.

McDowell, F.W., Wilson, J.A., and Clark, J., 1973, K-Ar data for biotite from two paleontologically significant localities, Duchesne River Formation, Utah, and Chadron Formation, South Dakota: Isochron/West, no. 7, p. 11–12.

McKelvey, V.E., and others, 1959, The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: U.S. Geological Survey Professional Paper 313-A, p. 47, 3 plates, various scales.

Merewether, E.A., and Cobban, W.A., 1986, Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas, *in* Peterson, J.A., editor, Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 443–467.

Merewether, E.A., Cobban, W.A., and Obradovich, J.D., 2007, Regional disconformities in Turonian and Coniacian (Upper Cretaceous) strata in Colorado, Wyoming, and adjoining states—biochronological evidence: Rocky Mountain Geology, v. 42, no. 2, p. 95–122.

Molenaar, C.M., and Cobban, W.A., 1991, Middle Cretaceous stratigraphy on the south and east sides of the Uinta Basin, northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787-P, 34 p., 1 plate.

Molenaar, C.M., and Wilson, B.W., 1990, The Frontier Formation and associated rocks of northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787-M, 21 p., 1 plate.

Molenaar, C.M., and Wilson, B.W., 1993, Stratigraphic cross section of Cretaceous rocks along the north flank of the Uinta Basin, northeastern Utah, to Rangely, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1797-D, 1 plate, scale 1:4800.

Molina-Garza, R.S., Geissman, J.W., and Lucas, S.G., 2003, Paleomagnetism and magnetostratigraphy of the lower Glen Canyon and upper Chinle groups, Triassic-Jurassic of northern Arizona and northeastern Utah: Journal of Geophysical Research (Solid earth), v. 108, no. B4, 2181, p. 1–24.

Morgan, C.D., Chidsey, T.C., Jr., McClure, K.P., Bereskin, R.S., and Deo, M.D., 2003, Reservoir characterization of the lower Green River Formation, Uinta Basin, Utah: Utah Geological Survey Open-File Report 411, p. 140.

Mori, H., 2009, Dinosaurian faunas of the Cedar Mountain Formation and LA-ICP-MS detrital zircon ages from three stratigraphic sections: Provo, Brigham Young University, M.S. thesis, 102 p.

Morris, H.T., and Lovering, T.S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geological Survey361, 145 p., 5 plates, various scales.

Munroe, J.S., 2001, Late Quaternary history of the northern Uinta Mountains, northeastern Utah: Madison, University of Wisconsin-Madison, Ph.D. dissertation, 398 p.

Munroe, J.S., and Laabs, B.J.C., 2009, Glacial geologic map of the Uinta Mountains area, Utah and Wyoming: Utah Geological Survey Miscellaneous Publication 09-4DM, 1 plate, scale 1:100,000.

Munroe, J.S., Laabs, B.J.C., Shakun, J.D., Singer, B.S., Mickelson, D.M., Refsnider, K.A., and Caffee, M.W., 2006, Latest Pleistocene advance of alpine glaciers in southwestern Uinta Mountains, Utah, USA—evidence for the influence of local moisture sources: Geology, v. 34, no. 10, p. 841–844, 10.1130/G22681.1.

Murphey, P.C., Townsend, K.E.B., Friscia, A.R., Westgate, J., Evanoff, E., and Gunnell, G.F., 2017, Paleontology and stratigraphy of middle Eocene rock units in the southern Green River and Uinta Basins, Wyoming and Utah: Geology of the Intermountain West, v. 4, p. 1–53.

Nelson, A.R., and Weisser, R.R., 1985, Quaternary faulting on Towanta Flat, northwestern Uinta Basin, Utah, *in* Picard, M.D., editor, Geology and energy resources, Uinta Basin of Utah: Utah Geological Association Publication 12, p. 147–158.

