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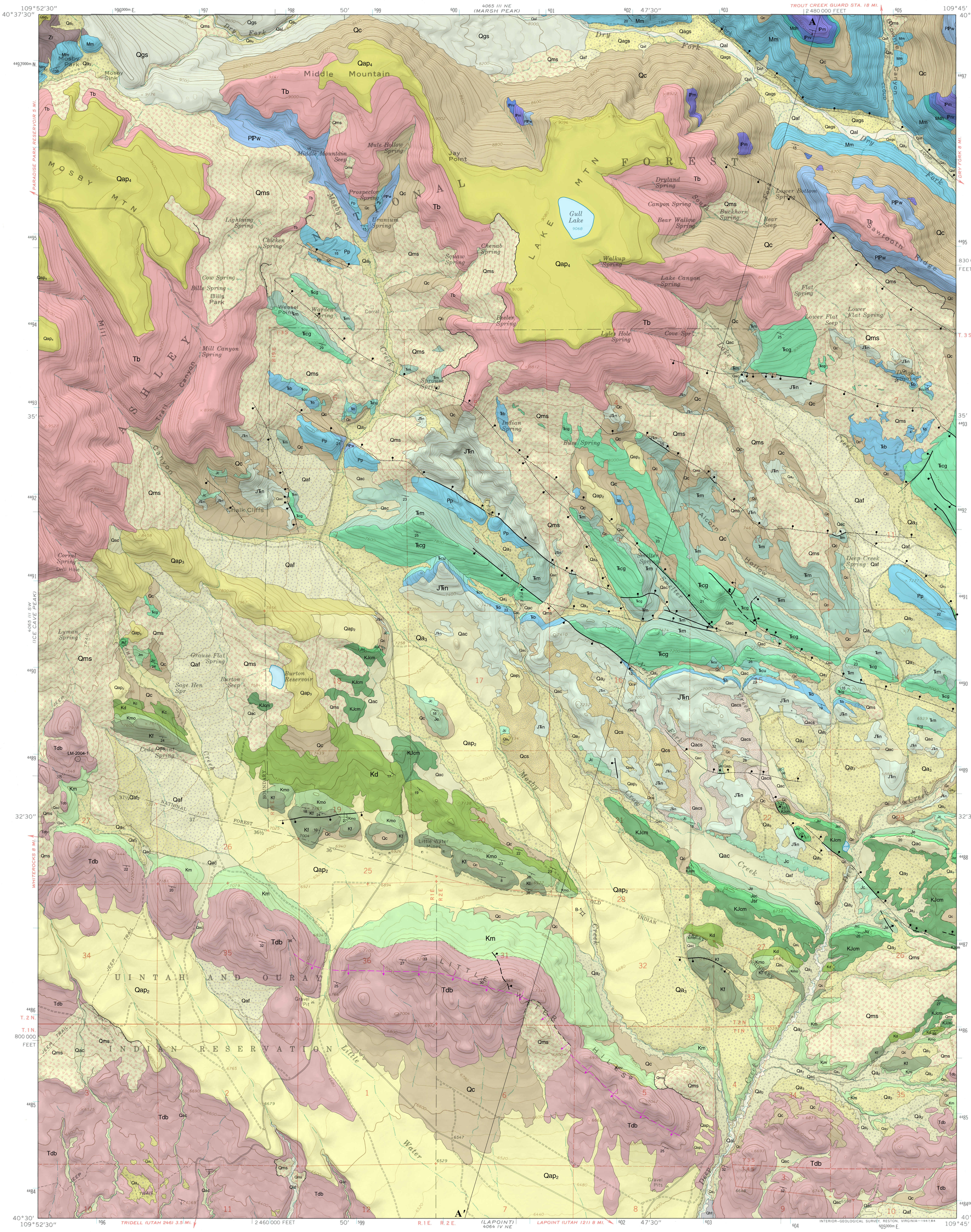


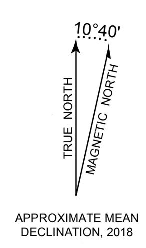

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

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# GEOLOGIC MAP OF THE LAKE MOUNTAIN QUADRANGLE, UINTAH COUNTY, UTAH

by

Bart J. Kowallis[1], John E. Hunt[1], Douglas A. Sprinkel[2], Skyler B. May[1], Todd D. Bradfield[1], and Kent D. Brown[2]

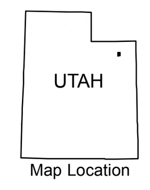
2018

[1]Brigham Young University, Department of Geological Sciences, Provo, Utah 84604
[2]Utah Geological Survey, P.O. Box 146100, Salt Lake City, Utah 84114

Base from USGS Lake Mountain 7.5' Quadrangle (1965)
Projection: UTM Zone 12
Datum: NAD 1927

Project Manager: Douglas A. Sprinkel
GIS and Cartography: Kent D. Brown and Douglas A. Sprinkel

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




Map Location

| | | |
|---|---|---|
| 1 | 2 | 3 |
| 4 | | 5 |
| 6 | 7 | 8 |

1. Paradise Park
2. Marsh Peak
3. Taylor Mountain
4. Ice Cave Peak
5. Dry Fork
6. Whiterocks
7. Lapoint
8. Vernal NW

ADJOINING 7.5' QUADRANGLE NAMES

9 781557 919496

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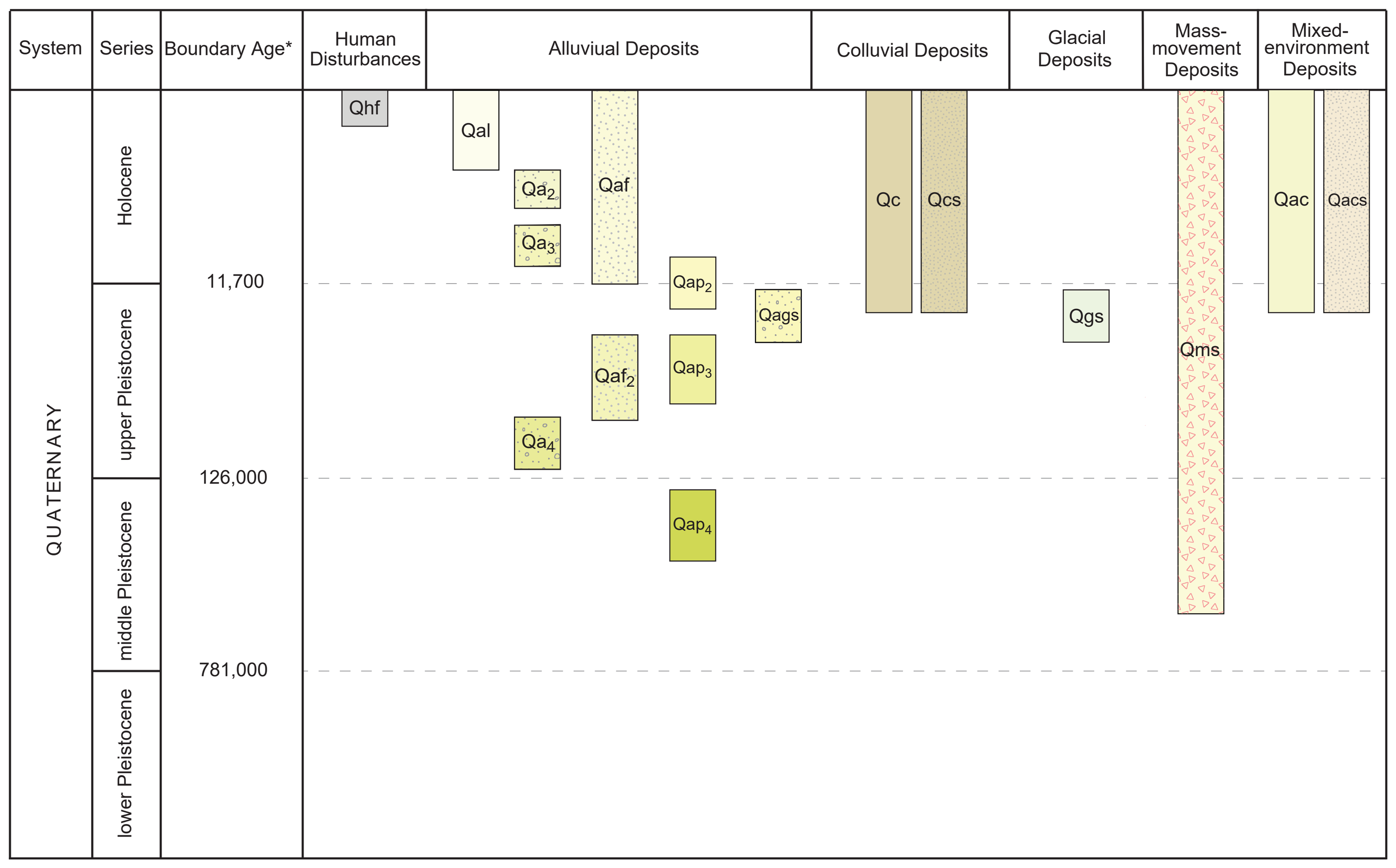
## GEOLOGIC SYMBOLS

