INTERIM GEOLOGIC MAP OF THE MORGAN 7.5′ QUADRANGLE, MORGAN COUNTY, UTAH

by

James C. Coogan[1], Jon K. King[2], and Greg N. McDonald[2]

[1]*now Principal, Coogan Geoscience, Lakewood, Colorado*
[2]*Utah Geological Survey*

Disclaimer

This open-file release makes information available to the public that may not conform to UGS technical, editorial, or policy standards; this should be considered by an individual or group planning to take action based on the contents of this report. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. For use at 1:24,000 scale.

This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program through U.S. Geological Survey STATEMAP award number 03HQAG0096. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

OPEN-FILE REPORT 643
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2015

INTRODUCTION

The Morgan 7.5′ quadrangle is located southeast of Ogden, Utah (figure 1) along a national east-west transportation corridor (U.S. Interstate Highway 84 and the Union Pacific Railroad). The major geographic features in and near the quadrangle are Morgan and Round Valleys, the northern Wasatch Range to the west, Durst Mountain to the east and north, the Weber River in Morgan Valley, and Upper Weber Canyon cut by the river east of Round Valley.

This is the third version of a large-scale geologic map of the Morgan 7.5′ quadrangle. Schick (1955) presented the first map of the area in his thesis on upper Weber Canyon, while Mullens and Laraway (1973) published a more complete bedrock map. For this study, Coogan mapped and improved the stratigraphy and structure of pre-Cenozoic rocks, as well as some younger units, in the Morgan, Durst Mountain, and Devils Slide quadrangles; King is responsible for the Cenozoic rocks; and King and McDonald worked on the Quaternary deposits, previously under-mapped. Coogan's work was prior to 2000, while most of King's and McDonald's work was in 2003 and 2004. The extent of human disturbances (Qh) on the map are as of September 1986, when the aerial photographs used to geologically map the Morgan quadrangle were taken; only the larger disturbances were mapped. Later development in Morgan Valley has obscured important geologic features after this date, in particular the fan-delta in the Roswells Canyon drainage, so 2006 and 2009 color orthophotographs of the quadrangle were examined and extensive newer disturbances were added to the map as brown lines. Due to land access constraints, geologic mapping of most of Durst Mountain and the southeastern part of the quadrangle is from interpretation of aerial photographs with limited field checking; most of the field-measured attitudes on our map in these areas are selected from Mullens and Laraway (1973). The fold trace mismatch to the Durst Mountain quadrangle (see Coogan and King, 2006) is due to the addition of field attitudes from Mullens and Laraway (1973) and photogrammetic attitudes of King. Paleontological data from rocks in the quadrangle is limited to some work on the Carboniferous (Williams, 1943; Sadlick, 1955; Nohara, 1966; Carey, 1973; appendix) and the geology would benefit from further examinations.

GENERAL GEOLOGY

The Precambrian (early Proterozoic) Farmington Canyon crystalline rock complex and unconformably overlying Paleozoic (Cambrian through Permian) marine sedimentary strata are exposed on Durst Mountain in the Morgan quadrangle; Mesozoic and Permian strata are exposed in the adjacent Durst Mountain and Devils Slide quadrangles. The Paleozoic and Mesozoic strata are on the Cretaceous Crawford thrust sheet and are exposed in an east-dipping homocline that is locally complicated by Cretaceous folding, west-directed thrusts, and other faults. The age of the roughly north-south trending faults in these rocks is unknown and might be related to 1) deformation during the Cretaceous that created the Crawford thrust sheet, 2) deformation of the Cretaceous and early Tertiary Absaroka and Medicine Butte thrust systems farther to the east, and/or 3) be related to later Cenozoic extension. Possible later extensional (normal fault) movement (bar and ball as well as teeth) on a west-directed thrust (older over younger) fault occurred in the eastern part of the Morgan quadrangle, though King and Coogan do not agree on the location of the northern part of the trace. King thinks Coogan's fault (shown as thrust on the map) is a stratigraphic contact between lower and upper Doughnut Formation (Mdl-Mdu) and the thrust may be to the east where a lineament is shown on the map. The Cretaceous Ogden roof thrust is exposed to the northwest in the Wasatch Range and on Durst Mountain; its trace between exposures is likely to the north in the Snow Basin and Durst Mountain quadrangles. South of exposures in the Morgan quadrangle, the Ogden roof thrust may be present in the deep subsurface in Morgan Valley (not shown as such on cross section since conjectural) because the Ogden roof thrust appears to be exposed to the south in the Hardscrabble Creek area, Porterville quadrangle (see Bryant, 1990; Yonkee and others, 1997). This roof thrust is east-directed and, due to rotation of Durst Mountain, is now east dipping; from a single calculated (three-point) dip, the Ogden roof thrust in the Morgan quadrangle appears to have been flat prior to the roughly 30 degree rotation of Durst Mountain. The rotation likely occurred during late Cretaceous to Eocene uplift of the Wasatch culmination (Yonkee and others, 1997), rather than during Cenozoic listric normal faulting, because evidence of significant normal faulting, in the form of a large valley, is not present to the east of Durst Mountain. This rotation created the east-dipping homocline and also rotated the folds mapped on Durst Mountain in

the Morgan quadrangle. The overturned monoclines are the hinges of rotated Z-folds, while the other monoclines are actually an open syncline-anticline fold pair (western and eastern) when the rotation is removed. These rotated folds have complicated measurement of stratal thicknesses because fold limbs are at least locally attenuated (see also cross section) and obscure fold hinges make strata appear thicker than they are.

Mississippian and older units are likely present in subsurface below the Wasatch Formation in Morgan Valley (see cross section). However, the width of the Wasatch culmination is uncertain, so subsurface structure and units present are uncertain (for possible variations see Bryant, 1990, cross section C–C′; Royse, 1993, cross section H-H′; Yonkee and others, 1997, cross section B–B′). Coogan's (Western State College, July 2, 2005, unpublished digital file) regional cross section shows eroded Mississippian and older strata below the Wasatch. Yonkee and others (2003) show the Ogden roof thrust in subsurface in Morgan Valley and Yonkee and others (1997, cross section A–A′) show the Ogden roof thrust leading edge on Durst Mountain.

LATE CRETACEOUS AND TERTIARY GEOLOGY

Northeast and east of the Morgan 7.5′ quadrangle in the Durst Mountain and Devils Slide quadrangles, the latest Cretaceous Evanston Formation unconformably overlies Paleozoic and Mesozoic rocks, and these rocks and the Cretaceous thrust sheets are unconformably overlain by the Cenozoic (Eocene and Paleocene) Wasatch Formation. These strata were deposited during Late Cretaceous and early Tertiary reactivation of the Willard (north of map area) and Crawford thrust faults, and uplift of the Wasatch culmination. In the Morgan 7.5′ quadrangle, the Wasatch Formation is present in scattered patches "resting" unconformably on Paleozoic rocks on Durst Mountain and in the southeast part of the quadrangle in west-dipping, extensive exposures in the east limb of the Morgan Valley syncline, though deposition of the Wasatch Formation pre-dates the formation of Morgan Valley.

The roughly north-south-trending normal faults near Morgan Valley are likely due to post-thrust (post-Wasatch) Cenozoic extension. In particular, offset is likely due to Eocene and Oligocene(?) relaxation (collapse) of the Cordilleran fold-and-thrust belt (see Constenius, 1996). This is indicated by thick latest Eocene and Oligocene Norwood Formation fill in Morgan Valley (see below). The Norwood is referred to as Formation rather than using the Norwood Tuff name of previous workers (see Eardley, 1944), because lithologies vary and the type area includes only part of the formation and a limited number of lithologies in the formation. Miocene and younger Basin and Range faulting (see for example McCalpin, 1993) has occurred in the map area (see paragraphs after Norwood Formation), and has apparently continued into the Quaternary.

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 name Norwood Tuff was proposed by Eardley (1944). Prior to work on the Ogden 30 x 60-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 in the Salt Lake Formation (see for example Williams, 1962).

Available isotopic dates now indicate a bimodal age distribution (~39–40 & 48–49 Ma) for Fowkes strata exposed along the Utah-Wyoming border. These dates include: K-Ar on hornblende from the Bulldog Hollow Member of the type area, 49 Ma when recalculated from 48 Ma in Oriel and Tracey (1970); K-Ar on biotite from near the base of the Fowkes, 49 Ma if recalculated from 48 Ma in Nelson (1979); $^{40}Ar/^{39}Ar$ on sanidine, 48 Ma in Smith and others (2008, p. 67); and $^{40}Ar/^{39}Ar$ 40 and 39 Ma (unpublished, this paragraph). K-Ar dates are recalculated using Dalrymple (1979). The young ages for the Fowkes ($^{40}Ar/^{39}Ar$ ages of 40.41 Ma and 38.78 Ma on biotite and

hornblende, respectively) are from strata a few hundred feet above the Wasatch Formation contact in the Yellow Creek graben in the Castle Rock quadrangle, Utah to the east near Wyoming, and are below strata mapped as Norwood Tuff by Bryant (1990). The old Fowkes ages are from farther north and are from different grabens, in particular the Almy graben along the Bear River north of Evanston, Wyoming that was dated by Nelson (1979). These older ages indicate these 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, old Fowkes cannot be distinguished in the field from young Fowkes. In Morgan Valley and the East Canyon graben, Norwood Formation isotopic ages (38–39 Ma) (recalculated from Evernden and others, 1964; Mann, 1974) are near the lower end of the Fowkes age distribution, but Norwood strata dated in Morgan Valley are at least 2500 feet (800 m) above the base of the Norwood and much older strata might be present. So Fowkes strata cannot be distinguished from Norwood-age strata when they are in the same basin.

Isotopic dates on 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 but 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 dates that are slightly (1–2 Ma) younger than their eruptive equivalents. 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, Idaho and/or Absaroka volcanic field, Wyoming (see Smith and others, 2008, in particular figure 5).

Similar volcanic to tuffaceous strata of about the same age are exposed near Salt Lake City and in Cache Valley, Utah. Tuffaceous rocks 70 miles (110 km) north of the Park City vents in southern Cache Valley, Utah that "rest" on Wasatch Formation strata were K-Ar dated at 44 and 49 Ma (hornblende and biotite, respectively) (Smith, 1997); though the older date is suspect, it is similar to isotopic dates from the Fowkes Formation. Volcanic strata near Salt Lake City, dated 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 dates and their relationships to the Norwood and Fowkes Formations.

Paleontological evidence on the Norwood is presented in Adamson (1955), Evernden and others (1964), and Nelson (1971, 1977); see also Gazin (1959, p. 137). Paleontological data on the Fowkes Formation near Evanston, Wyoming (where isotopically dated 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).

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 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 conglomerates and sandstones than the Morgan Valley rocks, and the clasts are easily recognizable as 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.

The thickness of fill (Norwood and younger) in Morgan Valley is uncertain, in part because Paleozoic rocks are not exposed on the west side of the Valley and their dip cannot be observed. Overall, the valley fill thickness seems to increase to the north with the plunge of the Morgan Valley syncline and possibly the throw on the Morgan fault zone. From Lum's (1957) gravity profile, about 8000 feet (2500 m) of low-density fill is in the valley (equal to about 100 m of low-density fill for each milligal on a Bouguer gravity map by Quitzau, 1961), though the profile location is not known because Lum's thesis plates are missing from the University of Utah library. This 8000 feet

(2500 m) is the amount of Norwood Formation fill that Coogan (Western State College, July 2, 2005, unpublished digital file) shows on his cross section just north of Morgan; he also shows about 900 feet (275 m) of Wasatch Formation in subsurface. King (cross section) chose to put ~1600 to 2500 feet (500–760 m) of Wasatch Formation, 6000 feet (1800 m) of overlying Norwood, and ~ 3500 feet (1100 m) post-Norwood, at least partially conglomeratic (higher density), Tertiary strata in the basin fill.

On the east side of Morgan Valley, the west-dipping Norwood-Wasatch contact is poorly exposed, and the only indication of an unconformity is a limited (<5 degrees) difference in dip. Despite previous mapping (Mullens and Laraway, 1973), this contact is not an exposed fault in the Morgan quadrangle and from reconnaissance geology by King does not appear to be a fault to the south in the Porterville quadrangle. On the west side of Morgan Valley, a conglomerate is exposed at the base of the Norwood above finer-grained Wasatch Formation strata in the Snow Basin quadrangle (King and others, 2008) and an inconsistent (Wasatch not always steeper than Norwood) and small (<5 degree) change in dip is present in the Peterson quadrangle. The Norwood is overlain by and intertongues with unnamed Oligocene(?) conglomeratic strata (Tcg) on the west side of Durst Mountain (east side of Morgan Valley). Some of this conglomerate may be present along the axis of the Morgan Valley syncline west of East Canyon Creek (shown as Tcg?), or these gravels may be Pleistocene-Pliocene alluvium (QTa) perched on the Norwood Formation like deposits east of East Canyon Creek on the north margin of the Porterville quadrangle. The Oligocene(?) conglomerate interpretation is shown on the map because conglomerate is reported in subsurface in water well logs just to the east in Morgan Valley (section 35, T. 4N., R. 2E.) (see Utah Division of Water Rights, well drilling database). The Oligocene(?) conglomeratic strata are unconformably overlain by still younger conglomeratic rocks north of Morgan (Tcy and Thv). Either or both of these younger units might be the lateral age-equivalents of the upper Miocene and Pliocene Salt Lake Formation, with deposition during Basin and Range faulting. The Norwood Formation and underlying Wasatch Formation, and possibly the overlying unnamed Oligocene(?) conglomerate, are folded in the north-plunging Morgan Valley syncline; the axis is in the Morgan and Porterville quadrangles. In the map area, other synclines are visible in the younger conglomeratic rocks (Tcg, Tcy, and Thv) north of Morgan just west of faults bounding Durst Mountain; Tcy and Thv are folded together with typically flat-lying to gently (<5°) dipping beds on both limbs and locally steeper dips (~10–30°) on east limbs of synclines. It is not known if these synclines are part of the Morgan Valley syncline; if they all formed at the same time, the Morgan Valley syncline could be as young as Pliocene. Unit Thv (Pliocene?) is offset about 800 feet (245 m) across the Morgan fault zone just south of Roswells Canyon.

