Interim Geologic Map of the Ogden 30′ x 60′ Quadrangle, Box Elder, Cache, Davis, Morgan, Rich, and Summit Counties, Utah, and Uinta County, Wyoming

by

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DESCRIPTION OF MAP UNITS

(units are queried where classification uncertain)

SURFICIAL DEPOSITS

Unconsolidated Material

QUATERNARY

Alluvial deposits

Qay, Qa2, Qa2?, Qa3, Qa3?, Qa4, Qa4?, Qa4-5, Qa5, Qa6

Alluvium (Holocene and Pleistocene) – Sand, silt, clay, and gravel in stream and alluvial-fan deposits that are not close to late Pleistocene Lake Bonneville and are geographically in the Huff Creek and upper Bear River drainages; variably sorted; variably consolidated; composition depends on source area; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage, or are shown where fans and terraces are too small to show separately at map scale; Qay is at to slightly above present drainages and not incised by active drainages, so is the youngest unit; generally 6 to 20 feet (2-6 m) thick.

Age-number and letter suffixes on alluvium (undivided, channel, flood plain, terrace, and fan) that is not close to late Pleistocene Lake Bonneville are relative and only apply to the local drainage, with suffix 2 being the second youngest; the relative age is queried where age uncertain, generally due to the height not fitting into the typical order of surfaces. The various numbered deposits listed, Qa2 through Qa6, are 20 to 180 feet (6-55 m) above the Bear River, Saleratus Creek, and Yellow Creek. Qa5 and Qa3? are only used in stacked units (Qa5/Tfb and Qa3?/Tfb).

Qa, Qa? **Alluvium, undivided (Holocene and Pleistocene)** – Sand, silt, clay, and gravel in stream and alluvial-fan deposits near late Pleistocene Lake Bonneville and are geographically in the Ogden and Weber River, and lower Bear River drainages; composition depends on source area; variably sorted; variably consolidated; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage, or are shown where fans and terraces are too small to show separately at map scale; Qa with no suffix used where age uncertain or alluvium of different ages cannot be shown separately at map scale; Qa queried where relative age uncertain, generally due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age (see following paragraphs); generally 6 to 20 feet (2-6 m) thick.

Where possible, alluvium is subdivided into relative ages, indicated by number and letter suffixes. This alluvium is listed and described separately below. The relative ages of alluvium, including terraces and fans, are in part based on deposit heights above present adjacent drainages in Morgan and Round Valleys, and this subdivision apparently works in and is applied in Ogden, Henefer, and Lost Creek Valleys and above the North, Middle, and South Forks of Ogden River (see table 1 and 2). Alluvial deposits mapped in the Henefer quadrangle (Coogan, 2010b) and Lost Creek drainage (Coogan, 2004a-c) were revised during mapping of the Devils Slide quadrangle (see table 2). Comparable alluvium along Box Elder Creek in the northwest part of the map area (Mantua quadrangle) seems to be slightly higher than in Morgan Valley. Units Qa2, Qay, Qap, Qab, Qapb, Qao, and Qaoe described below are near Lake Bonneville. Their relative age is queried where age uncertain, generally due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age.

Qa2, Qa2?, Qay

Younger alluvium (mostly Holocene) – Like undivided alluvium, with Qay at to slightly above present drainages, unconsolidated, and not incised by active drainages; likely mostly Holocene in age and post-dates late Pleistocene Provo shoreline of Lake Bonneville; height above present drainages is low and is within certain limits, with suffix 1 (not present on this map) being the youngest and being at to slightly (<10 feet [3 m]) above drainages and suffix 2 being slightly higher and older, with y suffix where ages 1 and 2 cannot be separated; Qa2 is up to about 20 feet (6 m) above drainage on south side of Round Valley indicating unit includes slightly older post Provo-shoreline alluvium; generally 6 to 20 feet (2-6 m) thick. Mapped as Qa2 (queried) where about 20 feet (6 m) above incised stream in Stephens Canyon (Devils Slide quadrangle).

Qap, Qap?, Qab, Qab?, Qapb

Lake Bonneville-age alluvium (upper Pleistocene) – Like undivided alluvium but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits, and unconsolidated to weakly consolidated; alluvium labeled Qap and Qab is related to Provo (and slightly lower) and Bonneville shorelines of Lake Bonneville (at ~4800 to 4840 feet [1463-1475 m] and 5180 feet [1580 m] in Morgan Valley), respectively; suffixes partly based on heights above adjacent drainages near Morgan Valley (see tables 1 and 2); Qap is typically about 15 to 40 feet (5-12 m) above present adjacent drainages, but is locally 45 feet (12 m) above; Qapb is used where more exact age cannot be determined, typically away from Lake Bonneville, or where alluvium of different ages cannot be shown separately at map scale; Qap is up to about 50 feet (15 m) thick, with Qapb and Qab, at least locally up to 40 and 90 feet (12 and 27 m) thick, respectively. Queried where classification or relative age uncertain (see Qa).

A prominent surface (“bench”) is present on Qap and Qatp at about 4900 feet (1494 m) elevation and about 25 to 40 feet (8-12 m) above the Weber River in Morgan Valley and along the South Fork Ogden River.

In the Devils Slide quadrangle, the Qab that is mapped about 80 to 95 feet (24-29 m) above Round Valley and 40 to 50 feet (12-15 m) above adjacent drainages at the mouth of Geary Hollow appears unique. Based on heights above adjacent drainages, these deposits would be Qao (see table 1), but similar alluvial deposits to the east near Phil Shop Hollow have a Bonneville shoreline cut in them and are much thinner than 40 feet (12 m). The lack of a Bonneville shoreline, and small thickness and heights above drainages indicate the deposits could be a Bonneville shoreline fan-delta.

Qao, Qao?

Older alluvium (mostly upper Pleistocene) – Sand, silt, clay, and gravel above and likely older than the Bonneville shoreline; mapped on surfaces above Lake Bonneville-age alluvium (Qap, Qab, Qapb); deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; also shown where areas of fans and terraces are too small to show separately at map scale; composition depends on source area; at least locally up to 110 feet (34 m) thick. Queried where classification or relative age is uncertain (see Qa for details); for example near head of Saleratus Creek.

Older alluvium is likely older than Lake Bonneville and the same age as Qafo, so likely Bull Lake age, 95,000 to 130,000 years old (see Chadwick and others, 1997, and Phillips and others, 1997); see table 1 and note revision from Coogan and King (2006) and King and others (2008). From our work in the Henefer (Coogan, 2010b) and Devils Slide quadrangles and ages in Sullivan and Nelson (1992) and Sullivan and others (1988), older alluvium (Qao, Qafo, Qato) may encompass an upper (pre-Bull Lake) and lower (Bull Lake) alluvial surface that is not easily recognized in Morgan Valley (see tables 1 and 2).

Qaoe, Qaoe?

Older eroded alluvium (middle and lower Pleistocene) – Eroded alluvium located above Bonneville shoreline (at 5180 feet [1580 m] in Morgan Valley) with upper surfaces apparently above and older than adjacent pre-Lake Bonneville older alluvium (Qao and Qafo); mostly sand, silt, and gravel in stream and alluvial fan deposits; composition depends on source area; deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; typically 120 to 230 feet (35-70 m) above adjacent drainages; typically about 10 to 60 feet (3-20 m) thick, but appears about 120 feet (37 m) thick in one exposure west of Henefer Valley at Roberts Hollow and queried exposures in Weber Canyon. Queried where classification or relative age is uncertain (see Qa for details).

In the Durst Mountain quadrangle, mapped on benches about 80 to 100 feet (24-30 m) above Cottonwood Creek, because deposits are higher than adjacent Qafo, though height above adjacent drainages is similar to Qao and Qafo (table 1) and deposits may be slightly older generation of older alluvium.

West of the Weber River in the Morgan quadrangle, dated by Sullivan and others (1988) as older than 730 ka [>780 ka, Bassinot and others, 1994], based on reversed paleomagnetism. But the sample site is one of the highest remnants of Qaoe (>200 feet [60 m] above Weber River) and may be unit QTay. If this high remnant is QTay, it is greater than 780 ka, and Qaoe and Qafoe may be related to the Pokes Point lake cycle (Marine Oxygen Isotope Stage 12 by Oviatt and others, 1999) (pre-Illinoian B continental glaciation, >300 ka) and/or be pre-Pokes Point (Marine Oxygen Isotope Stage 16, "Nebraskan" continental glaciation, >500 ka) (see table 3). The age(s) of units Qaoe and Qafoe may be refined if a Lava Creek B and/or Bishop ash were found in them (see table 3).

Qal, Qal1, Qal2, Qal2?

Stream alluvium and flood-plain deposits (Holocene and uppermost Pleistocene) – Sand, silt, clay, and gravel in channels, flood plains, and terraces typically less than 16 feet (5 m) above river and stream level; moderately sorted; unconsolidated; along the same drainage Qal2 is lower than Qat2 and has likely been subject to flooding, at least prior to dam building; present in broad plains along the Bear, Ogden, and Weber Rivers and larger tributaries like Deep, Cottonwood, East Canyon, Lost, and Saleratus Creeks, along Box Elder, Heiners, and Yellow Creeks, and in narrower plains of larger tributary streams; locally includes muddy, organic overbank and oxbow lake deposits; composition depends on source area, so in back valleys typically contains many quartzite cobbles recycled from the Wasatch Formation; mostly Holocene, but deposited after regression of Lake Bonneville from the late Pleistocene Provo shoreline; width in Morgan Valley is combined flood plain of Weber River and East Canyon and Deep Creeks; 6 to 20 feet (2-6 m) thick and possibly as much as 50 feet (15 m) along Weber River and thinner in the Kaysville quadrangle; greater thicknesses (>50 feet [15 m]) are reported in Morgan Valley (Utah Division of Water Rights, well drilling database), but likely include Lake Bonneville and older Pleistocene deposits.

Suffixes 1 and 2 indicate ages where they can be separated, with 1 including active channels and 2 including low terraces 10 to 20 feet (3-6 m) above the Weber and Ogden Rivers, and the South Fork Ogden River that may have been in the flood plain prior to damming of these waterways. Qal2 queried in low terraces above Bear River, Saleratus Creek, and Dry Creek where deposits may not be in the flood plain.

Qalp? **Lake Bonneville regression-age stream alluvium (upper Pleistocene?)** – Pebble and cobble gravel, gravelly sand and silty sand, with minor clay in channel incised into Lake Bonneville deltaic and lacustrine deposits (Qldb) in Ogden Valley; queried because age uncertain; thickness uncertain.

Qat2, Qat2? Qat2-3, Qat3, Qat3?, Qat3-4, Qat4, Qat4?, Qat5, Qat5?, Qat6, Qat6?

Stream-terrace alluvium (Holocene and Pleistocene) – Sand, silt, clay, and gravel in terraces above flood plains that are not close to late Pleistocene Lake Bonneville and are geographically in the Huff Creek and upper Bear River drainages; moderately sorted; variably consolidated; upper surfaces slope gently downstream; locally includes thin and small mass-movement and alluvial-fan deposits; subdivided into relative ages that only apply to the local drainage, indicated by number suffixes, with 2 being the lowest/youngest terraces, typically about 10 to 20 feet (3-6 m) above adjacent flood plains; 6 to at least 20 feet (2-6+ m) thick.

On the map Qat2 through Qat6 are less than 20 to at least 160 feet (6-50 m) above Yellow Creek (also above Saleratus, Rees, Chalk, Dry, and Huff Creeks, and Bear River), with Qat2 being younger than Qat3 but Qat3 may or may not be younger than Lake Bonneville. The relative age is queried where the age is uncertain, generally due to the height not fitting into the typical order of surfaces.

Qat, Qat2, Qaty, Qatp, Qatp?, Qatpb, Qato

Stream-terrace alluvium (Holocene and Pleistocene) – Sand, silt, clay, and gravel in terraces above flood plains near late Pleistocene Lake Bonneville and are geographically in the Ogden and Weber River, and lower Bear River drainages; moderately sorted; variably consolidated; upper surfaces slope gently downstream; locally includes thin and small mass-movement and alluvial-fan deposits; where possible, subdivided into relative ages, indicated by number and letter suffixes, with 2 being the lowest/youngest terraces, typically about 10 to 20 feet (3-6 m) above adjacent flood plains; Qat with no suffix used where age unknown or age subdivisions of terraces cannot be shown separately at map scale; 6 to at least 20 feet (2-6+ m) thick, with Qatp 50 to 80 feet (15-24 m) thick in Mantua Valley.

Relative ages are largely from heights above adjacent drainages in Morgan and Round Valleys. This subdivision apparently works in and is applied in Ogden, Henefer, and Lost Creek Valleys and above the North, Middle, and South Forks of Ogden River (see tables 1 and 2). Despite the proximity to Lake Bonneville, terraces along and near Box Elder Creek in the northwest corner of the Ogden map area (Mantua quadrangle) seem to be slightly higher than comparable terraces in Morgan Valley. Terraces labeled Qat2 are post-Lake Bonneville and are likely mostly Holocene in age. A terrace labeled Qaty is up to 20 feet (6 m) above the South Fork Ogden River, but may be related to the Provo or regressional shorelines. Terraces labeled Qatp are likely related to the Provo and slightly lower shorelines of Lake Bonneville (at and less than ~4820 feet [1470 m] in area), and with Qap form "benches" at about 4900 feet (1494 m) along the Weber River and South Fork Ogden River. Qato terraces pre-date Lake Bonneville. Relative age queried (Qatp?) where age is uncertain, generally due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age.

Qat2, Qat3

Stream-terrace alluvium (Holocene and Pleistocene) – Sand, silt, clay, and gravel in terraces inset into late Pleistocene Weber River delta above Weber River flood plain; moderately to well-sorted, pebble and cobble gravel and gravelly sand with subangular to rounded clasts; unconsolidated to weakly consolidated; upper surfaces slope gently downstream; locally includes thin and small mass-movement and alluvial-fan deposits; subdivided into relative ages, indicated by number suffixes, with 2 being the lowest/youngest terraces and 3 divided by a scarp on the map into an upper and lower terrace; terraces 20 to 50 feet (6-16 m) above the Weber River; exposed thickness less than 20 to 50 feet (6-16 m) (after Yonkee and Lowe, 2004). These terraces do not fit into table 1 or 2 because they post-date the regression of Lake Bonneville from the Provo shoreline and appear to be graded to lake levels below the Gilbert shoreline.

Qaf, Qafy, Qaf3, Qaf3?, Qaf4, Qaf4?, Qaf5

Alluvial-fan deposits (Holocene and Pleistocene) – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted and that is not close to late Pleistocene Lake Bonneville and is geographically in the Huff Creek and upper Bear River drainages; variably consolidated; includes debris flows, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick. Qaf with no suffix used where age uncertain or for composite fans where portions of fans with multiple ages cannot be shown separately at map scale; toes of some fans have been removed by human disturbances, so their age cannot be determined.

Where possible, subdivided into relative ages, indicated by letter and number suffixes (like Qa and Qat suffixes) and relative ages only apply to the local drainage, with unit Qafy being the lowest (youngest) fans and unit 3 may or may not post-date Lake Bonneville. Relative ages of these fans are partly based on heights above present drainages at drainage-eroded edge of fan. The relative age is queried where the age is uncertain, generally due to the height not fitting into the typical order of surfaces. The various deposits listed, Qafy and Qaf3 through Qaf5, are 20 to 140 feet (6-40 m) above and west of Saleratus Creek, and also above Yellow Creek and the Bear River. Qafy fans are active, impinge on present-day floodplains, divert active streams, and overlie low terraces.

Qaf, Qaf?

Alluvial-fan deposits, undivided (Holocene and Pleistocene) – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted and is near late Pleistocene Lake Bonneville and is geographically in the Ogden and Weber River, and lower Bear River drainages; variably consolidated; includes debris flows, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick; in subsurface, about 100 feet (30 m) thick in section 22, T. 9 N., R. 1 W. northwest of Mantua, and about 150 feet (45 m) thick beneath Qac in sections 9 and 16, T. 9 N., R. 1 W. (Utah Division of Water Rights website). Qaf with no suffix used where age uncertain or for composite fans where portions of fans with multiple ages cannot be shown separately at map scale; toes of some fans have been removed by human disturbances, so their age cannot be determined, for example in Upper Weber Canyon. Qaf queried where relative age uncertain, generally due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age (see following paragraphs).

Where possible, subdivided into relative ages, indicated by letter and number suffixes (like Qa and Qat suffixes). These alluvial fans near Lake Bonneville (Qaf1, Qaf2, Qafy, Qafp, Qafpb, Qafb, Qafm, Qafo, Qafoe) are listed and described separately below. Relative ages of these fans are partly based on heights above present drainages in Morgan Valley area, in this case at drainage-eroded edge of fan. This height-based subdivision apparently works in and is applied in Ogden, Henefer, and Lost Creek Valleys and above the North, Middle and South Forks of Ogden River (see tables 1 and 2) (note revisions from Coogan and King, 2006; King and others, 2008; Coogan, 2010a-b). Despite the proximity to Lake Bonneville, alluvial fans along and near Box Elder Creek in the northwest corner of the map area (Mantua quadrangle) do not fit into table 1 and overall appear to be higher than comparable fans in Morgan Valley. Their relative ages are queried where the age is uncertain, generally due to the height not fitting into the ranges in table 1 and/or the typical order of surfaces contradicts height-derived age.

Qaf1, Qaf2, Qaf2?, Qafy, Qafy?

Younger alluvial-fan deposits (Holocene and uppermost Pleistocene) – Like undivided alluvial fans, but all of these fans are unconsolidated and should be considered active; height above present drainages is low and is within certain limits; generally less than 40 feet (12 m) thick; near former Lake Bonneville, fans are shown as Qafy where Qaf1 and Qaf2 cannot be separated, and all contain well-rounded recycled Lake Bonneville gravel. Younger alluvial fan deposits are queried where relative age is uncertain (see Qaf for details).

Qaf1 fans are active because they impinge on and deflect present-day drainages. Qaf2 fans appear to underlie Qaf1 fans but may be active. Qafy fans are active, impinge on present-day floodplains, divert active streams, overlie low terraces, and/or cap alluvial deposits (Qap) related to the Provo and regressive shorelines. Therefore, Qafy fans are younger than the Provo shoreline and likely mostly Holocene in age, but may be as old as latest Pleistocene and may be partly older than Qaf1 fans.

Qafp, Qafp?, Qafb, Qafb?, Qafpb, Qafpb?

Lake Bonneville-age alluvial-fan deposits (upper Pleistocene) – Like undivided alluvial fans, but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits (see table 1); these fans are inactive, unconsolidated to weakly consolidated, and locally dissected; fans labeled Qafp and Qafb are related to the Provo (and slightly lower) and Bonneville shorelines of late Pleistocene Lake Bonneville, respectively, while unit Qafpb is used where fans may be related to the Provo or Bonneville shoreline (for example Qafpb is ~40 feet [12 m] above Lost Creek Valley), or where fans of different ages cannot be shown separately at map scale; Qafp fans typically contain well-rounded, recycled Lake Bonneville gravel and sand and are moderately well sorted; generally 10 to less than 60 feet (3-18 m) thick. Lake Bonneville-age fans are queried where relative age is uncertain (see Qaf for details); fans labeled Qafpb? are above the Bonneville shoreline and might be Qafo or like Qafm; see the note under Qao about two possible ages of older alluvium (Qao, Qato, and Qafo).

Most of the Lake Bonneville-age fans in the James Peak quadrangle are far from the Bonneville shoreline and their age is inferred from their stratigraphic relationship(s) to coeval Pinedale glacial outwash (see age equality in Table 3).

The channels (Qafp/Qdlb) on the Weber River delta and Lake Bonneville fines (Qafp on Qlfb) probably record scour and fill during the rapid drawdown of the lake as it fell from the Bonneville shoreline to the Provo shoreline.

Qafm **Pre-Lake Bonneville-age alluvial fan deposits (upper Pleistocene)** – Like older alluvial fans (Qafo), but mantle Qafo? in graben in Main Canyon valley in Devils Slide quadrangle (Qafm only used in stacked unit Qafm/Qafo?) and dated in U.S. Bureau of Reclamation trench (SW1/4SW1/4 section 5, T. 3 N., R. 4 E. SLBM) as older than Lake Bonneville and younger than Bull Lake glaciation (31-38 ka) (see table 2 and Piety and others, 2010); a surface on QTaf? and QTa? east of graben can be traced upstream to Qafm/Qafo? and this surface is about 80 feet (24 m) above adjacent active drainage into Main Canyon Creek, a height on the boundary between Qab and Qao (see table 2).

Qafo, Qafo?

Older alluvial-fan deposits (mostly upper Pleistocene) – Incised and at least locally dissected fans of mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows, particularly in drainages and at drainage mouths (fan heads); older fans are typically above the Bonneville shoreline, with an eroded bench at the shoreline; upstream and above the Bonneville shoreline, unit Qafo is topographically higher than fans graded to the Bonneville shoreline (Qafb), and is typically dissected; generally less than 60 feet (18 m) thick. In Mantua Valley, exposed thickness up to about 100 feet (30 m), but water wells (sections 26 and 27, T. 9 N., R. 1 W.) were still in gravelly to bouldery valley fill at depths of 505 and 467 feet (154 and 142 m), respectively, and red coloration that may indicate Wasatch Formation bedrock was not noted (see Bjorklund and McGreevy, 1973, p. 16).

Qafo queried where relative age is uncertain (see Qaf for details), for example in Mantua quadrangle where it is as high as Qafoe in Morgan Valley (see table 1). Qafo queried in East Canyon graben because the deposits are not dissected and some deposits mantle Qafoe (see also unit Qafm above), resulting in a reversal of relative height and only local incision. These irregular deposits are likely the result of salt movement in the East Canyon graben. Our Qafo is roughly shown to south by Bryant (1990) as Qgp (pediment gravel); farther south he showed Qoa (dissected alluvium) adjacent to the East Canyon fault, which may be the QTaf or Qafoe we mapped.

Amino-acid age estimates presented in Sullivan and Nelson (1992) imply Qafo north of Morgan considerably predates Lake Bonneville and is middle Pleistocene in age (≥400 ka). However, the Bonneville shoreline is obscure on this fan, and soil-carbonate age estimates (>70-100 ka) and other amino-acid age estimates (~98-155 ka) in Sullivan and others (1988) imply these older fans are related to Bull Lake glaciation (95,000 to 130,000 years old; see Chadwick and others, 1997; Phillips and others, 1997). As noted under Qao, Qafo deposits may contain two ages (levels) of alluvial surfaces that are not easily recognized in Morgan Valley but are recognized upstream in the Henefer and Lost Creek Valleys (Devils Slide quadrangle) and along the North and South Forks of Ogden River.

Qafoe, Qafoe?

Older eroded alluvial-fan deposits (middle and lower Pleistocene) – Typically eroded fan remnants located above and apparently older than pre-Lake Bonneville older alluvial deposits (Qafo, Qao); contains mostly sand, silt, and gravel that is poorly bedded and poorly sorted; less bouldery and lower relative to high-level alluvium (QTa, QTay, QTao, QTaf); in Morgan Valley caps ridges above drainages, like high-level alluvium and unit Qaoe, but also inset along drainages; 6 to 60 feet, or more (2-18+ m) thick. Likely same age as Qaoe (Marine Oxygen Isotope Stage 12 and/or 16; middle Pleistocene), but possibly greater than the 780 ka paleomagnetic reversal (see table 3) and early Pleistocene in age. Queried in Mantua Valley, and above Middle and North Forks of Ogden River, because as high as QTay in Morgan Valley (see table 1). Queried in North Ogden quadrangle on Pleasant View salient because not very eroded and may be unit Qafo; also compare mapping of af5 of Personius (1990) to afo of Nelson and Personius (1993).

In the Devils Slide quadrangle in Main Canyon graben, Qafoe? actually overlies unit QTaf? and underlies Qafo?. This stacking indicates filling of the graben as it subsides, and exposure due to periodic incision as the east side of the graben is breached by streams. All these features and unit Qafm are likely related to movement and dissolution of the salt welt in the graben.

Qafoe-QTaf

Older eroded fan and/or pediment-mantle deposits (middle or lower Pleistocene) – Gravel, sand, silt, and clay in alluvium and colluvium that cap surfaces that are partly correlative with the pre-Lake Bonneville McKenzie Flat geomorphic surface of Williams (1948) (see McCalpin, 1989); in Paradise quadrangle, McCalpin (1989) described this unit (his afo) as forming dissected surfaces 50 to 1000 feet (15-300 m) above active streams, and commonly present as a relatively thin discontinuous veneer, less than 33 feet (10 m) thick, on a surface (pediment) “cut” on Tertiary Salt Lake Formation; but our mapping, which reduces colluvium bias (“slough”), indicates the surface edges are about 100 to 400 feet (30-120 m) above adjacent drainages.

McKenzie Flat is a gently north-inclined little-dissected bench capped by these deposits in the James Peak and Paradise quadrangles, with the flat along the axis of a broad open syncline in the underlying Salt Lake Formation. Dissected surfaces on eroded remnants of these deposits dip west from the East Cache fault zone to McKenzie Flat, with dips that are nearly the same as bedding in the underlying Salt Lake Formation in the east limb of the syncline. This implies the west-dipping surfaces are capped by residual deposits rather than being tilted fan deposits, and the flat may have the same origin. Alternatively the flat and limb deposits have two different origins, fan and lag/residual, respectively. Fans on McKenzie Flat could be middle Pleistocene (McCalpin, 1989; see also Sullivan and Nelson, 1992) (Little Valley or Pokes Point lake cycle) and/or early Pleistocene (after Sullivan and others, 1988) in age; although the lower heights above the adjacent drainages fit this middle and early Pleistocene age (Qafoe), the upper limit is in the range of Quaternary-Pliocene fans (QTaf).

Mullens and Izett (1964) did not map the McKenzie Flat deposits, but described them as an upper 20 to 40 feet (6-12 m) of conglomerate that rests with angular unconformity on the main Salt Lake Formation conglomerate. They noted that exposures in the James Peak quadrangle, pointed out by Dr. C.T. Hardy of Utah State University, show this relationship. The angular unconformity supports a fan origin for the deposits on the north-inclined McKenzie Flat. Mullens and Izett (1964) also noted that subrounded boulders of quartzite derived from Precambrian and Cambrian formations are scattered on McKenzie Flat and boulders average about 1 foot (30 cm) in diameter, but some are as much as 3 feet (90 cm) in diameter.

The Precambrian (Neoproterozoic) and Cambrian quartzite boulders could be recycled from the Salt Lake Formation conglomerate, the Wasatch Formation, or be from quartzite exposures to the south in the James Peak quadrangle. The latter implies transport to the north into lower parts of Cache Valley. When the boulders were transported is more problematic, since they could be a lag from the underlying Salt Lake Formation rather than being transported during Pleistocene fan deposition.

Another gravel-armored surface (flat and possible fan remnant), the Hyrum Bench of Ezell (1953), is present on the Salt Lake Formation in the northwest part of the James Peak quadrangle (separated into Qafoe and QTa on the Ogden map) and southwest part of the Paradise quadrangle. This Hyrum Bench surface is at a slightly higher altitude than the surface on McKenzie Flat (~5800-6000 feet [1770-1830 m] versus ~5400-5600 feet [1650-1710 m]), but may be related because several normal faults mapped between the two flats in the James Peak quadrangle may offset the surfaces (see map).

Glacial deposits

Qg, Qg?, Qgm, Qgm?, Qga, Qga?

Glacial till and outwash, undivided age (Holocene and upper and middle? Pleistocene) – Qg is undivided glacial deposits (till and outwash) of various ages; till is non-stratified, poorly sorted clay, silt, sand, and gravel, to boulder size; Qgm is moraines of unknown age that are mapped where distinct shapes of end, recessional and lateral moraines are visible; outwash (Qga) is stratified and variably sorted, but better sorted and bedded than till due to alluvial reworking; Qga is mapped directly downslope from other glacial deposits where it is thick enough to obscure older deposits and bedrock, and where it can be separated from ground moraine (mapped as Qg) and alluvium (mapped as Qa_); locally include mass-movement (Qms, Qmt, Qct) and rock glacier deposits that are too small to show separately at map scale; 6 to 150 feet (2-45 m) thick. Undivided because age uncertain or where deposits with multiple ages cannot be shown separately at map scale; queried where interpretation as glacial deposits is uncertain. Glacial deposits are prone to slope failures.

Other possible glacial features are pimple mounds on Herd Mountain surface(s) in Bybee Knoll, Sharp Mountain, Huntsville, and Durst Mountain quadrangles and possible stone stripes (solifluction) in unit Qcg.

Qgy, Qgy?, Qgmy?

Younger glacial till and outwash (Holocene) – Mapped in cirques as undivided (Qgy) and distinct moraines or protalus deposits (hence query on Qgmy); moraines are mapped where distinct shapes of end and lateral moraines and, locally, recessional moraines are visible; include 8000- to 10,000-year-old and possibly middle Holocene (~5000 years old) deposits with very poorly developed soil and sharp, mostly non-vegetated moraines; ages modified from Madsen and Currey (1979); includes un-vegetated, angular, cobble- to boulder-sized debris with little matrix in protalus ramparts and rock glacier deposits (inactive, no ice matrix) with lobate crests; these rocky deposits may be as young as Little Ice Age (A.D. 1500 to 1800); Qgy queried where age uncertain; Pinedale glacial deposits (Qgp, Qgmp, Qgap) are downslope from younger deposits; estimate 6 to 60 feet (2-18 m) thick. Glacial deposits are prone to slope failures.

Qgp, Qgmp, Qgmp?, Qgap

Pinedale glacial till and outwash (upper Pleistocene) – Pinedale-age (~12,000 to 30,000 years old) (Gosse and others, 1995; Phillips and others, 1997) deposits mapped as undivided (Qgp), distinct moraines (Qgmp), and outwash (Qgap); moraines are mapped where distinct shapes of end, recessional, and lateral moraines are visible; mapped moraines have poorly developed soil and moderate to sharp moraine morphology; estimate 19,000 years old); upslope these units include partially vegetated recessional deposits from glacial stillstands and/or minor advances (deglacial pauses) about 13,000 to 14,000 years ago; ages modified from Madsen and Currey (1979); Qgmp queried where age uncertain; estimate 6 to 100 feet (2-30 m) thick; older glacial deposits (Qgo, Qgmo, Qgao) are downslope from Pinedale moraine. Glacial deposits are prone to slope failures.

Qgo, Qgo?, Qgmo, Qgmo?, Qgao, Qgao?

Older glacial till and outwash (upper and middle? Pleistocene) – Mapped down-drainage from and locally laterally above Pinedale deposits as undivided (Qgo), till in distinct vegetated moraines (Qgmo), and outwash (Qgao); see sub-unit differences under undivided glacial units (Qg, Qgm, Qga); mapped moraines have well-developed soil and subdued moraine morphology; may have two Bull Lake moraines and deposits, or Bull Lake and pre-Bull Lake deposits; Bull Lake age about 95,000 to 130,000 years old (see Chadwick and others, 1997; Phillips and others, 1997); Qgo queried where material may not be glacial deposits; Qgmo queried where age uncertain; Qgao queried where age uncertain or material may not be glacial outwash; estimate 6 to 160 feet (6-50 m) thick and even thicker, at least 200 feet (60 m) thick, along Cutler Creek (Mantua quadrangle). Glacial deposits are prone to slope failures.

Some glacial deposits mapped in several quadrangles are much farther from cirques than any other deposits and are potential pre-Bull Lake glacial deposits. These deposits are above Cutler Creek and the upper reaches of the North Fork Ogden River (Mantua quadrangle), in the Maples area (Snow Basin quadrangle), and at several locations in the Peterson quadrangle. The pre-Bull Lake deposits may be related to pre-Illinoian continental glaciation (>300 ka) (Pokes Point lake cycle >271 ka, see Balch and others, 2005; or most likely ~450 ka, Marine Oxygen Isotope Stage 12, see Oviatt and others, 1999), or be some pre-Pokes Point glaciation (possibly “Nebraskan” continental glaciation, >500 ka; or Sacagawea Ridge age, ~600 ka, see Chadwick and others, 1997; Phillips and others, 1997).

Mass-movement deposits

Qmdf, Qmdf?

Debris- and mud-flow deposits (Holocene and upper and middle? Pleistocene) – Very poorly sorted, clay- to boulder-sized material in unstratified deposits characterized by rubbly surface and debris-flow levees with channels, lobes, and mounding; variably vegetated; in drainages typically form mounds, an indication of more viscous Qmdf, rather than being flat like unit Qac; Qmdf queried where may not be mostly debris- and mud-flow deposits; many debris flows cannot be shown separately from alluvial fans at map scale; 0 to 40 feet (0-12 m) thick. Age(s) uncertain; deposits in drainages likely post-date the Provo shoreline of Lake Bonneville, while deposits above drainages, like north of the Right Hand Fork Peterson Creek, are likely as old as Bull Lake glaciation, but could pre-date Bull Lake glaciation and be middle Pleistocene.

Qms, Qms?, Qmsy, Qmsy?, Qmso, Qmso?

Landslide deposits (Holocene and upper and middle? Pleistocene) – Poorly sorted clay- to boulder-sized material; includes slides, slumps, and locally flows and floods; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; composition depends on local sources; morphology becomes more subdued with time and amount of water in material during emplacement; Qms may be in contact with Qms when landslides are different/distinct; thickness highly variable, up to about 20 to 30 feet (6-9 m) for small slides, and 80 to 100 feet (25-30 m) thick for larger landslides. Qmsy and Qmso queried where relative age uncertain; Qms queried where classification uncertain. Numerous landslides are too small to show at map scale and more detailed maps shown in the index to geologic mapping should be examined.

Qms without a suffix is mapped where the age is uncertain (though likely Holocene and/or late Pleistocene), where portions of slide complexes have different ages but cannot be shown separately at map scale, or where boundaries between slides of different ages are not distinct. Estimated time of emplacement is indicated by relative-age letter suffixes with: Qmsy mapped where landslides deflect streams or failures are in Lake Bonneville deposits, and scarps are variably vegetated; Qmso typically mapped where deposits are “perched” above present drainages, rumpled morphology typical of mass movements has been diminished, and/or younger surficial deposits cover or cut Qmso. Lower perched Qmso deposits are at Qao heights above drainages (95 ka and older) and the higher perched deposits may correlate with high level alluvium (QTa_) (likely older than 780 ka) (see table 1). Suffixes y and o indicate probable Holocene and Pleistocene ages, respectively, with all Qmso likely emplaced before Lake Bonneville transgression. These older deposits are as unstable as other slides, and are easily reactivated with the addition of water, be it irrigation or septic tank drain fields.

Qms(QTaf), Qms(QTms), Qms(rx), Qms(Tu), Qms(Trx), Qms(Tsl), Qms(Tcg), Qms(Ts), Qms(Tn), Qms(Tnf), Qms(Tf), Qms(Tn/Tw), Qms(Tw), Qms(TKJ?), Qms(Keh), Qms(Mg), Qms(Ml), Qms(Dwc), Qms(Sl), Qms(Cbm), Qms(Cm), Qms(Ct), Qms(Ct?), Qms(Zcc), Qms(Zkc), Qms(Zrx), Qms(Zmc), Qms(Zmcc), Qms(ZYp), Qms(Zpu), Qms(ZYpm), Qms(YXf), Qms(Xfc), Qms(Xfcg), Qms(Xfcg?)

Qms?(Qlf), Qms?(Qafoe?), Qms?(QTaf), Qms?(QTaf/Tw), Qms?(QTms), Qms?(rx), Qms?(Thv), Qms?(Tsnf), Qms?(Tu), Qms?(Tsl), Qms?(Tcg), Qms?(Tcg?), Qms?(Ts), Qms?(Tn), Qms?(Tf), Qms?(Tw), Qms?(Keh), Qms?(Kk), Qms?(PIPw), Qms?(Mh), Qms?(Ogc), Qms?(Cn), Qms?(Cbo), Qms?(Cm), Qms?(Co), Qms?(Ct), Qms?(Cgc), Qms?(Zm), Qms?(Zcc),, Qms?(Zpc), Qms?(Zkc), Qms?(Zrx), Qms?(Zmc), Qms?(Zmcc), Qms?(ZYp), Qms?(Zpu), Qms?(Zpu?), Qms?(Zpd?), Qms?(ZYpm), Qms?(YXf), Qms?(YXfq), Qms?(YXfs), Qms?(Xfc), Qms?(Xfcg)

Qmso(QTcg?), Qmso(Ts), Qmso(Tn), Qmso(Tf), Qmso(Keh), Qmso(Xfc)

Qmso?(Qafoe), Qmso?(QTcg?), Qmso?(Ts), Qmso?(Tcg), Qmso?(Tn), Qmso?(Tf), Qmso?(Xfc)

Block landslide and possible block landslide deposits (Holocene and upper and middle? Pleistocene) – Mapped where nearly intact block is visible in landslide (mostly block slide) with stratal strikes and dips that are different from nearby in-place bedrock; unit involved in landslide shown in parentheses, for example Qms(Tw) and composition depends bedrock unit; rx shown where bedrock unit in block not known or multiple units are in the block, with Zrx shown where the units are Neoproterozoic; see surficial deposits or rock unit in parentheses for descriptions of blocks; thickness highly variable, up to about 20 to 30 feet (6-9 m) for small slides, and cross sections show larger blocks are about 150 feet (45 m) thick. Relative ages are like those for other landslide deposits (Qms, Qmso).

Qms and Qmso queried (Qms?, Qmso?) where bedrock block may be in place, that is stratal strikes and dips in queried block are about the same as nearby in-place bedrock.

Qml, Qml?

Lateral-spread deposits (Holocene and upper Pleistocene?) – Clay, silt, and fine-grained sand, with minor gravel deposited mostly offshore in Lake Bonneville (unit Qlf) and later emplaced by lateral spreading due to liquefaction during earthquake ground shaking; largely poorly drained, possibly due to shallow groundwater; contain minor younger alluvial and marsh deposits and possibly lacustrine deposits; "break-away" scarps located upslope and at least locally cut foreshore Lake Bonneville (Qlg, Qls, Qlsp) and deltaic (Qdp) deposits, incorporating these coarser materials into lateral-spread deposits; lobate toes of spreads typically higher than surrounding topography; contain hummocks, ridges, swales, and irregular depressions; unstratified to tilted strata to highly contorted bedding visible in excavations like brick plant pit (see for examples Miller, 1980; Hylland and Lowe, 1998; Harty and Lowe, 2003); thickness highly variable. Queried where may not be part of lateral spread.

Age uncertain as younger alluvial fans deposited on the lateral spreads appear to be related to the regression from the Provo shoreline of Lake Bonneville (see Personius, 1990) as well as appear to post-date Lake Bonneville (Nelson and Personius, 1993; see also Harty and Lowe (2003).

In the North Ogden quadrangle, unit Qml is visible on 1937 aerial photographs as lighter toned irregular polygonal blocks that are topographically higher than adjacent darker toned material. Several lateral spreads of different ages appear to be present in the quadrangle because different lobes are visible and some spread margins appear to impinge on older spreads.

Qm **Mass-movement deposits, undivided (Holocene and Pleistocene)** – Poorly sorted to unsorted clay- to boulder-sized material; includes landslides (slides, slumps, and flows), colluvium, talus, and alluvium that is mostly composed of debris-flow deposits; mapped where several mass-movement processes may contribute to deposits or where mapping separate, small, intermingled areas of different kinds of mass movements is not possible at map scale; the larger debris-flow component in Qm is difference between Qm and Qmc; composition depends on local sources; 0 to 40 feet (12 m) thick.

Qmc **Landslide and colluvial deposits, undivided (Holocene and Pleistocene)** – Poorly sorted to unsorted clay- to boulder-sized material; mapped where landslide deposits are difficult to distinguish from colluvium (slopewash and soil creep) and where mapping separate, small, intermingled areas of landslide and colluvial deposits is not possible at map scale; locally includes talus and debris flow and flood deposits; typically mapped where landslides are thin ("shallow"); also mapped where the blocky or rumpled morphology that is characteristic of landslides has been diminished ("smoothed") by slopewash and soil creep; composition depends on local sources; 6 to 40 feet (2-12 m) thick. These deposits are as unstable as other landslide units (Qms, Qmsy, Qmso).

Qmt **Talus (Holocene and Pleistocene)** – Unsorted clay- to boulder-sized angular debris (scree) at the base of and on steep mostly unvegetated slopes; only larger debris fields can be shown at map scale and includes smaller rock-fall deposits; locally includes pro-talus ramparts and minor colluvium; also includes rock-glacier deposits too small to show separately at map scale; grades laterally into Qct; 0 to 30 feet (0-9 m) thick.

Qmrf **Rock-fall deposits (Holocene and Pleistocene)** – Unsorted, angular pebble- to block to small house-sized carbonate-rock debris at north edge of Dairy Ridge quadrangle and in Mantua quadrangle (section 38, T. 8 N., R. 1 W.); cliff-face sources distinct; only largest debris fields can be shown at map scale; may be from one or multiple events; thickness uncertain.

Qct **Colluvium and talus, undivided (Holocene and Pleistocene)** – Unsorted clay- to boulder-sized angular debris (scree) at the base of and on steep, typically partly vegetated slopes; shown mostly on steep slopes of resistant bedrock units; 6 to 30 feet (2-9 m) thick.

Qc **Colluvium (Holocene and Pleistocene)** – Unsorted clay- to boulder-sized material; includes material moved by slopewash and soil creep; composition depends on local sources; as shown generally 10 to 20 feet (3-6 m) thick; not shown where less than 10 feet (3 m) thick.

Lacustrine deposits

Qlmf **Post-Lake Bonneville mud-flat deposits (Historical and Holocene?)** – Silt, clay, and some fine-grained sand deposited below the historical-highstand shoreline (h) (4213 feet [1284.5 m]) of Great Salt Lake in Kaysville quadrangle; may include Holocene deposits.

Qly, Qly?

Younger lacustrine deposits (Holocene) – Fine-grained material and locally marsh deposits in lakes outside the Great Salt Lake basin; includes deposits in sinks near Mantua and near Maples recreation area (Snow Basin quadrangle); queried where may be mostly marsh deposits; some material may not be younger than Lake Bonneville; likely less than 20 feet (6 m) thick.

Ql, Ql?

Lake Bonneville deposits, undivided (upper Pleistocene) – Silt, clay, sand, and cobbly gravel in variable proportions; mapped where grain size is mixed, deposits of different materials cannot be shown separately at map scale, or surface weathering obscures grain size and deposits are not exposed in scarps or construction cuts; thickness uncertain.

Qlf, Qlf?, Qlfb, Qlfb?

Fine-grained lacustrine deposits (Holocene and upper Pleistocene) – Mostly silt, clay, and fine-grained sand deposited near- and off-shore in Lake Bonneville; typically mapped as Qlf below the Provo shoreline (P) because older transgressive (Qlfb) deposits are indistinguishable from younger regressive deposits; mapped as Qlfb above the Provo shoreline because these deposits can only be related to the Bonneville shoreline (B) and transgression; grades upslope with more sand into Qls or Qlsp; typically eroded from shallow Norwood Formation in Ogden and Morgan Valleys and at least 12 feet (4 m) thick near Mountain Green. Qlf and Qlfb queried where grain size is uncertain.

In the Kaysville quadrangle, Qlf deposits that are below the Gilbert (G) shoreline are at least partly the same age as this shoreline (Holocene-latest Pleistocene) and post-date late Pleistocene Lake Bonneville. Qlf deposits below the Holocene (H) highstand shoreline are Holocene. Both ages of deposits are generally less than 15 feet (5 m) thick.

Deeper water fine-grained deposits overlie older shoreline and delta gravels (Qlf/Qdlb) at the mouths of several drainages along the Weber River. These gravels were deposited above the Provo shoreline during transgression of Lake Bonneville to the Bonneville shoreline (see unit Qdlb).

Qls, Qls?, Qlsp, Qlsb, Qlsb?

Lake Bonneville sand (upper Pleistocene) – Mostly sand with some silt and gravel deposited nearshore below and near the Provo shoreline (Qlsp) and between the Provo and Bonneville shorelines (Qlsb); Qls mapped downslope from slope break below Provo shoreline beach deposits where thin Lake Bonneville regressional sand may overlie transgressional sand; grades downslope into unit Qlf with decreasing sand content and laterally with more gravel into units Qdlp, Qdlb, and upslope with more gravel into unit Qlgb; Qls and Qlsb queried where grain size or unit identification uncertain; may be as much as 75 feet (25 m) thick, and thickest near Ogden; typically less than 20 feet (6 m) thick in Morgan Valley; may include small deltas and deltas that lack typical delta shape.

Qlg, Qlg?, Qlgp, Qlgb, Qlgb?

Lake Bonneville gravel and sand (upper Pleistocene) – Mostly interbedded pebble and cobble gravel and sand deposited along beaches and slightly offshore; varies from clast supported to only rare gravel clasts in a matrix of sand and silt; grades downslope and, locally, laterally into finer grained deposits (Qls, Qlsp, Qlsb); mapped as Qlg downslope from topographic slope break of Provo and regressive beaches (Qlgp) because gravel and sand may be related to Lake Bonneville transgression on this gentler slope; also mapped as Qlg where Provo shoreline not distinct or relationships to shorelines uncertain; Qlg and Qlgb queried where grain size or unit identification uncertain; up to about 100 feet (30 m) thick in gravel pits but less than 20 feet (6 m) thick on most valley slopes. Constructional landforms (beach ridges, bars, and spits) and transgressive (t) shorelines limited in Ogden map area.

Qlgp is mapped in beaches near and below the erosional bench at the Provo shoreline (P); gravel typically subrounded to rounded, but locally along bedrock mountain fronts marked by a carbonate-cemented, poorly sorted, angular pebble to boulder gravel in a sandy matrix.

Qlgb is mapped in beaches mostly just downslope from Bonneville shoreline (B), typically an eroded bench, and above Provo shoreline; deposited during transgression to and occupation of the Bonneville shoreline; clasts typically subrounded to rounded but contains subangular to angular clasts on steep bedrock mountain fronts; mountain front Bonneville shoreline benches covered by locally mappable (> 6 feet [2 m] thick) colluvium and talus (Qmt, Qc, Qct).

Deltaic deposits

Lake Bonneville deltaic deposits (upper Pleistocene) – Pebble and cobble gravel in a matrix of sand and minor silt; interbedded with thin sand beds; moderately to well sorted within beds; clast to matrix supported; deposited as foreset beds with original dips of 30 to 35 degrees; distinct foresets allow separation from mixed lacustrine deposits (Qdlp, Qdlb).

Qdp **Provo-shoreline and regressive deltaic deposits** – Present at mouth of North Ogden Canyon and north of the mouth of Ogden Canyon below the Provo shoreline; clasts typically subrounded to rounded; much of

Qdp material may have been redeposited from Bonneville-shoreline lacustrine and alluvial deposits during and soon after Bonneville flood; may be as much as 100 feet (30 m) thick at mouth of Ogden Canyon. These deltaic deposits are prone to slope failures.

Qdb **Transgressive and Bonneville-shoreline deltaic and lacustrine deposits** – Only mapped separately on slope between Qafb and Qlgb just below the Bonneville shoreline in Mantua Valley; subangular to subrounded clasts; thickness not known.

Mixed lacustrine deposits

Qdlp **Provo-shoreline and regressive deltaic and lacustrine deposits (upper Pleistocene)** - Mostly sand, silty sand, and gravelly sand deposited near shore in Lake Bonneville; extensive below Provo shoreline between Ogden and Weber Rivers, and south of Weber River on deposits related to Bonneville shoreline (Qldb); related to the Provo and slightly lower regressional shorelines; regressive (r) shorelines on the Qdlp deposits indicate lake reworking of deltaic deposits (Qdp or Qadp) and a mixed origin; may be as much as 100 feet (30 m) thick. Near Hill Air Force Base, eolian fine-grained sand and silt reworked from Qdlp is not mapped since it is only 3 to 6 feet (1-3 m) thick, and mostly removed and obscured by development. These deposits are prone to slope failures.

Qdlb, Qdlb?

Transgressive and Bonneville-shoreline deltaic and lacustrine deposits (upper Pleistocene) – Mostly sand, silty sand, and gravelly sand deposited near shore in Lake Bonneville; extensive at mouth of Weber Canyon; related to transgression to and occupation of the Bonneville shoreline with lacustrine deposits covering deltaic deposits; in Morgan Valley and near mouth of Coldwater Canyon (North Ogden quadrangle) contain more cobbles and overall more gravel; 0 to at least 40 feet (12 m) thick in Ogden and Morgan Valleys; about 400 feet (120 m) thick in bluff at the mouth of Weber Canyon. These deposits are prone to slope failures.

Qadp, Qadp?

Provo-shoreline and regressive alluvial and deltaic deposits (upper Pleistocene) – Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where shorelines are obscure, so that line cannot be drawn between alluvial fan and delta; mapped below/near the Provo shoreline and related to the Provo and slightly lower regressional shorelines; deposits prominent east of Brigham City, at mouth of North Ogden Canyon, and on bench north of the Weber River; deposited as delta foreset beds with original dips of 30 to 35 degrees that allow separation from mixed lacustrine deposits (Qdlp); deltaic deposits at least 40 feet (12 m) thick and contain subrounded to well-rounded pebble and cobble gravel in a matrix of sand and silt with interbeds of sand and silt; capped by gently dipping alluvial-fan and stream topset beds that are less than 16 feet (5 m) thick, are poorly to moderately sorted, silty to sandy, subangular to well-rounded pebble and cobble gravel, and contain subangular to angular clasts in a matrix of sand and silt with interbeds of sand and silt (see units lpd and alp of Personius, 1990).

East of Brigham City at the mouth of Box Elder Canyon these deposits have been extensively excavated for sand and gravel. King estimates these deposits are about 200 feet (60 m) thick (from topographic contours) south of the mouth of Box Elder Creek, while Smith and Jol (1992) implied they are 400 feet (120 m) thick to the west of the Ogden map area.

The Provo shoreline fan-delta sediments were eroded from Bonneville-shoreline lacustrine and alluvial deposits, contain 20 to 70 percent rounded recycled Lake Bonneville clasts (Personius, 1990), and were redeposited during and soon after the Bonneville flood, which occurred during the drop of Lake Bonneville to the Provo shoreline. The Qadp unit probably includes Provo-stillstand deltaic deposits, sub-Provo-stillstand (regressional) alluvial-fan and lacustrine-deltaic deposits that contain abundant reworked materials from the Provo-shoreline delta, and locally overlying alluvial-fan deposits. Personius (1990) noted that deposits at the mouth of Box Elder Canyon are a fan-delta. A fan-delta is built when an alluvial fan enters a lake or ocean, and includes both the fan and the delta.

Qadb, Qadb?

Transgressive and Bonneville-shoreline alluvial and deltaic deposits (upper Pleistocene) – Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where shorelines are obscure, so that line cannot be drawn between alluvial fan and delta; include rounded to subangular clasts in a matrix of sand and silt with interbeds of sand and silt; mapped above the Provo shoreline and deposited as lake transgressed to and was at the Bonneville shoreline; typically better sorted delta and lake deposits over poorly sorted alluvial-fan deposits; Qadb prominent along Deep Creek (Morgan quadrangle) and Strawberry Creek (Snow Basin quadrangle); 0 to at least 40 feet (0-12+ m) thick. Note that the Bonneville-shoreline fan-delta unit (Qadb), at 80 to 100 feet (24-30 m) above present drainages, is typically higher than the related alluvial units (Qab, Qafb) (see table 1). A fan-delta is built when an alluvial fan enters a lake or ocean, and includes both the fan and the delta.

Qla, Qla?

Lake Bonneville lacustrine deposits and post- and pre-Lake Bonneville alluvial deposits, undivided (Holocene and upper? Pleistocene) – Mostly poorly sorted and poorly bedded sand, silt, and clay, with some gravel; mapped where Lake Bonneville deposits are reworked by later stream action or covered by thin stream and fan deposits, and where lake deposits are thin and overlie older alluvial deposits; unit queried where may be dominantly alluvium; deposits typically eroded from shallow Norwood Formation; mostly mapped near Bonneville shoreline; also mapped in Peterson quadrangle along upper Deep Creek above Bonneville shoreline where lake deposits seem to indicate landslide dam of creek; thickness uncertain.

Qlamh **Lacustrine, marsh, and alluvial deposits, undivided (Historical)** – Sand, silt, and clay mapped where streams enter Pineview Reservoir, and reservoir levels fluctuate such that lacustrine, marsh, and alluvial deposits are intermixed; thickness uncertain.

Spring deposits

Qsm **Spring deposits (Holocene and upper Pleistocene?)** – Wet, fine-grained, organic-rich sediment associated with springs, ponds, seeps, and wetlands; mapped below Bonneville shoreline in Ogden Valley, below Provo shoreline in North Ogden quadrangle, and along shore of Holocene Great Salt Lake in Kaysville quadrangle; at least 5 feet (1.5 m) thick.

Qst **Spring travertine (Holocene and Pleistocene)** – Hard, vesicular to compact carbonate mapped downstream from Causey Spring (Causey Dam quadrangle); likely at least as old as Pleistocene; up to 60 feet (18 m) thick. Source of spring apparently is fault contact between the Little Flat and Monroe Canyon Formations.

Mixed deposits

Qac **Alluvium and colluvium (Holocene and Pleistocene)** – Unsorted to variably sorted gravel, sand, silt, and clay in variable proportions; includes stream and fan alluvium, colluvium, and, locally, mass-movement deposits too small to show at map scale; typically mapped along smaller drainages that lack flat bottoms; more extensive east of Henefer where Wasatch Formation (Tw) strata easily weather to debris that "chokes" drainages; 6 to 20 feet (2-6 m) thick.

Some deposits are "perched" on benches 80 feet (25 m) and more above present-day drainages like Left Fork Heiners Creek (Heiners Creek quadrangle) and Harris Canyon (Henefer quadrangle). In the Devils

Slide quadrangle, some deposits are "perched" on benches about 60 to 130 feet (18-40 m) above Quarry Cottonwood Canyon indicating the alluvium is at least partly Lake Bonneville age and older (see Qab and Qao in tables 1 and 2).

Qcg **Gravelly colluvial deposits (Holocene and Pleistocene)** – Gravelly materials present downslope from gravel-rich deposits of various ages (for example units Keh, Tw, Tcg, Thv, QTaf, QTa, Qafoe, Qaoe, Qafo, and Qa); may contain residual deposits; typically differentiated from colluvium and residual gravel (Qc, Qng) by prominent stripes trending downhill on aerial photographs; stripes are concentrations of gravel up to boulder size; generally 6 to 20 feet (2-6 m) thick.

Qmg, Qmg?

Mass-movement and glacial deposits, undivided (Holocene and Pleistocene) – Unsorted and unstratified clay, silt, sand, and gravel; mapped where glacial deposits lack typical moraine morphology, and appear to have failed or moved down slope; also mapped in upper Strawberry Bowl (Snow Basin quadrangle) where glacial deposits have lost their distinct morphology and the contacts between them and colluvium and talus in the cirques cannot be mapped; likely less than 30 feet (9 m) thick, but may be thicker in Mantua, James Peak, North Ogden, Huntsville, and Peterson quadrangles.

Uncertain

Qng **Colluvial and residual gravel deposits (Holocene and Pleistocene)** – Poorly sorted pebble to boulder gravel in a matrix of silt and sand; gravel of uncertain origin, but probably includes colluvium and residuum, and at least locally glacial deposits (for example near Powder Mountain) and alluvium; mostly gravel-armored deposits on and near alluvial and colluvial deposits like units Qcg, QTay?, QTao?, and QTaf; locally on gravel-rich bedrock (Thv, Tcg, Tw, and Keh) and Paleozoic quartzite (Cgcu and Ct); typically have gently dipping upper surface; present on Durst Mountain, near high-level fans (QTaf) near head of Strawberry Creek (Snow Basin quadrangle), in northeast corner of Peterson quadrangle, and on benches above streams in east part of Peterson quadrangle; generally 6 to 20 feet (2-6 m) thick.

Human disturbances

Qh, Qh? **Human disturbances (Historical)** - Mapped disturbances obscure original deposits or rocks by cover or removal; only larger disturbances that pre-date the 1984 aerial photographs used to map the Ogden 30 x 60-minute quadrangle are shown; includes engineered fill, particularly along Interstate Highways 80 and 84, the Union Pacific Railroad, and larger dams, as well as aggregate operations, gravel pits, sewage-treatment facilities, cement plant quarries and operations, brick plant and clay pit, Defense Depot Ogden (Browning U.S. Army Reserve Center), gas and oil field operations (for example drill pads) including gas plants, and low dams along several creeks, including a breached dam on Yellow Creek.

QUATERNARY AND TERTIARY

The change in the Quaternary-Tertiary boundary favored by Europeans from about 1.8 Ma, roughly the top of the Olduvai normal paleomagnetism, to about 2.6 Ma, roughly the top of the normal paleomagnetism marking the top of the Gauss chron (Gibbard and Cohen, 2008), does not affect mapping and labeling of the following unconsolidated units because we do not have any paleomagnetic data. However, carving nearly a million years out of the episodically shrinking Pliocene means rocks we have listed as Pliocene, like the fanglomerate of Huntsville (Thv) and various Salt Lake Formation units (Tslc, Tsl, Tsnf), may be Quaternary even though they are consolidated (rock). We have chosen to keep rocks (consolidated and/or lithified) as Tertiary and unconsolidated deposits as Quaternary and Quaternary/Tertiary to emphasize their erosional and geotechnical differences.

QTa, QTa?, QTay?, QTao, QTao?

High-level alluvium (lower Pleistocene and/or Pliocene) – Gravel, sand, silt, and clay above other stream-terrace and alluvial-fan deposits; typically more bouldery than lower alluvium (including units Qafoe and Qaoe); at least locally gravel-armored and poorly sorted; where possible, divided into younger (y) and older (o) based on height of deposits above drainages (see table 1) and elevation difference of more than 150 feet (45 m) on adjacent deposits; but heights above drainages overlap and appear to decrease up slope; this height of QTa deposits apparently fits near late Pleistocene Lake Bonneville in the western part of the map area, as well as in the eastern part of the map area; estimate 10 to 80 feet (3-24 m) thick in Morgan Valley, at least 240 feet (75 m) thick in high bluffs next to Henefer Valley (QTay? ~200 feet [60 m] thick to south where bluffs could be Qaoe), and 240 feet (75 m) thick along Yellow Creek, Lost Creek, and Box Elder Creek.

Various QTa units are queried where relative age is uncertain due to overlap and wide range in heights above drainages (see tables 1 and 2). For example, alluvium above Main Canyon Creek is at the height boundary of Qaoe and QTa, but the height above the Weber River would make the deposits QTay, so this alluvium is labeled QTay?. Also, on east side of Morgan Valley, QTao queried (QTao?) where QTay? mapped downslope may be part of the same alluvial surface. The unit QTay? may be faulted north of Stoddard or may be terraces of several ages (units).

QTa along Box Elder Creek is about 240 to 300 feet (75-90 m) above the present creek and upper surface altitudes (5800 to 6000 feet [1770-1830 m]) are about those of McKenzie Flat surface (mapped as Qafoe-QTaf).

Near Henefer, above the Weber River terraces in the graben east of the East Canyon fault and west of Main Canyon, these deposits appear to be alluvial fans with gravel-armored surfaces, but may include terrace deposits related to the Weber River; at least locally poorly sorted (Eardley, 1944, p. 874).

Deposits in Eden Pass (North Ogden divide) are at elevations of up to about 6400 feet (1950 m) and were noted by Eardley (1944, p. 886), who suggested they were probably related to the Weber Valley surface.

High-level alluvium is likely 780 ka or older based on paleomagnetic reversal in Qaoe (see table 1) and location above Qaoe. The age(s) of these deposits and unit QTaf may be refined if a Lava Creek B, Bishop, Mesa Falls, and/or Huckleberry Ridge ash were found in them (see table 3).

QTaf, QTaf?

High-level alluvial-fan deposits (lower Pleistocene and/or Pliocene) – Gravel, sand, silt, and clay above other stream-terrace and alluvial-fan deposits (including QTao); typically more bouldery than alluvium lower than QTay (including units Qafoe and Qaoe); at least locally gravel-armored and poorly sorted (see for example Eardley, 1944, p. 874); forms slightly dissected fan south of Weber River, and fan-head remnants north of the Weber River near head of Strawberry Creek and on northwest flank of Durst Mountain; queried where may be unit QTa; estimate 30 to 200 feet (9-60 m) thick.

Upper surfaces of these high-level alluvial fans, with some high-level alluvium (QTa) in Morgan Valley, appear to be the Weber Valley surface of Eardley (1944), though our high-level alluvial fans (QTaf) extend to the mountain front at elevations of about 6800 to 7200 feet (2070-2195 m), rather than to the mountain ridgelines as suggested by Eardley (1944). Thin remnants of high-level alluvial deposits (QTao, QTaf) (boulder lags with unmappable extents) are present on some ridges in the Snow Basin and Peterson quadrangles.

Since open-filing of the Snow Basin quadrangle report (King and others, 2008), the stacked deposits (Qgo/Tw, Qgo/Tn/Tw) in the Maples area have been reinterpreted as alluvial-fan deposits, most likely unit QTaf.

In table 1, QTaf is shown as two varieties (ages?) of fans because several eroded fans are lower (above adjacent drainages and down slope) and may be the upstream equivalents of unit QTay. The best example of lower and upper varieties is south of Line Creek in the Peterson quadrangle.

In Main Canyon (East Canyon graben), the high-level fans are red gravel, sand, silt, and clay eroded from red conglomeratic Wasatch Formation (Tw) and Weber Canyon Conglomerate (Kwc), as well as sandy Preuss Redbeds (Jp, Jsp?). These red bedrock units, at least locally, shallowly underlie the red fans, making fan contacts difficult to map, and deposits are queried where their identification as a fan is uncertain. These QTaf fans are overlain downslope by units Qafo and Qafoe and upslope locally include thin, small, younger (likely Holocene) alluvial fans (Qafy) that cannot be shown at map scale. These Main Canyon QTaf fans are about 240 feet (75 m) thick. The surface on QTaf? and QTa? in Main Canyon is not the Weber Valley surface of Eardley (1944, see in particular his plate 7), despite these units being part of his surface in Morgan Valley. Our unit QTaf? was mapped as Wasatch Formation, with a down-to-the-east normal fault, to the south by Bryant (1990); farther south Bryant (1990) showed Qoa (dissected alluvium) adjacent to the fault, which may be our QTaf or Qafoe unit.

QTms(ZYp)

Quaternary and/or Tertiary mega-landslide (Pleistocene and/or Pliocene) – Jumbled mass of formation of Perry Canyon (ZYp) with blocks of rock from North Ogden divide klippe out of stratigraphic position and "floating" in muddy Perry Canyon; mostly mapped as ZYpm and ZYpg by Crittenden and Sorensen (1985b); inconsistent and divergent attitudes shown by Crittenden and Sorensen (1985b) also support mass movement; north margin of landslide uncertain due to overturned dips in adjacent ZYpm outcrop; mass seems to have slid down Willard thrust plane; estimate up to about 700 feet (210 m) thick. Younger landslides, including Qms(QTms) and Qms?(QTms) are mapped on this mass, indicating continued instability.

QTcg, QTcg?

Gravelly colluvial deposits (Pleistocene and/or Pliocene) – Unconsolidated, poorly sorted pebble to cobble to boulder clasts in light-colored gravelly silt and sand matrix that weathers to an indistinct soil; mapped on east side of Ogden Valley; no tuff noticed in soil but thin Norwood Formation may be present in subsurface; rounded quartzite and Paleozoic carbonate clasts are like those upslope in the gravel-rich Wasatch Formation, but matrix not reddish like material typically derived from Wasatch Formation; angular clasts appear to be from underlying Geertsen Canyon Quartzite; unlike younger colluvial gravels (Qcg), stone stripes, which trend downhill, are not present or visible on aerial photographs; generally 6 to 20 feet (2-6 m) thick, but may be as much as 80 feet (25 m) thick. Some QTcg deposits previously shown as Pliocene(?) (Huntsville) fanglomerate (see Lofgren, 1955, in particular figure 19). QTcg queried where material may be units QTng or QTaf.

QTng, QTng?

Quaternary and/or Tertiary gravel-armored deposits (Pleistocene and/or Pliocene) – Unconsolidated, poorly sorted pebble to boulder gravel in silt and sand matrix; caps Fowkes Formation near Porcupine Ridge (Porcupine Ridge quadrangle); dips about 3 degrees into Yellow Creek(?) fault zone, less steeply than underlying strata; much higher above active drainages than other QT deposits and may be Pliocene and/or Miocene in age like the Huntsville fanglomerate (Thv); possibly 80 feet (25 m) thick. Bryant (1990, his Toc) noted volcanic rock clasts that we think are from his QTg unit rather than weathering out of a Tertiary rock unit.