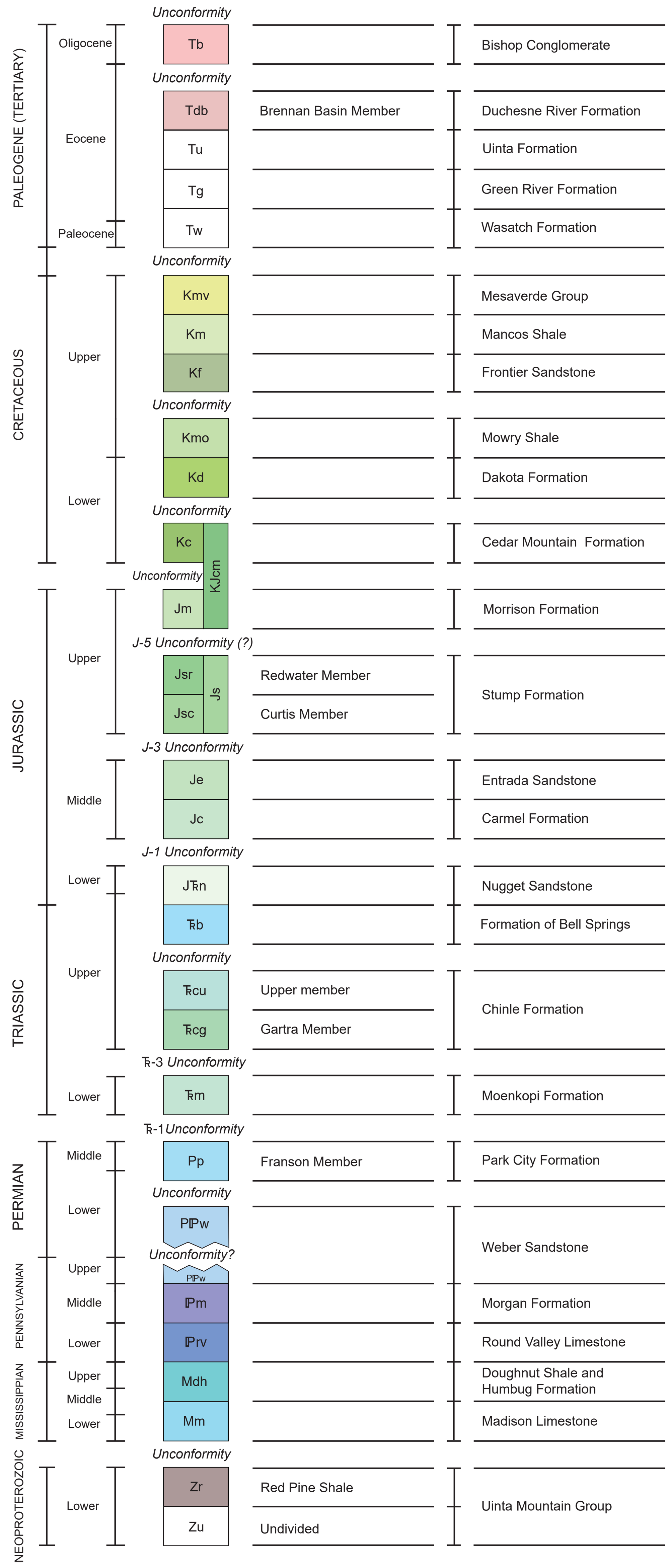
- Boundary, water
- Contact - Dashed where inferred or approximately located
- Normal fault - Dashed where inferred or approximately located, dotted where concealed; bar and ball on downthrown side
- Landslide scarp - Dashed where approximately located
- Monocline - Dashed where approximately located, dotted where concealed
- Strike and dip of beds
- Mine shaft
- Gravel pit
- Abandoned drill hole
- Sample
- Spring
- Apparent dip of bedding on cross secion

## CORRELATION OF SURFICIAL UNITS



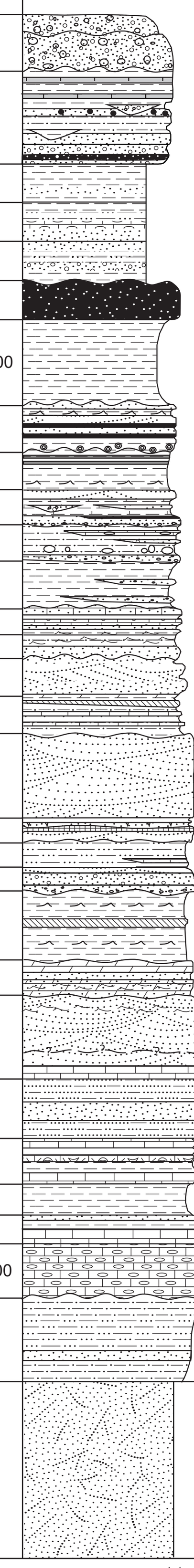

*Boundary ages taken from Cohen and others (2013)

