UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

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11°18'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2018

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

UTAH
QUADRANGLE LOCATION

Base from USGS Monte Qristo Peak 7.5' Quadrangle (1991)
Projection: UTM Zone 12
Datum: NAD 1927

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INTERIM GEOLOGIC MAP OF THE MONTE CRISTO PEAK QUADRANGLE, CACHE AND WEBER COUNTIES, UTAH

by
James C. Coogan

2018

INTERIM GEOLOGIC MAP OF THE MONTE CRISTO PEAK QUADRANGLE, CACHE, RICH, AND WEBER COUNTIES, UTAH

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Disclaimer

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OPEN-FILE REPORT 684
UTAH GEOLOGICAL SURVEY
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2018

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SUMMARY

The Monte Cristo Peak quadrangle is located northeast of Ogden, Utah, and southeast of Logan, Utah, in the southern Monte Cristo Range in Cache, Rich, and Weber Counties (figure 1). The range is the source of snow-melt runoff used in Utah and Idaho. Nearly all the runoff from this quadrangle flows westerly through Utah, while runoff from just east of the Cache County line and drainage divide flows into the Bear River and wends its way through Idaho. Although the range is largely unpopulated, an increasing number of summer and year-round homes are being built in and near the quadrangle. Geologically the quadrangle is on the leading margin of the Willard thrust sheet (figure 2), a western and older of several such sheets in the Cretaceous to Eocene "overthrust" belt of Utah, Idaho, and Wyoming (Coogan, 1992a; Royse, 1993), and part of the Cordilleran fold-and-thrust belt of North America. Erosion through cover of Tertiary (mostly Eocene) Wasatch Formation provides exposures of mostly marine lower Paleozoic (Cambrian into Mississippian) sedimentary rocks contiguous with rocks to the east in the Dairy Ridge and Horse Ridge quadrangles (Coogan, 2006a, 2000b). Strata on this leading margin of the thrust sheet are noticeably thinner and lithologically different than on the trailing edge of the thrust sheet, as exposed near Ogden and on the west side of the Bear River Range near Logan (Coogan, 1992a; Yonkee and others, 1997).

In contrast to the Dairy Ridge and Horse Ridge quadrangles to the east (Coogan, 2006a, 2000b), evidence for emplacement of the Willard thrust sheet in the Monte Cristo Peak quadrangle is limited. The largest folds in Paleozoic rocks in the map area are poorly exposed and have relatively little flexure (figure 2). From west to east they are the Beaver Creek syncline (named by Mullens [1969] to the south in the Causey Dam quadrangle), an unnamed anticline, and an unnamed syncline. The Beaver Creek syncline is the Causey syncline of Yonkee (1997, figure 17; 2005, figure 3). Smaller folds and faults that have relatively minor offset disrupt lower Paleozoic rocks in the Monte Cristo Peak quadrangle, but these structures may have formed during emplacement of younger thrust sheets or during Cenozoic normal faulting. The roughly east-west-trending normal faults that cut the Wasatch Formation and the roughly north-south-trending folds in the Wasatch Formation, like the Ant Valley syncline and an unnamed anticline on the east margin of the map area, are likely the result of Eocene (Hogsback) thrusting, that has a leading edge in Wyoming (Yonkee and others, 1997). The roughly north-south-trending normal faults cutting the Wasatch Formation, and some Paleozoic rocks, are likely related to post-thrust extension, either Eocene and Oligocene(?) relaxation (collapse) of the Cordilleran fold-and-thrust belt (see Constenius, 1996), or Miocene and younger Basin and Range extension (see for example McCalpin, 1993). The best example of these north-south trending faults is the graben in the east part of the Monte Cristo Peak quadrangle (not shown on figure 2), that has an estimated 100 to 500 feet (30–150 m) of throw on the east strand and less throw on the west strand (Jon K. King, Utah Geological Survey, verbal communication, 2012).

In their regional cross section across the south part of the Monte Cristo Peak quadrangle or just to the south, Peyton and others (2011) show a broad Browns Hole anticline west of the map area and a broad Beaver Creek-Causey syncline in the map area, ignoring more complex exposed folds. Coogan (1992a, plate 2, a-a′), in his cross section just to the south of the Monte Cristo Peak quadrangle across the Causey Dam quadrangle, shows this more complex folding.