New Mexico Geochronology Research Laboratory, and Utah Geological Survey, unpublished report NMGRL-IR-561, ^{40}Ar/^{39}Ar geochronology results from the Lake Mountain quadrangle, Uinta County, Utah: Utah Geological Survey, p. 12.

Newman, K.R., 1974, Palynomorph zones in early Tertiary formations of the Piceance Creek and Uinta Basins, Colorado and Utah, *in* Murray, D.K., editor, Energy resources of the Piceance Creek Basin, Colorado: Rocky Mountain Association of Geologists Twenty-fifth field Conference, p. 47–56.

Nichols, D.J., and Bryant, B., 1986, Palynology of the Currant Creek and Mesaverde Formations in the Currant Creek-Duchesne River area. Duchesne and Wasatch Counties, Utah: U.S. Geological Survey Open-File Report 86–160, 7 p.

Nichols, D.J., and Jacobson, S.R., 1982, Cretaceous biostratigraphy in the Wyoming thrust belt: The Mountain Geologist, v. 19, no. 3, p. 73–78.

Nichols, D.J., Jacobson, S.R., and Tschudy, R.H., 1982, Cretaceous palynomorph biozones for the central and northern Rocky Mountain region of the United States, *in* Powers, R.B., editor, Geologic Studies of the Cordilleran thrust belt, volume II: Rocky Mountain Association of Geologists, p. 721–733.

Oboh-Ikuenobe, F.E., Benson, D.G., Scott, R.W., Holbrook, J.M., Evetts, M.J., and Erbacher, J., 2007, Re-evaluation of the Albian-Cenomanian boundary in the U.S. Western Interior based on dinoflagellate cysts: Review of Palaeobotany and Palynology, v. 144, p. 77–97.

Obradovich, J.D., 1993, A Cretaceous time scale, *in* Caldwell, W.G.E., and Kauffman, E.G., editors, Evolution of the Western Interior basin: Geological Association of Canada Special Paper 39, p. 379–396.

Obradovich, J.D., Matsumoto, T., Nishida, T., and Inoue, Y., 2002, Intergrated biostratigraphic and radiometric study on the lower Cenomanian (Cretaceous) of Hokkaido, Japan, Proceedings of the Japan Academy: 78B, p. 149–153.

Ogg, J.G., Ogg, G., and Gradstein, F.M., 2008, The concise geologic time scale: Cambridge, Cambridge University Press, 177 p.

Osborn, H.F., 1895, Fossil mammals of the Uinta Basin, expedition of 1894: American Museum of Natural History Bulletin, v. 7, article 2, p. 71–105.

Osborn, H.F., 1929, The titanotheres of ancient Wyoming, Dakota, and Nebraska: U.S. Geological Survey Monograph 55, 2 volumes, 953 p., 1 appendix.

Oviatt, C.G., Thompson, R.S., Kaufman, D.S., Bright, J., and Forester, R.M., 1999, Reinterpretation of the Burmester core, Bonneville Basin, Utah: Quaternary Research, v. 52, p. 108–184.

Perry, D.G., and Chatterton, B.D.E., 1979, Late Early Triassic brachiopod and conodont fauna, Thaynes Formation, southeastern Idaho: Journal of Paleontology, v. 53, no. 2, p. 307–319.

Peterson, F., 1988, Stratigraphy and nomenclature of Middle and Upper Jurassic rocks, western Colorado Plateau, Utah and Arizona: U.S. Geological Survey Bulletin 1633-B, p. B17–B56.

Peterson, F., and Turner-Peterson, C.E., 1987, The Morrison Formation of the Colorado Plateau-recent advances in sedimentology, stratigraphy, and paleotectonics: Hunteria, v. 2, no. 1, p. 1–18.

Peterson, O.A., 1931, New species of the genus *Teleodus* from the upper Uinta of northeastern Utah: Annals of the Carnegie Museum, v. 20, no. 3-4, p. 307–312.