## CORRELATION OF BEDROCK UNITS



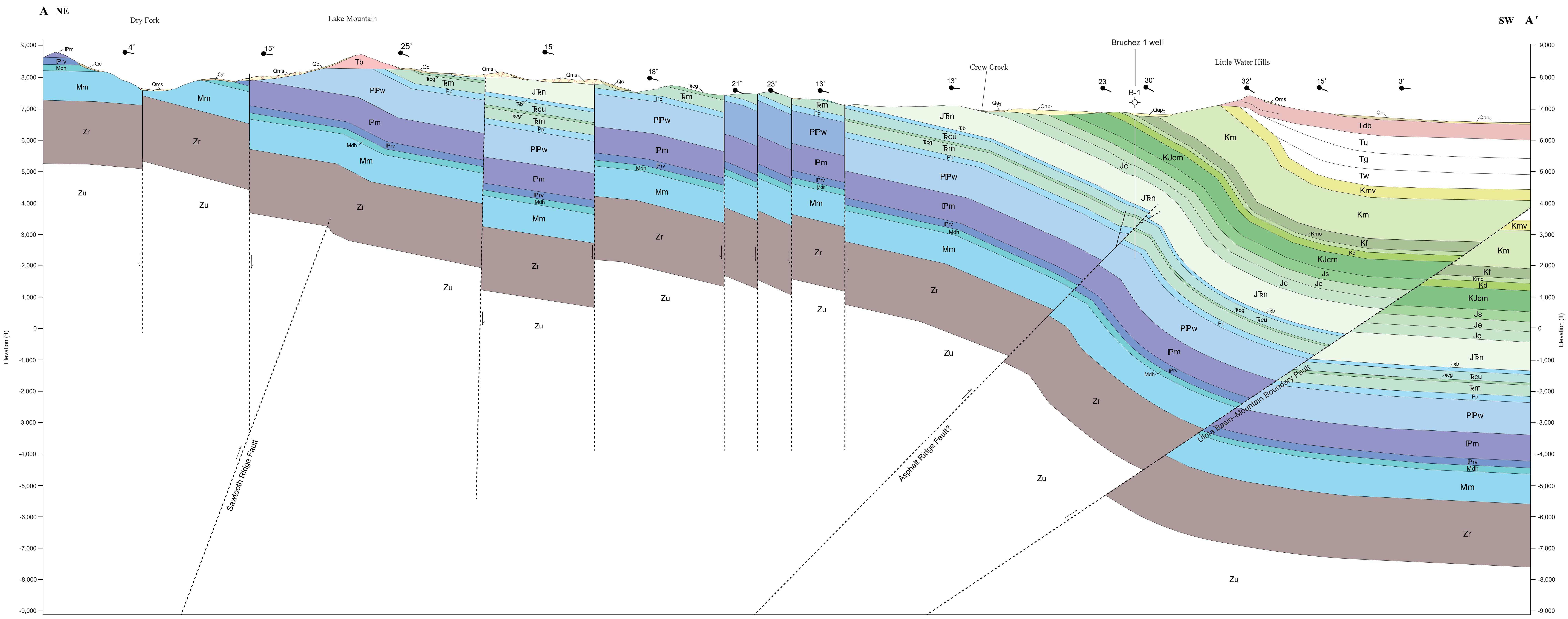

## STRATIGRAPHIC COLUMN

| AGE | | FORMATION | | | SYMBOL | THICKNESS Feet | | LITHOLOGY |
|---|---|---|---|---|---|---|---|---|
| Quat. | | unconsolidated deposits | | | Q* | | | |
| Paleogene (Tertiary) | Oligo-cene | Bishop Conglomerate | | | Tb | less than 500 | | upper part may be a younger unit |
| | Eocene | Brennan Basin Member of Duchesne River Formation | | | Tdb | 280-580 | | bentonitic ash beds; spheroidal iron concretions; may contain bitumen sands |
| | | Uinta Formation** | | | Tu | less than 625 | | section not exposed in quadrangle |
| | | Green River Formation** | | | Tg | less than 500 | | |
| | ? Paleocene | Wasatch Formation** | | | Tw | less than 500 | | |
| Cretaceous | | Mesaverde Group | | | Kmv | 250+ | | bituminous sandstone |
| | | Mancos Shale | | | Km | as much as 1200 | | |
| | | Frontier Formation | | | Kf | 140-400 | | ripples; coal; bivalve bed |
| | | Mowry Shale | | | Kmo | 90-135 | | ash beds; fish scales/bones; ripples |
| | | Dakota Formation | | | Kd | 115-280 | | permineralized wood and local coal |
| | | KJcm | Cedar Mountain Formation | | Kc | 665-810 | 210 | concretions; chert pebbles |
| Jurassic | | | Morrison Formation | | Jm | | 455-600 | |
| | | Js | Stump Formation | Redwater Mbr | Jsr | 220-325 | 180-235 | ooids; belemnites; glauconite |
| | | | | Curtis Mbr | Jsc | | 40-90 | |
| | | Entrada Sandstone | | | Je | 160-315 | | calcite veins |
| | | Carmel Formation | | | Jc | 230-325 | | gypsum |
| | | Nugget Sandstone | | | JTRn | 720-1030 | | |
| Triassic | | Formation of Bell Springs | | | TRb | 90-110 | | mudcracks; reduction spots |
| | | Chinle Formation | | Upper Mbr | TRcu | 260-310 | | |
| | | | | Gartra Mbr | TRcg | 20-95 | | permineralized wood |
| | | Moenkopi Formation | | | TRm | 400-500 | | ripples; gypsum; ripples |
| Permian | | Park City Formation | | Franson Mbr | Pp | 165-210 | | glauconite |
| | | Weber Sandstone | | | PIPw | 700-1275 | | |
| Carboniferous | Pennsylvanian | Morgan Formation | | | IPm | 360-835 | | |
| | | Round Valley Limestone | | | IPrv | 260 | | fossil bearing |
| | Mississippian | Doughnut Shale | | | Mdh | 40-200 | 20-95 | |
| | | Humbug Formation | | | | | 20-105 | |
| | | Madison Limestone | | | Mm | as much as 1000 | | abundant chert |
| Proterozoic | | Uinta Mountain Group | | Red Pine Shale | Zr | 1800-2000 | | |
| | | | | Undivided** | Zu | 14,000+ | | section not exposed in quadrangle |



*See Correlation of Surficial Units for symbols
**On cross section only

not to scale




scale: 1:24,000
no vertical exaggeration
not all surficial units shown

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**MISCELLANEOUS PUBLICATION 18-2DM**
**UTAH GEOLOGICAL SURVEY**
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**2018**

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*by Bart J. Kowallis[1], John E. Hunt[1], Douglas A. Sprinkel[2], Skyler B. May[1], Todd D. Bradfield[1], and Kent D. Brown[2]*

[1]Brigham Young University, Department of Geological Sciences, Provo, UT 84602
[2]Utah Geological Survey, P.O. Box 146100, Salt Lake City, UT 84114

SCALE: 1:24,000

***Cover photo:*** *Lake Mountain, the quadrangle's namesake, is to the right of center in the middle distance and Mosby Mountain to the left side of the photograph. The light-colored outcrops along Lake Mountain are mostly the Triassic-Jurassic Nugget Sandstone that have been cut by faults of the Deep Creek fault zone. The fault zone trends northwest-southeast (left to right in the photograph) and generally parallels Mosby Creek in this area. Overlying the moderately dipping Mesozoic strata along the flanks of Lake Mountain and Mosby Mountain are gently dipping beds of the Oligocene Bishop Conglomerate, capped by thin Pleistocene piedmont gravel deposits. Note the hummocky topography on Lake Mountain and Mosby Mountain indicating massive slope failures. Marsh Peak (12,198 ft) is the bald peak on the horizon in the center of the photograph. View is to the north.*

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**2018**

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# GEOLOGIC MAP OF THE LAKE MOUNTAIN QUADRANGLE, UINTAH COUNTY, UTAH

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## GEOLOGIC SUMMARY

### Introduction

The Lake Mountain quadrangle is about three miles north of the town of Tridell, Uintah County, Utah, along the south flank of the eastern Uinta Mountains and very northern margin of the Uinta Basin. The area is popular for outdoor recreation, including fishing, hunting, four-wheeling, snowmobiling, hiking, and camping, mostly in Ashley National Forest in the northern part of the quadrangle. Private lands include farmlands and homesteads in the central part of the map area. From the Little Water Hills and south, the land is part of the Uinta and Ouray Indian Reservation. Public access to these lands is restricted unless special permission is obtained from the Ute Indian Tribe. The quadrangle is home to a variety of wildlife including elk, mule deer, several species of birds, and the endangered Utah prairie dog, as well as a wide variety of native wildflowers and plants, all of which make it a beautiful place to visit.

Two important landmarks within the quadrangle are Dry Fork Canyon, which cuts across the northeast corner of the map area and contains glacial deposits of Smiths Fork age, and Lake Mountain, the quadrangle's namesake, located southwest of Dry Fork Canyon. The combined geology of the quadrangle makes for a majestic landscape that begins with low-lying hogbacks and broad valleys in the south and transitions to deep glacier-influenced canyons and broad mountain slopes in the north.

### Stratigraphy

Bedrock units in the quadrangle are commonly covered by various surficial deposits, but in some areas good exposures of tilted bedrock can be found. The southern half of the map area is characterized by several sets of hogbacks and flatirons that consist of Mesozoic bedrock units separated by broad piedmont surfaces or stream valleys. The oldest bedrock unit in the quadrangle is the middle Neoproterozoic Red Pine Shale of the Uinta Mountain Group, which crops out in the Mosby Peak area in the northwestern corner of the quadrangle. The youngest bedrock unit mapped is the Oligocene Bishop Conglomerate, which is exposed throughout the northern half of the map area.

Of stratigraphic note, the uppermost part of the upper Chinle Formation is dominated by ledge- and cliff-forming sandstone compared to the underlying slope-forming siltstone and mudstone middle part. We have chosen to apply the informal name "formation of Bell Springs" to the strata that lie between finer grained Triassic Chinle Formation and the Upper Triassic-Lower Jurassic Nugget Sandstone (Sprinkel and others, 2011b). Previous publications have included this interval as an informal upper member of the Chinle (Kinney, 1955; Irmis and others, 2015), basal part of the Navajo Sandstone (High and others, 1969), Bell Springs Formation of the Chinle Group (Lucas, 1993), and Bell Springs Member of the Nugget Sandstone (Jensen and Kowallis, 2005).