Lower Paleozoic exposures to the west on the Willard thrust sheet near Ogden and Logan, Utah, with exposures in the Monte Cristo Peak and adjacent quadrangles demonstrate thinning over and the crude extent of the Ordovician Tooele arch (see Hintze, 1959) and possibly show thinning over the Devonian Stansbury uplift (see Rigby, 1959). This thinning is complicated by the Stansbury uplift being superimposed on the Tooele arch. Work on the Ogden 30 x 60-minute quadrangle (Coogan and King, 2016) has shown that both features need to be re-examined by measuring more stratigraphic sections. The Cambrian Worm Creek Member of the St. Charles Formation, despite contact inconsistencies, appears to be the oldest unit that does not thin over the Tooele arch (Jon K. King, Utah Geological Survey, verbal communication, May 2001). The youngest unit that thins over the arch is thought to be the Swan Peak Formation (Hintze, 1959), which is missing in the Monte Cristo Peak quadrangle, because the overlying Ordovician Fish Haven Dolomite does not thin. However, the Silurian Laketown Dolomite, the next youngest unit, also thins to the south like other units thinning over the Tooele arch, and the overlying Devonian Water Canyon Formation is about the same thickness in the Monte Cristo Peak quadrangle as it is to the south on Durst Mountain, where all the Silurian and Ordovician are missing (see Coogan and King, 2006).

Karst is exposed in the northeast part of the Monte Cristo Peak quadrangle; the surface is developed on gently dipping and faulted lower Paleozoic carbonate strata, extends into the adjacent Dairy Ridge quadrangle, and likely extends beneath Wasatch Formation cover in the Monte Cristo Range. The age of the karst is uncertain, but multiple episodes of development are likely. For example, cover by the Paleocene(?) and Eocene Wasatch Formation indicates karst development prior to the Eocene and possibly the Paleocene, while karst in Wasatch limestone beds in the map area indicates post-Eocene karst development. Also, dissolution likely took place during wetter periods (lake cycles) in the Pleistocene (see for example table 3

in Coogan and King, 2016). In Wyoming, Pleistocene cave development is older than a cave-infall ash chemically correlated with the Lava Creek B ash (Stock and others, 2006), which is $^{40}Ar/^{39}Ar$ dated at about 640,000 years old (Lanphere and others, 2002). This ash is also reported in basin fill in a road cut of U.S. Highway 89-91 near Dry Lake (Oviatt, in Sullivan and others, 1988, p. 137), a sink valley in the Mount Pisgah quadrangle about 25 miles (40 km) northwest of the Monte Cristo Peak quadrangle.

Other geologic features of importance in the Monte Cristo Peak quadrangle are the broad Ant Valley syncline in the Wasatch Formation in the center of the quadrangle and possible periglacial features. The geologic setting of the Ant Valley syncline and the lacustrine Wasatch limestone in the syncline are possible evidence for a small piggy-back basin on the Willard thrust sheet, similar to the one located to the northeast on the Crawford thrust sheet (see Coogan, 1992b). The broad Ant Valley syncline, synclinal troughs in Paleozoic rocks, faulted and fractured Paleozoic bedrock, karst development, and typically abundant snow pack in the Monte Cristo Range provide for potential recharge of karstic carbonate aquifers, and the quadrangle may include the recharge area for voluminous Causey Spring, located about 10 miles (16 km) to the south in the Causey Dam quadrangle. Flow rates for the spring were estimated by Avery (1994, p. 25, also p. 56 location A-7-3, 23acb) as 21 cubic feet per second (cfs), equivalent to 13.6 million gallons per day, and estimated by Mulens (1969) as about 7 million gallons of water per day (Mullens, 1969), or 10.8 cfs.

The periglacial features are pimple mounds formed on Wasatch strata in Ant Valley and nivation hollows near Monte Cristo Peak (9148 feet [2789 m]). The pimple mounds are most noticeable in this quadrangle on Ant Flat and look like large ant mounds; the mounds are more extensive north of the quadrangle. Pimple mounds may be periglacial features (DeGraff, 1976a, 1976b) formed during Pinedale-age glaciation (~15,000 to 30,000 yrs old), but numerous other origins are possible (Google search pimple or mima mounds for examples). The nivation hollows are on northeast- and east-facing slopes in the Wasatch Formation near Utah State Highway 39 (Monte Cristo road); snow was still present in one northeast-facing hollow on aerial photographs taken the first week of August 1981.