STACKED UNITS

Numerous stacked units are on this map. This is partly a result of the compromise between showing surficial deposits and bedrock on the same map. By stacked, we mean a thin covering of one unit over another, which is shown by the upper map unit (listed first) then a slash and then the underlying unit (for example Qa/Tfb). The upper unit is typically a surficial deposit with the lower unit being rock (Q_/rx), but exceptions are present. We map the stacked units where it is important to show both units as they have potential geologic hazards and/or economic value (for example landslides or landslide-prone clayey bedrock units, and phosphate or sand and gravel). The upper unit is typically at least 6 to 10 feet (2-3 m) thick and conceals but does not obscure the lower unit. These thicknesses were chosen because a building foundation would penetrate a thinner upper unit, particularly colluvium (Qc), making it a small factor in construction. We have not mapped most of the colluvium as it is thinner than 6 to 10 feet (2-3 m) and we can tell what is underneath. We have simplified this map from more detailed geologic mapping (see index to geologic mapping, figure 1) to show bedrock by removing most of the surficial deposits that are less than these thicknesses. The exceptions to this simplification are where the thin deposits obscure the geologic details of faulting, lithologies, and age relationships. The underlying unit in the stack has been identified based on exposures at the edges of the stacked unit and exposure windows (gaps) in the cover, and materials in the cover that came from the underlying unit. The gaps can not be shown separately at our map scale (1:62,500), while on more detailed maps of the quadrangle (1:24,000 scale), the stacked units may be shown as separate areas.

Qh/Qml, Qh/Qml?, Qh?/Qml, Qaf1/Qml, Qafy/Qml, Qafy?/Qml, Qms/Qml, Ql/Qmc, Ql/Qms, Qapb/Qmso, Ql/Qmso, Qlf/Qmso, Qlfb/Qmso, Qlsb/Qmso, Qlsb/Qmso?, Qlgb/Qmso, Qcg/Qmso

Surficial deposits over mass-movement deposits – These units were mapped because they inform the map user about underlying potential geologic hazards.

Qmc/Qatp, Qmc/Qlg, Qmc/Tn, Qmc/Tsnf?

Mass-movement deposits over surficial deposits and bedrock – These units were mapped because they inform the map user about overlying potential geologic hazards.

Qaf/Tsnf, Qafp?/Tsnf, Qafo?/Tsnf, Qcg/Tsnf, Qcg/Tsnf?, Qac/Tsnf, Qc/Trx, Qac/Trx, Qafpb/Trx?, Qac/Tsl, Qaf/Tsl, Qaf/Tsl?, Qafo/Tsl, Ql/Tcg, Qng/Ts, Qat3/Ts, Qaf3?/Ts, Qaf4?/Ts, Qaf5/Ts, QTaf/Ts, Ql/Tn,Ql/Tn?, Qlf/Tn, Qls?/Tn, Qlsb/Tn, Qlsb/Tn?, Qac/Tn, Qaf/Tn?, QTaf/Tn, Qaf/Tnf, Qa4/Tf, Qa4-5/Tf, Qat6?/Tf, Qng/Tfb, Qa/Tfb, Qa3/Tfb, Qa3?/Tfb, Qaf3?/Tfb, Qa4/Tfb, Qa4?/Tfb, Qaf4/Tfb, Qa5/Tfb, Qaf5/Tfb, Qng/Tw, Qng/Tw?, Qg/Tw?, QTaf/Tw, QTao/Tw, Qc/Keh?, Qc/Jsp?, QTaf?/Jsp?, Qdlb/Zarx, Ql/Zarx, Ql/Zmcg?, Qgo?/ZYpm

Surficial deposits over bedrock – The units were mapped because they inform the map user about potential geologic hazards due to the underlying landslide-prone clayey bedrock.

Qc/Kwc?, Qc/Csn?, Qng/Cgcu, Qafoe?/rx, Qg?/Mh, Qgo?/rx

Colluvial, uncertain, and queried surficial deposits over bedrock – These units were mapped because they show where we are uncertain about which underlying unit is present (underlying unit queried or rx), and where the origin of the overlying unit is uncertain.

Thv/Ct, Thv/Xfc, Tsl/Tnf, Tslc/Mlf, Tn/Tw, Tw?/Jsp?, Twa?/Cgc, Keh?/Pp

Bedrock over bedrock – Thin, typically easily weathered bedrock over other bedrock, which means the overlying “bedrock” may actually be surficial deposits; also units Thv, Tsl, Tslc, Tn, Tnf, Tw, Twa, Keh, and Jsp are landslide prone.

Qaf1/Qlmf, Qa2/Qafp?, Qafy/Qap, Qafy/Qap?, Qafy/Qlsb, Qafy/Qdlb, Qaty/Qlsb, Qay/Qlsb, Qay/Qdlb, Qac/Qafp?, Qatp/Qlsb, Qafp/Qlsb, Qafp/Qadb, Qafp/Qdlb, Qap/Qlsb, Qap?/Qlsb, Qap/Qdlb, Qap/Qdlb?, Qap?/Qdlb, Qlf/Qdb, Qlf/Qdlb, Qlsp/Qdlb, Qlsb/Qac, Qlsb/Qafo?, Qafm/Qafo?, Qafo?/Qafoe?

Surficial deposits over surficial deposits – These units were mapped because they inform the map user about stratigraphic age-relation details seen in the field that went into the “Surficial Deposit” correlation charts.

Qh/Qac, Qh/Qlg, Qh/Qlg?

Human disturbances over surficial deposits – These units were mapped because they inform the map user that the area is disturbed and materials at the surface may not reflect the deposits encountered in a foundation excavation.

WILLARD THRUST SHEET COVER ROCKS

Strata that are younger than and overlie the Willard thrust sheet

TERTIARY

Tu, Tu? **Tertiary Formations, undivided** – Poorly exposed calcareous conglomerate, calcareous sandstone, siltstone, claystone, and oncolitic limestone in uncertain proportions; at least locally tuffaceous; unit has characteristics of Salt Lake, Norwood-Fowkes, and Wasatch Formations (see each unit for descriptions, in particular unit Twl); mapped east of Cache Valley in Pole Creek graben, east of McKenzie Mountain, because oncolitic (stromatolitic in older reports) limestone on west side of Cache Valley is in Norwood-Fowkes equivalent strata or the Wasatch(?) Formation (see Smith, 1997; Oaks and others, 1999) (see also descriptions of Tnf and Twa?), and Rauzi (1979) mapped these Pole Creek rocks as Salt Lake Formation; about 500 feet (150 m) thick (Rauzi, 1979). Unit queried where may be Paleozoic bedrock.

Rauzi (1979) stated the Pole Creek rocks were tuffaceous, yet described them as dominantly calcareous conglomerate, with rounded to subangular, mixed clast lithology (chert, dolomite and quartzite), and typically pebble-sized, but locally cobble-sized clasts. Like Mullens and Izett (1964), Rauzi (1979) noted float of white limestone chips and stromatolitic (oncolitic) limestone cobbles; these cobbles are cored by conglomerate clasts. See also Berry (1989) unit mapped as Tw? north of Pole Creek valley in the Porcupine Reservoir quadrangle.

Locally the upper part of the Pole Creek graben fill is regularly bedded and conglomeratic like unit Tcy near Durst Mountain (see Coogan and King, 2006) and locally a basal contact can be mapped. If this interpretation is correct the upper Pole Creek graben fill is likely Salt Lake Formation and the underlying strata are Norwood-Fowkes equivalent rocks (unit Tnf).

Trx, Trx?

Tertiary rocks, undivided – Red-weathering, non-conglomeratic rocks that dip about 16 degrees (between typical Tsnf and Tw dips); located in saddles between Sink Hole valley and Devils Gate Valley near Salt Lake Formation strata overlying Norwood and Fowkes Formation strata (Tsl/Tnf); though red like Wasatch Formation (Tw) and nearby rocks are mapped as Twa?, the red may be material eroded from the Wasatch Formation that was incorporated into Tsnf and/or be terra rossa since several sink holes are nearby and one saddle has off-white patches (tuffaceous?); queried, shown as Trx?, where may be terra rossa.

Thv? **Fanglomerate of Huntsville area(?) (Pliocene and/or Miocene)** – Brown to reddish-brown weathering sand, silt, and gravel (pebbles to boulders) on flat area near 7313-foot [2230 m] elevation hill on eastern margin of Mantua quadrangle; queried due to uncertain origin; located on Rendezvous Peak erosion surface of Williams (1948), so uncertain age (compare Williams, 1948 to 1958); similar patches on topographic highs to north and south are mapped as Salt Lake Formation conglomerate (Tslc); reddish color may be from erosion of Wasatch Formation and/or terra rossa development on underlying karstic carbonate rocks; may be post- or late-Salt Lake Formation age, like Thv on Durst Mountain.

Tslc, Tslc?

Salt Lake Formation conglomerate (Pliocene and Miocene) – Non-red-matrix conglomeratic tuffaceous strata, with Cambrian and Neoproterozoic quartzite clasts, likely from the Geertsen Canyon, Mutual, and Caddy Canyon Formations, and off-white to pinkish-gray to brownish-gray matrix; variably bedded and bouldery; weathers to colluvial deposits that inflate apparent outcrop size and dip; along Box Elder-Cache County line east of Devils Gate Valley and on hill southeast of Clay Valley (near 5492 UTM tick), Tslc bouldery, overlies tuffaceous strata (Tsl/Tnf), and dips <10 degrees, which supports it being upper part of Salt Lake Formation; elsewhere unit Tslc directly overlies Paleozoic rocks without any underlying tuffaceous strata and the only age indication is bedding dips of <10 degrees and non-red coloration; up to about 200 feet (60 m) thick between Clay Valley and Sink Hole valley, and along Box Elder-Cache County line.

Our Salt Lake Formation conglomerate should contain clasts that are not quartzites (see units Tnf and Twa?), and as presently mapped may include rocks as old as the Fowkes Formation and deposits as young as Pleistocene. For example, Tslc is red locally at its base and in thin skiffs on Paleozoic rocks such that this red material may be pre-Salt Lake Formation terra rossa. Brown coloration, in particular on Rendezvous Peak, and flat dips, at least locally, may indicate post- or late-Salt Lake Formation age (hence queried Tslc on map), like the revised Huntsville conglomerate on Durst Mountain (see Thv description).

Ezell's (1953) Tertiary boulder unit is similar to the Huntsville fanglomerate (see Coogan and King, 2006), in that what he mapped (his Tb) is actually several Quaternary deposits, including colluvium and residuum, Pliocene(?) to Eocene ash-bearing rocks, and the Wasatch Formation. If described correctly by Ezell (1953, part of his Tb unit) clasts in Tslc were recycled from eroded Wasatch Formation rocks. His picture (plate 3) of fractured clasts on Rendezvous Peak are strikingly like typical fractured Wasatch Formation clasts. Rendezvous Peak is not on the James Peak or Mantua topographic maps; it is the 7360-foot [2245 m] knob just to the west in the Mantua quadrangle (see map in Ezell, 1953), and is not Alex Beard Mountain (Hill) as stated by Williams (1958).

Ezell (1953) noted that his boulder deposits were on the Rendezvous Peak erosional surface of Williams (1948, p. 1160). On McKenzie Mountain, east of Cache Valley, similar variably fractured cobbly and bouldery deposits were noted by Mullens and Izett (1964) and Rauzi (1979, p. 41-44), but they did not describe any reddish or tuffaceous matrix or reddish patina on the boulders. Rauzi (1979) considered the boulders to be Tertiary remnants, likely because they look like clasts in the Wasatch Formation. Mullens and Izett (1964) stated their high-level boulders were probably deposited on the Rendezvous Peak erosion surface, which they and Williams (1948) reported as preserved along the hills south and west of the Paradise quadrangle.

We see little evidence of a widespread Rendezvous Peak erosion surface because planar surfaces, scattered deposits, and rocks of several origins are only locally present on the east and west sides of southern Cache Valley. The visible sites are on McKenzie Mountain, the James Peak-Sharp Mountain quadrangle boundary, and the Mantua-James Peak quadrangle boundary ridge. East of Cache Valley, an eroded brownish colored, nearly flat, west-dipping surface on the James Peak-Sharp Mountain quadrangle boundary is on Tertiary tuffaceous deposits at elevations of 6600 to 6800 feet (2010-2070 m), where the remnants are mapped as queried QTa, but may be unit Thv or Tslc. West of Cache Valley, we see what could be remnants along a ridge on the Mantua-James Peak quadrangle boundary, north and south of Rendezvous Peak; Coogan mapped Salt Lake Formation conglomerate (Tslc) along this ridge at elevations of about 6500 to 7360 feet (1980-2245 m), though patches with local flat dips and brown coloration are mapped as Thv?, like the revised Huntsville conglomerate on Durst Mountain (see Thv description).

Near Rendezvous Peak, Ezell's (1953) unit Tb looks like colluvium and lag on hills at elevations of about 6500 to 7360 feet (1980-2245 m) and appears 40 to 60 feet (12-18 m) thick near Rendezvous Peak. South of Rendezvous Peak on the Box Elder-Cache County line, the Tb Ezell (1953) mapped appears to be gently east-dipping boulder-bearing strata (our Tslc) overlain by nearly flat-lying boulder deposits (thin unmapped residual deposits) with a surface that dips from about 7500 to 7100 feet (2300 to 2165 m) to the south into Ogden Valley, not into Cache Valley like Ezell (1953) stated.

Ezell (1953) stated the Rendezvous Peak surface slopes into Cache Valley, this would be a North-Northeast slope, and remnant(s) are from 6000 to 7500 feet (1800-2300 m) in elevation. Following Williams (1948, p. 1160), Ezell (1953) stated that the Rendezvous Peak surface formed and was deeply dissected before the Miocene Salt Lake Formation was deposited, and shortly after Cache Valley began to form. But Cache Valley may have started to form during Eocene relaxation, since strata of this age (unit Tnf, ~44 and 49 Ma) are present in southern Cache Valley, and pre-date both Basin and Range faulting and Salt Lake Formation strata. Note that Basin and Range faulting in Cache Valley began about 18 Ma (see data in Long and others, 2006), so predates the Salt Lake Formation in southern Cache Valley (10.5 Ma to 4.4 or 5.1 Ma, see data in Oaks and others, 1999); and Coogan's mapping of Tslc would place the erosional planing of the surface prior to deposition of the conglomerate in the upper part of the Salt Lake Formation. Therefore, Williams' (1948) early supposition is feasible. Williams (1958) later expressed doubts about this pre-Salt Lake Formation age and considered it to be post-Salt Lake Formation. If post-Salt Lake Formation in age, the surface and boulder deposits would be younger than 4.4 to 5.1 Ma (Oaks and others, 1999) and older than middle (McCalpin, 1989; see also Sullivan and Nelson, 1992) and/or early Pleistocene (after Sullivan and others, 1988), the age of the McKenzie Flat surface. This would be a QT unit in UGS terminology, though it may be Thv.

Tsl, Tsl?

Salt Lake Formation (Pliocene and Miocene) – Grayish-white tuff, tuffaceous siltstone and sandstone, altered tuff/claystone, and conglomerate, with local limestone; poor exposures, lack of persistent beds, and probable structural complications prohibit measuring the thickness and recognizing less-resistant lithologies (like altered tuff/claystone and tuffaceous sandstone); about 450 feet (140 m) exposed in James Peak quadrangle east of Davenport Creek (from topography, bedding dip and contacts). The Salt Lake Formation is prone to slope failures.

North of the Ogden map area in the southern Cache Valley, the Salt Lake Formation is Pliocene in age based on fossil data (see Brown, 1949; Adamson and others, 1955; and for summary McClellen, 1977), and Pliocene and Miocene based on chemical correlations with isotopically dated tuffs (4.4-10.5 Ma; see Smith, 1997; Oaks and others, 1999). On our map, unit Tsl may include some Oligocene-Eocene Norwood Formation strata. Tsl queried where it may be older tuffaceous rocks of the Norwood-Fowkes Formation (Tnf).

Numerous authors have attempted subdivisions of the Salt Lake Formation/Group in Cache Valley (for synopsis see Oaks and others, 1999, table 3; see also Smith, 1997). Only crude Tertiary units (Tsl, Tslc, Tu, Tsnf, Tnf) are shown on our map because correlations based on lithology are ill-advised, marker beds are scarce and poor exposures make them difficult to trace, and because Salt Lake Formation conglomerate beds have multiple local sources, limited extents, and were generated during sporadic tectonic activity on multiple faults and/or fault segments.

North of the Ogden map area in Cache Valley, Williams (1962) described his upper conglomerate and sandstone unit of the Salt Lake Formation (entire Salt Lake Formation on our map) as predominantly conglomerate, with generally rounded pebbles and cobbles in a matrix of calcium carbonate and tuffaceous sand, and lesser interbedded tuffaceous sandstone, tuffaceous marl and compact limestone bearing ostracods, imprints of grass roots, and many impressions of a small clam. Williams (1962) described this unit west of the Little Bear River as 1000 to 2000 feet (300-600 m) of interbedded pebble conglomerate and tuffaceous sandstone, and noted remains of fish, terrestrial plants, and insects. Williams' (1962) lower tuff unit of his Salt Lake Formation is likely our Norwood-Fowkes equivalent strata (see Tnf below).

Williams (1962) reported a conspicuous basal conglomerate in his upper unit (basal Salt Lake Formation of this report) west of the Little Bear River. He described this conglomerate as containing cobbles of purple, brown, and buff Precambrian (and Cambrian) quartzite, Carboniferous (Pennsylvanian and Mississippian) strata, and cobbles of stromatolitic (oncolitic) and compact limestone from the underlying tuff unit (our

Norwood-Fowkes strata, Tnf). Adamson (1955, p. 25 and 51) had previously noted pebbles of stromatolitic limestone (oncolitic, see Adamson, 1955, figure 11), calcareous and tuffaceous rocks, and finely crystalline limestone in his units 5 (pebble conglomerate) and 8 (varied lithology) in his measured section 3 (near measured section 4 of Smith, 1997, and Oaks and others, 1999); but he did not note an angular unconformity. Because Williams' (1962) conspicuous conglomerate unconformably overlies his tuff unit, contains clasts from strata in his tuff unit, and contains quartzite clasts that he did not note elsewhere in his upper unit, this conspicuous conglomerate supports the interpretation that his entire tuff unit is our Norwood-Fowkes equivalent strata (Tnf). King thinks Smith's (1997) conglomerate, labeled lithosome-f, and Williams' (1962) conspicuous conglomerate are equivalent and are the basal unit of the Salt Lake Formation.

Also to the north of the Ogden map area, Mullens and Izett (1964) described Salt Lake Formation exposures east of the Little Bear River as mainly conglomerate that contained a large proportion of rocks (did they mean clasts?) derived from formations older than those exposed nearby in the Paradise quadrangle. Yet, Williams (1962) described the pebbles and cobbles from the same area as chert, sandstone, calcareous sandstone, and limestone mostly from Carboniferous formations that are exposed nearby. The implication is clasts are Cambrian and Neoproterozoic quartzite (older than strata nearby), like the boulder deposits on McKenzie Flat, and Mississippian and Pennsylvanian rocks from just east of the East Cache fault zone. Coogan and King (2006) described similar differences in Tertiary conglomeratic strata in another depositional basin to the south near Durst Mountain, Utah; there the non-quartzite clasts, dominant in older conglomerate beds, were from local Paleozoic strata and the quartzite clasts, dominant in younger conglomerate beds, were recycled from erosion of the Wasatch Formation (Coogan and King, 2006).

Tsnf, Tsnf?

Salt Lake, Norwood, and Fowkes Formations, undivided (Pliocene-Eocene?) – Pale-gray to greenish, altered tuff (claystone), altered tuffaceous siltstone and sandstone; tuff extensively altered to zeolites and bentonite (smectite and mixed layer clays); extensive alteration implies these strata are Norwood-Fowkes Formation (Tnf) or atypical altered Salt Lake Formation (Tsl) deposited in a lake or closed basin; mostly mapped in Devils Gate Valley, a closed basin with extensive colluvial cover and limited small outcrops (mapped as Qadl and Tn by Crittenden and Sorensen, 1985a), and with topographic relief great enough that pre-Salt Lake strata may be exposed in drainages; poorly exposed, with best exposures in landslide scarps; black soil and dark-gray alluvium described by Crittenden and Sorensen (1985a) likely a result of loess cover; locally bedded, with near-horizontal to about 5 degree dips (like Salt Lake Formation); exposed thickness up to about 160 feet (50 m); Oaks and others (1999, figure 7) showed about 3000 feet (900 m) of Tsnf west of the Little Bear River in Cache Valley in their measured section (5a, 5b) nearest the Ogden map area. These undivided strata lap onto considerable paleotopography of the underlying queried Wasatch Formation (Twa?), and have a somewhat consistent fill line (or shoreline?) at an elevation of about 6500 feet (1980 m) in Devils Gate Valley. Unit Tsnf is only queried where it is in a stacked unit, because it might be unit Twa?. This combined unit (Tsnf) is prone to slope failures.

We also mapped unit Tsnf rather than thin Tsl over Tnf (symbolized as Tsl/Tnf) where no bedding dips were found, stratal dips are intermediate between the shallower dips in Tsl and the steeper dips in Tnf, and between less gently dipping Tsl and Tnf strata on both sides of the southern Cache Valley where the angular unconformity between these units is not mappable and Tsnf strata may be in either unit.

We mapped unit Tsl/Tnf where the contact between Pliocene and late Miocene Salt Lake Formation (Tsl) and underlying Oligocene and Eocene Norwood Formation should be present but is not visible, despite an age gap of 20 to 40 million years and an angular unconformity; the Norwood contact with underlying Eocene Fowkes Formation equivalent strata is also not visible. North of the Ogden map area in the Mount Pisgah quadrangle, Salt Lake Formation rocks appear to lap onto (unconformably overlie) Paleozoic rocks, and may conceal (onlap) both the Norwood-Fowkes strata and redbeds tentatively correlated with the

Wasatch Formation. The Norwood-Fowkes strata also appear to lap onto (overlie with angular unconformity) Paleozoic rocks and conceal the Wasatch Formation. Oaks and others (1999) reported that the Norwood-Fowkes contact with the underlying Wasatch Formation is an angular unconformity and is sharp, but we do not see a change in dip at their contact and their limy marker horizon is discontinuous. Our Tnf-Tw contact is at the top of the redbeds and is at a change in bedding dip; our contact is lower in the Tertiary section than theirs.

Tn, Tn? **Norwood Formation (lower Oligocene and upper Eocene)** – Typically light-gray to light-brown altered tuff (claystone), altered tuffaceous siltstone and sandstone, and conglomerate; unaltered tuff, present in type section south of Morgan, is rare; locally colored light shades of red and green; variable calcareous cement and zeolitization; involved in numerous landslides of various sizes; estimate 2000-foot (600 m) thick in exposures on west side of Ogden Valley (based on bedding dip, outcrop width, and topography). Norwood Formation queried where poor exposures may actually be surficial deposits. For detailed Norwood Formation information see description under heading "Sub-Willard Thrust - Ogden Canyon Area" since most of this unit is in and near Morgan Valley and covers the Willard thrust, Ogden Canyon, and Durst Mountain areas.

Tnf, Tnf?

Norwood and Fowkes Formation equivalent strata, undivided (Oligocene? and Eocene) – Light-colored, altered tuffaceous fine-grained rocks (claystone and mudstone) with at least local conglomerate, limestone, and sandstone as exposed in southern Cache Valley; extensive altered tuff (claystone), tuff, and tuffaceous sandstone higher in section may or may not be in these equivalent strata (see Tsl notes above); estimate 600 to 1250 feet (180-380 m) thick or may be less than 600 feet (180 m) thick adjacent to Ogden map area, since contact with underlying Wasatch Formation and overlying Salt Lake Formation uncertain; about 500 feet (150 m) exposed below angular unconformity in James Peak quadrangle east of Davenport Creek (from topography, bedding dip and contacts). When the angular unconformity between Tsl and Tnf is not visible the strata have been mapped as Salt Lake Formation over Norwood and Fowkes equivalent strata (Tsl/Tnf). Unit Tnf queried where it may be tuffaceous Salt Lake Formation (Tsl). This combined unit (Tnf) is prone to slope failures.

North of the Ogden map area, Williams (1962) showed his tuff unit (Fowkes-Norwood strata of this report) as an irregular band next to Paleozoic rocks on the west side of Cache Valley, and described these strata as 1200 feet (360 m) of earthy gray tuff (actually altered, so claystone or mudstone), with two distinctive limestone beds near the base and a minor amount of pebble conglomerate. He described the upper limestone as stromatolitic (oncolitic, see Adamson, 1955, figure 11). Smith (1997) placed these limestones in her Norwood-Fowkes strata (Tfnx), while Oaks and others (1999) placed them in their Wasatch Formation (Twx) based on oncolites that are similar to those in the Wasatch Formation to the east in the Bear River Range (Oaks and Runnells, 1992). In the Pole Creek valley, east of Cache Valley, we mapped similar oncolitic limestones as undivided Tertiary rocks (Tu, see above).

K-Ar isotopic ages from samples taken near the base of the Norwood-Fowkes strata along Baxter Ridge to the north in the Mount Pisgah quadrangle are 44.2 ± 1.7 and 48.6 ± 1.3 Ma on hornblende and biotite, respectively (Smith 1997). Hornblende typically "sets" earlier than biotite, so the age inversion here implies reworking of the tuff prior to deposition (two separate air-fall events) or K-Ar disequilibrium (alteration of one of the minerals; biotite typically alters more easily than hornblende). These ages are older than the Norwood and younger Fowkes ages in Utah (38-40 Ma) (see also Tn under heading "Sub Willard Thrust - Ogden Canyon Area"), and are more like the older Fowkes Formation ages in Wyoming (48-49 Ma) (see also Tf under heading "Area East of Henefer and Along Saleratus Creek, and Thrust Sheets East of Crawford Thrust"). Fowkes isotopic ages and fossil evidence indicate the older Fowkes strata are essentially the time equivalent of the Bridger Formation in Wyoming (Nelson, 1973, 1974; see also Lillegraven, 1993, figures 4O and 4P). The most likely volcanic source(s) for the 38 to 40 Ma tuff is the Park City area, while the possible source(s) for the older (48-49 Ma) Fowkes-Bridger strata are the

Challis volcanic field in Idaho and/or the Absaroka volcanic field in Wyoming (see Chandler, 2006; Smith and others, 2008, in particular figure 5), though some volcanic material could be from the Park City area.

Oaks and others (1999) also reported a much older K-Ar hornblende isotopic age (64 Ma) for the Cache Valley fill along the Little Bear River to the north of the Ogden map area in the Paradise quadrangle (our sample number 96-38). Oaks and others (1999) reported a nearby sample was chemically correlated to a 30 Ma tuff. But, the locations of these samples as reported in Oaks and others (1999) are not consistent with the locations they showed in figures in their paper. In addition, Yonkee and Weil (2011, figure 7) showed an early Paleocene (~58-64 Ma) hiatus in uplift of the Wasatch anticlinorium, the source of the Eocene to Cretaceous basin fill in the area. Earlier, Williams (1964) reported K-Ar isotopic ages of 55 to 70 Ma (corrected) on mineral separates from Cache Valley fill, though with large uncertainties (±6-10 Ma). These large uncertainty margins suggest the ages Williams (1964) reported are inaccurate or they are averages of several air-fall events (that is, the deposits were reworked). If these uncommon Paleocene to Cretaceous ages are correct, they may indicate recycled hornblende in younger rocks or some previously unrecognized Evanston Formation-age rocks.

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – Typically red to brownish-red sandstone, siltstone, mudstone, and conglomerate with minor gray limestone and marlstone locally (see Twl); lighter shades of red, yellow, tan, and light gray present locally and more common in uppermost part, complicating mapping of contacts with overlying similarly colored Norwood and Fowkes Formations; clasts typically rounded Neoproterozoic and Paleozoic sedimentary rocks, mainly Neoproterozoic and Cambrian quartzite; basal conglomerate more gray and less likely to be red, and containing more locally derived angular clasts of limestone, dolomite and sandstone, typically from Paleozoic strata, for example in northern Causey Dam quadrangle; sinkholes indicate karstification of limestone beds; thicknesses on Willard thrust sheet likely up to about 400 to 600 feet (120-180 m) in Sharp Mountain, Dairy Ridge, and Horse Ridge quadrangles (Coogan, 2006a-b), about 1300 feet (400 m) in Monte Cristo Peak quadrangle, about 1100 feet (335 m) in northeast Browns Hole quadrangle, about 2200 feet (670 m) in southwest Causey Dam quadrangle, about 2600 feet (800 m) at Herd Mountain in Bybee Knoll quadrangle, and about 1300 feet (400 m) in northwest Lost Creek Dam quadrangle, estimated by elevation differences between pre-Wasatch rocks exposed in drainages and the crests of gently dipping Wasatch Formation on adjacent ridges (King); thickness varies locally due to considerable relief on basal erosional surface, for example along Right Fork South Fork Ogden River, and along leading edge of Willard thrust; much thicker, about 5000 to 6000 feet (1500-1800 m), south of Willard thrust sheet near Morgan. Wasatch Formation is queried (Tw?) where poor exposures may actually be surficial deposits. The Wasatch Formation is prone to slope failures. Other information on the Wasatch Formation is in Tw descriptions under the heading "Sub-Willard Thrust - Ogden Canyon Area" since Tw strata are extensive near Morgan Valley and cover the Willard thrust, Ogden Canyon, and Durst Mountain areas.

Along the South Fork Ogden River, Wasatch strata are mostly pebble, cobble, and boulder conglomerate with a matrix of smaller gravel, sand, and silt in the Browns Hole quadrangle, and coarse-grained sandstone to granule conglomerate as well as siltstone and mudstone to the east in the Causey Dam quadrangle; note thinning to east away from source area. The Wasatch weathers to boulder-covered dip(?) slopes north of the South Fork Ogden River, for example in Evergreen Park. Along the South Fork, the Wasatch Formation is separated from the underlying Hams Fork Member of the Evanston Formation by an angular unconformity of a few degrees, with the Hams Fork containing less siltstone and mudstone than the Wasatch and having a lighter color.

The Herd Mountain surface is developed on the Wasatch Formation at elevations of 7600 to 8600 feet (2300-2620 m) in the Bybee Knoll quadrangle and in remnants in the Huntsville, Browns Hole, and Sharp Mountain quadrangles. The origin of this boulder-strewn surface is debated (see Eardley, 1944; Hafen, 1961; Mullens, 1971). Eardley's (1944) Herd Mountain surface is flat lying or gently east dipping, about the same as the underlying Wasatch Formation, and is strewn with quartzite boulders to pebbles that King thinks are residual and colluvial deposits of uncertain age that were derived from the Wasatch Formation. The other characteristic of this surface is the presence of pimple mounds and, given the elevations of greater than about 7500 feet (2300 m), possible periglacial patterned ground. Photogrammetric dips on the Wasatch Formation under the surface are nearly flat (<3°) and an apparent angular unconformity is present in the Wasatch since dips on older Wasatch strata are greater than 3 degrees. King mapped this unconformity as a marker bed, but Coogan does not agree that this is an unconformity.

Twa? **Wasatch Formation or units of another age** – Reddish-brown weathering, weakly consolidated. quartzite-clast conglomerate and mudstone mapped near Devils Gate Valley; similar to Wasatch Formation but unqueried Wasatch strata are typically so well cemented that conglomerate clasts, as well as matrix, fracture; poorly bedded, with estimated 10 to 20 degree dips; boulders not obvious, despite Ezell (1953) mapping it as Tb; clasts mainly tan, greenish, and purple cobbles and boulders derived from Geertsen Canyon (tan) and upper Neoproterozoic quartzite (green=?; purple=Mutual?) bedrock, as reported by Crittenden and Sorensen (1985a), but their unit (TKwe) includes younger rocks (Tslc, Thv?) and unconsolidated material (Quaternary colluvium and lags, and possibly QT); unconformably overlies Paleozoic rocks with considerably more paleotopography than to north in Mount Pisgah quadrangle; if gently dipping, about 500 feet (150 m) thick west of Sink Hole valley (6975 feet [2126 m] hill crest south to Devils Gate Valley shoreline and/or basin fill line).

Another similar Twa? area, east of Devils Gate Valley, was mapped as TKwe by Crittenden and Sorensen (1985a). But, it is next to a sinkhole and the color may be reddish residuum (terra rossa) produced during karst development in the area, or be inherited from eroded Wasatch Formation rock, like the poorly resistant Tsl/Tnf exposures to the east. Other poorly resistant exposures adjacent to this Twa? look bouldery, with some brownish coloration like the Tslc exposures at Rendezvous Peak, and have been mapped as Qcg/Tsnf?.

The unit label is queried because the unit may be older and/or younger than Wasatch strata. Older Paleocene and Cretaceous K-Ar isotopic ages, similar to the age of the Evanston Formation, have been reported by Williams (1964) and Oaks and others (1999) for the basal "Tertiary" rocks that unconformably overlie the Oquirrh Formation in the southern Cache Valley. However, these ages are suspect due to large uncertainty margins on mineral separates, suggesting the ages are inaccurate or are averages of several air-fall events (that is, deposits are reworked). Also, lower Paleocene rocks (58-65 Ma) have not been documented in northern Utah (see figure 2). Younger, reddish, moderately to poorly cemented conglomerates and unconsolidated gravels are present on Durst Mountain, so part of the Twa? unit in the Mantua quadrangle may be derived from eroding Wasatch conglomerate. On Durst Mountain Eocene-Oligocene reddish conglomerates (Tcg) are interbedded with the tuffaceous Norwood Formation and Miocene, Pliocene (Tcy, Thv), and Quaternary conglomerate and gravel (QT) unconformably overlie the Norwood Formation (Coogan and King, 2006). So, red coloration alone is not an age indicator.

Twl, Twl?

Limestone of Wasatch Formation (Eocene and upper Paleocene) – Gray, oncolitic limestone and light-gray to white marlstone; discontinuous, grades laterally into Tw; mapped in Monte Cristo Peak and Sharp Mountain quadrangles; 0 to 300 feet thick (0-90 m). The setting of limestone in a syncline and likely lacustrine origin are possible evidence for a piggy-back basin on Willard thrust sheet; see Coogan (1992b) for the piggy-back basin on Crawford thrust sheet. Limestone of Wasatch Formation queried where poor exposures may actually be surficial deposits.

Similar limestones were described by Oaks and Runnells (1992) in the Cowley Canyon Member of the Wasatch Formation to the north in the Bear River Range. These Cowley Canyon strata directly overlie Paleozoic rocks, as well as being within the Wasatch red beds, and are thicker in north-south-trending grabens (Oaks and Runnells, 1992).

The Monte Cristo Peak and Sharp Mountain limestone outcrops were described as tuffaceous and stromatolitic (oncolitic) limestone in the Salt Lake Group by Hafen (1961) and Smith (1965). Smith (1965) collected one *Planorbis* sp. (his designation) fresh-water gastropod fossil from a limestone. This gastropod genus and the Planorbidae family of gastropods are not restricted to the Pliocene and/or Miocene, so they are present in rocks that are older than the Salt Lake Group/Formation (see for example Yen, 1948; Pierce, 1993).

Twc, Twc?

Basal conglomerate of Wasatch Formation (Eocene and upper Paleocene) – Red-orange- and tan-weathering, cobble conglomerate, mainly containing Neoproterozoic and Cambrian quartzite clasts; contains basal more gray colored, angular-clast conglomerate with clasts from nearby Paleozoic limestone, dolomite and sandstone on Baldy Ridge (mapped as Twc?) and in northern Causey Dam quadrangle (not mapped separately from Tw); 0 to 400 feet (0-120 m) thick. Unit queried where conglomerate may be Cretaceous (Keh, Kwc).

CRETACEOUS

Keh, Keh?

Hams Fork Member of Evanston Formation (Upper Cretaceous, Maastrichtian-Campanian) – Light-gray to tan conglomerate with lesser conglomeratic sandstone, and sandstone, with quartzite and chert clasts, as exposed along South Fork Ogden River; lower Hams Fork markedly coarsens to cobble conglomerate dominated by Cambrian and Neoproterozoic quartzite clasts (not mapped separately here, but mapped as Kehc to southeast); about 300 to 1000 feet (140-300 m) thick along South Fork Ogden River, thinning to west; thins to absence to north and west along regional angular unconformities. DeCelles and Cavazza (1999, figure 7A) showed a basal conglomerate as 66 feet (20 m) thick in the Causey Dam quadrangle. Unconformably truncated beneath Wasatch Formation and overlies Cretaceous Weber Canyon Conglomerate and Paleozoic rocks, with angular unconformity, along Right Fork South Fork Ogden River, indicating northern Causey Dam quadrangle, northwestern Horse Ridge, and western Dairy Ridge quadrangles were areas of high paleotopography (after Coogan, 2006a-b).

The age of the Hams Fork here is based on Mullens (1969; 1971, p. 13) note of Late Cretaceous pollen in a sample (D3971) that is from upper part of our Keh unit.

These South Fork Ogden River Keh exposures are not the same lithologically as those near Devils Slide, in the Lost Creek drainage, and in Echo Canyon; but these outcrops form a nearly continuous band down the South Fork and along the east flank of Durst Mountain to Devils Slide and other exposures to the east. The lithology of Keh along the east flank of Durst Mountain also differs from that in the other areas mentioned.

Kwc, Kwc?

Weber Canyon Conglomerate (Upper Cretaceous, Campanian-late Santonian) – Tan and gray conglomerate with cobbles of Mississippian Lodgepole Limestone (75-100%), and lesser amounts of Cambrian and Neoproterozoic quartzites and Paleozoic sandstone (Wells Formation?), as exposed along Right Fork South Fork Ogden River, entirely on the Willard thrust sheet; clasts derived from paleotopographic ridge developed on Lodgepole Limestone to northwest in Causey Dam quadrangle; note clast composition here is not like that to southeast in Lost Creek drainage and near Devils Slide, where the unit was named and dated by fossils; overlies older rocks with major angular unconformity and unconformably underlies Hams Fork Member of Evanston Formation (Keh); only about 300 feet (90 m) exposed.

Weber Canyon Conglomerate here is very different from that to the southeast in the Lost Creek drainage and near Devils Slide, particularly in clast composition, implying different source areas for each of the three exposure areas.

WILLARD THRUST SHEET

Outer shelf sequence or miogeoclinal basin sequence of Coogan (1992a)

TRIASSIC

Dinwoody Formation strata are inferred to be in the core of Beaver Creek syncline by Mullens (1969, cross section A-A'). However, no Triassic strata are exposed on the Willard thrust sheet. Triassic strata are exposed east of the Willard thrust sheet to the northeast near Laketown, Utah (see Valenti, 1980; Coogan, 1992a), to the east in the Dairy Ridge and Horse Ridge quadrangles (Coogan, 2006a-b), and to the south near Devils Slide (Coogan and others, 2016) (south and east of the Willard thrust sheet).

PERMIAN

Pp **Park City and Phosphoria Formations, undivided (Permian)** – Meade Peak and Grandeur Member descriptions from King (this report). Includes (in descending order):

Ppf **Franson Member of Park City Formation, and several thin members of both Formations (Permian) -** Interbedded chert, limestone, sandstone, and some phosphatic rock in upper 140 feet (40 m) (Shedhorn, Ervay, Retort, and Rex Members); mainly light- and medium-gray, cherty limestone and dolomite in lower 260 feet (80 m) (Franson Member); forms ledgy slopes in upper part over cliffy lower part; about 400 feet (120 m) total thickness (Mullens, 1969).

According to Schell and Gere (1964), total thickness is 412+ feet (125+ m) with (in descending order): 9+ feet (3+ m) of sandstone (Shedhorn Sandstone?); 60 feet (18 m) of Ervay Member of Park City (carbonate rock); 34 feet (10 m) of Retort Phosphatic Shale Member of Phosphoria; 33 feet (10 m) of Rex Chert Member of Phosphoria; and 276 feet (84 m) of Franson Member of Park City (Shedhorn, Ervay and Retort units may be upper cherty shale member in Idaho terminology).

Ppm **Meade Peak Phosphatic Shale Member of Phosphoria Formation (Lower Permian)** – Dark-gray phosphatic limestone, dolomite, siltstone and darker shale; slope and swale former; near Causey Dam, 262 feet (80 m) measured by Schell and Gere (1964) and reportedly 230 feet (70 m) thick (Mullens, 1969).

Ppg **Grandeur/Lower Member of Park City Formation (Lower Permian)** – Dark-gray limestone and dolomite that is phosphatic in upper part and locally cherty; near Causey Dam, 258 feet (77 m) measured by Schell and Gere (1964) and reportedly 250 to 280 feet (75-85 m) thick (Mullens, 1969).

PERMIAN AND PENNSYLVANIAN

PIPwe **Wells Formation (Lower Permian and Pennsylvanian)** – Light-gray to off-white to orangish-gray, thick-bedded, carbonate-cemented quartzose sandstone in upper part, interbedded with minor gray to light-gray, thick-bedded limestone and minor dolomite in lower part; only about 400 feet (120 m) thick in Causey Dam quadrangle (Mullens, 1969, upper Wells; this report). Later revised to entire Wells by Mullens (1972), based on Mississippian fossils in underlying units.

The Wells seems to be thicker to east of the Willard thrust sheet (opposite the expected), with about 1050 feet (320 m) of overturned Wells in the Dairy Ridge quadrangle, even with the base truncated by the Willard thrust (see Coogan, 2004a).

North of our map area, the top of the Wells is eroded; it is about 600 to 700 feet (180-210 m) thick in the Paradise and Porcupine Reservoir quadrangles (after Mullens and Izett, 1964; Berry, 1989), despite a reported thickness of 900 feet (270 m) in the latter quadrangle (see Berry, 1989). Evans and others (1996) showed at least 1200 feet (360 m) of Wells on Big Baldy in the eastern part of the Logan 7.5-minute quadrangle and Williams (1948) reported about 1000 feet (300 m) in the same area.

The Wells Formation is at least partly equivalent to the Weber Quartzite to the south near Morgan and Oquirrh Formation to the west near Brigham City. The Causey Dam section is very thin compared to the Weber near Morgan, where it is at least 2500 feet (>760 m) thick, even though the Morgan section is off the Willard thrust sheet (see Coogan and King, 2006). Also, the thinner Oquirrh Formation of Williams (1948, 1958), Mullens and Izett (1964), and later mappers in the Bear River Range on the Willard thrust sheet is probably Wells strata that was deposited on a shelf rather than in the Oquirrh basin (see basin extent in Jordan and Douglass, 1980). The lack of a discernable West Canyon Limestone in the Bear River Range also supports the Wells designation rather than the Oquirrh Formation.

MISSISSIPPIAN

Mgb, Mgb?

Great Blue Limestone, lower member (Upper Mississippian, Chesterian-Meramecian) – Ledge-forming, medium to dark-gray, fossiliferous limestone mapped on the north boundary of the Mantua and James Peak quadrangles, where it occupies the Monroe Canyon Limestone stratigraphic interval (note Mississippian stages); queried between Clay Valley and Sink Hole, where the Little Flat Formation would be too thick without a fault or the Great Blue being present; incomplete thickness of lower member exposed.

To the north of our map area, the Great Blue contains age-diagnostic *Faberophyllum* sp. and *Siphonodendron (Lithostrontion) whitneyi* corals, indicating coral zones IV and IIID, respectively (Oviatt, 1986; see also Sando and Bamber, 1985), *Cavusgnathus* sp. conodonts (Oviatt, 1986), and *Goniatites* sp. and *Girtyoceras* sp. cephalopods (Williams and Yolton, 1945), as well as fossil sponges, echinoderms, brachiopods, gastropods, other cephalopods, and other tabulate, rugose and horn corals (see Williams and Yolton, 1945); about 800 feet (245 m) thick north of our map area.

Mmo, Mmo?

Monroe Canyon Limestone (Upper Mississippian, Chesterian? and Meramecian) – Includes upper gray dolomite (or is it dolomitized limestone?) and limestone, middle gray, cherty limestone and minor siltstone, and lower thick-bedded and cliff-forming gray dolomite and limestone with lesser sandstone; varies from about 700 to 1100 feet (210-335 m) thick.

The Monroe Canyon may thicken to the south and east since it is about 700 to 1000 feet (210-300 m) thick in the James Peak quadrangle (Coogan, this report), about 950 to 1100 feet (290-335 m) thick near Causey Dam (this report), and to the north of our map area at the mouth of Blacksmith Fork Canyon, near the Paradise quadrangle, the entire Monroe Canyon is 830 feet (253 m) thick (upper Brazer of Williams, 1943).

In the Causey Dam quadrangle, King mapped the Monroe Canyon-Little Flat contact so the grayish-orange, sand-rich lower part of Mullens' units (upper Humbug [Mhu] of Mullens, 1969, and most of upper Humbug of Mullens, 1972) is in the Little Flat Formation and the lower Monroe Canyon Limestone does not thicken much to the south.

The Monroe Canyon is late Meramecian in age (coral zone IIID-IV of Sando and Bamber, 1985; zones E and F of Sando and others, 1969) based on *Faberophyllum* sp. coral reported by Mullens (1969); see also coral from locality U-9 in Sando and Bamber (1985, p. 43) and *Stratiferia* sp. brachiopod fossils reported in Mullens (1972). Late Meramecian is type Monroe Canyon and lower Great Blue-Humbug time. Sando and Bamber (1985, p. 43; see also Sando, 1983, p. 41) also noted *Petalaxis* sp. coral of zone IV (late Meramecian) that probably came from this unit in or near the Paradise quadrangle, just north of our map area. A note in Sando and Bamber (1985, p. 43) indicates *Schoenophyllum* sp. coral (zone V-A, Chesterian) came from this unit in the Paradise quadrangle. See also Mullens and Izett (1964) and Berry (1989) for Chesterian strata to the north that may be eroded away in our map area.

Monroe Canyon strata may or may not be present below the Wasatch Formation in the concealed syncline in the east-central part of the Monte Cristo Peak quadrangle. The Monroe Canyon interval is roughly equivalent to the Great Blue Limestone and upper Humbug Formation interval to the west near Brigham City on the Willard thrust sheet, and possibly the Doughnut Formation elsewhere in our map area. Monroe Canyon lithologies and fossils in our map area imply the upper and middle strata are the middle medium-bedded limestone of the type Monroe Canyon (see Dutro and Sando, 1963), though chert is atypical. The lower strata have the lithology and fossil characteristics of the massive limestone member of the Monroe Canyon in its type area (see Dutro and Sando, 1963), but here do not consistently weather to massive outcrops like the massive limestone member elsewhere.

Mlf, Mlf?

Little Flat Formation (Mississippian, Meramecian-Osagean) – Gray, tan, and reddish-tan, calcareous to dolomitic sandstone, and gray sandy limestone and dolomite; grades upward into mostly dolomite; less resistant than overlying and underlying map units; phosphatic shale at base (Delle Phosphatic Member); about 800 feet (245 m) thick, including Delle in lower Wheat Grass Canyon, Causey Dam quadrangle and does not thin to north as reported in Mullens (1969), and likely about 900 feet (270 m) thick to northwest (King this report).

North of the Ogden map area, the Little Flat is about 900 feet (270 m) thick in the Mount Pisgah quadrangle (Brazer 1 of Williams, 1943, 1948; Williams and Yolton, 1945), 905 feet (276 m) thick near the Blacksmith Fork River (lower Brazer of Williams, 1943), about 1000 feet (300 m) thick at Porcupine Reservoir (Sandburg and Gutzchick, (1979), and looks like about same thickness on the Porcupine Reservoir quadrangle map of Berry (1989) despite her report of a 1206-foot (370 m) thickness.

The Little Flat is roughly equivalent to the lower Humbug Formation and Deseret Limestone interval to the west. The Little Flat Formation name is used rather than Humbug, because the Deseret Limestone appears to be missing or is atypically much sandier, despite being shown by Welsh and Bissell (1979, figure 4). Further, the rocks we mapped as Little Flat are lithologically similar to the type Little Flat Formation in the Chesterfield Range in southeastern Idaho (W.J. Sando, U.S. Geological Survey, written communication, 1988; see Dutro and Sando, 1963, for type descriptions). The Little Flat unit is roughly equivalent to the lower Humbug and Deseret interval elsewhere in our map area.

The Little Flat Formation is likely present below the Wasatch Formation in the concealed axis of the syncline in the Monte Cristo Peak quadrangle, because it is exposed on both flanks of the syncline just to the south in the Causey Dam quadrangle.

To the north in the Bear River Range, the Little Flat Formation is early Osagean to middle Meramecian (Early and Late Mississippian) in age, based on conodonts (Sandberg and Gutschick, 1979). Parks (1951) reported *Ekvasophyllum* sp. coral (likely zone IIID of Sando and Bamber, 1985) that likely came from this unit at Leatham Hollow. See Williams (1943, 1948) and Williams and Yolton (1945) for fossils, mostly brachiopods (*Cleiothryidina obmaxima*—likely coral zone IIID) and some corals found in this unit to the north in the Mount Pisgah quadrangle.

Mlfd, Mlfd?

Delle Phosphatic Member of Little Flat Formation (Lower Mississippian, Osagean) – Mostly poorly resistant, typically vegetated, brownish-orange weathering, phosphatic shale; also dark resistant cherty limestone and less resistant calcareous siltstone; non-resistant zone is about 40 to 80 feet (12-25 m) thick.

Reported shale thicknesses vary from 4 to 15 feet (1-5 m) thick (Mullens, 1969), with a 126-foot (38 m) maximum (Blackwelder, 1910b, included limestone). See also Schell and Moore (1970) for measured section and chemical analyses from the richest phosphate at Wheat Grass Canyon (their site CP-44) in the Causey Dam quadrangle. Sandberg and Gutschick (1979) reported on the Delle exposures in the region, showing 33- and 92-foot (10 and 28 m) thicknesses in the Bear River Range north of our map area at Porcupine Reservoir and Leatham Hollow, respectively.

Mlf-Ml **Little Flat Formation or Lodgepole Limestone (Lower Mississippian, Merimecian-Osagean or Osagean-Kinderhookian)** – Gray limestone in fault contact with Lodgepole Limestone and on strike but not in contact with Little Flat Formation in Mantua quadrangle; might be either unit.

Ml, Ml? **Lodgepole Limestone (Lower Mississippian, Osagean-Kinderhookian)** – Gray, ledge and cliff-forming, fossiliferous limestone (lime mudstone [micrite] to wackestone); locally cherty, containing black chert nodules, particularly at top; capped by 100-foot (30 m) thick dolomite in Causey Dam quadrangle; estimate 750 to 900 feet (230-275 m) thick in our map area (see for example Ezell, 1953; Crittenden and Sorensen, 1985a); structurally thickened in the Horse Ridge quadrangle (Coogan, 2006b).

The better documented Lodgepole thicknesses are from near Causey Dam. An ~830-foot (275 m) thickness, excluding basal silty limestone (unit MDcl, see below), was reported north of Causey Dam (Mullens, 1969), and is likely based on Laraway's (1958) measurements of about 825 feet (252 m) of Lodgepole. Laraway (1958) put 30 to 35 feet (10 m) of Cottonwood-Leatham strata (our MDcl) in his underlying Three Forks (Beirdneau) Formation. About 790 feet (240 m) of Lodgepole-equivalent strata (Henderson Canyon Formation) was measured by Webster and others (1987) near Causey Reservoir. The Henderson Canyon name was introduced because the typical Lodgepole is overlain by the Mission Canyon Limestone (Sando and Dutro, 1974), so with the Delle marking the boundary between the Deseret and Gardison, this unit may better be called Gardison Limestone or Henderson Canyon Formation.

The Lodgepole is Kinderhookian and early Osagean in age, based on fossil conodonts (upper and lower *Siphonodella isostichia* - *S. crenulata* zones), crinoids, and corals found in the Bear River Range in northern Utah (Sandberg and Gutschick, 1979) and the Wellsville Mountains (Oviatt, 1986).

MISSISSIPPIAN AND DEVONIAN

MDcl, MDcl?

Cottonwood Canyon Member of Lodgepole Limestone and Leatham Formation (Lower Mississippian and Upper Devonian, Kinderhookian and Famennian) – Poorly exposed recess or a slope of dark-colored shale, siltstone, and thin-bedded silty to shaly limestone; reported thicknesses of 10 to 100 feet (3-30 m) (see shales of Williams, 1948; Holland, 1952; Brooks, 1954; Laraway, 1958; Mullens and Izett, 1964; Benson, 1965; Mullens, 1969, silty limestone) (see also Sandberg and Gutschick, 1979; Sandberg and Poole, 1977). Previously placed in both the Beirdneau and Lodgepole Formations.

This recessive interval likely includes the Cottonwood Canyon Member of the Lodgepole Limestone of Sandberg and Gutschick (1979) (see also Holland, 1952; Benson, 1965; Sandberg and Poole, 1977). The Cottonwood Canyon Member is Lower Mississippian (Kinderhookian) and the Leatham Formation is Upper Devonian (Famennian) (Sandberg and Gutschick, 1979); hence the Mississippian (Kinderhookian) age reported for the Leatham at the type section in Leatham Hollow (see Holland, 1952, p. 1719-1720). The characteristic recessive interval is distinct and is mapped here in Wheat Grass Canyon in the Causey Dam and Monte Cristo Peak quadrangles.

DEVONIAN

Descriptions modified from Coogan (2006a-b). Thickness estimates near Causey Dam are by King from outcrop pattern, dip, and topography in various locations. Devonian stage subdivisions are not noted due to the lack of fossils and age uncertainty.

Db **Beirdneau Sandstone (Upper Devonian)** – Tan, reddish-tan, and yellowish-gray dolomitic to calcareous sandstone and siltstone, and silty to sandy dolomite and limestone; contact ledge "limestone" 10 to 20 feet (3-6 m) at top, distinct below Leatham recessive zone in Wheat Grass Canyon, Causey Dam quadrangle (see above); locally contains distinctive beds of intraformational conglomerate consisting of small red fragments of siltstone and sandstone in silty limestone matrix, and scattered halite molds in fine-grained rock (Mullens, 1969); estimate 0 to 500 feet (0-150 m) thick and absent in west part of Ogden map area. Referred to as the "upper" Jefferson member or Three Forks Formation by some previous workers.

These Beirdneau strata are about 400 feet (120 m) thick in the Monte Cristo Peak area and near Causey Dam (King). Thickness to the east not known because the base is not exposed in the Dairy Ridge quadrangle and the unit is structurally thickened in the Horse Ridge quadrangle (Coogan, 2006a-b). To the west in the Mantua and James Peak quadrangles, the Beirdneau is missing at the unconformity between the Lodgepole and Hyrum Formations (Stansbury uplift of Rigby, 1959) and may not have been present over the uplift in the Sharp Mountain quadrangle, but the next oldest unit is on a ridge top and Beirdneau removal could post-date the Stansbury uplift.

North of our map area, Beirdneau strata are 500 to 1100 feet (150-335 m) thick, apparently thinning to the south (after Brooks, 1954; Mullens and Izett, 1964; Three Forks of Benson, 1965; Williams, 1971). So this unit thins rapidly to the south and west over the Stansbury uplift (compare to Rigby, 1959).

Beirdneau strata are Late Devonian (early Famennian) in age, based on fossils in the upper portion of the unit in northern Utah (Williams, 1971; Oviatt, 1986).

Dhw **Hyrum and Water Canyon Formations, undivided (Devonian**) – See descriptions below.

Dh, Dh? **Hyrum Dolomite (Upper and Middle Devonian)** – Dark- to medium-brownish-gray dolomite; weathers distinctive, chocolate-brown color and is typically more resistant than silty and sandy overlying Beirdneau and underlying Water Canyon Formations; estimate 0 to 675 feet (0-205 m) thick and absent in northwest part of our map area. This unit is "lower" Jefferson member of some previous workers.

In the Ogden map area, the Hyrum is thickest on the leading edge of the Willard thrust sheet, 500 to 675 feet (150 to 205 m) thick in the Horse and Dairy Ridge quadrangles (Coogan, 2006a-b) and is thicker yet north of our map area, for example 930 to 980 feet (280-300 m) thick along the Blacksmith Fork River (after Mullens and Izett, 1964; Eliason, 1969; Williams, 1971). The Hyrum is thinnest in the Mantua quadrangle and directly to the north (0 to 400 feet [0-120 m] thick) (King). The Hyrum is about 400 feet (120 m) thick near Causey Dam and in the Monte Cristo Peak area (King), with 400 to 435-foot (120-133 m) thicknesses reported near Causey Dam (Jefferson of Laraway, 1958). Hyrum strata are eroded in the Sharp Mountain area (Hafen, 1961) and covered in the James Peak quadrangle, so the thickness indeterminate. The Hyrum seems to thin to the south and west over Stansbury uplift (compare to Rigby, 1959).

A Middle Devonian age was assigned to the Hyrum based on fossils from the base (and possibly middle portion) of the formation in the Wellsville Mountains, Bear River Range, and West Hills in northern Utah (Williams, 1971; Oviatt, 1986). Fossils collected from the Hyrum a few miles north of the Paradise quadrangle, north of the Ogden map area (Williams, 1948, p. 1140) indicate a probable early Late Devonian age.

Dwc, Dwc?

Water Canyon Formation (Lower Devonian) – Thin- to medium-bedded, reddish-tan and gray siltstone and very light-gray to light-tannish-gray weathering, thinly laminated, at least locally sandy, typically medium-gray dolomite with some limestone; forms light-colored to orangish-hued slopes; contains fragments of fossil fish plates (Mullens, 1969); estimate 100 to 460 feet (30-140 m) thick in our map area and thinning to south.

Laraway (1958) measured 121 feet (37 m) of Water Canyon at Causey Dam and the unit appears to be about 100 feet (30 m) thick east of Causey Reservoir (King), though Mullens (1969) reported the unit is 150 to 250 feet (45-75 m) thick and thickening northward in the Causey Dam quadrangle. On the leading edge of the Willard thrust sheet, the Water Canyon is an estimated 200 feet (60 m) thick north of our map area in the Curtis Ridge quadrangle (see Hansen, 1964) and 100 to 150 feet (30 to 45 m) thick in the Dairy Ridge and Horse Ridge quadrangles (Coogan, 2006a-b). To the west, the Water Canyon is 460 feet (140 m) thick in the Sharp Mountain area (Hafen, 1961), which is about what Coogan mapped (this report), and about 400 feet (120 m) thick in the Mantua quadrangle (King, this report). Smith (1965) reported 296 feet (90 m) of Water Canyon in the Monte Cristo Peak area, but this Hyrum thickness is too low (see Hyrum Formation) and Hyrum strata may have been included in his Water Canyon map unit. So the Water Canyon thins to the east and apparently irregularly to the south, probably over the Tooele arch (see Hintze, 1959) or due to erosion during the Late Devonian Stansbury uplift (see Rigby, 1959). However, the uplift is complicated, possibly by paleotopography, because to the north near the Blacksmith Fork River the Water Canyon thins to 230 to 320 feet (70-100 m) (after Brooks, 1954; Taylor, 1963; Williams and Taylor, 1964; Mullens and Izett, 1964), yet it is about 1200 feet (365 m) thick in the Mount Pisgah quadrangle (King and others, 2016).

The Water Canyon is Early Devonian in age based on fish fossils found in the Wellsville Mountains (Oviatt, 1986) and in northern Utah (Williams, 1948, p. 1140; Taylor, 1963; Williams and Taylor, 1964).

SILURIAN AND ORDOVICIAN

SOlf **Laketown and Fish Haven Dolomites, undivided (Silurian and Ordovician)** – Dark- to light-gray, cherty dolomite; combined unit only mapped in the Horse Ridge and part of the Dairy Ridge quadrangles; thins southward from 600 feet (180 m) in the northern Dairy Ridge quadrangle to 360 feet (110 m) in the southern Horse Ridge quadrangle; farther west thins southward from 1365 feet (415 m) in the Sharp Mountain quadrangle (Hafen, 1961) to about 530 to 650 feet (160-200 m) in the Causey Dam area (Mullens, 1969).

Sl, Sl? **Laketown Dolomite (Silurian and Ordovician)** – Medium- to dark-gray, medium to very thick-bedded, cliff-forming dolomite; locally cherty, with irregular blebs, stringers, and layers of chert at various horizons; conodonts and sparse, poorly preserved corals reported by Mullens (1969); our lower contact appears to be what Williams (1948, 1958) mapped in the Bear River Range; 400 to 1240 feet (120-380 m) thick in our map area.

Some reported thicknesses for the Laketown may include part of the underlying Fish Haven Dolomite, because a different contact was used than is shown on our map. Our Laketown map unit is about 1100 feet (335 m) thick in the Pisgah Hills just north of the map area, because in a measured section east of Mantua Reservoir, probably in the Mount Pisgah quadrangle, Gunn (1965, p. 205) reported the Laketown was 973 feet (300 m) thick, and using our Laketown-Fish Haven contact, units 3 and 2 of his Fish Haven (30 and 66 feet [9 and 20 m] thick) would be in our Laketown (1072 feet [327 m] thick), leaving 166 feet (50 m) of Fish Haven (his unit 1 of Fish Haven). The Laketown thickness in the Monte Cristo Peak area appears to be about 500 feet (150 m), like the thickness in the northwest Dairy Ridge quadrangle (Coogan, 2006a). To the south near Causey Dam, the Laketown is 490 feet (149 m) thick based on Laraway's (1958) measurements (his Laketown plus units 2 and 3 of his Fish Haven), and is about 400 to 600 feet (120-180 m) thick, using the contact on our map. Our contact is at the bottom of the non-resistant basal Laketown beds above the resistant Fish Haven. So the Laketown thins to the south and apparently to the east, probably over the Tooele arch (see Hintze, 1959) and is missing south of the Willard thrust sheet at Ogden Canyon, but this may be influenced by erosion over the Stansbury uplift (see Rigby, 1959).

The Laketown Dolomite as shown on our map is late Late Ordovician and middle Early through Middle Silurian in age, and locally earliest Late Silurian in age in northern Utah (after Budge, 1966; Budge and Sheehan, 1980; Leatham, 1985; adjusting for all of their unmapable biostratigraphic Laketown-Fish Haven contact).

ORDOVICIAN

Ofh, Ofh?

Fish Haven Dolomite (Upper Ordovician, Cincinnatian and possibly Richmondian) – Dark-gray, thick- to very thick bedded dolomite with white chert as small nodules; commonly with dull-medium-gray to light-gray mottling on weathered surfaces; forms resistant ridge or cliff where distinguishable from more recessive dolomites at the base of the overlying Laketown Dolomite; contains fossil corals, particularly rugose corals, and tabulate (for example *Halysites* species) corals; in our map area 80 to 165 feet (25-50 m) thick. At least locally unconformably overlies shale of lower Swan Peak Formation.

In our map area, the Fish Haven is reportedly -- 80 to 165 feet (25-50 m) thick in the Mantua quadrangle (Crittenden and Sorensen, 1985a), but Laketown-Fish Haven contact may be inconsistent; 123 and 125 feet (38 and 41 m) thick in the Monte Cristo Peak area (Smith, 1965) and the Sharp Mountain quadrangle (Hafen, 1961), respectively; likely 135 feet (41 m) thick to the south in the Causey Dam quadrangle (after Laraway, 1958, unit 1); and about 100 feet (30 m) thick to the east in the northwest Dairy Ridge quadrangle (Coogan, 2006a). North of the map area, the Fish Haven is likely about 180 feet (55 m) thick near Brigham City (after Jensen and King, 1996), 140 feet (42.5 m) in Blacksmith Fork Canyon (Mecham, 1973), and 128 feet (39.0 m) thick to the northeast in the Curtis Ridge quadrangle (Hansen, 1964). So the Fish Haven thins to the south, but is about as thick off the Willard thrust sheet at Ogden Canyon as on the Willard thrust sheet.

Based on fossil corals collected in north-central Utah, the age of our Fish Haven map unit is probably late Late Ordovician (Cincinnatian, possibly Richmondian) (after Williams, 1948; *Paleofavocities* sp., Gelnett, 1958; Budge, 1972). Budge and Sheehan (1980) presented more detailed data, but they used a different Fish Haven-Laketown contact that was based on unmappable biostratigraphy (see also Leatham, 1985).

Osp, Ospq, Osps

Swan Peak Formation (Lower and Middle? Ordovician) – Tan to orangish-tan to pale-reddish-tan, cliff- and ridge-forming upper quartzite (Ospq) underlain by recessive weathering lower part (Osps) containing interbedded dark shale and siltstone, some similar quartzite, as well as limestone beds; 0 to about 250 feet (0-75 m) thick, thickest in northwest part of map area. Only lower part (Osps) is present below unconformity in eastern Mantua, James Peak, and Sharp Mountain quadrangles; entirely missing to east on leading edge of Willard thrust sheet and to south over Tooele arch (see Hintze, 1959).

The Fish Haven Dolomite unconformably overlies the Garden City Formation with the Swan Peak Formation missing in the Monte Cristo Peak area (Ross, 1949), to the south near Causey Dam (Laraway, 1958; Mullens, 1969), and to the east in the Curtis Ridge, Dairy Ridge, and Horse Ridge quadrangles (Hansen, 1964; Coogan, 2006a-b). About 20 feet (6 m) of recessive-weathering siltstone and shale (lower Swan Peak) are present to the west near Sharp Mountain (Hafen, 1961) and more lower Swan Peak is present farther west (see Ross, 1951; Ezell, 1953; Francis, 1972). In the Monte Cristo Peak quadrangle, the shale below the Fish Haven is placed in the upper Garden City Formation by Ross (1949) and Smith (1965) on the basis of paleontological evidence cited by Ross (1949). So the Swan Peak Formation is missing over the Tooele arch on the southeast part of the Willard thrust sheet. The upper part of the Garden City Formation was likely eroded, as well as Swan Peak, over the Tooele arch (see Hintze, 1959).