Peterson, O.A., 1932, New species from the Oligocene of the Uinta: Annals of the Carnegie Museum, v. 21, p. 61–78.

Peterson, O.A., and Kay, J.L., 1931, The upper Uinta Formation of northeastern Utah: Annals of the Carnegie Museum, v. 20, no. 3-4, p. 293–306.

Phillips, F.M., Zreda, M.G., Gosse, J.C., Klein, J., Evenson, E.B., Hall, R.D., Chadwick, O.A., and Sharma, P., 1997, Cosmogenic 36Cl and 10Be ages of Quaternary glacial and fluvial deposits of the Wind River Range, Wyoming: Geological Society of America Bulletin, v. 109, no. 11, p. 1453–1463.

Picard, M.D., 1955, Subsurface stratigraphy and lithology of Green River Formation in Uinta Basin, Utah: American Association of Petroleum Geologists Bulletin, v. 39, no. 1, p. 75–102.

Pierce, K.L., 2003, Pleistocene glaciation of the Rocky Mountains: Developments in Quaternary Science, v. 1, p. 63–76.

Pietras, J.T., and Carroll, A.R., 2006, High-resolution stratigraphy of an underfilled lake basin Wilkins Peak Member, Eocene Green River Formation, Wyoming, U.S.A: Journal of Sedimentary Research, v. 76, p. 1197–1214.

Pipiringos, G.N., 1968, Correlation and nomenclature of some Triassic and Jurassic rocks in south-central Wyoming: U.S. Geological Survey Professional Paper 594-D, 26 p.

Pipiringos, G.N., and Imlay, R.W., 1979, Lithology and subdivisions of the Jurassic Stump Formation in southeastern Idaho and adjoining areas: U.S. Geological Survey Professional Paper 1035-C, 25 p.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p., 1 plate.

Poole, F.G., and Stewart, J.H., 1964, Chinle Formation and Glen Canyon Sandstone in northeastern Utah and northwestern Colorado: U.S. Geological Survey Professional Paper 501-D, p. D30–D39.

Prothero, D.R., 1990, Magnetostratigraphy of middle Eocene Uinta Formation, Uinta Basin, Utah: Journal of Vertebrate Paleontology, v. 10, no. 3, p. 38A.

Prothero, D.R., and Swisher, C.C., 1992, Magnetostratigraphy and geochronology of the terrestrial Eocene-Oligocene transition in North America, *in* Prothero, D.R., and Berggren, W.A., editors, Eocene-Oligocene climate and biotic evolution, Princeton, New Jersey: Princeton University Press, p. 46–73.

Ramezani, J., Hoke, G.D., Fastovsky, D.E., Bowring, S.A., Therrien, F., Dworkin, S.I., Atchley, S.C., and Nordt, L.C., 2011, High-precision U-Pb zircon geochronology of the Late Triassic Chinle Formation, Petrified Forest National Park (Arizona, USA)—temporal constraints on the early evolution of dinosaurs: Geological Society of America Bulletin, v. 123, no. 11/12, p. 2142–2159, 10.1130/b30433.1.

Ray, R.G., Kent, B.H., and Dane, C.H., 1956, Stratigraphy and photogeology of the southwestern part of the Uinta Basin, Duchesne and Uintah Counties, Utah: U.S. Geological Survey Oil and Gas Investigations Map OM 171, 2 plates, scale 1:63,360.

Reeside, J.B., Jr., and Cobban, W.A., 1960, Studies of the Mowry shale (Cretaceous) and contemporary formations in the United States and Canada: U.S. Geological Survey 355, 126 p., 2 plates, various scales.

Refsnider, K.A., Laabs, B.J.C., Plummer, M.A., Mickelson, D.M., Singer, B.S., and Caffee, M.W., 2008, Last glacial maximum climate inference from cosmogenic dating and glacier modeling of the western Uinta ice field, Uinta Mountains, Utah: Quaternary Research, v. 69, no. 1, p. 130–144.