Several gently northwest-dipping surfaces are present on Ant Flat and they terminate up slope to the southeast above the East Fork of the Little Bear River. Any deposits left on these surfaces are less than a few feet thick. I typically do not map surficial deposits that are less than about 10 feet (3 m) thick on my 1:24,000 scale geologic maps. Smith (1965) showed some surfaces as Tertiary boulders (Tb) and described them as a field of quartzite clasts a few inches to 2 feet (~5–60 cm) in diameter that are likely residual deposits from the underlying Wasatch Formation. Jon K. King (Utah Geological Survey), mapping for the Ogden 30 x 60-minute quadrangle, notes they could be remnants of alluvial-fan gravels related to the East Fork of the Little Bear. He could not consistently map the thin deposits on any of the surfaces he placed on this map of the Monte Cristo Peak quadrangle. He thinks these surfaces are likely fluvial because the most distinct surface has anastomosing features on it that look like deposits streamlined by shallow flowing water, or bars and channels in a braided stream; this distinct surface terminates upstream near the sinkholes. One of the sinkholes presently has water in it; so with a higher water table during and/or soon after Pleistocene glaciation, the sinkholes might be the source of the water flowing across Ant Flat rather than the source being the paleo-East Fork of the Little Bear River (Jon K. King, Utah Geological Survey).

This map and report are part of work by the Utah Geological Survey to geologically map the Ogden 30 x 60-minute quadrangle (see Coogan and King, 2016). Jon K. King (Utah Geological Survey) provided some Quaternary mapping and mapped unit MDcl (Cottonwood Canyon Member of the Lodgepole Limestone and Leatham Formation), as shown in this open-file report (less than about 1/6 of map contacts), from his mapping for the larger Ogden project. This map and report are released to provide detail that cannot be shown at the smaller scale of a 30 x 60-minute map and was not shown in previous work. This quadrangle was previously geologically mapped by Smith (1965) for an M.S. thesis at Utah State University; but his map largely ignores Quaternary deposits and lacks a topographic base map, which makes it less accurate. Detailed (1:24,000 scale or larger) mapping in adjacent quadrangles includes (see figure 1): other Utah State University theses to the west in the Sharp Mountain quadrangle (Hafen, 1961; Rauzi, 1979) and to the northeast in the Curtis Ridge quadrangle (Hansen, 1964); U.S. Geological Survey mapping of the Causey Dam quadrangle (Mullens, 1969) and Browns Hole quadrangle (Crittenden, 1972), supported by Laraway's (1958) M.S. work at the University of Utah; M.S. work at Brigham Young University (Berry, 1989) to the northwest in the Porcupine Reservoir quadrangle; and my own work, with detailed Quaternary geologic mapping, to the east in the Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a, 2000b), and my unpublished mapping of the James Peak and Sharp Mountain quadrangles and parts of the Huntsville, Causey Dam, and Browns Hole quadrangles. The Hardware Ranch quadrangle, located directly north of the Monte Cristo Peak quadrangle, has not be mapped in detail and is extensively covered by Wasatch Formation strata and Quaternary deposits.

MAP AND CROSS SECTION (figure 2) UNIT DESCRIPTIONS

QUATERNARY

Qa **Alluvium, undivided** (Holocene and possibly upper Pleistocene) – Sand, silt, clay, and gravel in stream and alluvial-fan deposits; variably sorted; variably consolidated; composition depends on source area; distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainages; generally 0 to 20 feet (0–6 m) thick. Mapped above drainage west of Ant Flat where surface on alluvium slopes toward drainage, looking like mixed fan and stream alluvium.

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; composition depends on source area; mapped along part of East Fork of Little Bear River and in northwest corner of map area; 0 to 20 feet (0–6 m) thick.

Qat **Stream-terrace alluvium** (Holocene and possibly upper Pleistocene) – Sand, silt, clay, and gravel in terraces above floodplain of East Fork of Little Bear River; moderately sorted; upper surfaces slope gently downstream; 0 to 20 feet (0–6 m) thick.

Qaf **Alluvial-fan deposits, undivided** (Holocene and upper Pleistocene) – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted; variably consolidated; deposited mainly by debris flows in drainages and at drainage mouths (fan heads); mapped along Elk Creek in southwest part of map area where deposits may be of more than one age and similar deposits included in Qac; small part of larger fan also mapped in Scare Canyon along west edge of map area; likely less than 20 feet (6 m) thick.