The lower Swan Peak is late Early Ordovician in age based on Zone M trilobites, and brachiopods (*Orthoambonites-Orthidiella*) found in the Pisgah Hills and Wellsville Mountains (Ross, 1951; Gelnett, 1958, p. 28; Francis, 1972, p. 111 and 118; Jensen and King, 1996, table 2) north of our map area.

Ogc, Ogc?

Garden City Formation (Lower Ordovician) – Gray to tan weathering, dark-gray to gray, thin- to medium-bedded, silty limestone; contains tan to yellowish-weathering, less resistant, wavy, silty to argillaceous laminae to inch-scale layers that are more abundant in lower part; intraformational, flat-pebble conglomerate present in lower half; ledge forming; chert near the top of unit (black nodules and stringers) and in lowermost part; at least locally fossiliferous (see Mullens, 1969); 500 to 1200 feet (150-365 m) thick in our map area.

The Garden City Formation is an estimated 1185 feet (360 m) thick north of the Monte Cristo Peak quadrangle (Ross, 1949). To the east this unit may thin southward from 1280 feet (390 m) thick in a composite section in the Curtis Ridge quadrangle (Hansen, 1964) to about 1050 feet (320 m) thick along Sugar Pine Creek in the Dairy Ridge quadrangle to about 700 feet (215 m) thick in the southern Horse Ridge quadrangle, but Garden City strata are commonly structurally thickened on the leading margin of the Willard thrust sheet (Coogan, 2006a-b). This unit is reportedly about 500 feet (150 m) thick in the Causey Dam quadrangle (Mullens, 1969), but its base is not exposed. So the Garden City Formation thins to the south over the Tooele arch (see Hintze, 1959).

Exhibits faint, axial-planar cleavage where mesoscopically folded to the east nearer the Willard thrust (Coogan, 2006a-b), indicating potential for fracture porosity in subsurface.

The Garden City Formation is Early Ordovician as determined from its rich Zone L to B trilobite fauna in the Pisgah Hills and a *Buttsoceras* sp. cephalopod in the Wellsville Mountains, and disconformably overlies the St. Charles Formation (Ross, 1951; Oviatt, 1986). See also Taylor and others (1981) for conodont fauna in the Garden City in the Bear River Range.

ORDOVICIAN AND CAMBRIAN

Csn, Csn?

St. Charles and Nounan Formations, undivided (Lower Ordovician and Upper Cambrian) – See descriptions below.

Csc, Csc?

St. Charles Formation (Lower Ordovician and Upper Cambrian) – Mostly dark-gray, medium- to thick-bedded dolomite; contains subordinate medium-gray dolomite and limestone; all with tan-weathering mottling and recesses of crude laminae to inch-scale layers of sandstone and siltstone; overall gray to tan weathering and ledge forming; uppermost part contains light-colored, typically pink, chert; lower part is less resistant, light-gray, tannish-gray weathering, thin-bedded, silty and sandy limestone and dolomite, and silty shale, with tannish-gray, medium-bedded, cross-bedded Worm Creek Quartzite Member (Upper Cambrian) that is locally present; total thickness about 500 to 1000 feet (150-300 m) and may thin to south and east over Tooele arch (see Hintze, 1959).

The St. Charles Formation is 723 feet (220 m) thick, including the Worm Creek, in the Monte Cristo Peak area (Smith, 1965) and to the west it is 970 feet (295 m) thick, including Worm Creek, in the Sharp Mountain quadrangle (Hafen, 1961). To the south near Causey Dam, the entire St. Charles appears to be about 650 feet (200 m) thick (King). To the east the St. Charles thins southward from 700 feet (215 m) thick along Sugar Pine Creek in the Dairy Ridge quadrangle, with about 75 feet (25 m) of Worm Creek, to about 500 feet (150 m) thick in the Horse Ridge quadrangle, with no Worm Creek (Coogan, 2006a-b).

As determined from trilobite and conodont fossils in the Bear River Range, the St. Charles age is earliest Ordovician and Late Cambrian (Taylor and others, 1981).

The Worm Creek Quartzite Member has been inconsistently mapped. Carbonate and clastic sedimentary rocks are sometimes included, so it does not always contain a quartzite. Therefore this member is not shown separately on our map. The quartzite is about 0 to 90 feet (0-27 m) thick (Hafen, 1961; Rigo, 1968; Mullens, 1969; Coogan, 2006a-b) in the map area. In particular in the Mantua quadrangle, the quartzite is only locally recognizable and is an estimated 50 feet (15 m) thick south of the fish hatchery. Some geologists only map and report the quartzite portion of the member (see for example Ezell, 1953, versus Hafen, 1961), ignoring other lithologies and placing the contact at the top of the quartzite, and in Utah the quartzite is at least locally absent (Haynie, 1957). This has led to problems with the presence or absence of the member as well as thicknesses. Just north of the map area in the Wellsville Mountains, *Elvinia* zone trilobite fossils indicate a Late Cambrian age for the Worm Creek (Oviatt, 1986).

CAMBRIAN – Descriptions of units below Nounan Formation largely from Coogan (2006a-b).

Cn, Cn? **Nounan Formation (Upper Cambrian)** – Medium-gray to dark-gray, very thick to thick-bedded, light to medium gray and tan-weathering, typically cliff forming, variably sandy and silty dolomite and lesser limestone, with crude laminae to partings and mottling of sandstone and siltstone that weather tan or reddish; little sandstone and siltstone in more resistant lower part; about 600 to 1150 feet (180-350 m) thick.

The Nounan Formation thickness range in our map area is based on numerous studies. It is about 800 feet (245 m) thick in the Huntsville quadrangle, using Coogan's mapping of about 300 feet (90 m) each of the Blacksmith and Langston Formations; about 900- and 999-foot (275 and 300 m) thicknesses reported at the South Fork Little Bear River in the James Peak quadrangle (Ezell, 1953; Gardiner, 1974; respectively) and 1145 feet (350 m) thick at Sharp Mountain (Hafen, 1961). To the east the Nounan thins southward from 1025 feet (312.5 m) thick in the Curtis Ridge quadrangle (Hansen, 1964) to 800 feet (245 m) thick in Sugar Pine Canyon (Creek) in the Dairy Ridge quadrangle (Gardiner, 1974; Coogan, 2006a) to 675 feet (205 m) thick in the Horse Ridge quadrangle (Coogan, 2006b). The Nounan is about 630 feet (190 m) thick in the Causey Dam quadrangle (Mullens, 1969), possibly the "average" of the 571 feet (174 m) and 696 feet (210 m) measured by Rigo (1968, aided by Mullens) and Gardiner (1974), respectively, on Baldy Ridge in the quadrangle, with Gardiner's (1974) thickness more closely matching Mullens' (1969) mapped thickness. So the Nounan thins to the south and east over the Tooele arch (see Hintze, 1959).

Williams (1948) reported that the Nounan was Late Cambrian in age, using unpublished fossil collections (in part from Maxey, 1941). In the Wellsville Mountains north of our map, Oviatt (1986) reported the upper Nounan was Dresbachian (Late Cambrian) in age based on *Dunderbergia*(?) and *Crepicephalus* zone trilobite fauna.

Cbo **Bloomington Formation (Middle Cambrian)** – Olive to tan shale and gray, nodular limestone; 600 feet (180 m) thick near Sharp Mountain (Hafen, 1961), and 650 feet (200 m) thick to south near Causey Dam (Mullens, 1969); a report of a 918-foot (280 m) thickness in Baldy Ridge section (Rigo, 1968, aided by Mullens), Causey Dam quadrangle may be faulted strata, but east of Baldy Ridge about 935 feet (285 m) thick in Dairy Ridge quadrangle, thickening to south to 1550 feet (470 m) thick in Horse Ridge quadrangle (Coogan, 2006a-b). In the Wellsville Mountains, shale members are Middle Cambrian (*Bolaspidella* zone) in age (Oviatt, 1986; Jensen and King, 1996, table 2). Divided into members where possible (descending):

Cbc, Cbc?

Calls Fort Shale Member (Middle Cambrian) – Brown-weathering, slope-forming, olive-gray to tan-gray, thin bedded, shale and micaceous argillite with minor, thin-bedded, dark-gray, silty limestone; *Bolaspidella* sp. trilobite fossils reported by Rigo (1968, USGS No. 5965-CO) in the Causey Dam quadrangle; 75 to 125 feet (23-40 m) thick on the leading edge of the Willard thrust sheet (Coogan, 2006a-b; see Rigo, 1968, aided by Mullens), 100 to 120 feet (30-35 m) thick in Causey Dam quadrangle (King this report), and about 400 feet (120 m) thick in Huntsville quadrangle (King this report).

Cbm, Cbm?

Middle limestone member (Middle Cambrian) – Dark to medium-gray, thick- to thin-bedded, argillaceous limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; contains subordinate olive-gray and tan-gray, thin-bedded, shale and micaceous argillite; typically forms "rib" or cliff between less resistant shale members; on leading edge of Willard thrust sheet, thickens southward from 425 feet (130 m) along Sugar Pine Creek, Dairy Ridge quadrangle, to 850 feet (260 m) along Sawmill Canyon, Horse Ridge quadrangle (Coogan, 2006a-b), and 548 feet (167 m) thick at Baldy Ridge section (Rigo, 1968, aided by Mullens) in Causey Dam or Horse Ridge quadrangle, but may be faulted, since about 400 feet (120 m) thick on flanks of Baldy and Knighton Ridges (King this report); 680 feet (200 m) thick in Huntsville quadrangle (Coogan, this report).

Cbh, Cbh?

Hodges Shale Member (Middle Cambrian) – Brown-weathering, slope-forming, olive-gray to tan-gray, thin-bedded, shale and micaceous argillite, and thin- to thick-bedded, dark- to medium-gray limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; typically vegetated slope former; along leading edge of Willard thrust sheet thickens southward from 410 feet (125 m) along Sugar Pine Creek, Dairy Ridge quadrangle, to 600 feet (180 m) along Sawmill Canyon, Horse Ridge quadrangle (Coogan, 2006a-b); reportedly 281 feet (86 m) thick at Baldy Ridge section (Rigo, 1968, aided by Mullens) in Causey Dam or Horse Ridge quadrangle and about 300 feet (90 m) thick on flank of Baldy Ridge (King this report); 300 feet (90 m) thick in Huntsville quadrangle (Coogan, this report). The lower Bloomington of Mullens (1969) in the Causey Dam quadrangle is likely the Hodges Shale, and it is about 250 feet (75 m) thick.

Cbk, Cbk?

Blacksmith Formation (Middle Cambrian) – Typically medium-gray, very thick to thick-bedded, dolomite and dolomitic limestone with tan-weathering, irregular silty partings to layers; weathers to lighter gray cliffs and ridges; 250 to 760 feet (75-230 m) thick in our map area.

The Blacksmith Formation on the leading edge of the Willard thrust sheet thickens southward from 600 feet (180 m) along Sugar Pine Creek in the Dairy Ridge quadrangle, to about 760 feet (230 m) in the northwestern Horse Ridge quadrangle (Coogan, 2006a-b). To the south and west, the Blacksmith is about 500 feet (150 m) thick near Causey Dam (Mullens, 1969), with a 530-foot (161 m) thickness reported at the Baldy Ridge section (Rigo, 1968, aided by Mullens) in the Causey Dam or Horse Ridge quadrangle. Farther west, the Blacksmith is reportedly 409 feet (125 m) thick in the Sharp Mountain area (Hafen, 1961) and is about 250 feet (75 m) thick near the South Fork Wolf Creek in the Huntsville quadrangle (Coogan this report); still farther west, this unit is reportedly about 700 to 800 feet (210-245 m) thick near Mantua (Williams, 1948; Ezell, 1953; Sorensen and Crittenden, 1976a). So the thickness of the Blacksmith Formation is low in the Huntsville quadrangle and thickens to north, west, and east, and thickens southward on leading edge of thrust sheet.

The Blacksmith to the north of our map area is about 475 feet (144 m) thick in the Porcupine Reservoir quadrangle (Rigo, 1968; Hay, 1982), about 450 feet (137 m) thick near the Blacksmith Fork River (Maxey, 1958), and 410 feet (125 m) thick in Blacksmith Fork Canyon (Hay, 1982).

The Blacksmith thickness in the Browns Hole area is uncertain due to poorly exposed Cambrian strata. Laraway's (1958) Blacksmith contacts are not those of Crittenden (1972) or our mapping (see also Hodges member above); so his reported 730-foot (220 m) thickness is suspect. Laraway's (1958) report of *Bolaspidella* and *Ehmaniella* trilobite fossils in his Blacksmith is also problematic because these fossils are characteristic of the Bloomington and Ute Formations, respectively (Maxey, 1958). Also, Laraway's description of covered intervals in typically cliff-forming Blacksmith imply a fault repetition of the Ute or his measuring at least 986 feet (300 m) of Ute (see Ute description for comparison) and less than 403 feet (123 m) of Blacksmith; further, Crittenden's (1972) large thicknesses (~1300 or less likely 1150 feet [~400 or <350 m]) and mixed carbonates above Ute shale on his lithologic column imply fault repetition(s). Our Blacksmith-Bloomington contact is above a non-resistant Ute interval that overlies a resistant cliffy interval in the Ute. This makes the Ute about 700 feet (215 m) thick on Crittenden's (1972) lithologic column, and the Blacksmith and lower Bloomington about 650 feet (200 m) thick on his column. Finally, Crittenden's (1972) lithologies are not like what Laraway (1958) reported in his measured section.

Cu-Cl **Ute and Langston Formations, undivided (Middle Cambrian)** – Unit only used in Mantua quadrangle; see each formation for descriptions; about 800 feet (245 m) thick.

Cu, Cu?

Ute Formation (Middle Cambrian) – Interbedded gray thin- to thick-bedded limestone with tan-, yellowish-tan-, and reddish-tan-weathering, wavy, silty layers and partings, and olive-gray to tan-gray, thin-bedded shale and micaceous argillite; and minor, medium-bedded, gray to light-gray dolomite; sand content in limestone increases upward such that calcareous sandstone is present near top of formation; mostly slope and thin ledge former; base less resistant (more argillaceous) than underlying Langston Formation; *Zacanthoides*, *Kootenia*, *Bathyuriscus*, and *Peronopsis* sp. trilobite fossils reported by Rigo (1968, USGS No. 5960-CO) in Causey Dam quadrangle; estimate 450 to 1000 feet (140-300 m) thick and thinnest on leading edge of Willard thrust sheet.

The thickness range for the Ute Formation is based on multiple studies. It is reportedly 600 to 700 feet (180-210 m) thick west of Sharp Mountain (see Ezell, 1953; Crittenden, 1972; Deputy, 1984), and though a 840-foot (256 m) thickness was reported north of our map area in the Porcupine Reservoir area (Rigo, 1968), the Ute only looks about 600 feet (180 m) thick on the Porcupine Reservoir map of Berry (1989). The Ute is reportedly 1090 and 1380 feet (330 and 420 m) thick in the Sharp Mountain area (Hafen, 1961; Rigo, 1968, respectively), but these thicknesses are suspect since the Ute is thinner to the north, east, and west. We suspect that Hafen (1961) used dips that were too steep (~30 degrees vs ~16.5 degrees) so the real Ute thickness is about 620 feet (190 m) where he measured his section; we do not know what Rigo (1968) measured. North of our map area in the Hardware Ranch quadrangle, Deputy (1984) measured 681 feet (207.6 m) of Ute. To the east, the Ute is about 450 feet (137 m) thick in the Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a-b) and 515 feet (157 m) thick at the Baldy Ridge section (Rigo, 1968) in the Horse Ridge quadrangle. The thickest Ute may be near the South Fork Wolf Creek in the Huntsville quadrangle, where Coogan estimates a 1000-foot (300 m) thickness, 1150 feet (350 m) thick if steeper dip, while King estimates the Ute is about 1100 feet (335 m) thick, based on a higher Ute-Langston contact than Coogan picked. Rigo (1968) reported 1370 feet (418 m) of Ute near the South Fork Wolf Creek, but his contacts are not used on our map. To the south in the Browns Hole quadrangle, about 700 feet (210 m) of mixed shale and limestone was shown by Crittenden (1972) and his depiction is likely derived from the 659 feet (201 m) of Ute reported by Laraway (1958) along the South Fork Ogden River; this is about what Laraway (1958) mapped. But Crittenden (1972) did not map the Ute-Blacksmith contact; further, see problems above under Blacksmith Formation.

The Ute Formation as first mapped in the James Peak, Mantua, and Huntsville quadrangles was too thick because Coogan mapped the lower shale in the Langston Formation as the entire Langston, not realizing the base of the Ute is a shale above the upper carbonate (typically dolomite) of the Langston. He did this because the upper carbonate is not distinct in these quadrangles, like it is to the west in the Mount Pisgah quadrangle and to the east in the Sharp Mountain quadrangle. The same problem exists locally in the Sharp Mountain quadrangle. Though King revised the present map to place the upper Langston carbonate in the Langston, problems with this contact and Ute and Langston Formation thicknesses may persist.

Just north of our map area in the Wellsville Mountains, Maxey (1958) reported *Ehmaniella*(?) sp. and *Glossopleura* sp. trilobites in and at the base of the Ute Formation, respectively, making it Middle Cambrian. Deiss (1938) and Berry (1989) reported *Ehmaniella* sp. trilobites north of our map area near the Blacksmith Fork River.

Cl, Cl? **Langston Formation (Middle Cambrian)** – Upper part is gray, sandy dolomite and limestone that weathers to ledges and cliffs; middle part is yellowish- to reddish-brown to gray weathering, greenish-gray, fossiliferous shale and lesser interbedded gray, laminated to very thin-bedded, silty limestone (Spence Shale Member); basal part is light-brown-weathering, ledge forming gray limestone and dolomite with local poorly indurated tan, dolomitic sandstone at bottom; basal part that is less resistant (Naomi Peak Member) is present at least in northwest part of our map area; conformably overlies Geertsen Canyon Quartzite; 200 to 400 feet (60-120 m) thick. Designated "Formation" rather than "Dolomite" due to the varied lithologies.

The thickness of the Langston Formation is based on several studies. North of the map area, 410 feet (125 m) of Langston was measured along the upper Blacksmith Fork River in the Hardware Ranch quadrangle by Buterbaugh (1982). The Langston is 270 feet (80 m) thick in the Sharp Mountain area (Hafen, 1961) and to the east it is about 200 to 250 feet (60 to 75 m) thick in the Horse and Dairy Ridge quadrangles (Coogan, 2006a-b); the 85-foot (26 m) thickness reported at the Baldy Ridge section (Rigo, 1968) in the Horse Ridge quadrangle is likely incorrect. The 170 feet (50 m) of dolomite reported near Browns Hole (Crittenden, 1972) is likely only the basal dolomite of the Langston Formation; Laraway (1958) probably measured 120 feet (37 m) of this basal dolomite and 298 feet (91 m) of Langston along the South Fork Ogden River in the Browns Hole quadrangle. Laraway's (1958) reported 398-foot (121 m) Langston thickness is likely an error, since he measured and mapped about 300 feet (90 m) of Langston. Near the South Fork Wolf Creek in the Huntsville quadrangle, the Langston is about 300 feet (90 m) thick (Coogan's measurements), but King used a higher contact on our map making the Langston about 390 feet (120 m) thick. Farther west the Langston is about 400 to 460 feet (120-140 m) thick (see Ezell, 1953; Maxey, 1958; Rigo, 1968; Buterbaugh, 1982).

Just north of the map area near the Blacksmith Fork River, the Langston trilobite fauna (*Glossopleura* zone) is Middle Cambrian in age (Maxey, 1958), and near Brigham City, the fauna (*Glossopleura* trilobite zone in Spence Shale, *Albertella* trilobite zone in Naomi Peak) is earliest Middle Cambrian in age (Maxey, 1958; Jensen and King, 1996, table 2).

CAMBRIAN AND NEOPROTEROZOIC

Cgc, Cgc?

Geertsen Canyon Quartzite (Middle and Lower Cambrian and possibly Neoproterozoic) – In the west mostly buff (off-white and tan) quartzite, with pebble conglomerate beds; pebbles are mostly rounded light-colored quartzite; contains cross bedding, and pebble layers and lenses; colors vary from tan and light to medium gray, with pinkish, orangish, reddish, and purplish hues; outcrops darker than these fresh quartzite colors; cliff forming; some brown-weathering, interbedded micaceous argillite and quartzite common at top and mappable locally; pebble to cobble conglomerate lenses more abundant in middle part of quartzite, and basal, very coarse-grained arkose locally; near Huntsville, total thickness about 4200 feet (1280 m), including upper argillite about 375 feet (114 m) thick and basal coarse-grained arkose (arkosic to feldspathic quartzite) about 300 to 400 feet (90-120 m) thick (Crittenden and others, 1971). Overall seems to be thinner near Browns Hole. Called Prospect Mountain Quartzite and Pioche Shale (argillite at top) by some previous workers.

Upper and lower parts of Crittenden and others (1971; Crittenden, 1972; Sorensen and Crittenden, 1979) are not mappable outside the Browns Hole and Huntsville quadrangles, likely because the marker cobble conglomerate and change in grain size and feldspar content reported by Crittenden and others (1971) is not at a consistent horizon; quartz-pebble conglomerate beds are present in most of the Geertsen Canyon Quartzite.

To the east on leading margin of Willard thrust sheet, the Geertsen Canyon is thinner, an estimated 3200 feet (975 m) total thickness (Coogan, 2006a-b), and may be divided into different members, though informal members to west and east are based on conglomerate lenses near member contact and feldspathic lower member (see Crittenden and others, 1971; Coogan, 2006a-b).

Cgcu **Upper part in west** – Mostly buff quartzite with pebble conglomerate beds increasing downward; colors vary from tan and light to medium gray, with pinkish, orangish, reddish, and purplish hues; brown-weathering, interbedded micaceous argillite and quartzite common at top and mappable locally; reported thicknesses vary from 2250 to 3400 feet (685-1035 m) (Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979). Near Huntsville, separation of upper and lower parts based on 10- to 200-foot (3-60 m) thick zone of 1- to 8-foot (0.3-2 m) thick cobble conglomerate lenses at bottom of upper part.

Cgcl, Cgcl?
Lower part in west – Typically conglomeratic and feldspathic quartzite (only up to 20% feldspar reported by Crittenden and Sorensen, 1985a, so not an arkosic), with 300- to 400-foot (90-120 m), basal, very coarse-grained, more feldspathic or arkosic quartzite; 1175 to 1700 feet (360-520 m) thick (Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979) and at least 200 to 400 feet (60-120 m) thinner near Browns Hole (compare Crittenden, 1972 to Sorensen and Crittenden, 1979). Unit queried where poor exposures may actually be surficial deposits.

Cgu **Upper member in east** – Tan, white, and light-gray, medium- to coarse-grained, cross-bedded, thick-bedded quartzite; base of upper part is marked by a resistant, light-colored quartzite with quartz-pebble conglomerate containing white and pink quartz and rare jasper clasts; incompletely exposed, so thickness uncertain (Coogan, 2006a-b). Contact between members in east is partly based on purplish color of upper part of lower member (Coogan, 2006a-b), so upper-lower contact may shift in quartzite and is uncertain in Sawmill and Hansen Canyons, southern Dairy Ridge quadrangle.

Cgl **Lower member in east** – Typically conglomeratic and feldspathic; contains a purplish-gray upper part and a light-colored lower part; thickness about 600 to 1300 feet (180-400 m), thickening northward in Dairy Ridge quadrangle (Coogan, 2006a-b).

NEOPROTEROZOIC

Zrx **Neoproterozoic formations, undivided (Neoproterozoic)** – Unit used in parentheses in block landslides or possible block landslide where the bedrock is an unknown Neoproterozoic formation or is several formations.

Zb **Browns Hole Formation (Neoproterozoic)**

Zbq, Zbq?
Quartzite member (Neoproterozoic?) – Locally mappable north of the Middle Fork Ogden River due to lighter colored, more resistant beds than adjacent overlying Geertsen Canyon Quartzite, but has same resistance as quartzite higher in Geertsen Canyon unit, and is not distinctly red or terra-cotta colored despite previous descriptions (see Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979); this “terra-cotta” (reddish-orange) quartzite is absent on leading edge of Willard thrust sheet and obscure near North and South Forks of Ogden River; 0 to 285 feet (0-85 m) thick.

Much of the reddish orange color seems to be along fault zones and be "bleeding" from the underlying hematitic Browns Hole, such that the member may be part of the lithologically similar Geertsen Canyon Quartzite (King's interpretation); further work is need to resolve this problem.

Zbv, Zbv?

Volcanic member (Neoproterozoic) – Poorly resistant, gray to reddish-gray weathering, typically vegetated, metamorphosed (but with no fabric), brownish- to purplish-red (hematitic) volcanic-clast meta-sedimentary and fragmental(?) meta-volcanic rock; volcanic material and clast size decreases to south and east, so mostly volcanic meta-sandstone with some argillite near South Fork Ogden River and on leading margin of Willard thrust sheet (Coogan, 2006a); reportedly basaltic andesite to trachytic in composition (Crittenden and Sorensen, 1985a); meta-andesite lava flows reported in James Peak quadrangle (Blau, 1975); 180 to 460 feet (55-140 m) thick near Ogden River forks (after Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979); only 20 to 200 feet (6-60 m) thick in exposures on leading edge of Willard thrust sheet in Dairy Ridge quadrangle (Coogan, 2006a); hornblende K-Ar age of 570 ± 7 Ma (580 Ma corrected) from a trachyte cobble in Huntsville quadrangle (Crittenden and Wallace, 1973; Sorensen and Crittenden, 1979).

Zm?c **Mutual Formation? and Caddy Canyon Quartzite (Neoproterozoic)** – Unit mapped on leading margin of Willard thrust sheet where Inkom Formation is absent and exposures have characteristics of both formations (see Coogan, 2006a). Reddish-gray, pink, tan, and light-gray, thick-bedded, locally vitreous quartzite, and conglomeratic and feldspathic quartzite; upper part of unit darker colored, but because the Inkom is not present, dark part may or may not be the Mutual Formation; total exposed thickness about 725 to 1300 feet (220-400 m) (calculated from outcrop pattern, dip, topography), apparently thickening northward (or underlying argillitic strata mapped as Zpc? pinches out northward); base truncated by Willard thrust where Zpc? not mapped.

Zm, Zm?

Mutual Formation (Neoproterozoic) – Grayish-red to purplish-gray, medium to thick-bedded quartzite with pebble conglomerate lenses; also reddish-gray, pink, tan, and light-gray in color and typically weathering to darker shades than, but at least locally indistinguishable from, Geertsen Canyon Quartzite; commonly cross-bedded and locally feldspathic; contains argillite beds and, in the James Peak quadrangle, a locally mappable medial argillite unit; 435 to 1200 feet (130-370 m) thick in Browns Hole quadrangle (Crittenden, 1972) and thinnest near South Fork Ogden River (W. Adolph Yonkee, Weber State University, verbal communication, 2006); thicker to northwest, up to 2600 feet (800 m) thick in Huntsville quadrangle (Crittenden and others, 1971) and 2556 feet (780 m) thick in James Peak quadrangle (Blau, 1975); may be as little as 300 feet (90 m) thick south of the South Fork Ogden River (King this report); absent or thin on leading edge of Willard thrust sheet (see unit Zm?c); thins to south and east.

Zi, Zi? **Inkom Formation (Neoproterozoic)** – Overall gray to reddish-gray weathering, poorly resistant, psammite and argillite, with gray-weathering meta-tuff lenses in lower part; upper half dominantly dark-green, very fine-grained meta-sandstone (psammite) with lower half olive gray to lighter green-gray, greenish gray-weathering, laminated, micaceous meta-siltstone (argillite); lower greenish-weathering part missing near South Fork Ogden River and the Inkom is less than 200 feet (60 m) thick; in Mantua quadrangle, Inkom typically 300 feet (90 m) thick, and is only less than 200 feet (60 m) thick where faulted (King this report); 360 to 450 feet (110-140 m) thick northeast of Huntsville (Crittenden and others, 1971), and absent on leading edge of Willard thrust sheet (Coogan, 2006a); location of "pinch-out" not exposed.

Zcc, Zcc?

Caddy Canyon Quartzite (Neoproterozoic) – Mostly vitreous, almost white, cliff-forming quartzite; colors vary and are tan, light-gray, pinkish-gray, greenish-gray, and purplish-gray, that are typically lighter shades than the Geertsen Canyon Quartzite; 1000 to 2500 feet (305-760 m) thick in west part of our map area, thickest near Geertsen Canyon in Huntsville quadrangle (Crittenden and others, 1971; Crittenden, 1972); 1500 feet (460 m) thick near South Fork Ogden River (Coogan and King, 2006); thinner, 725 to 1300 feet (220-400 m) thick, and less vitreous on leading edge of Willard thrust sheet.

Lower contact with Kelley Canyon Formation is gradational with brownish-gray quartzite and argillite beds over a few tens to more than 200 feet (3-60 m) (see Crittenden and others, 1971). Where thick, this gradational-transitional zone is what is mapped as the Papoose Creek Formation. Near Geertsen Canyon, this transition zone is 600 feet (180 m) thick and was mapped with and included in the Caddy Canyon Quartzite by Crittenden and others (1971, figure 7), and in the Caddy Canyon and Kelley Canyon Formations by Crittenden (1972, see lithologic column).

Zpc-Zcc

Papoose Creek and Caddy Canyon Formations, undivided (Neoproterozoic) – North of Perry Canyon in the Mantua quadrangle, these strata previously mapped as Zpc contains brown-weathering, medium- to coarse-grained quartzite (see Sorensen and Crittenden, 1976a; Crittenden and Sorensen, 1985a). This likely resulted in difficulty identifying the gradational contact with the overlying Caddy Canyon Quartzite and resulted in King mapping a Zpc-Zcc gradational unit of variable thickness, rather than mapping complex structure like Crittenden and Sorensen (1985a).

Zpc, Zpc?

Papoose Creek Formation (Neoproterozoic) – Gray to brownish-gray to olive-gray argillite to psammite; metasiltstone interbedded with quartzose metasandstone and quartzite; argillite darker colored with greenish-gray, micaceous bedding surfaces; 750 to 1000 feet (230-300 m) thick in Mantua quadrangle.

The Papoose Creek unit seems to be the transition zone between the Caddy Canyon Quartzite and the Kelley Canyon Formation. Crittenden and others (1971) reported a 100- to 200-foot (30-60 m) thick transitional zone north of the Middle Fork Ogden River in the Browns Hole quadrangle, but we could not map their zone. We mapped a queried Zpc south of the Middle Fork where the unit was not field checked.

Interbedded gray quartzite (like Caddy Canyon) and reddish- and greenish-gray argillite (like Kelley Canyon) is mapped as Zpc? in the Dairy Ridge quadrangle; it is up to about 300 feet (90 m) thick, with its base truncated by the Willard thrust (see Zkc? of Coogan, 2006a). Other exposed Neoproterozoic units thin to east, so this may be the entire Papoose Creek thickness.

Zkc, Zkc?

Kelley Canyon Formation (Neoproterozoic) – Dark-gray to black, gray to olive-gray-weathering argillite to phyllite, with rare metacarbonate (for example basal meta-dolomite); grades into overlying Caddy Canyon quartzite with increasing quartzite; gradational interval mapped as Papoose Creek Formation (Zpc); 1000 feet (300 m) thick in Mantua quadrangle (this report), where Papoose Creek Formation is mapped separately, and reportedly 2000 feet (600 m) thick near Huntsville (Crittenden and others, 1971, figure 7), but only shown as about 1600 feet (500 m) thick to Papoose Creek transition zone by Crittenden (1972). The Kelley Canyon Formation is prone to slope failures.

Zmc, Zmc?

Maple Canyon Formation, undivided (Neoproterozoic) – Upper part green to greenish-gray, feldspathic quartzite to metaconglomerate, separated by laminated argillite, with buff quartzite and thin bed of gray meta-limestone near Perry Canyon; lower part feldspathic meta-sandstone and argillite; about 1000 feet (300 m) total thickness. Member thicknesses add up to more than 1000 feet (300 m), even without lower argillite that is part of the formation of Perry Canyon (see Crittenden and others, 1971; Sorensen and Crittenden, 1976a-b; Crittenden and Sorensen, 1985a). Members are actually lithosomes, so more work is needed to justify formal Formation designation.

Zmcc, Zmcc?, Zmcc1, Zmcc1?, Zmcc2, Zmcc2?, Zmcc3, Zmcc3?

Upper (conglomerate) member (Neoproterozoic) – At top (Zmcc3) and bottom (Zmcc1), light-gray coarse-grained, quartzite to pebble and small cobble meta-conglomerate with local tan-weathering, dark-gray, meta-graywacke matrix; thin olive-gray, laminated, weakly resistant argillite in middle (Zmcc2); 60 to 500 feet (20-150 m) total thickness; thickness of sub-units varies considerably and these sub-units may be absent locally; conglomerate beds appear thickest in northeast part of Huntsville quadrangle, possibly more than 200 feet (60 m) thick, while middle argillite appears less than 50 feet (15 m) thick; only divided into subunits to show structure in Huntsville quadrangle.

Zmcg, Zmcg?

Lower (green arkose) member (Neoproterozoic) – Grayish-green, fine-grained arkosic (feldspathic) meta-sandstone and sandy argillite (meta-graywacke), with local quartzite lenses up to 200 feet (60 m) thick; weathers darker gray to brown to greenish-gray and greenish-brown; 500 to 1000 feet (150-305 m) thick and lower thickness would eliminate the need for faulting in southwest part of Huntsville quadrangle. This unit is prone to slope failures.

NEOPROTEROZOIC AND MESOPROTEROZOIC

Zarx **Argillite of lower member of Maple Canyon Formation or upper member of Formation of Perry Canyon (Proterozoic)** – Greenish-gray argillite to meta-graywacke in poor exposures on east side of Ogden Valley (Zarx and Qdlb/Zarx) and on dip slope west of Ogden Valley; weathering, lack of bedding, and lack of exposures of overlying conglomerate member of Maple Canyon preclude separation of these stratigraphically adjacent units. This unit is prone to slope failures.

ZYp, ZYp?

Formation of Perry Canyon (Neoproterozoic and possibly Mesoproterozoic) – Argillite to meta-graywacke upper unit, middle meta-diamictite, and basal slate, argillite, and meta-sandstone; phyllitic at least south of Pineview Reservoir; due to overturned folding, only one diamictite unit (Adolph Yonkee, Weber State University, February 2, 2011, email communication) rather than two (see Crittenden and others, 1983); total thickness likely less than 2000 feet (600 m) (this report). Queried in knob west of North Fork Ogden River in North Ogden quadrangle because rock is quartzite that may be in this unit or the Papoose Creek Formation. The formation of Perry Canyon is prone to slope failures.

Balgord's (2011; Balgord and others, 2013) detrital zircon uranium-lead and lead-lead maximum depositional ages (~950-1030 Ma) on the basal mudstone unit straddle the Upper and Middle Proterozoic boundary, but other maximum ages (925 Ma) on this mudstone unit are Upper Proterozoic; her maximum ages on the upper unit are about 640, 660, and 690 Ma.

Lower part of formation not measured where thick in the Wasatch Range and stratigraphy not worked out, because upper and lower parts incompletely measured and at least locally the upper and lower parts in the Wasatch Range are lithologically indistinguishable. Unit ("member") thicknesses vary due to syndepositional faulting (see Balgord and others, 2013). The best stratigraphic section of the lower unit (ZYpm), volcanic unit (Zpb), and diamictite (Zpd) is 30 miles (50 km) to the southwest on Fremont Island in Great Salt Lake, but the base of ZYpm is not exposed (see Balgord, 2011, figure 14, p. 51; Balgord and others, 2013, figure 5). The Fremont Island section is likely in a different Proterozoic faulted basin; compare thicknesses and lithologies between Fremont Island and Willard Peak shown by Balgord (2011, Balgord and others (2013). Also, although both localities are shown on the Willard thrust sheet by Yonkee and Weil (2011), they may be on different thrust sheets. Therefore, the formal term Perry Canyon Formation is not used. Where possible divided into several lithosomes which have been called members.

Zpu, Zpu?

Upper member (Neoproterozoic) – Olive drab to gray, thin-bedded slate to argillite to phyllite to micaceous meta-siltstone to meta-graywacke to meta-sandstone in variable proportions such that unit looks like both the "greywacke-sandstone" and "mudstone" members of previous workers; unit identification based on underlying diamictite in Mantua quadrangle; rare meta-gritstone and meta-diamictite (actually conglomerate?); locally schistose; meta-sandstone contains poorly sorted lithic, quartz, and feldspar grains in silty to micaceous matrix; meta-sandstone is quartzose in outcrops on west margin of Mantua quadrangle (Crittenden and Sorensen, 1985a) and medial zone of sandstone is feldspathic east of Ogden Valley, where mapped and described as argillite member of Maple Canyon Formation by Crittenden (1972) and Sorensen and Crittenden (1979); thickness uncertain, but appears to be about 600 feet (180 m) thick on west flank of Grizzly Peak in the Mantua quadrangle and about 1000 feet (300 m) thick between Ogden Canyon and North Ogden divide. In Ogden Valley typically non-resistant and tan weathering such that gray to green to dark-gray fresh color is seldom seen except in cut slopes and excavations. This unit is prone to slope failures.

Zpi **Altered meta-intrusive diorite (Proterozoic)** – North-northeast trending, green-weathering dike(?), about 300 to 400 feet (90-120 m) wide, cutting the mudstone unit (ZYpm) north of Cobble Creek as mapped by Crittenden and Sorensen (1985b).

Described by Balgord (2011) as greenstone that cuts the meta-basalt and overlying meta-diamictite in klippe north of North Ogden Pass, but not described differently than meta-basalt rocks.

Other greenstone bodies are involved in the large Ogden Valley landslide block, such that stratigraphic relationships are obscured and their age relationships with Zpu, Zpd, and ZYpm are not known.

Zpd, Zpd?

Diamictite member (Neoproterozoic) – Tan to gray weathering, gray to dark-gray meta-diamictite containing pebble to boulder-sized quartzite and granitoid (quartzo-feldspathic gneiss) clasts in dark-gray sandy (up to granule size) to micaceous argillite matrix; fuschsite-bearing quartzite clasts minor but distinctive; local meta-pillow lava (unit Zpb) and meta-limestone at and near base, and local altered intrusive diorite (unit Zpi) (Crittenden and Sorensen, 1985b); appears to be up to 200 to 400 feet (60-120 m) thick in our map area but is about 1000 feet (300 m) thick to the west in the Willard quadrangle.

From Balgord and others (2013, and Balgord, 2011) detrital zircon uranium-lead and lead-lead maximum depositional ages on the upper part of the diamictite are about 650 to 690 Ma with about a 120 million year gap to about 800 Ma on the lower part of the diamictite. This major unconformity is within the meta-volcanic (Zpb) unit to the west of the map area on Fremont Island, such that the diamictite above the meta-volcanics and where the meta-volcanics are missing in the Ogden map area may be considerably younger than the lower diamictite.

In Perry Canyon a "felsic tuff" is present at the base of the diamictite (or top of "mudstone"), and it contains columbite-tantalite and monazite (reworked felsic lava flow of Balgord, 2011, p. 60; volcanic sandstone in her figure 16, p. 53).

The diamictite reportedly has a large volcanic component in the klippe north of the North Ogden divide with the majority of clasts being mafic volcanic rocks from the underlying meta-basalt (Zpb) and a few large "basement" clasts in a greenish-colored matrix with about 50% sand and silt (Balgord, 2011). This implies the klippe diamictite lacks the quartzite and granitoid clasts of the typical diamictite, and may be a volcanic unit rather than part of the diamictite member.

Near Lewis Peak in the North Ogden quadrangle, the diamictite contains typical granitoid and quartzite clasts with minor sedimentary and volcanic rock clasts of cobble to boulder size in a dark gray quartzose pebbly to sandy to micaceous argillite matrix (after Balgord, 2011). Granitoid clasts look like they are from the Farmington Canyon Complex.

Zpb **Basaltic meta-volcanic rocks (Proterozoic)** – Green meta-basalt pillow lava and other basaltic fragmental material north of North Ogden Pass; appears to underlie meta-diamictite; thickness uncertain.

ZYpm, ZYpm?

"Mudstone" member (Neoproterozoic and possibly Mesoproterozoic) – Gray- and green-weathering, black, non-foliated argillite and sandy argillite, and slate; grades laterally into black chloritoid schist that contains scattered pyrite cubes; reportedly 1650 to 3300 feet (500-1000 m) thick (after Crittenden and Sorensen, 1985a), but appears to be about 1000 feet (300 m) thick in Willard Basin and 1800 feet (550 m) thick on North Ogden-Mantua quadrangle boundary. This unit is prone to slope failures.

The "mudstone" member unconformably overlies the Facer Formation near Willard Peak (Balgord, 2011). The relationship between the mudstone and diamictite is uncertain. No meta-diamictite is present near Willard Peak, so we cannot tell if the mudstone-diamictite contact is conformable. Crittenden and Sorensen (1985b) mapped a band of mudstone in diamictite on the north margin of the Ogden Valley landslide mass (QTms?) that may or may not be in-place bedrock. "Mudstone" also overlies diamictite and is in contact with the sandstone-graywacke member across a fault in the southeast part of the North Ogden quadrangle (Crittenden and Sorensen, 1985b), but colors on their map in this area are incorrect and the map "polygon" could be mis-labeled ZYpm as well as being mis-colored.

MESOPROTEROZOIC AND PALEOPROTEROZOIC?

YXf, YXf?

Facer Formation (Proterozoic) – Contains (in order of abundance): quartzite (YXfq), pelitic phyllite and schist (YXfs), and quartz-muscovite (or sericite) schist (meta-tuff?) (not mapped separately), with sparse mafic bodies (discordant meta-diorite, mapped as YXfdi, and unmapped concordant meta-gabbro [<90% amphibole]), leucocratic gneiss (YXfgn), meta-carbonate (too small to show separately on this map) and meta-conglomerate; also contains distinctive green micaceous quartzite, lustrous, reddish-black quartz hematite (specularite) schist (not mapped separately), and tourmaline-bearing pegmatite (not mapped separately); truncated by Willard thrust fault; estimate 2500 feet (760 m) total thickness (Crittenden and Sorensen, 1980), with about 1700 feet (500 m) of schist exposed east of Willard Canyon and about 800 feet (240 m) of unconformably underlying leucogneiss exposed on west margin of our map area (this report). Facer Formation queried where poor exposures may actually be surficial deposits. The Facer Formation is prone to slope failures.

Dr. Adolph Yonkee (Weber State University, February 2, 2011, email communication) stated (using the Xf unit symbols of Crittenden and Sorensen, 1985a) that the upper part of the Facer (south of Facer Creek and best exposed near Willard Canyon) is phyllitic and schistose (Xfs) with interbedded quartzite (Xfq) and lesser conglomerate beds (Xfcg), mafic bodies (unmapped), and carbonates (Xfd, Xfls). He stated the lower part of the Facer (north and barely south of Facer Creek) is quartzitic gneiss (Xfgn) with pegmatite (Xfp), mafic bodies (Xfdi), and quartzite (Xfvq, Xfq [in landslide block]) bodies. So the lower Facer is only exposed near Facer Creek.

The age of the Facer has not been resolved. It may be Mesoproterozoic (Y) and/or Paleoproterzoic (X); so for the present we show it as YXf. The Facer was thought to be metamorphosed at about the same time as the Farmington Canyon Complex (~1700 Ma); however, Balgord's (2011; Balgord and others, 2013) detrital zircon uranium-lead and lead-lead maximum depositional ages on the upper Facer are about 1200 Ma, which indicates later metamorphism or deposition in the Mesoproterozoic. The upper Facer isotopic ages are compatible with Farmington Canyon metamorphism, with Rb-Sr age of about 1660 Ma and K-Ar age of about 1340 Ma (on muscovite from same sample [67-MC-82, table 2, Crittenden and Sorensen, 1980] of unit Xfs of Crittenden and Sorensen, 1985a), and, based on lithology, may be a lower grade assemblage of the Farmington Canyon rocks. The tourmaline-bearing pegmatite isotopically dated by Rb-Sr analyses as about 1580 Ma and by K-Ar analyses as about 1360 Ma, both on muscovite (Crittenden and

Sorensen, 1980, 67-MC-84, table 2), is in the upper part of the Facer and is not the same as the pegmatites (Xfp of Crittenden and Sorensen, 1985a) in the lower part of the Facer. These isotopic ages may date the upper Facer, or be late or modified from Farmington Canyon Complex metamorphism. An isotopic analysis of the lower Facer yielded a hornblende K-Ar age of about 1680 Ma on a meta-diorite pod (unit Xfdi of Crittenden and Sorensen, 1980, 72-MC-130c, table 2), which is about that of the Farmington Canyon Complex metamorphism (see unit Xfc).

Members of previous workers are actually lithosomes, and are poorly exposed and mapped, with much undivided Xf (our YXf) on their maps. So more work is needed to justify formal Formation designation. From previous mapping divided into lithosomes, with descriptions, except for thicknesses, after Crittenden and Sorensen (1980).

YXfq, YXfq?

Quartzite (Proterozoic) – Off-white- to tan-weathering, white to very pale-gray, vitreous to translucent, highly jointed or fractured, yet cliff-forming quartzite with minor white mica (sericite or muscovite) and rare chlorite; intercalated with fine- to coarse-grained quartz-muscovite (sericite) schist; locally "intruded" by thin (<1 m) tourmaline-bearing pegmatites (Crittenden and Sorensen, 1985a) and associated with coarser quartz-muscovite schist (Crittenden and Sorensen, 1980); from 3-point solutions in the Mantua quadrangle, quartzite bands are about 100 to 550 feet (30-160 m) thick; (Adam McKean, Utah Geological Survey, email communication, February 18, 2016; 1300-foot (~400 m) thickness reported in Crittenden and Sorensen (1985a) is probably the combined thickness of their interlayered Xfq and Xfs units.

Locally includes light to apple-green (chromian) micaceous (fuchsitic) quartzite layers 3 to 7 feet (1-2 m) thick (Xffq of Crittenden and Sorensen, 1985a). These layers are present along vague fractures subparallel to bedding in their Xfq, but were also mapped at high angles to bedding in probable fractures and along a fault in the north wall of Willard Canyon.

YXfs, YXfs?

Pelitic phyllite and schist (Proterozoic) – Grayish-green and grayish-purple (chloritic to hematitic) pelitic rocks (siltstone and mudstone) metamorposed into slate and phyllite, and sericite, chlorite, and/or chloritoid schist; near Willard Peak includes 16- to 33-foot (5-10 m) thick, meta-conglomerate beds, Xfcg of Crittenden and Sorensen (1985a), with clasts that are mainly (80%) white to pale-gray quartzite from Facer Formation in a sparse gray pelitic matrix; from previous mapping interlayered with quartzite (Xfq of Crittenden and Sorensen, 1985a) and local dolomite (Xfd of Crittenden and Sorensen, 1985a); from 3-point solutions in the Mantua quadrangle, schist and phyllite bands are about 30 to 350 feet (10-100 m) thick (Adam McKean, Utah Geological Survey, email communication, Febuary 18, 2016); 1300-foot (~400 m) thickness Crittenden and Sorensen (1985a; see also 1985b) is probably the combined thickness of interlayered quartzite and phyllite-schist (their Xfq-Xfs) units. This unit (our YXfs) is prone to slope failures.

YXfdi **Meta-diorite pod (Proterozoic)** – Fine-grained hornblende diorite in undivided Facer (YXf) on north side of Facer Creek in Mantua quadrangle; discordant with primary hornblende and feldspar, so atypical of amphibolites elsewhere in Facer Formation and isotopically dated meta-diorite pod; 33 to 130 feet (10-40 m) thick (Crittenden and Sorensen, 1985a), though shown as much thicker on their map.

YXfgn, YXfgn?

Leucocratic gneiss (Proterozoic) – Composed of quartz and microcline with minor sericite and mucsovite; mapped between Perry Canyon and Facer Creek northeast of White Rock; locally intercalated with quartzite and quartz-muscovite schist (both in our undivided unit YXf), grading into these rocks to the south (Crittenden and Sorensen, 1985a); meta-arkose of Crittenden and Sorensen (1980) is feldspathic meta-sandstone since they reported <50% feldspar; thickness indeterminate.

This quartzitic gneiss may be metamorphosed igneous rock (orthogneiss) or sedimentary rock (paragneiss). The gneiss appears to unconformably underlie YXfs and YXfq and be the lower Facer, but its base is not exposed. Crittenden and Sorensen (1985a) showed it as undivided Xf down slope and to the south, so this gneiss does not appear to grade into their quartzite map unit (Xfq).

SUB-WILLARD THRUST – OGDEN CANYON AREA

and Tertiary strata that are younger than the Willard thrust sheet

These strata are a transitional shelf sequence between deeper-water strata now exposed on the Willard thrust sheet and shallower-water strata exposed to the east on Durst Mountain and the Crawford thrust sheet (see for example Coogan, 1992a). Therefore the use of Devonian Beirdneau, Hyrum, and Water Canyon names, along with the Cambrian St. Charles, Nounan, and Bloomington names from the outer shelf sequence (Willard thrust sheet) may not be appropriate for the strata in Ogden Canyon (Ogden thrust sheet) and strata to the south in the Wasatch Range near Salt Lake City, as well as on Durst Mountain and the Crawford thrust sheet.

We have chosen to retain the Devonian and Cambrian formation names because: (1) they have been used previously (Williams, 1971; Sorensen and Crittenden, 1979; Crittenden and Sorensen, 1985b; Yonkee and Lowe, 2004); (2) previous work on the Devonian and upper Cambrian strata in the area is confusing (see previous references as well as Eardley, 1944; Brooks and Andrichuk, 1953; Brooks, 1954; Schick, 1955; Brooks, 1959; Mullens and Laraway, 1973; Coogan and King, 2006); and (3) except for the Water Canyon Formation, the strata, though thinner, are like that on the Willard thrust sheet. To the south near Salt Lake City, Bryant (1984, 1988, 1990) mapped different Devonian lithologies (Pinyon Peak and Stansbury Formations) related to the Stansbury uplift, with erosion and clastic sediment deposition. Devonian age subdivisions are not noted due to the unit name uncertainty.

Further complicating the geology, Silurian and some Ordovician strata are missing in the Ogden Canyon, Wasatch Range, and Durst Mountain areas (for example, Laketown Dolomite and Swan Peak Quartzite), and Devonian through upper Cambrian strata are thinner over the Stansbury uplift and Tooele arch (see Rigby, 1959; Hintze, 1959). Also, strata in the Ogden Canyon area have been tectonically thinned and duplicated to triplicated during movement on the Ogden and Willard thrust faults (see for example Yonkee and others, 1997; Yonkee and Lowe, 2004). This means the map-unit thicknesses are highly variable and, though we have attempted to present numbers that are undeformed thicknesses, the thicknesses reported may be inaccurate due to deformation.

It is not known which units are present in the subsurface below the Wasatch Formation in Morgan Valley. We are uncertain because the width and height of the Wasatch anticlinorium is uncertain, and because the amount of erosion of the Ogden thrust and sub-Willard thrust strata is uncertain (for different interpretations see Bryant, 1990, cross section C-C'; Royse, 1993, cross section H-H'; Yonkee and others, 1997, cross section B-B'; Yonkee and others, 2003). Also, the Paleozoic Tooele arch and Stansbury uplift have affected the area, so the units exposed to the north in the Ogden Canyon area (Yonkee and Lowe, 2004; King and others, 2008) are not the same as those to the east on Durst Mountain (Coogan and King, 2006; Coogan and others, 2015) or those exposed to the south in the Wasatch Range near Salt Lake City (see Bryant, 1990).

TERTIARY

Ts **Tertiary strata, undivided** – Only used in Ogden Canyon area where Norwood and Wasatch Formations are in landslide block [Qms?(Ts)] in Line Creek drainage, Peterson quadrangle, and below old fan (QTaf/Ts) near Maples recreation area (formerly campground), Snow Basin quadrangle; latter may be on or below the Willard thrust.

Tn, Tn? **Norwood Formation (lower Oligocene and upper Eocene)** – Typically light-gray to light-brown altered tuff (claystone), altered tuffaceous siltstone and sandstone, and conglomerate; unaltered tuff, present in type section to south, is rare; locally colored light shades of red and green; variable calcareous cement and zeolitization; involved in numerous landslides of various sizes; exposed thickness up to 7000 feet (2135 m), thickest between Morgan and Huntsville; thins to south to about 2800-foot (850 m) thickness exposed in type area adjacent to map area; type area thicknesses noted in Coogan and King (2006) and King and others (2008) are incorrect; may thin to north since estimated 2000-foot (600 m) thickness exposed on west side of Ogden Valley (based on bedding dip, outcrop width, and topography).

Mixed off-white and red Norwood strata are present south of Morgan, giving the appearance that the Norwood (Tn) and Wasatch (Tw) Formation strata are interbedded. These strata were shown by Coogan and King (2001) as Tw, but altered tuffaceous strata are in the road cuts, and as noted in the descriptions of units Tcg and Thv, an eroded red contribution from the Wasatch Formation will make the younger rocks look red like the Wasatch Formation.

The Norwood Formation is generally considered younger than the Fowkes Formation (isotopically dated at 39-40 Ma and 48-49 Ma) (see also unit Tnf in text on Willard thrust sheet cover rocks). However, the Norwood K-Ar isotopic ages of 38.4 Ma (sanidine, corrected), from a sample taken along Utah Highway 66 near Norwood type area (Evernden and others, 1964, p. 182-183) south of Morgan, Utah, and 39.3 Ma (biotite, corrected), from a sample farther south in a different depositional basin (in the East Canyon graben) (Mann, 1974), are not much different than the younger Fowkes ages. The basal part of a similar unit to the north in western Cache Valley was isotopically dated at 44 and 49 Ma (see unit Tnf under Willard thrust sheet cover rocks). Also the strata near Morgan that were isotopically dated are at least 2500 feet (800 m) above the base of the Norwood and much older strata may be present in Morgan Valley. Paleontological evidence on the Norwood Formation is presented in Adamson (1955), Evernden and others (1964), and Nelson (1971, 1977). Paleontological studies by Gazin (1959, p. 137) indicate that some Norwood beds in or near the type area are Eocene, which agrees with the isotopic age.

The name Norwood Tuff was introduced by Eardley (1944), but his paper did not conform to the requirements in the North American Code of Stratigraphic Nomenclature. The Norwood is referred to here as "Formation" rather than using "Tuff" in the name, because the type area includes only part of the formation, the Norwood contains many lithologies, and using "Formation" emphasizes that it is not tuffaceous away from the type area. Even near the type area, the Norwood has cut-and-fill structures (fluvial), volcanic-clast conglomerate, and local limestone and silica-cemented rocks. Further, the upper Norwood Formation between Ogden and Morgan Valleys contains granule to small pebble conglomerate, with chert and carbonate clasts, as well as claystone and fine- to coarse-grained sandstone (see Coogan and King, 2006).

The relationship(s) between the Norwood Formation, Keetley Volcanics, Fowkes Formation, and other pre-Miocene volcaniclastic rocks in northern Utah has been discussed periodically (Wingate, 1961; Eardley, 1969; Nelson, 1971, 1979; Bryant and others, 1989) since the Norwood was named by Eardley (1944). Prior to work on the Ogden 30x60-minute quadrangle, the Norwood Formation was considered to be younger than the Fowkes Formation. However, neither formation is well dated due to alteration of datable minerals and the considerable thicknesses of partially exposed volcaniclastic fill in multiple basins. Further, Veatch (1907), who named the Fowkes, and Eardley (1944) mistakenly placed the Fowkes Formation within the Eocene and Paleocene Wasatch Formation strata (their Almy and Knight Formations), raising questions about whether Fowkes is an appropriate name. Also complicating the naming problems, strata of the type Norwood Tuff were originally named and placed in the Salt Lake Formation/Group by Hayden (1869), and Fowkes-age strata in Cache Valley (see Smith, 1997; Oaks and others, 1999) were mapped as part of the Salt Lake Formation (see for example Williams, 1962).

Isotopic ages indicate a bimodal age distribution (~39-40 & 48-49 Ma) for Fowkes strata exposed along the Utah-Wyoming border (see Tf under heading "Area East of Henefer and Along Saleratus Creek, and Thrust Sheets East of Crawford Thrust"), with one outlier. Our sample 96-53 came from the Fowkes just above the top of the Wasatch Formation and was isotopically dated by K-Ar analyses on hornblende at 32.3 $\pm$ 1.2 Ma, but this sample is stratigraphically below the samples isotopically dated at about 39-40 Ma. The young ages for the Fowkes are from strata below the unit shown as Norwood Tuff by Bryant (1990). The older Fowkes ages and paleontological evidence indicate the older Fowkes strata are essentially the time equivalent of the Bridger Formation to the east in the Green River Basin, Wyoming (Nelson, 1973, 1974; see also Lillegraven, 1993, figures 4O and 4P). As yet, older Fowkes cannot be distinguished in the field from younger Fowkes, so abandoning the Fowkes name for just the older Bridger-age strata and using the Norwood name on the younger strata is premature.

Isotopic ages of the Keetley Volcanics and their intrusive equivalents are generally younger than or as old as the younger Fowkes and Norwood ages (~33 to 39 Ma) (see Vogel and others, 1997; see also Nelson, 1976), but the ages of some intrusions near Park City are reportedly within the Fowkes age range (38-39 to 48-49 Ma), but some are between the bi-modal age sets (40-47 Ma) (John and others, 1997). Because intrusions cool more slowly than volcanic rocks, the datable minerals in source intrusions pass through their setting temperatures later than they do in their eruptive equivalents and therefore the intrusions can have isotopic ages that are several million years younger than their eruptive equivalents (Lipman and Bachmann, 2015). Based on these ages and the "lag" in intrusion ages, the Park City area may be the source of the younger volcanic material in the Fowkes Formation more than 25 miles (40 km) to the northeast as well as the Norwood Formation 20 to 50 miles (30-80 km) to the north-northwest. The most likely volcanic source(s) for the older (48-49 Ma) Fowkes-Bridger strata is the Challis volcanic field in Idaho, and/or the Absaroka volcanic field in Wyoming (see Smith and others, 2008, in particular figure 5), though with the intrusive lag some volcanic material could be from the Park City area.

Similar volcanic to tuffaceous strata of about the same age are exposed near Salt Lake City. Volcanic strata near Salt Lake City, isotopically dated by K-Ar analyses at 38, 39 (two samples), and 45 Ma, were reported by Van Horn (1981; Van Horn and Crittenden, 1987). However, the sample locations and analytical data were never reported, making it impractical to evaluate these ages and their relationships to the Norwood and Fowkes Formations.

Based on similar ages (discussed above) and geology, the type Norwood Formation appears to be the more distal sedimentary equivalent of the volcano comprised by the Keetley Volcanics to the south near Park City, Utah. This correlation is likely because the Norwood Formation to the southeast in the East Canyon graben is transitional between the Morgan Valley and Park City locations and lithologies, a relationship previously noted by Eardley (1944) and Bryant and others (1989). The Norwood Formation in East Canyon looks like proximal volcano apron deposits because it contains more tuff and variably rounded volcanic-rock sedimentary clasts and fragments in conglomerate and sandstone beds than the Morgan Valley rocks, and the clasts are large enough that they are easily recognizable as the volcanic lithologies present in the Keetley Volcanics. Though the ages are similar (see above), the geologic setting and stratigraphy of similar volcaniclastic rocks near Salt Lake City (Tn and Tkb of Bryant, 1990) has not been worked out.

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – Typically red to brownish-red sandstone, siltstone, mudstone, and conglomerate with minor gray limestone and marlstone locally; conglomerate clasts mainly rounded Neoproterozoic and Paleozoic sedimentary rocks, typically Neoproterozoic and Cambrian quartzite; basal conglomerate more gray and less likely to be red, and contains more locally derived angular clasts of limestone, dolomite and sandstone, typically from Paleozoic strata; lighter shades of red, yellow, tan, and light gray present locally and more common in uppermost part of Wasatch strata, complicating mapping of contacts with overlying similarly colored Norwood and Fowkes Formations; greatest thickness about 5000 to 6000 feet (1500-1800 m) southeast of Morgan and thinner to north and west with about 2500 feet (760 m) exposed in Peterson quadrangle; thinner east of leading edge of Willard thrust sheet, typically 600 feet (180 m) thick or less in Lost Creek drainage, and up to about 800 feet (240 m) thick in Meachum Ridge quadrangle; thicknesses vary locally due to considerable relief on basal erosional surface, for example along leading edge of Willard thrust, and also note onlap of Wasatch strata north and south of Round Valley, east of Morgan. The Wasatch Formation is at least locally prone to slope failures.

The age of the Wasatch Formation is based on the Eocene-Paleocene boundary used in Jacobson and Nichols (1982), which is likely the C24 paleomagnetic reversal (see Hicks and others, 2003). Other Eocene-Paleocene boundaries would put P6 palynomorphs in the Eocene, and the P stands for Paleocene. Wasatch strata contain P4-5 palynomorphs in the Mecham Ridge quadrangle (Coogan, 2010a-b, sample 97-7). To the southeast in the Salt Lake City 30x60' quadrangle, Wasatch strata contain P5-6 palynomorphs, but also the palynomorph *Platycarya platycaryoides* (Nichols and Bryant plate 2 in Bryant, 1990, sample D6052), which is Eocene (see Nichols, 2003). See also Jacobson and Nichols (1982) for P5 and P5-6 palynomorphs from samples taken south of our map area (P3055-2A, 3B and P3387-2; their figure 7 updated with mapping by Bryant, 1990), and P5-P6 palynomorphs from another sample from the Wasatch Formation (P2833-1, 2; their figure 11 updated with mapping in this report).

North of our map area and east of the Willard thrust sheet, about 200 to 1600 feet (60-500 m) of Wasatch Formation was reportedly penetrated in oil and gas exploration wells in Birch Creek fold belt (see API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, Utah DOGM well and log files), but these thicknesses may include the Evanston Formation.

South of Morgan and west of Henefer Valley, Mullens (1971, p. 18) reported scattered beds up to 15 feet (5 m) thick of pale-red silty and gray algal limestone. Mann (1974) also noted these resistant oncolitic limestone beds in the same area. We mapped Wasatch limestone beds (Twl) separately on the Willard thrust sheet where they are thicker and more continuous than the beds near Morgan.

Td **Igneous dikes (Tertiary?)** – Strongly chloritically altered, dark-colored, non-foliated mafic dikes intruding Farmington Canyon Complex in Ogden 7.5' quadrangle; contain altered hornblende, biotite, and feldspar phenocrysts in a fine-grained matrix. May be Tertiary, but most chloritic alteration in the enclosing rocks is Cretaceous (Yonkee and Lowe, 2004), suggesting the dikes are Cretaceous.

CRETACEOUS

KXc **Chloritic gneiss, cataclasite, mylonite, and phyllonite (Cretaceous and Proterozoic)** – Dark- to gray-green, variably fractured and altered rock with local micaceous cleavage; contains variable amounts of fine-grained, recrystallized chlorite, muscovite, and epidote; present in shear and fracture zones, and in diffuse altered zones associated with quartz pods that crosscut basement rocks (Yonkee, 1992; Yonkee and others, 1997); locally includes quartz veins (see Bryant, 1988, p. 5-6, 8); some linear zones of this unit mapped as faults by Bryant (1988). Unit produced by mostly Cretaceous deformation and greenschist-facies alteration that overprints various Farmington Canyon Complex protoliths (Yonkee and Lowe, 2004). However, Bryant (1988) indicated that some quartz veins and pods may be related to Neoproterozoic (late Precambrian) alteration.

MISSISSIPPIAN

Mh **Humbug Formation (Mississippian, Merimecian?)** – Gray- to tan- to reddish-gray and reddish-tan weathering, interbedded calcareous to dolomitic, quartzose sandstone, and sandy limestone and dolomite; lower part contains more sandstone and is less resistant than upper part; contact with Deseret Limestone may not be consistent; about 700 to 800 feet (215-245 m) thick and reportedly up to 1000 feet (300 m) thick (Sorensen and Crittenden, 1972) where upper contact not exposed. On this map Humbug-Deseret contact in Snow Basin quadrangle is corrected from King and others (2008), so the Deseret is now thicker.

Mde **Deseret Limestone (Mississippian)** – Pale-brown weathering, ledge- and cliff-forming dolomite and limestone, becoming sandy upward; about 500 feet (150 m) thick.

Mded **Delle Phosphatic Member of Deseret Limestone (Lower Mississippian, Osagean?)** – Dark, poorly resistant, shaly, phosphatic strata at base of Deseret mapped separately where possible at map scale.

Mg, Mg?

Gardison Limestone (Lower Mississippian) – Gray, ledge and cliff forming, fossiliferous limestone and lesser dolomitic limestone; widespread crinoid and brachiopod fossil fragments; locally cherty; bedding becomes thicker upward; about 500 to 800 feet (150-245 m) thick (King and others, 2008). Lodgepole or Madison Limestone of some workers.