Conglomeratic strata and deposits unconformably overlying the Norwood Formation in the Durst Mountain area were first named Huntsville fanglomerate by Eardley (1955), though he did not map the unit. His Huntsville unit was described and mapped by Lofgren (1955), Schick (1955), and Coody (1957), and is likely equal to the QTc unit of Mullens and Laraway (1973). As mapped, their units have several ages and origins, so are here divided into units Qcg, QTaf, Thv (fanglomerate of Huntsville), Tcy, and Tcg in the Morgan quadrangle, as well as Tcw, Tct, and Tca in the Durst Mountain quadrangle (see Coogan and King, 2006). Mullens and Laraway (1973) noted larger quartzite clasts in their Huntsville unit than in the Wasatch Formation, but we have never seen this and most quartzite clasts in their Huntsville unit are recycled from the Wasatch Formation.

LATEST TERTIARY AND QUATERNARY GEOLOGY

Remnants of Pliocene and/or Pleistocene alluvial deposits are present on both sides of Morgan Valley. Upper surfaces of high-level alluvial deposits (QTaf? with QTao, and possibly QTa and QTay?) in the Morgan, Durst Mountain, Peterson, and Snow Basin quadrangles appear to be the Weber Valley surface of Eardley (1944). However, high-level alluvial fans (QTaf) extend to the mountain front at elevations of about 6800 to 7200 feet (2070–2195 m) (see Coogan and King, 2006; King and others, 2008), rather than to the mountain ridgelines as suggested by Eardley (1944). Thin remnants of high-level alluvial deposits (boulder lags, typically quartzite, with unmappable extents) are present on some ridges in the Snow Basin quadrangle (for example between the new and old Snow Basin ski area access roads [southeast T. 6N., R. 1E.] and in NW1/4 section 14, T. 5N., R. 1E.). Pre-Lake Bonneville Pleistocene alluvial and landslide deposits are present in the Morgan and adjacent quadrangles.

Quaternary (upper Pleistocene) lacustrine, deltaic, and alluvial deposits related to Lake Bonneville are in the center of Morgan Valley, though the lake did not occupy the valley after it dropped to the Provo shoreline (~ 4820 feet [1470 m]). Quaternary deposits that post-date Lake Bonneville are mostly Holocene and uppermost Pleistocene alluvium in the Weber River floodplain and landslides in the Norwood Formation. As documented in water wells in the Weber River floodplain (Utah Division of Water Rights, well drilling database), Quaternary valley fill is about 200 to 250 feet (60–75 m) thick. Note that no landslides are mapped that are younger than the September 1986 aerial photographs used to create the map. Other significant post-Lake Bonneville Quaternary units in the quadrangle are debris flows and rock falls because these deposits are adjacent to the transportation (railroad, highway, and pipeline) corridor through Round Valley, and alluvial-fan deposits (containing debris flows) on which development is occurring.

In the Morgan quadrangle, ages of alluvium, including terraces and fans, are in part based on heights above present adjacent drainages in Morgan Valley, including the Snow Basin, Durst Mountain, and Peterson quadrangles; see table 1 and note revisions from Coogan and King (2006), and King and others (2008). This approach was taken, rather than relating them to elevations (including Lake Bonneville shorelines), because the slopes of alluvial surfaces west of the Weber River off the Wasatch Range and those off Durst Mountain east of the Weber River are not the same. Also many surfaces predate Lake Bonneville and drainages were likely backfilled during the rise of Lake Bonneville. The alluvium ages may extend through the Quaternary (1.8 Ma, but may not be as old as the 2.6 Ma Quaternary-Pliocene boundary adopted by the International Union of Geological Sciences).

Quaternary deposits are likely cut by extensional faults along the east side of Morgan Valley (west side of Durst Mountain). Scarps along the mountain front are part of the 10-mile (16-km) long fault system that bounds the west side of the Durst-Elk Mountain block, extending from or slightly south of Morgan to north of Cottonwood Creek in the Durst Mountain quadrangle. In the Morgan quadrangle, one scarp is visible in older eroded alluvial fan (Qafoe) deposits along the Morgan fault zone at the mouth of Pine Canyon and a co-linear scarp may be present in adjacent Qafoe deposits north of the drainage. To the north in the Durst Mountain quadrangle, possible fault scarps are present in Quaternary mass-movement deposits along the eastern margin of Morgan Valley, and on middle or lower Pleistocene alluvial deposits (Qaoe) north of Cottonwood Creek (see Coogan and King, 2006). West of the mountain front in the Morgan quadrangle, 30 to 45 foot (9–14 m) high scarps are present north of Stoddard. These scarps may be faults cutting QTay? or they may be paleo-Weber River terraces with QTay? above Qaoe, so they are shown as lineaments.

UNRESOLVED GEOLOGIC PROBLEMS

Devonian strata on Durst Mountain are problematic for several reasons. First the thicknesses, lithologies, and names are atypical of those on the Crawford thrust sheet, and lithologies and small thicknesses are atypical of Devonian units named on the Willard thrust sheet. Also, a recessive-weathering interval at the top of the Devonian is distinct and locally mappable south of Mahogany Canyon in the Morgan quadrangle, but it is not visible (too thin and/or covered) to the north on Durst Mountain (see Coogan and King, 2006). In northern Utah, the Mississippian Cottonwood Canyon Member of the Lodgepole Formation(?) and the Devonian Leatham Formation occupy this distinct and characteristic thin, recessive-weathering interval. Devonian strata merit additional work in northern Utah.

Devonian Beirdneau, Hyrum, and Water Canyon Formations are names from the Willard thrust sheet and may not be appropriate for strata deposited in shallower water on the 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 formation (see Benson, 1966; Johnson and others, 1991). We chose to retain the Willard thrust sheet names on Durst Mountain because they have been used previously (Eliason, 1969; Williams, 1971), previous work on the Durst Mountain Devonian and upper Cambrian strata is confusing (see previous references as well as Eardley, 1944; Brooks and Andrichuk, 1953; Brooks, 1954; Schick, 1955; Brooks, 1959; Mullens and Laraway, 1973), and the distinct light-colored dolomite at the top of our Water Canyon unit is typical

of Water Canyon strata on the Willard thrust sheet. The diagrams of Rigby (1959, figures 1 and 2), which show the Stansbury uplift and Devonian thinning, need refinement in this area, because lower Devonian (Water Canyon) rocks are present below and carbonates (Hyrum) are present above an unconformity here, as well as at Ogden Canyon (Yonkee and Lowe, 2004), Causey Dam (Mullens, 1969), and in the Monte Cristo Range (Smith, 1961; Coogan, 2006).

Though not noted by Coogan and King (2001) in northern Utah, the recessive-weathering Cottonwood Canyon Member of the Lodgepole Formation(?) and Leatham Formation interval was later mapped by King farther north on the leading edge of the Willard thrust sheet in Wheat Grass Canyon in the southeast part of the Monte Cristo Peak quadrangle and the Causey Dam quadrangle. It was not noted by Coogan (2006) to the east in the Horse Ridge quadrangle, on or east of the Willard thrust sheet, but is locally mappable on the Willard thrust sheet. Well data from the Birch Creek fold belt (see Utah DOGM well files and logs), east of the Willard thrust sheet (like Durst Mountain) and north of figure 1, indicate shaly Cottonwood Canyon Member of Madison/Lodgepole and Leatham Formation are both 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 Devonian references below).

Regionally the Leatham and Cottonwood Canyon Member are poorly exposed or a slope of dark-colored shale, siltstone and thin-bedded silty to shaly limestone that is 10 to 100 feet (3–30 m) thick (see shales of Williams, 1948; Holland, 1952; Brooks, 1954; Mullens and Izett, 1964; Benson, 1965) (see also Sandberg and Gutschick, 1979). In the Causey Dam quadrangle, Laraway (1958) noted 30 to 35 feet (10 m) of what is likely this interval and included it in his Beirdneau Formation, while Mullens (1969) reported a basal, thin-bedded, very silty limestone in the Lodgepole Limestone, as much as 70 feet (20 m) thick, that is probably the Leatham–Cottonwood Canyon interval, though he typically mapped the recess with the Beirdneau Formation. Regionally, this recessive interval between Lodgepole and Beirdneau likely includes Cottonwood Canyon Member of the Lodgepole Limestone of Sandburg and Gutschick (1979) (see also Holland, 1952; Benson, 1965), hence the Lower Mississippian (Kinderhookian) age reported by Holland (1952, p. 1719–1720) for the Upper Devonian (Famennian) (Sandberg and Gutschick, 1979) Leatham at the type section in Leatham Hollow.

Como Springs likely issue from the lower Humbug Formation or the upper Deseret Limestone before surfacing in the Weber River alluvium. The spring shown on the map is the location of the spring pool visible on the 1986 aerial photographs used to geologically map the Morgan quadrangle; this pool no longer exists and the actual spring source is now obscure. Patches of spring travertine are present in the road cut in lower Humbug Formation uphill along the lineament trend south of the former spring pool location, but they are not extensive enough to be mapped. These Humbug and Deseret Formations are part of the Mississippian carbonate strata that contain caves in Utah (see for example White, 1979). The recharge area for the springs could be to the south, with water moving down the plunge of the Morgan Valley syncline from outcrops in the Wasatch Range, but this pathway would have to cross at least one fault, and likely several faults, to get to springs. Ground water could travel to the springs from exposures to the north on Durst Mountain, but would need to go <u>under</u> the Weber River to reach the springs and should come to the surface north of the river. With either source, mapping of Mullens and Laraway (1973) implies fault control of the spring location; because offset is uncertain, we show a lineament on our map.

MAP AND CROSS SECTION UNIT DESCRIPTIONS

QUATERNARY

Qa2, Qay

Younger alluvium (mostly Holocene) – Sand, silt, clay, and gravel on surfaces above present drainages; deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent drainage, or are shown where fans and terraces are too small to show separately at map scale; composition depends on source area; relative ages are indicated by number and letter suffixes with 2 being the youngest; height above present drainages is low and is within certain limits; typically Qay is at to

slightly above present drainages in Morgan Valley in the Morgan and Durst Mountain quadrangles, Qa2 is about 15 feet (5 m) above drainages in the Durst Mountain quadrangle; generally 0 to 20 feet (0–6 m) thick. In the Morgan quadrangle and other quadrangles around Morgan Valley, ages of alluvium, including terraces and fans, are in part based on heights above present adjacent drainages (see table 1).

Qap, Qab, Qa3

Lake Bonneville-age alluvium (upper Pleistocene) – Like younger alluvium but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits; alluvium labeled Qap and Qab are graded to the Provo (and slightly lower) and Bonneville shorelines of Lake Bonneville (at ~ 4820 feet [1470 m] and 5180 feet [1580 m] in area), respectively; in the Morgan and Durst Mountain quadrangles (see table 1), Qap is ~25 feet (8 m) and 15 to 40 feet (5–12 m) above, and Qab is 40 to 50 (and locally 90) feet (12–15, locally 27 m) and 40 to 80 feet (12–24 m) above present adjacent drainages, respectively; Qa3 is used where we cannot determine which shoreline the alluvium is graded to. Note that the Bonneville-level fan-delta unit (Qfdb) at 80 to 100 feet (24–30 m) above present drainages is typically higher above present drainages than the related alluvial units (Qab, Qafb).

A prominent surface ("bench") is present on Qap at about 4900 feet (1494 m) about 25 to 40 feet (8–12 m) and 30 to 40 feet (9–12 m) above the Weber River in Morgan Valley in the Morgan and Durst Mountain quadrangles, respectively; Qap up to 50 feet (15 m) thick.

Qao **Older alluvium (Pleistocene)** – Sand, silt, clay, and gravel on surfaces above Lake Bonneville-age alluvium; deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent drainage; Qao is ~100 feet (30 m) above present adjacent drainages in the Morgan quadrangle and 70 to 120 feet (20–37 m) above in the Durst Mountain quadrangle; likely older than Lake Bonneville and same age as Qafo (likely Bull Lake glaciation age; 95,000 to 130,000 yrs old, see Chadwick and others, 1997; Phillips and others, 1997) (see table 1 and note revisions from Coogan and King, 2006, and King and others, 2008). From our work in the Devils Slide quadrangle 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.

Qaoe **Eroded old alluvium (middle and lower Pleistocene)** – Sand, silt, clay, and gravel on surfaces above adjacent older alluvium (Qafo, Qao); deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent drainage; located above the Bonneville shoreline and apparently above and older than adjacent pre-Lake Bonneville older alluvium (Qao and Qafo); in Durst Mountain quadrangle, mapped on benches about 80 to 100 feet (24–30 m) above Cottonwood Creek (higher than adjacent Qafo), but with height above adjacent drainages similar to Qao and Qafo (table 1), and might be slightly older generation of older alluvium; also mapped on benches about 120 to 230 feet (35–70 m) above the Weber River in Morgan Valley at an elevation of about 5300±50 feet (1615±15 m); contains mostly sand, silt, and gravel in stream and alluvial-fan deposits; about 10 feet (3 m) thick; west of the Weber River in the Morgan quadrangle, dated by Sullivan and others (1988) as older than 730 ka [>780 ka, see 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 might be QTay.

Qal **Stream alluvium and floodplain deposits (Holocene)** – Sand, silt, clay, and gravel in channels, floodplains, and terraces less than 10 feet (3 m) above stream level; locally includes muddy, organic overbank and oxbow lake deposits; present in broad plains along Weber River, East Canyon Creek, and Deep Creek, and in narrow plains of larger tributary streams; width in Morgan Valley is combined floodplain of Weber River and East Canyon and Deep Creeks; composition depends on source area; 0 to 20 feet (0–6 m) thick and possibly as much as 50 feet (15 m) along Weber River; 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.

Qat2, Qatp

Stream-terrace alluvium (Holocene and Pleistocene) – Sand, silt, clay, and gravel in terraces above floodplains, mostly along the Weber River; number and letter suffixes indicate relative ages, with 2 being the youngest terraces; 0 to at least 20 feet (0–6+ m) thick. Near late Pleistocene Lake Bonneville, deposits with suffix 2 are younger than Lake Bonneville, and mostly Holocene in age; elsewhere relative-age numbers and letters may only apply to local drainages. Terraces labeled Qatp are graded to the Provo and slightly lower shorelines of Lake Bonneville (at and less than ~4820 feet [1470 m] in area), and with Qap form a "bench" at about 4900 feet (1494 m) along the Weber River in Morgan Valley. In the Morgan and Durst Mountain quadrangles, terrace ages are partly based on heights above present drainages, with Qat2 about 10 to 20 feet (3–6 m) and 20 feet (6 m) above, Qatp 20 to 25 feet (6–8 m) and 25 to 30 feet (8–9 m) above, respectively; and Qato not mapped in these quadrangle but about 100 feet (30 m) above present drainages in Morgan Valley.