Rigby, J.K., and Gosney, T.C., 1983, First reported Triassic lyssakid sponges from North America: Journal of Paleontology, v. 57, no. 4, p. 787–796.

Riggs, E.S., 1912, New or little known titanotheres from the lower Uintah Formations, with notes on the stratigraphy and distribution of fossils: Field Museum of Natural History Publication 159, v. IV, no. 2, p. 17–41.

Ryder, R.T., Fouch, T.D., and Elison, J.H., 1976, Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of America Bulletin, v. 87, no. 4, p. 496–512.

Ryer, T.A., and Lovekin, J.R., 1986, The Upper Cretaceous Vernal delta of Utah—depositional or paleotectonic feature?, *in* Peterson, J.A., editor, Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, p. 497–510.

Sadlick, W., 1955, The Mississippian-Pennsylvanian boundary in northeastern Utah: Salt Lake City, University of Utah, M.S. thesis, 77 p.

Sadlick, W., 1957, Regional relations of Carboniferous rocks of northeastern Utah, *in* Seal, O.G., editor, Guidebook to the geology of the Uinta Basin: Intermountain Association of Petroleum Geologists 8th Annual Field Conference, p. 57–77.

Sandau, S.D., 2005, The paleoclimate and paleoecology of a Uintan (late middle Eocene) flora and fauna from the Uinta Basin, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 107 p.

Sandberg, C.A., and Gutschick, R.C., 1980, Sedimentation and biostratigraphy of Osagean and Meramecian starved basin and foreslope, western United States, *in* Fouch, T.D., and Magathan, E.R., editors, Paleozoic paleogeography of the west-central United States-Rocky Mountain Symposium 1: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists (Society for Sedimentary Geology), p. 129–147.

Sandberg, C.A., and Gutschick, R.C., 1984, Distribution, microfauna, source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah, *in* Woodward, J., Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists, p. 135–178.

Sandberg, C.A., Gutschick, R.C., Johnson, J.G., Poole, F.G., and Sando, W.J., 1982, Middle Devonian to Late Mississippian geologic history of the overthrust belt region, western United State, *in* Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt: Rocky Mountain Association of Geologists Guidebook, p. 691–719.

Sato, T., 2014, Fluvial-lacustrine sequence stratigraphy, provenance, ichnology, and sandstone reservoir modeling of the Tertiary Uinta and Duchesne River Formations, northern Uinta Basin, Utah: Salt Lake City, University of Utah, M.S. thesis, 134 p.

Sato, T., and Chan, M.A., 2015a, Fluvial facies architecture and sequence stratigraphy of the Tertiary Duchesne River Formation, Uinta Basin, Utah, U.S.A: Journal of Sedimentary Research, v. 85, p. 1438–1454.

Sato, T., and Chan, M.A., 2015b, Source-to-sink fluvial systems for sandstone reservoir exploration—example from the basal Brennan Basin Member of Tertiary Duchesne River Formation, northern Uinta Basin, Utah, *in* Birgenheier, L.P., Ressetar, R., and Vanden Berg, M.D., editors, The Uinta Basin: Utah Geological Association Publication 44, p. 91–107.

Schell, E.M., and Yochelson, E.L., 1966, Permian-Triassic boundary in eastern Uintah County, Utah, and western Moffat County, Colorado: U.S. Geological Survey Professional Paper 550-D, p. D64–D68.

Schelling, D.D., Strickland, D.K., Johnson, K.R., and Vrona, J.P., 2007, Structural geology of the central Utah thrust belt, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 1–29.

Scott, R.W., 2007, Calibration of the Albian/Cenomanian boundary by ammonite biostratigraphy, U.S. Western Interior: ACTA Geologica Sinica, v. 81, no. 6, p. 940–948.