DEVONIAN – Named on western Willard thrust sheet so names may not be appropriate here. Devonian stage subdivisions are not noted due to the lack of fossils and age uncertainty.

Db **Beirdneau Sandstone** – Reddish-tan to tan to yellowish-gray, dolomitic to calcareous sandstone and siltstone, some silty to sandy dolomite and limestone, and lesser intraformational (flat-pebble) conglomerate; less resistant than adjacent map units; likely 250 to 300 feet (75-90 m) thick.

The contact with the Hyrum Dolomite does not appear to be mapped at a consistent horizon. Argillaceous uppermost part of Beirdneau reported in the Huntsville quadrangle by Yonkee and Lowe (2004) is likely the Cottonwood Canyon Member of the Lodgepole Limestone and underlying Leatham Formation (Devonian).

Dhw, Dhw?

Hyrum and Water Canyon Formations, undivided – Estimate 300 to 440 feet (90-135 m) thick. Both formations missing to south near Salt Lake City.

Hyrum Dolomite – Brownish-gray and gray, ledge-forming dolomite and minor limestone; weathers distinctive dark-chocolate brown; about 200 to 350 feet (60-107 m) thick; thinner over the Stansbury uplift and thicker to east. Unconformably overlies Water Canyon Formation.

Water Canyon Formation – Interbedded, slope forming, light-colored dolomitic to calcareous sandstone and siltstone and silty to sandy dolomite and limestone; 30 to 100 feet (9-30 m) thick; thinned by erosion over Stansbury uplift or limited deposition over the Tooele arch and thicker to the east.

SILURIAN

The Laketown Dolomite is missing over the Tooele arch (see Hintze, 1959), so missing at Ogden Canyon and to the south near Salt Lake City, as well as missing to the east at Durst Mountain and on the Crawford thrust sheet.

ORDOVICIAN

Ordovician formations were named on the eastern Paris-Willard thrust sheet so usage below the Willard thrust in the Wasatch Range may not be appropriate.

Ofg, Ofg?

Fish Haven and Garden City Formations, undivided (Ordovician) – Swan Peak Formation, which is between these units, is missing over Tooele arch, so missing at Ogden Canyon and also to east at Durst Mountain.

Ofh, Ofh?

Fish Haven Dolomite (Ordovician) – Medium- to dark-gray, cliff-forming dolomite; locally cherty; in less deformed areas, likely 200 to 225 feet (60-70 m) thick (see Sorensen and Crittenden, 1972, 1974), so not thinned here over Tooele arch.

Ogc, Ogc?

Garden City Formation (Ordovician) – Pale-gray to buff-weathering, ledge-forming dolomite, silty dolomite and limestone, and minor siltstone, typically as bedding partings; lower part typically less resistant than upper part, so slope and ledge forming; 200 to 400 feet (60-120 m) thick; thins over Tooele arch.

ORDOVICIAN AND CAMBRIAN

Units were named on the eastern Paris-Willard thrust sheet so names may not be appropriate below the Willard thrust in the Wasatch Range.

Csn **St. Charles and Nounan Formations, undivided (Ordovician and Cambrian)** – See descriptions below.

Csc, Csc?

St. Charles Formation (Ordovician and Cambrian) – Light- to medium-gray, cliff and ledge-forming dolomite; lower part calcareous sandstone and sandy dolomite that forms slopes, locally containing Worm Creek Quartzite Member at base; 400 to 660 feet (120-200 m) thick (Rigo, 1968; Sorensen and Crittenden, 1972) and thickens to north; thins over Tooele arch.

CAMBRIAN

Nounan, Bloomington, Maxfield and Tintic Formations are thinner to the east on Durst Mountain, though the Ophir Formation is about the same thickness (compare Yonkee and Lowe, 2004, to Coogan and King, 2006). These marine strata should thin to the east on the paleo-continental shelf. Nounan and Bloomington Formations were named on the Paris-Willard thrust sheet, so usage below the Willard thrust in the Wasatch Range may not be appropriate and is compounded by the Bloomington and Maxfield being partly equivalent from fossil data. Cambrian age subdivisions are not noted where fossil data are limited and age is uncertain.

Cn, Cn? **Nounan Dolomite (Cambrian)** – Medium-gray, typically thick-bedded, cliff-forming dolomite and some limestone; 500 to 750 feet (150-230 m) thick and thinning over Tooele arch.

Nounan not mapped to the south near Salt Lake City by Bryant (1990), but his overly thick Maxfield Limestone unit may include the upper two members of the Ophir Formation and/or all of the Nounan Formation. Also, the Bloomington Formation, typically present between the Nounan and Maxfield strata, was not mapped to the south in the Wasatch Range (see Bryant, 1984, 1988, 1990).

Cbom, Cbom?

Bloomington Formation and Maxfield Limestone, undivided (Cambrian) – Used where these units are thinned by deformation directly below Willard thrust fault.

Cbo, Cbo?

Bloomington Formation (Cambrian) – Lithologically similar to Calls Fort (upper) and Hodges (lower) Shale Members of this formation; contains brown-weathering, slope-forming, gray to olive-gray, silty argillite interlayered with gray- to yellowish- and orangish-gray-weathering, thin- to medium-bedded, silty limestone, flat-pebble conglomerate, nodular limestone, and wavy-bedded (ribbon) limestone; 40 to 200 feet (12-60 m) thick and thickens to north, but likely highly deformed; thins over Tooele arch. *Eldoradia* sp. trilobite fossil in Ogden Canyon (Rigo, 1968, USGS No. 5949-CO) supports correlation with the Calls Fort Member, but this would require the Maxfield Limestone to be partly equivalent to the Bloomington Formation.

Cmo, Cmo?

Maxfield Limestone and/or Ophir Formation (Middle Cambrian) – Used for carbonate and argillite rocks in thrust windows directly below Willard thrust fault in North Ogden quadrangle; rocks are similar to carbonate and argillite strata in both units.

Cm, Cm?

Maxfield Limestone (Middle Cambrian) – From top down includes dolomite, limestone, argillaceous to silty limestone and calcareous siltstone and argillite, and basal limestone with argillaceous interval (see Yonkee and Lowe, 2004; King and others, 2008 for more member details); members mappable at 1:24,000 scale, but like Ophir Formation thicknesses highly variable due to deformation; total thickness about 600 to 900 feet (180-270 m) (King and others, 2008).

According to Yonkee and Lowe (2004), the *Bathyuriscus* sp., *Elrathina* sp., *Peronopsis* sp., and *Ptychagnostus* sp. trilobite fossils reported by Rigo (1968, USGS No. 5948-CO in the middle limestone of the Ophir Shale) in Ogden Canyon are in the basal limestone member of the Maxfield. *Elrathia* can be used as a proxy for the Middle Cambrian *Bolaspidella* zone (see Robison, 1976, figure 4) and this zone is in the Bloomington Formation shales on the Willard thrust sheet (see Oviatt, 1986; Jensen and King, 1996, table 2). This supports the Maxfield Limestone as partly equivalent to the Bloomington Formation, but leaves the Blacksmith Dolomite without an equivalent carbonate unit below the Willard thrust sheet. However, Rigo (1968) did not provide a usable sample location and the sample location is not on the map of Crittenden and Sorensen (1985b).

Co, Co?

Ophir Formation (Middle Cambrian) – Upper and lower brown-weathering, slope-forming, gray to olive-gray, variably calcareous and micaceous to silty argillite to slate with intercalated gray, silty limestone beds; middle ledge-forming, gray limestone; total thickness about 450 to 650 feet (140-200 m) (Sorensen and Crittenden, 1972) where likely less deformed, but highly deformed in most outcrops.

Rigo (1968, USGS No. 5947-CO) reported *Ehmaniella* sp., *Alokistocare* sp., and *Zacanthoides* sp. trilobites from the lower member indicating an early Middle Cambrian age. These trilobites may be in the upper and, possibly, lower Ute Formation on the Willard thrust sheet (see unit Cu), leaving the Langston Formation and possibly the lower Ute Formation without lithologically equivalent strata below the Willard thrust sheet.

Only subdivided north of Ogden Canyon to show structure.

Cou **Upper shale (Middle Cambrian)** – About 130 to 260 feet (40-80 m) thick.

Com-Col

Middle limestone and lower shale (Middle Cambrian) – Middle limestone about 100 feet (30 m) thick, but deformed to 15 to 165 feet (5-50 m) thick. Lower shale about 100 to 145 feet (30-45 m) thick.

Ct, Ct? **Tintic Quartzite (Middle and Lower Cambrian)** – Tan-weathering, cliff-forming, very well-cemented quartzite, with lenses and beds of quartz-pebble conglomerate, and lesser thin argillite layers; quartzite is tan, white, reddish tan and pale-orange tan with abundant cross-bedding; argillite more abundant at top and quartz-pebble conglomerate increases downward; greenish-tan to purplish-tan to tan, arkosic sandstone, conglomerate, and micaceous argillite at base that is 50 to 200 feet (15-60 m) thick and derived from unconformably underlying gneissic and schistose Farmington Canyon Complex; about 1100 to 1500 feet (335-450 m) thick.

PALEOPROTEROZOIC

Xa **Mafic bodies (Paleoproterozoic?)** – Dark greenish-gray to black pods and dikes of plagioclase and hornblende referred to as amphibolites despite greater abundance of plagioclase; typically non- to strongly foliated pods in granitic gneiss (Yonkee and Lowe, 2004); only larger bodies mapped; few to 330 feet (100 m) long and up to 65 feet (20 m) wide (Crittenden and Sorensen, 1985b). Unit appears to post-date Farmington Canyon Complex, and may be related to lamprophyres elsewhere in Wasatch Range, but unit may include intrusions that are part of the complex.

Xfc **Farmington Canyon Complex (Paleoproterozoic)** – Migmatitic gneiss, granitic gneiss, quartz-rich gneiss, and biotite-rich schist, with lesser layers to pods of white quartzite, pegmatite, amphibolite, mafic rocks, and meta-ultramafic rocks; migmatitic gneiss contact with granitic gneiss is gradational (after Yonkee and Lowe, 2004) and migmatitic gneiss seems to be interlayered with granitic gneiss west of Middle Peak (sections 17 and 20, T. 5 N., R. 1 E.); pods and layers are typically gradational into surrounding rock, with diffuse unmappable contacts and/or too small to show at map scale; gneisses contain widespread mafic bodies and are cut by variably deformed pegmatite dikes (mostly unmapped). Barnett and others (1993) reported the various isotopic ages of the complex and concluded it is Paleoproterozoic (~1700 Ma) in age.

Bryant (1988) described these rocks as less migmatitic to the south and mapped a schist and gneiss unit (his Afs, our Xfcgs) south of a gradational contact with more migmatitic rocks (his Afm, our Xfcm) in the Peterson quadrangle. All Farmington Canyon units display local retrograde alteration, largely chloritic, partly related to Cretaceous hydrothermal fluids. More detailed information on the complex is available in Bryant (1988) and Yonkee and Lowe (2004). Where possible divided into:

Xfcm, Xfcm?

Migmatitic gneiss (Paleoproterozoic) – Medium- to light-pink-gray, strongly foliated and layered (migmatitic) quartzo-feldspathic rock with widespread garnet and biotite; also contains unmapped granitic gneiss pods, and some thin layers of sillimanite-bearing, biotite-rich schist.

Xfcg **Granitic gneiss (Paleoproterozoic)** – Present in both footwall and hanging wall of Ogden floor thrust. Light- to pink-gray, moderately to strongly foliated, fine- to medium-crystalline, hornblende-bearing, quartzo-feldspathic rock with minor orthopyroxene.

Xfch **Hornblende-plagioclase gneiss (Paleoproterozoic)** – Only present in footwall of Ogden floor thrust. Dark-gray to black, moderately to strongly foliated, with minor garnet, quartz, and biotite in some layers.

Xfcb, Xfcb?

Biotite-rich schist (Paleoproterozoic) – Medium-gray to dark-brown, strongly foliated, biotite-rich schist with widespread garnet and sillimanite; displays alternating biotite-rich and quartz-feldspar-rich bands that are rotated into complex fold patterns; cut by garnet-bearing pegmatite dikes; also contains some thin layers of amphibolite, quartz-rich gneiss, and granitic gneiss; gradational contacts with migmatitic gneiss.

Xfcq **Quartz-rich gneiss (Paleoproterozoic)** – Milky- to green-white with plagioclase and chrome-green mica; locally contains thin layers of biotite-rich schist and amphibolite.

Xfcu **Meta-ultramafic and mafic rocks (Paleoproterozoic)** – Black to green-black, variably foliated, pyroxene-bearing meta-gabbro to amphibolite, with varying amounts of plagioclase, and dark-green to black pyroxene-amphibole-olivine-bearing ultramafic rock, hornblendite, and amphibolite; form pods in granitic gneiss but only larger bodies mapped.

Xfcs **Mica-rich schist and gneiss (Paleoproterozoic)** – Only present in footwall of Ogden floor thrust. Gray-brown, strongly foliated, schist to gneiss containing variable amounts of muscovite, biotite, quartz, and feldspar, with minor garnet in some layers; contains some thin layers of hornblende-plagioclase gneiss.

Xfcgs, Xfcgs?

Gneiss and schist (Paleoproterozoic) – Biotite-feldspar-quartz gneiss and biotite schist, with less abundant layers of white quartzite; locally contains sillimanite-rich layers but does not contain widespread sillimanite or garnet like the biotite-rich schist mapped and described by Yonkee and Lowe (2004) because the "degree" of metamorphism increases to the north. Our very approximately located contact with Xfcm is south of Bryant's (1988, p. 15) contact and is based on the change in weathering from less resistant to north to more resistant with brighter colored, strongly foliated or fractured ribs of quartzite(?) to south. Unit queried where poor exposures may actually be surficial deposits.

CRAWFORD THRUST SHEET, HORSE RIDGE AND DAIRY RIDGE QUADRANGLES AND LOST CREEK DRAINAGE, AND DURST MOUNTAIN AND UPPER WEBER CANYON AREA

Tertiary strata and the Cretaceous Hams Fork Member of the Evanston Formation are younger than and overlie the Crawford thrust sheet. Exposed Paleozoic rocks are part of a transitional shelf sequence. Subsurface thicknesses outside the map area are included due to the lack of drill holes into the Crawford thrust sheet within the map area.

TERTIARY

Ts **Tertiary strata, undivided** – Used where multiple Tertiary map units are in landslide blocks [Qms(Ts), Qms?(Ts), Qmso(Ts), and Qmso?(Ts)], and for a very poorly exposed outcrop with characteristics of units Thv, Tcy, Tcg, Tn, and Tw near Elk Mountain.

Thv, Thv?

Fanglomerate of Huntsville area (Pliocene and/or Miocene) – Typically dark-weathering, poorly to moderately consolidated, pebble to boulder gravel in brown to reddish-brown silt and sand; gravel and matrix reflect erosion of red Wasatch Formation, as well as Paleozoic and Precambrian rocks exposed on Durst Mountain; in contrast, where fanglomerate is next to Tintic Quartzite (Ct) exposures, clasts are mostly angular to subangular Tintic Quartzite, with less red matrix; overlies conglomeratic rocks (Tcy, Tcg) with angular unconformity, yet is folded with unit Tcy into syncline just west of faults bounding Durst Mountain; estimate 0 to 500 to possibly 1000 feet (0-150-300 m) thick on west flank of Durst Mountain, with upper estimate assuming unit not faulted or folded; several hundred feet of reddish-hued strata are exposed in graben on Durst Mountain but this graben fill may include unit Tcg. Unit Thv queried where may be underlying conglomerate (Tcy) and where poor exposures may actually be surficial deposits.

Our Thv unit is more age restricted than the Huntsville fanglomerate named by Eardley (1955). His unit included Holocene, Pleistocene, Pliocene, Miocene, and Oligocene(?) fanglomerates (our Qcg, Qng, QTaf, Thv, and Tcy units). The age of our Thv may overlap with the Salt Lake Formation.

Tcy, Tcy?

Younger unnamed Tertiary conglomeratic rocks (Pliocene and Miocene?) – Rounded, pebble- to boulder-sized, quartzite-clast conglomerate with gray, tan, or reddish-gray to reddish-tan matrix and some mudstone, siltstone, and sandstone; since lithologically like unit Tcg, Tcy-Tcg contact based on change in dip across angular unconformity (5-10° vs >10° in Morgan quadrangle) and more regular bedding in Tcy; unconformity becomes less distinct to north and unit Tcy apparently pinches out in Durst Mountain quadrangle; estimate up to 200 to 400 feet (60-120 m) thick.

Given bedding dips of less than 10 degrees, unit Tcy may be the same age (Pliocene and late Miocene) as the Salt Lake Formation conglomerate (Tslc) on the Willard thrust sheet. Our unit Tcy was included in Huntsville fanglomerate (see Thv) of Eardley (1955). Our Tcy-Thv contact (lithologic change and unconformity) is more distinct than our Tcy-Tcg contact (unconformity with no consistent lithologic change).

Tcg, Tcg?

Unnamed Tertiary conglomeratic rocks (Oligocene?) – Characterized by rounded, cobble- to boulder-sized, quartzite-clast conglomerate with pebbles and less than 10 percent to more than 50 percent gray, tan, or reddish-gray to reddish-tan matrix; conglomerate clasts locally angular to subangular Tintic Quartzite and angular to rounded lower Paleozoic carbonate rocks; interbedded with tan, gray, and reddish-brown pebble-bearing mudstone to sandstone and some claystone (altered tuff); most beds poorly indurated and poorly exposed; mudstone likely constitutes matrix of conglomeratic beds; in Morgan and Durst Mountain quadrangles, about 500 to 700 feet (150-210 m) thick and thickening northward to possibly 3000 feet (900 m), though faulting may make this estimate too large.

Reddish-hued Tcg strata mostly contain recycled Wasatch Formation clasts (quartzite and carbonate) with a distinct reddish patina in a reddish matrix. Some non-conglomeratic beds in Tcg look like gray upper Norwood Formation (Tn) and are locally tuffaceous, indicating the units are interbedded. Further, some Tcg pebble beds have carbonate and chert clasts (like the Norwood) and lesser quartzite clasts, and Tcg conglomerate includes rare altered tuff clasts from the Norwood Formation. Despite tuffaceous matrix, unit Tcg seems to be less prone to mass movements than Norwood strata.

Tn, Tn? **Norwood Formation (lower Oligocene and upper Eocene)** – For information see descriptions that precede Sub-Willard Thrust Sheet strata.

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – For information see descriptions that precede Sub-Willard Thrust Sheet strata.

Twl **Limestone of Wasatch Formation (Eocene and upper Paleocene)** – Gray limestone and light-gray to white marlstone; discontinuous, grades laterally into Tw; mapped in Meachum Ridge quadrangle; 0 to 10 feet thick (1-3 m).

Twc **Basal conglomerate (upper Paleocene)** – Red-orange- and tan-weathering, cobble conglomerate, mainly containing Neoproterozoic and Cambrian quartzite clasts (DeCelles, 1994); forms prominent cliffs along western tributaries of Lost Creek; likely more extensive than mapped because thinner exposures are poorly cemented and are likely masked by colluvium from adjacent mudstones; 0 to 400 feet (0-120 m) thick. The upper thicker-bedded conglomerates, shown as about 100 feet (32.5 m) thick on the Pine Creek [Canyon] section of DeCelles and Cavazza (1999, figure 6), are probably in the basal Wasatch conglomerate unit (Twc).

Lithologically different than unit Twc? that is mapped on the Willard thrust sheet in the Causey Dam quadrangle, particularly the clast lithologies.

This unit is mapped as Wasatch Formation rather than Tertiary Evanston Formation based on P5-6 palynology in samples (see Coogan, 2010a-b, tables; appendix tables 1 and 2 this report). The Paleocene Wasatch age is also based on palynomorphs in Wasatch Formation strata as shown by Nichols and Bryant (1990) and as noted in unit Tw description under "Sub-Willard Thrust Sheet - Ogden Canyon Area" heading.

CRETACEOUS

Keh, Keh?

Hams Fork Member of Evanston Formation (Upper Cretaceous, Maastrichtian-Campanian) – Light-gray, brownish-gray, and tan sandstone, conglomeratic sandstone, and quartzite- and chert-pebble conglomerate, and variegated gray, greenish-gray, and reddish-gray mudstone; in Phil Shop Hollow (Devils Slide quadrangle) and Echo Canyon, dark-gray, carbonaceous shale and coal in lower part (see Mullens and Laraway, 1964); coal beds are present up to 200 feet (60 m) above contact with basal conglomerate, or, if conglomerate is missing, the base of Hams Fork Member in the Lost Creek Dam quadrangle, and about 400 feet (120 m) above the contact with the basal conglomerate up Coal Hollow in the Francis Canyon quadrangle (see Doelling, 1972); lacks carbonaceous shale and coal elsewhere; member coarsens downward and westward becoming basal conglomerate (unit Kehc); in Durst Mountain quadrangle, lower Hams Fork coarsens downward to gray and brownish-gray, cobble conglomerate containing distinctive Neoproterozoic quartzite clasts (not mapped separately) (Coogan and King, 2006); unit Keh thickens northward from 300 feet (90 m) at Echo Canyon to about 600 feet (180 m) in Devils Slide quadrangle to 1200 feet (365 m) near Lost Creek Dam, then thinning to north to less than 450 feet (140 m) thick in Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a-b); mostly obscured by Wasatch Formation farther to north, but appears to be about 160 feet (50 m) thick in Walton Canyon, Meachum Ridge quadrangle; about 300 to 1000 feet (140-300 m) thick along South Fork Ogden River, thinning to west, with about 1000-foot (300 m) thickness to south in Durst Mountain quadrangle (Coogan and King, 2006); unconformably truncated and locally absent beneath Wasatch Formation. Hams Fork queried (Keh?) where outcrop may be Wasatch Formation (Tw) and queried in stacked unit (Keh?/Pp) where it may be surficial deposits.

A palynology sample (P3903-2), taken stratigraphically above the coal in Phil Shop Hollow, is Maastrichtian-upper Campanian (Jacobson and Nichols, 1982, p. 740), though reported as latest Maastrichtian in Lamerson (1982, p. 324) (see also appendix table 1).

The Hams Fork Member is absent west of the Willard thrust and north of the South Fork Ogden River on the Willard thrust sheet below the angular unconformity at the base of the Wasatch Formation and above the basal angular unconformity with the underlying Mesozoic and Paleozoic rocks (Coogan, 2006a-b). The northern Causey Dam, northwestern Horse Ridge, and western Dairy Ridge quadrangles were an area of high paleotopography on the Willard thrust sheet.

This unit was named the Hams Fork Conglomerate Member by Oriel and Tracey (1970), but conglomerate in the name is dropped in the Ogden 30 x 60-minute quadrangle because strata are mostly sandstone and mudstone with only local basal conglomerate. Further, as demonstrated by contained clasts (quartzite with lesser chert and limestone from Paleozoic rock), these geographically separate conglomerates have different source areas (compare Oriel and Tracey, 1970, p. 9 to DeCelles, 1994 and DeCelles and Cavazza, 1999, figure 10). Our Hams Fork unit has lithologies, in particular coaly beds and chert and quartzite granule and pebble beds like the lower member of Oriel and Tracey (1970), which underlies their Hams Fork Conglomerate Member. But, they reported that the lower member pinches out to the south (Oriel and Tracey, 1970, p. 6), north of our map area. Our basal conglomerate and their Hams Fork conglomerate likely have slightly different ages.

DeCelles and Cavazza (1999, figure 9) showed clast count data for the Hams Fork conglomerates from various locations in the Lost Creek drainage, but did not differentiate between the distinctive conglomerate at the base of the Hams Fork (Kehc) and conglomerate beds higher in the section (Keh). From their figure 8, their clast counts from localities east of the Crawford thrust may have come from conglomerate beds that are above the basal conglomerate (Kehc). Their pie diagrams showed almost entirely quartzite clasts about equally divided between Neoproterozoic and Cambrian Tintic Quartzite (like Tertiary Wasatch Formation conglomerate clasts). Therefore the clast descriptions in DeCelles (1994) noted below may be for conglomerate beds in unit Keh, rather than the basal conglomerate that is unit Kehc.

Kehc, Kehc?

Basal conglomerate of Hams Fork Member (Upper Cretaceous, Maastrichtian-Campanian?) – Tan, brownish-gray, and gray, cobble to boulder conglomerate with minor interbedded gray, carbonaceous mudstone; conglomerate contains greater than 80% Neoproterozoic and Cambrian quartzite clasts, but locally contains roughly 5% clasts of Jurassic and Triassic sandstone and Precambrian crystalline basement (schist and gneiss) (DeCelles, 1994); west of East Canyon fault in Devils Slide quadrangle, about 200 to 240 feet (60-70 m) thick and to north apparently up to 400 feet (120 m) thick, with base not exposed and upper contact uncertain; 150 feet (45 m) thick in the hanging wall of the Crawford thrust in Lost Creek drainage; thickness varies in the Crawford thrust footwall from about 115 to 300 feet (35-90 m) in Lost Creek drainage (Coogan, 2004a-b, 2010a); appears to pinch-out in lower Echo Canyon to south in Coalville 7.5' quadrangle (Coogan, unpublished mapping) and to west above Powder Hollow in Devils Slide quadrangle. The basal conglomerate is queried (Kehc?) near Devils Slide where outcrops may be conglomerate in unit Keh.

In the Devils Slide quadrangle, Kehc is not mapped separately from Keh north of the Weber River and may pinch out to the north because the distinctive cliff-forming strata are not present at the base of Keh north of the river. The basal Hams Fork conglomerate is absent to the north along the regional basal angular unconformity in the Peck Canyon quadrangle.

The pie diagram of DeCelles and Cavazza (1999, figure 9) for the Hams Fork conglomerate west of the Crawford thrust near Lost Creek Reservoir likely came from this basal conglomerate (see their figure 8 locations), and they showed about 65% Neoproterozoic and Cambrian quartzite clasts, with Mesozoic, Paleozoic, and Precambrian basement clasts not seen to the east in what are here interpreted as younger Evanston or Wasatch Formation conglomerates. Their two pie diagrams for a locality to the southwest may be from the Toone Canyon and Pine Creek [Canyon] exposures of Kehc. One of the diagrams is similar to the Lost Creek Reservoir Kehc diagram indicating the clasts counts are from the basal conglomerate, but the basal conglomerate (Kehc) is not mapped at Pine Canyon, the location of a DeCelles and Cavazza (1999, figure 6) measured section, only the younger part of the Hams Fork (Keh) is exposed. The basal conglomerate (Kehc) is exposed in Toone Canyon. The other pie diagram tie-lined to the same locality showed clasts that are almost entirely quartzite, like the basal Wasatch Formation conglomerate (Twc) mapped near Pine Canyon. The upper thicker bedded conglomerates on their Pine Creek section (DeCelles and Cavazza, 1999, figure 6) are probably the basal Wasatch Formation conglomerate (Twc).

Kwc, Kwc?

Weber Canyon Conglomerate (Upper Cretaceous, Campanian-late Santonian) – Red, gray, and tan, boulder to cobble conglomerate with minor sandstone and mudstone interbeds; near Devils Slide, clasts from Tintic Quartzite, Weber Sandstone, Nugget Sandstone, Lodgepole Limestone, Park City Formation, and Twin Creek Limestone (DeCelles, 1994) (list order not by age or abundance); Coogan (2003, unpublished) noted clasts of Neoproterozoic quartzite and Paleozoic carbonate at Toone Canyon (no note of Twin Creek clasts) that are not present to south at DeCelles (1994) site near Devils Slide; cliff forming near Devils Slide; contains progressive intraformational unconformities (Coogan, 2010a-b) in growth syncline above buried Crawford thrust trace in Lost Creek drainage and near Devils Slide; overlies older rocks with angular unconformity; at least 1900 feet (580 m) thick near Devils Slide, base not exposed.

Also mapped entirely on Willard thrust sheet along Right Fork South Fork Ogden River in Causey Dam quadrangle. This conglomerate is very different, implying a different source area (see Kwc description under "Willard Thrust Sheet" heading).

TERTIARY, CRETACEOUS, and/or JURASSIC

TKJ? **Wasatch Formation and other units?** – Reddish-colored strata with visible bedding northwest of Henefer, and pale gray strata with visible bedding on divide between Lost Creek and Henefer Valleys that may be some other unit than the Wasatch (red Preuss Redbeds [Jp], and light gray to tan Weber Canyon [Kwc], Hams Fork Member of Evanston Formation [Keh, Kehc], and/or Stump and Preuss Formations [Jsp]). Unit queried because poor exposures indicate it may actually be surficial deposits.

CRETACEOUS

Kk **Kelvin Formation (Lower Cretaceous, Albian-Aptian)** – Upper half contains tan and gray, coarse-grained, cross-bedded sandstone and pebbly sandstone with abundant chert; interbedded with reddish-gray and minor gray-green mudstone; middle part contains thin, discontinuous beds of nodular, blue-gray and lavender, micritic limestone; lower half is chert-pebble conglomerate beds separated by recessive reddish-gray mudstone and sandstone zones; conglomerate is synorogenic from Willard thrust sheet; approximately 2500 feet (700 m) thick in Toone Canyon, Lost Creek Dam quadrangle, but top not exposed (Coogan, 2004b); east of Crawford thrust, at least 5700 feet (1740 m) thick near Henefer, though base not exposed (Coogan, 2010a-b).

South of the Ogden map area between Peoa and Wanship conglomerate clasts in four conspicuous beds were described as black, red, and yellow-colored chert in a lower bed, with a few quartzite pebbles that may be from Weber Sandstone in a second bed, and in an upper conglomerate bed most of the large boulders were quartzite (Weber?) and small pebbles are mostly chert. Some pebbles of Nugget Sandstone and Paleozoic limestone are present (Eardley, 1944, p. 838).

JURASSIC

Subsurface thicknesses from outside the map area are included due to the lack of drill holes into the Crawford thrust sheet within the map area.

Jsp, Jsp?

Stump and Preuss Formations, undivided (Upper and Middle Jurassic) – Poorly exposed, mostly reddish, poorly bedded strata; about 1000 feet (300 m) thick at Toone Canyon (Coogan, 2004b).

Much of the material in the Devils Slide quadrangle is reddish-colored soil with no bedding that may be residual deposits above the dissolving salt welt in Main Canyon Creek valley and the divide between Henefer Valley and Lost Creek valley; so shown as queried Wasatch Formation over Jsp (Tw?/Jsp?) and as TKJ? where reddish-hued Cretaceous strata may be present. So unit Jsp queried (Jsp?) where poor exposures may actually be surficial deposits and where Jsp? may be unit TKJ?.

Js **Stump Formation (Upper and Middle Jurassic)** – Pale red, yellow, and gray shale and calcareous sandstone; at least locally glauconitic green and greenish-gray; 220 to 250 feet (68-76 m) thick (Pipiringos and Imlay, 1979).

Jp **Preuss Redbeds (Middle Jurassic)** – Red and purplish-red sandstone, siltstone, and shale, with anhydrite; halite near base in subsurface; mapped separately at the head of Lost Creek and along the East Canyon fault zone; about 900 feet (270 m) exposed.

Subsurface thickness south of the map area in the East Canyon graben is about 900- to 1250-foot (275-380 m), likely including Stump and about the same as exposed thickness in the map area. An additional 0 to 700 feet (210 m) of saline strata was cut in the Gulf Richins well (API 43-043-30256, Utah DOGM) and possibly as much as 6000 to 7500 feet (1800-2300 m) of salt was penetrated in the Amoco Franklin Canyon well (Lamerson, 1982, p. 325; API 43-043-30070, Utah DOGM files) in the East Canyon Reservoir quadrangle, but bed dips seem to indicate this well is in steeply dipping Preuss strata. See Yonkee and others (1997, figure 28) for a complex interpretation of the Franklin Canyon well.

Jtc **Twin Creek Limestone (Middle Jurassic)** – Mostly white- to gray-weathering, shaly limestone with some shale; in Lost Creek drainage member thicknesses total about 2850 feet (870 m) (Coogan, 2004b); similar, though incomplete thicknesses of 2722 and 2600 feet (825 and 790 m) measured at Devils Slide and to north at Watton (now Walton) Canyon/Birch Creek, respectively (Imlay, 1967, p. 11 and 13), with top thrust truncated at Devils Slide; Imlay (1967) documented thinning to east.

North of the map area in subsurface, about 2400 feet (730 m) of Twin Creek was cut in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM), but this Twin Creek is overlain by conglomerate indicating this may be a partial thickness. Due to complex folding, reported thicknesses from exploration boreholes in the Birch Creek fold belt are not used. In the Ogden map area in subsurface, 2542 feet (775 m) of Twin Creek was cut in the Louisiana Land & Exploration 1-34 well (API 43-033-30030, Utah DOGM).

Member descriptions are from Coogan (2004b; 2006a-b) because Imlay's (1967) Watton (now Walton) Canyon/Birch Creek descriptions would make it an atypical section. Subsurface penetrations are from north of the map area in the American Quasar Hoffman well near Randolph, Utah (see API 40-033-30001, Utah DOGM) and do not include corrections for bedding dip.

Jtgc **Giraffe Creek Member (Middle Jurassic)** – Gray, greenish-gray and tannish-gray, calcareous sandstone and lime grainstone, with intraformational conglomerate in Woodruff Creek area; structurally thickened in synclinal hinges between Lost Creek Dam and Woodruff Creek; 225 feet (70 m) exposed total thickness; in subsurface about 450 feet (135 m) cut. Subsurface thicknesses likely based on a different Giraffe Creek and Leeds Creek contact than Coogan (2004b) and Imlay (1967) used.

Jtl **Leeds Creek Member (Middle Jurassic)** – Light-gray, thin- to very thick bedded, clay-rich, micritic limestone with tan silt partings; locally exhibits bedding-normal, pencil cleavage; forms barren, scree-covered slopes; 1000 to 1300 feet (300-395 m) exposed thickness; in subsurface about 865 feet (265 m) cut.

Jtw **Watton Canyon Member (Middle Jurassic)** – Dark-gray, lime micrite (mudstone) and wackestone and minor oolite packstone; forms prominent ridges; locally exhibits bedding-normal, stylolitic, spaced cleavage; about 400 feet (120 m) exposed thickness; in subsurface about 345 feet (105 m) cut.

Jtb **Boundary Ridge Member (Middle Jurassic)** – Gray, very thick bedded, ridge-forming, oolitic, lime grainstone to wackestone beds in middle and upper part that separate red and purple siltstone and gray, silty limestone beds in middle and lower part; 100 to 250 feet (30-75 m) exposed thickness; in subsurface about 165 feet (50 m) cut.

Jtr **Rich Member (Middle Jurassic)** – Light-gray, thin- to very thick bedded, clay-rich, micritic limestone in upper part and gray lime wackestone in lower part; locally exhibits bedding-normal pencil cleavage; forms barren, scree-covered slopes; about 425 to 540 feet (130-165 m) exposed thickness; in subsurface about 350 feet (105 m) cut.

Jts **Sliderock Member (Middle Jurassic)** – Dark-gray, very thick bedded, lime wackestone in upper part and dark-gray, pelecypod and crinoid grainstone in lower part; covered middle part at Devils Slide may be variegated siltstone and shaley sandstone exposed at Birch Creek (see Imlay, 1967); forms small ridges; 100 to 227 feet (30-70 m) exposed thickness; in subsurface about 220 feet (70 m) cut.

Jtgs **Gypsum Spring Member (Middle Jurassic?)** – Red siltstone and sandstone, and gray, vuggy dolomite, with anhydrite in subsurface; 208 feet (65 m) exposed thickness; in subsurface about 200 feet (60 m) cut. This unit is a formation to the east in Wyoming.
Despite its sharp upper and lower contacts (Imlay, 1967, p. 18), the Gypsum Spring is separated from overlying and underlying units by unconformities (see Imlay, 1980, figures 26-28). Kowallis and others' (2011) isotopic dating of the Gypsum Spring in the Devils Slide quadrangle implies that a 10 Ma unconformity is present between the Gypsum Spring and the overlying Twin Creek Limestone.

Jn **Nugget Formation (Lower Jurassic)** – Pale-grayish-orange, pinkish-tan, and locally off-white, well-cemented, cross-bedded quartz sandstone with frosted sand grains; 1100 to 1360 feet (335-415 m) thick.

Subsurface Nugget penetrations north of the map area are about 1200 feet (365 m) cut in the Birch Creek fold belt in the Sohio Birch Creek and American Quasar Putnam wells (API 43-033-30042 and 43-033-30002, Utah DOGM) and to the northeast about 1120 feet (340 m) cut in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM). In the map area Nugget penetrations are 1330 feet (405 m) in the Louisiana Land & Exploration 1-34 well (API 43-033-30030, Utah DOGM), estimate 1615 feet (492 m) cut in Amoco Deseret WIU well, but not dip corrected (King after AMSTRAT log D-4948, and API 43-029-30009, Utah DOGM well file), and 1259 feet (384 m) was reportedly penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file).

In the Durst Mountain quadrangle, a major fault must be present between Quarry Hollow and the Cambrian rocks to the north near the South Fork Ogden River. The stratigraphic separation between the Nugget and Cambrian exposures is about 10,500 feet (3200 m) in less than a mile, but the location and type of fault is uncertain. An east-west-trending normal fault is mapped to the east but the amount of throw on this fault is likely hundreds of feet. The Cambrian strata, along with the Cambrian window in the Browns Hole quadrangle north of the South Fork Ogden River, may be a sliver (horse) within the Willard thrust fault, an origin that was implied by Schirmer (1985, p. 151). If so, the Willard thrust sheet ramps upward from Permian in the north to Jurassic in the south in the footwall.

TRIASSIC

TRa **Ankareh Formation, Higham Grit, and Timothy Sandstone and Portneauf Limestone Members of Thaynes Formation, undivided (Triassic)** – Mixture of reddish shale, siltstone, sandstone, and limestone; about 1250 to 1400 feet (380-425 m) thick near Devils Slide; to north, structurally thinned where exposed near leading edge of Willard thrust (Coogan, 2006a-b).

In subsurface north of the map area, about 1475 feet (450 m) of this unit was penetrated in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM). In the map area, 1414 feet (431 m) of this unit was penetrated in the Louisiana Land & Exploration well 1-34 (API 43-033-30030, Utah DOGM) and reportedly 1405 feet (428 m) was penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file).
Contains mappable subunits:

TRaw **Wood Shale Tongue of the Ankareh (Triassic)** – Brownish orange-red to brownish-red shale, siltstone and sandstone; locally mica-bearing; called Stanaker or upper member by some workers; 600 to 680 feet (180-210 m) thick near Devils Slide.

In subsurface north of the map area, about 500 feet (150 m) of Wood Shale was cut in the Birch Creek fold belt in the Sohio Birch Creek and American Quasar Putnam wells (API 43-033-30042 and 43-033-30002, Utah DOGM well files). In the map area, an estimated 585 feet (178 m) of Wood Shale was penetrated in the Amoco Deseret WIU well, but not dip corrected (King after AMSTRAT log D-4948, and API 43-029-30009, Utah DOGM well file).

TRht **Higham Grit, and Timothy Sandstone and Portneuf Limestone Members of the Thaynes Formation (Triassic)** – Gray and greenish-gray, mica-bearing, quartz-granule sandstone at top (Higham); greenish-gray, lithic-pebble conglomerate with green siltstone clasts and rare fossil wood fragments in middle (Timothy); and locally gray and lavender, mottled micritic limestone (with gray chert) at base (Portneuf); up to 200 feet (9-60 m) thick.

In subsurface north of the map area, estimate 55 to 90 feet (15-27 m) of this unit was cut in the Birch Creek fold belt (after API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, Utah DOGM files), with about 145 feet (45 m) cut in the American Quasar Hoffman well to the northeast near Randolph, Utah (after AMSTRAT log D-4528, API 43-033-30001). In the map area, estimate 85 feet (25 m) of this unit was penetrated in the Amoco Deseret WIU well, but not dip corrected (King after AMSTRAT log D-4948, and API 43-029-30009, Utah DOGM well file).

TRag **Gartra Grit(?) (Triassic) –** Red, buff and gray, gritty micaceous sandstone; 43 to 76 feet (15-23 m) thick (Shinarump of Scott, 1954; Schick, 1955), though Smith (1969) reported a 30-foot (9 m) thick, locally conglomeratic unit; mapped in middle of Ankareh near Devils Slide where Thaynes Members (Timothy and Portneuf) are absent and a grit, rather than a granule sandstone and Timothy conglomerate, occupies the same stratigraphic position, separating the tongues of the Ankareh. However, equating the Gartra Grit to either the Higham Grit or Timothy Sandstone, or Shinarump conglomerate is problematic because Thomas and Krueger (1946, p. 1273) indicated the conglomerates called Gartra have at least two different source areas. Each of these coarser units have their own geographic distribution (depositional area) and source area, as indicated by differing clasts (see Kummel, 1954; Stewart and others, 1972; and references above), and likely have their own timing, following the Middle Triassic unconformity.

TRal **Lanes Tongue of the Ankareh (Triassic)** – Brownish-red shale, siltstone, and sandstone, with some buff to gray siltstone and sandstone; called Mahogany Member by some workers; 600 to 725 feet (180-220 m) thick near Devils Slide.

In subsurface north of the map area, the about 840 feet (256 m) of Lanes cut in the Birch Creek fold belt in the American Quasar Putnam well (API 43-033-30002, Utah DOGM) may be structurally thickened, while the about 765 feet (233 m) cut to the northeast in the American Quasar Hoffman well near Randolph, Utah (after AMSTRAT log D-4528, API 43-033-30001) seems reasonable. In the map area, an estimated 945 feet (288 m) of Lanes was penetrated in the Amoco Deseret WIU well, but this is not dip corrected and may be more structurally inflated than other units in this well (after Amstrat log D-4948 and API 43-029-30009, Utah DOGM well file).

TRt **Thaynes Formation, undivided (Lower Triassic)** – Brownish-gray, thin-bedded, calcareous siltstone; gray, thin-bedded, silty shale; and thin- to medium-bedded, gray, fossiliferous limestone in upper and lower part; separated by a resistant ridge of gray, very thick- to medium-bedded, fossiliferous limestone in middle part (Coogan, 2004a, 2006a-b; this report); estimated thickness of 1850 feet (565 m) (upper tongue of Dinwoody not included) from several miles south of Weber River in Devils Slide quadrangle, about the same total thickness as to northeast in Lost Creek drainage, 1835 feet (560 m) (Coogan, 2006a-b; note revision to Coogan, 2004a) that may or may not include upper tongue of Dinwoody; structurally thinned to about 1300 feet (400 m) in Dairy Ridge quadrangle (Coogan, 2006a).

In subsurface north of the map area, about 1930 feet (590 m) of Thaynes was cut in the American Quasar Putnam well in the Birch Creek fold belt (API 43-033-30002, Utah DOGM) and about 1700 to 1800 feet (510-540 m) was cut in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM). In the map area, estimate 2273 feet (693 m) of Thaynes penetrated in the Amoco Deseret WIU well, but not dip corrected (King after AMSTRAT log D-4948 and API 43-029-30009, Utah DOGM well file), and 2057 feet (627 m) of Thaynes was reportedly penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file).

Member names are after Kummel (1954). Note that Kummel's (1954) members, from about 70 miles (110 km) to the north near Bear Lake in Idaho, are recognizable near Devils Slide and that most of these members are recognizable another 25 miles (40 km) to the southwest near Salt Lake City, Utah (see Mathews, 1931; Solien and others, 1979). Member descriptions from Coogan (2004a, 2006a-b) and this report.

TRtums **Upper calcareous siltstone member and middle shale member, undivided (Lower Triassic)** – Used in Dairy Ridge and Francis Canyon quadrangles.

TRtu **Upper calcareous siltstone member (Lower Triassic)** – Brownish-gray, thin-bedded, calcareous siltstone and thin-bedded, gray, fossiliferous limestone; about 1040 feet (315 m) thick.

TRtms, TRtms?

Middle shale member (Lower Triassic) – Poorly resistant, gray, thin-bedded, calcareous, silty shale; about 100 feet (30 m) thick.

TRtml **Middle and lower units, undivided (Lower Triassic)** – Includes middle limestone member, both lower members and possibly upper tongue of Dinwoody Formation. Subdivided where possible.

TRtm **Middle limestone member (Lower Triassic)** – Gray, thick- to medium-bedded, fossiliferous, ridge-forming limestone; about 110 to 230 feet (33-70 m) thick.

TRtls **Lower shale member (Lower Triassic)** – Gray to brownish-gray, thin-bedded, calcareous siltstone to silty shale; at Devils Slide lower half is likely reddish-colored sandy siltstone of Decker tongue of Ankareh Formation; structurally thinned beneath and near the Willard thrust (Coogan 2006a-b); about 185 to 375 feet (55-115 m) thick.

TRtll **Lower limestone member (Lower Triassic)** – Gray to grayish-brown, thick- to thin-bedded, fossiliferous limestone; *Meekoceras* ammonite zone at base; about 250 feet (75 m) thick.

TRdu **Upper tongue of Dinwoody Formation (Lower Triassic)** – Greenish-gray and tan, calcareous siltstone and silty limestone; about 250 feet (75 m) thick.

TRwd **Woodside and Dinwoody Formations, undivided (Lower Triassic)** – Red sandy shale and siltstone over greenish-gray calcareous siltstone and silty limestone; about 900 feet (300 m) total thickness near Devils Slide. Structurally thinned where exposed near leading edge of Willard thrust sheet in Dairy Ridge quadrangle. Mapped separately in Devils Slide quadrangle.

To the north in Idaho, these formations intertongue (Kummel, 1954). Upper tongue of Dinwoody recognized at Devils Slide and Dairy Ridge, and placed in map units TRtd and TRdu.

Subsurface thickness of combined unit in map area is about 1040 feet (320 m). North of the map area about 1130 feet (345 m) of this unit was cut in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM).

TRw **Woodside Formation (Lower Triassic)** – Dark-red, sandy shale and siltstone, with some sandstone; 500 to 600 feet (150-180 m) thick at Devils Slide (this report; see also Eardley, 1944).

North of the map area in subsurface, about 700 to 750 feet (215-230 m) of Woodside was cut in the Birch Creek fold belt, with the upper tongue of Dinwoody likely included in the Thaynes in the American Quasar Putnam and Sohio Birch Creek wells (see API 43-033-30002 and 43-033-30042, Utah DOGM well files and logs) and about 700 feet (210 m) of Woodside was cut in the American Quasar Hoffman well to the northeast near Randolph, Utah (after API 43-033-30001, Utah DOGM). In the map area, 959 feet (292 m) of Woodside cut in the Louisiana Land & Exploration well 1-34 (API 43-033-30030, Utah DOGM) is likely too thick; estimate 787 feet (240 m) of Woodside penetrated in the Amoco Deseret WIU well, but not dip corrected (King after AMSTRAT log D-4948, and API 43-029-30009, Utah DOGM well file) and about 675 feet (208 m) of Woodside was cut in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file).

TRd **Dinwoody Formation (Lower Triassic)** – Greenish-gray and tan, calcareous siltstone and silty limestone; about 300 feet (90 m) thick at Devils Slide.

To the north of the map area, about 325 feet (100 m) of Dinwoody was cut in subsurface in the Birch Creek fold belt in the American Quasar Putnam and Sohio Birch Creek wells (API 43-033-30002 and 43-033-30042, Utah DOGM well files and logs), and about 430 feet (130 m) was cut in the American Quasar Hoffman well near Randolph, Utah (after API 43-033-30001, Utah DOGM). In the map area, 266 feet (81 m) of Dinwoody was cut in the Louisiana Land & Exploration well 1-34 (API 43-033-30030, Utah DOGM), estimate 292 feet (89 m) of Dinwoody penetrated in the Amoco Deseret WIU well (King after AMSTRAT log D-4948 and API 43-029-30009, Utah DOGM well file), and 350 feet (107 m) of Dinwoody was reportedly penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file).

PERMIAN

Pp, Pp? **Park City and Phosphoria Formations, undivided (Permian)** – Interbedded carbonate rock and highly organic to phosphatic shale; total thickness 857 and 675 feet (260 and 205 m) at Devils Slide and Durst Mountain, respectively, but the former may be faulted thickness. See Williams (1943), Cheney and others (1953), Cheney (1957), Schell and Moore, (1970), Coogan (2006a), and Coogan and King (2006) for more details.

North of the map area in subsurface, about 650 feet (200 m) of this unit was cut in the American Quasar Hoffman well near Randolph, Utah (after AMSTRAT log D-4528, API 43-033-30001).

In the Durst Mountain quadrangle, the stratigraphic offset between this unit and the lower Humbug Formation (Mhl) across the Bennett Creek fault (thrust?) is in excess of 4000 feet (1200 m).

Member descriptions and thicknesses are from exposures (Coogan, 2006a; and this report); subsurface subunit thicknesses north of the map area are from the Sohio Sugarloaf, Sohio Birch Creek, Marathon Hawk Springs, and American Quasar Putnam wells in the Birch Creek fold belt (API 43-033-30043, 43-033-30042, 43-033-30028, and 43-033-30002, Utah DOGM); in the map area subsurface subunit thicknesses from the Amoco Deseret WIU well (King after AMSTRAT log D-4948, and API 43-029-30009, Utah DOGM well file). Members queried where member identification is uncertain.

Ppf, Ppf?

Franson Member of Park City and Rex Chert Member of the Phosphoria Formation (Permian) - Interbedded gray to pinkish-gray to dark-gray, vuggy, cherty limestone, with lesser gray shale and calcareous sandstone, and dark-gray and black, bedded chert; about 240 to 300 feet (75-90 m) thick. In subsurface, complete unit 300 feet (90 m) thick in Birch Creek fold belt; in map area estimate 270 feet (82 m) thick.

Ppm, Ppm?

Meade Peak Phosphatic Shale Member of the Phosphoria Formation (Permian) – Gray limestone, dark-gray to black, phosphatic siltstone and shale, and gray, calcareous sandstone; 170 to 300 feet (50-90 m) thick. In subsurface, about 180 feet (55 m) thick in Birch Creek fold belt; in map area estimate 220 feet (67 m) thick.

Ppg, Ppg?

Grandeur Member of Park City Formation (Permian) – Light-gray, calcareous to dolomitic sandstone with some gray chert; about 220 to 310 feet (65-95 m) thick. In subsurface, about 240 feet (75 m) thick in Birch Creek fold belt; in map area, estimate 190 feet (57 m) thick, but contact with Wells Formation may not be correct.

PERMIAN AND PENNSYLVANIAN

PIPwe **Wells Formation (Lower Permian and Pennsylvanian)** – Light-gray to tannish-gray, very thick-bedded, cross-bedded, fine-grained sandstone; greater than 1050 feet (320 m) thick, because base of overturned Wells is truncated by Willard thrust (Coogan, 2006a).

In subsurface in the map area, 1033 feet (315 m) of Wells was cut in the Louisiana Land & Exploration 1-34 well (API 43-033-30030, Utah DOGM), thicker than nearby but reasonable since Wells thickens to south and west. Thinner to east in subsurface, with about 600 feet (180 m) of Wells cut north of the map area in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM well file), and 619 feet (189 m) of Wells was reportedly penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file). Wells is only present north and east of Weber Sandstone, and is a thinner version of Weber Sandstone.

PIPw, PIPwls, IPwl, PIPwu

Weber Sandstone (Lower Permian and Pennsylvanian) – Gray, well-cemented, quartzose sandstone with dolomite and siltstone in lower part; estimate 2600 feet (790 m) thick near Morgan (this report). Previously reported thicknesses (Eardley, 1944; Bissell and Childs, 1958; Mullens and Laraway, 1973) are likely from complexly folded strata and are likely across a back thrust. Equivalent to at least part of the Wells Formation. See Williams (1943, p. 598) for fossils. Likely at least partly non-marine eolian (see Fryberger, 1979).

On Durst Mountain, where possible and to show structure, the Weber is divided into a lower part (IPwl) with distinct regular bedding and an upper part (PIPwu) with less distinct bedding, and a marker limestone (PIPwls). The relationship of limestone marker (PIPwls) to the lower and upper units and the disconformity reported by Welsh and Bissell (1979, p. Y22) in the Weber is not known, though the marker appears to be in the upper unit. The lower Weber (IPwl) may be units 1-3 of Eardley (1944), *Fusulina*-bearing and older strata of Bissell and Childs (1958), or Desmoinesian and older strata of Welsh and Bissell (1979, p. Y18 and Y23). The disconformity of Welsh and Bissell (1979, p. Y22) may or may not be at the IPwl-PIPwu contact and may actually be the back thrust in the upper Weber (PIPwu) in the Devils Slide quadrangle.

Weber strata south of Sheep Herd Creek in the Durst Mountain quadrangle are separated from Mississippian strata to the north by Sheep Herd Creek such that a fault with 1000 to 3000 feet (300-900 m) of stratigraphic offset must be between these outcrops. The orientation of the fault is not known, but the Weber strata are displaced down relative to the Mississippian rocks.

PENNSYLVANIAN

IPm, IPm?

Morgan Formation (Pennsylvanian, Desmoinesian) - Reddish brown-weathering sandstone, siltstone and limestone that grade northward into light-gray lower part of Weber Sandstone; queried on leading edge of west-directed back thrust where carbonate-bearing strata identified as Morgan may be in the lower Weber Sandstone (IPwl); 0 to 1000 feet (0-300 m) thick in Morgan quadrangle. See Williams (1943, p. 598) for fossils. Type Morgan Formation is Desmoinesian (see Sadlick, 1955). Thrust faulted "into" Weber rather than intertongued.

Blackwelder (1910a) described the Morgan Formation and underlying Round Valley Limestone contact as an unconformity with red strata that bear clasts of the underlying limestone and chert over a cavernous weathered surface of limestone. This description is significant enough that Eardley (1944, p. 832-833) quoted Blackwelder (1910a) and we include it here. This contact relationship explains the rapid thinning of the Morgan to the north (it was not deposited everywhere above the unconformity) and is similar to the Amsden-Madison contact in Wyoming (though the Amsden and Madison are older).

IPr **Round Valley Limestone (Pennsylvanian, Atokan and Morrowan, and possibly Mississippian)** – Mostly light-gray, fine-grained limestone with regular bedding visible on aerial photographs; about 375 to 400 feet (115-120 m) thick near Morgan (Crittenden, 1959, p. 70; Mullens and Laraway, 1973). Carey (1973) reported a thickness of 335 feet (102 m) at the type section east of Morgan, while Sadlick (1955) reported 394 feet (120 m). See Sadlick (1955) and Carey (1973) for fossils; age is Morrowan and Atokan (see Sadlick, 1955). Possibly time equivalent to Amsden Formation (IPMa) in Wyoming, though Amsden is lithologically more like the Morgan Formation.

About 440 feet (135 m) of Morgan-like strata was cut in subsurface north of the map area in the American Quasar Hoffman well near Randolph, Utah (API 43-033-30001, Utah DOGM well file) and 425 feet (130 m) of Amsden is exposed in the Crawford Mountains (after Ott, 1980) on Crawford thrust sheet north of the map area.

MISSISSIPPIAN

King thinks the Mississippian and Devonian (Mmo, Mlf, Ml, Db, and Dh) exposures in Howard Hollow in the Horse Ridge quadrangle are part of the Willard thrust sheet because the concealed gap between upright steeply dipping Monroe Canyon Limestone (Mmo) and Thaynes (TRt) Formation exposures is only about one-third that needed for the about 3000 feet (900 m) of Triassic (TRw and TRd) and Permian (Pp and PIPwe) strata needed between the outcrops. Coogan (1992a, 2006b) placed the Howard Hollow strata on the Crawford thrust sheet while Peyton and others (2011) showed them in a Willard thrust fault sliver west of a Willard thrust fault imbricate. At the minimum, a fault is required between these exposures; this fault may be a footwall imbricate of the Willard thrust. To the west only about one-half of the ~3000 feet (900 m) of stratigraphic separation that is needed is present between outcrops of the Devonian Hyrum Formation (Dh) in Howard Hollow and the middle member of the Bloomington Formation (Cbm) to the west on the Willard thrust sheet.

Doughnut Formation (Upper Mississippian) – Possibly equivalent to upper Monroe Canyon to north, while interval to east is in an unconformity.

Mdu **Upper member (Upper Mississippian)** – Limestone and siltstone; about 300 feet (90 m) thick at Durst Mountain (Mullens and Laraway, 1973; Crittenden, 1959, p. 70, his units 3-6; this report). See Williams

(1943, unit 5, p. 598) and Nohara (1966), and Coogan and others (2015, appendix) for fossils; note possible Pennsylvanian (Morrowan) age in Coogan and others (2015, appendix, sample MV-1).

Mdl, Mdl?

Lower shale member (Upper Mississippian) – Poorly exposed siltstone, black shale, and limestone; about 200 feet (60 m) thick at Durst Mountain (Coogan and others, 2015) (see also Mullens and Laraway, 1973; Crittenden, 1959, p. 70, his unit 2). See Williams (1943, unit 4, p. 598) and Nohara (1966) for fossils.

Mmo **Monroe Canyon Limestone (Mississippian, Chesterian? and Meramecian)** – Tannish-gray, fossiliferous, vuggy, sandy dolomite; incomplete section about 1200 feet (365 m) thick in Howard Hollow, top not exposed (Coogan, 2006b). This is four times thicker than near Laketown, Utah on Willard thrust sheet (see Sandberg and Gutshick, 1979), but the top of the Monroe Canyon is truncated by an unconformity at Laketown and the Howard Hollow thickness is comparable to that in Idaho (see Sando and others, 1981). In subsurface about 950 feet (290 m) of Monroe Canyon was cut in American Quasar Hoffman well to northeast near Randolph, Utah (after AMSTRAT log D-4528 API 43-033-30001).

Mh **Humbug Formation (Mississippian, Meramecian?)** – Interbedded carbonate and calcareous to dolomitic quartzose sandstone (see also Crittenden, 1959, p. 70, his unit 1). Roughly equivalent to lower Monroe Canyon Limestone and upper Little Flat Formation to north; interval to east is in an unconformity.

Mhu **Upper part (Mississippian, Meramecian?)** – Limestone with sandstone beds near base, about 400 feet (120 m) thick at Durst Mountain (Coogan and King, 2006). See Nohara (1966) for fossils.

Mhl **Lower part (Mississippian, Meramecian?)** – Sandstone with limestone and dolomite interbeds, about 300 feet (90 m) thick at Durst Mountain. Contact placed so lower member is less resistant than upper member (Coogan and King, 2006).

Mlf **Little Flat Formation (Mississippian, Meramecian-Osagean)** – White to light-tan, light-orange to tan weathering, fine-grained, calcareous sandstone; 970 feet (295 m) thick in Howard Hollow (Coogan, 2006b), slightly (~15%) thicker than near Laketown on Willard thrust sheet (see Sandberg and Gutschick, 1979). Outcrops of Little Flat Formation on the Willard thrust sheet in the map area are darker colored and contain about half carbonate rocks and the basal Delle Phosphatic Member.

North of the map area on the Crawford thrust sheet in the Crawford Mountains, 14 to 43 feet (4-13 m) of Delle Phosphatic Member are in the Brazer Formation of Sandberg and Gutschick (1979, 1984). The Brazer is dolomitized Little Flat Formation and the lower part of the Monroe Canyon Formation. See Norris (1981) on Mission Canyon-lower Little Flat-Brazer age equivalency and Osagean age.

In subsurface north of the map area between the Crawford Mountains and Horse Ridge, about 650 feet (200 m) of Little Flat was cut in the American Quasar Hoffman well near Randolph, with 10 feet (3 m) of Delle phosphatic strata (King after AMSTRAT log D-4528 API 43-033-30001).

Mde **Deseret Limestone (Mississippian)** – Limestone, dolomite and sandstone, with dark, non-resistant phosphatic shale at base (Delle Phosphatic Member, Mded); about 500 feet (150 m) thick at Durst Mountain (Coogan and King, 2006). Deseret probably equivalent to most of Little Flat Formation (Mlf) mapped in Horse Ridge quadrangle.

Ml **Lodgepole Limestone (Mississippian, Osagean-Kinderhookian)** – Dark-gray, thin-bedded, lime micrite (mudstone) to wackestone; locally cherty; at least locally fossiliferous; about 650 feet (200 m) thick on Durst Mountain (Coogan and King, 2006). Structurally thickened to 1300 feet (395 m) in Howard Hollow, even thicker than the 900-foot (270 m) thickness on Willard thrust sheet (Coogan, 2006b).

The type Lodgepole is overlain by the Mission Canyon Limestone (Sando and Dutro, 1974), so, with the Delle marking the boundary between the Deseret and Gardison, this unit may better be called Gardison.

In subsurface east of the Willard thrust, 764 feet (233 m) of Lodgepole was reportedly penetrated in the Champlin 432-Amoco C well in the Peck Canyon quadrangle (see API 043-29-30011, Utah DOGM well file) and, north of the map area near Randolph, Utah, about 740 feet (225 m) of Lodgepole was cut in the American Quasar Hoffman well, with an additional 45 feet (14 m) of shaly Cottonwood Canyon Member of Madison/Lodgepole and Leatham Formation (after AMSTRAT log D-4528, API 43-033-30001), with about 820 feet (250 m) of total Lodgepole reported in the Utah DOGM well file (API 43-033-30001). Well data from the Sohio Birch Creek, Sohio Sugarloaf, Marathon Hawk Springs, and American Quasar Putnam wells in the Birch Creek fold belt north of the map area indicate about 680 to 930 feet (210-280 m) of Lodgepole was cut (API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, respectively, Utah DOGM), and the shaly Cottonwood Canyon Member of Madison/Lodgepole and Leatham Formation are likely present.

These shaly units (and their characteristic double spike on gamma-ray logs) are truncated and eliminated by an unconformity in the region (see references on Willard thrust sheet). On Durst Mountain, a basal recessive interval that is likely the Cottonwood Canyon Member of Lodgepole Limestone and the underlying Leatham Formation (Devonian) is not consistently mapped in the Lodgepole or underlying Beirdneau Formations (Coogan and others, 2015). The Leatham Formation, likely including the Cottonwood Canyon Member, is also exposed in the Crawford Mountains, west of the Crawford thrust and north of the map area (see descriptions in Sando and others, 1959; Sandburg and Gutchick, 1979; Ott, 1980).

DEVONIAN

The Beirdneau, Hyrum, and Water Canyon names are from the Willard thrust sheet and may not be appropriate for strata deposited in shallower water on the paleo-continental shelf, in what is now the Crawford thrust sheet. Typically on the Crawford thrust sheet to the north and east, Beirdneau=Three Forks and Hyrum=Jefferson with no Water Canyon equivalent (see Benson, 1966, p. 2570; Johnson and others, 1991). We chose to retain the Willard thrust sheet names because they have traditionally been used. These strata are also called the Darby (Three Forks plus Jefferson) in subsurface (Wyoming terminology). Unit thickness estimates are by King and are based on outcrop pattern, bedding dip, and topography south of Cottonwood Canyon in the Durst Mountain quadrangle (see Coogan and King, 2006). Devonian age subdivisions are not noted due to unit name and age uncertainty, and the lack of fossils.

Darby Formation (Upper Devonian) – Subsurface unit (Dd) in map area. Calcareous to dolomitic shale, sandstone, and dolomite; similar to Beirdneau and Hyrum Formations on Durst Mountain (see Db and Dh below).

Db **Beirdneau Sandstone (Devonian)** – Tan, reddish-tan, and yellowish-gray, calcareous to dolomitic sandstone, siltstone, some sandy dolomite and limestone, and lesser intraformational conglomerate; less resistant than adjacent units; brownish-gray dolomite resembling Hyrum Dolomite in middle part; about 200 to 300 feet (60-90 m) thick in Howard Hollow and on Durst Mountain (Coogan, 2006b; Coogan and King, 2006). Beirdneau-Hyrum contact may not be consistently mapped on Durst Mountain (Coogan and others, 2015).

The Beirdneau is typically called Three Forks Formation (Dtf) (Wyoming terminology) in subsurface. In the Birch Creek fold belt, Coogan (1992a, figure 33) showed an upper Darby about 400 feet (120 m) thick with a log signature like the Beirdneau/Three Forks, while the Sohio Birch Creek, Sohio Sugarloaf, Marathon Hawk Springs, and American Quasar Putnam wells apparently penetrated about 400 to 500 feet

(120-150 m) of Three Forks (API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, respectively, Utah DOGM well files). The Beirdneau is about 300 or 400 feet (90 or 120 m) thick in the American Quasar Hoffman well near Randolph, Utah (after API 43-033-30001, Utah DOGM and AMSTRAT log D-4528, respectively). To the south in the map area in the Amoco Deseret WIU well about 485 feet (148 m) of Beirdneau was cut (King after AMSTRAT log D-4948, API 43-029-30009) and 460 feet (140 m) was reportedly penetrated in Champlin 432-Amoco C well in the Peck Canyon quadrangle (API 043-29-30011, Utah DOGM well file).

Dhw **Hyrum and Water Canyon Formations, undivided (Devonian)** – See descriptions below.