Qaf **Alluvial-fan deposits, undivided (Holocene and Pleistocene)** – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick. Mapped where fan age uncertain or for composite fans where portions of fans with multiple ages cannot be shown separately at map scale.

Qaf1, Qaf2, Qafy

Younger alluvial-fan deposits (Holocene and uppermost Pleistocene) – Like undivided alluvial fans but height above present drainages is low and is within certain limits; here these fans cap alluvial deposits (Qap) related to the Provo shoreline and are therefore younger than the shoreline and likely mostly Holocene in age, but may be as old as latest Pleistocene; generally less than 40 feet (12 m) thick; fans are shown as Qafy where Qaf1 and Qaf2 cannot be separated. All of these fans should be considered active; 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 drainages, and may be partly older than Qaf1 fans. The tops of stacked unit Qafy/Qap are 40 to 50 feet (12–15 m) above Qal at the mouths of Dalton and Smith Creeks, implying Qafy there is 15 to 25 feet (5–8) thick on top of Qap.

Qafb, Qaf3?

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; Qafb is graded to the Bonneville shoreline of late Pleistocene Lake Bonneville, while unit Qaf3 is used where fans might be graded to the Provo or Bonneville shoreline; generally less than 60 feet (18 m) thick.

Like Qa and Qat suffixes, fan ages in the Morgan and Durst Mountain quadrangles are partly based on heights above present drainages at the drainage-eroded edge of fan, with Qafp about 40 to 45 feet (12–14 m) above in the Durst Mountain quadrangle and not mapped in the Morgan quadrangle, and Qafb more than about 40 to 55 feet (>12–17 m) and more than about 40 feet (>12 m) above present drainages in the Morgan and Durst Mountain quadrangles, respectively.

Qafo **Older alluvial-fan deposits (upper and middle(?) Pleistocene)** – Incised fans of mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows; near Lake Bonneville, older fans are above and typically incised/eroded at the Bonneville shoreline; upstream and above the Bonneville shoreline, unit Qafo is topographically higher than fans graded to the Bonneville shoreline (Qafb), and is typically dissected by active drainages; generally less than 60 feet (18 m) thick.

Like Qa and Qat suffixes, ages in Morgan Valley are partly based on heights above present drainages, in this case at drainage-eroded edge of fan, with Qafo about 70 to 120 feet (20–37 m), or possibly higher (for example Spring Hollow), and 70 to 110 feet (20–35 m) above present drainages in the Morgan and Durst Mountain quadrangles, respectively. 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 Bull Lake glaciation age (95,000 to 130,000 yrs old, see Chadwick and other, 1997; Phillips and others, 1997). As noted under Qao, these alluvial deposits may contain 2 ages (levels) of alluvial surfaces that are not easily recognized in Morgan Valley but are recognized upstream in Henefer and Lost Creek Valleys in the Devils Slide quadrangle.

Qafoe **Eroded old alluvial-fan deposits (middle and lower Pleistocene)** – Eroded fans located above and apparently older than pre-Lake Bonneville older alluvial-fan deposits (Qafo) in Morgan Valley in Morgan quadrangle; upper surface is about 120 to 200 feet (35–60 m) above present streams in Morgan Valley, with no difference between the east and west sides of the valley; contains mostly sand, silt, and gravel that is poorly bedded and poorly sorted; less bouldery and lower relative to high-level alluvium (QTay, QTao, and QTaf); in the Morgan quadrangle caps ridges above drainages, like high-level alluvium and unit Qaoe, but also inset into drainages; 0 to 60 feet or more (0–18+ m) thick; likely same age as Qaoe (>780 ka).

Qac **Alluvium and colluvium (Holocene and Pleistocene)** – Includes stream and fan alluvium, colluvium, and, locally, mass-movement deposits; 0 to 20 feet (0–6 m) thick.

Qc **Colluvium (Holocene and Pleistocene)** – Includes material moved by slopewash and soil creep; composition depends on local sources; generally 6 to 20 feet (2–6 m) thick; not mapped where less than 6 feet (2 m) thick.

Qcg **Gravelly colluvial deposits (Holocene and Pleistocene)** – Present downslope from and on gravel-rich deposits of various ages (for example units Thv, QTao, Qaoe) in Morgan quadrangle, but more extensive on west side of Durst Mountain in Durst Mountain quadrangle; 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.

Qng? **Colluvial and residual gravel deposits (Holocene and Pleistocene)** – Gravel of uncertain origin, but probably mostly colluvium and residuum; poorly sorted pebble to cobble gravel in a matrix of silt and sand; mostly gravel-armored, nearly flat surfaces on bedrock; generally 6 to 20 feet (2–6 m) thick; queried because might be same as nearby Qcg.

Qmc **Landslide and colluvial deposits, undivided (Holocene and Pleistocene)** – Mapped where landslides are difficult to distinguish from colluvium (slopewash and soil creep) and where mapping separate, small, intermingled areas of landslides and colluvial deposits is not possible at map scale; locally includes talus and debris flows; 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; 0 to 40 feet (0–12 m) thick. These deposits are as unstable as other landslide units (Qms, Qmsh, Qmsy, Qmsb, Qmso).

Qms, Qmsh, Qmsy, Qmsb, Qmso

Landslide deposits (Holocene and Pleistocene) – Poorly sorted clay- to boulder-sized material; includes slides and slumps and locally flows; 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; thickness highly variable. Qms without suffix is mapped where age uncertain (though likely Holocene and/or late Pleistocene), where portions of slide complexes of different ages cannot be shown separately at map scale, or where boundaries between slides of different ages are not distinct. Qms may be in contact with Qms where different slides abut. Locally, unit involved in slide is shown in parentheses when a nearly intact block is visible, for example Qms(Tw). Near late Pleistocene Lake Bonneville, estimated time of emplacement indicated by relative-age letter suffixes, with (h) emplaced in the last 80 to 150 years, historical; (y) post-Lake Bonneville in age, and mostly prehistoric; (b) likely emplaced when Lake Bonneville was at or slightly below the Bonneville shoreline; and (o) likely emplaced before Lake Bonneville transgression. Suffixes y and o indicate probable

Holocene and Pleistocene ages, respectively. Qms and Qmso queried where bedrock block may be in place. Qmso mapped where rumpled morphology typical of mass movements has been diminished and/or younger surficial deposits cover or cut Qmso. These older deposits are as unstable as other landslides and are easily reactivated with the addition of water, be it irrigation or septic tank drain fields.

Qmdfh **Historical debris-flow deposits (Holocene)** – Mostly sand, silt, clay, gravel, and cobbles in debris flows; deposits are visually distinct from alluvial fans in the Morgan quadrangle based on lack of vegetation and fresh appearance of natural levees, channels, and debris; 0 to 40 feet (0–12 m) thick; in Morgan quadrangle only mapped on active alluvial fans (Qafy) on the north side of Round Valley where debris flows in 1958 are documented.

Qmrf **Rock fall (Holocene and Pleistocene)** – Angular, mostly little weathered Mississippian carbonate debris at base of cliff north of Interstate Highway 84 and east of Morgan (section 31, T. 4N., R. 3E.); distinct due to fresh-looking scarp up hill and larger block debris than most talus in the quadrangle; estimate 0 to 40 feet (0–12 m) thick.

Qmt **Talus (Holocene and Pleistocene)** – Angular debris at the base of and on steep slopes; only larger debris fields can be shown at map scale and include colluvium locally; mapped on Tintic Quartzite north of Dry Hollow and on Mississippian rocks north of Round Valley; likely less than 20 feet (6 m) thick.

Qla **Lake Bonneville 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 near Bonneville shoreline; in Morgan quadrangle, deposits typically eroded from Norwood Formation and mapped where lake deposits are reworked by stream action; also mapped along Deep Creek above Bonneville shoreline where lake deposits seem to indicate landslide dam of creek.

Ql **Lake Bonneville deposits, undivided (upper Pleistocene)** – Includes cobbly gravel, sand, silt and clay along both sides of Weber River in Morgan quadrangle; mapped where grain size is mixed or indistinct and deposits are not exposed in scarps or construction cuts; thickness uncertain; queried north of Morgan due to construction on toes of fans.

Qlf **Lake Bonneville fine-grained deposits (upper Pleistocene)** – Mostly silt, clay and sand (slightly reworked) on both sides of Morgan Valley; deposited near and offshore in lake; at least 12 feet (4 m) thick to northwest near Mountain Green in Morgan Valley. Queried where grain size is uncertain. Some deeper water fine-grained deposits overlie older shoreline and delta gravels (Qlf/Qdlg) at the mouths of several drainages along the Weber River.

Qls **Lake Bonneville sand (upper Pleistocene)** – Mostly sand with some silt and gravel deposited nearshore; mapped on both sides of Morgan Valley; typically less than 20 feet (6 m) thick to northwest near Mountain Green in Morgan Valley.

Qdb **Deltaic deposits in Lake Bonneville (upper Pleistocene)** – Mostly sand, silty sand, gravelly sand, and cobbles deposited in deltas as the lake transgressed to the Bonneville shoreline; only mapped as stacked unit Qlf/Qdb at mouth of Roswells Canyon drainage.

Qdlg **Lake Bonneville delta and lacustrine deposits, undivided (upper Pleistocene)** – Mostly sand, silty sand, gravelly sand, and cobbles deposited near shore as the lake transgressed to and was at the Bonneville shoreline; similar to unit Qdb, but contains more gravel; mapped where poor exposures preclude separation of lake and delta deposits; in Morgan quadrangle mapped on both sides of the Weber River; mapped as stacked unit Qlf/Qdlg between Roswells Canyon and Big Hollow; zero to at least 40 feet (0–12+ m) thick.

Qfdb **Lake Bonneville alluvial-fan and delta deposits, undivided (upper Pleistocene)** – Cobbly gravel, sand, silt, and clay deposited above (subaerially) and in Lake Bonneville (subaqueous) as lake transgressed to

and was at the Bonneville shoreline; mapped where Bonneville shoreline obscure so that line cannot be drawn between delta and fan; prominent along Deep Creek and present on both sides of Weber River in Morgan and Peterson quadrangles; typically should be better sorted delta and lake deposits over poorly sorted alluvial-fan deposits; 0 to at least 40 feet (0–12+ m) thick. Note that the Bonneville-level fan-delta unit (Qfdb) is typically higher above drainages, 80 to 100 feet (24–30 m), than the related alluvial units (Qab, Qafb) (see table 1).

Qh **Human disturbance (Historical)** – Obscures original deposits by cover or removal; only larger disturbances are shown; includes engineered fill, particularly along Interstate Highway 84 and Union Pacific Railroad, as well as aggregate operations, gravel pits, and sewage-treatment facilities. Edges of disturbances that post-date the 1986 aerial photographs used to map the geology in this quadrangle are shown in brown and were added from and are visible on later 2006 and 2009 orthophotographs of the quadrangle; note in particular the Stoddard Diversion Dam addition, the quarry north of Round Valley, and the gravel pit in the Rowells Canyon drainage; the operations at the latter two sites expanded significantly from 2006 to 2009.

QUATERNARY AND TERTIARY

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; divided into younger (y) and older (o) based on relative height (also see table 1); QTao queried (QTao?) where QTay? mapped downslope might be part of the same alluvial surface; present about 215 to 700 feet (66–210 m) above the Weber River in the Morgan quadrangle; located above Qaoe; due to uncertainty in correlating alluvial remnants QTay may be 780 ka or older; estimate 30 to 70 feet (9–20 m) thick, based on thicknesses in Durst Mountain, Snow Basin, Morgan, and Peterson quadrangles. Unit QTay? may be faulted north of Stoddard or may be terraces of several ages (units).

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); in the Durst Mountain, Peterson and Snow Basin quadrangles typically more bouldery than alluvium lower than QTay (including units Qafoe and Qaoe); at least locally gravel-armored and poorly sorted; only mapped above QTay? between Pine Canyon and Big Hollow about 800 feet (240 m) above Morgan Valley; queried because from location might be QTao; estimate 30 to 100 feet (9–30 m) thick based on work in the Durst Mountain, Peterson, and Snow Basin quadrangles (see Coogan and King, 2006; King and others, 2008). Though it does not extend to the mountain front like QTaf in these other quadrangles, it appears to be part of the Weber Valley surface of Eardley (1944) noted in the summary of this report.

TERTIARY

Ts **Tertiary strata, undivided** – Used where several Tertiary map units are in a possible landslide block, Qms?(Ts), north of Dry Hollow and north of Pine Canyon.

Thv **Fanglomerate of Huntsville (Pliocene and Miocene?)** – Typically dark-weathering, poorly to moderately consolidated, pebble to boulder gravel in brown to reddish brown silt and sand that can erode to gravel-covered slopes with stone stripes; gravel and matrix reflects source of red Wasatch Formation as well as Paleozoic and Precambrian rocks exposed on Durst Mountain; in contrast, where fanglomerate is next to Tintic Quartzite (Ꞓt) exposures on west flank of Durst Mountain and in The Valleys graben on Durst Mountain, clasts are mostly angular to subangular Tintic Quartzite, with less red matrix; unconformably overlies conglomeratic strata, typically unit Tcy with slight (less than several degrees) angular discordance; in Morgan quadrangle on west flank of Durst Mountain, the fanglomerate (Thv) is typically darker colored

and better bedded, than in Durst Mountain quadrangle; may include Tcy-equivalent strata in The Valleys graben on Durst Mountain, but lack of exposures precludes identification; dips several degrees where bedding is visible on west flank of Durst Mountain and possibly steeper dipping in The Valleys graben; caps bench at ~6000 to 6200 feet (1800-1890 m) on west side of Durst Mountain in Morgan quadrangle; estimate 40 to 1000 feet (12–300 m) and less than 200 feet (<60 m) thick on west flank of Durst Mountain in Durst Mountain and Morgan quadrangles, respectively; may be thicker in subsurface; thickness in The Valleys on Durst Mountain in Morgan quadrangle not known but several hundred feet of reddish strata is exposed in a graben on Durst Mountain quadrangle (Coogan and King, 2006); queried where identification uncertain; locally includes landslides that are too small to show at map scale, especially on Durst Mountain.