Scott, R.W., Oboh-Ikuenobe, F.E., Benson, D.G., Jr., and Holbrook, J.M., 2009, Numerical age calibration of the Albian/Cenomanian boundary: Stratigraphy, v. 6, no. 1, p. 17–32.

Smith, M.E., Carroll, A.R., and Singer, B.S., 2008, Synoptic reconstruction of a major ancient lake system—Eocene Green River Formation, western United States: Geological Society of America Bulletin, v. 120, no. 1/2, p. 54–84, 10.1130/B26073.1.

Snoke, A.W., 1993, Geologic history of Wyoming within the tectonic framework of the North American Cordillera, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., editors, Geology of Wyoming—volume 1: Geologic Survey of Wyoming Memoir 5, p. 2–56.

Solien, M.A., 1979, Conodont biostratigraphy of the Lower Triassic Thaynes Formations, Utah: Journal of Paleontology, v. 53, no. 2, p. 276–306.

Solien, M.A., Morgan, W.A., and Clark, D.L., 1979, Structure and stratigraphy of Lower Triassic conodont locality: Brigham Young University Geology Studies, v. 26, no. 3, p. 165–177.

Sprinkel, D.A., 1982, Twin Creek Limestone-Arapien Shale relations in central Utah, *in* Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 169–179.

Sprinkel, D.A., 2007, Interim geologic map of the Vernal 30′ x 60′ quadrangle, Uintah and Duchesne Counties, Utah, Moffat and Rio Blanco Counties, Colorado: Utah Geological Survey Open-File Report 506DM, compact disc, GIS data, 3 plates, scale 1:100,000.

Sprinkel, D.A., 2009, Interim geologic map of the Seep Ridge 30′ x 60′ quadrangle, Uintah, Duchesne, and Carbon Counties, Utah, and Rio Blanco and Garfield Counties, Colorado: Utah Geological Survey Open-File Report 549DM, compact disc, GIS data, 3 plates, scale 1:100,000.

Sprinkel, D.A., 2014, The Uinta Mountains—a tale of two geographies and more: Utah Geological Survey, Survey Notes, v. 46, no. 3, p. 1–4.

Sprinkel, D.A., Doelling, H.H., Kowallis, B.J., Waanders, G., and Kuehne, P.A., 2011a, Early results of a study of Middle Jurassic strata in the Sevier fold and thrust belt, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt-northern and central Utah and adjacent area: Utah Geological Association Publication 40, p. 151–172.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011b, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Sprinkel, D.A., Madsen, S.K., Kirkland, J.I., Waanders, G., and Hunt, G.J., 2012, Cedar Mountain and Dakota Formations around Dinosaur National Monument—evidence of the first incursion of the Cretaceous Western Interior Seaway into Utah: Utah Geological Survey Special Study 143, 20 p., 7 appendices.

Stagner, W.L., 1941, The paleogeography of the eastern part of the Uinta Basin during Uinta B (Eocene) time: Annals of the Carnegie Museum, v. 28, article 14, p. 273–308.

Stewart, J.D., 1996, Cretaceous acanthomorphs of North America, *in* Arratia, G., and Viohl, G., editors, Mesozoic fishes—systematics and paleontology, Munchen, Germany: Verlag Dr. Friedrich Pfeil, p. 383–394.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Upper Triassic Chinle Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p., 5 plates, scale 1:2,500,000.

Stewart, J.H., Poole, F.G., Wilson, R.F., and Cadigan, R.A., 1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p., 5 plates, scale 1:2,500,000.

Stokes, W.L., 1952, Lower Cretaceous in Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1766–1776.

Stone, D.S., 1993, Tectonic evolution of the Uinta Mountains—palinspastic restoration of a structural cross section along longitude 109°15', Utah: Utah Geological Survey Miscellaneous Publication 93-8, 19 p.

Tänavsuu-Milkevicience, K., and Sarg, J.F., 2012, Evolution of an organic-rich lake basin—stratigraphy, climate, and tectonics; Piceance Creek basin, Eocene Green River Formation: Sedimentology, v. 59, no. 6, p. 1735–1768.