Dh **Hyrum Dolomite (Devonian)** – Dark- to medium-brownish-gray and gray, medium-bedded dolomite; weathers distinctive, dark-chocolate brown; more resistant at top and bottom with center of less resistant beds that grade laterally into reddish, dirty carbonate and limy sandstone and siltstone like the Beirdneau Sandstone; about 250 to 450 feet (75-140 m) thick at Durst Mountain (Coogan and King, 2006).

In Howard Hollow, 725 feet (220 m) of Hyrum are present but the base is not exposed, and this is thicker than the Hyrum is on the Willard thrust sheet (675 feet [205 m]) (Coogan, 2006b). So this large thickness and proximity to concealed Willard thrust fault implies structural thickening of the Hyrum and/or the Howard Hollow Dh unit includes Water Canyon Formation strata.

The Hyrum is typically called Jefferson Formation (Dj) (Wyoming terminology) in subsurface. In the Birch Creek fold belt north of the map area, Coogan (1992a, figure 33) showed a lower Darby about 600 feet (180 m) thick with a log signature like the Hyrum/Jefferson, and the Sohio Birch Creek, Sohio Sugarloaf, and Marathon Hawk Springs wells apparently penetrated about 540 feet (165 m) of Jefferson (API 43-033-30042, 43-033-30043, and 43-033-30028, respectively, Utah DOGM well files). To the south in the map area, about 625 feet (190 m) of Jefferson was cut in the Amoco Deseret WIU well (King after AMSTRAT log D-4948, API 43-029-30009).

Dwc, Dwc?
Water Canyon Formation (Devonian) – Light-yellow-gray to medium-gray, interbedded calcareous to dolomitic sandstone and silty to sandy dolomite and limestone, with sandstone below carbonate; less resistant than underlying and overlying units; estimated thickness 200 feet (60 m) at Durst Mountain (Coogan and King, 2006; see also Eardley, 1944, Cambrian units 9-12). Queried because altered along fault and may be Hyrum Dolomite (Dh).

In the Amoco Deseret WIU well, about 400 feet (120 m) of what appears to be Devonian Water Canyon strata was cut (King after AMSTRAT log D-4948, API 43-029-30009), but the Water Canyon does not appear to be present north of the map area in the Birch Creek fold belt (API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, Utah DOGM), likely due to an unconformity.

SILURIAN AND ORDOVICIAN

Silurian and Ordovician strata are missing, along with the Cambrian part of St. Charles Formation, on Durst Mountain due to thinning over the Stansbury uplift and/or Tooele arch (see Rigby, 1959; Hintze, 1959). Use of the Laketown Dolomite name might be a leftover from incorrect identification of these rocks in the Crawford Mountains as Silurian rather than Ordovician (see Berdan and Duncan, 1955, for correction). This unit is shown correctly as the Ordovician Bighorn Dolomite at the state line by Dover (1985, 1995) and M'Gonigle and Dover (1992), while the Silurian mistake is present on the Wyoming state geologic map (see Love and Christiansen, 1985) though later corrected by a note in Love and others (1993).

Note that about 15 miles (25 km) northwest of Durst Mountain in Ogden Canyon, 1000 feet (300 m) of Ordovician and upper Cambrian strata are present (Fish Haven, Garden City, and St. Charles Formations), as is part of the Bloomington Formation, present between the Nounan and Maxfield Formations. The Nounan, Maxfield, and Tintic Formations are also thicker in Ogden Canyon than on Durst Mountain, though the Ophir Formation is about the same thickness (see Yonkee and Lowe, 2004).

ORDOVICIAN

Bighorn Dolomite (Upper Ordovician) – Subsurface unit (Ob) in map area. Gray, finely crystalline, thick-bedded dolomite with diverse fossils as exposed in the Crawford Mountains north of the map area; identified as Fish Haven Dolomite in some reports (for example Ott, 1980), though Ordovician is missing on Durst Mountain (see Coogan and King, 2006).

Strata identified as Ordovician Bighorn Dolomite are present in subsurface and are bounded by unconformities. Coogan (1992a, figure 33) showed about 900 feet (270 m) of Bighorn in the Sohio Birch Creek well, but other interpretations of this and other deep wells in the Birch Creek fold belt north of the map area are possible; the Hawk Springs well AMSTRAT log (D-5302, API 43-043-30028) indicated about 890 feet (270 m) of Bighorn, but the shale break about 100 feet (30 m) above the base and underlying strata could be Cambrian. To the south in the map area, about 900 feet (270 m) of Bighorn was cut in the Amoco Deseret WIU well (King after AMSTRAT log D-4948 and API 43-029-30009, Utah DOGM well file).

CAMBRIAN

Nounan, Maxfield, Ophir and Tintic Formation descriptions are from exposures on Durst Mountain, with thickness estimates based on outcrop pattern, bedding dip, and topography south of Cottonwood Canyon in the Durst Mountain quadrangle (Coogan and King, 2006).

Cn **Nounan Formation (Cambrian)** – Medium-dark-gray, thick-bedded dolomite and some limestone; estimated thickness 350 to 400 feet (105-120 m); see also Eardley (1944, his Cambrian units 6-8).

The Nounan Formation does not appear to be present to the north of the map area in the Birch Creek fold belt (API 43-033-30042, 43-033-30043, 43-033-30028, and 43-033-30002, Utah DOGM), likely due to the unconformity that excised Silurian and Ordovician strata, and the Cambrian part of the St. Charles Formation elsewhere in the map area (see above).

Gallatin Limestone and Gros Ventre Formation, undivided (Middle Cambrian) - Subsurface unit (Cg) in map area. Thin-bedded, silty limestone, oolitic limestone, and shale. The Gallatin is mostly limestone like the Maxfield Limestone on Durst Mountain, while the Gros Ventre is shale over limestone over shale like the Ophir Shale on Durst Mountain.

Coogan (1992a, figure 33) showed about 250 feet (75 m) of Gallatin and about 750 feet (230 m) of Gros Ventre in the Sohio Birch Creek well, but other interpretations of this and other deep wells in the Birch Creek fold belt are possible. The Hawk Springs well AMSTRAT log (D-5302, API 43-043-30028) showed a Cambrian top at a change from dolomite (Bighorn) to limestone with about 400 feet (120 m) of carbonate at the top (likely Gallatin) above about 400 feet (120 m) of mixed carbonate and shale (Gros Ventre?).

Cm, Cm?

Maxfield Limestone (Middle Cambrian) – Limestone and calcareous siltstone; estimated thickness 300 feet (60 m); see also Eardley (1944, his Cambrian units 3-5). Queried where may be Nounan Formation (Cn). Bloomington Formation is not present on Durst Mountain. Strata in subsurface that are lithologically similar to Maxfield are called Gallatin Limestone (Cg) (Wyoming terminology).

Cm-Com

Maxfield Limestone and/or middle limestone of Ophir Formation (Middle Cambrian) – Highly fractured limestone and calcareous siltstone exposed in thrust window in Cottonwood Canyon in Durst Mountain quadrangle.

Co **Ophir Formation (Middle Cambrian)** – Upper slope-forming, brown-weathering, olive-gray argillite with intercalated gray limestone beds; middle, ledge-forming, thin to medium bedded, gray micritic limestone with silty partings and layers; and lower brown-weathering, olive-gray argillite and siltstone with lesser gray limestone beds, and mainly siltstone and sandstone in lower 60 feet (20 m); argillites typically have micaceous sheen; estimated total thickness 440 to 725 feet (135-220 m). See also Eardley (1944, his Ophir and Cambrian units 1 and 2). In subsurface, lithologically similar strata (shale over limestone over shale) are called Gros Ventre Formation (Cg) (Wyoming terminology) and are thrust truncated.

Ct **Tintic Quartzite (Middle and Lower? Cambrian)** – Tan quartzite, conglomeratic in lower half with Neoproterozoic quartzite pebbles and cobbles; basal 50 to 100 feet (15-30 m) arkosic conglomerate of Farmington Canyon Complex material; about 1000 feet (300 m) thick. See also Eardley (1944).

PALEOPROTEROZOIC

Xfc **Farmington Canyon Complex (Paleoproterozoic)** – Micaceous schistose and gneissic crystalline rocks with small bodies of amphibolite and pegmatite, variously called dikes and pods. More detailed information on the complex to the west in the Wasatch Range is available in Bryant (1988), Barnett and others (1993), and Yonkee and Lowe (2004).

AREA EAST OF HENEFER AND ALONG SALERATUS CREEK, AND THRUST SHEETS EAST OF CRAWFORD THRUST

Tertiary strata and at least part of the Cretaceous Hams Fork Member of the Evanston Formation are younger than and overlie the thrust sheets. Paleozoic rocks are part of a marine inner shelf sequence exposed to the east in Wyoming.

TERTIARY

Ts **Tertiary strata, undivided** – Used in stacked map units where multiple Tertiary units (Tf, Tfb, Tfs?, and Tw) are below terrace deposits west of Evanston Wyoming (Qat3/Ts), below fan deposits along Saleratus Creek (Qaf3?/Ts, Qaf4?/Ts, and Qaf5/Ts), and below gravel deposits of uncertain origin near Minnow Hill (Qng/Ts).

Norwood Formation (Tuff) (lower Oligocene and upper Eocene) – Lithologically similar to Fowkes Formation; typically light-gray to light brown altered tuff (claystone), altered tuffaceous siltstone and sandstone, and conglomerate; to west present south of Ogden map area in East Canyon graben; may be present in subsurface on east side of Main Canyon Creek valley in Devils Slide quadrangle; details on Norwood Formation to west are under heading "Sub-Willard Thrust – Ogden Canyon Area."

The Norwood Formation is noted here because Constenius (1996) labeled some Fowkes strata near Porcupine Ridge (Porcupine Ridge quadrangle) as Norwood, based on isotopic ages in our basal Fowkes, but his well numbers, dips, and Wasatch-Fowkes contacts are different than ours. His Fowkes-Norwood contact appears to be our Wasatch-Fowkes contact, such that his dip change (unconformity) is not in tuffaceous strata. Also, Norwood K-Ar isotopic ages (38 and 39 Ma) to the west overlap with Fowkes isotopic ages (39 and 40 Ma) in the southern Yellow Creek graben. Our sample 96-53 came from the Fowkes just above the top of our Wasatch Formation and was isotopically dated by K-Ar analyses on hornblende at 32.3 $\pm$ 1.2 Ma, but our sample is stratigraphically below the samples isotopically dated by Ar-Ar analyses at about 39-40 Ma.

Norwood strata have been mapped and reported directly to the east and south of the Ogden map area, where the basal strata are reportedly volcanic clast conglomerate. These Norwood strata are located in the Acocks graben east of the Bear River in the Evanston 7.5' quadrangle, Wyoming, where a basal conglomerate reportedly contains clasts of Keetley Volcanics flows (Tnc of Dover and M'Gonigle, 1993), as well as to the south in the southern Yellow Creek graben in the Upton quadrangle, Utah, where a conglomerate (Toc) that overlies the Fowkes Formation is rich in volcanic rock clasts (Tf under Toc under Tn of Bryant, 1990).

We have yet to see similar volcanic-clast conglomerate in the Ogden map area, even at the head of Huff Creek adjacent to Bryant's (1990) outcrops, or below the isotopically dated rocks in the southern Yellow Creek graben. When contacts for the Upton area conglomerate unit (Toc) are extended north into the Castle Rock quadrangle, the unit is uppermost Wasatch Formation and lower Fowkes Formation, which would be the interval occupied by the Sillem Member of the Fowkes Formation (a non-volcanic-clast conglomerate). The volcanic clasts in the southern Yellow Creek graben actually seem to be residual and colluvial deposits from the capping gravels (QTg of Bryant, 1990) rather than a "concentrate" of the underlying Toc. Further, we have been unable to separate older Fowkes from younger Fowkes-Norwood in the field in any Eocene-Oligocene graben in northern Utah.

In the Acocks graben, located east of the Ogden map area, only some of the Tnc of Dover and M'Gonigle (1993) contains conglomerate; it has local pebble conglomerate beds and near Pleasant valley thicker conglomerate, but no Keetley Volcanics clasts. Near Pleasant Valley, their geologic map showed their Norwood conglomerate (Tnc) overlying the Sillem Member of the Fowkes (see unit Tfs? below), and/or the similar appearing upper Wasatch Formation, with the typical green Bulldog Hollow Member missing. This area has red and white strata interbedded such that the Fowkes appears to contain an admixture of eroded Wasatch Formation material, including conglomerate clasts (see Tf below), and the Sillem (our Tfs?) may or may not be present. The Norwood of Dover and M'Gonigle (1993) to the east may just be more Fowkes; it needs to be isotopically dated, as does the Norwood below (older than) the dated rocks to the west in the Morgan Valley graben.

Tf, Tfs?, Tfb, Tfb?

Fowkes Formation (middle? Eocene) – Typically green to gray altered tuff (claystone), altered tuffaceous siltstone, sandstone, and conglomerate; partially exposed in four grabens in the Ogden map area -- the Saleratus Creek, Almy (along the Bear River), Yellow Creek, and southern Yellow Creek grabens; Tf and Tfb up to about 500 feet (150 m) thick in exposures, and 400 or 500 feet (120 or 150 m) thick in subsurface along Saleratus Creek and up to about 2000 feet (600 m) thick in subsurface in other graben. The Fowkes Formation is prone to slope failures.

The Fowkes Formation is generally considered to be older than the Norwood Formation, but neither is well dated due to alteration. Limited isotopic ages (discussed below) have a bimodal distribution (~39-40 and 48-49 Ma) for the Fowkes strata exposed along the Utah-Wyoming border with an age (~44 Ma) in the gap from a sample taken north of the Ogden map area in the southern Cache Valley (see Oaks and others, 1997).

Paleontological data on the Fowkes Formation near Evanston, Wyoming (where isotopically dated as older by Nelson, 1979), is presented in Nelson (1971); see also Oriel and Tracey (1970, p. 16 on white beds west of Bear River) and Nelson (1973, 1974, 1979). The fossil mammal data and isotopic ages indicate the older Fowkes strata are essentially the time equivalent of the Bridger Formation in Wyoming (Nelson, 1973, 1974; see also Lillegraven, 1993, figures 4O and 4P). The Fowkes name was introduced because Veatch (1909) misunderstood the faulted stratigraphy along the Bear River, and might best be abandoned because the Fowkes name is only used in the Fossil Basin and the Fossil Basin is part of the greater Green River Basin, where the Bridger name is used. As yet, old Fowkes cannot be distinguished in the field from young

Fowkes and Fowkes strata cannot be distinguished from Norwood-age strata when they are in the same basin (Coogan and others, 2015). So abandoning the Fowkes name for just the older strata is premature.

As mapped our Fowkes (Tf) is mostly green altered tuff, which would be the Bulldog Member of the type Fowkes Formation, because the underlying, variably conglomeratic Sillem Member of the Fowkes Formation of the type area (see Oriel and Tracey, 1970), if present in the Ogden map area, cannot easily be discriminated from the underlying light-colored Wasatch Formation that contains light-gray to white marlstone and limestone like the Sillem Member. The Sillem grades upwards into the Bulldog Member with increasing altered tuffaceous (greenish) material, a contact that is difficult to map and further confused by greenish-colored strata in the type Sillem measured section (see Oriel and Tracey, 1970, p. 47).

As mapped separately, our Bulldog Member (Tfb) is altered green tuff that is underlain by pink claystone-mudstone and limestone west of Saleratus Creek that may or may not be the Sillem Member. Our Sillem is queried (Tfs?) because the rocks could be part of the Wasatch Formation, though not red or reddish. Our exposed Sillem (all queried, Tfs?) is less than about 200 feet (60 m) thick. Our queried Bulldog Member (Tfb?) may be either the Sillem Member or the Wasatch Formation (Tw), because it is light-gray claystone, mudstone, siltstone, and sandstone rather than being green Fowkes or red Wasatch Formation.

Oriel and Tracey (1970, p. 34) reported Sillem Member strata at the mouth of Acock[s] Canyon in the Neponset Reservoir NE quadrangle, where we map both Wasatch Formation and Fowkes Formation. The light-colored lacustrine deposits of the Green River Formation that Oriel and Tracey (1970, p. 16) noted near Evanston, Wyoming, are actually in the Fowkes Formation and include the Thomas Canyon (stateline) fossil quarry and K-Ar sample site of Nelson (1971, 1979) in the Murphy Ridge quadrangle in the Ogden map area. These rocks may be a more lacustrine part of the upper part of the Sillem Member, which according to Oriel and Tracey (1970, p. 35) contains mostly mudstone-claystone with thin beds of marlstone, limestone, and sandstone, and chert conglomerate lentils, and, in the upper part of the upper part, some volcanic grains (biotite, magnetite, amphibole, glass) and secondary silica (opal).

In subsurface, about 2300 feet (700 m) of Fowkes was shown in the Almy graben north of Evanston, Wyoming (see Constenius, 1996, figure 9-FWK-1) and about 1600 feet (500 m) was shown in the southern Yellow Creek graben (see Norwood of Constenius, 1996, figure 8; his figure 8 Fowkes is light-colored upper Wasatch Formation). In subsurface in the Yellow Creek graben, between the Almy and southern Yellow Creek grabens, West (1983, Anschutz exhibit on 8/25/1983 for Utah Division of Oil, Gas, and Mining) showed 1000 feet (300 m) of Fowkes where penetrated by the 12-30 well in the Cave Creek field thickening to 2250 feet (685 m) in the Yellow Creek valley east of the field. Up to about 2000 feet (610 m) of Fowkes was shown east of the Yellow Creek field (Lamerson, 1982, plates 10 and 11, and figure 26) in the Yellow Creek (not Acocks) graben with penetration by the Mesa 2-13, Cities Service A-2, and Gulf 1-12 Herman Federal wells and surface dips opposite what would be expected (steeper farther from fault in half graben). These dips may be more related to salt tectonics than to listric normal faulting.

The older set of Fowkes isotopic ages are: (1) 49 Ma (K-Ar on hornblende; recalculated) from Bulldog Hollow Member of Fowkes type area to the north in Wyoming (47.7 $\pm$ 1.5 Ma in Oriel and Tracey, 1970); (2) 49 Ma (K-Ar on biotite) (recalculated, but analyzed in 1977 and decay constant not reported, so may not need to be recalculated) (47.9 $\pm$ 1.9 Ma in Nelson, 1979), that likely came from near the base of the Fowkes in the Almy graben west of the Bear River in the Murphy Ridge quadrangle (Nelson, 1973 - [NE1/4] NE1/4 sec. 2, T. 15 N., R. 121 W.); and (3) 47.94 $\pm$ 0.17 Ma ($^{40}Ar/^{39}Ar$ on sanidine) reported by Smith and others (2008, p. 67) is from a sample collected in Wyoming at the northeast end of the Crawford Mountains, south of the Fowkes type area. K-Ar ages were recalculated using Dalrymple (1979).

The basal part of an altered tuffaceous unit (undivided Norwood and Fowkes Formations, see Tnf in thrust overlap descriptions, “resting” on Wasatch) has been isotopically dated by K-Ar (hornblende and biotite) analyses at 44.2 $\pm$ 1.7 Ma and 48.6 $\pm$ 1.3 Ma, respectively, from samples taken adjacent to the Odgen map area in the southern Cache Valley, Utah (Smith, 1997). Though the biotite age is suspect, this age is similar to isotopic ages on the older Fowkes Formation in Wyoming.

Younger Fowkes isotopic ages on samples from the Ogden map area imply part of our Fowkes map unit is the lateral equivalent of at least part of the Norwood Formation (38-39 Ma). The Fowkes was isotopically dated by $^{40}Ar/^{39}Ar$ analyses at 40.41 Ma and 38.78 Ma on biotite and hornblende (samples KNC53094-5 and KNC53094-3), respectively, from basal greenish-hued altered tuffs, likely the Bulldog Member, a few hundred feet above the Wasatch Formation contact in the southern Yellow Creek graben in the Castle Rock quadrangle. To the south in the Upton quadrangle, these tuffs are overlain by strata mapped as Norwood Formation by Bryant (1990). Isotopic ages on the Keetley Volcanics and their intrusive equivalents are generally younger to the same age (~33 to 39 Ma) (see Vogel and others, 1997; see also Nelson, 1976), but some intrusions near Park City are 40 to 47 Ma (John and others, 1997), and nearly overlap with the older part of the Fowkes age range (48-49 Ma). Based on similar ages and geology, the younger Fowkes Formation appears to be the more distal sedimentary equivalent of the volcano comprised by the Keetley Volcanics more than 25 miles (40 km) to the southwest near Park City, Utah, and is basically the Norwood Formation in a different basin.

The Fowkes Formation contact with the underlying Wasatch Formation is problematic. The contacts in the Neponset Reservoir NW, Neponset Reservoir NE, McKay Hollow, and Murphy Ridge quadrangles are based on (1) the off-white to green color of the Fowkes versus the pale pink to light-gray upper Wasatch, (2) less defined bedding in and less weathering resistance of the Fowkes than the Wasatch, (3) a slight change in dip (1-3 degrees) that is locally recognizable across the Fowkes-Wasatch contact, and (4) the presence of angular (volcanic?) biotite and hornblende grains in the Fowkes Formation. The contact is a problem because light-colored sandstone and conglomerate beds, and off-white carbonate beds (typically marls) are present in both formations. Also, interbedded off-white and reddish-hued strata to the west in Morgan Valley, that look on aerial photographs like interbedded tuffaceous Norwood Formation (similar to Fowkes strata) and Wasatch Formation strata, are actually eroded red material from the Wasatch Formation that was mixed into younger deposits before lithification into Norwood and younger rocks. This makes the younger strata look like the Wasatch Formation. This leaves using an obscure unconformity and numerous transects to observe abundances of angular mafic (volcanic) grains to map the contact. The contact is particularly difficult to map in the Almy and Yellow Creek grabens, because of the Fowkes Formation and light-colored beds in the upper Wasatch Formation are in fault contact, and contact relationships in the Yellow Creek graben are further complicated by salt tectonics. Lamerson (1982) mapped the Fowkes as more extensive than King did in these grabens, and he may be correct, because King has tried to map the Fowkes-Wasatch contact using tuffaceous (greenish- to grayish-hued) strata as opposed to lighter colored strata.

Tfw **Limestone of Fowkes or Wasatch Formation (Eocene?)** – Gently dipping light-gray limestone east of Saleratus Creek that dips as gently as the Fowkes and appears to unconformably overlie the Wasatch Formation, but is much thicker and more prominent than any limestone in the Fowkes; looks most like limestones in the Wasatch Formation; at least 60 feet (18 m) thick.

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – Typically red sandstone, siltstone, mudstone, and conglomerate with minor gray limestone and marlstone locally; lighter shades of red, yellow, tan, and light gray more common in uppermost part; light-colored, resistant limestone and marlstone are distinct in Shearing Corral and Castle Rock quadrangles; note that sinkholes in unit indicate karstification of limestone beds; from variations in exposed thicknesses to the west (Coogan, 2004a-c, 2006a-b), thickness likely varies locally due to considerable relief on subsurface basal erosional surface; in northeast Heiners Creek quadrangle about 1200 feet (365 m) thick from lower contact in valley bottom to eroded top on ridge, and in Castle Rock quadrangle appears to be about 750 feet (230 m) thick from ridge top to valley bottom east of Aspen Creek and lower Rees Creek, with neither top nor bottom exposed. The Wasatch

Formation is queried (Tw?) where light-colored rocks may be part of the Fowkes Formation (Tf). The Wasatch Formation is at least locally prone to slope failures.

The subsurface Wasatch thickness in the Shearing Corral quadrangle is estimated as 1000 feet (300 m) from penetration shown for the Champlin 392-Amoco A well by Lamerson (1982, plate 11). To the east the Wasatch thickens to 2000 feet (600 m), including 500 feet (150 m) of basal conglomerate (see Lamerson, 1982, figure 26) where penetrated by the Hatch and Urroz wells in the Yellow Creek field (see also Lamerson, 1982, plate 10). In the Anschutz 14-33 well in the Yellow Creek field 2130 feet (650 m) of Wasatch was penetrated, including about 200 feet (60 m) of conglomerate at the base, but the well was spudded in the Wasatch (API 43-043-30315, Utah DOGM). The Wasatch may thicken in the Yellow Creek graben, due to preservation (less erosion). About 1000 feet (300 m) of Wasatch was shown in the Cave Creek field where penetrated by the Fawcett & Son well (Lamerson, 1982, plate 11). West (1983 Anschutz exhibit on 8/25/1983 for Utah Division of Oil, Gas, and Mining) showed 2000 feet (600 m) of Tertiary (likely Wasatch and Cretaceous Evanston) where penetrated by the 12-30 well in the Cave Creek field. About 700- to 800-foot (210-240 m) thickness was shown for the Wasatch by Lamerson (1982, plate 11) where penetrated by four wells in and near Anschutz Ranch East field.

Paleocene (P5-P6) age for the Wasatch is based on palynology, using the Eocene-Paleocene boundary of Jacobson and Nichols (1982) that is likely the C24 paleomagnetic reversal (see Hicks and others, 2003). Other Eocene-Paleocene boundaries would put P6 palynomorphs in the Eocene. Wasatch strata to the southeast in Salt Lake City 30x60- minute quadrangle contain P5-6 palynomorphs, but also contain the palynomorph *Platycarya platycaryoides* (Nichols and Bryant plate 2 in Bryant, 1990, sample D6052), which is Eocene (see Nichols, 2003). See also Jacobson and Nichols (1982) for P5 and P5-6 in other samples (P3055-2A, 3B; P3387-2) to the south of the Ogden map area (their figure 7 updated with mapping by Bryant, 1990). Also, upper Paleocene (P5-6) palynomorphs were recovered from a sample (P2833-1,2, Jacobson and Nichols, 1982) taken near the Tw-Twc contact in Porcupine Ridge quadrangle. Sample 96-3a from our unit Tw in the Porcupine Ridge quadrangle had middle Paleocene (P4) palynomorphs, but this is too old, and this age is like the Tertiary Evanston Formation east of the Bear River north of Evanston, Wyoming (Lamerson, 1982, figure 11; Jacobson and Nichols, 1982). The P4 age likely indicates recycled (inherited) palynomorphs.

Twd? **Limestone of Red Hill dome (Eocene?)** – Wasatch Formation strata, typically limestone, that dip radially outward forming a dome in the Neponset Reservoir NW quadrangle; lacks vuggy character that is typical of spring deposits; thickness indeterminate.

Fowkes Formation strata around the dome may not be domed; they appear to unconformably overlie Wasatch strata and dip several degrees more steeply near the dome, but dip less than half as steeply as the gentlest dips in the domed Wasatch strata. A dome origin uncertain because the subsurface saline welts in the Jurassic Preuss Redbeds are to the east near the Bear River (see Lamerson, 1982, figure 29). Red Hill may be mud "volcano/diapir" with fluid movement localized along the subsurface Crawford thrust fault. Queried because origin of unit is uncertain.

Twc **Basal conglomerate of Wasatch Formation (Paleocene)** – Red-orange- and tan-weathering, cobble conglomerate, mainly containing Neoproterozoic and Cambrian quartzite clasts; mapped along Medicine Butte thrust on east side of Porcupine Ridge (Porcupine Ridge quadrangle), where it locally intertongues with the rest of the Wasatch Formation, and in the Wahsatch quadrangle; 0 to 400 feet (0-120 m) thick in these exposures; thickness varies locally due to considerable relief on basal erosional surface.

We estimate the basal conglomerate is greater than 500 feet (150 m) thick in the canyon north of the Island Ranching 2E well (top of ridge to bottom of canyon perpendicular to ridge, with base not exposed in canyon, and top may be eroded away). About 800 feet (240 m) of basal conglomerate was cut in the Champlin 458 Amoco A well east of Porcupine Ridge (Red Hole quadrangle) just south of the Ogden map area (see Knight unit of AMSTRAT log D-5215, API 43-043-30067, Utah DOGM). About 500-foot (150 m) thickness of Twc shown where penetrated by the Hatch and Urroz wells in the Yellow Creek field (Lamerson, 1982, figure 26).

This conglomerate is mapped as Wasatch Formation rather than Tertiary Evanston Formation (see Lamerson, 1982, figure 27) based on palynology (P5-6) (see sample P2833-1,2 of Jacobson and Nichols (1982) and sample 96-19 in Twc in Coogan (2010a-b, tables; appendix tables 1 and 2 this report). A problem exists with the P3-4 age from our sample 96-5a from unit Twc; this is a Tertiary Evanston age but the pollen might be recycled from the Tertiary Evanston Formation. For subdivisions of the Paleocene (P) based on palynology see Jacobson and Nichols (1982).

TERTIARY AND CRETACEOUS

TKe **Evanston Formation, undivided (Paleocene and Upper Cretaceous, Maastrichtian-Campanian)** – Variegated tan, light-gray, light green-gray, and reddish-gray sandstone, siltstone, mudstone, and conglomerate, with minor carbonaceous shale, and coal; thickness uncertain.

This undivided unit is used on the east border of the Ogden map area where the marker conglomerate at the base of the Tertiary is missing or obscure (see Tev of Lamerson, 1982, figure 11, p. 300-303; see also marker bed in Te of Dover and M'Gonigle, 1993). This marker conglomerate unconformably overlies the Cretaceous Hams Fork Member of the Evanston Formation (Keh), with a boulder conglomerate marker bed at the base of Tertiary P3-4 palynomorph-bearing strata, at least locally north of Evanston, Wyoming. These Tertiary strata contain the Almy coal beds of Veatch (1909) and he (p. 79-80) implied the Tertiary Evanston rocks and coal beds, and overlying lower Wasatch (his Almy) Formation, and its conglomerate, pinch out against the Bear River Formation outcrop (paleo-high) on the east margin of the Ogden map area, just east of the Bear River. Dover and M'Gonigle's (1993) Te map unit includes Cretaceous Evanston Formation because the conglomerate marker bed is entirely in their unit.

As used by Lamerson (1982, in particular p. 300-303, 317-323), his units Tev and TKe at least locally include Wasatch Formation rocks, as demonstrated by P5-6 palynomorphs in Lamerson's diagrammatic section (1982, figure 11, also see p. 300-303). The Tertiary Evanston Formation contact with the overlying Wasatch Formation is difficult to map when the basal Wasatch conglomerate (Twc) is missing and Veatch (1909, p. 79-80) noted its uneven extent. The exposed Tertiary part of the Evanston Formation (P3-4 strata) may be less than 200 feet (60 m) thick (see P3-4 strata in Lamerson, 1982, figure 11).

Although Lamerson (1982) likely includes Wasatch Formation strata in his Evanston units, his work is typically the lone source of information on the upper parts of boreholes. Lamerson (1982, plate 4) showed about 650 and 500 feet (200 and 150 m) of TKe where cut by the Chevron 1-35 Federal and AMFC wells, respectively, in the Murphy Ridge quadrangle. To the south, Lamerson (1982, plate 11) showed TKe about 1000 feet (300 m) thick in the Cave Creek field where penetrated by the Fawcett & Son well, and more than about 1500 feet (450 m) thick where cut in the Amoco 404B well east of the field. About 1500 feet (450 m) of TKe was shown where cut by the Hatch well in the Yellow Creek field (Lamerson, 1982, figure 26). Lamerson (1982, plate 5) showed about 700 feet (215 m) of his Tev where cut by the Amoco 505A well south of Minnow Hill. Lamerson (1982, p. 302-303, plate 4) showed his Tev unit as about 1000 feet (300 m) thick where exposed east of the Bear River and about 1500 feet (450 m) thick in subsurface to the southwest. Lamerson (1982, plate 11) showed his Tev unit as about 1500 feet (450 m) thick where penetrated by the Bountiful Livestock, Anschutz W12-26, and Amoco 404-A wells, with Paleocene noted near top (P5-6?) and bottom (P3-4?) of unit in the 404-A well in the Anschutz Ranch East field. However, this 1500-foot (450 m) thickness likely includes our Wasatch Formation conglomerate unit (Twc) that is likely 800 feet (240 m) thick in the Champlin 458 Amoco A well east of Porcupine Ridge (Red Hole quadrangle) just south of the Ogden map area; below this Wasatch conglomerate, about 700 feet (210 m) of

Evanston Formation was cut, with the Evanston being mostly conglomerate (Cretaceous?) (after AMSTRAT log D-5215, API 43-043-30067, Utah DOGM).

CRETACEOUS

Keh, Keh?

Hams Fork Member of Evanston Formation (Upper Cretaceous, Maastrichtian-Campanian) – Gray and tan sandstone and conglomeratic sandstone, and variegated gray, greenish-gray, and reddish-gray mudstone, with minor quartzite- and chert-pebble conglomerate; locally contains dark-gray, carbonaceous shale and coal in lower part; Lamerson (1982, p. 321) reported a 757-foot (230 m) thickness in middle Echo Canyon and it may be as much as 1600 feet (500 m) thick near Thirtyfive Canyon (see Coogan, 2010a-b), but bed dips are uncertain. See unit Keh description under CRETACEOUS strata under the headings "Willard Thrust Sheet Cover Rocks" and "Crawford Thrust Sheet" for more details.

In the subsurface, about 1000 feet (300 m) of Hams Fork was shown by Lamerson (1982, plate 11) where penetrated by Bountiful Livestock, Anschutz W12-26 and Amoco 404-A wells in the Anschutz Ranch East field, and 1500 feet (450 m) was shown to the east where penetrated by the Gulf Harding Hollow and Amoco 404-B wells (Lamerson, 1982, plate 11). Keh is exposed to the south of the Ogden map area in the Red Hole quadrangle, south of Pinecliff along the East Fork Chalk Creek and east of Pinecliff on the north side of Chalk Creek, and King has inferred from the AMSTRAT log D-5215 (API 43-043-30067) that about 700 feet (210 m) of Cretaceous conglomerate-rich Evanston Formation is present in the subsurface in the Champlin 458 Amoco A well to the east of Pinecliff (after AMSTRAT log D-5215, API 43-043-30067, Utah DOGM).

DeCelles (1994) reported 50 to 100 feet (15 to 30 m) of Hams Fork conglomerate near Evanston, Wyoming, and showed about 50 feet (15 m) of conglomerate underlain by 30 feet (~9 m) of Evanston mudstone and overlain by about 200 feet (65 m) of mudstone and sandstone with some limestone and conglomerate (DeCelles, 1994, figure 10A; see also DeCelles and Cavazza, 1999, figure 6, column 4). However, neither paper provides locations for the measured sections, and DeCelles (1994) showed mudstones as red with pebble-sized limestone nodules, implying the 50 feet (15 m) of conglomerate and overlying rocks are part of the Wasatch Formation. Given the unique clast contents in their two pie diagrams for conglomerates north of Evanston, Wyoming (DeCelles and Cavazza, 1999, figure 9) and similar thicknesses of the Tertiary Evanston marker-bed conglomerate in Lamerson (1982, in particular figure 11), at least these conglomerate data in DeCelles (1994; DeCelles and Cavazza, 1999) might be from this prominent Tertiary conglomerate and belong to our TKe map unit.

Near Aspen Tunnel east of Evanston, Wyoming, Cook (1977) also noted a "Hams Fork" conglomerate that might be Tertiary. He described a pebble to cobble or boulder (typically 1 to 10 inch [2.5-25 cm]), Eocambrian (Neoproterozoic) and Cambrian quartzite-clast conglomerate with a coarse sand matrix that is 15 feet (5 m) thick. It is underlain by tan to gray sandstone and siltstone, and gray mudstone of the Hams Fork Member with overlying gray, tan and red mudstone, and tan and gray sandstone and siltstone of the main body of the Evanston Formation that is more gray and has steeper dips than the Wasatch Formation.

Kehc, Kehc?

Basal Conglomerate of Hams Fork Member of Evanston Formation (Upper Cretaceous, Maastrichtian-Campanian?) – See unit Kehc description under CRETACEOUS strata under the headings "Willard Thrust Sheet Cover Rocks" and "Crawford Thrust Sheet" for more details for more details; exposed in Sawmill Canyon and middle Echo Canyon; base of Hams Fork should be at bottom of cliffs of the basal conglomerate; appears more than about 360 feet (110 m) thick and thickest along South Fork Heiners Creek, with base not exposed (Coogan, 2010a); DeCelles and Cavazza (1999) showed about 150-foot (45 m) thickness at Sawmill Creek [Canyon], but seem to show their basal mudstone as much thicker than the 10-foot (3 m) thick carbonaceous mudstone that is present; appears to pinch out in lower Echo

Canyon to south in Coalville 7.5-minute quadrangle (Coogan, unpublished mapping). Carbonized plant remains, fossil freshwater bivalves and gastropods, reported by Crawford (1979) in the underlying mudstone, might provide age constraints on the mudstone and its unit designation. The mudstone is not part of the lower member of the Evanston Formation of Oriel and Tracey (1970). The basal conglomerate is queried (Kehc?) along Heiners Creek where poor exposures may actually be surficial deposits.

DeCelles and Cavazza (1999, figure 9) showed two pie diagrams of clast contents from this unit near Sawmill Canyon in the topographic Echo Canyon, with about 65% to 85% quartzites, lesser Paleozoic sandstone and carbonate, roughly 5% Precambrian basement clasts and lesser Mesozoic sandstone clasts. Coogan (2003, p. 18) stated that distinctive Neoproterozoic quartzite clasts from the Willard thrust sheet and basement (Precambrian crystalline rock) clasts occur in this unit in topographic Echo Canyon.

Kehc was reported on the east margin of the Ogden map area (DeCelles, 1994; DeCelles and Cavazza, 1999), but these rocks may not be the same conglomerate as that mapped to the west and some may be Tertiary (see above). The Evanston Formation was deposited after an antiform formed above the ramp in the Absaroka thrust fault (see Lamerson, 1982, in particular plates 4, 5, 10, and 11, and figure 26). This antiform should have been a north-south-trending paleo-topographic ridge by the Campanian (age of Absaroka thrusting and Stevenson syncline folding, and pre-Hams Fork), with erosion of the Upper Cretaceous Henefer (Hillard) and Frontier Formations and Lower Cretaceous Aspen, Bear River and Gannett (Kelvin of some workers) Formations (see Sieverding and Royse, 1990, p. 7). The amount of strata removed by erosion is variable, as can be seen in the cross sections of Lamerson (1982), Coogan (1992a, plate 2, a-a'), and Yonkee and others (1997, figure 28). From figure 23 in Lamerson (1982) the antiform should have a north-northeast trend, but his closely spaced ramp contours are far west of the observed antiform where the Utah-Wyoming border changes from north-south to east-west. The antiform may be exposed along Porcupine Ridge (Porcupine Ridge quadrangle) and it appears that the age of the strata eroded remains roughly the same to the north (compare Lamerson's [1982] plates and figure). Except for two of Lamerson's (1982, figure 26, plate 10) five cross sections, previous workers have assumed the Evanston Formation overtopped this ridge (see references in this paragraph), but the differing clast pie-diagrams in DeCelles and Cavazza (1999, figure 9) support the idea that the ramp antiform divided Cretaceous Hams Fork strata into a western basin in Utah and an eastern basin in Wyoming, that contains exposed Tertiary Evanston Formation.

Kwc **Weber Canyon Conglomerate (Upper Cretaceous, Campanian-late Santonian)** – Cliff-forming conglomerate with minor sandstone and mudstone interbeds. More than 1900 feet (580 m) thick along Crawford thrust near Devils Slide; for details see Kwc description under CRETACEOUS strata under headings "Willard Thrust Sheet Cover Rocks" and "Crawford Thrust Sheet"; unconformably overlies older units including the Echo Canyon Conglomerate, Henefer Formation, and Frontier Formation in the northwest limb of the Stevenson syncline (see Coogan, 2010a-b).

Borehole data for the Amoco-Marathon WI 1A well, (API 43-029-30006, Utah DOGM files) indicates that at least 3600 feet (1100 m) of Weber Canyon Conglomerate and Echo Canyon Conglomerate was penetrated in the Stevenson syncline in front of the Crawford thrust; despite different clast compositions, the conglomerates cannot be separated in available well data.

Echo Canyon Conglomerate (Upper Cretaceous, Santonian-Coniacian) – On map divided into upper and lower members described below; not subdivided in subsurface (so Kec); based on exposures and geophysical logs, King estimates 3100 feet (945 m) total thickness in Champlin 475 Amoco A1 exploration hole in Henefer quadrangle (API 43-029-30004, Utah DOGM log and well files), but is not certain that total depth was in targeted Henefer Formation or was still in Echo Canyon Conglomerate, as upper Henefer Formation is conglomerate in this area. Age from palynology (see Jacobson and Nichols, 1982). Likely restricted to Stevenson syncline and "pinching out" in Heiners Creek quadrangle or northwest corner of Castle Rock quadrangle. Folded with underlying Cretaceous strata in Stevenson syncline, so lacks marked angular unconformity with Henefer Formation (compare dips across Kel-Khen contact in Heiners Creek quadrangle of Coogan, 2010a).

Keu **Upper member (Upper Cretaceous, Santonian-Coniacian)** – Reddish-gray and tan, very thick bedded, cliff-forming, pebble to boulder conglomerate, and minor gray and tan sandstone and gray mudstone; 790 feet (240 m) thick in Echo Canyon.

Conglomerate clasts are dominated by sandstone and quartzite derived from Jurassic, Triassic, and upper Paleozoic strata exposed near Devils Slide above the Crawford thrust; more specifically, clasts are dominantly from Weber Quartzite, with noticeable clasts of red Ankareh and Preuss Formations, of Nugget Sandstone, and of micritic Twin Creek Limestone (DeCelles, 1994) shed from the front of the Crawford thrust sheet (list order not by age or abundance).

Kel **Lower member (Upper Cretaceous, Santonian-Coniacian)** – Light-gray and tan pebble to boulder conglomerate, light-gray to tan sandstone and pebbly sandstone, and minor varicolored mudstone; 950 feet (290 m) thick in Echo Canyon.

Conglomerate clasts include sandstone and quartzite from Jurassic and upper Paleozoic formations, up to 20% limestone clasts mainly derived from Mississippian strata, as well as Neoproterozoic quartzites; more specifically clasts are from Weber, Park City, Nugget, Twin Creek, Preuss, Lodgepole and Humbug Formations (DeCelles, 1994) (list order not by age or abundance); Coogan (2003, p. 18, unpublished) added distinctive red to green quartzite and graywacke derived from Neoproterozoic rocks of the Willard thrust sheet.

Khen **Henefer Formation (Upper Cretaceous, Coniacian, Santonian, and Turonian?)** – Tan and gray, coarse-grained to conglomeratic sandstone, cyclically interbedded with gray mudstone, shale, and carbonaceous mudstone; non-marine; coarsens upward and westward, so dominantly very thick bedded, yellow-weathering, bioturbated sandstone in upper Echo Canyon underlain by light-colored mudstone-shale; near Coalville reportedly about 2500 feet (760 m) thick (Hale, 1960, 1962, 1976; Trexler, 1966), but top not exposed in Hale's reports and 300 feet (90 m) at top covered in Trexler's report; penetrated in Amoco-Marathon WI 1A well and about 2500 feet (760 m) thick (after API 43-029-30006, Utah DOGM files). Eardley (1944) named the unit, but he included some Kelvin and Frontier Formation strata in his Henefer unit and therefore overstated its thickness. Coniacian-Santonian age based on palynology from Nichols and Bryant plate 2 in Bryant (1990)

DeCelles (1994) noted local conglomerate at the top of the Henefer Formation with clasts from the Frontier, Kelvin, Preuss, Twin Creek, Nugget, Ankareh, Gartra-Higham, Park City, and Weber Formations (clasts of the last two formations might be recycled from older Cretaceous conglomerates) (list order not by age or abundance), and showed (figure 5) the upper 165 feet (50 m) in the southwest part of the Henefer quadrangle as pebble to cobble conglomerate beds.

The Henefer was eroded from the antiform above the ramp in the Absaroka thrust fault and is not present along the Utah-Wyoming state line (see Lamerson, 1982, plates 4 and 11). The Henefer Formation is not penetrated in the subsurface in the Yellow Creek, Cave Creek, and Anschutz Ranch East fields (see Lamerson, 1982, plates 10 and 11, figure 26). The Henefer Formation is likely present in the subsurface on the west side of the ramp antiform in the western parts of the McKay Hollow and Neponset Reservoir NW quadrangles, because an estimated basal about 200 to 300 feet (60-90 m) of Henefer is exposed to the south on the west margin of the Castle Rock quadrangle.

Frontier Formation (Upper Cretaceous, Coniacian-Turonian-Cenomanian) – Typically gray shale, mudstone, and siltstone, light-gray to tan to brown sandstone and conglomeratic sandstone, and carbonaceous shale; marine and non-marine; to west, about 4500 feet (0-1370 m) thick near Henefer; less than or about 4670 to 5130 feet (1425-1560 m) exposed to south near Coalville (see Trexler, 1966); however, member thicknesses and conglomerates are highly variable and reported total thickness in subsurface is up to about 8000 feet (2440 m) (see Hale, 1960, 1962, average 7850 feet [2390 m]); about 2850 feet (870 m) exposed in Castle Rock quadrangle, with an additional 3600 feet (1100 m) (from addition of remaining members) likely present in subsurface, all on west flank of Absaroka-thrust-ramp antiform. The Wanship Formation of Williams and Madsen (1959) is actually the upper Frontier Formation (Kfum of this report).

Lower Frontier Formation and Aspen Shale are present south of the map area on Porcupine Ridge (Red Hole quadrangle) (see Randall, 1952), but overturned Cokeville (Kc) and Sage Junction (Ksj) Formations were shown by Bryant (1990) in roughly the same locations. Frontier strata are likely present in subsurface below the Crawford thrust in the Louisiana Land & Exploration well (API 43-033-30030) in the western part of the Neponset Reservoir NW quadrangle (see Chevron palynology report in UGS files).

Queried west-dipping Frontier Formation exposures east of the Crawford thrust in the Neponset Reservoir NE quadrangle are unconformably overlain by the Wasatch and Fowkes Formations and are likely part of the subsurface west-dipping cuesta shown by Lamerson (1982, plate 5). These cuesta exposures west of Minnow Hill are likely Frontier Formation because Bear River Formation (reported in AMSTRAT log D-4952) and Cokeville Formation lithologies were encountered in the Minnow Hill well just to the east (King interpretation after AMSTRAT log D-4952, and API 43-033-30018, Utah DOGM well file). These exposures look most like upper Frontier Formation (Kfm, Kfg, Kfd) outcrops east of Coalville, Utah, but this does not fit with what Lamerson (1982, plate 5) showed or with the lower Frontier interpreted in the Neponset 6-35 well (see API 43-033-30047, Utah DOGM). At present King cannot subdivide these outcrops better than queried Chalk Creek Member of Frontier Formation (Kfcc?). The Frontier Formation is completely eroded from the Absaroka-thrust-ramp antiform along the Utah-Wyoming state line (see Lamerson, 1982, plates 4, 5, and 11); see also Amoco A-MF-Chev well (API 43-033-30011, Utah DOGM; AMSTRAT log D-4943), and partly eroded to the west in the Champlin 391 Amoco A well (AMSTRAT log D-4952; API 43-033-30018, Utah DOGM well file).

To the south, the Frontier Formation was not penetrated (completely eroded) in the subsurface in the Yellow Creek or Cave Creek fields (see Lamerson, 1982, figure 26, plates 10 and 11); but about 3200 feet (975 m) of Frontier was shown in the Anschutz Ranch East field where cut by well 14-20 and 3500 feet (1070 m) was shown east of the field where cut by the Amoco 404-B well (West and Lewis, 1982, figure 4). Frontier strata were also shown where penetrated by the Bountiful Livestock well in the Anschutz Ranch East field, east of the field in the Amoco 404-B well (Lamerson, 1982, plate 11), and where penetrated by the Bountiful No. 1 well (Lelek, 1982, figure 7b).

On our map the Frontier is divided into members following those of Hale (1960, 1962) near Coalville. Descriptions are from the Huff Creek area, Castle Rock quadrangle, as are Upton, Judd, and Meadow Creek Member thicknesses.

Kfu **Upper members, undivided (Upper Cretaceous, Coniacian)** – Gray to yellowish-gray, calcareous, fine-grained sandstone interbedded with gray calcareous shale; mapped east of Henefer; probably includes Upton Sandstone (Kfup), Judd Shale (Kfj), Meadow Creek Sandstone (Kfm), and, possibly, upper part of Dry Hollow Members of Coalville area; about 1100 feet (335 m) thick near Henefer.

Kfup **Upton Sandstone Member (Upper Cretaceous, Coniacian)** – Gray to yellowish-gray, calcareous, fine-grained sandstone; 221 feet (67 m) thick. Age is Coniacian (molluscan fossil zone 27) near Coalville (Molenaar and Wilson, 1990).

Kfj **Judd Shale Member (Upper Cretaceous, Coniacian)** – Gray calcareous shale; poorly exposed; about 225 feet (70 m) thick.

Kfm **Meadow Creek Sandstone Member (Upper Cretaceous, Coniacian)** – Light-yellowish-gray, calcareous, fine-grained, cross-bedded sandstone; about 285 feet (87 m) thick.

Kfg **Grass Creek Member (Upper Cretaceous, Coniacian)** – Gray calcareous shale; poorly exposed; about 235 feet (72 m) thick.

Kfd **Dry Hollow Member (Upper Cretaceous, Coniacian and? Turonian)** East of Henefer, tan and reddish-gray, very thick bedded, cobble conglomerate; conglomerate includes clasts of Cambrian(?) and Upper Paleozoic quartzite, Mississippian limestone, Mesozoic sandstone and siltstone, and chert; conglomerate zone thickens markedly northward from 520 feet (160 m) at Bald Rock Canyon to over 1200 feet (365 m) in Harris Canyon, Henefer quadrangle.

The conglomerate is likely related to movement on the Willard thrust sheet (Yonkee and others, 1997) and from the clast content, noted above, is also related to erosion of the Lost Creek fold-thrust belt east of the Willard thrust sheet.

In the Heiners Creek quadrangle along Green Creek, the capping resistant sandstone is less than about 300 feet (90 m) thick and thins to the east. In the Huff Creek area, Castle Rock quadrangle, the Dry Hollow Member contains light-yellowish-gray, fine-grained, calcareous sandstone in the upper 70 feet (21 m); gray-brown and tan, calcareous siltstone and shale in the middle part; and contains interbedded lenses of light-gray, coarse-grained sandstone and chert- and quartzite-pebble conglomerate in the lower 100 feet (30 m); total thickness in the Huff Creek area is about 550 feet (168 m).

To south near Coalville, Hale (1960, 1962) reported that this member contains only 40 to 100 feet (12-30 m) of conglomerate overlain by 880 feet (270 m) of silty shale, sandstone, and lenses of conglomerate, 90 feet (27 m) of carbonaceous rocks, and was capped by 200 feet (60 m) of cliff-forming white sandstone. The capping sandstone of the Dry Hollow Member near Coalville is Coniacian (molluscan fossil zone 27) in age (Molenaar and Wilson, 1990).

Kfo **Oyster Ridge Sandstone Member (Upper Cretaceous, Turonian)** – Tan to buff, fine-grained, calcareous sandstone with local pebble layers and disarticulated pelecypod shells; weathers to light-yellow- to orange-gray resistant ridge characterized by *Ostrea soleniscus* fossils, with resistant sandstones above and below this member (see Cook, 1977); thins northward in Henefer area from 260 to 140 feet (80-43 m); about 80 feet (25 m) thick along Huff Creek, Castle Rock quadrangle. Age is Turonian (molluscan fossil zone 19) near Coalville (Molenaar and Wilson, 1990).

Kfac **Allen Hollow and Coalville Members (Upper Cretaceous, Turonian)** – 550 to 625 feet (168-190 m) thick where poorly exposed near Henefer; much thinner than to east along Huff Creek.

Kfa **Allen Hollow Member (Upper Cretaceous, Turonian)** – Gray calcareous shale; poorly exposed; about 780 feet (240 m) thick along Huff Creek though base not exposed. Age is Turonian (molluscan fossil zone 19) near Coalville (Molenaar and Wilson, 1990). Allan [sic] Hollow in Hale (1960, 1962) is typographical error.

Kfc **Coalville Member (Upper Cretaceous, Turonian)** – Yellow-gray calcareous sandstone with interbedded carbonaceous shale and coal; about 225 feet (70 m) thick along Huff Creek, Castle Rock quadrangle, but neither top nor base exposed. Age is Turonian (molluscan fossil zone 18) near Coalville (Molenaar and Wilson, 1990).

Kfcc, Kfcc?

Chalk Creek Member (Upper Cretaceous) – Reddish-gray and tan-gray, very thick bedded, cobble conglomerate east of Henefer; conglomerate includes clasts of Cambrian(?) and upper Paleozoic quartzite, Mississippian limestone, Mesozoic sandstone and siltstone, and chert; conglomerate thickens markedly northward from 460 feet (140 m) thick at Bald Rock Canyon to about 1960 feet (600 m) thick in Harris Canyon, Henefer quadrangle; much thicker to south of our map at Coalville, where member is 3150 feet (960 m) thick (Hale, 1960). The outcrop west of Minnow Hill in the Neponset Reservoir NE quadrangle is mapped as Kfcc?; see introductory text above on the Frontier Formation for details.

The conglomerate is likely related to movement on the Willard thrust sheet (Yonkee and others, 1997) and from the clast content, noted above, is also related to erosion of the Lost Creek fold-thrust belt east of the Willard thrust sheet.

In the Huff Creek area, Castle Rock quadrangle, the Chalk Creek Member contains gray to reddish-gray, coarse-grained, medium-bedded sandstone, with discontinuous chert- and quartzite-pebble conglomerate lenses, and is interbedded with reddish-tan and reddish-gray, tan, and gray mudstone and siltstone; neither top nor base is exposed along Huff Creek.

Kfl **Lower members, undivided (Upper Cretaceous)** – Gray to reddish-gray, coarse-grained, medium-bedded sandstone with discontinuous chert- and quartzite-pebble conglomerate beds; interbedded with reddish-tan and reddish-gray, tan, and gray mudstone and siltstone; some yellowish-gray, fine-grained, calcareous sandstone and gray, calcareous siltstone in lower part; includes lower Chalk Creek, Spring Canyon, and Longwall Sandstone Members of the Coalville area; Spring Canyon Member contains thin coal beds near Coalville; about 850 feet (260 m) thick near Henefer; basal 250 feet (75 m) mapped above Aspen Shale on southeast flank of Porcupine Ridge (Porcupine Ridge quadrangle).

The lower Frontier unit may be exposed in the widest outcrop (cuesta) west of Minnow Hill, with the less resistant Spring Canyon Member between the cuestas and the Chalk Creek Member exposed in the western cuesta, but the widest outcrop is too thick compared to the 100 feet (30 m) of Longwall Member near Coalville, Utah (see Hale, 1960, 1962).

Ka **Aspen Shale (Cretaceous, lower Cenomanian and Albian)** - Light-gray, almost white weathering, dark-gray, fissile, siliceous shale and silty shale with teleost fish scales, and bentonite and porcelainite beds; on southeast flank of Porcupine Ridge (Porcupine Ridge quadrangle), about 300 feet (90 m) thick where exposed in map area and about 400 feet (120 m) thick south of map area (see Randall, 1952), though not shown by Bryant (1990). These exposures may be on the east limb of the Absaroka-thrust-ramp antiform (see West and Lewis, 1982, figure 4). The Aspen age is early Cenomanian (molluscan fossil zone 2) near Coalville (Molenaar and Wilson, 1990).

The only subsurface Aspen penetration near these exposures and west of the Medicine Butte thrust fault that King found in Utah DOGM well files is the 320 feet (98 m) of Aspen cut in the Anschutz 28-1 well in the Anschutz Ranch (west) field (API 43-043-30032, Utah DOGM). However, the Cretaceous strata in this field were seldom logged (see Utah DOGM). This well is portrayed as being slightly west of the broad crest of the Absaroka thrust-ramp antiform by West and Lewis (1982, figure 4).

The Aspen Shale is not exposed to the west near Henefer, Utah, and the western extent of the marine Aspen as it pinches out (thins to absence) in non-marine rocks is unknown. The western extent is constrained by the about 300-foot (90 m) thickness in the Champlin 461-Amoco A well in the Heiners Creek quadrangle (API 43-043-30059, Utah DOGM log file). Also, the Aspen is mapped 3 miles (5 km) east of Coalville by Bryant (1990), a location roughly due south of 2 miles (3 km) west of the 461-A well.

In subsurface north of the Porcupine Ridge exposures (Porcupine Ridge quadrangle), the Aspen Shale is likely eroded from Absaroka-thrust-ramp antiform and is shown as missing near Utah-Wyoming state line from the Woodruff Narrows field south through the Yellow Creek field (Lamerson, 1982, plates 4, 5, 8, 10, and 11, and figure 26). In particular, the Aspen Shale was not shown in the American Quasar Minnow Hill well (AMSTRAT log D-4952, API 43-033-30018). However, high gamma readings at about 1600 and 1710 to 1750 feet (~490 and 520-535 m) in the Minnow Hill well may be the markers in the Aspen Shale; also a log-interpreted fining upward sequences begins at about 1400 feet (425 m). The Aspen was not shown by Lamerson (1982, plate 4) in the Amoco A-MF-Chev well nor noted as present in AMSTRAT log D-4943 (API 43-033-30011). The maximum Aspen Shale thickness Lamerson (1982, plate 5) showed near the Woodruff Narrows field (~1500 feet [460 m]) likely includes lithologies of the Cokeville and Bear River Formations.

South of the Yellow Creek field, the Aspen Shale is present in subsurface east of (and below) the Medicine Butte thrust fault, in and near the Anschutz Ranch East field, with about 400 to 600 feet (120-180 m) shown in reports (Lelek, 1982, figure 2; West and Lewis, 1982, figure 2, respectively) and cut by numerous wells. Thicknesses of Aspen cut are 413 feet (126 m) in the ARE W30-10 well; 596 feet (182 m) in the Champlin 458-Amoco D2 well, but not dip corrected; about 440 feet (135 m) in the ARE W31-6 (458 E6) and ARE W31-12 (458 E3) wells; and 265 feet (81 m) in the Thousand Peaks E (may be structural problem) well (API 43-043-30096, 43-043-30136, 43-043-30217, 43-043-30190, and 43-043-30241 respectively, Utah DOGM). West and Lewis (1982, figure 4) showed about 500 feet (150 m) of Aspen Shale in the Anschutz Ranch East field where penetrated by well 14-20 and 550 feet (170 m) east of the field in the Amoco 404-B well. About 600 feet (180 m) of Aspen was shown where penetrated by the Bountiful Livestock well in the Anschutz Ranch East field and in the Amoco 404-B well east of the field (Lamerson, 1982, plate 11).

Kbr **Bear River Formation (Lower Cretaceous, Albian)** – Gray, medium- to coarse-grained, calcareous sandstone; black, fossiliferous, carbonaceous shale; and gray to gray-brown, gastropod and pelecypod, limestone coquina; bedding thickness is regular, a feature seen in outcrop and geophysical logs; only about 300 feet (90 m) of lowermost strata exposed east of Bear River in northeast corner of map area.

The Bear River outcrop is more extensive but was incorrectly shown as Cokeville Formation to the east and north in the adjacent Evanston and Logan 30x60-minute quadrangles (see Dover and M'Gonigle, 1993; Dover, 1995; see also M'Gonigle and Dover, 1992). Ott (1980) measured 1900 feet (580 m) of Bear River Formation near Woodruff Narrows in this outcrop, but he misidentified rocks to the west in a different outcrop as Bear River Formation, though they are probably Sage Junction Formation (see Dover, 1995), or possibly Cokeville or Frontier Formation. Ruby (1973) presented the characteristic lithologies and extents for the Sage Junction and Cokeville Formations north of the Ogden and Evanston map areas. The Bear River Formation is up to 840 feet (260 m) thick near Aspen Tunnel east of Evanston, Wyoming, though the unit description reads more like Cokeville Formation lithologies (see Cook, 1977).

Both Ogden map area and regional extents of the Bear River Formation are uncertain but appear limited and are less than what was shown by Royse and others (1975, figure 10) because they showed Bear River and equivalent strata, which when repeated in Fursich and Kauffman (1984, figure 1) became Bear River Formation. Only the offshore and nearshore deposits (lithosomes 1 and 2, respectively) are conceivably Bear River Formation and offshore deposits might be the Aspen Shale. The palinspastic shift from Royse and others (1975, figure 10) further confuses geographic distributions. South of Rubey's (1973) studies, the characteristic Bear River Formation lithologies may not extend far west of the Utah-Wyoming border. South of the Ogden map area, Royse and others (1975) do not show Aspen Shale or Bear River Formation. Further, Lamerson (1982, figure 10) does not show the Bear River Formation in subsurface, either above or below the Medicine Butte thrust, using well penetrations in the Pineview field south of Porcupine Ridge; but he does show Aspen. North of the map area, other Albian (and older Cretaceous) lithologies change to the west from marine to non-marine such that the Bear River Formation and Aspen Shale are not present to the west (see Ruby, 1973). The Bear River Formation was deposited between the Willard thrust sheet synorogenic conglomerates and Moxa arch forebulge, so should have a north-south elongate extent.

The Bear River Formation extent is uncertain due to later cover, mostly by the Tertiary Wasatch Formation, erosion of Cretaceous rocks from the antiform above the Absaroka thrust ramp, and misidentification of Cretaceous strata related to synorogenic non-marine deposits from the west entering marine waters to the east. As portrayed by Lamerson (1982), the subsurface ramp antiform is a broad arch that is roughly located along the Utah-Wyoming state line from which the Bear River Formation was completely to partly eroded. The Bear River Formation may not be present west of this ramp antiform, but interpretations of subsurface data are inconclusive. The Bear River Formation extent does not appear to be related to the Medicine Butte thrust. Near the Woodruff Narrows, the Bear River Formation is exposed west of the Medicine Butte thrust. But the Bear River Formation is not present between the Aspen Shale and Kelvin Formation on the east flank of Porcupine Ridge (Porcupine Ridge quadrangle), east limb of Absaroka-thrust-ramp antiform, and west of the concealed trace of the Medicine Butte thrust, and these overturned to upright strata lack the unique character of Bear River strata. To the west near Henefer, the non-marine Kelvin Formation is exposed and Bear River strata are not present. Coals reported in the Bear River Formation can be misidentifications of black shales deposited in brackish to fresh water of a restricted bay (see Fursich and Kauffman, 1984) or in an estuary, and not recognizing that the non-marine Cokeville Formation is the coal-bearing unit. In and near the Ogden map area, the name Bear River seems best restricted to usage with the underlying Gannett Group because Bear River-equivalent strata to the west are part of the non-marine upper Kelvin Formation.

In the Ogden map area in subsurface on the west limb of the Absaroka-thrust-ramp antiform, about 1035 feet (315 m) of Cokeville Formation lithologies appear to overlie 1000 feet (300 m) of Bear River Formation lithologies in the American Quasar Minnow Hill well (King after AMSTRAT log D-4952, API 43-033-30018). Lamerson (1982, plate 5) showed about 1750 feet (540 m) of eroded Bear River, in the Champlin 505-Amoco A well, but geophysical logs indicate bedding is not regular enough to be the Bear River Formation (API 49-041-20132, WOGCC), and might be Cokeville Formation rocks. South of Minnow Hill, about 1190 feet (363 m) of Bear River Formation lithologies, under about 755 feet (240 m) of Cokeville Formation lithologies, was cut in the Amoco A-MF-Chev well (King after AMSTRAT log D-4943, API 43-033-30011), with about 1550 feet (475 m) of eroded Bear River shown by Lamerson (1982, plate 4) on the crest of the ramp antiform where penetrated by the Amoco A-MF-Chev and Chevron 1-35 Fed wells (no data for upper part of Chevron 1-35 Fed well). West of the A-MF-Chev well, mixed Cokeville and Bear River Formation lithologies are also present in the Crane 6-7 well (see API 43-033-30053, Utah DOGM) on the west flank of the ramp antiform.

South of Evanston, Wyoming, the Bear River Formation was shown as 1750 feet (535 m) and 1650 feet (505 m) thick west of the Cave Creek and Yellow Creek fields, respectively, and the Absaroka thrust ramp antiform, but these thicknesses were not supported by well penetrations (Lamerson, 1982, figure 26, plate 10, 11). Therefore, these strata may be upper Kelvin Formation or more mixed Cokeville-Bear River strata. Farther south, West and Lewis (1982) seemed to show (unlabeled) Bear River and Aspen strata penetrated in the upper parts of the 34-1 and Island Ranching C-1 wells in the Anschutz Ranch (west) field on the east limb of the Absaroka-thrust ramp antiform, but no well data are available for the upper parts of these wells (see API 43-043-30076 and API 43-043-30139, Utah DOGM) and no Bear River lithologies are exposed on Porcupine Ridge in the same structural setting in the Porcupine Ridge and Red Hole quadrangles.