Numerous bentonitic ash beds occur in the Cretaceous Mowry Shale, Eocene Brennan Basin Member of the Duchesne River Formation, and Oligocene Bishop Conglomerate. The abundant ash beds of the Mowry Shale have not been isotopically dated along the south flank of the Uintas, but ages in other localities of 99 to 97 Ma, as well as fossils, constrain the age of the unit (Reeside and Cobban, 1960; Obradovich, 1993; Oboh-Ikuenobe and others, 2007). The Mowry Shale in the quadrangle and along the south flank is particularly abundant in fish scales, disarticulated fish bones, and occasional shark teeth, besides the ash beds (Anderson and Kowallis, 2005).

Other units bearing fossil remnants include the Lower Pennsylvanian Round Valley Limestone, which contains some invertebrate fossils; the Upper Jurassic Redwater Member of the Stump Formation, which has ooids and belemnites; and the Upper Cretaceous Frontier Formation (Molenaar and Wilson, 1990), which has a very distinctive bivalve bed that also contains plant stems and other plant material. Permineralized wood can be found in the Upper Triassic Gartra Member of the Chinle Formation, Upper Jurassic Morrison Formation, and the Lower Cretaceous Dakota Formation.

The age of the Duchesne River Formation ranges from about 41 to 39 Ma based on $^{40}Ar/^{39}Ar$ (sanidine and biotite) and U-Pb (zircon) analysis from ash and tuffaceous sandstone beds from the Brennan Basin, Dry Gulch Creek, and Lapoint Members (Utah Geological Survey and Apatite to Zircon Inc., 2014; Sprinkel, 2015; Jensen and others, 2017; Webb and others, 2017; New Mexico Geochronology Research Laboratory and Utah Geological Survey, unpublished report). An ash sample collected from the Brennan Basin Member in the southwestern part of the Lake Mountain quadrangle has yielded a $^{40}Ar/^{39}Ar$ biotite age of 41.10 ± 0.32 Ma (table 1). Ashes from the Bishop Conglomerate have isotopic ages ranging from 34 to 30 Ma (Kowallis and others, 2005).

The Lake Mountain quadrangle has a variety of unconsolidated surficial deposits of Quaternary age, dominated by landslide and slump deposits. Large landslides are located along the flanks of Lake Mountain and Mosby Mountain. Head scarps develop mostly in the Bishop Conglomerate, as the recessive and weak Mesozoic formations commonly undermine it. Other unconsolidated deposits include colluvium, stream alluvium, three levels of alluvium, three levels of large piedmont deposits, and glacial till and outwash. Each higher level of alluvium represents subsequently older stream valleys and each higher level of piedmont alluvium represents subsequently older broad alluviated surfaces. The numbers assigned to each level are applicable to the Lake Mountain quadrangle only and do not imply regional correlation of similarly numbered alluvial deposits mapped in other quadrangles.

### Structural Geology

The Lake Mountain quadrangle is on the south flank of the Uinta Mountains, a mountain range that was uplifted during the Laramide orogeny and coeval with the subsidence of the Uinta Basin (Hintze and Kowallis, 2009). The bedrock has been moderately tilted towards the south and southwest about 15° to 25° throughout the quadrangle with some beds of the Eocene Duchesne River Formation (Tdb) locally steepening to nearly 35° in the Little Water Hills. We interpret that the increased bedding dip is attributed to a monocline formed by movement on the blind Asphalt Ridge fault zone (see cross section A-A′ on plate 2). Bedding dips decrease significantly to less than 5° south of the Little Water Hills.

Fault systems along the south flank of the Uinta Mountains are commonly buried beneath Quaternary and Tertiary strata; however, the Deep Creek fault zone (DCFZ), a northwest-southeast-trending strain transfer zone of normal, reverse, strike-slip, and oblique faults (Haddox, 2005), is exposed in several places within the quadrangle. This fault system consists of several grabens and half-grabens, which topographically form an array of hogbacks and broad valleys that extends across the area north of Little Water Hills and cut through the adjoining Ice Cave Peak quadrangle to the west as well as the Dry Fork, Steinaker Reservoir, and Vernal NW quadrangles to the east. The DCFZ terminates just northeast of Asphalt Ridge (Hansen, 1986b, 1986a; Haddox and others, 2005; Sprinkel, 2006; Haddox and others, 2010a, 2010b; Schamel, 2013; Poduska and others, 2015). The DCFZ formed as a transfer zone between offsets in the frontal Uinta Basin-Mountain boundary fault zone (UB-MBFZ) (Haddox and others, 2005; Poduska and others, 2015), which had multiple periods of reactivation as smaller thrust wedges continued to shift independently during late-Laramide orogenic episodes (Ritzma, 1969, 1971; Hansen, 1986b; Stone, 1993). In our cross section A-A′ (plate 2), we model the subsurface using multiple fault blocks to best account for the attitudes of bedrock exposed at the surface, especially for the monocline within the Duchesne River Formation. Multiple fault blocks seems plausible because (1) smaller fault segments have been mapped along the UB-MBFZ, for example near Asphalt Ridge (Ritzma, 1971; Hansen, 1986b, 1986a; Sprinkel, 2007; Schamel, 2013); (2) previous interpretations of the subsurface geology of the surrounding area are similar to our model (Ritzma, 1974; Campbell and Ritzma, 1979; Hamilton, 1981; Covington and Young, 1985; Blackett, 1996); and (3) small thrusts in nearby areas have been proposed (Hansen, 1986b). Our model is also consistent with previous mapping of the UB-MBFZ (Johnson and Roberts, 2003; Sprinkel, 2018), though it assumes structural elements from Ritzma (1974) and Hansen (1986b). Having multiple faults also seems to fit with the Haddox (2005) interpretation of the DCFZ as small fault segments oriented orthogonally to each other with reverse, oblique, and strike-slip Laramide movement that later reactivated during extension as indicated by kinematic slip data preserved on some of the faults as well as some faults that cut the Oligocene Bishop Conglomerate. Timing of late Uinta Mountain uplift is constrained to between 39 and 34 Ma because of monoclinal flexure related to movement on the Asphalt Ridge fault and the low dips (generally between 0 to less than 5°) in the Oligocene Bishop Conglomerate, a unit considered by Hansen (1986b) to mark the end of Laramide uplift.

## GEOLOGIC RESOURCES

Geologic resources located within the quadrangle include bituminous sand, coal, iron, gypsum, gravel, oil and gas, ornamental stone, and uranium deposits. While there have been several studies, much prospecting, some mining, and a little small-scale production of these resources in the past, currently there are no ongoing commercial natural resource development projects anywhere in the quadrangle. Water is also a critical natural resource, as it represents the sustainability of local agriculture and communities. Visit the Utah Geological Survey's website https://geology.utah.gov/resources/ for more information on natural resources in the area.

## Bituminous Sands

Bituminous sand accumulations occur within the Duchesne River Formation and Mesaverde Group in the Uinta and Ouray Reservation, along the north slope of the Little Water Hills. The deposit was originally noted by Kinney (1955) and was proposed to be an extension of the Asphalt Ridge deposit. Covington (1963, 1964) briefly mentioned the deposit in his reports on the bituminous sands of Utah and said it was of little economic interest, but no thorough study was conducted at that time to determine the deposit's total reserves, chemical composition, or origin. Ritzma (1979) estimated 10 to 12 million barrels of tar sand present in the Little Water Hills deposit, thus classifying it as a "large" deposit. Crysdale and Schenk (1988) and later Blackett (1996) studied the chemical composition of the bitumen and concluded that it was probably derived from the Green River Formation. The problem in mining the bitumen is that larger and more economical outcrops exist to the southeast on Asphalt Ridge and in other places throughout Utah. As a result, no commercial development has occurred in the quadrangle.