Tcy **Younger unnamed Tertiary conglomeratic rocks (Miocene?)** – Rounded, pebble- to boulder-sized, quartzite-clast conglomerate with gray, tan, or reddish matrix and some mudstone, siltstone, and sandstone; locally erodes to gravel-covered slopes; 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; Tcy-Tcg contact is easily visible angular unconformity at Durst Mountain-Morgan quadrangle boundary but unconformity becomes less distinct to north and unit Tcy apparently pinches out in the Durst Mountain quadrangle (see Coogan and King, 2006); estimate 0 to 400 feet (0–120 m) thick in Durst Mountain quadrangle (Coogan and King, 2006) and 200 feet (60 m) thick and possibly thinning to south in Morgan quadrangle; may be thicker in subsurface; mapped Tcy-Thv contact (lithologic change and unconformity) is more distinct than Tcy-Tcg contact (unconformity with no consistent lithologic change); locally includes landslides that are too small to show at map scale. Might be same age as Salt Lake Formation (Pliocene and upper Miocene).

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 matrix; interbedded with tan, gray, and reddish-brown pebble-bearing mudstone to sandstone and some claystone (altered tuff); most beds poorly indurated and poorly exposed; some non-conglomeratic beds in Tcg look like the gray upper Norwood Formation (Tn) and are locally tuffaceous; mudstone likely constitutes the matrix of the conglomeratic beds; some Tcg pebble beds have carbonate and chert (like Norwood) and lesser quartzite clasts; Tcg conglomerate includes rare altered tuff clasts from Norwood Formation; locally erodes to gravel-covered slopes; about 700 feet (210 m) thick where the upper and lower contacts are exposed on the north margin of the Morgan quadrangle; it may approach 3000 feet (900 m) thick if the gravels labeled Tcg? west of East Canyon Creek are really rock outcrops rather than alluvial or lag gravels; similar thicknesses are present to the north in the Durst Mountain quadrangle, though unit Tcg can be subdivided into several lithosomes (see Coogan and King, 2006); locally includes landslides that are too small to show at map scale; despite tuffaceous matrix, seems to be less prone to mass movements than Norwood strata.

In the Morgan quadrangle, Tcg is queried in four settings. The unit is queried where small outcrops are poorly exposed on steep slopes near the Tcy contact and might be unit Tcy; because there is no consistent lithologic change between Tcg and Tcy and their contact is a minor (<5°) angular unconformity. Queried south of Pine Canyon because correlation across lineament (fault?) is uncertain. Queried west of East Canyon Creek, where gravel on "benches" is in the axis of the syncline and might be conglomerate younger than Norwood (that is Tcg), or the gravel is residual (lag) and/or alluvial material; mapped as Tcg? because heights above drainages vary down the plunge of the syncline like a bedrock unit would vary. The Tcg? gravels on the east side of East Canyon Creek are discontinuous, thinner, and less extensive than those to the west, more like a lag or alluvium, but are at about the same heights above the creek as Tcg? to the west.

Some beds, like those up Big Hollow (marked with Tcw? on map), are red like unit Tcw in the Durst Mountain quadrangle. There, unit Tcw has mostly recycled Wasatch Formation clasts (quartzite and

carbonate) with a distinct reddish patina. Tcw looks like the fanglomerate of Huntsville (Thv), but typically Tcw matrix is less red than and lacks red sandstone/claystone clasts of Thv.

Tn **Norwood Formation (lower Oligocene and upper Eocene)** – Typically light-gray to light-brown, altered tuff (claystone), tuffaceous siltstone, sandstone, and conglomerate; locally colored light shades of red and green; variable calcareous cement and zeolitization, but less common than to northwest in Snow Basin quadrangle, so extensive unaltered tuff in Morgan quadrangle; in southern Morgan quadrangle near type area, has cut-and-fill structures (fluvial) and includes volcanic-clast conglomerate, and local limestone and silica-cemented rocks; upper Norwood Formation, as exposed in northern Morgan quadrangle and on west margin of Durst Mountain quadrangle (see Coogan and King, 2006), is gray, granule to small pebble conglomerate, with chert and carbonate clasts, as well as claystone and fine- to coarse-grained sandstone; based on outcrop pattern, dip, and topography, Norwood strata are at least 7000 feet (2135 m) thick to northwest in Snow Basin quadrangle (King and others, 2008) and thin to the south, with exposed thickness of about 5000 feet (1525 m) west of Weber River north of Morgan and about 2800 feet (850 m) exposed east of East Canyon Creek (well east of Morgan Valley syncline axis) in type area (Eardley, 1944) in Porterville quadrangle. The type area thicknesses noted in Coogan and King (2006) and King and others (2008) are incorrect. The thickness of the Norwood in the Morgan quadrangle falls within the previously noted range. The cross section accompanying this report shows 6000 feet (1800 m) of Norwood and about 3500 feet (1070 m) of younger Tertiary valley fill; Coogan's (Western State College, July 2, 2005, unpublished digital file) cross section shows 8000 feet (2400 m) of Norwood at the expense of younger Tertiary valley fill. Norwood locally includes landslides that are too small to show at map scale.

Norwood Formation outcrops are queried (Tn?) near Morgan cemetery and in the unnamed valley to the south, because identification is uncertain. Also queried along Tcg-Tn contact where the thin, incompletely exposed Tn? outcrop could be underlain by conglomeratic beds of Tcg and the contact may actually be downslope under Quaternary deposits.

Mixed off-white and red strata are present south of Morgan, giving the appearance that Norwood (Tn) and Wasatch (Tw) Formation strata are interbedded (present below marker bed in Tn, with Tw to east). These strata were shown by Coogan and King (2001) as Tw, but Tn is in road cut, and as noted above in units Tcg and Thv, an eroded red contribution from the Wasatch Formation will make the younger rocks look red like Wasatch Formation.

It is not known if the type area is the age equivalent of <u>all</u> the thicker Norwood strata to the north; the type area is the east limb of a syncline and unconformably overlies the Wasatch Formation with a limited (<5 degrees) difference in dip; the type section is less altered than the thicker sections, this could be a function of more alteration in the deeper and more likely lacustrine part of the depositional basin; the isotopic age from the type area is at least 2500 feet (800 m) above the base of the Norwood (contact with Wasatch Formation) and the same or a greater thickness of Norwood may be younger than the top of the type area; until isotopic ages are obtained for Morgan Valley basin fill close to the lower (Wasatch) and upper Norwood (Tcg-Tn) contacts, it is not known if younger and/or older strata are in the basin fill; isotopic ages indicate the strata at the top of the type area are the same age as the younger part of the Fowkes Formation.

Corrected Norwood K-Ar ages are 38.4 Ma (sanidine) from a sample taken along Utah Highway 66 near Norwood type area (Evernden and others, 1964) in the adjacent Porterville quadrangle, and 39.3 Ma (biotite) from farther south in a different depositional basin, the East Canyon graben (Mann, 1974). The sample from near the type area (and the *Protoreodon* fossil) (Adamson, 1955, p. 39) are from near the top of the section exposed east of East Canyon Creek. The relationships to other volcanic deposits of similar age is in the Late Cretaceous-Tertiary section of this report.

Tw **Wasatch Formation (Eocene and upper Paleocene)** – Typically red to reddish brown sandstone, siltstone, mudstone, and conglomerate; clasts usually rounded and from Precambrian and Paleozoic

sedimentary rocks; lighter shades of red, yellow/tan, and light gray more common in uppermost Wasatch near Morgan; basal conglomerate contains locally derived clasts where contact with underlying Paleozoic rocks is exposed and is less likely to be red; Mullens (1971, p. 18) reported scattered beds up to 15 feet (5 m) thick of pale red silty and gray algal limestone south of Morgan, and Mann (1974) also noted these resistant oncolitic limestone beds; only an incomplete section of Wasatch Formation is present in the Morgan quadrangle; total thickness estimated by King from unfaulted Tn-Tw contact in southeast Morgan quadrangle to Tw-Keh contact in southwest Devils Slide quadrangle to be 5000 to 6000 feet (1500–1800 m), from bedding dip (~20–25°), outcrop pattern, and topography; Wasatch strata thin to west onto Wasatch Range culmination and are likely thinner under Morgan Valley (see cross section); estimated thickness of 1300 feet (400 m) on west side of Morgan Valley in Snow Basin quadrangle (King and others, 2008) and 1600 feet (500 m) with 40 degree dip in Peterson quadrangle; thickness varies locally due to considerable relief on basal erosional surface, for example note onlap of Wasatch north and south of Round Valley; locally includes landslides that are too small to show at map scale.

Age based on the Eocene-Paleocene boundary used in Jacobson and Nichols (1982) that is likely the C24 paleomagnetic reversal; other Eocene-Paleocene boundaries would put P6 palynomorphs in the Eocene. See Jacobson and Nichols (1982) for Paleocene (P) biozones based on palynology, and upper Paleocene (P5 and P5-6) samples (P3055-2A, 3B; P3387-2) to south (their figure 7 updated with mapping by Bryant, 1990), and P5-P6 sample (P2833-1,2) in the Wasatch Formation in the Porcupine Ridge quadrangle (their figure 11). Wasatch strata to northeast in the Meachum Ridge quadrangle contain upper Paleocene (P4-5) palynomorphs (Coogan, 2010a-b, sample 97-7).

Total thickness reportedly up to about 5000 feet (1525 m) with 4500 feet (1370 m) measured in incomplete section to south in Morgan Valley in Porterville quadrangle (Mann, 1974). Roughly 5000 feet (1500 m) is portrayed on Bryant's (1990) map near the measured section. However, the exact location of this measured section is uncertain; it may not have started at the top of the Wasatch Formation (compare Mann, 1974 location to upper contact on map of Bryant, 1990), nor ended at the bottom of the Wasatch. Also, Mann (1974) reported about 950 feet (290 m) of covered strata with schist boulder float at the base of his Wasatch section northwest of East Canyon Reservoir; however, boulder conglomerate with crystalline rock clasts is characteristic of the basal conglomerate of the Cretaceous Hams Fork Member of the Evanston Formation to the north near Devils Slide (see DeCelles, 1994).

The identification of the Wasatch Formation is uncertain at one site just north of Norwood Creek on the south edge of the Morgan quadrangle. This site is next to red and white banded Norwood Formation (see Tn), with a landslide to the east; the site appears to be Wasatch Formation but might be Norwood Formation, hence the query.

PERMIAN AND PENNSYLVANIAN

PIPw, PIPwu, IPwl

Weber Sandstone (Lower Permian and Pennsylvanian) – Gray, indurated, quartzose sandstone with dolomite and siltstone in lower part; undivided unit PIPw only used on cross section; in the Morgan quadrangle, King divided Weber into IPwl (lower) with distinct regular bedding and PIPwu (upper) with less distinct bedding; lower unit queried (IPwl?) just north of Round Valley where complex structure just to east in Devils Slide quadrangle makes it difficult to determine if any of upper unit is present west of thrust fault; upper PIPwu contact located to east in Devils Slide quadrangle; reportedly 2500 to >3300 feet (760–>975 m) thick near Morgan (after Williams, 1943 [plus part of his Park City]; Eardley, 1944; Bissell and Childs, 1958 [2260 feet Weber plus 381 feet their Park City]; Mullens and Laraway, 1973), but these thicknesses are likely from near the Weber River, so are likely from complexly folded strata and are across a back thrust; best estimate of thickness is ~2600 feet (790 m), and is based on outcrop pattern, bedding dip (15 degree), and topography (<100 feet [30 m] elevation difference) from about 2 miles (3 km) north of Weber River where two monoclines are present but Weber strata are not thrust faulted; see Williams (1943,

p. 598) for fossils. The lower Weber (ℙwl) 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. Y23); the disconformity of Welsh and Bissell (1979, p. Y22) may or may not be at the ℙwl-PℙPwu contact and may actually be the back thrust in the Devils Slide quadrangle.

The limestone marker (PℙPwls) mapped in the Durst Mountain quadrangle (Coogan and King, 2006) appears to be in the upper unit (PℙPwu) mapped in the Morgan quadrangle, as do both units (Pwu and PℙPwl) mapped north of Hardy Hollow in the Durst Mountain quadrangle (see Coogan and King, 2006).

PENNSYLVANIAN

ℙmr **Morgan Formation and Round Valley Limestone** – Only combined on cross section. Type Morgan Formation is Desmoinesian while Round Valley Limestone is Morrowan and Atokan (see Sadlick, 1955).

ℙm **Morgan Formation (Pennsylvanian, Desmoinesian)** – Reddish brown-weathering sandstone, siltstone and limestone that grades northward into light-gray lower part of Weber Sandstone, "pinching" out to north in southern Durst Mountain quadrangle (Coogan and King, 2006); thrust faulted "into" Weber rather than intertongued; 0 to 1000 feet (0–300 m) thick in Morgan area (Eardley, 1944; Bissell and Childs, 1958; Mullens and Laraway, 1973)(see also Williams, 1943, though he missed Round Valley Limestone); see Williams (1943, p. 598) for fossils.

Blackwelder (1910) described the Morgan-Round Valley contact as an unconformity with red strata that bears clasts of the underlying limestone and chert over a cavernous weathered surface of limestone. This description is significant enough that Eardley (1944) quoted Blackwelder (1910) 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).

ℙr **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), Carey (1973), and appendix for fossils.

MISSISSIPPIAN

Thickness estimates by King are based on outcrop pattern, bedding dip, and topography on Durst Mountain in the Durst Mountain quadrangle (see Coogan and King, 2006).

Mdo **Doughnut Formation (Upper Mississippian)** – Not subdivided on cross section.

Mdu **Upper member** – Limestone and siltstone; about 290 and 334 feet (90 and 100 m) thick near Morgan (Mullens and Laraway, 1973; and Crittenden, 1959, p. 70, his units 3–6, respectively), and an estimated 300 feet (90 m) thick in Durst Mountain quadrangle. Nohara (1966) called this the upper Great Blue Limestone and reported it is about 400 feet (120 m) thick, with upper contact concealed. See Williams (1943, unit 5, p. 598), Nohara (1966), and appendix for fossils; note possible Pennsylvanian (Morrowan) age in appendix.