Qafo **Older alluvial-fan deposits** (upper Pleistocene) – Incised fans of mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows; fan edge topographically higher than nearby active drainage; likely less than 40 feet (12 m) thick, based on fan edge height about 40 feet (12 m) above Beaver Creek. Mapped by Jon K. King (Utah Geological Survey) in southwest part of quadrangle west of Monte Cristo Road along with similar fan deposits to south in Causey Dam quadrangle. At this 40-foot (12 m) height above active drainage these fans would be Lake Bonneville age (Qafpb) in Morgan Valley (see Coogan and others, 2015).

Qac **Alluvium and colluvium** (Holocene and Pleistocene) – Unsorted to variably sorted gravel, sand, silt, and clay in variable proportions; includes stream and fan alluvium, colluvium, and, locally, small mass-movement deposits too small to show at map scale; typically mapped along smaller drainages that lack flat bottoms; likely includes residual deposits from karstification near Dry Bread Pond and near sinkholes in northeast part of map area; 0 to 20 feet (0–6 m) thick.

Qc **Colluvium** (Holocene and Pleistocene) – Unsorted clay- to boulder-size material; includes material moved by slopewash and soil creep; composition depends on local bedrock sources; likely pebble to boulder gravel in reddish matrix of silt and sand when mapped on Wasatch Formation (Tw); likely includes or is mostly residual deposits where mapped as Qc/Tw (thin Qc over Tw) on ridge east of Dry Bread Hollow in southeast part of quadrangle; generally 6 to 20 feet (2–6 m) thick, and not mapped where less than 6 feet (2 m) thick.

Qmc **Mass-movement and colluvial deposits, undivided** (Holocene and Pleistocene) – Poorly sorted to unsorted clay- to boulder-size material; includes landslide, slump, slopewash, and soil creep deposits; mapped where landslides are difficult to distinguish from colluvium (slopewash and soil creep) and where mapping separate, small, intermingled areas of landslide and colluvial deposits is not possible at map scale; locally includes talus and debris-flow and flood deposits; typically mapped where mass movements 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. Description from Jon K. King (Utah Geological Survey). These deposits are as unstable as other landslide units (Qms, Qmso).

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

Qms, Qms?, Qmso

Landslide deposits (Holocene and Pleistocene) – Poorly sorted clay- to boulder-size material derived from local source terrain; includes slides and slumps and locally flows; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; mostly Qms mapped because age(s) uncertain and slides lack distinct main scarps typical of younger slides; morphology becomes more subdued with age and amount of water in material during emplacement; Qmso (Pleistocene) mapped at lone slide where rumpled morphology typical of mass movements is less noticeable than other deposits; thickness highly variable. Qms may be in contact with Qms when different/distinct slides/slumps/flows abut. Locally, unit involved in slide is shown in parentheses where a nearly intact block is visible; here Tw is used for Wasatch Formation and rx is used for undivided bedrock. Qms queried where identification of deposits is uncertain. The 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.

Qst **Spring travertine and tufa deposits** (Holocene and upper Pleistocene) – Dense travertine cementing gravel from Wasatch Formation; located downslope from Limestone Spring just east of Monte Cristo highway (section 34, T. 8 N., R. 3 E.). Tufa deposits in terraces block Sheep Creek and are from a spring in a fracture in Garden City Formation (section 19, T. 9 N., R. 4 E.) (Smith, 1965, p. 52).

Qh **Human disturbance** (Historical) – Mapped disturbances obscure original deposits or rocks by cover or removal; only larger disturbance(s) shown; may be gravel pit (see Utah Department of Highways, 1963).

TERTIARY

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – Typically red to brownish-red sandstone, siltstone, mudstone, and conglomerate with minor gray limestone and marlstone locally (see Twl); lighter shades of red, yellow, tan, and light gray are present locally; conglomerate clasts typically rounded Neoproterozoic and Paleozoic sedimentary rocks, mainly Neoproterozoic and Cambrian quartzite; conglomerates near base more gray and less likely to be red, and containing more locally derived angular clasts of limestone, dolomite and sandstone, typically from Paleozoic strata, for example on south margin of map area and in northern Causey Dam quadrangle, a relative high during deposition; thickness up to about 1300 feet (400 m) in Monte Cristo Peak quadrangle and to southwest in adjacent Browns Hole quadrangle; thinner to west, about 400 to 600 feet (120–180 m) thick in Sharp Mountain quadrangle, and to east and southeast, absent to at least 400 to 600 feet (0–180 m) thick in the Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a, 2000b); thicker to southwest, with about 2200 feet (670 m) in southwest Causey Dam quadrangle; thicknesses estimated by elevation differences between pre-Wasatch rocks exposed in drainages and the crests of gently dipping Wasatch Formation on adjacent ridges; thickness varies due to considerable relief on basal erosional surface on underlying Paleozoic rocks. Tw? used where Wasatch Formation underlies colluvium (Qc/Tw?) but identification is uncertain. Sinkholes in Wasatch Formation indicate karstification of limestone beds in Wasatch as well as subcrob Paleozoic carbonate rocks.