## Coal

The Dakota, Frontier, and Mesaverde Formations contain several bituminous coal beds, each from 2 to 5 feet thick (Doelling and Graham, 1972). Coal beds within the Frontier Formation were mined in what is called the Vernal coal field during the early 1900s, but were mostly abandoned by 1910 when economic conditions became too poor to continue production (Lupton, 1910); however, some mines operated until 1957 (Doelling and Graham, 1972). Production from these mines probably only totaled around a few thousand tons (Keighin and Hibpshman, 1975). The abandoned mines are now called the Little Water Hills Mines and are located along the north flank of the Little Water Hills: latitude 40° 32′ 16″ north, longitude 109° 49′ 18″ west (Doelling and Graham, 1972; Utah Trails TrainWeb, 2002). The remaining coal beds are thin and poor quality.

## Iron

Doelling and Tooker (1983) published a map of prospected metal accumulations for the state of Utah. They mapped an iron occurrence and prospect within the Lake Mountain quadrangle. Minor iron accumulations are present in the Brennan Basin Member of the Duchesne River Formation, the Cedar Mountain Formation, and the Nugget Sandstone. Most often these accumulations occur as small iron nodular concretions. While these occurrences have been noted, no known development has ever been attempted.

## Gypsum

The Middle Jurassic Carmel Formation contains a bed of gypsum approximately 4 to 6 feet thick. The Lower Triassic Moenkopi Formation also contains extensive gypsum beds up to 6 feet in thickness, which are interbedded with red, soft mudstones. Minor gypsum mining to produce plaster has occurred in the Whiterocks area (Pruitt, 1961), and some prospecting in the Lake Mountain area has been done; however, no production has occurred in the Lake Mountain area to date. The reason is probably because the quality of the gypsum deposit is low and there is a lack of a local market (Keighin and Hibpshman, 1975).

## Gravel

Gravel deposits are mostly in piedmont alluvium (Qap2) of late Pleistocene age located in the southern half of the quadrangle. These deposits usually occur as longitudinal hills or conical piles of unconsolidated cobbles and pebbles as much as 100 feet thick that sit on relatively planar surfaces. No calculation of the amount of gravel resources in the Lake Mountain area has been published, probably because these deposits are generally small, not on public lands, and located away from local markets.

## Oil and Gas

The only oil and gas well in the quadrangle was drilled by Cotton Petroleum Company in 1974 just north of the Little Water Hills in the NW¼NW¼NW¼ section 32, T. 2 N., R. 2 E., Uinta Base Line and Meridian (B-1 on plate 1). Blackett (1996) reported that the well (No. 1 Bruchez, API #43-047-30159) drilled into the Weber Sandstone and produced water at a depth of 4555 feet (see table 2). A formation test within the Mancos Shale found gas reserves and produced about 5 million cubic feet per day. The well was plugged and abandoned later in 1974.

## Ornamental Stone

Basin residents and visitors of the surrounding area are familiar with the permineralized wood that weathers out of the Gartra Member of the Chinle Formation, the Morrison Formation, and the Dakota Formation. Many residents collect permineralized wood and display it in front of their homes and businesses. Liesegang banding in the reddish sandstone and orthoquartzite beds of the Neoproterozoic Uinta Mountain Group are also sought after as evidenced by blocks that are displayed at local residences and businesses in the surrounding area.

## Phosphate

The Park City Formation crops out along the south flank of the Uinta Mountains and includes rich phosphate deposits in the Meade Peak Member. Phosphate is currently mined east of the Lake Mountain quadrangle along U.S. Highway 191 in the

*Table 1. Summary of $^{40}Ar/^{39}Ar$ age analysis of the Brennan Basin Member of the Duchesne River Formation.*

| Map Number | Sample Number | Map Unit | Formation Name | Rock Type | Material Dated | Age + 2sd (Ma) | Laboratory | Reference/ Report | Comments | Latitude (N) NAD27 | Longitude (W) NAD27 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | LM-2004-1 | Tdb | Duchesne River Formation, Brennan Basin Member | Ash | Biotite | 41.10 ± 0.32 | New Mexico Geochronology Research Laboratory | NMGRL-IR-561 | Furnace incremental heating | 40° 32′ 51.81″ | 109° 52′ 10.62″ |

*Table 2. Information for the Cotton Oil Company Bruchez 1 well from the Utah Division of Oil,Gas and Mining online database.*

| ID | Well Information | Kelly Bushing Elevation (feet) | Formation | Depth (feet) | Thickness (feet) | Elevation (feet) | Remarks |
|---|---|---|---|---|---|---|---|
| B-1 | Cotton Oil Company | 6780 | Stump Formation | 1313 | 117 | 5467 | Reported as Curtis in well file |
| | Bruchez 1 | | Entrada Sandstone | 1430 | 250 | 5350 | |
| | NW1/4 NW1/4NW1/4 | | Carmel Formation | 1680 | 228 | 5100 | |
| | Section 32 | | fault | 1908 | 0 | 4872 | |
| | T. 2 N., R. 2 E. (UBL&M) | | Carmel Formation | 1908 | 97 | 4872 | |
| | Uintah County, Utah | | Nugget Sandstone | 2005 | 895 | 4775 | Reported as Navajo in well file |
| | API # 43-047-30159 | | upper Chinle Formation | 2900 | 240 | 3880 | Includes bed of the formation of Bell Springs |
| | UTM 12N, 601559E, 4487246N | | Gartra Member, Chinle Formation | 3140 | 90 | 3640 | Reported as Shinarump in well file |
| | | | Moenkopi Formation | 3230 | 410 | 3550 | |
| | | | Park City Formation | 3640 | 5 | 3140 | |
| | | | fault | 3645 | 0 | 3135 | |
| | | | upper Chinle Formation | 3645 | 20 | 3135 | |
| | | | Gartra Member, Chinle Formation | 3665 | 95 | 3115 | Reported as Shinarump in well file |
| | | | Moenkopi Formation | 3760 | 470 | 3020 | |
| | | | Park City Formation | 4230 | 170 | 2550 | |
| | | | Weber Sandstone | 4400 | 155 | 2380 | |
| | | | Total Depth | 4555 | | 2225 | Plugged and abandoned; 01-08-1974 |

Donkey Flat and Steinaker Reservoir quadrangles. Park City Formation outcrops west of the Lake Mountain quadrangle are also rich and thick enough to be considered a potential resource (Pruitt, 1961; Keighin and Hibpshman, 1975), but no mining has taken place. In the east-adjoining Dry Fork quadrangle, the Park City Formation crops out but is significantly faulted, which diminishes the potential for continuous minable beds. Only relatively small isolated outcrops of the Park City Formation are found in the northern half of the Lake Mountain quadrangle where the formation is mostly unconformably overlain by Tertiary Bishop Conglomerate or Quaternary surficial deposits and is cut by numerous faults. Like in the Dry Fork quadrangle, the potential for continuous minable phosphate beds in the Lake Mountain quadrangle is probably limited.

### Uranium

Minor uranium mineralization is found in several formations of the Uinta Basin. Most occurrences are sub-ore quality within the Chinle, Morrison, Mesaverde, and Uinta Formations (Noble and Annes, 1957; Chenoweth, 1992; Gloyn and others, 2005). However, some uranium ore was produced from 1949 to 1958 from the Uinta Formation and a minor amount from the Mesaverde Group (Chenoweth, 1992). Gloyn and others (2005) identified a uranium prospect likely from the Morrison Formation within the Lake Mountain quadrangle area. Uranium resource potential within the quadrangle is minor.

## DESCRIPTION OF MAP UNITS

### Quaternary Surficial Map Units

#### Human Disturbances

Qhf **Farm-related disturbance** (Historical) – Unconsolidated, fine-grained sediments modified by human activities related to agriculture; 1 to 12 feet thick.

#### Alluvial Deposits

Qal **Stream alluvium** (Holocene) – Unconsolidated sand and rounded pebble- to boulder-size clasts mixed within a fine-grained matrix; deposits contain conglomerate lenses and may be occasionally stratified; derived from locally weathered material; locally grades into Qac and Qaf deposits; restricted to modern floodplains of Dry Fork and lower reaches of Deep Creek; as much as 45 feet thick.