Thomas, H.D., 1939, “Park City” beds on southwest flank of Uinta Mountains—comment: American Association of Petroleum Geologists Bulletin, v. 43, no. 8, p. 1249–1250.

Thomas, H.D., and Krueger, M.L., 1946, Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains: American Association of Petroleum Geologists Bulletin, v. 30, no. 8, p. 1255–1293.

Thompson, M.L., 1945, Pennsylvanian rocks and fusulinids of east Utah and northwest Colorado correlated with Kansas sections: Kansas Geological Survey Bulletin 60, part 2, 84 p.

Töro, B., and Pratt, B.R., 2015, Characteristics and implications of sedimentary deformation features in the Green River Formation (Eocene) in Utah and Colorado, *in* Birgenheier, L.P., Ressetar, R., and Vanden Berg, M.D., editors, The Uinta Basin: Utah Geological Association Publication 44, p. 371–422.

Townsend, K.E.B., Friscia, A.R., and Rasmussen, D.T., 2006, Stratigraphic distribution of upper middle Eocene fossil vertebrate localities in the eastern Uinta Basin, Utah, with comments on Uintan biostratigraphy: The Mountain Geologist, v. 43, no. 2, p. 115–134.

Townsend, K.E.B., Rasmussen, D.T., Murphey, P.C., and Evanoff, E., 2010, Middle Eocene habitat shifts in the North America western interior—a case study: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 297, no. 1, p. 144–158.

Trujillo, K.C., and Kowallis, B.J., 2015, Recalibrated legacy ^{40}Ar/^{39}Ar ages for the Upper Jurassic Morrison Formation, Western Interior, U.S.A.: Geology of the Intermountain West, v. 2, no. 1, p. 1–8.

Turner, C.E., and Fishman, N.S., 1991, Jurassic Lake T'oo'dichi-a large alkaline, saline lake, Morrison Formation, Colorado Plateau: Geological Society of America Bulletin, v. 103, no. 4, p. 538–558.

Turner, C.E., and Peterson, F., 1999, Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A., *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 77–114.

Turner, C.E., and Peterson, F., 2004, Reconstruction of Upper Jurassic Morrison Formation extinct ecosystem—a synthesis: Sedimentary Geology, v. 167, p. 309–355.

Utah Geological Survey, and Apatite to Zircon Inc., 2014, U-Pb detrital zircon geochronology result for the Brennan Basin Member of the Duchesne River Formation, Duchesne 30′ x 60′ quadrangle, Duchesne and Wasatch Counties, Utah: Utah Geological Survey Open-File Report 635, 56 p.

Vanden Berg, M.D., and Birgenheier, L.P., 2017, An examination of the hypersaline phases of Eocene Lake Uinta, upper Green River Formation, Uinta Basin, Utah: Journal of Paleolimnology, v. 58, no. 3, p. 353–371, 10.1007/s10933-017-9983-x.

Vanden Berg, M.D., Lehle, D.R., Carney, S.M., and Morgan, C.D., 2013, Geological characterization of the Birds Nest aquifer, Uinta Basin, Utah—assessment of the aquifer's potential as a saline water disposal zone: Utah Geological Survey Special Study 147, 47 p., 31 plates, various scales.

Verbeek, E.R., and Grout, M.A., 1993, Geometry and structural evolution of gilsonite dikes in the eastern Uinta Basin, Utah: U.S. Geological Survey Bulletin 1787-HH, 42 p., 1 plate, scale 1:250,000.

Vogel, T.A., Feher, F.W., Constenius, K.N., and WIB Research Team, 1997, Petrochemistry and emplacement history of the Wasatch igneous belt, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains: Society of Economic Geologists Guidebook Series 29, p. 47–64.