Wasatch strata in and near the map area have not been dated and the Wasatch is essentially undated on the Willard thrust sheet. Elsewhere the Wasatch age is based on the Eocene-Paleocene boundary used in Jacobson and Nichols (1982), which is likely the C24 paleomagnetic reversal (see Hicks and others, 2003). Other Eocene-Paleocene boundaries would put P6 (Paleocene) palynomorphs in the Eocene. To the east of the Monte Cristo Peak quadrangle and not far to the east of the Willard thrust, Wasatch strata contain P4-5 palynomorphs in the Meachum Ridge quadrangle (Coogan and King, 2016, sample 97-7). Elsewhere, Wasatch strata contain P5-6 palynomorphs, but also the palynomorph *Platycarya platycaryoides* (Nichols and Bryant, 1990, sample D6052), which is Eocene (see Nichols, 2003). See also Jacobson and Nichols (1982) and Coogan and King (2016) for data on other P5 and P5-6 palynomorphs from the Wasatch Formation.

Twl **Limestone unit of Wasatch Formation** (Eocene and upper Paleocene?) – Gray, oncolitic limestone and light-gray to white marlstone that can be mapped separately in Monte Cristo Peak quadrangle; discontinuous, grades laterally into Tw; 0 to 300 feet thick (0–90 m).

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

Smith (1965) placed this unit in the Salt Lake Group and described it as tuffaceous and oolitic limestone; noted as stromatolitic (oncolitic?) by Hafen (1961). Smith (1965) collected one *Planorbis* sp. (his designation) fresh-water gastropod fossil from the limestone. This gastropod genus and the Planorbidae family of gastropods are not restricted to the Pliocene and/or Miocene, so they are in rocks older than the Salt Lake Group/Formation (see for example Yen, 1948; Pierce, 1993).

Williams (1948, p. 1146–7) noted *Planorbis* sp. and *Physa bridgerensis* Meek at his Cowley Canyon locality 10 on the east side of the Hardware Ranch quadrangle, not far north of the Monte Cristo Peak quadrangle (see Williams, 1958, p. 71, for township and range), but quoted F. Stearns MacNeil of the U.S. Geological Survey, who stated the specimens are like those from near Ft. Bridger, Wyoming, (Bridger Formation) and *P. bridgerensis* is lower and middle Eocene. Bridgerian is the Fowkes Formation age, not Wasatch Cowley Canyon age, so the limestone could be tuffaceous Fowkes Formation.

The setting of the limestone in a syncline and likely lacustrine origin are possible evidence for a piggy-back basin on the Willard thrust sheet. Coogan (1992b) described limestone and conglomerate in the Wasatch Formation on the Bear Lake Plateau in the piggy-back basin on the Crawford thrust sheet east of Bear Lake, northeast of the Monte Cristo Peak quadrangle and east of the Willard thrust sheet.

Smith (1965) also mapped and described a residual quartzite boulder field that has a gentle northwest dip on Ant Flat and noted that it overlies what he described as Wasatch Formation and Salt Lake Group; it overlies what I mapped as Twl and may be weathering of related Wasatch conglomerate beds.

Willard Thrust Sheet

Strata of the Willard thrust sheet (miogeoclinal/basin sequence of Coogan, 1992a) that are younger than the Mississippian Lodgepole Limestone are not exposed in the Monte Cristo Peak quadrangle, but extrapolating from exposures to the south in the Causey Dam quadrangle, these strata are likely present in subsurface below the Wasatch Formation in the south part of the map area (see figure 2). The subcrop likely includes Mississippian Little Flat and Monroe Canyon Formations and may include Permian and Pennsylvanian Wells (Weber) strata. Descriptions of these units are included to help with identifications if they are penetrated by well bores. The younger Permian Phosphoria and Park City Formations are probably not present in the Monte Cristo Peak quadrangle. Fossil data and related geologic ages are from outside the map area.