$Qa_2$ **Level-2 alluvium** (Holocene) – Unconsolidated medium-grained sand with some pebble- to cobble-size clasts mixed within fine-grained matrix similar to the composition of Qal; deposited in broad, flat intermittent stream valleys that may include thin Qal deposits in drainage bottoms that are too small to map; deposits are typically 20 to 25 feet above the modern floodplain and locally dissected; some deposits along the lower Deep Creek drainage have been modified by farming; 10 to 30 feet thick.

$Qa_3$ **Level-3 alluvium** (Holocene) – Unconsolidated medium-grained sand and pebble- to cobble-size clasts mixed within fine-grained matrix similar to the composition of other alluvium; deposited in broad valleys that have been subsequently dissected; may include thin Qal deposits in drainage bottoms that are too small to map; deposits are about 50 to 55 feet above modern floodplain; some deposits have been modified by farming; 10 to 30 feet thick.

$Qa_4$ **Level-4 alluvium** (upper Pleistocene) – Unconsolidated medium-grained sand and pebble- to cobble-size clasts mixed within fine-grained matrix similar to the composition of the other alluvium; deposits are dissected remnants of stream drainages and are usually 70 to 75 feet above modern drainages; 10 to 30 feet thick.

Qaf **Alluvial-fan deposits** (Holocene) – Unconsolidated, mostly coarse-grained sand, pebbles, cobbles, and boulders mixed within a silt and clay matrix; poorly sorted but may be locally poorly stratified; deposited by debris flows at decreases in gradient to form fan-shape deposits at the mouths of drainages and as broad coalescing deposits along the base of highlands that have several drainages along their length; less than 50 feet thick.

$Qaf_2$ **Older alluvial-fan deposits** (upper Pleistocene) – Unconsolidated, mostly coarse-grained sand, pebbles, cobbles, and boulders mixed within a sandy matrix that may contain cobble lenses, poorly sorted to locally poorly stratified with normal grading; deposited by debris flows at a decrease in gradient at the mouths of drainages; deposits are dissected, incised, and are 5 to 10 feet above Qaf deposits on average; less than 30 feet thick.

$Qap_2$ **Level-2 piedmont gravel deposits** (Holocene and upper Pleistocene) – Unconsolidated to poorly consolidated, cobble- to sand-size clasts in a fine-grained silty matrix with occasional boulder lenses; poorly to moderately sorted, subangular to subrounded; poorly developed soil profile similar to $Qas_2$ deposits mapped by Sprinkel (2006); deposited on lowest relatively planar surface; some of the deposits have been modified by farming; 40 to 70 feet above Deep Creek; less than 60 feet thick.

$Qap_3$ **Level-3 piedmont alluvium** (upper Pleistocene) – Unconsolidated to poorly consolidated pebble and cobble clasts within a sandy matrix and includes local boulder- to cobble-rich lenses; poorly sorted, subangular to subrounded, clasts dominated by quartz arenite and arkosic sandstone of Uinta Mountain Group; poorly to moderately developed soil profile; deposited on a higher relatively planar surface; 350 to 400 feet above local drainage and about 90 feet above $Qap_2$; less than 100 feet thick.

$Qap_4$ **Level-4 piedmont alluvium** (middle Pleistocene) – Unconsolidated to poorly consolidated, pebble to boulder clasts within sandy matrix; scattered boulders litter the surface of $Qap_4$ deposits; poorly sorted, subrounded to rounded clasts dominated by quartz arenite and arkosic sandstone of Uinta Mountain Group (Sprinkel, 2006; Sprinkel and others, 2013); well-developed soils deposited on highest relatively planar surface about 900 to 1000 feet above Dry Fork and about 600 to 700 feet above $Qap_3$; regionally mapped as the highest piedmont gravel on the Diamond Mountain and Yampa Plateaus (Sprinkel, 2006, 2007) and dated as about 173 to 187 ka (Sprinkel and others, 2013); less than 100 feet thick.

Qags **Glacial outwash of Smiths Fork Age** (upper Pleistocene) – Unconsolidated to poorly consolidated, cobble to gravel-size clasts in a sandy or silty matrix along Dry Fork Canyon; well-rounded, poorly sorted clasts; carbonate coating common; clasts typically derived from the Uinta Mountain Group; deposit is approximately 12 to 32 ka (Laabs and Carson, 2005; Munroe and Laabs, 2009); less than 60 feet thick.

### Colluvial Deposits

Qc **Colluvium** (Holocene and Pleistocene) – Unconsolidated, heterogeneous mix of silt, sand, and pebble to boulder gravel; transported downslope mostly by soil creep and locally derived from surficial map units and bedrock formations; thin on steep slopes; less than 20 feet thick.

Qcs **Colluvium, sand-rich** (Holocene and Pleistocene) – Unconsolidated, heterogeneous mix of silt, sand, and pebbles within a sandy matrix; transported downslope mostly by soil creep and locally derived from surficial map units and bedrock formations; thin on steep slopes; less than 20 feet thick.

### Glacial Deposits

Qgs **Smiths Fork till** (upper Pleistocene) – Unconsolidated, very poorly sorted boulders and cobbles in a sandy matrix along Dry Fork Canyon; forms low ridge in valley due to armoring effect of boulders; Smiths Fork till was deposited approximately 14 to 32 ka but cosmogenic $^{10}Be$ surface-exposure dating reveals that terminal moraines were abandoned by retreating glaciers before 16 ka (Laabs and Carson, 2005; Laabs and others, 2009; Munroe and Laabs, 2009); less than 35 feet thick.

### Mass-movement Deposits

Qms **Landslides and slumps** (Holocene and Pleistocene) –Landslide and slump deposits; vary in size; most small slumps are a few thousand square feet that typically failed in the Chinle Formation or Mowry Shale; most large landslides are as much as 6 $mi^2$ and are covered with cobbles and boulders of Uinta Mountain Group derived from the Bishop Conglomerate; common where the Bishop Conglomerate rests on less competent units; some Qms units may include Qc and Qac; less than 100 feet thick.

### Mixed-environment Deposits

Qac **Mixed alluvium and colluvium** (Holocene and Pleistocene) – Unconsolidated mix of silt, sand, pebbles, and cobbles deposited by streams, sheet wash, and slope creep; moderately sorted with angular to subrounded clasts; locally derived from bedrock units or reworked from other unconsolidated deposits; thin on steeper slopes but generally less than 10 feet thick.

Qacs **Mixed alluvium and colluvium, sand-rich** (Holocene and Pleistocene) – Unconsolidated mix of mostly sand deposited by streams, sheet wash, and slope creep; well sorted with angular to subrounded pebble-size clasts; locally derived from the Nugget Sandstone; some deposits may be reworked by eolian processes; thin on steeper slopes but generally less than 15 feet thick.

## Bedrock Map Units

### Tertiary

Tb **Bishop Conglomerate** (Oligocene) – Polymictite conglomerate interbedded with sandstone and siltstone lenses and beds, and ash beds; boulder and pebble conglomerate, sandy matrix, loosely cemented, poorly sorted, subangular to subrounded clasts, and very thick bedded to massive; limestone, sandstone, and chert clasts from Paleozoic formations and quartz arenite clasts from the Neoproterozoic Uinta Mountain Group; generally slope-forming with locally resistant beds; sandstone and siltstone, light gray to pinkish gray on fresh surfaces, weathers moderate reddish orange to very pale orange; sandstone, friable, medium grained, ledge forming; siltstone, fine grained, and ledge to slope forming; tuffaceous sandstone, white to very light gray, thin bedded, restricted to upper part of unit; isotopic ages from ash beds range from 30 to 34 Ma (Kowallis and others, 2005); prone to landslides in the quadrangle; less than 500 feet thick.