East of the ramp antiform and the Medicine Butte thrust in the Anschutz Ranch East field area, Bear River strata were shown as about 1200 to 1300 feet (370-400 m) thick where penetrated by wells (see Lelek, 1982, figure 2; West and Lewis, 1982, figure 2), and about 1600 feet (490 m) was shown where penetrated by the Bountiful Livestock well in the Anschutz Ranch East field and 1500 feet (460 m) was shown where cut by the Amoco 404-B well east of the field (Lamerson, 1982, plate 11). West and Lewis (1982, figure 4) showed 1200 feet (360 m) of Bear River in the field where penetrated by the 14-20 well and 1000 feet (300 m) east of the field in the Amoco 404-B well. Examples of Bear River thicknesses in the Anschutz Ranch

East field are 1757 feet (536 m) in the Champlin 458-Amoco D2 well, not dip corrected; 1355 and 1346 feet (413 and 410 m) in the ARE W31-6 (458 E6) and ARE W31-12 (458 E3) wells; and 1155 feet (352 m) in the Thousand Peaks E well (458-D2 = API 43-043-30136, W31-6 = API 43-043-30217, W31-12 = API 43-043-30190,Thousand Peaks E = API 43-043-30241, respectively, Utah DOGM). As noted above, closer examinations may show these penetrations are mixed Cokeville and Bear River lithologies.

Kk **Kelvin Formation (Lower Cretaceous, Albian-Aptian)** – Upper part mainly light-gray, tan, and light-reddish-gray, coarse-grained sandstone and chert pebbly sandstone interbedded with gray, tan, and minor reddish-gray and gray-green mudstone and siltstone; middle part dominantly reddish-weathering, reddish-tan and tan mudstone and siltstone, with thin, discontinuous, gray and lavender nodular limestone; lower part reddish-hued mudstone to sandstone between gray and reddish-gray, coarse-grained, pebbly sandstone and reddish-gray, chert-pebble conglomerate; 5600 to 6000 feet (1710-1830 m) thick near Henefer based on topography, outcrop pattern, and bedding dip. Roughly time equivalent of Albian part of Aspen Shale, entire Bear River Formation, and Cretaceous part of Gannett Group.

Coogan mapped two Kelvin units on Porcupine Ridge in the southeast corner of the map area (Kku, Kkc), with the base not exposed and a total thickness of about 3000 feet (920 m). These exposures are likely on the east limb of the Absaroka-thrust-ramp antiform (see West and Lewis, 1982, figure 4), and are the only rocks on the east limb that we would label Kelvin, because these are the only exposures where the Bear River Formation is absent. This state-line-area Kelvin unit is not the same as the Kelvin to the west, because the overlying Bear River Formation is not present to the west. Elsewhere along the state line, the Aspen Shale and Bear River Formation are missing (eroded), or strata identifications are questionable because the Bear River or (upper Kelvin) has been removed from the Absaroka ramp antiform. So, determining if the rocks are Kelvin (which to the west includes Bear River strata) or Gannett Group (which underlies the Bear River) is not possible. Where the Bear River Formation is present on the east limb of the ramp antiform, the term Gannett (Kg) is used rather than Kelvin, though as noted under the description of Kg, this may be incorrect. These are the reasons that similar rocks are referred to as the Gannett Group in the gas and oil fields along the Utah-Wyoming state line, even where thick lower conglomerate beds are present.

About 2000 feet (600 m) of Kelvin was noted in the Yellow Creek field by Moklestad (1979), though these strata were shown as Gannett Group in exposures on Porcupine Ridge (Porcupine Ridge quadrangle) by Constenius (1996, figure 8) and in subsurface by Lamerson (1982, plates 10, 11 and figure 26), Lelek (1982), and West and Lewis (1982). Given the description of the basal conglomerate, the Gannett of Lelek (1982) and West and Lewis (1982, figure 2) for the Anschutz Ranch (west) area, as well as the areas of the Yellow Creek and Cave Creek fields, is our state-line Kelvin. In the Anschutz Ranch (west) field, 2220 to 2240 feet (670-685 m) of Kelvin (or Gannett) was cut in the Anschutz 28-1 and 34-2 wells (API 43-043-30032 and 43-043-30106, respectively, Utah DOGM), with the upper Kelvin (or Bear River) likely eroded, hence the naming confusion. West and Lewis (1982, figure 4) showed 3000 feet (900 m) of Gannett [Kelvin] where penetrated by wells 28-1, 34-2 and 34-1, but this appears to be an error. About 2300 feet (700 m) of Gannett [Kelvin] was cut in the Anschutz 14-33 well in the Yellow Creek field (API 43-043-30315, Utah DOGM), with about 1700 feet (500 m) cut in the Anschutz 4-31 well (API 49-041-21058, WOGCC). Lamerson (1982, plates 10 and 11, respectively; see also figure 26) showed the Gannett [Kelvin] as about 2000 and 1700 feet (600 and 500 m) thick where penetrated by Amoco-Gulf WI well and Bradbury well, respectively, in the Yellow Creek field area and where cut by the Fawcett & Son well in the Cave Creek field, with the upper Gannett (Kelvin?) eroded.

Kku **Upper member (Lower Cretaceous)** – Brown, gray, and minor reddish-gray, coarse-grained sandstone and pebbly sandstone; interbedded with gray, green, and tan mudstone; partly time correlative to Bear River Formation; about 1500 feet (460 m) thick along Porcupine Ridge (Porcupine Ridge quadrangle).

Kkc **Conglomeratic member (Lower Cretaceous)** – Reddish-tan and reddish-gray, pebble to cobble conglomerate beds with interbedded reddish hued mudstone and tan-gray sandstone; top is marked by a distinctive 10-foot (3-m) thick zone of limestone-pebble conglomerate with sutured clast boundaries; about 1500 feet (460 m) thick in Porcupine Ridge area (Castle Rock and Porcupine Ridge quadrangles), but base not exposed. South of the Ogden map area between Peoa and Wanship conglomerate clasts in 4 conspicuous beds were described as black, red, and yellow colored chert in a lower bed, with a few quartzite pebbles that might be from Weber Sandstone in a second bed, and in a upper conglomerate most of the large boulders are quartzite and small pebbles are mostly chert. Some pebbles of Nugget Sandstone and Paleozoic limestone are present (Eardley, 1944, p. 838). Chert-clast conglomerate member is called Ephraim Conglomerate where overlying Kelvin strata are referred to as Gannett strata, but these synorogenic conglomerates likely had different sources and may be different ages; see Eyer (1969, figure 4) for Ephraim isopach indicating source far north of the Kelvin name usage. Also, the "Ephraim" is only 6 to 25 feet (2-8 m) thick, chert and quartzite pebble (½ to 1 inch) conglomerate and is 450 feet (140 m) above the base of the Gannett near Aspen Tunnel east of Evanston, Wyoming (Cook, 1977). Cook's (1977) basal 450 feet (140 m) of Gannett is likely Jurassic, and might be the Redwater Shale or Stump Formation. Pipiringos and Imlay (1979) do not call it all Redwater Shale east of Evanston, but all 288 feet (88 m) of their Stump is shale.

Kg **Gannett Group (Cretaceous, Aptian)** – As exposed near Woodruff Narrows Reservoir between fault and overlying Bear River Formation, upper part is gray mudstone with brownish-weathering sandstone, and lower part is red, pink, and green mudstone with brownish-weathering sandstone; exposed thickness 400 to 500 feet (120-150 m); both parts are in upper Gannett Group and are missing the conglomerate beds in the lower part. Gannett, as exposed east of Evanston, Wyoming, near Aspen Tunnel, is 2650 feet (808 m) thick including 500 feet (150 m) of basal conglomeratic beds, calculated from 3100 feet (945 m) of Cook (1977) minus lowest 450 feet (137 m) that is Stump Formation.

Except for the muddy Jurassic rocks (likely Stump Formation), the Gannett Group is lower Kelvin Formation equivalent (see note 53 in Love and others, 1993). To the west the upper Kelvin is the stratal equivalent of the Bear River Formation and after it pinches out the Aspen Shale. The difference between the Kelvin and Cretaceous Gannett seems to be the proximity to the uplift related to the Willard thrust fault. So, the Kelvin has more and thicker conglomerate beds and should be the preferred name where the Bear River Formation is not present. The problems with the Bear River extent are noted above, so alternatively Kelvin is used where multiple conglomerate beds (like in Castle Rock and Porcupine Ridge quadrangles) are present. Both names were used in well data in the Anschutz Ranch (west) field (see Utah DOGM), so see Kelvin for thicknesses.

In the north part of Ogden map area, an estimated 2500 feet (760 m) of Gannett was cut in the American Quasar Minnow Hill well (King after AMSTRAT log D-4952, API 43-033-30018). This Gannett thickness is about what Lamerson (1982, plate 4) showed to the south where penetrated by the Amoco A-MF-Chev well, but only about 1600 feet (490 m) of Gannett was cut in the Amoco A-MF-Chev well and thicknesses of units above and below the Gannett seem reasonable (after AMSTRAT log D-4943, API 43-033-30011). To the south in the Yellow Creek field, 2326 feet (709 m) of Gannett was cut in the Anschutz 14-33 well (API 43-043-30315, Utah DOGM), but, like other wells in this field, the Gannett may be partly eroded (see Lamerson, 1982, figure 26 and plate 10) and Moklestad (1979) labeled these strata Kelvin Formation, and the Bear River Formation is missing. Lamerson (1982, plate 11) also showed the Gannett (our Kelvin) as partly eroded in the Cave Creek field. Strata in the Anschutz Ranch (west) field are noted under the Kelvin Formation (Kk) description.

In the Anschutz Ranch East field, 3668 and 3854 feet (1118 and 1175 m) of Gannett was cut in the Champlin 458-Amoco D2 and Anschutz 16-20U wells (neither dip corrected), 3105 and 3003 feet (947 and 916 m) was cut in the ARE W31-6 (458 E6) and ARE W31-12 (458 E3) wells, and 3925 feet (1197 m) was cut in the Thousand Peaks E well, though likely deformed (API 43-043-30136, API 43-043-30148, 43-043-

30217, 43-043-30190, and 43-043-30241 respectively, Utah DOGM). West and Lewis (1982, figure 4) showed about 3000 feet (900 m) of Gannett where penetrated by well 14-20. About 3000 feet (900 m) of Gannett was shown where penetrated by the Bountiful Livestock B and Bountiful Livestock wells in the Anschutz Ranch East field and in the Amoco 404-B well east of the field (Lamerson, 1982, plate 11). Note that the 1892 feet (577 m) of Gannett penetrated in the Amoco 2-36 well in the Chicken Creek field (Holm, 1992) is much smaller.

Jurassic and older units on the thrust sheets east of the Crawford thrust are not exposed in the Ogden map area, though they were penetrated by numerous drill holes. Unit symbols shown are used on the lithologic column titled "Ogden 30' x 60' Subsurface South State Line" and are those used on exposures to the west in the map area.

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Jsp **Stump and Preuss Formations, undivided (Upper and Middle Jurassic)** – See each formation for lithologies; estimate 900 to 1000 feet (275-300 m) thick in subsurface, not including salt.

In the Woodruff Narrows field 1186 feet (362 m) of Jsp, plus 3262 feet (995 m) salt, was cut in the Chevron-Amoco 1-32G well (API 49-041-20627, WOGCC) and just east of the Ogden map area, 3000 feet (900 m) total Jsp was cut in the Amoco 1-4H well, with no salt top noted (API 49-041-20289, WOGCC). Nearby Jsp was shown as about 1050 feet (320 m) thick, with an additional 200 feet (60 m) of salt and 3000 feet (900 m) of salt in welt (Lamerson, 1982, plate 5), but these thicknesses were not supported by well penetrations. South of Woodruff Narrows, 950 feet (290 m) of Jsp, plus 825 feet (252 m) salt, was cut in the Amoco A-MF-Chev well (after AMSTRAT log D- 4943, API 43-033-30011), with about 2000 feet (600 m) of Jsp shown nearby by Lamerson (1982, plate 4). Farther south in the Yellow Creek field in the Yellow Creek 4-31directional well, about 1000 feet (300 m) of Jsp and an additional about 900 feet (270 m) of salt was cut (API 49-041-21058, WOGCC), and in the Amoco-Gulf-Chevron WIU well 1072 feet (327 m) of Jsp with an additional 122 feet (37 m) of salt cut (Moklestad, 1979). In the Cave Creek field in the Champlin 846-Amoco A well 1144 feet (340 m) of Jsp and an additional 666 feet (203 m) of salt was cut (API 43-043-30100, Utah DOGM). In the Anschutz Ranch East field, 1416 feet (432 m) of Jsp, 1422 feet (434 m) of Jsp, 1324 feet (404 m) of Jsp plus 180 feet (55 m) salt, 1239 feet (378 m) of Jsp plus 243 feet (74 m) salt, 1475 feet (450 m) of Jsp, 1453 feet (443 m) of Jsp, and 1115 feet (340 m) of Jsp plus 161 feet (49 m) salt was cut in the Anschutz U14-20, Champlin 458-Amoco D2, Anschutz 16-20U, Champlin 458-Amoco D1, ARE W31-4 (458 E2), ARE W31-12 (458 E3), and Thousand Peaks E wells, respectively (API 43-043-30145, 43-043-30136, 43-043-30148, 43-043-30129, 43-043-30165, 43-043-30190, 43-043-30241 respectively, Utah DOGM). West and Lewis (1982, figure 4) showed about 1200 feet (365 m) of Jsp where penetrated by multiple wells in the Anschutz Ranch East field and Lamerson (1982, plate 11) showed the same thickness, with about 200 feet (60 m) of additional salt where cut by the Bountiful Livestock well. He (Lamerson, 1982, plate 11) showed about 1600 feet (490 m) of Jsp, including 300 feet (90 m) of salt, west of the field where cut by the Bountiful Livestock B well. In the Anschutz Ranch (west) field, the Island Ranching D-1 well cut 1158 feet (353 m) salt (API 43-043-30161, Utah DOGM), while West and Lewis (1982, figure 4) showed 1600 feet (490 m) of Jsp with 100 feet (30 m) salt where penetrated by well 28-1, and to the east of this well they showed the lower part of Jsp as fault truncated; West and Lewis (1982, figure 2) also showed 1000 feet (300 m) of Jsp plus 0-500 feet (0-150 m) salt, and this 1000-foot (300 m) thickness seems more reasonable.

Js **Stump Formation (Upper and Middle Jurassic)** – Pale red, yellow, gray, and green-gray shale and calcareous sandstone; locally glauconitic; thickness uncertain.

Stump is 210 feet (64 m) thick where cut in American Quasar Minnow Hill well (King after AMSTRAT log D-4952, API 43-033-30018); about 300 feet (90 m) was cut in the Yellow Creek field in the Celsius 4-36 well (API 49-041-20578 WOGCC), and 244 feet (74 m) was cut in the Anschutz 14-33 well in the

Yellow Creek field (King after API 43-043-30315, Utah DOGM). The Stump was reportedly about 60 feet (20 m) thick in the Anschutz Ranch East field (Lelek, 1982, text) and in the Amoco 2-36 well in the Chicken Creek field (Holm, 1992).

Jp **Preuss Redbeds (Middle Jurassic)** – Red and purple-red sandstone, siltstone, shale, and anhydrite, with halite near base; red beds likely about 1000 feet (300 m) thick, but total thickness variable and uncertain due to evaporite movement. See Lamerson (1982, figure 29) for salt (evaporite) isopach, based on well and seismic data (his figure 20), which showed over 4000 feet (1200 m) of salt near the Woodruff Narrows field, over 2000 feet (600 m) of salt at the Yellow Creek field, and over 1500 feet (450 m) of salt at the Anschutz Ranch East field.

In the north part of the Ogden map area in the American Quasar Minnow Hill well 1210 feet (369 m) of Preuss was cut (including salt?) (King after AMSTRAT log D-4952, API 43-033-30018), over 3000 feet (900 m) of salt was cut in the Woodruff Narrows field in the 1-32G well (API 49-041-20627, WOGCC). To the south in the Yellow Creek field 2220 feet (677 m) of Preuss was cut in the Celsius [Mountain Fuel] 4-36 well including salt (API 49-041-20578, WOGCC), and 1206 feet (368 m) of redbeds was cut with 345 feet (105 m) of salt in the Anschutz 14-33 well (King after API 43-043-30315, Utah DOGM). In the Cave Creek field in the Champlin 846-Amoco A well, 666 feet (203 m) of salt was cut (after API 43-043-30100, Utah DOGM). In the Amoco 2-36 well in the Chicken Creek field 897 feet (273 m) of redbeds plus 526 feet (160 m) of salt was reported (Holm, 1992). In the Anschutz Ranch East field, the redbeds are about 1000 feet (300 m) thick, with additional salt up to 1200 feet (367 m) thick (Lelek, 1982).

Jtc **Twin Creek Limestone (Middle Jurassic)** – Variably shaly limestone with some calcareous shale and sandstone, and sabkha Gypsum Spring Member (Formation) at base. Near Utah-Wyoming state line Twin Creek reportedly about 1500 to 1900 feet (460-580 m) thick (Moklestad, 1979; Lamerson, 1982; Lelek, 1982; West and Lewis, 1982), though from well data the largest thickness seems to about 1700 feet (520 m).

In wells, about 1900 feet (580 m) of Twin Creek was cut in the American Quasar Minnow Hill well (API 43-033-30018, Utah DOGM; AMSTRAT log D-4952), with Lamerson (1982, plate 8) showing about 1700 feet (520 m) of Twin Creek just to the north. About 1850 feet (565 m) of Twin Creek was cut in the Woodruff Narrows field in the Chevron-Amoco 1-32G and Amoco 1-4H wells (API 49-041-20627 and 49-041-20289, WOGCC), with the 1-4H well east of the Ogden map area. South of Woodruff Narrows about 1800 feet (550 m) of Twin Creek was cut in the Amoco A-MF-Chev well (after AMSTRAT log D-4943, API 43-033-30011), with Lamerson (1982, plate 4) showing 1600-foot (490 m) thickness where penetrated by this well. Farther south in the Yellow Creek field 1660, 1710, and 1725 feet (506, 521, and 526 m) of Twin Creek was cut in the Amoco Bradbury, Celsius [Mtn Fuel] 4-36, and Amoco Gulf WIU wells, respectively (API 49-041-20421, 49-041-20578, and 49-041-20057, respectively, WOGCC), and 1622 feet (495 m) of Twin Creek was cut in the Anschutz 14-33 well (API 43-043-30315, Utah DOGM). In the Yellow Creek field about 1600 feet (490 m) of Twin Creek was shown where penetrated by the Bradbury well (see Lamerson, 1982, plate 10) and about 1700 feet (520 m) was shown where penetrated by the Urroz and Amoco-Gulf WI wells (Lamerson, 1982, figure 26). In the Cave Creek field about 1600 feet (490 m) of Twin Creek was shown where cut by the Fawcett & Son well (see Lamerson, 1982, plate 11); see also AMSTRAT log D-5672 (API 43-043-30078). In the Anschutz Ranch (west) field, 1630 to 1650 feet (497-503 m) of Twin Creek was cut in the Anschutz 28-1, 34-2, and 10-27 wells (API 43-043-30032, 43-043-30106, and 43-043-30321, Utah DOGM), with 1550-foot (473 m) thickness shown in West and Lewis (1982, figure 4) where penetrated by wells 28-1, 34-2 and 34-1. In the Anschutz Ranch (west) field Island Ranching D-1 well 1917 feet (584 m) of Twin Creek was cut (API 43-043-30161, Utah DOGM), but not dip corrected. In the Anschutz Ranch East field, 1442 feet (440 m) of Twin Creek was cut in the Anschutz U14-20, 1473 feet (450 m) was cut in the Champlin 458-Amoco D2 well, 1474 feet (450 m) was cut in the Anschutz 16-20U well, 1597 feet (485 m) was cut in the Champlin 458-Amoco D1 well, 1623 feet (495 m) was cut in the ARE W31-12 well (458 E3), and 1564 feet (475 m) of Twin Creek was cut in the Thousand

Peaks E well (U14-20 = API 43-043-30145, 458-D2 = API 43-043-30136, 16-20U = API 43-043-30148, 458-D1 = API 43-043-30129, W31-12 = API 43-043-30190, Thousand Peaks E = API 43-043-30241, Utah DOGM). Reportedly 1846 feet (560 m) of Twin Creek was penetrated in the Amoco 2-36 well in the Chicken Creek field (Holm, 1992).

The Twin Creek is divided into members due to their importance as reservoir rocks in gas and oil fields. Member descriptions are after Coogan (2004b). Subsurface member thicknesses for the Anschutz Ranch area are from Bruce (1988) and King (this report), after Bruce's member picks using figure TB1.4, well 34-1 from Sprinkel and Chidsey (1993). These subsurface thicknesses are likely based on a different Giraffe Creek and Leeds Creek contact than the surface contact Coogan (2004b) and Imlay (1967) used. See for example Fawcett & Son well AMSTRAT log D-5672 (API 43-043-30078) where, despite the lack of sample recovery, a Coogan-Imlay contact would roughly reverse the Giraffe Creek and Leeds Creek thicknesses.

Jtgc **Giraffe Creek Member (Middle Jurassic)** – Gray, greenish-gray, and tannish-gray, calcareous sandstone and lime grainstone; about 400 feet (120 m) thick near Anschutz Ranch. Subsurface contact with underlying Leeds Creek Member is the most difficult to pick of member contacts; this has likely led to the disparate thicknesses reported for these members.

Jtl **Leeds Creek Member (Middle Jurassic)** – Light-gray, thin- to very thick-bedded, clay-rich, micritic limestone with tan silt partings; locally exhibits bedding-normal, pencil cleavage; 210 to 240 feet (64-73 m) thick near Anschutz Ranch. Permeability reported for Yellow Creek field core (Bruce, 1988).

Jtw **Watton Canyon Member (Middle Jurassic)** – Dark-gray, lime micrite and wackestone and minor oolite packstone; locally exhibits bedding-normal, styolitic, spaced cleavage (Coogan, 2004b); about 320 to 360 feet (100-110 m) thick near Anschutz Ranch. Permeability reported for Yellow Creek field core (Bruce, 1988).

Jtb **Boundary Ridge Member (Middle Jurassic)** – Gray, very thick-bedded, ridge-forming, oolitic, lime grainstone to wackestone beds in middle and upper part that separate red and purple, and locally green siltstone and gray, silty, limestone beds in middle and lower part; 50 to 65 feet (15-20 m) thick near Anschutz Ranch.

Jtr **Rich Member (Middle Jurassic)** – Light-gray, thin- to very thick-bedded, clay-rich, micritic limestone in upper part and gray, lime wackestone in lower part; locally exhibits bedding-normal, pencil cleavage; about 260 to 390 feet (80-120 m) thick and average about 300 feet (90 m) near Anschutz Ranch. Permeability reported for Yellow Creek field core (Bruce, 1988).

Jts **Sliderock Member (Middle Jurassic)** – Dark-gray, very thick-bedded, lime wackestone in upper part and dark-gray, pelecypod and crinoid grainstone in lower part; 70 to 90 feet (20-27 m) thick near Anschutz Ranch.

Jtgs **Gypsum Spring Member (Formation) (Middle Jurassic?)** – Red siltstone and sandstone, and gray, vuggy dolomite, with anhydrite in subsurface; about 60 to 130 feet (18-40 m) thick near Anschutz Ranch. The Gypsum Spring is a separate Formation where named in Wyoming.

Jn **Nugget Formation (Lower Jurassic)** – Pale-grayish-orange, pinkish-tan, and locally white, well-cemented, cross-bedded, quartz sandstone with frosted sand grains; typically about 1000 to 1100 feet (300-335 m) thick in subsurface.

Numerous subsurface thicknesses have been reported because the Nugget is a reservoir rock in the gas and oil fields near the Utah-Wyoming state line. About 1050 feet (320 m) of Nugget was cut in the American

Quasar Minnow Hill well (API 43-033-30018, Utah DOGM; AMSTRAT log D-4952); about 1000 feet (300 m) of Nugget was cut in the Woodruff Narrows field Amoco 1-4H and Chevron-Amoco 1-32G wells (API 49-041-20289 and 49-041-20627 wells, WOGCC), with the 1-4H well just east of the Ogden map area. South of Woodruff Narrows 1011 feet (308 m) and 956 feet (291 m) of Nugget was cut in the Amoco Bradley and Chevron 1-35 wells (API 49-041-20509 and 49-041-20315, respectively, WOGCC), and 1040 feet (317 m) was cut in the Amoco A-MF-Chev well (after AMSTRAT log D-4943, API 43-033-30011). Farther south in the Yellow Creek field 1050 to 1150 feet (320-350 m) of Nugget was cut in the Champlin 375-Amoco C, Amoco Bradbury, Celsius [Mtn Fuel] 4-36, and Urroz wells, (API 49-041-20413, 49-041-20421, 49-041-20578, and API 49-041-20321, WOGCC), and 1050 feet (320 m) of Nugget was cut in the Anschutz 14-33 well (API 43-043-30315, Utah DOGM). In the Cave Creek field about 1100 feet (335 m) of Nugget was cut in the Champlin 846-Amoco A (API 43-043-30100, Utah DOGM well file) and Fawcett & Son wells (AMSTRAT log D-5672, API 43-043-30078). In the Anschutz Ranch East field, 1145 feet, 1118 and 1056 feet (349, 340, and 322 m) of Nugget was cut in the ARE 30-10, U14-20, and Champlin 458-Amoco D1 wells (API 43-043-30215, 43-043-30145 and 43-043-30129, respectively, Utah DOGM). In the Anschutz Ranch (west) field 1096 and 1053 feet (334 and 321 m) of Nugget was cut in the Anschutz 28-1 and 34-2 wells (API 43-043-30032 and 43-043-30106, respectively, Utah DOGM), while the 1209 feet (369 m) of Nugget was cut in the Island Ranching D-1 well (API 43-043-30161, Utah DOGM) seems too large.

TRIASSIC

TRa **Ankareh Formation, Higham (Gartra?) Grit, and Timothy Sandstone and Portneauf Limestone Members of Thaynes Formation, undivided (Triassic)** – Dark red shale, siltstone, and sandstone (Wood Shale tongue), over sandstone and limestone (middle units), over purplish-brown to red-brown shale, siltstone, and sandstone (Lanes tongue); about 1000 feet (300 m) thick in subsurface along Utah-Wyoming state line.

About 975 feet (300 m) of unit TRa was cut in the Woodruff Narrows field Amoco 1-4H and Chevron-Amoco 1-32G wells (API 49-041-20289 and 49-041-20627, WOGCC), with the 1-4H well just east of the Ogden map area. South of Woodruff Narrows 954 feet (288 m) and 964 feet (293 m) of TRa was cut in the Amoco Bradley and Chevron 1-35 wells (API 49-041-20509 and 49-041-20315, respectively, WOGCC). Total TRa about 1000 feet (300 m) thick, with Wood shale tongue about 590 feet (177 m) thick, middle unit about 20 feet (6 m) thick, and Lanes tongue 398 feet (120 m) thick in the Amoco A-MF-Chev well (after AMSTRAT log D-4943, API 43-033-30011). Father south in Yellow Creek field 870, 1024, 1047 and 974 feet (265, 312, 320, and 297 m) of TRa was cut in Champlin 375-Amoco C, Amoco Bradbury, Celsius [Mtn Fuel] 4-36, and Urroz wells, respectively (API 49-041-20413, 49-041-20578, 49-041-20421, and 49-041-20321, respectively, WOGCC), with 1023 feet (312 m) of TRa cut in the Anschutz 14-33 (API 43-043-30315, Utah DOGM). In the Cave Creek field about 1020 and 890 feet (310 and 270 m) of TRa was cut in the Champlin 846-Amoco A (API 43-043-30100, Utah DOGM well file) and Fawcett & Son wells (King after Amstrat log D-5672, API 43-043-30078), respectively, while Lamerson (1982, plate 11) showed about 1000 feet (300 m) of TRa in the Cave Creek field where penetrated by the Fawcett & Son well. In the Anschutz Ranch (west) field, 1024 and 1000 feet (312 and 305 m) of TRa was cut in the Anschutz 34-2 and 10-27 wells (API 43-043-30106 and 43-043-30321, respectively, Utah DOGM), while the 1151 (351 m) of TRa was cut in the Island Ranching D-1 well (API 43-043-30161, Utah DOGM) seems too large and West and Lewis (1982, figure 4) showing only about 600 feet (200 m) of TRa is too small.

TRt **Thaynes Formation, undivided (Lower Triassic)** – Gray silty limestone, calcareous siltstone and shale in upper and lower part, separated by resistant limestone ridge; the Thaynes is likely self-sourced in the Whitney Canyon-Carter Creek field with pay zones in silty and dolomitic limestones (Sieverding and Royse, 1990); near Utah-Wyoming state line in map area, may or may not include the upper tongue of Dinwoody, so Thaynes may not or may thin and then thicken to south; about 1300 to 1400 feet (400-440 m) thick and thinner to north.

About 1350 feet (410 m) of Thaynes was penetrated in the Woodruff Narrows field in the Amoco 1-4H and Chevron-Amoco 1-32G wells (API 49-041-20289 and 49-041-20627, WOGCC), with the 1-4H well just east of the Ogden map area. South of Woodruff Narrows 1138 feet (347 m) of Thaynes was cut in the Chevron 1-35 well (API 49-041-20315, WOGCC) and about 1150 feet (350 m) was cut in the Amoco A-MF-Chev well (API 43-033-30011, Utah DOGM; AMSTRAT log D-4943), with about 1150 to 1250 feet (350-380 m) of Thaynes shown by Lamerson (1982, plate 4) where penetrated by these wells. To the south in the Yellow Creek field 1325, 1370 and 1444 feet (404, 418, and 440 m) of Thaynes was cut in the Champlin 375-Amoco C, Celsius [Mtn Fuel] 4-36, and Urroz wells, respectively (API 49-041-20413, 49-041-20578, and 49-041-20321, respectively, WOGCC), with about 1350-foot (410 m) Thaynes thickness shown where cut by the Urroz well (Lamerson, 1982 figure 26) indicating dip correction, and about 1300 feet (400 m) of Thaynes was cut in the Anschutz 14-33 (API 43-043-30315, Utah DOGM). In the Cave Creek field about 1460 feet (445 m) of Thaynes was cut in the Champlin 846-Amoco A (API 43-043-30100, Utah DOGM well file) and Fawcett & Son wells (King after AMSTRAT log D-5672, API 43-043-30078), but about 1300-foot (400 m) Thaynes thickness was shown in Cave Creek field where cut by Fawcett & Son well (Lamerson, 1982, plate 11), with dip nearly flat. In the Anschutz Ranch (west) field in the Island Ranching D-1 and Anschutz 10-27 wells 1519 and 1440 feet (463 and 440 m) of Thaynes was cut (API 43-043-30161 and 43-043-30321, respectively, Utah DOGM).

TRwd **Woodside and Dinwoody Formations, undivided (Lower Triassic)** – Dark-red, sandy shale and siltstone, with some sandstone, and greenish-gray and tan calcareous siltstone and silty limestone (Coogan, 2010a-b); about 900 feet (270 m) thick.

Upper tongue of Dinwoody (greenish-gray and tan, calcareous siltstone and silty limestone) present at Devils Slide and about 240 feet (75 m) thick; likely lumped with Thaynes in subsurface data.

In wells near the Utah-Wyoming state line, about 900 feet (270 m) total thickness of TRwd shown in the Yellow Creek field where cut by the Urroz well (Lamerson, 1982, figure 26), with a total of 1030 feet (314 m) of TRwd cut in the Celsius [Mountain Fuel] 4-36 well, (API 49-041-20578, WOGCC). To south, West (1983 Anschutz exhibit on 8/25/1983 for Utah Division of Oil, Gas, and Mining) showed about 850-foot (260 m) thickness of TRwd where penetrated by the Champlin 846-Amoco A and Fawcett & Son wells in the Cave Creek field, with Woodside plus Dinwoody totals for these wells of about 900 feet (270 m) (see below).

TRw **Woodside Formation (Lower Triassic)** – Dark-red, sandy shale and siltstone, with some sandstone (Coogan, 2010a-b); about 550 to 650 feet (165-200 m) thick.

About 700 feet (210 m) of Woodside was cut in the American Quasar Minnow Hill well (AMSTRAT log D-4952, API 43-033-30018). About 640 feet (195 m) of Woodside was cut in the Woodruff Narrows field in the Amoco 1-4H and Chevron-Amoco 1-32G wells (API 49-041-20289 and 49-041-20627, respectively, WOGCC), with the 1-4H well just east of the Ogden map area. South of Woodruff Narrows, about 700 feet (210 m) of Woodside was cut in the Amoco A-MF-Chev well (API 43-033-30011, Utah DOGM; AMSTRAT log 4943). Farther south in Yellow Creek field, about 640 and 740 feet (195 and 226 m) of Woodside was cut in the Amoco Bradbury and Celsius [Mountain Fuel] 4-36 wells, respectively (API 49-041-20421 and API 49-041-20578, respectively, WOGCC) with only about 600 feet (180 m) of Woodside shown where penetrated by Urroz well (Lamerson, 1982, figure 26) and likely dip corrected. In the Cave Creek field about 670 feet (204 m) of Woodside was cut in the Champlin 846-Amoco A (API 43-043-30100, Utah DOGM well file) and Fawcett & Son wells (King after AMSTRAT log D-5672, API 43-043-30078), with only about 500 feet (150 m) of Woodside shown where cut by the Fawcett & Son well (see Lamerson, 1982, plate 11). In the Anschutz Ranch (west) field 550 feet (168 m) of Woodside was cut in the Anschutz 10-27 well (API 43-043-30321, Utah DOGM).

TRd **Dinwoody Formation (Lower Triassic)** – Greenish-gray and tan, calcareous siltstone and silty limestone (Coogan, 2010a-b); about 250 feet (75 m) thick along Utah-Wyoming state line with variation that might be due to difficulty picking contact with lithologically similar upper Park City Formation.

About 260 feet (80 m) of Dinwoody was cut in the American Quasar Minnow Hill well (AMSTRAT log D-4952, API 43-033-30018). About 240 and 280 feet (73 and 85 m) of Dinwoody was cut in the Woodruff Narrows field in the Amoco 1-4H and Chevron-Amoco 1-32G wells, respectively (API 49-041-20289 and 49-041-20627, respectively, WOGCC), with the 1-4H well just east of the Ogden map area. South of Woodruff Narrows 265 feet (81 m) and 282 feet (86 m) of Dinwoody was cut in the Amoco Bradley and Chevron 1-35 wells, respectively (API 49-041-20509 and 49-041-20315, respectively, WOGCC), and about 250 feet (75 m) of Dinwoody was cut in the Amoco A-MF-Chev well (API 43-033-30011, Utah DOGM; AMSTRAT log D-4943). Farther south, in Yellow Creek field 290 feet (88 m) of Dinwoody was cut in the Celsius [Mtn Fuel] 4-36 well, (API 49-041-20578, WOGCC), and 220 feet (67 m) was cut in the Anschutz 14-33 well (King after API 43-043-30315, Utah DOGM well file). In the Cave Creek field about 250 and 210 feet (75 and 65 m) of Dinwoody was cut in the Champlin 846-Amoco A (API 43-043-30100), Utah DOGM well file) and Fawcett & Son wells (AMSTRAT log D-5672, API 43-043-30078), respectively. In the Anschutz Ranch (west) field, 205, 260, 245, and 304 feet (63, 79, 75, and 93 m) of Dinwoody was cut in the Anschutz 34-2, 10-27, Island Ranching D, and Anschutz 4-26 wells, respectively (API 43-043-30106, 43-043-30321, 43-043-30161, 43-043-30320, respectively, Utah DOGM).

PERMIAN

Pp **Phosphoria and Park City Formations, undivided (Permian)** – Interbedded carbonate and clastic rocks and highly organic to phosphatic shale; variably cherty. Includes: Franson Member of Park City Formation, an interbedded gray to pinkish-gray to dark-gray, vuggy, cherty limestone, with lesser gray shale and calcareous sandstone; dark-gray and black, bedded chert of Rex Chert Member of Phosphoria Formation; Meade Peak Phosphatic Shale Member of Phosphoria, gray limestone, dark-gray to black, phosphatic siltstone and shale, and gray, calcareous sandstone; and Grandeur Member of Park City, light-gray, thick-bedded, dolomitic sandstone with gray chert nodules; estimated 450 to 650 feet (140-200 m) thick along Utah-Wyoming state line and may thicken to south, but contacts with lithologically similar Dinwoody and Weber Formations are probably not picked consistently.

Unit about 450 feet (140 m) thick in the American Quasar Minnow Hill well, with upper Park City, Meade Peak Member of Phosphoria, and Grandeur Member of Park City 183, 155 and 112 feet (56, 47, and 34 m) thick, respectively (King after AMSTRAT log D-4952, API 43-033-30018). In the Woodruff Narrows field, Pp unit 482 feet (147 m), 476 feet (145 m), and 464 feet (142 m) thick in the Amoco 1-4H, Chevron-Amoco 1-32G, and Champlin 804-Amoco C wells, respectively (API 49-041-20289, 49-041-20627, and 49-041-20567 WOGCC), with only the 1-32G well in the Ogden map area. South of Woodruff Narrows, 465 feet (142 m) and 540 feet (164 m) of Pp cut in the Amoco Bradley and Chevron 1-35 wells, respectively (API 49-041-20509 and 49-041-20315, respectively, WOGCC), with 500 feet (150 m) of Pp, with subunits 180, 130, and 182 feet (55, 40, and 55 m) thick, in the Amoco A-MF-Chev well (API 43-033-30011, Utah DOGM; subunits after AMSTRAT log D-4943). Farther south in Yellow Creek field about 500 feet (150 m) of Pp was cut in the Urroz well (API 49-041-20321 WOGCC), and about 450 and 515 feet (137 and 157 m) of Pp was cut in the Amoco Bradbury and Celsius [Mtn Fuel] 4-36 wells (API 49-041-20421, and 49-041-20578, WOGCC). In the Cave Creek field about 480 and 500 feet (145 and 150 m) of Pp was cut in the Champlin 846-Amoco A and Fawcett & Son wells, respectively (API 43-043-30100 and 43-043-30078, respectively, Utah DOGM files, AMSTRAT log D-5672) with 210, 120, and 160? feet (64, 37, and 49? m) of subunits cut (King after Amstrat log D-5672). In the Anschutz Ranch (west) field 685, 650 and 665 feet (209, 198, and 203 m) of Pp was cut in the Anschutz 34-2, Anschutz 10-27, and Island Ranching D-1 wells, respectively (API 43-043-30106, 43-043-30321), and 43-043-30161, respectively, Utah DOGM), with about 600 and 650 feet (180 and 200 m) of Pp shown in West and Lewis (1982, figure 2 and 4, respectively) where penetrated by the Anschutz 34-2 well.

Descriptions for the following Permian and older units are modified from Sieverding and Royse (1990) descriptions for Whitney Canyon-Carter Creek field, located north of Evanston, Wyoming and east of the Ogden map area, because the exposed counterparts on Durst Mountain to the west of the Henefer and Heiners Creek quadrangles are significantly different (see Coogan and King, 2006).

PERMIAN AND PENNSYLVANIAN

PIPwe **Wells Formation (Lower Permian and Pennsylvanian)** – Upper thick-bedded to cross-bedded sandstone with thin shaly beds and lower thin-bedded sandstone, shale and some limestone; sandstones are well sorted and fine grained with quartz overgrowths (Weber of Sieverding and Royse, 1990) and are quartzose; near Utah-Wyoming state line thicknesses vary enough that contacts are likely inconsistent, but Wells should thicken to west; estimated thickness 525 to 750 feet (160-230 m).

An estimated 625 feet (190 m) of Wells Formation was cut in the American Quasar Minnow Hill well (King after AMSTRAT log D-4952, API 43-033-30018). About 470 and 445 feet (143 and 136 m) of Wells was cut in the Woodruff Narrows field in the Amoco 1-4H and Chevron-Amoco 1-32G wells, respectively (API 49-041-20289 and 49-041-20627, respectively, WOGCC) with the 1-4H well east of the Ogden map area. South of Woodruff Narrows 600 feet (180 m) and 372 feet (113 m) of Wells was cut in the Amoco Bradley and Chevron 1-35 wells, respectively (API 49-041-20509 and 49-041-20315, respectively WOGCC), with 393 feet (120 m) of Wells cut in the Amoco A-MF-Chev well (after AMSTRAT log D-4943, API 43-033-30011). Farther south, 750 feet (230 m) of Wells was cut in the Yellow Creek field in the Champlin 375-Amoco C well (API 49-041-20413, WOGCC) and 526 feet (160 m) was cut in the Celsius [Mtn Fuel] 4-36 well (Weber of API 49-041-20578, WOGCC). In the Cave Creek field, about 500 feet (150 m) of Wells was cut in the Fawcett and Son well (King after Amstrat log D-5672), (see also Lamerson (1982, plate 11). In the Anschutz Ranch (west) field in the Island Ranching D-1 well 748 feet (228 m) of Wells was penetrated (API 43-043-30161, Utah DOGM).

PENNSYLVANIAN AND MISSISSIPPIAN

IPMa **Amsden Formation (Pennsylvanian and Mississippian)** – Subsurface only. Interbedded reddish-hued shale, siltstone, sandstone and dolomite; thicknesses near Utah-Wyoming state line vary from about 250 to 450 feet (75-140 m). Lithologically like the Morgan Formation in eastern Utah on the flanks of the Uinta Mountains (see Sadlick, 1957) and on Durst Mountain (see Coogan and King, 2006), but note that Amsden includes older (Mississippian) strata.

Amsden appears 360 feet (110 m) thick in the American Quasar Minnow Hill well (King after AMSTRAT log D-4952, API 43-033-30018), but only about 240 and 250 feet (73 and 76 m) of Amsden was cut in the Woodruff Narrows field in the Chevron-Amoco 1-32G and Amoco 1-4H wells, respectively (Morgan of API 49-041-20627 and 49-041-20289, respectively WOGCC), with the 1-4H well east of the Ogden map area. South of Woodruff Narrows, 398 feet (121 m) and 204 feet (62 m) of Amsden was cut in the Amoco Bradley and Chevron 1-35 wells, respectively (API 49-041-20509 and API 49-041-20315, respectively WOGCC), and about 250 feet (75 m) of Amsden was cut in the Amoco A-MF-Chev well (after AMSTRAT log D-4943, API 43-043-30011). Still farther south in the Yellow Creek field, about 425 feet (130 m) and 500 feet (150 m) of Amsden was cut in the Urroz and Amoco Bradbury wells, respectively (API 49-041-20321 and 49-041-20421, respectively, WOGCC) though Lamerson (1982, figure 26 and plate 10) showed the Amsden thinner (350 and 450 feet [107 and 137 m] thick, respectively), more like regional thicknesses, and deformed in these wells. In the Cave Creek field, about 320 feet (98 m) of Amsden was cut in Fawcett and Son and Champlin 846-Amoco A wells (API 43-043-30078 and 43-043-30100, Utah DOGM) (see also Morgan of Lamerson, 1982, plate 11).

MISSISSIPPIAN – Only limited well data in map area allow the separation of individual units in subsurface, so Mm for Madison Group is used east of the Crawford thrust. The distinct markers (red Amsden Formation at top, Delle Phosphatic Member in middle, and Cottonwood Canyon-Leatham shaly unit at base), that help with identifications, are seldom noted in well data. Though written about Wyoming subsurface rocks, see also Sieverding and Royse (1990) for lithologies.

Mm **Madison Group, Mission Canyon and Lodgepole Limestones (Mississippian)** – Subsurface only. Thick-bedded dolomite and limestone, with shale and siltstone at base; basal strata at least locally include Cottonwood Canyon Member of Madison/Lodgepole Formation (Mississippian) and Devonian Leatham Formation; thicknesses vary near Utah-Wyoming state line and unit may thin to north; estimated thickness 1300 to 1650 feet (400-500 m). The Delle does not separate the Mission Canyon from the Lodgepole, and the Mission Canyon contains strata that are time equivalent to the Osagean(?) Delle.

About 1230 and 1340 feet (375 and 410 m) of Madison was cut in the Woodruff Narrows field Amoco 1-4H and Chevron-Amoco 1-32G wells, respectively (API 49-041-20289 and API 49-041-20627, respectively WOGCC [1-4H location fsl NOT fnl]) with the 1-4H well east of the Ogden map area. South of Woodruff Narrows, 1448 feet (441 m) and 1255 feet (383 m) of Madison was cut in the Amoco Bradley and Chevron 1-35 wells, respectively (API 49-041-20509 and 49-041-20315, respectively, WOGCC). About 1650 feet (500 m) of Madison was cut in the Fawcett & Son well in the Cave Creek field (King after Amstrat log D-5672; API 43-043-30078, Utah DOGM), but dip not flat and shown as 1500 feet (457 m) thick by Lamerson (1982, plate 11) below a fault in this well. West (1983 Anschutz exhibit on 8/25/1983 for Utah Division of Oil, Gas, and Mining) showed about 1400 feet (425 m) of Madison where penetrated by the Champlin 846-Amoco A and Fawcett & Son wells in the Cave Creek field.

Mission Canyon Limestone (Mississippian, middle Meramecian to Kinderhookian?) – Dolomite and limestone with some anhydrite at top; see Norris (1981) on Mission Canyon-lower Little Flat-Brazer age equivalency; also note that Mission Canyon Member of the Madison at north Georgetown Canyon, Idaho (Sando and others, 1981) likely contains the upper Chinese wall that is in the Lodgepole Limestone near Logan, Utah, since the wall underlies the Delle phosphate beds. This may be why the reported Osagean and Kinderhookian ages for the Mission Canyon (see for example Sando and Gutschick, 1984; Sando and Bamber, 1985; Poole and Sandburg, 1991) overlap with the Lodgepole age as determined from fossils in Utah (see unit Ml on Willard thrust sheet). Thicknesses vary widely near Utah-Wyoming state line, and upper and lower contacts may not be picked consistently; estimated thickness 700 to 900 feet (210-275 m).

Northeast of the Ogden map area in Wyoming in the Whitney Canyon-Carter Creek fields, the Mission Canyon is 700 to 800 feet (210-240 m) thick (Hoffman and Kelly, 1981) but was shown as over 1000 feet (300 m) thick in the Whitney Canyon type log of Ver Ploeg and De Bruin (1982, p. 48), with no sign of a phosphatic zone at the base and an upper 100 feet (30 m) that might be Amsden and/or Morgan (King). To the south in the Woodruff Narrows field, 682 and 743 feet (208 and 227 m) of Mission Canyon was cut in the Amoco 1-4H and Chevron-Amoco 1-32G wells, respectively (API 49-041-20289 and API 49-041-20627, respectively WOGCC), with the 1-4H well east of the Ogden map area. To the south the Mission Canyon is thrust repeated in the Yellow Creek field. In the Cave Creek field in the Fawcett and Son well, about 900 feet (270 m) of Mission Canyon was cut with no sign of the Delle phosphatic beds (King after AMSTRAT log D-5672; API 43-043-30078, Utah DOGM), and about 800 feet (240 m) of Mission Canyon was cut in the Champlin 846-Amoco A well (API 43-043-30100, Utah DOGM). Farther south in the Anschutz Ranch (west) field, 974 feet (297 m) of Mission Canyon was cut in the Island Ranching D-1 well ("Madison" of API 43-043-30161, Utah DOGM).

Lodgepole Limestone (Mississippian, Osagean-Kinderhookian) – Dolomite and limestone; note that distinctive Cottonwood Canyon-Leatham log interval has been included in Darby by Ver Ploeg and De Bruin (1982, p. 47); thicknesses vary near Utah-Wyoming state line, likely due to difficulty picking Mission Canyon-Lodgepole contact; estimated thickness 600 to 750 feet (180-230 m).

Ver Ploeg and De Bruin (1982, p. 48) showed only about 500 feet (150 m) of Lodgepole on their type log for the Whitney Canyon field in Wyoming. About 550 and 600 feet (168 and 180 m) of Lodgepole was cut in the Woodruff Narrows field in the Amoco 1-4H and Chevron-Amoco 1-32G wells, respectively (API 49-041-20289 and 49-041-20627, respectively WOGCC), including 32 feet (10 m) of Cottonwood Canyon-Leatham in the 1-32G well, with the 1-4H well east of the Ogden map area. South of Woodruff Narrows, about 880 feet (270 m) of Lodgepole was cut in the Yellow Creek field in the Urroz well (API 49-041-20321, WOGCC), but this seems too large. In the Cave Creek field in the Fawcett and Son well, about 750 feet (230 m) of Lodgepole was cut, including the Cottonwood Canyon Member (King after AMSTRAT log D-5672, API 43-043-30078).

DEVONIAN

Dd **Darby Formation (Upper Devonian)** – Subsurface only. Calcareous to dolomitic shale, sandstone, and thick-bedded dolomite; subdivided into Three Forks and underlying Jefferson Formations in some areas (see for example Benson, 1966); thicknesses vary near Utah-Wyoming state line, but mostly are about 525 to 600 feet (160-180 m).

North of the Ogden map area, the Three Forks is 187 feet (57 m) thick and Jefferson is 400 feet (120 m) thick in the Louisiana Land & Exploration Christmann well east of the Crawford Mountains (API 43-033-30031, Utah DOGM). In the Ogden map area, the Darby is about 525 (160 m) thick in the Woodruff Narrows field in the Chevron-Amoco 1-32G well and, just to east of the map area, 600 feet (180 m) thick in the Woodruff Narrows Amoco 1-4H well (API 49-041-20627 and 49-041-20289, WOGCC, respectively). South of Woodruff Narrows in the Cave Creek field, the Fawcett and Son well cut about 700 feet (210 m) of Darby (King after AMSTRAT log D-5672 and API 43-043-30078, Utah DOGM), but was shown as faulted by Lamerson (1982, plate 11). Farther south in the Anschutz Ranch (west) field in the Island Ranching D-1 well, 253 and 348 feet (77 and 106 m) of Three Forks and Jefferson, respectively, was cut (API 43-043-30161, Utah DOGM).

ORDOVICIAN

Ob **Bighorn Dolomite (Upper Ordovician)** – Subsurface only. Gray, finely crystalline, thick-bedded dolomite with diverse fossils; exposed north of the Ogden map area in the Crawford Mountains, west of the Crawford thrust fault (Fish Haven Dolomite of Ott, 1980); subsurface thickness uncertain due to faulting, but likely at least 600 feet (180 m) thick. These strata are not Silurian (see Berdan and Duncan, 1955), and Silurian strata are missing in an unconformity.

East of the Crawford thrust near the Utah-Wyoming state line, the Bighorn was shown as about 600 feet (180 m) thick where penetrated by wells (see Lamerson, 1982, plate 8); also compare Hoffman and Kelly (1981) to Ver Ploeg and De Bruin (1982, p. 47). About 690 feet (210 m) of Bighorn was penetrated in the Champlin 804-Amoco C well in the Woodruff Narrows field east of the Ogden map area, but other penetrations in this well seem too thick (API 49-041-20567, WOGCC). The Bighorn is possibly greater than 825 feet (250 m) thick (thrust truncated) in the Yellow Creek field in the Urroz well (API 49-041-20321, WOGCC), but the stratal dip is not known and Lamerson (1982, figure 26) showed the Bighorn as faulted where penetrated by this well and to the west showed the Bighorn as about 600 feet (180 m) thick.

CAMBRIAN

Cg **Gallatin Limestone and Gros Ventre Formation, undivided (Middle Cambrian)** – Subsurface only. Thin-bedded, silty limestone, oolitic limestone, and shale in subsurface with formation identification suspect. Total Cg thickness east of Crawford thrust is depicted as a maximum of about 1250 feet (380 m) above regional thrust fault (decollement) (Lamerson, 1982, plate 8).

See Shaw and DeLand (1955) for descriptions of exposed Cambrian strata in southwestern Wyoming. The Gallatin is mostly limestone like the Maxfield on Durst Mountain, where the Maxfield is about 300 feet (90 m) thick (Coogan and King, 2006). The Gros Ventre is shale over limestone over shale like the Ophir on Durst Mountain, where the Ophir is about 440 to 725 feet (135-220 m) thick (see Coogan and King, 2006).

Ct, Cf **Tintic Quartzite or Flathead Sandstone (lower Middle Cambrian)** – Basal Cambrian strata not penetrated in boreholes, since below regional thrust fault (decollement). Flathead label (Cf) used on cross section by Coogan (1992a). A change to the thicker less feldspathic Tintic (Ct) may be near the western edge of the Archean Wyoming Province (see PCx below).

To the east in Wyoming the basal Cambrian is the feldspathic to arkosic Flathead Sandstone, and in Utah should be less feldspathic and thicker than the 280 feet (85 m) reported by Shaw and DeLand (1955) in the Wind River Range, Wyoming. The Flathead, though younger, occupies the stratigraphic interval of the Tintic Quartzite (Ct). The Tintic is about 1000 feet (300 m) thick on Durst Mountain (see Coogan and King, 2006).

PRECAMBRIAN

PCx **Precambrian rocks** – Subsurface only. Not penetrated in boreholes, but to east in Wyoming are Archean crystalline rocks.

The western edge of the Archean Wyoming Province has not been documented, but the aeromagnetic map of the United States (USGS, 2002) showed a roughly north-south trending change from near Devils Slide through the Bear River Range. This means the Precambrian rocks in the Ogden map area east of Henefer are likely Archean crystalline rocks. The Paleoproterozoic Farmington Canyon Complex (Xfc), which is younger, is exposed to the west on Durst Mountain. The still younger Proterozoic Uinta Mountain Group is likely restricted to south of the map area, roughly south of the North Flank fault of the Uinta Mountains.

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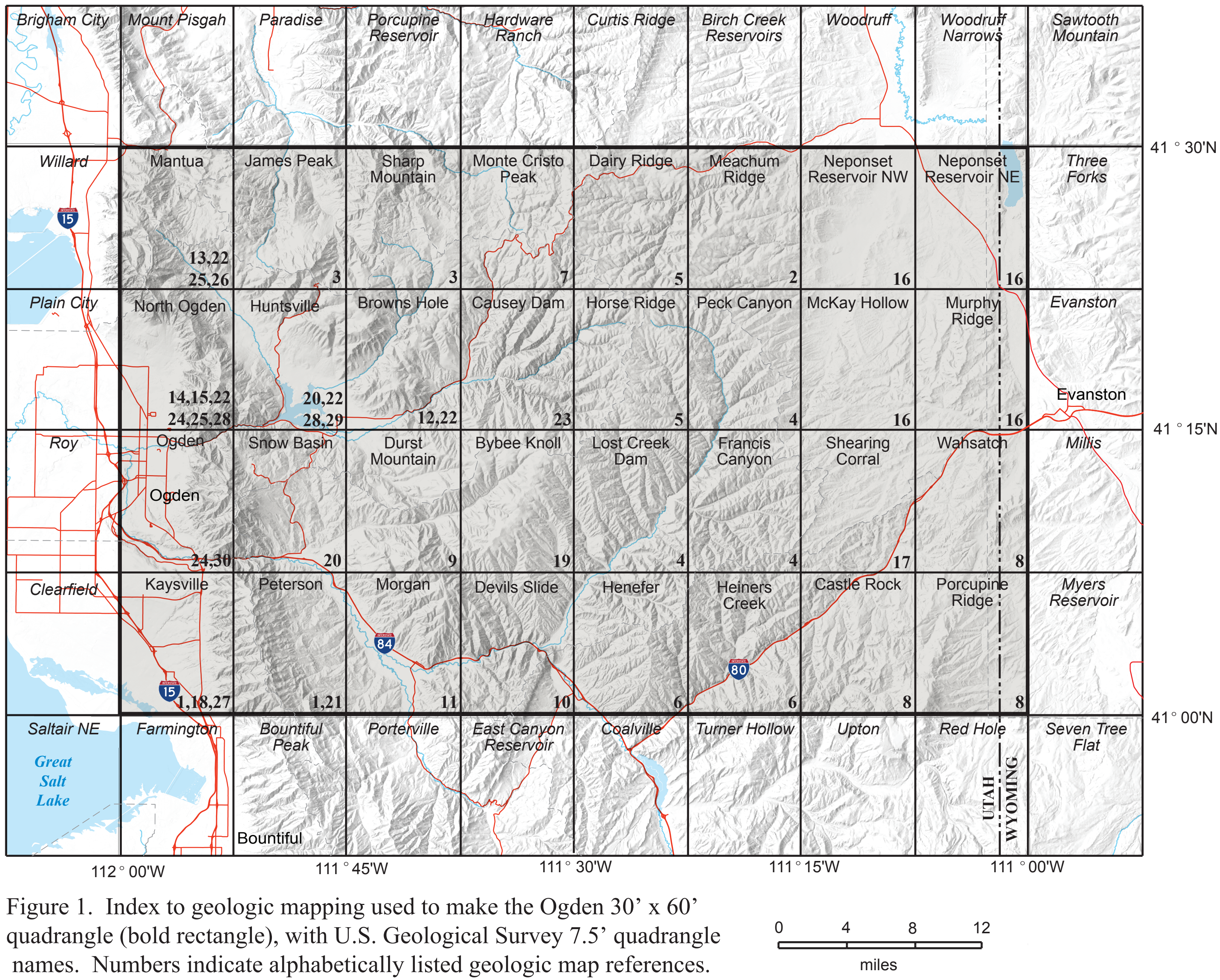

Figure 1. Index to geologic mapping used to make the Ogden 30' x 60' quadrangle (bold rectangle), with U.S. Geological Survey 7.5' quadrangle names. Numbers indicate alphabetically listed geologic map references.

INDEX TO GEOLOGIC MAPPING
(Numbers refer to maps as shown on figure 1)

1 Bryant, Bruce, 1984, Reconnaissance geologic map of the Precambrian Farmington Canyon Complex and surrounding rocks in the Wasatch Mountains between Ogden and Bountiful, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1447, scale 1:50,000. [parts of Kaysville and Peterson quadrangles]

2 Coogan, J.C., 1998, Preliminary geologic map of the **Meachum Ridge** quadrangle and part of the Birch Creek Reservoir quadrangle, Utah: Utah Geological Survey unpublished map, scale 1:24,000 [minor revisions in 1999 and 2016].

3 Coogan, J.C., 1999, Preliminary geologic maps of the **Sharp Mountain** and **James Peak** quadrangles, Utah: Utah Geological Survey unpublished maps, scale 1:24,000. [revisions by King, J.K., various years, with major revision of James Peak Cenozoic in 2014]

4 Coogan, J.C., 2004, Interim geologic maps of the **Peck Canyon**, **Lost Creek Dam**, and **Francis Canyon** quadrangles, Lost Creek drainage, Morgan, Rich, Summit, and Weber Counties, Utah: Utah Geological Survey Open-File Report 427, 426, 425, respectively, 10 p., scale 1:24,000. [Crawford thrust revision in 2016]

5 Coogan, J.C., 2006, Interim geologic maps of the **Dairy Ridge** and **Horse Ridge** quadrangles, leading margin of Willard thrust sheet, Cache, Morgan, Rich, and Weber Counties, Utah: Utah Geological Survey Open-File Report 479 and 480, respectively, 19 p., scale 1:24,000 [Willard thrust revisions in 2016].

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11 Coogan, J.C., King, J.K., and McDonald, G.N., 2015, Interim geologic map of the **Morgan** 7.5' quadrangle, Morgan County, Utah: Utah Geological Survey Open-File Report 643, 30 p., scale 1:24,000.

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13 Crittenden, M.D., Jr., and Sorensen, M.L., 1985a, Geologic map of the **Mantua** quadrangle and part of the Willard quadrangle, Box Elder, Weber, and Cache Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1605, scale 1:24,000; with clarification from Sorensen, M.L., and Crittenden, M.D., Jr., 1976, Preliminary geologic map of the Mantua quadrangle and part of the Willard quadrangle, Box Elder, Weber, and Cache Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-720, scale 1:24,000. [eastern third of Mantua quadrangle revised by Coogan, J.C., 1999; revised by King, J.K., various years, but mostly in 2014 and 2015, Utah Geological Survey unpublished mapping, scale 1:24,000]

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17 King, J.K., 2010, Interim geologic map of the **Shearing Corral** quadrangle, Morgan, Rich, and Summit Counties, Utah: Utah Geological Survey Open-File Report 565, 10 p., scale 1:24,000.

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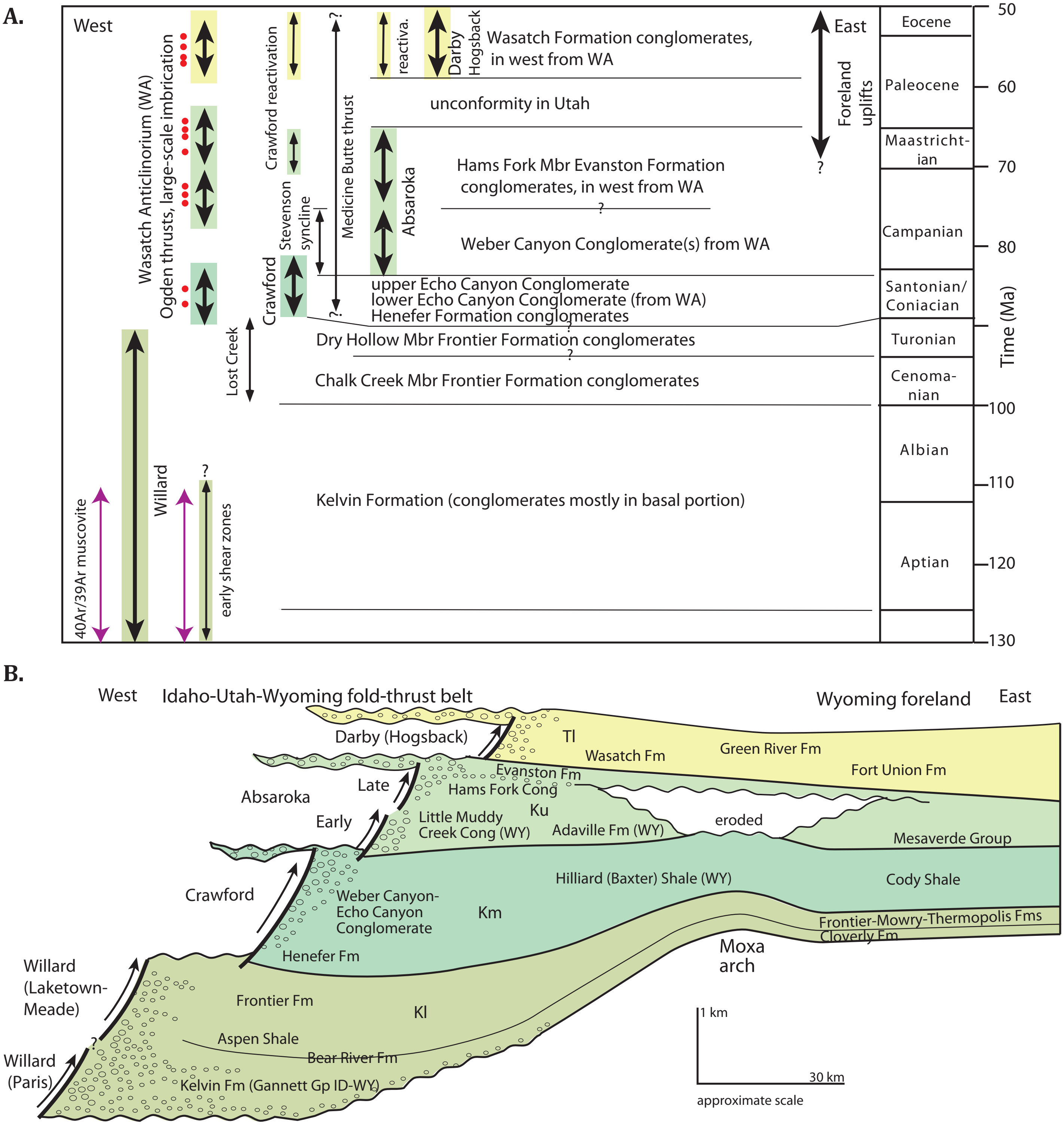


Figure 2. History of thrusting in the Idaho-Utah-Wyoming fold and thrust belt (modified from Yonkee and Weil, 2011; who modified Wiltschko and Dorr, 1983 for A; and Royse and others, 1975 for B). A) Ages of thrusting and synorogenic strata from this compilation and Coogan (2010a-b, appendix). Apatite fission-track ages (red dots) from Naeser and others (1983) and Burtner and Nigrini (1994). Argon-argon ages from Yonkee and others (1989). B) General thicknesses and names of synorogenic strata in relation to major thrusts from Utah and Wyoming going into the southern Green River Basin. Note that conglomeratic intervals (ellipses) are east and west of associated thrusts, and Cretaceous divisions are informal. Lower Cretaceous strata (Kl) are thickest in the foredeep associated with movement on the Willard-Paris-Laketown (Meade) thrusts. Middle Cretaceous strata (Km) record movement on the Crawford thrust and regional subsidence, indicated by thick shales. Upper Cretaceous strata (Ku) record two episodes of movement on the Absaroka thrusts, along with the uplift of and erosion over the Moxa arch. Paleocene and Eocene strata (Tl) record movement on the Darby-Hogsback thrust. Thrusts get younger to the east, with limited reactivation and uplift along older thrusts and the Wasatch anticlinorium (WA).