PERMIAN AND PENNSYLVANIAN

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

The top of the Wells is eroded northwest of the map area in the Bear River Range, where the Wells is about 600 feet (180 m) thick in the Paradise quadrangle (after Mullens and Izett, 1964), and about 600 to 700 feet (180–210 m) thick as mapped in Porcupine Reservoir quadrangle despite a reported thickness of 900 feet (270 m) (see Berry, 1989). These are eroded thicknesses because Evans and others (1996) showed at least 1200 feet (360 m) of Wells on Big Baldy in the eastern part of the Logan 7.5-minute quadrangle and Williams (1948) reported about 1000 feet (300 m) of "Oquirrh" in the same area. Even these greater thicknesses may be incomplete because the upper contact of the unit is not present in the Bear River Range.

The Wells may or may not be thicker to the east of the Willard thrust sheet (thicker would be opposite to the expected trend); about 1050 feet (320 m) of overturned Wells is present in the Dairy Ridge quadrangle, where the base is truncated by the overlying Willard thrust (see Coogan, 2006a).

The Wells Formation is at least partly equivalent to the Weber Sandstone to the south near Morgan and the Oquirrh Formation to the west in the Mount Pisgah quadrangle near Brigham City. The Wells Formation is very thin compared to the ~5000 feet (1525 m) of Oquirrh, including basal West Canyon Limestone to the northwest in the Wellsville Mountains (after Oviatt, 1986). The Wells is also very thin compared to the Weber Formation near Morgan, where the Weber is at least 2500 feet (>760 m) thick, and is off the Willard thrust sheet (see Coogan and King, 2006) and

paleogeographically east of Causey Dam and the Bear River Range. Also, the thinner "Oquirrh Formation" of Williams (1948, 1958), Mullens and Izett (1964), and later mappers in the Bear River Range on the Willard thrust sheet is probably Wells strata that were deposited on a marine shelf rather than in the Oquirrh basin (see basin extent in Jordan and Douglass, 1980). The lack of a discernable West Canyon Limestone in the Bear River Range also supports the Wells designation rather than being labeled Oquirrh Formation.

MISSISSIPPIAN

The identifications of Mississippian units above the Lodgepole Limestone on this concealed part of the Willard thrust sheet are uncertain because strata described by Mullens (1969, 1972) to the south in the Causey Dam quadrangle are not like the typical Monroe Canyon and Little Flat Formations. Instead his descriptions read more like Great Blue Limestone (of the Mount Pisgah quadrangle), that has a shaly middle, and some other geologic unit that is under the Great Blue. However, Mullens' (1969, 1972) fossil data for the upper strata indicate coral zone IIID-IV of Sando and Bamber (1985) (zones E and F of Sando and others, 1969) which is Monroe Canyon (and lower Great Blue/Humbug) time and the shaly middle would be older than the Great Blue. This fossil information and some lithologic data support using the Monroe Canyon name as done below.

Mmo **Monroe Canyon Limestone** (Mississippian, Chesterian? and Meramecian) (subsurface only) – Not exposed in Monte Cristo Peak quadrangle and may or may not be present below the Wasatch Formation in the concealed syncline in the east-central part of Monte Cristo Peak quadrangle. Regionally includes upper gray dolomite (or dolomitized limestone) and limestone; middle gray, cherty limestone and minor siltstone; and lower thick-bedded and cliff-forming gray dolomite and limestone with lesser sandstone. If present, total thickness could be up to 950 to 1000 feet (290–300 m) based on the geology to the south in the Causey Dam area (see Doughnut and "upper" Humbug revised stratigraphy of Mullens, 1969, 1972); about 700 to 1000 feet (210–300 m) thick to the west in the James Peak quadrangle; northwest of the map area at the mouth of Blacksmith Fork Canyon, near the Paradise quadrangle, the entire Monroe Canyon is 830 feet (253 m) thick (upper Brazer of Williams, 1943).