Tdb **Duchesne River Formation, Brennan Basin Member** (middle Eocene) – Conglomerate interbedded with sandstone, siltstone, mudstone, and bentonitic ash beds; boulder and pebble conglomerate, boulder-(up to 5 feet in size) and pebble-size clasts in a coarse sandy to muddy matrix; very poorly sorted, subangular to rounded; mixed clasts of dark-gray to moderate-gray limestone from Paleozoic formations and moderate-reddish-orange arkosic sandstone and quartz arenite from the Neoproterozoic Uinta Mountain Group; matrix is moderate red to pale yellowish orange and well cemented; thick bedded to massive; forms resistant cliffs to ledges; local clay lenses as much as 4 feet thick and 8 feet across that weather to form alcoves; most pebbly conglomerate beds restricted to scour channels; sandstone, pale yellowish orange to grayish pink on fresh surfaces but weathers moderate reddish orange to moderate orange pink, coarse to medium grained, moderately sorted, well cemented, very thick to thin bedded, massive to planar laminated; forms resistant cliffs to ledges; locally contains spheroidal iron concretions; some traces of bitumen probably derived from the Green River Formation (Blackett, 1996); sandstone lenses (as much as 15 feet thick and about 1500 feet in length) pinch and swell and scour underlying mudstone beds; siltstone and mudstone, light brown to pale yellowish orange on fresh surfaces but weather moderate red to dark yellowish orange, thick to thin bedded, planar laminated; muddy units contain ripples and are slope forming; bentonitic ash beds (2 to 8 feet thick), yellowish gray to light gray on fresh surfaces, weather grayish yellow green and can contain gravel to sand-size lithics; ash, purplish gray, biotite rich, and thin bedded; U-Pb zircon ages range from 40.66 ± 1.9 to 41.10 ± 0.32 Ma (Utah Geological Survey and Apatite to Zircon Inc., 2014; this report); 280 to 580 feet thick.

Tu **Uinta Formation** (middle Eocene) – Shown only in cross section; less than 625 feet thick.

Tg **Green River Formation** (middle Eocene) – Shown only in cross section; bitumen analyses on samples collected from Asphalt Ridge suggest the Green River Formation is the source for bitumen saturation found in the Mesaverde Group and locally in the Duchesne River Formation (Blackett, 1996; Lillis and others, 2003); less than 500 feet thick.

Tw **Wasatch Formation** (Eocene to Paleocene) – Shown only in cross section; less than 500 feet thick.

## Cretaceous

Kmv **Mesaverde Group** (Upper Cretaceous, Maastrichtian(?) to Santonian) – Sandstone (bitumen saturated), dark gray to brownish black on fresh surfaces, weathers moderate gray to very light gray on bleached surfaces, coarse to fine grained, subangular grains, well sorted, medium to thin bedded, massive bedding, and cliff to ledge forming; bitumen derived from the Green River Formation (Blackett, 1996); 250+ feet thick.

Km **Mancos Shale** (Upper Cretaceous, Coniacian) – Shale, dusky yellow to light olive gray on fresh surfaces, weathers grayish yellow green to grayish yellow, thin to medium laminated bedding, nonresistant, slope forming, weathers to form badlands topography along the northern flank of the Little Water Hills; typically capped by Quaternary piedmont deposits; as much as 1200 feet thick.

Kf **Frontier Formation** (Upper Cretaceous, upper to middle Turonian) – Sandstone and interbedded calcareous shale with local coal beds; sandstone, grayish orange on fresh surfaces, weathers light brown (turns moderately reddish orange near coal beds), medium to fine grained, subrounded grains, well sorted, thick to thin bedded, mainly massive bedding but contains rare planar laminations, ripples, and cross-bedding; cliff to ledge forming; distinct bivalve bed midway through the unit; shale, dark gray on fresh surfaces, weathers light gray, slope forming; coal, weathers into small 1 inch chips; 140 to 400 feet thick.

Kmo **Mowry Shale** (Upper Cretaceous, early Cenomanian) – Shale interbedded with bentonitic ash beds; shale, grayish blue to dusky blue on fresh surfaces, weathers bluish white to very pale blue, siliceous, irregularly laminated, and rippled, ledge forming where iron oxide staining occurs and slope forming elsewhere; weathers characteristically into small, hard chips; commonly deformed; contains abundant fish scales and disarticulated fish bones in some layers; bentonitic ash, white to very light gray, thin bedded to thinly laminated, soapy texture; ash beds are abundant but difficult to see because of poor exposures; 90 to 135 feet thick.

Kd **Dakota Formation** (Lower Cretaceous, Albian) – Sandstone interbedded with pebble and gravel conglomerate lenses, separated by carbonaceous shale and local coal beds; sandstone, moderate yellow to yellowish gray on fresh surfaces, weathers dark yellowish orange to grayish yellow, coarse to medium grained, subangular grains, moderately sorted, thin to very thin bedded, planar laminated to trough cross-stratified; limonite stained, Liesegang banded, and commonly jointed, cliff to ledge forming; conglomerate, pebble- to gravel-size clasts in a sandy matrix, angular to subangular, poorly sorted, medium to thin bedded, well to loosely cemented, vuggy and friable where loosely cemented, ledge forming; shale, dark gray on fresh surfaces, weathers light gray, slope forming, locally contains permineralized wood at base of formation; coal, soft, very thin and discontinuous; 115 to 280 feet thick.

Kc **Cedar Mountain Formation** (Lower Cretaceous, Albian to Barremian) – Mudstone interbedded with minor carbonate and pebbly conglomerate lenses and beds; mudstone, moderate red, pale purple, light gray, or pale greenish yellow; contains abundant carbonate-soil concretions, chert pebbles, forms slope; pebble conglomerate, pebble- to sand-size clasts in a silty or muddy matrix, subangular to subrounded, poorly sorted, medium to very thin bedded, and ledge forming; conglomerate channels generally occur at base of unit; exposures of this formation are very poor in the quadrangle; 210 feet thick.

## Cretaceous – Jurassic

KJcm **Cedar Mountain and Morrison Formations, undivided** (Lower Cretaceous and Upper Jurassic) – We have generally mapped the Cedar Mountain and Morrison Formations as a single unit because of poor exposures, making identification of the subtle contact between the two formations uncertain; combined thickness of 665 to 810 feet.

## Jurassic

Jm **Morrison Formation** (Upper Jurassic, Tithonian to Kimmeridgian) – Mudstone interbedded with channel conglomerate and sandstone lenses; mudstone, variegated, moderate red to light red, dusky yellow green, and light gray, and slope forming; pebbly conglomerate, poorly sorted, thin bedded, resistant, ledge forming, channel form and scours underlying beds; sandstone, moderate reddish orange lenses, coarse to medium grained, moderately sorted, friable, and ledge forming; Morrison Formation is regionally composed of four members (Brushy Basin, Salt Wash, Tidwell, and Windy Hill Members in descending stratigraphic order); a single outcrop is mapped just east of Grouse Creek near the west-central margin of the quadrangle and likely represents a part of the Salt Wash Member; 455 to 600 feet thick.

Js **Stump Formation** (Upper Jurassic, Oxfordian) – Consists of the Redwater and Curtis Members (see descriptions below); members of the Stump are mapped separately on the geologic map (plate 1), but they are not differentiated on cross section A-A′ (plate 2); 220 to 325 feet thick.

Jsr **Stump Formation, Redwater Member** (upper Jurassic, Oxfordian) – Sandy limestone interbedded with sandstone and shale; limestone, moderate brown, fine grained, well cemented, oolitic and fossiliferous, cross-stratified, and ledge forming; sandstone, very light gray on fresh surfaces, weathers moderate gray (greenish gray where glauconitic), coarse grained, subrounded, well sorted, cross-stratified, and glauconitic; limonite staining at certain outcrops; loosely cemented, crumbly, and generally slope forming; shale, olive gray on fresh surfaces, weathers light olive gray; contains resistant and ledge-forming gypsum; contains belemnites; 180 to 235 feet thick.

Jsc **Stump Formation, Curtis Member** (Upper Jurassic, Oxfordian) – Sandstone, light gray to grayish orange on fresh surfaces, weathers moderate gray (greenish gray where glauconitic), fine to very fine grained, subangular to angular, very well sorted, loosely cemented and friable, contains secondary gypsum, and slope forming; 40 to 90 feet thick.

Je **Entrada Sandstone** (Middle Jurassic, Callovian) – Sandstone, light gray to pinkish gray on fresh surfaces, weathers very pale orange to pale yellowish orange, medium to fine grained, moderately well sorted, medium to very thin bedded, some cross-stratified beds, friable, and commonly slope forming; secondary calcite veins common; 160 to 315 feet thick.