Table 1. Heights of alluvial deposits above adjacent active drainages near Morgan and Round Valleys, and apparently Ogden, Henefer, and Lost Creek Valleys. Younger ages (<20 ka) from Lake Bonneville history in C-14 years (see Oviatt and others, 1992). See Chadwick and others (1997) and Phillips and others (1997) for "Bull Lake" and Qaoe ages (cosmogenic ages). Other age estimates from Sullivan and others (1988) and Sullivan and Nelson (1992).

Unit(s)	Feet (m) above drainage	Age (ka=1000) years	Comments
Qal, Qay, Qafy	at to slightly above	<~13 ka	Post Lake Bonneville
Qa2	~15 feet (5 m)	<~13 ka	Younger age limit uncertain, post Lake Bonneville
Qat2	~10 to 20 feet (3-6 m)		
Qaf2	~20 to 40 feet (6-12 m)		
Qap	~15 to 40 feet (5-12 m)		
Qatp	20 to 30 feet (6-9 m)	~13-15 ka	Provo shoreline occupation, Lake Bonneville
Qafp	~ 30 to 45 feet (9-14 m)		
Qab	~40 to 90 feet (12-27m)		sites >50 feet (15 m) may be part of unit Qfdb
Qafb	~40 to 70 feet (14-20 m)	~15-20 ka	Bonneville shoreline occupation, Lake Bonneville
Qfdb	~50 to 100 feet (15-30 m)		fans that go into lake and become deltas
Qao	~70 to 120 feet (20-37 m)	~95-130 ka	"Bull Lake" glaciation-related deposits
Qato	~100 feet (30 m)		
Qafo	~70 to 120 feet (20-37 m)	~98-155 ka	amino acid ages, also >70-100 ka soil carbonate age
			$\geq$ 400 ka amino acid age is possible if two alluvial surfaces
Qaoe	120 to 230 feet (35-70 m)	>247ka	>780 ka paleomag age, but this age may be on QTay;
Qafoe	~120 to 200 feet (35-60 m)		suspect marine oxygen isotope stage 16
QTay	~215 to 450 feet (66-137 m)	>780 ka	note height overlap with Qaoe
QTao	~320 to 800 feet (100-240 m)	>780 ka	
QTaf	~230 to 300 feet (70-90 m)	>780 ka	may be upstream equivalent of QTay
	~320 to 1000 feet (100-300 m)	>780 ka	may be entirely Pliocene

Table 2. Alluvial surfaces and deposits in Devils Slide quadrangle compared to those in Henefer quadrangle (Henefer and Lost Creek valleys) (Coogan, 2010b), Lost Creek drainage (Lost Creek Dam, Francis Canyon, and Peck Canyon quadrangles) (Coogan, 2004a-c) and Morgan Valley (Durst Mountain, Snow Basin, Peterson, and Morgan quadrangles) (Coogan and King, 2006; King and others, 2008; Coogan and others, 2015); for Round Valley - see Morgan Valley units. Heights are feet above adjacent active drainages.

surface	height above, feet	Devils Slide quad units	Henefer quad units	Lost Creek drainage units	Morgan Valley units
2	10-20	Qat2?, Qa2?	Qa2, Qat2	Qat2, Qaf2	Qa2, Qat2
2-3	20-30, 40?	Qap, Qatp?, Qafpb?	Qa2-3, Qat2 [Qatp?]	Qaty, Qaf2?	Qap, Qatp, Qaf2
3	40-60	Qab, Qafpb, Qapb	Qa3, Qat3	Qat3, Qaty?	Qab, Qafb
3-4	60-80	Qab, Qafm	Qa3, Qat3 [Qab], Qaf3?	Qat3, Qaf3	Qab, Qfdb
4	80-100	Qafm, Qao, Qmso	Qa4 (lower), Qaf3 [Qaf4]	Qa3, Qaf3?	Qao, Qafo
4-5	100-120	Qao, Qato?, Qafo?, Qmso	Qa4 (upper)	Qao	Qao, Qato, Qafo
5	120-150	Qaoe, Qao?, Qato?, Qafo?	Qa4?		Qaoe, Qafoe
6	160, 170?	Qaoe?	Qa5	Qa5?, Qat4, Qaf4	Qaoe, Qafoe
6-7	170-220	QTay, QTay?	Qa5?	Qa5	Qaoe, Qafoe
7	220 & 240	QTay, QTa?, QTaf?			QTay, QTaf?
8	300?	Qmso			QTa, QTaf
9?	>320	QTa?			QTao, QTaf

Table 3. Comparison of Marine Oxygen Isotope Stages (OIS) to middle Rocky Mountain glaciation, Great Basin lake cycles, and North American continental glaciation, with ages in kilo-years (ka). Ages approximate since determined by different methods. Marine OIS ages from Bassinot and others (1994) and when marked with * from en.wikipedia.org/wiki/Marine_isotope_stage accessed April 20, 2016*. Middle Rocky Mountain glacial ages mostly from data in Phillips and others (1997). Great Basin lake cycle ages from numerous sources, in particular McCalpin (1986)=a, Kaufman and others (2001)=b, and Balch and others (2005)=c.

Marine OIS **(bold),** in ka	middle Rocky Mtn glaciation in ka	Great Basin lake cycle in ka	North American continental glaciation in ka	Notes, in ka
				Mazama ash, 6.74 Hallett and others, 1997
2, 11-24, 14-29*	"Pinedale" 12-23	Bonneville 12-30; Lake Lahontan	**major**, late Wisconsin end 10	major continental=middle Rocky Mtn glaciers
4, 57-71 both	likely obliterated by "Pinedale"	Cutler Dam 59b; 82a	early Wisconsin start 75	
6, 127-186, 130-191*	"Bull Lake" 101?, 111-131, 163?	Little Valley >112-126; 138a; 153-187c; Lake Manly in Death Valley	**major**, late Illinoian end 125	major continental=middle Rocky Mtn glaciers
8, 242-301, 243-300*	"Sacagawea Ridge"? >245	Pokes Point?, >271c	early Illinoian start 265	moraine age from Phillips and others, 1997
10, 334-364, 337-374*			pre-Illinoian A, formerly Kansan 300?-435	type Kansan is Nebraskan in age, so now use pre-Illinoian
12, 427-474, 424-478*	"Sacagawea Ridge" >245 on moraine; best guess for "Sacagawea Ridge" since major continental glaciers	Pokes Point by Oviatt and others, 1999	**major**, pre-Illinoian B, formerly Kansan 300?-435	moraine age from Phillips and others, 1997; major continental=middle Rocky Mtn glaciers
14, 528-568, 533-563*		pre Pokes Point 600? (>500<610)	"Nebraskan" end 500, pre-Illinoian C	
16, 621-659, 621-676*	"Sacagawea Ridge"?, Lava Creek B ash (640) in fluvial deposits correlated across Dinwoody Lake by Chadwick and others, 1997	"Lava Creek" lake, pre Pokes Point 600?	**major**, pre-Illinoian D, Nebraskan	ash age Lanphere and others, 2002; major continental=middle Rocky Mtn glaciers; could be "Cedar Ridge"
18, 712-760, 712-761*	older "Cedar Ridge"? Washakie Point?	"Lake Dominguez" top, Bishop ash (760)	pre-Illinoian E?	ash age Izett and Obradovich, 1991
20, 787-<820, 790-814*	type "Washakie Point", not reverse polarized, so not Marine OIS 20			775±10 bottom of Brunhes paleomagnetism from Bassinot and others, 1994
22, 865->879, 866-900*. **24**, 917-936*			pre-Illinoian F	
38, 1244-1264*. **40**, 1286-1304*			pre-Illinoian G	Mesa Falls ash, 1285 Lanphere and others, 2002
64, 1782-1802.5*			pre-Illinoian I?, "Nebraskan" start 1800	1770 top of Olduvai paleomagnetism
78?, 2043-2088*		"Lake Dominguez" bottom, Huckleberry Ridge ash (2060)		ash age Lanphere and others, 2002

TABLE 4. Summary of $^{40}Ar/^{39}Ar$-age analyses from the area of the Ogden 30' x 60' quadrangle.

Sample number	Unit	Latitude	Longitude	Age+2sd (Ma)	Mineral	Type of analysis
KNC53094-3	Fowkes, lower	41.048°	111.1374°	38.78±0.62	hornblende	furnace step-heating$
KNC53094-5	Fowkes	41° 02' 20"	111° 07' 40"	40.41±0.84	biotite	furnace step-heating$

$ Analyses performed at the New Mexico Geochronology Research Laboratory, Socorro, New Mexico, and paid for by STATEMAP funding.

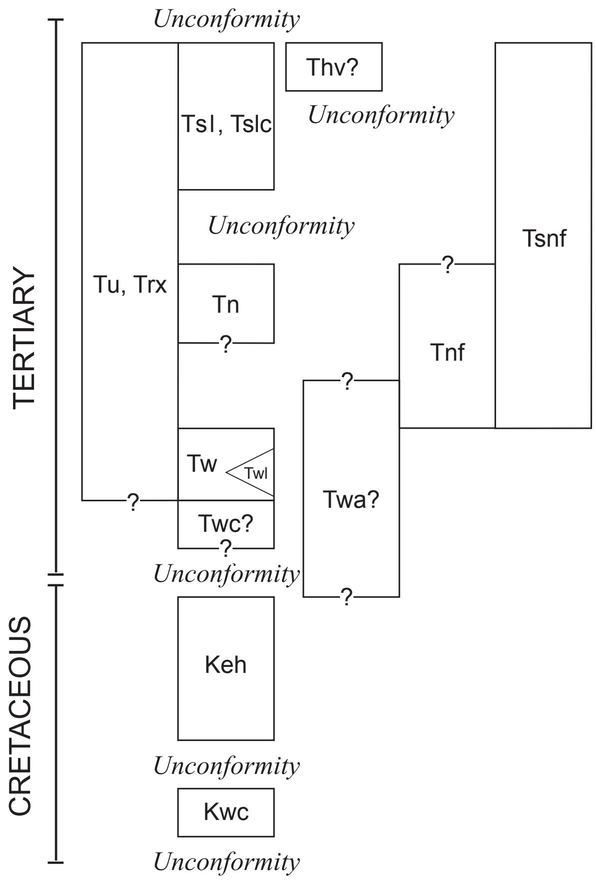
Table 5. Preliminary geochronologic results for Gypsum Spring Formation/Member (Jtgs) samples in Devils Slide quadrangle reported in abstract of Kowallis and others (2011). Toarcian and Aalenian stages missing, indicating an unconformity between these samples and overlying Bajocian-stage Twin Creek Limestone samples. Data provided by Doug Sprinkel of the Utah Geological Survey, but lithology changed to tuff (lithified) from ash (unconsolidated, unlithified). Locations are in WGS84 decimal degrees. Sample DS-040709-4 not plotted on map because no analysis performed.

Sample No.	Map Mbr	Latitude	Longitude	Lithology	Analysis	Age Ma	Error ±Ma	Stage
2000-DS-1	Jtgs	41.066529	-111.549277	Tuff	Ar/Ar sanidine	184.6	0.2	Pliensbachian
DS-040709-1A	Jtgs	41.066535	-111.549278	Tuff	U-Pb zircon	184.3	2.3	Pliensbachian
DS-040709-4		41.066531	-111.549263	Tuff	no crystals recovered			

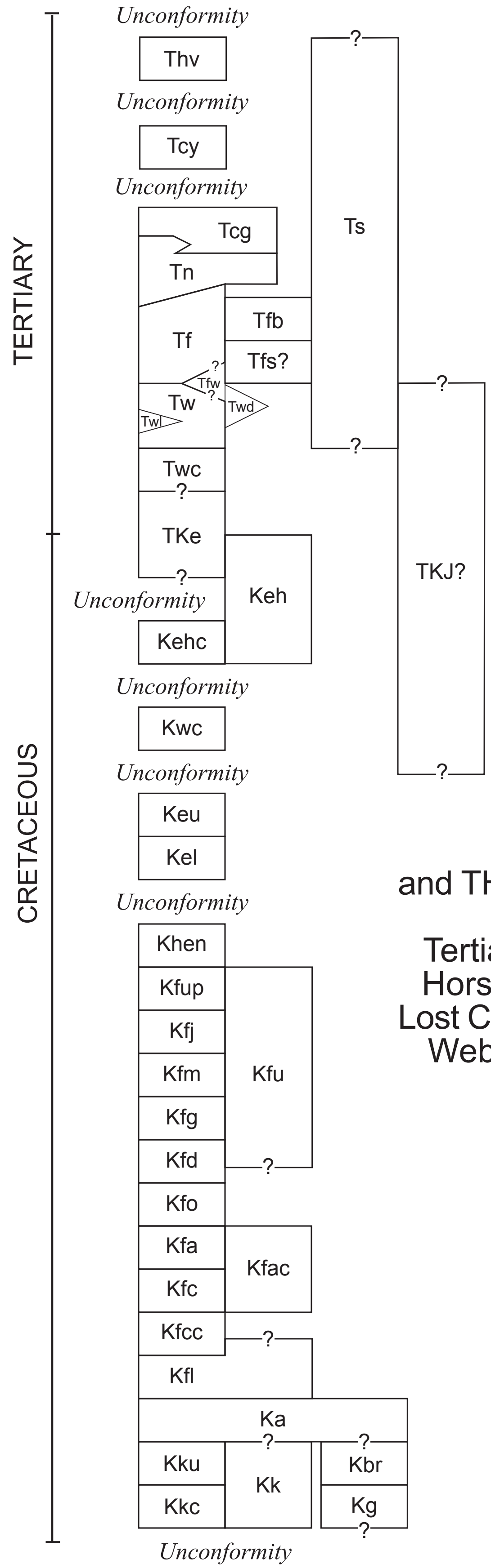
Table 6. Preliminary palynological results of Twin Creek Limestone samples from the Devils Slide quadrangle analyzed by Dr. Gerald Waanders and are provided with locations and units by Doug Sprinkel of the Utah Geological Survey (written communications, March 30, 2010 and December 12, 2012). Locations are in WGS84 decimal degrees. Barren samples are not plotted on map.

Map no.	Sample No.	Map Mbr	Age/Stage	Lithology	Latitude	Longitude	lower Sprinkel unit	upper Sprinkel unit
	DS-063003-1		barren	Limestone	41.066529	-111.549301	8 (Jgs)	
	DS-063003-3		barren	Mudstone	41.066527	-111.549211	10 Jgs)	
	DS-063003-4		barren	Limestone	41.066531	-111.548979	15 Jgs)	
1	DS-063003-5	Jts	Bajocian to Bathonian	Limestone	41.067222	-111.547778	20 (Jts)	
2	DS-063003-6	Jts	Bajocian to Bathonian	Limestone	41.067222	-111.547500	21 (Jts)	
3	DS-092603-1	Jtr	Jurassic undiff.	Limestone	41.068314	-111.545721		7 (Jtr)
4	DS-092603-2	Jtw	Jurassic undiff.	Siltstone-Mudstone	41.068333	-111.544620		18 (Jtb)
5	DS-092603-3	Jtw	Bajocian to Bathonian	Limestone	41.068258	-111.544342		22 (Jtw)
6	DS-092603-4	Jtw	Bajocian to Bathonian	Limestone	41.067464	-111.544489		28 (Jtl)
	DS-092603-5		barren	Limestone	41.066718	-111.542778		21 (Jtw)
7	DS-102403-1	Jtl	Bathonian	Limestone	41.066726	-111.542216		32a (Jtl)
8	DS-102403-2	Jtl	Bathonian	Limestone	41.066393	-111.540965		32c (Jtl)
9	DS-102403-3	Jtgc	Callovian	Mudstone	41.064431	-111.539400		32d (Jtl)

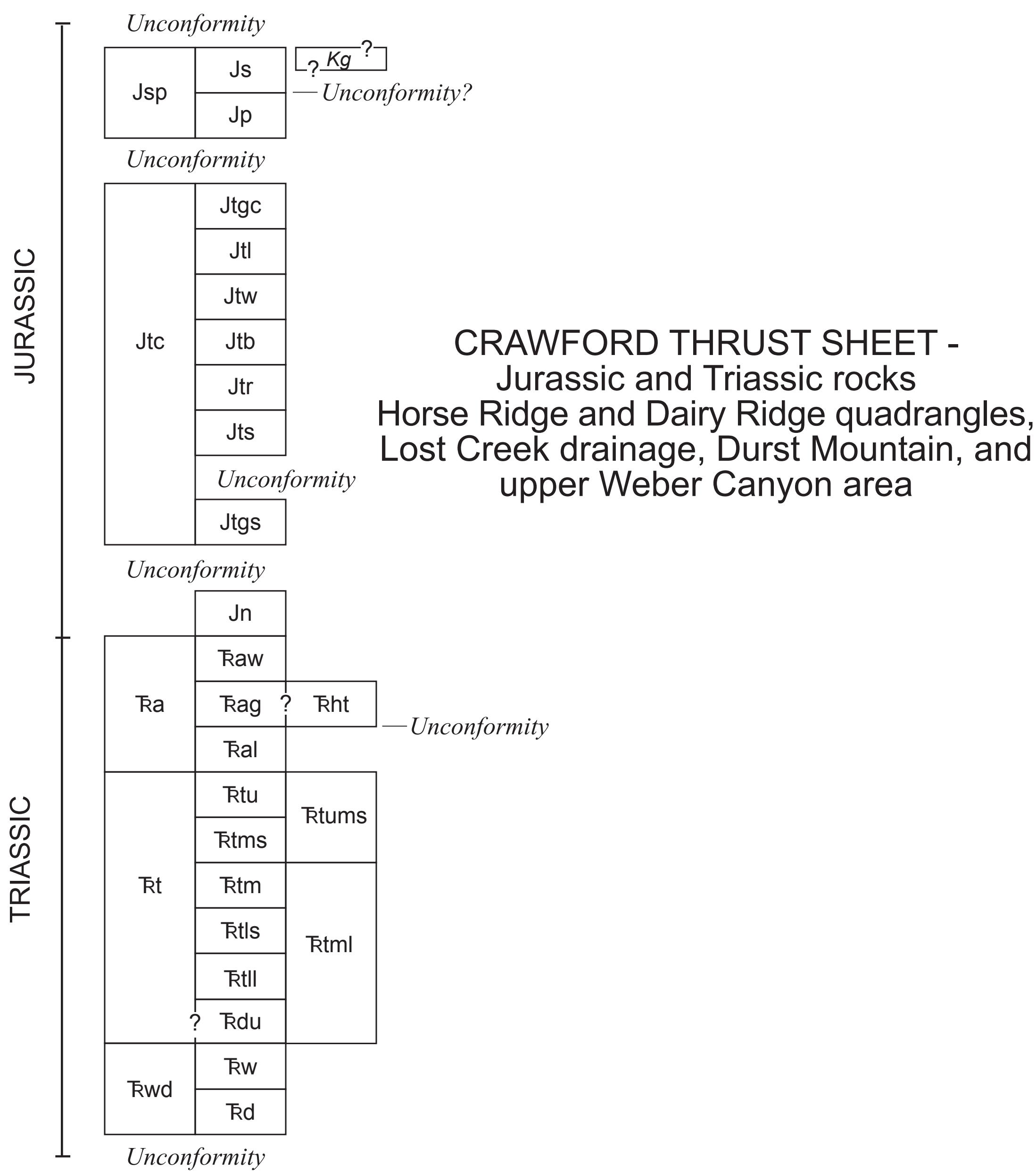
Jts=Sliderock Member
Jtr=Rich Member
Jtw=Watton Canyon Member
Jtl=Leeds Creek Member
Jtgc=Giraffe Creek Member

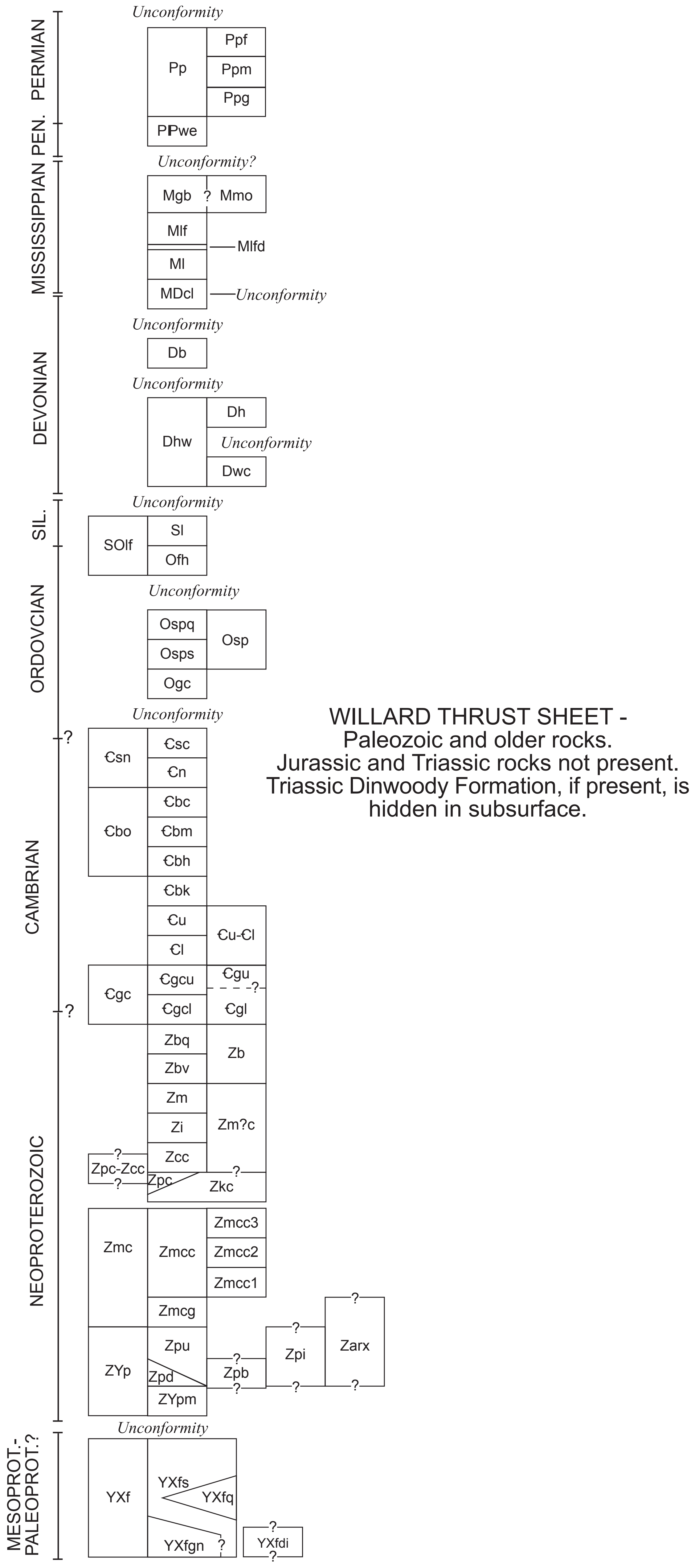


WILLARD THRUST SHEET
Overlapping Tertiary and Cretaceous
sedimentary cover rocks

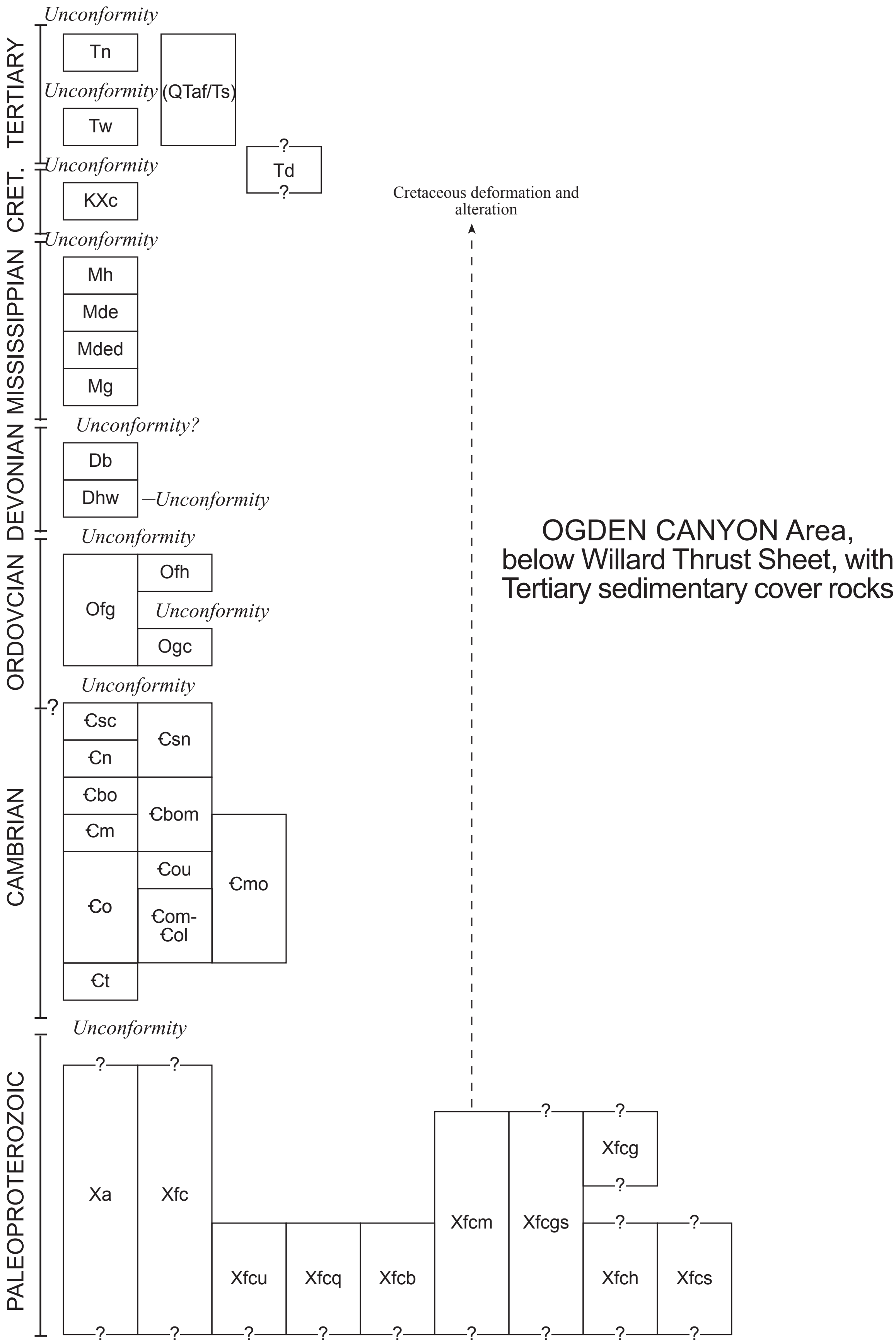


CRAWFORD THRUST SHEET
and THRUST SHEETS EAST OF CRAWFORD
THRUST AND HENEFER
Tertiary and Cretaceous sedimentary rocks
Horse Ridge and Dairy Ridge quadrangles,
Lost Creek drainage, Durst Mountain, and upper
Weber Canyon area; and Henefer, Utah to
Evanston, Wyoming

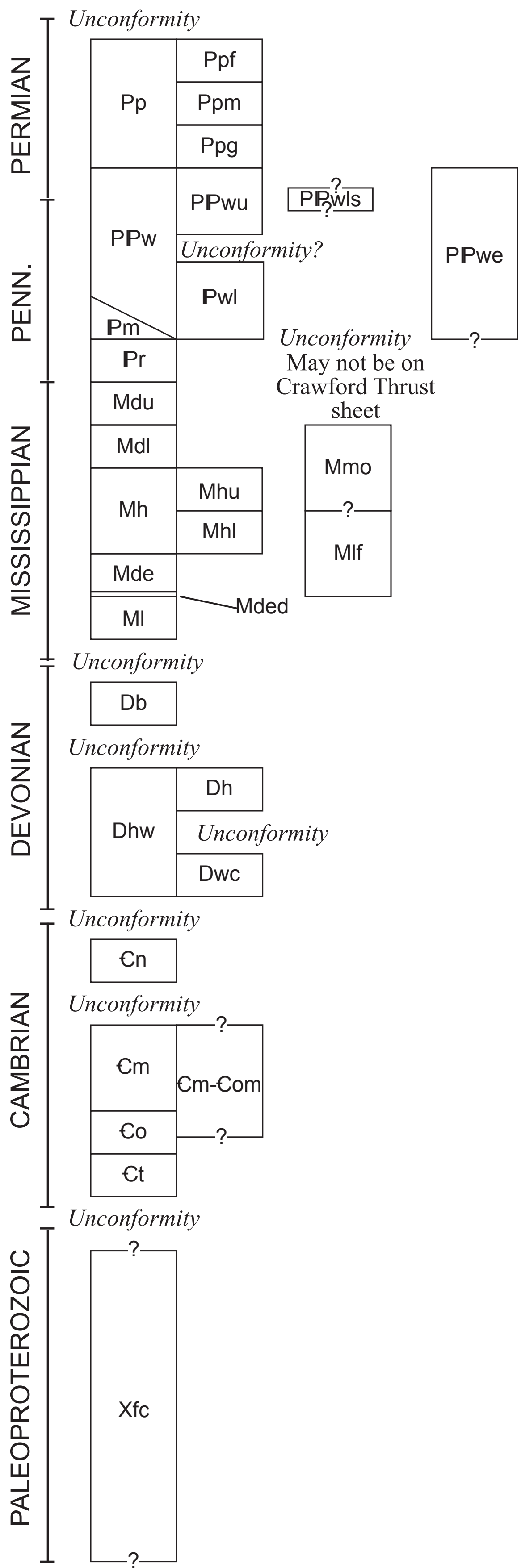

CRAWFORD THRUST SHEET -
Jurassic and Triassic rocks
Horse Ridge and Dairy Ridge quadrangles,
Lost Creek drainage, Durst Mountain, and
upper Weber Canyon area
JURASSIC
TRIASSIC
Unconformity
Jsp
Js
Jp
Kg
Unconformity?
Unconformity
Jtc
Jtgc
Jtl
Jtw
Jtb
Jtr
Jts
Unconformity
Jtgs
Unconformity
Jn
₮a
₮aw
₮ag
₮ht
Unconformity
₮al
₮t
₮tu
₮tms
₮tums
₮tm
₮tls
₮tll
₮du
₮tml
₮wd
₮w
₮d
Unconformity



PERMIAN
PEN.
MISSISSIPPIAN
DEVONIAN
SIL.
ORDOVCIAN
CAMBRIAN
NEOPROTEROZOIC
MESOPROT.-
PALEOPROT.?
Unconformity
Pp
Ppf
Ppm
Ppg
PIPwe
Unconformity?
Mgb
Mmo
Mlf
Mlfd
Ml
MDcl
Unconformity
Unconformity
Db
Unconformity
Dhw
Dh
Unconformity
Dwc
Unconformity
SOlf
Sl
Ofh
Unconformity
Ospq
Osps
Osp
Ogc
Unconformity
Ꞓsn
Ꞓsc
Ꞓn
Ꞓbo
Ꞓbc
Ꞓbm
Ꞓbh
Ꞓbk
Ꞓu
Ꞓl
Ꞓu-Ꞓl
Ꞓgc
Ꞓgcu
Ꞓgcl
Ꞓgu
Ꞓgl
Zbq
Zbv
Zb
Zm
Zi
Zcc
Zm?c
Zpc-Zcc
Zpc
Zkc
Zmc
Zmcc
Zmcc3
Zmcc2
Zmcc1
Zmcg
ZYp
Zpu
Zpd
ZYpm
Zpb
Zpi
Zarx
Unconformity
YXf
YXfs
YXfq
YXfgn
YXfdi
WILLARD THRUST SHEET -
Paleozoic and older rocks.
Jurassic and Triassic rocks not present.
Triassic Dinwoody Formation, if present, is
hidden in subsurface.



OGDEN CANYON Area,
below Willard Thrust Sheet, with
Tertiary sedimentary cover rocks
TERTIARY
CRET.
MISSISSIPPIAN
DEVONIAN
ORDOVCIAN
CAMBRIAN
PALEOPROTEROZOIC
Unconformity
Tn
Tw
(QTaf/Ts)
Td
KXc
Mh
Mde
Mded
Mg
Unconformity?
Db
Dhw
Ofg
Ofh
Ogc
Ꞓsc
Ꞓn
Ꞓsn
Ꞓbo
Ꞓm
Ꞓbom
Ꞓmo
Ꞓo
Ꞓou
Ꞓom-Ꞓol
Ꞓt
Xa
Xfc
Xfcu
Xfcq
Xfcb
Xfcm
Xfcgs
Xfcg
Xfch
Xfcs
Cretaceous deformation and alteration



CRAWFORD THRUST SHEET
- Pre-Triassic rocks
Horse Ridge and Dairy Ridge quadrangles,
Lost Creek drainage, Durst Mountain, and upper
Weber Canyon area
Subsurface units not included, since not on map,
but shown in subsurface lithologic column.

LITHOLOGIC COLUMN - Willard Thrust Sheet and cover rocks

AGE	UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.	Q- various	Alluvial and lake deposits	0-500	0-150	Thv? deposit or rock
TERTIARY	Tsnf: Tsl	Salt Lake Formation (conglomerate locally, Tslc)	0-500	0-150	ANGULAR UNCONFORMITY
TERTIARY	Tsnf: Tn	Norwood Formation (and Fowkes Fm, Tnf)	0-5000	0-1525	38.4 Ma (corrected), 44.2 Ma K-Ar
TERTIARY	Tu, Trx ?: Tw	Wasatch Formation Twa? is at least partly Wasatch Formation	0-3400	0-1035	Twl - limestone Twc - conglomerate
CRET.	Keh	Hams Fork Member of Evanston Formation	0-1000	0-300	Different than type area
CRET.	Kwc	Weber Canyon Conglomerate	300?	90?	MAJOR ANGULAR UNCONFORMITY
PERM.	Pp: Ppf	Franson Member of Park City Formation	400+	120+	Includes Rex Chert, Retort Shale
PERM.	Pp: Ppm	Meade Peak Member of Phosphoria Fm	230-260	70-80	Phosphate
PERM.	Pp: Ppg	Grandeur Member of Park City Formation	250-280	75-85	
IP.	PIPwe	Wells Formation	400	120	UNCONFORMITY?
MISSISSIPPIAN	Mmo	Monroe Canyon Limestone	700-1100	210-335	Mgb - Great Blue Limestone west of Cache Valley
MISSISSIPPIAN	Mlf	Little Flat Formation	800-900	245-275	Mlfd - Delle Phosphatic Member
MISSISSIPPIAN	Ml	Lodgepole Limestone	750-900	230-275	Fossiliferous MDcl - Cottonwood Cyn Mbr of Lodgepole and Leatham Fm
DEV.	Db	Beirdneau Sandstone	0-500	0-150	Absent to west
DEV.	Dhw: Dh	Hyrum Dolomite	0-675	0-205	Absent to northwest
DEV.	Dhw: Dwc	Water Canyon Formation	100-460	30-140	Thins to south
S.	SOlf: Sl	Laketown Dolomite	400-1240	120-378	Thins to south
ORD.	SOlf: Ofh	Fish Haven Dolomite	80-165	25-50	Absent to south
ORD.	Osp	Swan Peak Formation	0-250	0-75	Ospq Absent to south and east Osps
ORD.	Ogc	Garden City Formation	500-1200	150-365	Thins to south Intraformational conglomerate
CAMBRIAN	Ꞓsn: Ꞓsc	St. Charles Formation	500-1000	150-300	May thin to east Worm Creek quartzite (Ꞓsw)
CAMBRIAN	Ꞓsn: Ꞓn	Nounan Formation	600-1150	180-350	Thins to south
CAMBRIAN	Ꞓbo: Ꞓbc	Bloomington Formation: Calls Fort Shale Member	100-400	30-120	Intraformational conglomerate Thins to east
CAMBRIAN	Ꞓbo: Ꞓbm	Bloomington Formation: Middle limestone member	400-850	120-260	Thins to west and north
CAMBRIAN	Ꞓbo: Ꞓbh	Bloomington Formation: Hodges Shale Member	300-600	90-180	Thins to west and north
CAMBRIAN	Ꞓbk	Blacksmith Formation	250-760	75-230	Limestone in places Thins to west
CAMBRIAN	Ꞓu	Ute Formation	450-1000	140-300	Thins to east
CAMBRIAN	Ꞓl	Langston Formation	200-400	60-120	
CAMBRIAN / PROTEROZOIC	Ꞓgc	Brigham Group: Geertsen Canyon Quartzite	3000?-4200	900?-1280	Thinner to east Ꞓgcu, Ꞓgcl, Ꞓgu, Ꞓgl subunits are local and the contacts are probably inconsistent
PROTEROZOIC	Zb: Zbq	Brigham Group: Browns Hole Formation: Quartzite member	0-285	0-85	Absent to east
PROTEROZOIC	Zb: Zbv	Brigham Group: Browns Hole Formation: Volcanic member	100-460	30-140	590 Ma basaltic andesite
PROTEROZOIC	Zm?c: Zm	Brigham Group: Mutual Formation	435-2600	135-790	Purple to pink Cross bedded Some feldspar locally
PROTEROZOIC	Zm?c: Zi	Brigham Group: Inkom Formation	200-450	60-140	Meta-tuff lenses Inkom absent to east
PROTEROZOIC	Zm?c: Zcc	Brigham Group: Caddy Canyon Quartzite	725-2500?	220-760?	Thinner to east Largest thickness may include 600 feet (180 m) of Zpc
PROTEROZOIC	Zpc	Papoose Creek Formation	0-1000	0-300	Zpc is quartzite and argillite to phyllite that seems to be transition zone between Zcc and Zkc
PROTEROZOIC	Zkc	Kelley Canyon Formation	1000-2000?	300-600?	Phyllite to argillite Thin limestone locally
PROTEROZOIC	Zmc: Zmcc	Maple Canyon Formation: Conglomerate member	100-500	30-150	Zmcc3 upper conglomerate Zmcc2 argillite Zmcc1 lower conglomerate
PROTEROZOIC	Zmc, Zarx: Zm cg	Maple Canyon Formation: Greywacke (green arkose) mbr	500-1000	150-300	Meta-greywacke to argillite
PROTEROZOIC	ZYp, Zarx: Zpu	Formation of Perry Canyon: Upper member	600-1000?	180-300?	Slate to meta-argillite to phyllite to meta-greywacke to meta-ss
PROTEROZOIC	ZYp: Zpd	Formation of Perry Canyon: Diamictite member	0-400	0-120	Zpd - mixed clast sizes; glacial
PROTEROZOIC	ZYp: ZYpm	Formation of Perry Canyon: Mudstone member	1000-1800	300-550	Local lava (Zpb) and intrusive diorite (Zpi) associated with Zpd Slate to argillite
PROTEROZOIC	YXf, YXfdi: YXfs, YXfq	Facer Formation	est 1700	est 550	Schist, quartzite and minor carbonate
PROTEROZOIC	YXf, YXfdi: YXfgn	Facer Formation	est 800	est 245	Gneiss
					WILLARD THRUST

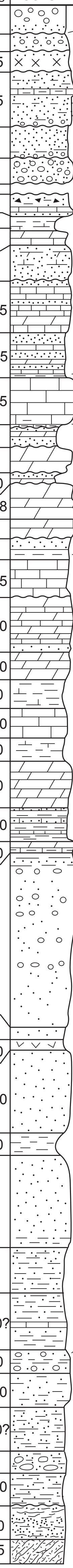


Diagram is schematic - no fixed thickness scale

LITHOLOGIC COLUMN - Ogden Canyon area, below Willard Thrust Sheet

AGE	UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	SCHEMATIC COLUMN	OTHER INFORMATION
TERTIARY	Tn	Norwood Formation	0 to 5000	0 to 1525		Distal equivalent to Keetley Volcanics Altered tuff 38.4 Ma K-Ar (corrected) *Protoreodon* sp. mammal
TERTIARY	Tw	Wasatch Formation	~1600-2700	~490-825		About half as thick as near Morgan
T.	Td	Chloritically altered mafic dikes in Xfc	indeterminable			Age uncertain
K.	KXc	Chloritic gneiss and tectonites, quartz veins	indeterminable			Farmington Canyon Complex protolith
MISSISSIPPIAN	Mh	Humbug Formation	700-800?	215-245?		MAJOR UNCONFORMITY
MISSISSIPPIAN	Mde	Deseret Limestone	500	150		Mded - Delle Phosphatic Member
MISSISSIPPIAN	Mg	Gardison Limestone	500-800	150-245		Madison of some workers Lodgepole Ls to East
DEV.	Db	Beirdneau Sandstone	250-300	75-90		UNCONFORMITY?
DEV.	Dhw	Hyrum Dolomite	200-350	60-107		UNCONFORMITY,
DEV.	Dhw	Water Canyon Formation	30-100	9-30		Water Canyon thicker to east
ORD.	Ofg: Ofh	Fish Haven Dolomite	200-225	60-70		UNCONFORMITY, Silurian gone
ORD.	Ofg: Ogc	Garden City Formation	200-400	60-120		UNCONFORMITY
CAMBRIAN	Ꞓsn: Ꞓsc	St. Charles Formation	400-660	120-200		UNCONFORMITY Worm Creek quartzite
CAMBRIAN	Ꞓsn: Ꞓn	Nounan Dolomite	500-750	150-230		
CAMBRIAN	Ꞓbom: Ꞓbo	Bloomington Formation	40-200	12-60		Intraformational conglomerate Bloomington Fm. absent to east
CAMBRIAN	Ꞓbom: Ꞓm	Maxfield Limestone	600-900	180-275		Boundstone Thinner to east
CAMBRIAN	Ꞓo	Ophir Formation	450-650	140-200		Ꞓou 130-260 feet (40-80 m) Ꞓom 100 feet (30 m) Ꞓol 100-145 feet (30-45 m)
CAMBRIAN	Ꞓt	Tintic Quartzite	1100-1500	330-460		MAJOR UNCONFORMITY
PALEO PROTER.	various Xfc	Farmington Canyon Complex	indeterminable			1700± Ma; older than Facer Fm Gneiss and schist

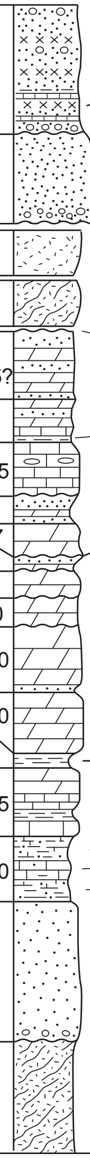
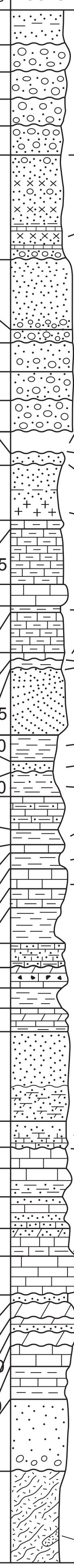


Diagram is schematic - no fixed thickness scale

LITHOLOGIC COLUMN - Crawford Thrust Sheet and cover rocks,
Durst Mountain and Upper Weber Canyon area

AGE	UNIT SYMBOL		GEOLOGIC UNIT		THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.	Q-various		alluvium, lake beds, mass movements		0-300	0-90	
TERTIARY — Plio.	QT-var.		alluvium, gravel		0-160	0-50	
TERTIARY — ?M.?	Ts	Thv	fanglomerate of Huntsville		0-1000	0-300	
TERTIARY — Oligocene	Ts	Tcy	younger unnamed conglomeratic rocks		0-400	0-120	
TERTIARY — Oligocene	Ts	Tcg	unnamed conglomeratic rocks		0-700	0-210	May be up to 3000 ft thick Tcg-Tn interbedded
TERTIARY — Oligocene ?	Ts	Tn	Norwood Formation		0 to 2800-7000	0 to 850-2135	Distal equivalent to Keetley Volcanics Altered tuff 38.4 Ma K-Ar (corrected) *Protoreodon* sp. mammal
TERTIARY — Paleo.-Eo.	Tw		Wasatch Formation		0 to ~5000	0 to ~1525	Thinner to north
TERTIARY — Paleo.-Eo.		Twc	basal conglomerate		0-400	0-120	
CRET.	Keh		Hams Fork Member of Evanston Formation		0-1000	0-300	
CRET.		Kehc	basal conglomerate		0-400	0-120	ANGULAR UNCONFORMITY
CRET.	Kwc		Weber Canyon Conglomerate		0-1900	0-580	No other Cretaceous strata on Crawford thrust sheet, see Henefer to Evanson lith. column for strata to east of thrust
JURASSIC	Jsp?		Stump Sandstone		220-250	67-76	
JURASSIC		Jp	Preuss Redbeds		~900	~270	UNCONFORMITY Additional 0 to 700 feet (0-210 m) of salt in subsurface "welt"
JURASSIC	Jtgc		Twin Creek Limestone (Jtc)	Giraffe Creek Member	225	70	
JURASSIC	Jtl		Twin Creek Limestone (Jtc)	Leeds Creek Member	1000-1300	300-395	
JURASSIC	Jtw		Twin Creek Limestone (Jtc)	Watton Canyon Member	~400	~120	
JURASSIC	Jtb		Twin Creek Limestone (Jtc)	Boundary Ridge Member	100	30	Thicker to north
JURASSIC	Jtr		Twin Creek Limestone (Jtc)	Rich Member	~500	~150	
JURASSIC	Jts		Twin Creek Limestone (Jtc)	Sliderock Member	100	30	UNCONFORMITY
JURASSIC	Jtgs		Twin Creek Limestone (Jtc)	Gypsum Spring Member	~200	~60	Thinner to north
JURASSIC ?	Jn		Nugget Sandstone		1250-1360	380-415	
TRIASSIC	TRa	TRaw	Stanaker (or upper) Member of Ankareh Fm		600-680	180-210	Wood Shale Tongue to north
TRIASSIC	TRa	TRag	Gartra Grit Member of Ankareh Fm		30-75	9-23	Higham Grit, Timothy Ss and Portneuf Ls (TRht) to north
TRIASSIC	TRa	TRal	Mahogany Member of Ankareh Fm		600-725	180-220	Lanes Tongue to north
TRIASSIC	TRtu		Thaynes Fm & upper Dinwoody tongue (TRt)	upper calcareous siltstone member	1040	315	may be thicker
TRIASSIC	TRtms		Thaynes Fm & upper Dinwoody tongue (TRt)	middle shale member	~115	~35	Includes Decker Tongue of Ankareh Formation
TRIASSIC	TRtm		Thaynes Fm & upper Dinwoody tongue (TRt)	middle limestone member	~230	~70	
TRIASSIC	TRtls		Thaynes Fm & upper Dinwoody tongue (TRt)	lower shale member	~185	~55	*Meekoceras* sp. ammonites
TRIASSIC	TRtll		Thaynes Fm & upper Dinwoody tongue (TRt)	lower limestone member	~285	~85	
TRIASSIC	TRdu		Thaynes Fm & upper Dinwoody tongue (TRt)	Dinwoody Fm, upper tongue	~285	~85	
TRIASSIC	TRwd	TRw	Woodside Shale		~500	~150	
TRIASSIC	TRwd	TRd	Dinwoody Formation		~300	~90	
PERM.	Pp	Ppf	Franson Member of Park City Formation		240-285	75-85	UNCONFORMITY Includes Rex Chert
PERM.	Pp	Ppm	Meade Peak Member of Phosphoria Fm		170-300	50-90	Phosphatic
PERM.	Pp	Ppg	Grandeur Member of Park City Formation		220-310	65-95	
PERM. / PENN.	PIPw	PIPwu IPwl	Weber Sandstone		2600	790	Wells Fm to north; older rocks not exposed Back thrust and folding instead of disconformity?
PENN.	IPm		Morgan Formation		0-1000	0-300	Absent to north on Durst Mtn
PENN.	IPr		Round Valley Limestone		400	120	UNCONFORMITY
MISS.	Mdu, Mdl		Doughnut Formation (Mdu=upper, Mdl=lower)		~500	~150	To north Monroe Cyn Ls (Mmc) and Little Flat Fm (Mlf) may not be on Crawford Thrust sheet
MISS.	Mh		Humbug Formation (upper=Mhu, lower=Mhl)		~700	~215	
MISS.	Mde		Deseret Limestone		~500	~150	Delle Phosphatic Member (Mded)
MISS.	Ml		Lodgepole Limestone		650	200	Gardison Limestone to west
DEV.	Db		Beirdneau Sandstone		~300	~90	MAJOR UNCONFORMITY- Laketown, Fish Haven, Swan Peak, Garden City and St. Charles Fms missing
DEV.	Dhw	Dh	Hyrum Dolomite		~350	~105	
DEV.	Dhw	Dwc	Water Canyon Formation		200	60	
CAMB.	Ꞓn		Nounan Formation		350-400	105-120	Bloomington Fm missing; Nounan and Maxfield thicker to west
CAMB.	Ꞓm		Maxfield Limestone		300	90	
CAMB.	Ꞓo		Ophir Formation		440-725	135-220	
CAMB.	Ꞓt		Tintic Quartzite		1000	300	Thicker in west
PALEO PROTER.	Xfc		Farmington Canyon Complex		indeterminable		MAJOR UNCONFORMITY Mica schist and gneiss 1700± Ma Pegmatite



Diagrams are schematic - scale approximate

LITHOLOGIC COLUMN - Crawford Thrust Sheet and cover rocks

Horse Ridge and Dairy Ridge Quadrangles and Lost Creek drainage

AGE	UNIT SYMBOL		GEOLOGIC UNIT		THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.	Q-various			Alluvium, colluvium, mass movements	0-100	0-30	
TERT. Pal.-Eo.	Tw			Wasatch Formation	0-1300	0-400	Twl - limestone
		Twc		Basal conglomerate	0-400	0-120	UNCONFORMITY
CRET.	Keh			Hams Fork Member of Evanston Formation	0-1200	0-365	Thins to north UNCONFORMITY
		Kehc		Basal conglomerate of Hams Fork Member	0-300	0-90	Units Tw, Keh and Kwc also overlie Willard thrust sheet
	Kwc			Weber Canyon Conglomerate	0-400	0-120	MAJOR ANGULAR UNCONFORMITY
	Kk			Kelvin Formation	2500+	700+	For missing strata see lithologic column for area east of Henefer
JURASSIC	Jsp	Js?		Stump Sandstone	250	75	UNCONFORMITY
		Jp		Preuss Redbeds	~900	~270	UNCONFORMITY Salt in subsurface
	Jtgc		Twin Creek Limestone	Giraffe Creek Member	~225	~70	Atypical lithology
	Jtl			Leeds Creek Member	1000-1200	300-365	
	Jtw			Watton Canyon Member	400	120	
	Jtb			Boundary Ridge Member	100-250	30-75	
	Jtr			Rich Member	~500	~150	
	Jts			Sliderock Member	100-230	30-70	Thinner to south UNCONFORMITY
	Jtgs			Gypsum Spring Member	210	65	
	Jn			Nugget Sandstone	1100	305	
? TRIASSIC	TRa	TRaw		Wood Shale Tongue of Ankareh Fm	500	150	Structurally thinned
		TRht		Higham Grit and Timothy Ss Mbr of Thaynes Fm	~200	~60	
				Portneuf Limestone Mbr of Thaynes Fm	50-100	15-30	
		TRal		Lanes Shale Tongue of Ankareh Fm	~450	~140	
	TRt	TRtums	Thaynes Fm	Upper calcareous siltstone member	~1050	~320	Structurally thinned in north; includes middle shale member in north
				Middle shale member	~100	~30	
		TRtml		Middle limestone member	~110	~33	
				Lower shale member	~375	~115	
	?			Lower limestone member	~200	~60	
		TRdu		Upper tongue of Dinwoody Formation	~250	~75	
	TRw			Woodside Shale	~700	~215	Sub-surface thicknesses, Birch Creek and Peck Canyon areas
	TRd			Dinwoody Formation	300	90	UNCONFORMITY
PERM.	Pp			Franson Member of Park City Formation	300+	90+	Includes Rex Chert
				Meade Peak Member of Phosphoria Fm	100-300	30-90	Phosphatic, may be structurally thinned
				Grandeur Member of Park City Formation	~300	~90	
IP	PIPwe			Wells Formation	1050+	320+	Base truncated by Willard thrust
MISSISSIPPIAN	Mmo			Monroe Canyon Limestone	1200+	365+	Top not exposed May be in splay of Willard thrust
	Mlf			Little Flat Formation	970	295	
	Ml			Lodgepole Limestone	1300?	395?	Fossiliferous Likely structurally thickened
DEV.	Db			Beirdneau Sandstone	175	55	
	Dh			Hyrum Dolomite	725+	220+	Base not exposed

SCHEMATIC COLUMN

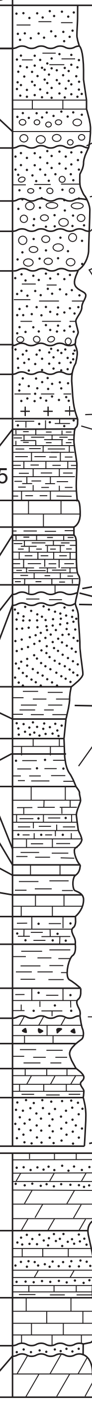


Diagram is schematic - no fixed thickness scale

LITHOLOGIC COLUMN - Tertiary and Cretaceous rocks, Area east of Henefer, Utah to Evanston, Wyoming

AGE	UNIT SYMBOL	GEOLOGIC UNIT		THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q	Q-various	Alluvium and mass movements		0-500	0-150	
TERT. P.	QT	Alluvium, gravel		0-240	0-75	
TERT. O.	Tf, Tfs?, Tfb	Fowkes (Bridger) Formation		up to 3300	up to 1000	39-40 Ma Ar-Ar ~48-49 Ma K-Ar Altered
TERT. PAL.-EO.	Tw	Wasatch Formation		up to ~2000	up to ~600	Locally Twl=limestone and Twd=limestone of Red Hill dome
TERT. PAL.-EO.	Twc	basal conglomerate		0-400	0-120	Total subsurface thickness
TERT. PAL.-EO.	TKe	Evanston Formation		0-2000?	0-600?	Coal bearing in Wyoming UNCONFORMITY
CRETACEOUS	Keh	Hams Fork Member of Evanston Formation		0-1200	0-365	Coal bearing
CRETACEOUS	Kehc	Hams Fork Member, basal conglomerate		~0-400	~0-120	unconformity?
CRETACEOUS	Kwc	Weber Canyon Conglomerate		0-1900	0-580	ANGULAR UNCONFORMITY
CRETACEOUS	Keu	Echo Canyon Conglomerate	Upper	0-790	0-240	ANGULAR UNCONFORMITY Echo Cyn Fm.~2x thicker in subsurface
CRETACEOUS	Kel	Echo Canyon Conglomerate	Lower	0-950	0-290	unconformity?
CRETACEOUS	Khen	Henefer Formation		up to 2500	up to 760	UNCONFORMITY Coarsens upward and to west
CRETACEOUS	Kfu: Kfup	Frontier Formation	Upton Sandstone Member	220	67	In subsurface, Khen and older Cretaceous units eroded from anticline above Absaroka thrust ramp, and TKe thru Kel not present over anticline
CRETACEOUS	Kfu: Kfj	Frontier Formation	Judd Shale Member	225	70	
CRETACEOUS	Kfu: Kfm	Frontier Formation	Meadow Creek Sandstone Mbr	285	90	
CRETACEOUS	Kfu: Kfg	Frontier Formation	Grass Creek Member	~235	~72	
CRETACEOUS	? Kfd	Frontier Formation	Dry Hollow Member	520-1200	160-365	Cong. thickens member to north Coal bearing
CRETACEOUS	Kfo	Frontier Formation	Oyster Ridge Member	80-260	25-80	
CRETACEOUS	Kfac: Kfa	Frontier Formation	Allen Hollow Member	780+	240+	Kfac thinner to west
CRETACEOUS	Kfac: Kfc	Frontier Formation	Coalville Member	225+	70+	Coal bearing
CRETACEOUS	Kfcc ?	Frontier Formation	Chalk Creek Member	460-1960, 3150?	140-600, 960?	Thinner to west Locally Kfl may include lower Kfcc
CRETACEOUS	Kfl	Frontier Formation	lower members	850	260	Spring Canyon Mbr; coal bearing Longwall Sandstone Mbr
CRETACEOUS	Ka	Aspen Shale		0-300	0-90	pinches out near Henefer
CRETACEOUS	Kk	Kelvin Fm (Bear River Fm [Kbr] overlies Gannett Gp [Kg] in this interval on east margin of map)		5800	1770	300 feet (120 m) of Kbr and 500 feet (150 m) of Kg exposed in map area
CRETACEOUS	Kku	Upper member		~1500	~460	Top of Kku not exposed
CRETACEOUS	Kkc	Conglomeratic member		~1500	~460	UNCONFORMITY

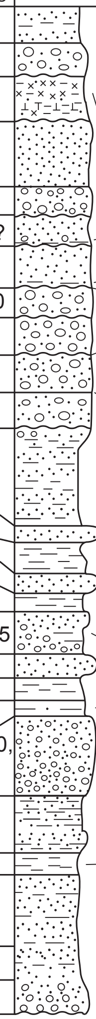


Diagram is schematic - no fixed thickness scale

LITHOLOGIC COLUMN - Crawford Thrust Sheet, in subsurface

AGE	UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.	Q	Alluvium	0-500	0-150	
TERTIARY	Tf	Fowkes (Bridger) Formation	0-1000	0-300	Altered tuffaceous 39-49 Ma elsewhere
	Tw	Wasatch Formation	0-600-1600	0-215-490	Thins to north Some algal limestone
	Twc	Basal conglomerate	0-400	0-120	
CRET.	Keh	Hams Fork Member of Evanston Formation	0-1200	0-365	Thins to north
	Kehc	Basal conglomerate of Hams Fork	0-150	0-45	
	Kwc	Weber Canyon Conglomerate	0-400	0-120	Other Cretaceous units not present on Crawford thrust sheet. See exposed Crawford thrust sheet lithologic column for post Woodside Triassic and Jurassic units.
TRIAS.	Ŧwd Ŧw	Woodside Shale	~700	~215	
	Ŧd	Dinwoody Formation	300	90	
PERM.	Pp	upper Park City & Phosphoria Mbrs	300	90	
		Meade Pk Mbr Phosphoria Fm	180	55	
		Grandeur Mbr Park City Fm	240	75	
PENN.	PIPwe	Wells (Weber) Sandstone	600	180	
	IPMa	Amsden (Morgan and Round Valley?) Formations	450	140	Amsden older than Morgan
?	?				
MISS.	Mm=Madison Ls Mmo	Monroe Canyon Limestone	950	290	Thicknesses from just north of map area; much thinner to east; in Crawford Mtns the faulted and dolomitized strata called Brazer Dol; to SE strata called Mission Canyon Ls
	Mlf	Little Flat Formation	650	200	Delle Phosphatic Mbr
	Ml	Lodgepole Limestone	~750	~230	Fossiliferous
?					Cottonwood Canyon Mbr and Leatham Fm?
DEVON.	Dtf	Three Forks Formation	400-500	120-150	aka Beirdneau Sandstone
	Dj	Jefferson Formation	540-600	165-180	Darby (Dd=Dtf+Dj); thins to NE aka Hyrum Dolomite
	Dwc?	Water Canyon Formation?	0-400	0-120	Dwc? thins to north
O.	Ob	Bighorn Dolomite	900+?	275+?	Ob and Ꞓg typically thrust truncated
CAMB.	Ꞓg	Gallatin Limestone	250	75	Ꞓg has some dolomite Gallatin like Maxfield; and Gros Ventre like Ophir lithologies
		Gros Ventre Formation	750+?	230+?	
		Precambrian and basal Cambrian not penetrated by drilling			Crawford thrust fault with Mesozoic strata below

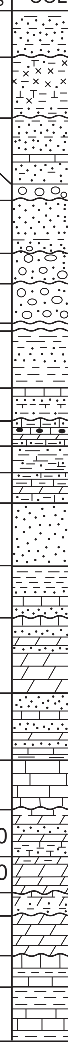


Diagram is schematic - no fixed thickness scale

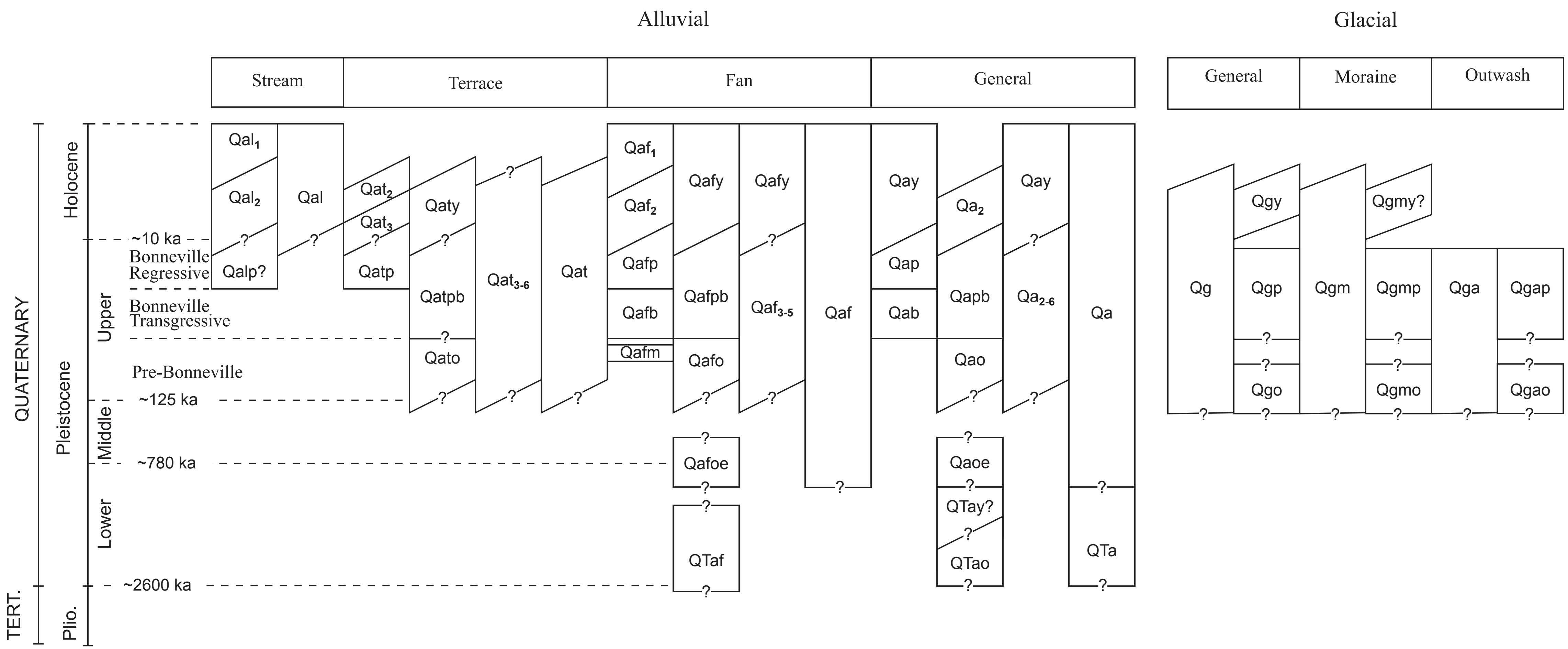
Thicknesses mostly from well penetrations