Mdl **Lower, shale member** – Poorly exposed siltstone, black shale, and limestone; typically less resistant than adjacent map units; about 100 to 200 feet (30–60 m) thick near Morgan (Mullens and Laraway, 1973; Crittenden, 1959, p. 70 his unit 2), and an estimated 200 feet (60 m) thick in Durst Mountain quadrangle.

Nohara (1966) called this the middle shale in Great Blue Limestone and reported about 100 feet (30 m) thickness. See Williams (1943, unit 4, p. 598) and Nohara (1966) for fossils.

Mh **Humbug Formation (Upper Mississippian)** – Not subdivided on cross section. About 600 feet (180 m) of tan- to reddish- weathering, quartzose sandstone and interbedded limestone reported by Crittenden (1959, p. 70, his unit 1); estimate total thickness as 700 feet (215 m); contact within Humbug placed so lower member is less resistant than upper member.

Mhu **Upper member** – Limestone with sandstone beds near base; estimate thickness as 400 feet (120 m); reportedly about 300 to 350 feet (90–105 m) thick in Morgan quadrangle (Mullens and Laraway, 1973). Lower Great Blue Limestone of Nohara (1966), about 330 or 400 feet (100–120 m) thick. See Nohara (1966) for fossils.

Mhl **Lower member** – Sandstone with limestone and dolomite interbeds; estimate thickness as 300 feet (90 m); reportedly about 400 to 600 feet (120–185 m) thick in Morgan quadrangle (Mullens and Laraway, 1973). Contact with underlying Deseret Limestone may not be placed at a consistent horizon as both units contain sandstone and carbonate strata in varying proportions.

The Humbug map unit of King and others (2008) in the Snow Basin quadrangle likely contains about 300 feet (90 m) of Deseret Limestone; however, adding about 300 feet (90 m) to the Deseret in the Snow Basin quadrangle would put the contact at a change from less-resistant (sandy?) Deseret to more resistant (clastic poor?) Humbug, the opposite of typical weathering resistance and lithology; further, the Delle Phosphatic Shale Member appears to comprise the entire Deseret map unit of King and others (2008) on the slope north of Wheeler Creek.

Mde, Mdd
Deseret Limestone (Mississippian) – Limestone, dolomite and sandstone, with dark, non-resistant, phosphatic shale at base (Delle Phosphatic Shale Member, locally mapped as Mdd); total Deseret about 500 feet (150 m) thick in Morgan quadrangle (Mullens and Laraway, 1973) and estimated in Durst Mountain quadrangle.

Ml **Lodgepole Limestone (Lower Mississippian)** – Gray, fossiliferous limestone, locally cherty; estimate thickness as 650 feet (200 m); reported thicknesses about 650, 755, and 800 feet (200, 230, 245 m) (Eardley, 1944, Madison near Morgan; Williams, 1943, Madison at Durst Mountain; Mullens and Laraway, 1973, near Morgan, respectively); called Gardison Limestone to west in Ogden Canyon area by Sorensen and Crittenden (1972), Yonkee and Lowe (2004), and King and others (2008) and shown as such (Mg?) below Morgan Valley on cross section.

The Ml-Db contact on the map seems to be at the top of a thin non-resistant zone in some places and at the bottom of this zone in other places. King attempted to map this zone but was unable to consistently map the top and bottom. As noted in the section on Unresolved Geologic Problems, this non-resistant interval is probably the undivided Cottonwood Canyon Member of Lodgepole Formation(?) and Leatham Formation.

DEVONIAN

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/age uncertainty and the dearth of fossils.

Db **Beirdneau Sandstone** – Reddish-tan to tan to yellowish-gray, calcareous sandstone, siltstone, some sandy dolomite and limestone, and lesser intraformational conglomerate; less resistant than adjacent map units; estimate thickness as 200 feet (60 m); field thickness in Durst Mountain quadrangle of about 300 feet (90 m) (Coogan and King, 2006); reported thicknesses near Morgan about 185 and 230 feet (55 and 70 m)

(Eliason, 1969; Three Forks of Mullens and Laraway, 1973, respectively); like the Hyrum, Eliason (1969) measured the Beirdneau where it appears to be at its thinnest in the map area; to west in Ogden Canyon area, likely 250 to 300 feet (75–90 m) thick (see Sorensen and Crittenden, 1972, 1974).

The Beirdneau Sandstone contact with underlying Hyrum Dolomite may not be consistently mapped on Durst Mountain, because the Beirdneau contains a thin (~10-20 feet [3–6 m]) dolomite bed that looks like the Hyrum, and the Hyrum contains a reddish, dirty carbonate like the Beirdneau. The carbonate bed in the Beirdneau appears thicker and more noticeable south of Mahogany Canyon. Also, a bed of brownish-gray dolomite, resembling Hyrum Dolomite, is present in middle part of Beirdneau to northeast on the Crawford thrust sheet in Horse Ridge quadrangle (Coogan, 2006), though this color is slightly different than the bed on Durst Mountain.

Dhw **Hyrum and Water Canyon Formations** – Except for normal-faulted mountain front north of Morgan and cross section subdivided into:

Dh **Hyrum Dolomite** – Dark- to medium-brownish-gray and gray, medium-bedded, coarsely crystalline 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 like the Beirdneau Formation; this gradation created problems in mapping Db-Dh contacts and faults cutting these units, and estimating thicknesses; estimate thickness as 250 to 450 feet (75–140 m); reported thickness, about 136 feet (40 m) (Eliason, 1969), is too thin relative to adjacent units and Eliason (1969) measured the Hyrum where it appears to be at its thinnest in the map area; about 200 to 350 feet (60–105 m) thick to west near Ogden Canyon (after Sorensen and Crittenden, 1972, 1974; Yonkee and Lowe, 2004).

Dwc **Water Canyon Formation** – Interbedded calcareous sandstone and sandy dolomite and limestone with sandstone below carbonate and a distinctive very light-gray, yellow-weathering dolomite at top; estimate 200 feet (60 m) thick; see also Eardley (1944), his Cambrian units 9 through 12 are 155 feet (47 m) thick in total; about 100 to 150 feet (30–45 m) thick to northeast on leading edge of Willard thrust sheet (Coogan, 2006), and reportedly 30 to 100 feet (9–30 m) thick to west in Ogden Canyon area below Willard thrust sheet (Yonkee and Lowe, 2004).

SILURIAN and ORDOVICIAN – Missing on Durst Mountain, along with all or most(?) of St. Charles Formation equivalent strata (uppermost Cambrian), due to thinning over Stansbury uplift (see Rigby, 1959) and/or Tooele arch (see Hintze, 1959). Note that about 15 miles (25 km) to the northwest 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 between the Nounan and Maxfield. The Nounan, Maxfield, and Tintic Formations are also thicker in Ogden Canyon, though the Ophir Formation is about the same thickness (see Yonkee and Lowe, 2004).

CAMBRIAN

Thickness estimates by King based on outcrop pattern, bedding dip, and topography south of Cottonwood Canyon in the Durst Mountain quadrangle; see Coogan and King (2006).

Ꞓn **Nounan Formation (Upper and Middle Cambrian)** – Medium-dark-gray, thick-bedded dolomite and limestone; estimate 350 to 400 feet (105–120 m) thick; see also Eardley (1944), his Cambrian units 6, 7, and 8 are 315 feet (95 m) thick in total. Bloomington Formation not present in Morgan or Durst Mountain quadrangles. Nounan about 500 to 750 feet (150–230 m) thick to west in Ogden Canyon area (Yonkee and Lowe, 2004); underlying shale, apparently 40 to 200 feet (10–60 m) thick (after Sorensen and Crittenden,

1972; Yonkee and Lowe, 2004), is lithologically similar to Calls Fort (upper) and Hodges (lower) Shale Members of Bloomington Formation (King and others, 2008).

Ꞓm **Maxfield Limestone (Middle Cambrian)** – Limestone and calcareous siltstone; estimate thickness as 300 feet (90 m); at least 280 foot (80 m) thickness inferred from Eardley (1944, Cambrian units 3–5), that is, at least to top of his limestone edgewise (flat-pebble) conglomerate; not consistently divisible into members; much thicker to west in Wasatch Range where it is about 600 to 900 feet (180–270 m) thick (Rigo, 1968; after Yonkee and Lowe, 2004). Cambrian limestone of Mullens and Laraway (1973) includes Maxfield and upper shale member of Ophir Formation. The outcrop width of the Maxfield north and south of Big Hollow is much wider than elsewhere on Durst Mountain, such that a fold is needed to cause the width, like the overturned fold to the south near Pine Canyon. Attempts to find marker beds to determine dips and folds in these wide outcrops were unsuccessful.

Ꞓo **Ophir Formation (Middle Cambrian)** – Estimate at least 440 to 725 feet (135–220 m) thick in Morgan and Durst Mountain quadrangles; about 300 to 660 feet (90–200 m) thick in Ogden Canyon west of map area (Yonkee and Lowe, 2004); Ophir of Eardley (1944) and Mullens and Laraway (1973) is lower argillite member and their lower marker bed is likely the middle limestone member of the Ophir on Durst Mountain; only combined on cross section. Subdivided on map into:

Ꞓou **Upper argillite member** – Dark-brown-gray to olive-gray argillite with intercalated medium-gray limestone beds; slope-forming and rarely exposed; thickness highly variable, about 425 feet (130 m) thickness inferred from Eardley (1944, his Cambrian unit 2), but likely structurally doubled where he measured; actual thickness here estimated as 180 feet (55 m); to west near Ogden Canyon thickness highly variable but likely about 130 to 260 feet (40–80 m) (Yonkee and Lowe, 2004).

Ꞓom **Middle limestone member** – Thin- to medium-bedded, light- to medium-gray, ledge-forming, micritic limestone with local orange-gray silty ribbons; generally highly deformed, apparent thickness 60 to 165 feet (18–50 m); actual thickness about 100 feet (30 m) (this report; Cambrian unit 1 of Eardley, 1944); to west in Ogden Canyon area apparent thickness only 15 to 65 feet (5–20 m) (Yonkee in King and others, 2008).

Ꞓol **Lower argillite member** – Dark-brown, orange-brown, and olive-gray argillite, silty argillite, and siltstone with rare gray limestone beds; slope forming; interbedded siltstone and sandstone at base grades downward into Tintic Quartzite; thickness highly variable, about 100 to 400 feet (30–120 m) thick, due to structural deformation; actual thickness here estimated as 200 feet (60 m), the same as Eardley (1944) reported; near Odgen Canyon, actual thickness likely about 100 to 145 feet (30–45 m) (King and others, 2008).

Ꞓt **Tintic Quartzite (Middle and(?) Lower Cambrian)** – Tan, very well cemented quartzite; conglomeratic in lower half with Precambrian quartzite pebbles and cobbles; basal 50 to 100 feet (15–30 m) is arkosic conglomerate derived from unconformably underlying Farmington Canyon Complex; Eardley (1944) reported about 1000-foot (300 m) thickness at Durst Mountain; about 1100 to 1500 feet (335–450 m) thick to west in Wasatch Range (Sorensen and Crittenden, 1972; Yonkee and Lowe, 2004; King and others, 2008). Highly fractured along fault zone on west side of Durst Mountain (east side of Morgan Valley).

PROTEROZOIC

Xfc **Farmington Canyon Complex (lower Proterozoic)** – Micaceous schistose and gneissic crystalline rocks with small bodies of amphibolite and pegmatite, variously called dikes and pods; queried along fault east of The Valleys where the "sliver" might be fault rock rather than Xfc; locally includes landslides that are too small to show at map scale; Barnett and others (1993) reported the various isotopic ages of the complex in the Wasatch Range and concluded it is early Proterozoic (about 1700 Ma) in age. More detailed information on the complex to the west in the Wasatch Range is available in Bryant (1988) and Yonkee and

Lowe (2004).

Xfpg **Farmington Canyon Complex, pegmatite (lower Proterozoic)** – Several conspicuous pegmatites are mapped separately from Xfc in this report. The three small bodies are on the Utah Mineral Occurrence System (UMOS) files draft Morgan 15' topographic map (Utah Geological Survey), and the largest body and two of the small UMOS bodies were shown by Mullens and Laraway (1973); the dashed contacts are from Mullens and Laraway (1973). Other pegmatites shown by Mullens and Laraway are not discernable on aerial photographs but are shown with red labels (Xfpg?) and dashed contacts.

REFERENCES

Adamson, R.D., 1955, The Salt Lake Group in Cache Valley, Utah and Idaho: Logan, Utah State Agricultural College [now Utah State University], M.S. thesis, 59 p. [*Protoreodon* jaw at Norwood type area]

Barnett, D., Bowman, J.R., and Smith, H.A., 1993, Petrologic and geochronologic studies in the Farmington Canyon Complex, Wasatch Mountains and Antelope Island, Utah: Utah Geological Survey Contract Report 93-5, 34 p.

Bassinot, F.C., Labeyrie, L.D., Vincent, E., Quidelleur, X., Shackleton, N.J., and Lancelot, Y., 1994, The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal: Earth and Planetary Science Letters, v. 126, p. 91–108.

Benson, A.L., 1965, The Devonian System in western Wyoming and adjacent areas: Columbus, Ohio State University, Ph.D. dissertation, 141 p.

Benson, A.L., 1966, Devonian stratigraphy of western Wyoming and adjacent areas: American Association of Petroleum Geologists Bulletin, v. 50, no. 12, p. 2566–2603. [p. 2570]

Bissell, H.J., and Childs, O.E., 1958, The Weber Formation of Utah and Colorado, *in* Symposium on Pennsylvanian rocks of Colorado and adjacent areas: Denver, Colorado, Rocky Mountain Association of Geologists, p. 26–30, plate 1.

Blackwelder, E., 1910, New light on the geology of the Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 21, p. 517–542.

Brooks, J.E., 1954, Regional Devonian stratigraphy in [northern,] central and western Utah [and eastern Nevada]: Seattle, University of Washington, Ph.D. dissertation, 193 p. [p. 179 on Durst Mountain]

Brooks, J.E., 1959, Devonian regional stratigraphy in north central Utah, *in* Williams, N.C., editor, Guidebook to the geology of the Wasatch and Uinta Mountains transition area: Intermountain Association of Petroleum Geologists Tenth Annual Field Conference, p. 54–59.