Jc **Carmel Formation, undivided** (Middle Jurassic, Callovian to Bajocian) – Upper siltstone and mudstone with gypsum (Winsor Member) and lower micritic and sandy limestone and gypsiferous siltstone (Paria River, Crystal Creek, and Co-op Creek Limestone Members); upper siltstone and mudstone, moderate red brown to pale green on fresh surfaces, weathers moderate reddish orange; siltstone, fine to very fine grained, subangular to subrounded, well sorted, medium bedded to thickly laminated, massive to planar laminated, slope forming; mudstone, moderate reddish brown, and slope forming; gypsum, light gray, thin beds to veinlets; lower limestone, micritic to sandy, moderate gray, thick to thin bedded, fossiliferous, and ledge forming; contains altered volcanic ash; local and regional $^{40}Ar/^{39}Ar$ (sanidine and biotite) and U-Pb (zircon) yield ages between 166 and 168 Ma (Sprinkel and others, 2011a); 230 to 325 feet thick.

## Jurassic – Triassic

JTRn **Nugget Sandstone** (Lower Jurassic to Upper Triassic, Toarcian to Rhaetian) – Sandstone, light brown (buff) to yellowish gray, medium to fine grained, subrounded, well sorted, very thick to thick bedded, high-angle cross-stratification, cliff to ledge forming; weathers into monoliths and spires, commonly jointed, locally weathers to form pockets and holes; iron oxide staining common; 720 to 1030 feet thick.

## Triassic

TRb **Formation of Bell Springs** (Upper Triassic, Rhaetian) – Sandstone and siltstone, grayish orange to light brownish gray on fresh surfaces, weathers grayish red to moderate brown; sandstone, fine to medium grained, ripple laminated to massive bedded, mottled in places with greenish-gray reduction spots, salt casts, and crinkly beds; lower sandstone forms prominent cliff; upper sandstone beds are medium cross-stratified and interbedded with siltstone and thin mudstone beds; mud cracks locally preserved; 90 to 110 feet thick.

TRcu **Chinle Formation, upper member** (Upper Triassic, Rhaetian to Carnian) – Shaly mudstone interbedded with siltstone; mudstone, moderate yellow, grayish red, pale purple, or variegated, locally fissile, locally contains nodular carbonate lenses, and slope forming; siltstone, grayish red to dark reddish brown, fine grained, well sorted, and slope forming; unit poorly exposed in the quadrangle; 260 to 310 feet thick.

TRcg **Chinle Formation, Gartra Member** (Upper Triassic, Carnian) – Conglomerate and sandstone, grayish yellow or very light gray on fresh surface, weathers very pale orange to pale yellow orange; conglomerate, pebble- to cobble-size clasts in a sandy matrix, subrounded to rounded clasts, moderately sorted, massive, and ledge forming; sandstone, very coarse to medium grained, subangular to subrounded, moderately well sorted, thick to medium bedded, and ledge forming; may be cross-stratified and contains permineralized wood; 20 to 95 feet thick.

TRm **Moenkopi Formation** (Lower Triassic, Olenekian to Induan) – Siltstone and mudstone interbedded with gypsum; siltstone, reddish orange to reddish brown, indistinct bedding, and ledge to slope forming; mudstone, reddish orange to reddish brown, thinly bedded, ripple laminated, and slope forming; gypsum, light red to grayish orange pink, thin bedded, massive weathering, and ledge forming; 400 to 500 feet thick.

## Permian

Pp **Park City Formation, Franson Member** (Middle to Lower Permian, Wordian to Artinskian) – Dolomite and sandstone, light brown to light pink gray on fresh surfaces, weather light gray to moderate yellowish orange with iron oxide staining; dolomite, glauconitic, may be sandy, and ledge forming; sandstone, coarse to medium grained, subangular to subrounded, moderately well sorted, very thick to thick bedded, planar laminated, may be cross-stratified, and cliff to ledge forming; Park City Formation typically includes (in descending order) the Franson Member (Park City Formation), Meade Peak Member (Phosphoria Formation), and Grandeur Member (Park City Formation) in the Uinta Mountains; however, the Grandeur Member is typically missing along the south flank of the eastern Uinta Mountains (see Jensen and others, 2016); the Meade Peak is not exposed in the quadrangle because of faulting and surficial cover, but it is exposed to the east in the Dry Fork quadrangle (Haddox and others, 2010b); 165 to 210 feet thick.

## Permian – Pennsylvanian

PPw **Weber Sandstone** (Lower Permian to Upper Pennsylvanian, Sakmarian to Kasimovian) – Sandstone interbedded with limestone; sandstone, light pink gray on fresh surfaces, weathers light gray to very pale orange, medium to fine grained, subangular to subrounded, well sorted, very well cemented, very thick to thick bedded, planar laminated to large-scale cross-stratified with locally large-scale fluid-escape structures, locally glauconitic and cliff forming; limestone, interbedded with sandstone in the lower part of the formation, medium gray, thin bedded, and ledge forming; 700 to 1275 feet thick.

## Pennsylvanian

Pm **Morgan Formation** (Middle Pennsylvanian, Moscovian) – Sandstone interbedded with wackestone and mudstone; sandstone, moderate red, coarse to medium grained, and ledge forming; wackestone, dark gray to pale purple, dense, and ledge forming; mudstone, variegated (shades of red, green, purple), thin bedded, and slope forming; forms alcoves; 360 to 835 feet thick.

Prv **Round Valley Limestone** (Lower Pennsylvanian, Bashkirian) – Limestone (mudstone to packstone), dark gray to light gray, cherty , and fossiliferous; chert varies from blue gray and yellowish gray to characteristic red and pink shades; outcrops form small step-like ledges where not covered by colluvium; mudstone, variegated (mainly shades of green, red, and purple), thinly bedded, and slope forming; 260 feet thick.

### Mississippian

Mdh **Doughnut Shale and Humbug Formation, undivided** (Upper to Middle Mississippian, Serpukhovian to Visean) – Shale, limestone, and sandstone; Doughnut Shale – Shale, dark gray and organic rich with some reddish-gray shale near the base of the unit, fissile, and clay rich; sandstone, light yellow-gray, coarse grained; limestone, dark gray, thin bedded; Humbug Formation – sandstone, light gray to reddish gray, very fine grained, and locally cross-bedded with some interbedded light-gray limestone and reddish-gray to dark-gray shale; hematitic near the top of the unit; unit is poorly exposed and mostly covered by colluvium and vegetation; 40 to 200 feet thick.

Mm **Madison Limestone** (Middle to Lower Mississippian, Visean to Tournaisian) – Limestone (packstone), dark gray to medium gray, massive, cliff forming, and contains abundant light gray chert; some mudstone interbeds; unit not fully exposed in quadrangle; as much as 1000 feet thick.

### Neoproterozoic

Zr **Uinta Mountain Group, Red Pine Shale** (lower Neoproterozoic, Tonian) – Shale and interbedded silty sandstone; shale, grayish yellow green on fresh surfaces, weathers pale olive, dark yellowish-orange and light brown to moderate reddish-brown, medium to very thin bedded, irregularly laminated, rippled, load structures, weathers to small chips, and slope forming; limonite may be present on weathered surfaces and Liesegang banding common; sandstone, light brown to moderate reddish-brown, medium to fine grained, moderately sorted, very thick to medium bedded, well cemented, and ledge forming; unit poorly exposed in the northwest corner of the quadrangle; Red Pine Shale age is 770 Ma from U-Pb detrital zircon analysis (Dehler and others, 2010) and assigned to the Tonian based on redefinition of the Tonian/Cryogenian boundary (Shields-Zhou and others, 2016); 1800 to 2000 feet thick.

Zu **Uinta Mountain Group, undivided** (lower Neoproterozoic, Tonian) – Shown only in cross section; formations below the Red Pine Shale (of Uinta Mountain Group); sandstone (quartz arenite and arkosic), reddish brown to purplish brown, medium to coarse grained; shale, greenish gray to dark gray; few pebble conglomerate beds; more than 14,000 feet thick.

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