LITHOLOGIC COLUMN - Ogden 30' X 60' Subsurface
South State Line

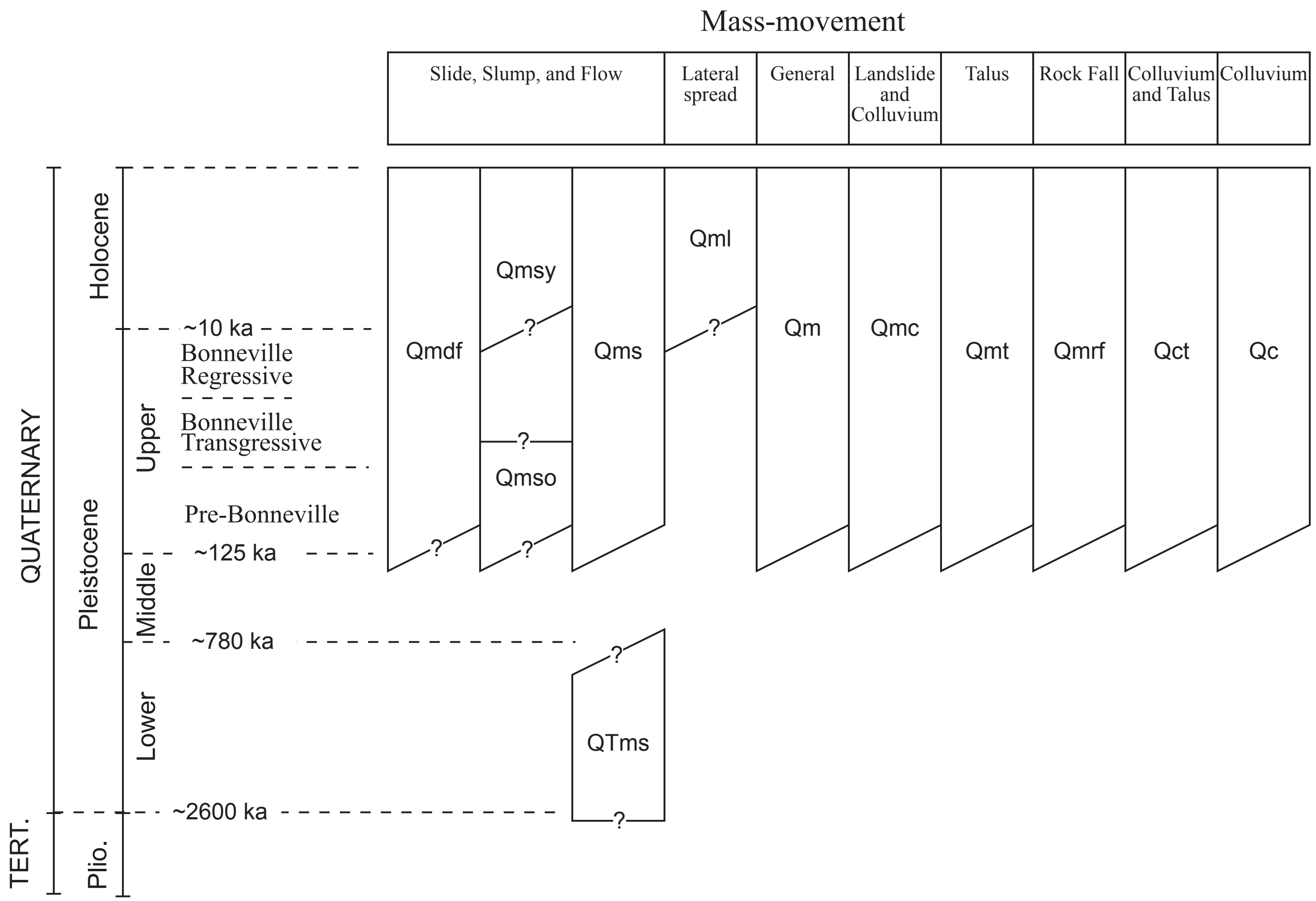
AGE	UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	SCHEMATIC COLUMN	OTHER INFORMATION
Q.	Q	Alluvium	0-500	0-150		
TERTIARY	Tf	Fowkes (Bridger) Formation	0-3300	0-1000		Altered tuffaceous 38.8 and 40.4 Ma Ar/Ar 48 Ma Ar-Ar 49 Ma K-Ar
	Tw	Wasatch Formation	up to 2200	up to 670		Thinner to north
		Basal conglomerate	0-500	0-150		Some algal limestone
	TKe	Evanston Formation	0-1500?	0-450?		Along stateline Cretaceous eroded from anticline above Absaroka thrust ramp and TKe not present over anticline
CRETACEOUS	Khen	Henefer Formation	0-500?	0-150?		Hilliard Shale interval east of ramp anticline
	Kf	Frontier Formation	up to 6450?	up to 1965?		Thickness speculative
	Ka	Aspen Shale	300-600	90-185		
	Kbr	Bear River Formation	0-1600	0-490		Upper Kelvin Fm to west Ka, Kk, KKc exposed nearby
	Kk	Kelvin Formation	up to 3000+	up to 915+		Aka Gannett Group
		Kkc basal conglomerate	0-1500	0-450		
JURASSIC	Jsp	Stump Formation	~60-250	~20-75		Morrison? in some wells Jurassic and older strata not exposed nearby
		Preuss Redbeds	~900-1000	~275-300		Salt, additional 0-1300 ft (0-400 m); 2000 ft (600 m) on isopach
	Jtgc	Twin Creek Limestone (Jtc): Giraffe Creek Member	400?	120?		
	Jtl	Leeds Creek Member	210-240	65-75		Giraffe Ck-Leeds Ck contact varies with different workers
	Jtw	Watton Canyon	320-360	100-110		Twin Creek much thicker in exposures to west
	Jtb	Boundary Ridge Member	50-65	15-20		
	Jtr	Rich Member	260-390	80-120		
	Jts	Sliderock Member	70-90	20-27		
	Jtgs	Gypsum Springs Member	60-130	18-40		
	Jn	Nugget Sandstone	1000-1150	300-350		
?						
TRIASSIC	Ŧa	Ankareh Formation	~1000	~300		Members not broken out Upper mbr Garta Grit Lower mbr
	Ŧt	Thaynes Formation	1300-1450	400-440		Thinner to north
	Ŧwd	Woodside Shale	550-650	165-200		
		Dinwoody Formation	200-300	60-90		Upper sub-unit-210 feet (65 m)
PER.	Pp	Park City and Phosphoria Formations	450-650	140-200		Meade Peak Mbr-120 feet (35 m) Grandeur Mbr-160 feet (50 m)
PENN.	PIPw	Weber (Wells) Sandstone	525-750?	160-230?		
	IPMa	Amsden (Morgan?) Formation	250-450	75-140		
? MISS.	Mm	Madison Group (Mission Canyon Limestone above Lodgepole Limestone)	1300-1650?	400-500?		Mission Cyn-700-900? feet (210-275? m) over Lodgepole-600-750? feet (180-230? m)
? D.	Dd	Darby Formation	~525-600	~160-180		Cottonwood Canyon Mbr (and Leatham Fm?) Not subdivided into Three Forks and Jefferson Fms
O.	Ob	Bighorn Dolomite	600?	180?		Ob and Ꞓg typically thrust truncated
CAMB.	Ꞓg	Gallatin Limestone	300+?	90+?		Ꞓg has some dolomite; thicknesses from well to west in Crawford thrust sheet
		Gros Ventre Formation	750+?	230+?		
	Ꞓf	Flathead Formation	300?	90?		Arkosic; should be thicker than this exposed thickness to east
PꞒ	PꞒ	Likely Wyoming Province Archean crystalline (basement) rocks	--	--		Precambrian and most of Cambrian not penetrated by drilling near stateline

Diagram is schematic - no fixed thickness scale

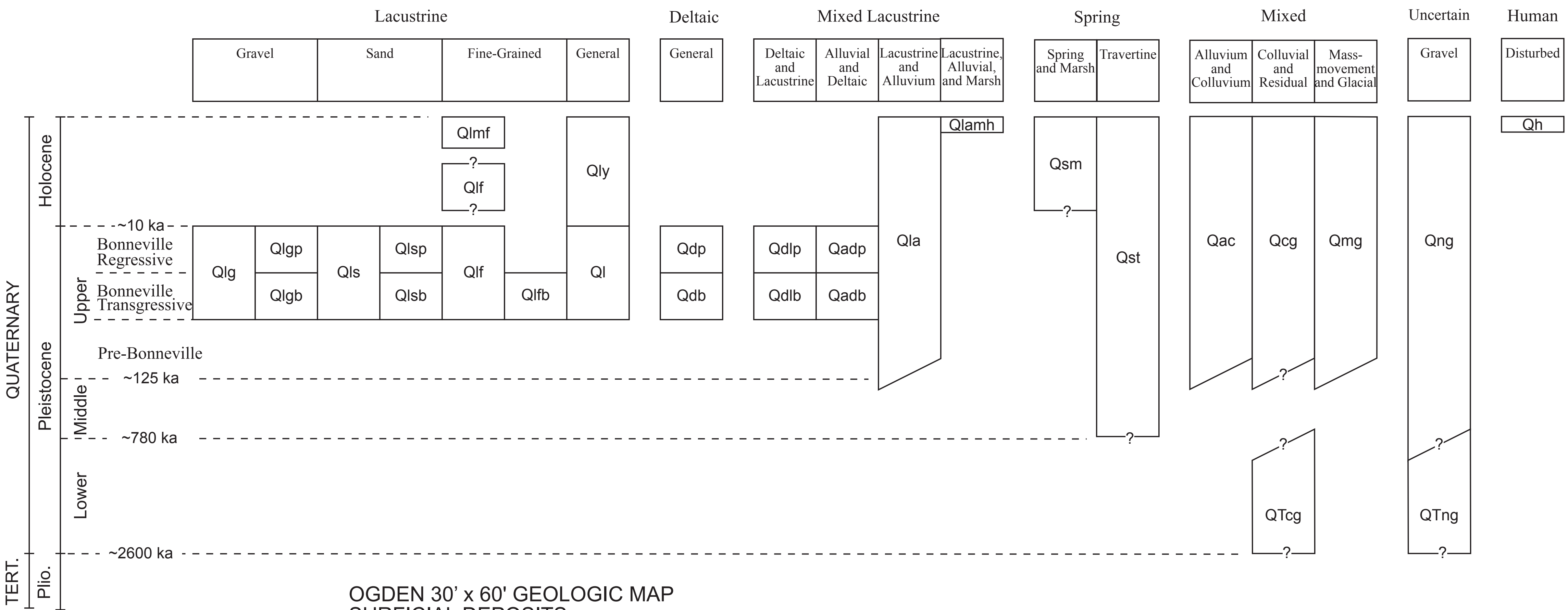
Thicknesses mostly from well penetrations



OGDEN 30’ x 60' GEOLOGIC MAP
SURFICIAL DEPOSITS
page 1 alluvial and glacial



OGDEN 30’ x 60' GEOLOGIC MAP
SURFICIAL DEPOSITS
page 2 mass movement



OGDEN 30’ x 60' GEOLOGIC MAP
SURFICIAL DEPOSITS
page 3 lake, spring, mixed, other

APPENDICES

Appendix Table 1. Palynology samples from Ogden 30'x60' quadrangle, ages by Gerald Waanders for Utah Geological Survey (UGS) in 1996-2000. *= stereo map location in UGS digital files used rather than feet from location

Sample #	recovery	comment	Age	Map unit	7.5' quadrangle	Spot location-feet from section lines	Comments
96-1		need better loc	Albian or older. Turonian or older	Kfo?	Castle Rock	2320fnl 78fwl sec 6, T3N-R7E*	Immediately below Oyster Ridge Mbr. Feet from location wrong. Stereo map location on Kfo. *Cicatricosisporites australiensis* and *C. brevilaesuratus* Turonian and older morphotaxa in Nichols and Bryant (1990).
96-2		need better loc	Middle Cretaceous		Castle Rock	1480 fsl 800fwl sec 4, T3N-R7E	Above Oyster Ridge Mbr. Feet from location plots in Tw
96-3			Paleocene, P4? P5-P6	Tw	Porcupine Ridge	1470fnl 1400fwl sec 21, T4N-R8E*	*Momipites coryloides* P5-P6 in Nichols and Bryant (1990). Nichols and Ott (1978) - P4. 150-200 ft above base of main body of Wasatch Fm. Location much farther above base and not on attitude sheet in UGS files. Location fits with P5-P6.
96-4			Cretaceous?	Tw-Twc contact	Porcupine Ridge	2500fnl 2500fwl sec 18, T4N-R8E*	Contaminants or more likely recycled. Also plotted on attitude sheet in UGS files
96-5			Paleocene, P3/P4? P5-P6	Twc	Porcupine Ridge	1850fnl 425fwl sec 19, T4N-R8E*	*Momipites coryloides* P5-P6 in Nichols and Bryant (1990). Waanders best fit Nichols and Ott (1978) - P3/P4. Also plotted on attitude sheet in UGS files in gravel pit. Also coal. P3-P4=Tertiary Evanston
96-6	barren			Twc	Porcupine Ridge	1850fnl 425fwl sec 19, T4N-R8E*	Also plotted on attitude sheet in UGS files
96-7			Cretaceous?	Keh	Heiners Creek	1650fnl 1480fel sec 30, T4N-R6E*	
96-8			indeterminate. Turonian or younger	Keh-Kehc contact	Heiners Creek	80fnl 450fwl sec 29, T4N-R6E*	Stereo map location 80fsl 450fwl sec 20. *Lycopodiumsporites* sp. Turonian and younger (Nichols and Bryant, 1990). originally thought to be 8 ft above Evanston-Echo Canyon Fm contact
96-9			not submitted	Kel	Heiners Creek	2340 fnl 1900fwl sec 17, T4N-R6E*	Plotted on stereo map. yellow-red mudstone deemed unsuitable for palynology
96-10			indeterminate. Turonian or younger	Kehc	Heiners Creek	1900fnl 2080fwl sec 17, T4N-R6E*	Originally thought to be Keu. *Lycopodiumsporites* sp. Turonian and younger (Nichols and Bryant, 1990).
96-11	barren			basal Keh	Heiners Creek	1280fnl 1410fwl sec 17, T4N-R6E*	Originally thought to be cong in Kehc
96-12	barren			Keh-Kehc contact	Heiners Creek	1210fnl 350fel sec 18, T4N-R6E*	
96-13			Cretaceous	Keh	Heiners Creek	200fsl 1130 fwl sec 7, T4N-R6E*	Originally thought to be cong in Keh
96-14			Cretaceous	Khen	Heiners Creek	860fsl 1840fwl sec 15, T4N-R6E*	Originally thought to be basal Khen or uppermost Kf
96-15	barren			Tw	Heiners Creek	1240fnl 1870fwl sec 22, T4N-R6E*	
96-16			Middle? Cretaceous. Turonian or older	Khen	Heiners Creek	520fnl 2130fwl sec 22, T4N-R6E*	Originally thought to be basal Khen or uppermost Kf, stratigraphically a couple hundred feet below 96-14. *Cicatricosisporites australiensis* Turonian and older morphotaxa in Nichols and Bryant (1990)
96-17			indeterminate	Kku	Wahsatch	640fnl 920fwl sec 26, T14N-R121W*	Also plotted on attitude sheet in UGS files
96-18	barren			Twc	Wahsatch	2260fsl 400fel sec 3, T13N-R121W*	Also plotted on attitude sheet in UGS files
96-19			mid-Paleocene to Eocene	Twc	Porcupine Ridge	130fnl 1960fwl sec 1, T3N-R7E*	Nichols and Ott (1978) - P6 or younger. Also plotted on attitude sheet in UGS files. Eocene in Waanders report. Paleocene (P3-6) into Eocene *Carya(pollenites)* and Paleocene (P1-P2) *Momipites tenuipolus* (Nichols, 2003), but P1-P2 should be unconformity
96-20			indeterminate	Kku	Porcupine Ridge	1290fnl 1570fwl sec 1, T3N-R7E*	Also plotted on attitude sheet in UGS files
96-21			indeterminate	QTa/Tf?	Castle Rock	200fsl 390fwl sec 2, T3N-R7E	Not plotted on stereo map. overlain by Kelvin float (fan on Fowkes Fm?)
96-22		see 99-21	Eocene?	Kku	Porcupine Ridge	780fsl 1550fel sec 11, T3N-R7E*	Eocene age is reason for resample. No Wasatch Fm uphill to source Eocene. Also plotted on attitude sheet in UGS files. Paleocene (P3-6) into Eocene *Carya(pollinites)* and Paleocene (P1-P2) *Momipites tenuipolus* (Nichols, 2003), but P1-P2 should be unconformity
96-23		see 99-20	Late Cretaceous	Ka	Porcupine Ridge	1240fsl 2110fel sec 12, T3N-R7E	Platy blk sh. Cenomanian or younger age is reason for resample. Jkk notes Kelvin may have been sampled. Not plotted on stereomap
96-24			Maastrichtian	Keh	Henefer	430fnl 10fwl sec 19, T4N-R5E	See '98 blueline (from CADMAP digital file) in UGS files; location 100fwl?
96-25		need better loc	Santonian? To Cenomanian? Turonian or older	plots on Kfo	Henefer	1020fsl 2530fel sec 23, T4N-R4E	Not plotted on stereo map. Originally thought to be Echo Canyon Cong, but Dry Hollow mbr conglomeratic here. *Cicatricosisporites australiensis and C. brevilaesuratus* Turonian and older morphotaxa in Nichols and Bryant (1990).
96-26			Cretaceous	Keh	Henefer	880fnl 220fel sec 23, T4N-R4E*	Reworked Carboniferous pollen, lower Doughnut Fm?
96-27			Albian or older. Turonian or older	Kk, upper	Henefer	2000fnl 400fel sec 15, T4N-R4E*	*Cicatricosisporites australiensis* as young as Turonian in Nichols and Bryant (1990)
96-28	barren			Keh	Henefer	1560fsl 950fel sec 14, T4N-R4E	
96-29			indeterminate	Keh	Peck Canyon	1000fwl 1100fwl sec 14, T7N-R5E*	No Kehc here. Also plotted on attitude sheet in UGS files
96-30			Maastrichtian	Tw-Keh contact	Horse Ridge	2500fnl 100fel sec 16, T7N-R5E	Hams Fork Mbr. Jkk notes stereo map sample location likely incorrect, so used location on attitude sheet in UGS files
96-31			indeterminate	Tw	Horse Ridge	825fsl 2150fel sec 26, T7N-R4E*	Also plotted on attitude sheet in UGS files
96-32			Santonian to Coniacian? To Turonian	Keh	Horse Ridge	2500fnl 2450fel sec 2, T6N-R4E*	Also plotted on attitude sheet in UGS files. TOO OLD? Nyssapollenites albertensis is Santonian through Cenomanian (see Nichols, 1994).
96-33		see 99-22	indeterminate	Tw	Meachum Ridge	50fnl 2350fel sec 34, T9N-R5E*	Near contact with Keh; also plotted on attitude sheet in UGS files. Sample to west near Tw-Keh contact shown as P3 by Jacobson and Nichols (1982, figure 6)
96-34		tuffaceous ss for K-Ar		plots on Tw	Dairy Ridge	650fsl 1900fwl sec 30, T9N-R5E	"Salt Lake fm" Not plotted on stereo map
96-35sup	barren			Tw	Dairy Ridge	1200fsl 1100fel sec 30, T9N-R5E	Not plotted on stereo map. *Aquilapollenites trilatus* is Campanian (Nichols and others, 1982)
96-36			Maastrichtian	Keh	Lost Creek Dam	1000fsl 1450fwl sec 36, T6N-R4E*	Also plotted on attitude sheet in UGS files
96-37		tuff for K-Ar		Tn	Huntsville	2450fsl 720fwl sec 33, T7N-R1E	
96-38		tuffaceous ss for K-Ar			Paradise/James Pk	1700fsl 300fel sec 22, T9N-R1E	"Salt Lake fm" need better location, plots in stream valley Qal
96-39		tuffaceous ss for K-Ar		Tn	Snow Basin	1700fnl 2400fwl sec 25, T5N-R1E	
96-40			Maastrichtian	Keh	Francis Canyon	1300fnl 1000fwl sec 10, T6N-R5E*	Also plotted on attitude sheet in UGS files
96-41			Maastrichtian and Campanian	Kehc	Francis Canyon	1100fwl 450fwl sec 11, T5N-R5E	As plotted on attitude sheet in UGS files. *Proteacidites (Tschudypollis) retusus* is Maastrichtian-Coniancian (Nichols, 1994).
96-42	barren			Kehc	Lost Creek Dam	1580fsl 2500fel sec 21, T5N-R5E	As plotted on attitude sheet in UGS files
96-43sup	barren			Keh	Devils Slide	250fnl 2050fel sec 19, T4N-R4E	Not plotted on stereo map, Evanston? split for pollen and K-Ar
96-44				?	Devils Slide	250fnl 2050fel sec 19, T4N-R4E	Jurassic Leeds Ck Mbr Twin Creek Ls to compare to 96-43 clay
96-45				?	Devils Slide	250fnl 2050fel sec 19, T4N-R4E	Gratuitous basement clast
96-46	barren			Keh	Devils Slide	2000fsl 1000fwl sec 18, T4N-R4E	Not plotted on stereo map
96-47			indeterminate	Keh	Devils Slide	1250fnl 1300fel sec 19, T4N-R4E	Not plotted on stereo map
96-48			Maastrichtian and Campanian	Keh	Francis Canyon	650fsl 850fel sec 31, T6N-R6E*	Also plotted on attitude sheet in UGS files. Proteacidites (Tschudypollis) retusus is Maastrichtian-Coniacian (Nichols, 1994).
96-49				Kwc	Francis Canyon	1225fnl 550fwl sec 11, T5N-R5E	As plotted on attitude sheet in UGS files. Weber Cyn? Echo Cyn? green siltstone, possibly tuffaceous
96-50			Maastrichtian and Campanian	Kwc	Francis Canyon	1825fnl 1900fel sec 10, T5N-R5E*	Also plotted on attitude sheet in UGS files. Proteacidites (Tschudypollis) retusus is Maastrichtian-Coniacian (Nichols, 1994).
96-51			Santonian to Cenomanian	Keu-Kel contact	Henefer	1600fnl 250fel sec 9, T3N-R5E	Feet from different from stereo map
96-52			Campanian? Turonian or younger	Keu-Kel contact	Henefer	1870 fnl 30fwl sec 10, T3N-R5E	50ft below 96-51 horizon. Feet from different from stereomap. Multiple Turonian morphotaxa so Campanian too young.
96-53		for K-Ar		Tf	Castle Rock	2100fsl 1800fel sec 34, T4N-R7E	Norwood-Fowkes, younger Norwood K-Ar age

fel=feet from east line, fwl=feet from west line, fsl=feet from south line, fnl=feet from north line

Appendix Table 1. Palynology samples from Ogden 30'x60' quadrangle, ages by Gerald Waanders for Utah Geological Survey (UGS) in 1996-2000. *= stereo map location in UGS digital files used rather than feet from location

Sample #	recovery	comment	Age	Map unit	7.5' quadrangle	Spot location-feet from section lines	Comments
97-1mh	barren			Tw	McKay Hollow	1800fel, 2450fnl sec 30, T7N-R7E	Not plotted on map. Typo in fnl? 2200 on map. upper Wasatch.
97-1			indeterminate nonmarine	Tw	Meachum Ridge	1030fwl, 520fsl sec 22, T9N-R6E*	Also plotted on attitude sheet in UGS files
97-2			Maastrichtian	Keh	Dairy Ridge	700fwl, 500fnl sec 16, R8N-R5E*	No Kehc here. Also plotted on attitude sheet in UGS files. *Aquilispollenites quadrilobus* is late Campanian and Masstrichtian (Nichols, 1994).
97-3			Maastrichtian	Keh	Dairy Ridge	1780fel, 1910fsl sec 32, R8N-R5E*	No Kehc here. Also plotted on attitude sheet in UGS files. *Aquilispollenites quadrilobus* is late Campanian and Masstrichtian (Nichols, 1994).
97-4			Maastrichtian	Keh	Dairy Ridge	1450fwl, 2530fsl sec 33, T8N-R5E*	No Kehc here. Also plotted on attitude sheet in UGS files
97-5	barren			Tw	Meachum Ridge	720fel, 50fnl sec 13, T8N-R5E*	Also plotted on attitude sheet in UGS files
97-6	barren			Tw	Meachum Ridge	1830fwl, 2300fnl sec 4, T8N-R6E*	Also plotted on attitude sheet in UGS files
97-7			Late Paleocene, P4/P5?	Tw	Meachum Ridge	110fel, 2230fsl, sec 11, T8N-R5E*	Near contact with Keh. Also plotted on attitude sheet *Momipites inaequalis* is upper Maastrichtian (Nichols and Fleming 2002) and *M. inaequalis* and *M. tenuipolus* are P1-P2 (Nichols, 2003), but P1-P2 should be unconformity.
97-8			Maastrichtian	Keh	Peck Canyon	2240fwl, 1450fsl sec 24, T7N-R5E*	No Kehc here
97-9			Maastrichtian to Campanian	plots on Tw	Neponset Res NW	2540fel, 2280fnl sec 23, R8N-R6E	Jkk notes no Cretaceous exposed in this quad; NOT sample of cuttings from Home Canyon borehole.
97-11	barren	extant pollen		Keh	Henefer	1280fwl, 2310fsl sec. 22, T4N-R4E	Not plotted on stereo map
97-12	barren			Tw	Meachum Ridge	690fel, 1910fsl sec 8, T8N-R6E*	Also plotted on attitude sheet in UGS files
97-13			Late Paleocene to Eocene	Tw	Meachum Ridge	500fel, 2380fnl sec 8, T8N-R6E*	Also plotted on attitude sheet in UGS files. Jkk notes above marker bed and sample 97-7. Momipites inaequalis is upper Maastrichtian (Nichols and Fleming 2002) with Carya(pollenites) veripites P5-P6, and M. inaequalis and M. tenuipolus are P1-P2 (Nichols, 2003), but P1-P2 should be unconformity.
97-14			indeterminate	Tw?	Devils Slide	2000fwl, 2000fnl sec. 21, T4N-R4E	Not plotted on stereo map. 200fnl in Waanders report would put it in Qac
97-15			Tertiary?	Kk	Henefer	2690fel, 2210fsl sec. 21, T4N-R4E*	*Momipites tenuipolus* (rare) would be upper Maastrichtian (Nichols and Fleming, 2002) and Paleocene (P1-P2) (Nichols, 2003), but P1-P2 should be unconformity.
97-16			Cenomanian to Albian	upper Kk	Henefer	2080fel, 2190fsl sec. 27, T4N-R4E*	Possibly Middle Albian or older
97-17			Cenomanian to Albian	Kk	Henefer	1260fwl, 580fsl sec. 15, T4N-R4E*	Possibly Middle Albian or older
97-18			Cretaceous	Kk	Henefer	750fwl, 910fsl sec. 15, T4N-R4E*	
97-19			indeterminate	Tw	Castle Rock	500fel, 510fsl sec. 11, T4N-R6E	Taxodiaceae
97-20			Maastrichtian to Campanian	Tw	Shearing Corral	1550fwl, 2750fsl sec. 22, T5N-R7E	Likely recycled, no Cretaceous exposed in this quadrangle
97-21		diverse	Paleocene, P5-P6	Tw	Castle Rock	1870fwl, 3210fnl sec. 32, T5N-R7E	From umapped thin rib of Tw into creek bed. *Momipites inaequalis* is upper Maastrichtian (Nichols and Fleming 2002) with *Carya(pollenites) veripites* P5-P6 and *Momipites inaequalis* P1-P2 in Nichols (2003), but P1-P2 should be unconformity
98-1p			Early Cret to Middle Jurassic	Tw	Porcupine Ridge	2600fwl, 1450fsl sec 9, T3N-R8E	Dark shale, Bear River Fm? Kelvin? Clast? Cuttings from Pineview field?
98-1			Cretaceous, Cenomanian to Albian?	Kk	Henefer	2580fel, 175fnl sec 16, T3N-R4E*	
98-2			Cretaceous, Cenomanian to Albian?	Kk	Henefer	2510fel, 1920fsl sec 9, T3N-R4E*	
98-3			Cretaceous, Cenomanian to Albian?	Kfcc, lower	Henefer	2080fwl, 90fnl sec 10, T3N-R4E*	
98-4			Cretaceous, Cenomanian to Albian?	Kfcc	Henefer	2440fel, 80fsl sec 3, T3N-R4E	See '98 blueline [CADMAP file]
98-5			Cretaceous, Cenomanian to Albian?	Kfcc, middle	Henefer	1850fel, 675fnl sec 10, T3N-R4E*	*Cicatricosisporites australiensi* s Turonian and older morphotaxa in Nichols and Bryant (1990)
98-6			Turonian or younger	Kfu	Henefer	1500fwl, 200fnl sec 14, T3N-R4E*	
98-7			Turonian	Kfu	Henefer	880fwl, 200fnl sec 11, T3N-R4E*	Should be Coniancian, Turonian and younger?
98-8			Turonian or younger	Kfu	Henefer	975fwl, 1500fnl sec 11, T3N-R4E*	
98-9			Turonian	Kfo-Kfac contact	Henefer	710fel, 2120fsl sec 10, T3N-R4E*	
98-10	partly marine		Turonian	Kfu-Kfd contact	Henefer	50fel, 825fnl sec 10, T3N-R4E*	Should be Coniancian, Turonian and younger?
98-11	partly marine		Turonian	Kfo-Kfac contact	Henefer	950fel, 810fnl sec 10, T3N-R4E*	
98-12			Cretaceous, Cenomanian to Albian?	Kfac	Henefer	1150fel, 825fnl sec 10, T3N-R4E*	*Cicatricosisporites brevilaesuratus* is Turonian and older morphotaxa in Waanders for samples 98-7 and 98-11
98-13	yes	diverse	Late Cret or Early Tert	Keh	Causey Dam	2000fwl, 1000fsl sec 2, T6N R3E	No stereo map. Lt gy mdstn & intbdd gy sltstn w/ carbncs flecks near uncertain Wasatch-Evanston Fm contact
98-14	yes		Late Cret or Early Tert. Campanian-Maastrichtian	Keh	Causey Dam	875fwl, 2500fsl sec 34, T7N R3E	No stereo map. yel, grn, rd, & rd-br sltstn & mdstn near uncertain Tw-Keh contact. Campanian-Maastrichtian morphotaxa in Nichols and Bryant (1990)
99-1	barren	100% woody		plots on Keh	Browns Hole	2550fwl, 250fnl sec 31, T7N R3E	No stereo map. Lt yel-gy to wht mdstn near uncertain Wasatch-Evanston Fm contact
99-2	yes	diverse	Maastrichtian	basal Kehc	Heiners Creek	820fwl, 1710fnl sec 29, T4N R6E*	Coaly mdstn & sltstn above basal Evanston oversize clast cgl
99-3	yes	diverse	Maastrichtian	Keh	Causey Dam	1200fwl, 1200fnl sec 11, T6N R3E	No stereo map. Lt gy mdstn & gy sltstn w/ carbncs flecks below rd mudstn near uncertain Tw-Keh contact.
99-4	yes	diverse	Paleocene? Cretaceous?	Keh, upper	Lost Creek Dam	500fwl, 1230fsl sec 15, T5N R4E*	Gy clystn below tn ss overhang. Tertiary fungal morphotaxa (*Diporornites* sp.) may be younger than Cretaceous rock indicated by other morphotaxa (*Densosporites* sp.)
99-5	yes	diverse	Late Cret or Early Tert	Keh	Lost Creek Dam	1220fwl, 650fsl sec 26, T5N R4E*	Gn-gy clystn, dk gy carbncs mdstn
99-6	barren	100% woody		Keh	Henefer	100fel, 1600fsl sec 33, T5N R4E	Not plotted on stereo map. Gy clystn between tn ss & cgl ribs. upper Evanston Fm
99-7	yes		indeterminate	Keh	Devils Slide	1300fel, 810fsl sec 8, T4N R4E	Not plotted on stereo map. Dk gy sltstn w/ cly lam between tn ss ribs. upper Evanston Fm plots on fault
99-8	barren	100% woody		Keh	Devils Slide	1420fel, 210fsl sec 18, T4N R4E	Not plotted on stereo map. Gy-gn mdstn roadcut. Evanston Fm
99-9	barren	100% woody		Keh	Devils Slide	1000fwl, 2025fsl sec 18, T4N R4E	Not plotted on stereo map. Gy-gn clystn roadcut in Evanston Fm. adj to Wasatch fault contact
99-10	yes		Late? Cretaceous	Keh	Devils Slide	1570fwl, 10fnl sec 14, T4N R3E*	Gy-br sltstn to mdstn w/ carbncs flecks. 10fnl typo?
99-11	yes	diverse	probable Jurassic, Cretaceous?	Jsp	Devils Slide	1825fel, 1440fsl sec 20, T4N R4E*	Gn soft clystn betwn rd-br clystn layers. First mapped as Jurassic Stump-Preuss and/or Wasatch. Cretaceous morphotaxa (*Densosporite* s sp. And *Lycopodiumsporites* spp.) are reason on TKJ map unit.
99-12	barren	100% woody		Keh	Henefer	950fel, 1550fsl sec 14, T4N R4E	Not plotted on stereo map. Gy sltstn betwn tn ss & rd sltstn near Evanston-Wasatch contact
99-13	barren	100% woody		Keh	Heiners Creek	1310fwl, 1120fnl sec 5, T3N R6E	Not plotted on stereo map. Gy carboncs mdstn near Henefer-Evanston Fm contact
99-14	barren	100% woody		Tw	Heiners Creek	410fwl, 390fnl sec 10, T3N R6E	Not plotted on stereo map. Gy slty clystn beneath tn ss & rd mdstn near Wasatch-Evanston Fm contact
99-15	barren	100% woody		Keh	Heiners Creek	2325fel, 2120fsl sec 33, T4N R6E	Not plotted on stereo map. Gy, gy-gn, tn, & purp mdstn near Henefer-Evanston Fm contact
99-16	yes	diverse	Early Maastrichtian to Late Campanian	basal Keh	Heiners Creek	2000fwl, 1350fnl se. 33, T4N R6E*	Dk gy sli [slty] fissile clystn near Henefer-Evanston Fm contact; no Kehc here
99-17	yes		indeterminate	Kkc	Porcupine Ridge	1150fel, 2580fsl sec 32, T5N R8E	Not plotted on stereo map. Gn-gy mdstn w/ purp mottling in roadcut. Kelvin Fm

fel=feet from east line, fwl=feet from west line, fsl=feet from south line, fnl=feet from north line

Appendix Table 1. Palynology samples from Ogden 30'x60' quadrangle, ages by Gerald Waanders for Utah Geological Survey (UGS) in 1996-2000. *= stereo map location in UGS digital files used rather than feet from location

Sample #	recovery	comment	Age	Map unit	7.5' quadrangle	Spot location-feet from section lines	Comments
99-18	barren			Kku	Porcupine Ridge	1810fwl, 1100fnl sec 12, T3N R7E*	Br-gy mdstn
99-19	barren			Twc	Porcupine Ridge	1790fel, 1050fsl sec 12, T3N R7E*	Basal gy mdstn beneath Evanston or Wasatch cgl bed and immediately above K. Aspen-Frontier
99-20		partly marine	Late Albian, *Ovoidinium verrucosum* subzone	Ka	Porcupine Ridge	2100fel, 1200fsl sec 12, T3N R7E*	Dk gy fiss sh w/ fish scales. Aspen Fm field ID. Resample of Ogden 96-23 which was probably contaminated
99-21		partly marine	Late Albian, *Ovoidinium verrucosum* subzone	Kku	Porcupine Ridge	1575fel, 640fsl sec 11, T3N R7E*	Lt gy mdstn. Resample of Ogden 96-22 (Eocene) which was probably contaminated. Aspen Fm age subzone
99-22	barren			Tw?	Meachum Ridge	2375fel, 100fnl sec 34, T9N-R5E*	Resample of Ogden 96-33. Gy mdstn from north wall of borrow pit above poss Evanston cong.

fel=feet from east line, fwl=feet from west line, fsl=feet from south line, fnl=feet from north line

Appendix Table 2. Palynology samples from Ogden 30'x60' quadrangle, ages from Jacobson and Nichols (1982), Chevron-U.S. Geological Survey. Chevron biostrat studies on file at Utah Geological Survey Core Research Center.

Sample #	recovery	comment	Age	Map unit	7.5' quadrangle	Spot location	Comments
P3849-4			Paleocene (P3)-Eocene	Tw	Castle Rock	nw sec 14, T4N-R6E	*Tilia* sp. (P3 into Eocene) Chevron biostrat study 1060 and map
P3850-2			Paleocene (P5-P6)-Eocene?	Tw	Castle Rock	se sec 11, T4N-R6E	*Caryapollenites inelegans* (P5-6) Chevron biostrat study 1060 and map
P3043-1			Paleocene P3	Tw	Meachum Ridge	200fnl, 850fel sec. 33, T9N-R5E	(p. 740 and 743, figure 6). P3 is Tertiary Evanston age, but not mapped here
P2833-1,2			Paleocene P5-P6	Tw-Twc contact	Porcupine Ridge	1000fwl, 3200fsl sec. 33, T5N-R8E	(p. 738 and 744, figure 11)
P3903-2			Maastrichtian-upper Campanian	Keh	Devils Slide	nenwnw sec 3, T3N-R3E	(p. 740 and 747, figure 19) *Proteacidites* (*Tschudypollis*) sp. and *Momipites* sp. possibly upper Maastrichtian (Chevron biostrat study 1072)
P3040-1B			Maastrichtian-upper Campanian	Keh or Kehc	Lost Creek Dam	150fwl, 1000fnl sec. 17, T5N-R5E	(p. 740 and 747, figure 20). Location may be to east at Smith coal mine.
P3041-1			Maastrichtian-upper Campanian	Kehc	Lost Creek Dam	400fsl, 2300fwl sec. 28, T5N-R5E	(p. 740 and 747, figure 20)
D6176			Maastrichtian-upper Campanian	guess Keh or Kehc	Francis Canyon	nwnw sec 10 T5N-R5E	(p. 740 and 747, figure 20). Need better location, so not on map.
D6118A,B			Maastrichtian-upper Campanian	guess Kehc or Kel	Heiners Creek	swsese sec 35, T4N-R5E	(p. 740 and 747, figure 20). Need better location, so not on map.
D6175			Maastrichtian-upper Campanian	guess Keh or Kehc	Lost Creek Dam	nesesw sec 28 T5N-R5E	(p. 740 and 747, figure 20). Need better location(s). Two figure locations with one sample number
D6175			Maastrichtian-upper Campanian	guess Keh or Kehc	Lost Creek Dam	nesesw sec 28 T5N-R5E	(p. 740 and 747, figure 20). Need better location(s). Two figure locations with one sample number
D6278A-D			Maastrichtian-upper Campanian	Kehc?	Lost Creek Dam	swswnw sec 17 T5N-R5E	(p. 740 and 747, figure 20).
D3971			Late Cretaceous	Keh	Devils Slide	sec 13, T6N-R3E	Mullens, 1969 map TKe; Mullens, 1971 p. 13 age from Tschudy
P3060-1			Santonian-Coniacian	Khen	Heiners Creek	*nwswne sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-3			Santonian-Coniacian	Khen	Heiners Creek	*seswnw sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-4			Santonian-Coniacian	Khen	Heiners Creek	*swswnw sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-5			Santonian-Coniacian	Khen	Heiners Creek	*nwnwsw sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-6			Santonian-Coniacian	Khen	Heiners Creek	*nwsese sec 20 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-7			Santonian-Coniacian	Khen	Heiners Creek	*nwsese sec 20 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-8			Santonian-Coniacian	Kel-Khen contact	Heiners Creek	*nwnwsw sec 29 T4N-R6E	(p. 741 and 749, figure 24). *Location from map in Chevron biostrat study 1060.
P3060-9			Santonian-Coniacian	Kel	Heiners Creek	*nenesw sec 36 T4N-R5E	(p. 741 and 749, figure 24). *Location from map in Chevron biostrat study 1060.
P3060-10			Santonian-Coniacian	Kel	Heiners Creek	senenw sec 10 T3N-R5E	(p. 741 and 749, figure 24). Need better location, so not on map.
P3060-13			Santonian-Coniacian	Kel	Heiners Creek	seswse sec 3 T3N-R5E	(p. 741 and 749, figure 24). Need better location, so not on map.
P3060-14			Santonian-Coniacian	Kel	Heiners Creek	nenwsw sec 2 T3N-R5E	(p. 741 and 749, figure 24). Need better location, so not on map.
P3060-14A			Santonian-Coniacian	Kel	Heiners Creek	nenwnw sec 2 T3N-R5E	(p. 741 and 749, figure 24). Need better location, so not on map.
P3060-15			Santonian-Coniacian	Kel	Heiners Creek	*nesese sec 36 T4N-R5E	(p. 741 and 749, figure 24). *Location from map in Chevron biostrat study 1060.
P3060-16			Santonian-Coniacian	Khen	Heiners Creek	*nwswsw sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-16A			Santonian-Coniacian	Khen	Heiners Creek	*nwswsw sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P3060-18			Santonian-Coniacian	Khen	Heiners Creek	*nesene sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. *Location from map in Chevron biostrat study 1060.
P2826-5			Santonian-Coniacian	Kel	Heiners Creek?	1500fsl 1600fwl nw1/4 sec 10, T3N-R5E	(p. 741 and 749, figure 24).
D6129-1			Santonian-Coniacian	Keu or Kel	Henefer?	e1/2 sec 9 T3N-R5E	(p. 741 and 749, figure 24). Need better location
D6128-2			Santonian-Coniacian	guess Kel	Henefer?	ne1/4 sec 16 T3N-R5E	(p. 741 and 749, figure 24). Need better location, so not on map; may not be in map area
D6279A,B			Santonian-Coniacian	Kel	Heiners Creek	sec 10 T3N-R5E	100m SW of Sawmill Canyon (p. 741 and 749, figure 24). Location approximate
P3848-1			Santonian-Coniacian	Khen	Heiners Creek	senwne sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. Hilliard age not Adaville age since *Proteacidites* (*Tschudypollis*) sp. but no *Pseudoplicapollis newmanii* in Chevron biostrat study 1060, which are Maastrichtian to Coniacian, and Campanian, respectively in Nichols (1994)
P3848-2			Santonian-Coniacian	Khen	Heiners Creek	senwne sec 21 T4N-R6E	(p. 741 and 749, figure 24). Not Echo Canyon Cong. Hilliard age based on similar morphotaxa to P3848-1 in Chevron biostrat study 1060

fel=feet from east line, fwl=feet from west line, fsl=feet from south line, fnl=feet from north line

Appendix, Table 3. Key oil and gas exploration wells in Utah and Wyoming used to determine subsurface geologic unit thicknesses

Map number	API Number	Drilled by (Company)	Well (lease or unit) name	Revised well number	Latitude (north) decimal degrees	Longitude decimal degrees	7.5-minute Quadrangle	Map location verified?	County	State
1	**43-029-30004**	Amoco Production Co	Champlin 475 Amoco-A1		41.0757	-111.4148	Henefer	approximate	Morgan	Utah
2	**43-029-30006**	Amoco Production Co	Amoco Marathon WIU 1-A	skid	41.1863	-111.3222	Francis Canyon	yes	Morgan	Utah
3	**43-029-30009**	Amoco Production Co	Amoco Deseret WIU		41.2833	-111.3601	Peck Canyon	approximate	Morgan	Utah
4	**43-029-30011**	Amoco Production Co	Champlin 432 Amoco-C1		41.2797	-111.326	Peck Canyon	yes	Morgan	Utah
	43-033-30001	American Quasar Petroleum Co	Hoffman 1		41.65309	-111.19493	Randolph	not on map	Rich	Utah
	43-033-30002	American Quasar Petroleum Co	Putnam 23-1		41.50336	-111.23781	Woodruff	not on map	Rich	Utah
5	**43-033-30011**	Amoco Production Co	#1 Amoco MtnFuel Chevron (Deseret)		41.2866	-111.0492	Murphy Ridge	yes	Rich	Utah
6	**43-033-30018**	American Quasar Petroleum Co	Minnow Hill 29-1		41.4935	-111.0544	Neponset Reservoir NE	uncertain	Rich	Utah
	43-033-30028	Marathon Oil Co	Hawk Springs 1-10		41.61959	-111.26291	Birch Creek Reservoir	not on map	Rich	Utah
7	**43-033-30030**	Amoco Production Co	Louisiana Land & Exploration 1-34		41.3832	-111.2484	Neponset Reservoir NW	uncertain	Rich	Utah
	43-033-30042	Sohio Petroleum Co	Birch Creek 14B		41.5201	-111.24209	Woodruff	not on map	Rich	Utah
	43-033-30043	Sohio Petroleum Co	Sugarloaf 11-6		41.61937	-111.23666	Woodruff	not on map	Rich	Utah
8	**43-033-30047**	Fat Chance	Neponset 6-35		41.38766	-111.1228	Neponset Reservoir NE	uncertain	Rich	Utah
9	**43-033-30053**	Fellows	Crane 6-7		41.26918	-111.0853	Murphy Ridge	approximate	Rich	Utah
10	**43-043-30032**	Anschutz Corp	Anschutz Ranch 28-1		41.0482	-111.1575	Castle Rock	uncertain	Summit	Utah
11	**43-043-30059**	Amoco Production Co	Champlin 461 Amoco-A1		41.0063	-111.2775	Heiners Creek	approximate	Summit	Utah
12	**43-043-30076**	Anschutz Corp	Anschutz Ranch 34-1		41.0371	-111.1386	Castle Rock	yes	Summit	Utah
13	**43-043-30078**	Union Pacific Resources Co	Fawcett & Sons	1(?)	41.1284	-111.1038	Wahsatch	uncertain	Summit	Utah
14	**43-043-30096**	Amoco Production Co	Bountiful Livestock #1	W16-14	41.0799	-111.0518	Porcupine Ridge	yes	Summit	Utah
15	**43-043-30100**	Amoco Production Co	Champlin [846 Amoco A]	846	41.1438	-111.1032	Wahsatch	uncertain	Summit	Utah
16	**43-043-30129**	Amoco Production Co	Champlin 458 Amoco D1	29-04ST1	41.0587	-111.0725	Porcupine Ridge	yes	Summit	Utah
17	**43-043-30136**	Amoco Production Co	Champlin 458 Amoco D2	W29-02	41.0607	-111.0639	Porcupine Ridge	yes	Summit	Utah
18	**43-043-30139**	Amoco Production Co	Island Ranching C1		41.0501	-111.1185	Porcupine Ridge	uncertain	Summit	Utah
19	**43-043-30145**	Anschutz Corp	Anschutz Ranch E U14-20	W20-14	41.0660	-111.0684	Porcupine Ridge	yes	Summit	Utah
20	**43-043-30148**	Anschutz Corp	Anschutz Ranch E U16-20	W20-16	41.0641	-111.0614	Porcupine Ridge	yes	Summit	Utah
21	**43-043-30161**	Amoco Production Co	Island Ranching D1		41.0840	-111.1274	Castle Rock	uncertain	Summit	Utah
22	**43-043-30165**	Amoco Production Co	Champlin 458 Amoco-E2	W31-04	41.0472	-111.0915	Porcupine Ridge	yes	Summit	Utah
23	**43-043-30190**	Amoco Production Co	Champlin 458 Amoco-E3	W31-12	41.0402	-111.0916	Porcupine Ridge	yes	Summit	Utah
24	**43-043-30215**	Amoco Production Co	Anschutz Ranch E U10-30	W30-10	41.0516	-111.083	Porcupine Ridge	yes	Summit	Utah
25	**43-043-30217**	Amoco Production Co	Champlin 458 Amoco-E6	W31-06	41.0437	-111.0855	Porcupine Ridge	yes	Summit	Utah
26	**43-043-30241**	Amoco Production Co	Thousand Peaks Amoco E1	1E	41.0023	-111.0918	Porcupine Ridge	uncertain	Summit	Utah

Appendix, Table 3. Key oil and gas exploration wells in Utah and Wyoming used to determine subsurface geologic unit thicknesses

Map number	API Number	Drilled by (Company)	Well (lease or unit) name	Revised well number	Latitude (north) decimal degrees	Longitude decimal degrees	7.5-minute Quadrangle	Map location verified?	County	State
27	**43-043-30315**	Anschutz Exploration Corp	Anschutz 14-33		41.20472	-111.0495	Wahsatch	uncertain	Summit	Utah
28	**43-043-30320**	Anschutz Corp	Anschutz deep 4-26		41.05614	-111.1278	Castle Rock	uncertain	Summit	Utah
29	**43-043-30321**	Anschutz Exploration Corp	Anschutz deep 10-27		41.04834	-111.1371	Castle Rock	uncertain	Summit	Utah
30	**49-041-20057**	Amoco	Amoco-Gulf-Chevron WIU discovery		41.214751	-111.040164	Wahsatch	uncertain	Uinta	Wyoming
31	**49-041-20132**	Amoco	Champlin 505 Amoco A-1		41.454611	-111.041327	Neponset Reservoir NE	uncertain	Uinta	Wyoming
32	**49-041-20315**	Chevron USA Inc	Chevron-Mesa-Amoco 1-35 Fed		41.317655	-111.028543	Murphy Ridge	uncertain	Uinta	Wyoming
33	**49-041-20321**	Amoco	Urroz WIU		41.224293	-111.038815	Wahsatch	uncertain	Uinta	Wyoming
34	**49-041-20413**	Anschutz Corporation	Champlin 375 Amoco C-1		41.281071	-111.001513	Murphy Ridge	uncertain	Uinta	Wyoming
35	**49-041-20421**	Amoco	Bradbury B-1H		41.24639	-111.0125	Wahsatch	uncertain	Uinta	Wyoming
36	**49-041-20509**	Amoco	Amoco Bradley		41.332353	-111.038715	Murphy Ridge	uncertain	Uinta	Wyoming
37	**49-041-20578**	Amoco	Celsius (Mtn Fuel) 4-36H		41.239034	-111.019897	Wahsatch	uncertain	Uinta	Wyoming
38	**49-041-20627**	Amoco	Chevron Amoco Federal 1-32G		41.49799	-111.0055	Neponset Reservoir NE	uncertain	Uinta	Wyoming
39	**49-041-21058**	Anschutz Exploration Corp	Yellow Creek deep 4-31		41.24611	-111.01167	Murphy Ridge	uncertain	Uinta	Wyoming

Plate 1
Utah Geological Survey Open-File Report 653DM
Interim Geologic Map of the Ogden 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE OGDEN 30' X 60' QUADRANGLE, BOX ELDER, CACHE, DAVIS, MORGAN, RICH, AND SUMMIT COUNTIES, UTAH AND UINTA COUNTY, WYOMING

by
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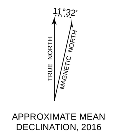
SCALE 1:62,500

CONTOUR INTERVAL 50 METERS



APPROXIMATE MEAN DECLINATION, 2016

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The projection of the geospatial data included in this digital dataset are UTM Zone 12, North American Datum 1927, and spheroid Clarke 1866. The units are in meters.

This Open-File Report series map was created from geographic information system (GIS) files. It may contain many features that do not meet formal Utah Geological Survey GIS or cartographic standards, such as automatically generated labels that may overlap other labels and lines. For identification of map units not labeled on this PDF see Interactive Maps on Utah Geological Survey website.

Most surficial colluvial and some other surficial deposits are not shown on this intermediate-scale map because of scale and to show bedrock relationships. Refer to more detailed 7.5' quadrangle geologic maps, where available, for more detailed surficial mapping (see index to geologic mapping).

Base from USGS Ogden 30' x 60' Quadrangle (1987)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

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Plate 2
Utah Geological Survey Open-File Report 653DM
Interim Geologic Map of the Ogden 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
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Utah Department of Natural Resources

Ogden 30'x60' Quadrangle Map Unit Explanation

QUATERNARY AND QUATERNARY/TERTIARY UNITS

Alluvial Deposits

Qa
Qa?
Qay
Qa2
Qa2?
Qap
Qap?
Qafy/Qap
Qafy/Qap?
Qapb
Qab
Qab?
Qa3
Qao
Qao?
Qa4
Qa4?
Qa6
Qaoe
Qaoe?
Qal
Qal1
Qal2
Qal2?
Qalp?
Qat
Qat2
Qat2?
Qaty
Qat2-3
Qat3
Qat3?
Qatp
Qatp?
Qmc/Qatp
Qatpb
Qat3-4
Qat4
Qat4?
Qat5
Qat5?
Qat6
Qat6?
Qato
Qaf
Qaf?
Qaf1
Qaf2
Qaf2?
Qafy
Qafy?
Qafp
Qafp?
Qa2/Qafp?
Qac/Qafp?
Qafpb
Qafpb?
Qafb
Qafb?
Qaf3
Qaf3?
Qaf4
Qaf4?
Qaf5
Qafm/Qafo?
Qafo
Qafo?
Qlsb/Qafo?
Qafoe?/rx
Qafoe
Qafoe?
Qafo?/Qafoe?
Qafoe-QTaf
QTa
QTa?
QTay?
QTao
QTao?
QTaf
QTaf?

Glacial Deposits

Qg
Qg?
Qgm
Qgm?
Qga
Qga?
Qgmy?
Qgy
Qgy?
Qgp
Qgmp
Qgmp?
Qgap
Qgo
Qgo?
Qgo?/rx
Qgmo
Qgmo?
Qgao
Qgao?

Mass Movememt Deposits

Qmdf
Qmdf?
Qms
Ql/Qms
Qms(---)
Qms?
Qms?(---)
Qmsy
Qmsy?
Qmso
Qmso?
Qapb/Qmso
Ql/Qmso
Qlf/Qmso
Qlfb/Qmso
Qlsb/Qmso
Qlsb/Qmso?
Qlgb/Qmso
Qcg/Qmso
Qmso(---)
Qmso?(---)
Qml
Qml?
Qh/Qml
Qh/Qml?
Qh?/Qml
Qms/Qml
Qaf1/Qml
Qafy/Qml
Qafy?/Qml
Qm
Qmc
Ql/Qmc
Qmt
Qmrf
Qct
Qc
QTcg
QTcg?
QTms(ZYp)

Lacustrine Deposits

Qlmf
Qaf1/Qlmf
Qly
Qly?
Ql
Ql?
Qlf
Qlf?
Qlfb
Qlfb?
Qls
Qls?
Qlsp
Qlsb
Qlsb?
Qafy/Qlsb
Qaty/Qlsb
Qay/Qlsb
Qap/Qlsb
Qap?/Qlsb
Qatp/Qlsb
Qafp/Qlsb
Qlg
Qlg?
Qh/Qlg
Qh/Qlg?
Qmc/Qlg
Qlgp
Qlgb
Qlgb?

Deltaic Deposits

Qdp
Qdb
Qlf/Qdb

Mixed Lacustrine Deposits

Qdlp
Qdlb
Qdlb?
Qlf/Qdlb
Qafy/Qdlb
Qay/Qdlb
Qap/Qdlb
Qap/Qdlb?
Qap?/Qdlb
Qafp/Qdlb
Qlsp/Qdlb
Qadp
Qadp?
Qafp/Qadb
Qadb
Qadb?
Qla
Qla?
Qlamh

Spring Deposits

Qsm
Qst

Mixed Deposits

Qac
Qh/Qac
Qlsb/Qac
Qcg
Qmg
Qmg?

Uncertain Deposits

Qng
QTng
QTng?

Human Disturbance

Qh
Qh?

WILLARD THRUST SHEET COVER ROCKS

Tu
Tu?
Trx
Trx?
Qac/Trx
Qc/Trx
Qafpb/Trx?
Thv?
Tslc
Tslc?
Tsl
Tsl?
Qac/Tsl
Qaf/Tsl
Qaf/Tsl?
Qafo/Tsl
Tsnf
Qaf/Tsnf
Qac/Tsnf
Qafp?/Tsnf
Qafo?/Tsnf
Qcg/Tsnf
Qcg/Tsnf?
Qmc/Tsnf?
Tn
Tn?
Qaf/Tn?
Qmc/Tn
Qac/Tn
Ql/Tn
Ql/Tn?
Qlf/Tn
Qlsb/Tn
Qlsb/Tn?
Tnf
Tnf?
Qaf/Tnf
Tsl/Tnf
Twa?
Tw
Tw?
Qg/Tw?
Qng/Tw
Qng/Tw?
Twl
Twl?
Twc
Twc?
Keh
Keh?
Qc/Keh?
Kwc
Kwc?

WILLARD THRUST SHEET

Pp
Ppf
Ppm
Ppg
PIPwe
Mgb
Mgb?
Mmo
Mmo?
Mlf
Mlf?
Tslc/Mlf
Mlfd
Mlfd?
Mlf-Ml
Ml
Ml?
MDcl
MDcl?
Db
Dhw
Dh
Dh?
Dwc
Dwc?
SOlf
Sl
Sl?
Ofh
Ofh?
Osp
Ospq
Osps
Ogc
Ogc?
Csn
Csn?
Qc/Csn?
Csc
Csc?
Cn
Cn?
Cbo
Cbc
Cbc?
Cbm
Cbm?
Cbh
Cbh?
Cbk
Cbk?
Cu-Cl
Cu
Cu?
Cl
Cl?
Cgc
Cgc?
Twa?/Cgc
Cgu
Cgcu
Qng/Cgcu
Cgcl
Cgcl?
Cgl
Zb
Zbq
Zbq?
Zbv
Zbv?
Zm?c
Zm
Zm?
Zi
Zi?
Zcc
Zcc?
Zpc-Zcc
Zpc
Zpc?
Zkc
Zkc?
Zmc
Zmc?
Zmcc
Zmcc?
Zmcc3
Zmcc3?
Zmcc2
Zmcc2?
Zmcc1
Zmcc1?
Zmcg
Zmcg?
Ql/Zmcg?
Zarx
Ql/Zarx
Qdlb/Zarx
ZYp
ZYp?
Zpu
Zpu?
Zpi
Zpd
Zpd?
Zpb
ZYpm
ZYpm?
Qgo?/ZYpm
YXf
YXf?
YXfs
YXfs?
YXfq
YXfq?
YXfdi
YXfgn
YXfgn?

SUB-WILLARD THRUST - OGDEN CANYON AREA

QTaf/Ts
Tn
Tn?
Ql/Tn
Qlf/Tn
QTaf/Tn
Tn/Tw
Tw
Tw?
QTaf/Tw
Td
KXc
Mh
Qg?/Mh
Mde
Mded
Mg
Mg?
Db
Dhw
Dhw?
Ofg
Ofg?
Ofh
Ofh?
Ogc
Ogc?
Csn
Csc
Csc?
Cn
Cn?
Cbom
Cbom?
Cbo
Cbo?
Cmo
Cmo?
Cm
Cm?
Co
Co?
Cou
Com-Col
Ct
Ct?
Xa
Xfc
Xfcm
Xfcm?
Xfcg
Xfcgs
Xfcgs?
Xfch
Xfcb
Xfcb?
Xfcq
Xfcu
Xfcs

UPPER WEBER CANYON, DURST MOUNTAIN, LOST CREEK AREAS, AND CRAWFORD THRUST SHEET

Ts
Thv
Thv?
Tcy
Tcy?
Tcg
Tcg?
Ql/Tcg
Tn
Tn?
Ql/Tn
Qlf/Tn
Qls?/Tn
Tw
Tw?
Qng/Tw
Qng/Tw?
QTao/Tw
Twl
Twc
TKJ?
Keh
Keh?
Kehc
Kehc?
Kwc
Kwc?
Qc/Kwc?
Kk
Jsp
Jsp?
Qc/Jsp?
QTaf?/Jsp?
Tw?/Jsp?
Js
Jp
Jtc
Jtgc
Jtl
Jtw
Jtb
Jtr
Jts
Jtgs
Jn
TRa
TRaw
TRht
TRag
TRal
TRt
TRtums
TRtu
TRtms
TRtms?
TRtml
TRtm
TRtls
TRtll
TRdu
TRwd
TRw
TRd
Pp
Pp?
Keh?/Pp
Ppf
Ppf?
Ppm
Ppm?
Ppg
Ppg?
PIPwe
PIPw
PIPwu
PIPwls
IPwl
IPm
IPm?
IPr
Mdu
Mdl
Mdl?
Mmo
Mh
Mhu
Mhl
Mlf
Mde
Mded
Ml
Db
Dhw
Dh
Dwc
Dwc?
Cn
Cm
Cm?
Cm-Com
Co
Ct
Thv/Ct
Xfc
Thv/Xfc

AREA EAST OF HENEFER AND ALONG SALERATUS CREEK

Qng/Ts
Qat3/Ts
Qaf3?/Ts
Qaf4?/Ts
Qaf5/Ts
Tf
Qa4/Tf
Qa4-5/Tf
Qat6?/Tf
Tfb
Tfb?
Qng/Tfb
Qa/Tfb
Qa3/Tfb
Qa3?/Tfb
Qat3?/Tfb
Qaf3?/Tfb
Qaf4/Tfb
Qa4/Tfb
Qa4?/Tfb
Qa5/Tfb
Qaf5/Tfb
Tfs?
Tfw
Tw
Tw?
Qng/Tw
Qng/Tw?
Twd?
Twc
TKe
Keh
Keh?
Kehc
Kehc?
Kwc
Keu
Kel
Khen
Kfu
Kfup
Kfj
Kfm
Kfg
Kfd
Kfo
Kfac
Kfa
Kfc
Kfcc
Kfcc?
Kfl
Ka
Kbr
Kk
Kku
Kkc
Kg

Plate 3
Utah Geological Survey Open-File Report 653DM
Interim Geologic Map of the Ogden 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Ogden 30’x60’ Quadragle Map Symbols Explanation

- Boundary, map
- Boundary, water, reservoir
- Cirque headwall
- Contact, approximately located
- Contact, approximately located, queried
- Contact, concealed
- Contact, concealed, queried
- Contact, scratch, used where map units combined
- Contact, well located
- Arete, ice-carved bedrock ridge
- Beach ridge
- Older moraine crest, asymmetrical
- Older moraine crest, symmetry unknown
- Moraine crest, asymmetrical
- Moraine crest, symmetry unknown
- Sinkhole extent
- Detachment fault, approximately located, queried
- Detachment fault, concealed
- Detachment fault, well located
- Normal fault, concealed, inferred from gravity data
- Fault, gravity slide, approximately located, queried
- Fault, gravity slide, concealed
- Fault, gravity slide, concealed, queried
- Fault, gravity slide, well located
- Normal fault, approximately located
- Normal fault, approximately located, queried
- Normal fault, concealed
- Normal fault, concealed, queried
- Normal fault, well located
- Shear zone, concealed
- Shear zone, well located
- Thrust fault, approximately located
- Thrust fault, approximately located, queried
- Thrust fault, concealed
- Thrust fault, concealed, queried
- Thrust fault, well located
- Older thrust fault, concealed
- Older thrust fault, well located
- Thrust fault with later normal offset, approximately located
- Thrust fault with later normal offset, approximately located, queried
- Thrust fault with later normal offset, concealed
- Thrust fault with later normal offset, well located
- Fault, uncertain sense of movement, approximately located
- Fault, uncertain sense of movement, approximately located, queried
- Fault, uncertain sense of movement, concealed
- Fault, uncertain sense of movement, concealed, queried
- Fault, uncertain sense of movement, well located
- Scarp, landslide
- Scarp, terrace
- Scarp, undefined
- Bonneville shoreline, approximately located
- Bonneville shoreline, well located
- Shoreline, Gilbert, well located
- Shoreline, Holocene highstand, well located
- Provo shoreline, well located
- Lake Bonneville regressional shoreline, approximately located
- Lake Bonneville regressional shoreline, well located
- Lake Bonneville transgressional shoreline, approximately located
- Lake Bonneville transgressional shoreline, well located
- Shoreline, uncertain, well located

- Marker bed, Cambrian & older, approximately located
- Marker bed, Cambrian & older, well located
- Marker bed, Cretaceous, approximately located
- Marker bed, Cretaceous, well located
- Marker bed, Tertiary, approximately located
- Marker bed, Tertiary, well located
- S-fold, approximately located
- Anticline, overturned, approximately located
- Anticline, overturned, concealed
- Anticline, overturned, well located
- Anticline, upright, approximately located
- Anticline, upright, concealed
- Anticline, upright, well located
- Monocline, antiformal bend, approximately located
- Monocline, antiformal bend, concealed
- Monocline, antiformal bend, well located
- Monocline, approximately located
- Monocline, concealed
- Monocline, overturned, approximately located
- Monocline, overturned, concealed
- Monocline, overturned, well located
- Monocline, synformal bend, approximately located
- Monocline, synformal bend, concealed
- Monocline, synformal bend, well located
- Monocline, well located
- Antiformal syncline, approximately located
- Antiformal syncline, concealed
- Antiformal syncline, well located
- Syncline, overturned, approximately located
- Syncline, overturned, concealed
- Syncline, overturned, well located
- Syncline, upright, approximately located
- Syncline, upright, approximately located, queried
- Syncline, upright, concealed
- Syncline, upright, concealed, queried
- Syncline, upright, well located
- Lineament - contact, fold trace, or fault (offset uncertain)

- Select adit
- Bedding, horizontal
- Bedding, strike & dip, upright, approximate
- Bedding, strike & dip, upright
- Bedding, strike & dip, inclined, approximate, photo-interpreted
- Bedding, strike & dip, upright, photogrammetric (3-point)
- Bedding, strike & dip, overturned
- Bedding, strike & dip, overturned, photogrammetric (3-point)
- Bedding, strike & dip, overturned, top known
- Bedding, strike & dip, upright, top known
- Bedding, strike & dip, vertical
- Cleavage, strike & dip, inclined
- Cleavage, strike & dip, inclined, photogrammetric (3-point)
- Cleavage, strike & dip, vertical
- Select borehole, dry hole, abandoned
- Select borehole, gas show, abandoned
- Gas well
- Gas & condensate well, abandoned
- Gas well, shut-in
- Select borehole, oil & gas show, abandoned
- Oil & gas well, shut-in
- Water well
- Normal fault ball & bar
- Fault dip with dip number
- Fault dip with dip number, photogrammetric (3-point)
- Minor M fold
- Minor S fold
- Minor Z fold
- Minor anticline, upright, field mapped
- Minor anticline, overturned
- Minor antiform, upright
- Minor syncline, upright, field measured
- Minor syncline, overturned
- Minor synform, upright
- Fold trace plunge arrow
- Foliation, cataclastic, strike & dip, inclined
- Foliation, high grade, strike & dip, inclined
- Foliation, cataclastic, strike & dip, vertical
- Joint, strike & dip, inclined
- Select mine or quarry, abandoned
- Planar feature, strike & dip, inclined photogrammetric (3-point)
- Zircon U-Pb isotopic sample, see Table 5
- Other isotopic sample, see text
- Ar-Ar isotopic sample, see Tables 4 & 5
- Palynology sample, see Appendix & Table 6
- Sinkhole
- Select spring