Walton, P.T., 1944, Geology of the Cretaceous of the Uinta Basin, Utah: Geological Society of America Bulletin, v. 55, no. 1, p. 91–130.

Walton, P.T., 1957, Cretaceous stratigraphy of the Uinta Basin, *in* Seal, O.G., editor, Guidebook to the geology of the Uinta Basin: Intermountain Association of Petroleum Geologists 8th Annual Field Conference, p. 97–101.

Walton, P.T., 1964, Late Cretaceous and early Paleocene conglomerates along the margin of the Uinta Basin, *in* Sabatka, E.F., editor, Guidebook to the geology and mineral resources of the Uinta Basin—Utah's hydrocarbon storehouse: Intermountain Association of Petroleum Geologists Thirteenth Annual Field Conference, p. 139–143.

Webb, C.A., 2017, Geologic mapping of the Vernal NW quadrangle, Uintah County, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 68 p.

Webb, C.A., Jensen, M., Kowallis, B.J., Christiansen, E.H., and Sprinkel, D.A., 2017, Stratigraphic relationships within the Duchesne River Formation and Bishop Conglomerate—conclusions for mapping the Vernal NW quadrangle, Utah [abs.]: Geological Society of America Abstracts with Program, v. 49, no. 9.

Weiss, M.P., Witkind, I.J., and Cashion, W.B., 1990, Geologic map of the Price 30′x 60′quadrangle, Carbon, Uintah, Utah, and Wasatch Counties, UtahMiscellaneous Investigations Series Map I-1981, 1 plate, scale 1:100,000.

Whitaker, R.M., 1975, Upper Pennsylvanian and Permian of northeast Utah and northwest Colorado, *in* Boylard, D.W., editor, Symposium on deep drilling frontiers in the central Rocky Mountains: Rocky Mountain Association of Petroleum Geologists Guidebook, p. 75–85.

Wilcox, W.T., 2007, Sequence stratigraphy of the Curtis, Summerville and Stump Formations, Utah and northwest Colorado: Oxford, Miami University (Ohio), M.S. thesis, 98 p.

Wilcox, W.T., and Currie, B.S., 2006, Depositional age and sequence stratigraphy of the Jurassic Curtis, Summerville, and Stump Formations, Utah and Colorado [abs.]: Geological Society of America Abstracts with Programs v. 38, no. 7, p. 388.

Wilcox, W.T., and Currie, B.S., 2008, Sequence stratigraphy of the Jurassic Curtis, Summerville, and Stump Formations, eastern Utah and northwest Colorado, *in* Longman, M.W., and Morgan, C.D., editors, Hydrocarbon systems and production in the Uinta Basin, Utah: Rocky Mountain Association of Geologists and Utah Geological Association Publication 37, p. 9–41.

Williams, J.S., 1939, “Park City” beds on the southwest flank of the Uinta Mountains: American Association of Petroleum Geologists Bulletin, v. 23, no. 1, p. 82–100.

Williams, J.S., 1943, Carboniferous formations of the Uinta and northern Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 54, no. 4, p. 591–624.

Williams, N.C., 1953, Late Pre-Cambrian and early Paleozoic geology of western Uinta Mountains, Utah: American Association of Petroleum Geologists Bulletin, v. 37, no. 12, p. 2734–2742.

Witkind, I.J., 1994, The role of salt in the structural development of central Utah: U.S. Geological Survey Professional Paper 1528, 145 p.

Wood, H.E., II, 1934, Revision of the Hydrachyidae: Bulletin of American Museum of Natural History, v. 67, Article V, p. 181–295.

Zuchuat, V., Sleveland, A.R.N., Sprinkel, D.A., Rimkus, A., Braathen, A., and Midtkandal, I., in press, New insights on the impact of tidal currents on a low-gradient, semi-enclosed, epicontinental basin—the Curtis Formation, east-central Utah, USA Geology of the Intermountain West, v. 5, p. 131–165.