Brooks, J.E., and Andrichuk, J.M., 1953, Regional stratigraphy of the Devonian System in northeastern Utah, southeastern Idaho and western Wyoming, *in* Guide to the geology of northern Utah and southeastern Idaho: Intermountain Association of Petroleum Geologists Fourth Annual Field Conference, p. 28–31 and figure.

Bryant, B., 1988, Geology of the Farmington Canyon Complex, Wasatch Mountains, Utah: U.S. Geological Survey Professional Paper 1476, 54 p., scale 1:50,000.

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

Bryant, B., Naeser, C.W., Marvin, R.F., and Mehnert, H.H., 1989, Ages of late Paleogene and Neogene tuffs and the beginning of rapid regional extension, eastern boundary of the Basin and Range Province near Salt Lake City, Utah: U.S. Geological Survey Bulletin 1787K, 12 p.

Carey, M.A., 1973, Chesterian-Morrowan conodont biostratigraphy from northeastern Utah: Salt Lake City, University of Utah, M.S. thesis, 84 p.

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

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, p. 20–39.

Coody, G.L., 1957, Geology of the Durst Mountain-Huntsville area, Morgan and Weber Counties, Utah: Salt Lake City, University of Utah, M.S. thesis, 63 p., scale 1:31,680.

Coogan, J.C., 2006, Interim geologic map of the Horse Ridge quadrangle, leading margin of Willard thrust sheet, Morgan, Rich, and Weber Counties, Utah: Utah Geological Survey Open-File Report 480, 19 p., scale 1:24,000.

Coogan, J.C., and King, J.K., 2001, Progress report geologic map of the Ogden 30' x 60' quadrangle, Utah and Wyoming, year 3 of 3: Utah Geological Survey Open-File Report 380, 30 p., scale 1:100,000.

Coogan, J.C., and King, J.K., 2006, Interim geologic map of the Durst Mountain quadrangle, Morgan and Weber Counties, Utah: Utah Geological Survey Open-File Report 498, scale 1:24,000, 29 p.

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

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology v. 7, p. 558–560.

DeCelles, P.G., 1994, Late Cretaceous-Paleocene synorogenic sedimentation and kinematic history of the Sevier thrust belt, northeast Utah and southwest Wyoming: Geological Society of America Bulletin, v. 106, p. 32–56.

Eardley, A.J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 55, p. 819–894, plate 1, scale 1:125,000. [Norwood Tuff proposed and type area]

Eardley, A.J., 1955, Tertiary history of north-cental Utah, *in* Eardley, A.J., editor, Tertiary and Quaternary geology of the eastern Bonneville Basin: Guidebook to the geology of Utah, number 10, p. 37–44. [Huntsville fanglomerate proposal]

Eardley, A.J., 1969, Early Tertiary volcanism near west end of Uinta Mountains, *in* Lindsay, J.B., editor, Geologic guidebook of the Uinta Mountains, Utah's maverick range: Intermountain Association of Geologists, Sixteenth Annual Guidebook, p. 219–220.

Eliason, J.F., 1969, The Hyrum and Beirdneau Formations of north-central Utah and southeastern Idaho: Logan, Utah State University, M.S. thesis, 86 p.

Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, p. 145–198. [date on Norwood volcanic rocks in Morgan Valley, Peterson quadrangle]

Gazin, D.L., 1959, Paleontological exploration and dating of the early Tertiary deposits in basins adjacent to the Uinta Mountains, *in* Williams, N.C., editor, Guidebook to the geology of the Wasatch and Uinta Mountains: Intermountain Association of Geologists, Tenth Annual Field Conference Guidebook, p. 131–138.

Hayden, F.V., 1869, Preliminary field report [third annual] of the United States Geological Survey of Colorado and New Mexico: U.S. Geological and Geographical Survey of the Territories (Hayden), Annual Report [3], 155 p. (reprint 1873, p. 103–251).

Hintze, L.F., 1959, Ordovician regional relationships in north-central Utah and adjacent areas, *in* Williams, N.C., editor, Guidebook to the geology of the Wasatch and Uinta Mountains transition area: Intermountain Association of Petroleum Geologists Tenth Annual Field Conference Guidebook, p. 46–53.

Holland, F.D., Jr., 1952, Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1697–1734. [Cottonwood Canyon Mbr. of Lodgepole Limestone and Leatham Fm.]

Jacobson, S.R., and Nichols, D.J., 1982, Palynological dating of syntectonic units in the Utah-Wyoming thrust belt - The Evanston Formation, Echo Canyon Conglomerates, and Little Muddy Creek Conglomerate, *in* Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt: Denver, Rocky Mountain Association of Geologists, v. 2, p. 735–750.

John, D.A., Turrin, B.D., and Miller, R.J., 1997, New K-Ar and ages of plutonism, hydrothermal alteration, and mineralization in the central Wasatch Mountains, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains: Society of Economic Geologists Guidebook Series vol. 29, second edition, Guidebook prepared for Society of Economic Geologists field trip 23–25 October, 1997, p. 47–57.

Johnson, J.G., Sandberg, C.A., and Poole, F.G., 1991, Devonian lithofacies of western United States, *in* Cooper, J.D., and Stevens, C.H., editors, Paleozoic paleogeography of the western United States II: Los Angeles, California, Pacific Section, Society of Economic Paleontology and Mineralogy, p. 83–105.

King, J.K., Yonkee, W.A., and Coogan, J.C., 2008, Interim geologic map of the Snow Basin quadrangle and part of the Huntsville quadrangle, Davis, Morgan, and Weber Counties, Utah: Utah Geological Survey Open-File Report 536, 31 p., scale 1:24,000.

Laraway, W.H., 1958, Geology of the South Fork of the Ogden River area, Weber County, Utah: University of Utah M.S. thesis, 66 p., scale ~1:20,000.

Lillegraven, J.A., 1993, Correlation of Paleogene strata across Wyoming, a users' guide, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., editors, Geology of Wyoming: Geological Survey of Wyoming Memoir no. 5, p. 415–477.

Lofgren, B.H., Resume of the Tertiary and Quaternary stratigraphy of Ogden Valley, Utah, *in* Eardley, A.J., editor, Tertiary and Quaternary geology of the eastern Bonneville Basin: Guidebook to the geology of Utah, number 10, p. 70–84. [Huntsville fanglomerate described]

Lum, D., 1957, Regional gravity survey of the north-central Wasatch Mountains and vicinity, Utah: Salt Lake City, University of Utah, 27 p., 2 plates [missing].

Mann, D.C., 1974, Clastic Laramide sediments of the Wasatch hinterland, northeast Utah: Salt Lake City, University of Utah, M.S. thesis, 112 p.

McCalpin, J., 1993, Neotectonics of the northeastern Basin and Range margin, western USA: Zeitschrift fur Geomorphologie N.F., Supplement to Band (v.) 92, p. 137–157.

Mullens, T.E., 1969, Geologic map of the Causey Dam quadrangle, Weber County, Utah: U.S. Geological Survey Geologic Quadrangle Series Map GQ-790, scale 1:24,000.

Mullens, T.E., 1971, Reconnaissance study of the Wasatch, Evanston, and Echo Canyon Formations in part of northern Utah: U.S. Geological Survey Bulletin 1311-D, 31 p.

Mullens, T.E., and Izett, G.A., 1964, Geology of the Paradise quadrangle, Cache County, Utah: U.S. Geological Survey Bulletin 1181-S, 32 p., scale 1:24,000. [replaces 1963 GQ-185]

Mullens, T.E., and Laraway, W.H., 1973, Geologic map of the Morgan quadrangle, Morgan County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-318, scale 1:24,000.

Nelson, M.E., 1971, Stratigraphy and paleontology of the Norwood Tuff and Fowkes Formation, northeastern Utah and southwestern Wyoming: Salt Lake City, University of Utah, Ph.D. dissertation, 169 p.

Nelson, M.E., 1973, Age and stratigraphic relations of the Fowkes Formation, Eocene, of southwestern Wyoming and northeastern Utah: University of Wyoming, Contributions to Geology, v. 12, p. 27–32.

Nelson, M.E., 1974, Middle Eocene rodents (Mammalia) from [Fowkes Formation] southwestern Wyoming: University of Wyoming, Contributions to Geology, v. 13, p. 1–10.

Nelson, M.E., 1976, A new Oligocene faunule from northeastern Utah: Transactions of the Kansas Academy of Science, v. 79, p. 7–13. [Keetley Volcanics]

Nelson, M.E., 1977, Middle Eocene primates (Mammalia) from [Fowkes Formation] southwestern Wyoming: Southwestern Naturalist, v. 22, p. 487–493.

Nelson, M.E., 1979, K-Ar age for the Fowkes Formation (middle Eocene) of southwestern Wyoming: Contributions to Geology, University of Wyoming, v. 17 no. 1, p. 51–52.

Nohara, T., 1966, Microfauna of the Upper Mississippian Great Blue Limestone [Doughnut Formation] near Morgan, Utah: Salt Lake City, University of Utah M.S. thesis, 88 p.

Oaks, R.Q., Jr., Smith, K.A., Janecke, S.U., Perkins, M.E., and Nash, W.P., 1999, Stratigraphy and tectonics of Tertiary strata of southern Cache Valley, north-central Utah, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 71–110.

Oriel, S.S., and Tracey, J.I., Jr., 1970, Uppermost Cretaceous and Tertiary stratigraphy of Fossil Basin, southwestern Wyoming: U.S. Geological Survey Professional Paper 635, 56 p. [defines Members, with type sections, for Fowkes Fm]

Oviatt, C.G., Currey, D.R., and Sack, D., 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225–241.

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

Quitzau, R.P., 1961, A regional gravity survey of the back valleys of the Wasatch mountains and adjacent areas in Utah, Idaho and Wyoming: University of Utah, M.S. thesis, 48 p., 3 plates.

Rigby, J.K., 1959, Upper Devonian unconformity in central [northern] Utah: Geological Society of America Bulletin, v. 70, p. 207–218.

Rigo, R.J., 1968, Middle and upper Cambrian stratigraphy in the autochthon and allochthon of northern Utah: Brigham Young University Geology Studies, v. 15, part 1, p. 31–66.

Royse, F., Jr., 1993, An overview of the geologic structure of the thrust belt in Wyoming, northern Utah, and eastern Idaho, *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., editors, Geology of Wyoming: Geological Survey of Wyoming Memoir no. 5, p. 273–311, 2 plates.

Sadlick, W., 1955, The Mississippian-Pennsylvanian boundary in northeastern Utah: M.S. thesis, University of Utah, 77 p. [proposed Round Valley Limestone]

Sandberg, C.A., and Gutschick, R.C., 1979, Guide to conodont biostratigraphy of Upper Devonian and Mississippian rocks along the Wasatch Front and Cordilleran hingeline, Utah: Brigham Young University Geology Studies, v. 26, part 3, p. 107–134. [Leatham]

Schick, R.B., 1955, Geology of the Morgan-Henefer area, Morgan and Summit Counties, Utah: Salt Lake City, Utah, University of Utah, M.S. thesis, 60 p., scale 1:31,680.

Smith, K.A., 1997, Stratigraphy, geochronology, and tectonics of the Salt Lake Formation (Tertiary) of southern Cache Valley, Utah: Logan, Utah State University M.S. thesis, 245 p.

Smith, R.B., 1961, Geology of the Monte Cristo [Peak quadrangle] area, Bear River Range, Utah: Logan, Utah, Utah State University, M.S. thesis, 77 p., scale 1:24,000.

Smith, M.E., Carroll, A.R., and Singer, B.S., 2008, Synoptic reconstruction of a major lake system [basin] - Eocene Green River Formation, western United States: Geological Society of America Bulletin, v. 120, p. 54–84 and Data Repository Item 2007211, 90 p.

Sorensen, M.L., and Crittenden, M.D., Jr., 1972, Preliminary geologic map of the Wasatch Range near North Ogden [North Ogden quadrangle and part of Huntsville quadrangle], Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-428, scale 1:24,000.

Sorensen, M.L., and Crittenden, M.D., Jr., 1974, Preliminary geologic map of the Huntsville quadrangle, Weber and Cache Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-592, scale 1:24,000.

Sullivan, J.T., and Nelson, A.R., 1992, Late Quaternary displacement on the Morgan fault, a back valley fault in the Wasatch Range of northeastern Utah, *in* Gori, P.L. and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500, p. I1–I19.

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for U.S. Bureau of Reclamation dams in the Wasatch Mountains: Denver Colorado, U.S. Bureau of Reclamation, Seismotectonic Report 88-5, 269 p.

Utah Division of Water Rights, various, Well drilling database: Utah Division of Water Rights accessed at http://nrwrt1.nr.state.ut.us/wellinfo/default.asp

Van Horn, R., 1981, Geologic map of pre-Quaternary rocks of the Salt Lake City North quadrangle, Davis and Salt Lake Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1330, scale 1:24,000.

Van Horn, R., and Crittenden, M.J., Jr., 1987, Map showing surficial units and bedrock geology of the Fort Douglas quadrangle and parts of the Mountain Dell and Salt Lake City North quadrangles, Davis, Salt Lake, Morgan Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1762, scale 1:24,000.

Vogel, T.A., Cambray, F.W., Feher, L., and Constenius, K.N., and others, 1997, Petrochemistry and emplacement history of the Wasatch igneous belt, *in* John, D.A., and Ballantyne, G.H., editors., Geology and ore deposits of the Oquirrh and Wasatch Mountains: Society of Economic Geologists Guidebook Series vol. 29, second edition, Guidebook prepared for Society of Economic Geologists field trip 23–25 October, 1997, p. 35–46.

Welsh, J.E., and Bissell, H.J., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States, Utah: U.S. Geological Survey Professional Paper 1110-Y, 35 p.

White, W.B., 1979, Karst landforms in the Wasatch and Uinta Mountains, Utah: National Speleological Society Bulletin v. 41, no. 3, p. 80–88. (in E. Werner, editor, Alpine karst in the Rocky Mountains symposium, v. 41, no. 3)

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

Williams, J.S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geological Society of America Bulletin, v. 59, no. 11, p. 1121–1164, scale 1:125,000.

Williams, J.S., 1962, Lake Bonneville—Geology of southern Cache Valley, Utah: U.S. Geological Survey Professional Paper 257-C, p. 133–135.

Williams, J.S., 1971, The [Devonian] Beirdneau and Hyrum Formations of north-central Utah: Smithsonian Contributions to Paleobiology no. 3, p. 219–229.

Wingate, F.H., 1961, Geology of a part of northwestern Uinta County, Wyoming: Salt Lake City, University of Utah, M.S. thesis, 104 p., map scale ~1:20,000.

Yonkee, W.A., DeCelles, P.G., and Coogan, J.C., 1997, Kinematics and synorogenic sedimentation of eastern frontal part of the Sevier orogenic wedge, northern Utah: Brigham Young University Geology Studies, v. 42, part 1, p. 355–380.

Yonkee, W.A., and Lowe, M., 2004, Geologic map of the Ogden 7.5′ quadrangle, Davis and Weber Counties, Utah: Utah Geological Survey Map 200, 42 p., scale 1:24,000.

Yonkee, W.A., Parry, W.T., Bruhn, R.L., 2003, Relations between progressive deformation and fluid-rock interaction during shear-zone growth in a basement-cored thrust sheet, Sevier orogenic belt, Utah: American Journal of Science, v. 303, p. 1–59.

General

Carley, J.A., Jensen, E.H., Cambell, L.B., Barney, M., Fish, R.H., Chadwick, R.S., and Winkelaar, P., 1980, Soil survey of Morgan area, Morgan County and eastern part of Weber County: U.S. Department of Agriculture, Soil Conservation Service and Forest Service, 300 p., 62 plates.

Coogan, J.C., 1992, Thrust systems and displacement transfer in the Wyoming-Idaho-Utah thrust belt: Laramie, University of Wyoming, Ph.D. dissertation, 240 p., 17 plates.

Coogan, J.C., 2004, Interim geologic map of the Lost Creek Dam quadrangle, Lost Creek drainage, Morgan and Weber Counties, Utah: Utah Geological Survey Open-File Report 426, 10 p., 1 plate, scale 1:24,000.

Egbert, R.L., 1954, Geology of the East Canyon area, Morgan County, Utah: Salt Lake City, University of Utah, M.S. thesis, 34 p., scale 1:31,680.

Gates, J.S., Steiger, J.I., and Green, R.T., 1984, Ground-water reconnaissance of the central Weber River area, Morgan and Summit Counties, Utah: Utah Department of Natural Resources Technical Publication 77, 59 p.

Mullens, T.E., and Laraway, W.H., 1964, Geology of the Devils Slide quadrangle, Morgan and Summit Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-290, scale 1:24,000.

Saxon, F.C., 1972, Water-resource evaluation of Morgan Valley, Morgan County, Utah: Salt Lake City, University of Utah, M.S. thesis, 118 p.

Mineralization

Blackwelder, E., 1910, Phosphate deposits east of Ogden, Utah: U.S. Geological Survey Bulletin 430[-I], p. 536–551.

Cheney, T.M., 1957, Phosphate in Utah: Utah Geological and Mineralogical Survey Bulletin 59, 54 p., 3 plates. [includes information on Permian Phosphoria Formation and Mississippian Delle Phosphatic Mbr]

Gloyn, R.W., Shubat, M.A., and Mayes, B.H., 1995, Mines and prospects in and around the Farmington Canyon Complex, northern Utah: Utah Geological Survey Open-File Report 325, 96 p.

Loughlin, G.F., 1920, The ore deposits of Utah, Morgan mountain: U.S. Geological Survey Professional Paper 120, p. 218–\221.

Mayes, B.H., and Tripp, B.T., 1991, Zeolite minerals in Utah: Utah Geological Survey Open-File Report 210, 170 p.

Schell, E.M., and Moore, K.P., 1970, Stratigraphic sections and chemical analyses of phosphatic rocks of Permian and Mississippian age in Weber County, Utah: U.S. Geological Survey Circular 635, 11 p.

Utah Department of Highways (now Transportation), 1963, Materials inventory, Morgan County: Utah Department of Highways, Materials and Research Division, Materials Inventory Section, 11 p.

APPENDIX

This appendix contains the preliminary results of samples analyzed by Dr. Gerald Waanders as part of a United States Department of Energy (DOE) Research Partnership to Secure Energy for America (RPSEA) subcontract No. 07122-45 titled "Paleozoic shale-gas resources of the Colorado Plateau and eastern Great Basin, Utah - Multiple frontier exploration opportunities" and are provided by Craig Morgan of the Utah Geological Survey. Revisions to the data provided by Craig Morgan are shown in bold.

Sample No.	Location	Fm.	map Fm.	Age	UTM East	UTM North	Date	Comments
MV-1	Morgan Valley	Prv	**Mdo**	Morrowan	445917	4543677	04/22/2009	at Golf Course in Round Valley
MV-2	Morgan Valley	Prv	**Mdo**	?	446068	4544077	04/22/2009	at Interstate roadcut in Round Valley
MV-3	Morgan Valley	Prv	**Mdo**	?	446029	4544069	04/22/2009	at Interstate in Round Valley
MV-4	Morgan Valley	Mc	**Mdo**	Chesterian	445972	4544054	04/22/2009	at Interstate in Round Valley
MV-5B	Morgan Valley	Prv	correct	Morrowan?	446184	4544373	03/25/2010	several thin beds in quarry north of Round Valley

MV-1 youngest to MV-4 oldest **(MV-3 may be same age as MV-1)**

Prv=Pennsylvanian Round Valley
Mdo=Mississippian Doughnut Formation
Mc=Mississippian Manning Canyon **(not present)**

UTM locations are in NAD 27

Gerald Waanders
Consulting Palynologist

1475 Rancho Encinitas Drive
Encinitas, California 92024-7031
Phone: (858) 759-0180
FAX: (858) 759-9028
Email: waanpaly@adelphia.net

October 5, 2009

TO: Mr. Craig D. Morgan
Utah Geological Survey,
P.O. Box 146100
Salt Lake City, UT 84114

RE: Palynology and Thermal Maturation Analysis of 13 miscellaneous samples from Utah Basin and Range outcrops.

PALYNOLOGY AND THERMAL MATURATION REPORT

The data generated from this analysis has been assembled in two separate Excel files for the samples collected from Santaquin Canyon and Morgan Valley. A summary of the findings for these two sections is provided below along with results on six additional samples collected in Provo Canyon, Payson Canyon, and Allens Ranch.

Morgan Valley: Samples MV-1 to MV-4, (See attached Figures)

The samples from this section show some age variation. In the highest sample (MV4), *Florinites* sp and *Schopfipollenites* sp. were noted to suggest a Morrowan age. The lowest sample has Spelaeotriletes sp. which is more typical of a Chesterian age. The two samples in the middle of the section are indeterminate and with the taxa present could be either age.
The samples from this section were calcareous and consisted mostly of amorphous kerogens. The only possible marine organisms noted were a few scolecodonts in the lowest sample. This would indicate a lacustrine or marginal marine paleoenvironment for these samples.

The TAI values for the entire section were consistent and in a range of 0.8-1.0 R_0. This suggests past peak generation for oil and early generation for gas. The total organic recoveries ranged from fair to very good.

Gerald Waanders
Consulting Palynologist

1475 Rancho Encinitas Drive
Encinitas, California 92024-7031
Phone: (858) 759-0180
FAX: (858) 759-9028
Email: waanpaly@roadrunner.com

April 20, 2010

TO: Mr. Craig D. Morgan
Utah Geological Survey,
P.O. Box 146100
Salt Lake City, UT 84114

RE: Palynology and Thermal Maturation Analysis of 1 outcrop sample: Morgan Valley (Prv), MV-5B.

RE: Palynology and Thermal Maturation Analysis of 18 core samples from Shell Carbon Canal 5-12 Well, Sec. 12, 16S-10E, Emery Co., Utah. API: 4301530709.

PALYNOLOGY AND THERMAL MATURATION REPORT

A total of 19 samples were processed and analyzed for palynomorphs. The samples consist of one outcrop sample from Morgan Valley and 18 core chips collected from depths ranging from 8,830-9,351'. The results are provided in Figures 1 and 2 and summarized below.

MV-5B, Morgan Valley, Prv, 3/25/2010, 446184E-4544373N. Round Valley Formation.

Spores and Pollen:

Densosporites spp.	(R)
Lycospora spp.	(R)
Punctatisporites spp.	(R)

HCl Reaction:	Weak
Organic Recovery:	Good
Kerogen Content:	50% Amorphous, 10% Cuticular and 40% Woody/Inertinite
T.A.I:	0.8-1.0 R_0 Equivalent
AGE:	**Namurian B-C? (Morrowan?)**
ENVIRONMENT:	**Swamp/Shallow Lacustrine**

Gerald Waanders
Consulting Palynologist

Figure 1 10/05/2009

		Spores									
Age	**Depth**	*Densosporites* spp.	*Lycospora* spp.	*Florinites* sp.	*Punctatisporites* spp.	*Schopfipollentes* sp.	*Verrucosisporites* sp.	*Apiculatisporis* sp.	*Acanthotriletes hastatus*	*Spelaeotriletes* sp.	Scolecodont sp.
Morrowan	MV-1	R	R	R	R	R	R				
?	MV-2		R		R			R			
	MV-3	**F**	**F**		**F**						R
Chesterian	MV-4	R	**C**		**F**				R	R	R

Morgan Valley
Manning Canyon/Round Valley Section

R = Rare, less than 6 specimens/slide
F = Frequent, 6-15 specimens/slide

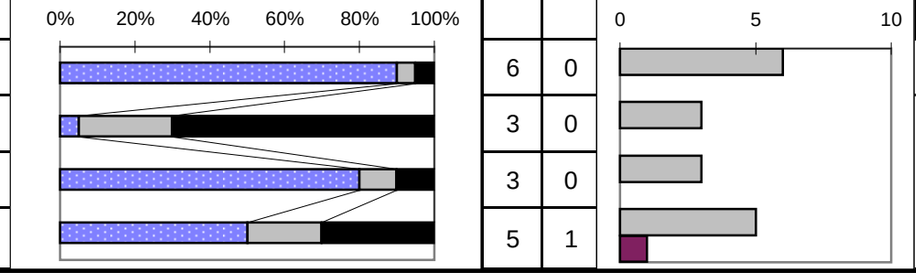
1475 Rancho Encinitas Drive, Encinitas, CA 92024
(858) 759-0180, FAX: (858) 759-9028, waanpaly@roadrunner.com

Gerald Waanders
Consulting Palynologist

Figure 2

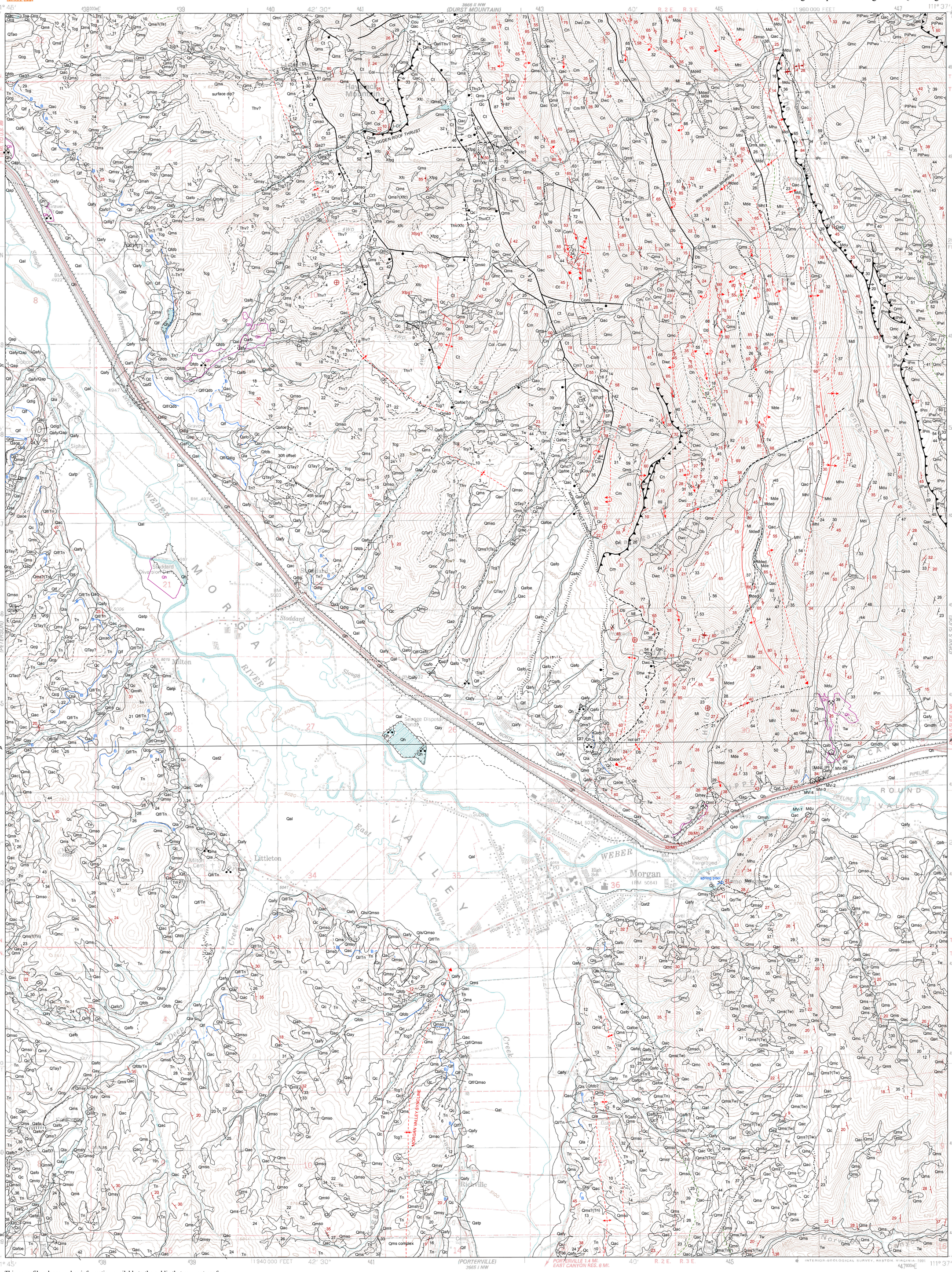
10/05/2009

Age	Depth	HCl Reaction	T.A.I.	Kerogen Distribution: Amorphous	Cuticular	Woody/Inertinite	Organic Recovery	Kerogen Content	Taxa Distribution: Spores	Marine taxa	Species Diversity	Paleoenvironment
								0% 20% 40% 60% 80% 100%			0 5 10	
Morrowan	MV-1	Strong	0.8-1.0	90%	5%	5%	Good		6	0		Lacustrine/Resstricted Marine
?	MV-2	Strong	0.8-1.0	5%	25%	70%	Fair		3	0		
	MV-3	Strong	0.8-1.0	80%	10%	10%	Good		3	0		
Chesterian	MV-4	Weak	0.8-1.0	50%	20%	30%	Very Good		5	1		



Morgan Valley
Manning Canyon/Round Valley Section

1475 Rancho Encinitas Drive, Encinitas, CA 92024
(858) 759-0180, FAX: (858) 759-9028, waanpaly@roadrunner.com



This open-file release makes information available to the public that may not conform to UGS technical, editorial, or policy standards; this should be considered by an individual or group planning to take action based on the contents of this report. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. For use at 1:24,000 scale.

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through U.S. Geological Survey STATEMAP award number 03HQAG0096. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GN MN 0°27' 8 MILS 14° 249 MILS
UTM GRID AND 1991 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

ROAD CLASSIFICATION
Primary highway, hard surface
Light-duty road, hard or improved surface
Secondary highway, hard surface
Unimproved road
Interstate Route
U. S. Route
State Route

UTAH
QUADRANGLE LOCATION

INTERIM GEOLOGIC MAP OF THE MORGAN 7.5' QUADRANGLE, MORGAN COUNTY, UTAH

by James C. Coogan, Jon K. King, and Greg N. McDonald

2015

MORGAN, UTAH
41111-A6-TF-024
1991
DMA 3666 II SW-SERIES V897

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

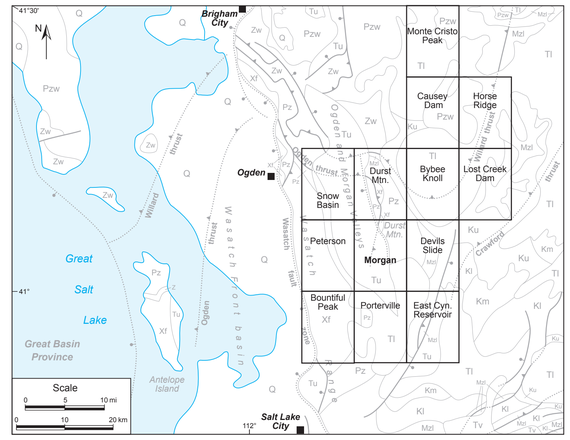
LITHOLOGIC COLUMN
Morgan 7.5' Quadrangle

AGE	UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	SCHEMATIC COLUMN	OTHER INFORMATION
Q	Q-various	alluvium, lake beds, mass movements	0-300	0-90		
TERTIARY Mi.,Plio.	QT-var.	alluvium, gravel	0-100	0-30		
	Thv	fanglomerate of Huntsville	40-1000	12-300		
	Tcy	younger unnamed conglomeratic rocks	200-400	60-120		
	Ts, Tcg	unnamed conglomeratic rocks	700-3000	210-900		Tcg-Tn interbedded
Pal.-Eo.; Oligocene	Tn	Norwood Formation	~2800-7000	~850-2135		Tn thins to south Altered tuff 38.4 Ma K-Ar (corrected) *Protoreodon* sp. mammal Tn may be thicker in subsurface
	Tw	Wasatch Formation	~5000-6000	~1500-1800		Thinner to west in subsurface ANGULAR UNCONFORMITY
Cretaceous Evanston Formation not deposited or eroded away, present to north (Keh) in Durst Mountain quadrangle						
PENN. P.	IPPw	Weber Sandstone	~2600	~790		Back thrust and folding, or disconformity?
	IPwl					
IPmr	IPm	Morgan Formation	0-1000	0-300		Absent to north UNCONFORMITY
	IPr	Round Valley Limestone	400	120		
MISS. Mdo	Mdu	Doughnut Formation	~500	~150		upper Mdu ~300 feet (90 m)
	Mdl					lower Mdl ~200 feet (60 m)
Mh	Mhu	Humbug Formation	~700	~215		upper Mhu ~400 feet (120 m)
	Mhl					lower Mhl ~300 feet (90 m)
	Mde	Deseret Limestone	~500	~150		Delle Phosphatic Member- Mdd
	Ml	Lodgepole Limestone	~650	~200		Fossiliferous
DEV.	Db	Beirdneau Sandstone	~250	~75		Cottonwood Cyn Mbr and Leatham Formation
Dhw	Dh	Hyrum Dolomite	~350	~105		MAJOR UNCONFORMITY
	Dwc	Water Canyon Formation	~200	~60		Silurian, Ordovician, and St. Charles Fm missing
CAMBRIAN	Cn	Nounan Formation	~350	~105		Bloomington Fm missing; Nounan and Maxfield Fms thicker to west
	Cm	Maxfield Limestone	~300	~90		
Co	Cou	Ophir Formation	440-725	135-220		upper Cou 180 feet (55 m)
	Com					middle Com ~100 feet (30 m)
	Col					lower Col ~200 feet (60 m)
	Ct	Tintic Quartzite	~1000	~300		*Skolithus* trace fossils
						MAJOR UNCONFORMITY
EARLY PROTER.	Xfc	Farmington Canyon Complex	indeterminable			1700± Ma Gneiss and schist Xfpg = pegmatite

Diagrams are schematic - scale approximate

Table 1. Heights of alluvial deposits above adjacent active drainages in the Morgan quadrangle. Some units (*) and heights are from Weber River Valley in adjacent Durst Mountain, Snow Basin, and Peterson quadrangles. Younger ages (<20 ka) from Lake Bonneville history in carbon-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*	~ 40 to 45 feet (12-14 m)		
Qab	40 to 90 feet (12-27m)		sites >50 feet (15 m) may be part of unit Qfdb
Qafb	~45 to 55 feet (14-17 m)	~15-20 ka	Bonneville shoreline occupation, Lake Bonneville
Qfdb	80 to 100 feet (24-30 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 ≥ 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 paleomag 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	~800 to 1000 feet (240-300 m)	>780 ka	may be entirely Pliocene



Q	Quaternary deposits	Kl	Cretaceous, lower
Tu	Tertiary, upper	Mzl	Mesozoic, lower
Tl	Tertiary, lower	Pz	Paleozoic
Tv	Tertiary volcanics	Pzw	Paleozoic, Willard thrust sheet
Ku	Cretaceous, upper	Zw	Late Proterozoic, Willard thrust sheet
Km	Cretaceous, middle	Xf	Farmington Canyon Complex

Figure 1. Generalized geologic map (modified from Yonkee and others, 1997), showing adjacent quadrangles and those noted in text.

GEOLOGIC SYMBOLS
Morgan 7.5' quadrangle

- Contact, dashed where approximately located, dotted where concealed; queried on cross section where existence uncertain
- Marker bed
- Fault, dashed where approximately located, dotted where concealed, sense of movement unknown
- Normal fault, bar and ball on downthrown side, dashed where approximately located, dotted where concealed; arrow and number indicate photogrammetric dip on fault; arrows on cross section shows sense of offset
- Thrust fault, teeth on upper plate, dotted where concealed; arrow and number indicate photogrammetric dip on fault; bar and ball indicates later normal fault offset; dashed on cross section where approximately located, query on cross section indicates existence uncertain
- Lineament, possible fault, but offset uncertain; with s-fold symbol, also possible s-fold trace

Major folds, for clarity projected under surficial deposits

- Antiform hinge-zone trace, dashed where approximately located, dotted where concealed, arrow shows plunge
- Synform hinge-zone trace, dashed where approximately located (very approximate for broad synforms in Tertiary units), dotted where concealed, arrow shows plunge
- Overturned antiform hinge-zone trace, dashed because approximately located
- S-fold hinge-zone trace, dashed because approximately located
- Z-fold hinge-zone trace, dashed because approximately located
- Monocline (anticlinal flexure) hinge zone trace, dashed where approximately located
- Monocline (synclinal flexure) hinge zone trace, dashed where approximately located
- Overturned monocline hinge zone trace, typically hinge of *z*-folds with overturned common limb, dashed where approximately located, dotted where concealed, arrow shows plunge

Minor folds

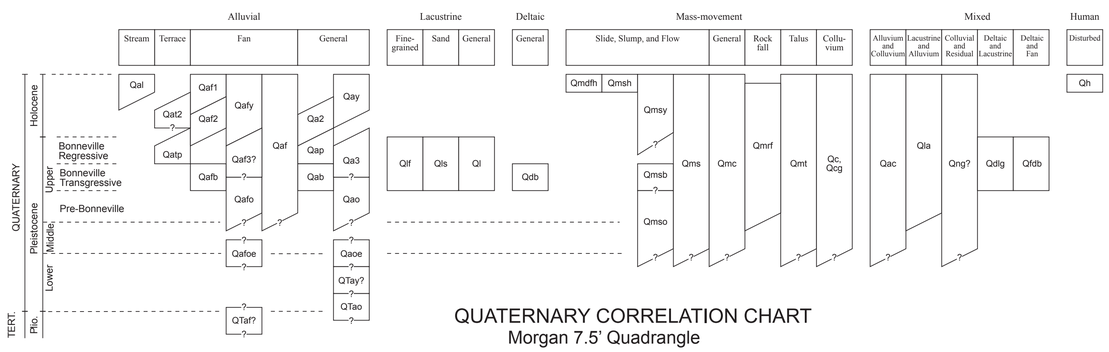
- antiform
- synform
- s-fold
- z-fold
- m-fold

Lake Bonneville shoreline, dashed where approximately located

- Bonneville (about 5180 feet [1579 m])
- transgressional (prominent at about 5060 feet [1542 m])
- Mass-movement scarp
- Topographic scarp (likely fluvial)

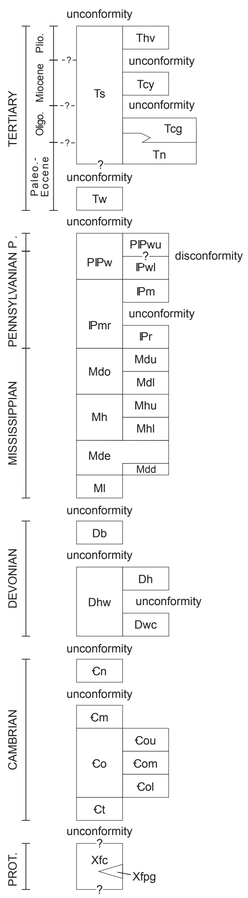
Strike and dip of bedding (attitudes in red from Mullens and Laraway, 1973)

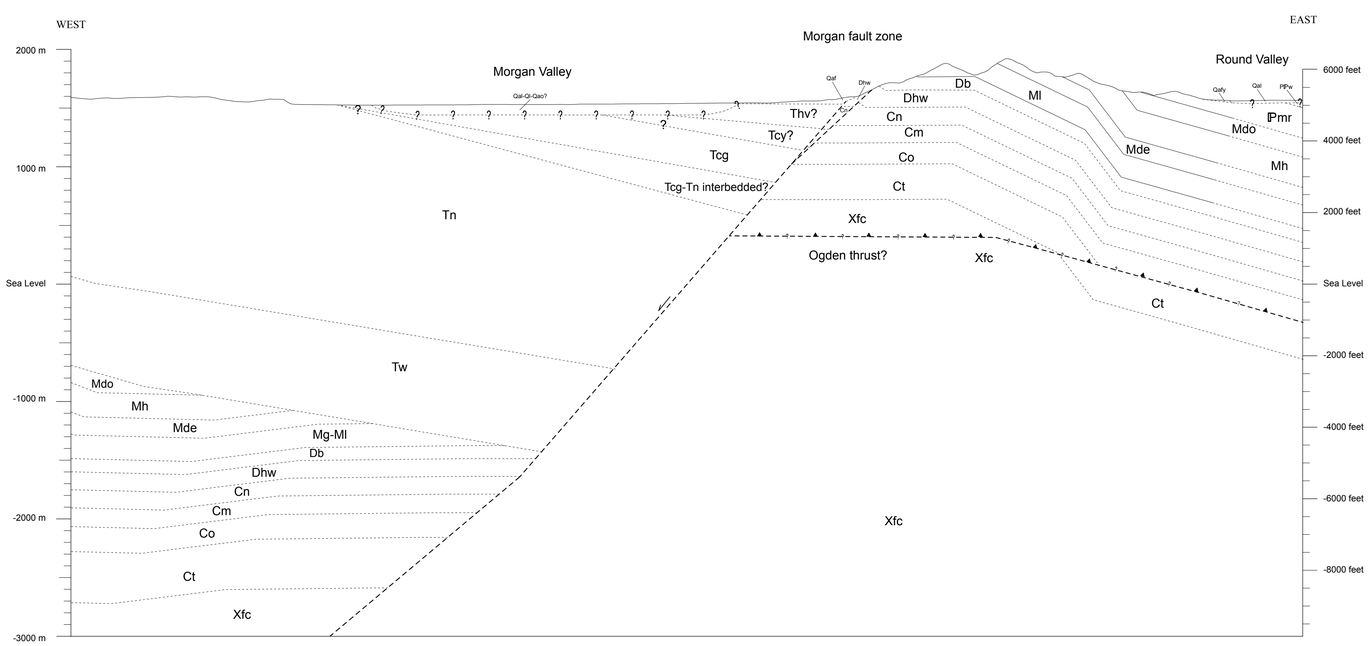
- 50 / 45 — Upright
- 65 / 75 — Overturned
- Vertical
- Horizontal
- 45 / 75 — Photogrammetric, upright on left; overturned on right
- 70 — Strike and dip of foliation
- Gravel pit
- Aggregate pit or quarry
- Prospect (in red from Mullens and Laraway, 1973)
- Adit
- Spring
- MV-1 — Palynology sample location and number (see appendix)
- Qc/ — Thin Quaternary unit over another unit (for example Qc/Itc)
- Qms(Ibrick) Qms?(Tw) — Landslide with nearly intact rotated blocks of unit in parentheses; for example Qms(Tw); queried where blocks may be in place.



QUATERNARY CORRELATION CHART
Morgan 7.5' Quadrangle

BEDROCK CORRELATION CHART





Depth to pre-Tertiary rocks is poorly constrained and lack of Paleozoic outcrops on west side of Morgan Valley means geology conjectural.

Geologic Cross Section of the Morgan 7.5' Quadrangle

Thin Quaternary omitted for clarity