Lithologies and fossils in the Causey Dam quadrangle (see Mullens, 1969, 1972) imply upper and middle strata are middle medium-bedded limestone of type Monroe Canyon (see Dutro and Sando, 1963), although chert is atypical. The lower strata have the lithology and fossil characteristics (see Mullens, 1969, 1972) of the massive limestone member of the Monroe Canyon in its type area (see Dutro and Sando, 1963), but do not consistently weather to massive outcrops like the massive limestone member elsewhere. From looking at stereo aerial photographs of the Causey Dam quadrangle and field observations in Wheat Grass Canyon, Jon K. King (Utah Geological Survey) mapped the Monroe Canyon–Little Flat contact so the grayish-orange, sand-rich lower part of Mullens' units (upper Humbug [Mhu] of 1969, and most of upper Humbug of 1972) is in the Little Flat and the lower Monroe Canyon Limestone does not thicken much to the south.

The Monroe Canyon is late Meramecian in age (coral zone IIID-IV of Sando and Bamber, 1985; zones E and F of Sando and others, 1969) based on *Faberophyllum* sp. coral reported by Mullens (1969) to the south in the Causey Dam quadrangle; see also coral from locality U-9 in Sando and Bamber (1985, p. 43) and *Stratiferia* sp. brachiopod fossils reported in Mullens (1972) that are from the Causey Dam quadrangle. Sando and Bamber (1985, p. 43; see also Sando, 1983, p. 41) also noted *Petalaxis* sp. coral of zone IV (late Meramecian) that probably came from this unit in or near the Paradise quadrangle, northwest of the Monte Cristo Peak quadrangle. A note in Sando and Bamber (1985, p. 43) indicates *Schoenophyllum* sp. coral (zone V-A, Chesterian) came from this unit in the Paradise quadrangle. See also Mullens and Izett (1964) and Berry (1989) for Chesterian strata to the northwest in the Paradise and Porcupine Reservoir quadrangles, respectively, that may be eroded away in the Monte Cristo Peak quadrangle. Late Meramecian is type Monroe Canyon and lower Great Blue-Humbug time. The entire Monroe Canyon interval is roughly equivalent to the Great Blue Limestone and upper Humbug Formation interval to the west near Brigham City on the Willard thrust sheet, and possibly the Doughnut Formation to the south of the map area below the Willard thrust sheet.

Mlf **Little Flat Formation** (Mississippian, Meramecian and Osagean) (subsurface only) – Not exposed in the Monte Cristo Peak quadrangle, but likely present below the Wasatch Formation in the concealed axis of a syncline, because it is exposed on both flanks of this syncline just to the south in the Causey Dam quadrangle (after Mullens, 1969; Coogan and King, 2016). Regionally, gray, tan and reddish-tan, calcareous to dolomitic sandstone, and gray sandy limestone and dolomite; grades upward into mostly dolomite; less resistant than overlying and underlying map units; phosphatic shale at base (Delle Phosphatic Member) (Coogan and King, 2016). Sandberg and Gutschick (1979) reported on the Delle exposures in the region. The Little Flat is about 800 feet (245 m) thick, including the Delle in lower Wheat Grass

Canyon in the Causey Dam quadrangle (see lower Humbug of Mullens, 1969) and does not thin to north as reported in Mullens (1969) (Coogan and King, 2016); and it is 800 feet (244 m) thick to the north near Laketown, Utah, on the Willard thrust sheet (see Sandberg and Gutschick, 1979).

Northwest of the map area, the Little Flat is about 900 feet (270 m) thick in the Mount Pisgah quadrangle (Brazer 1 of Williams, 1943, 1948; Williams and Yolton, 1945), 905 feet (276 m) thick near the Blacksmith Fork River (lower Brazer of Williams, 1943), about 1000 feet (300 m) thick at Porcupine Reservoir (Sandburg and Gutzchick, 1979), and is about same thickness on the Porcupine Reservoir quadrangle map of Berry (1989) despite her report of a 1206-foot (370 m) thickness that is likely from Mullens and Izett (1964).

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

The Little Flat is roughly equivalent to the lower Humbug Formation and Deseret Limestone interval to the west. The Little Flat Formation name is used rather than Humbug because the Deseret Limestone appears to be missing or is atypically much sandier, despite what was shown by Welsh and Bissell (1979, figure 4). Further, the rocks I mapped as Little Flat are lithologically similar to the type Little Flat Formation in the Chesterfield Range in southeastern Idaho (see Dutro and Sando, 1963, for type descriptions).

Ml, Ml? **Lodgepole Limestone** (Mississippian, Osagean? and Kinderhookian) – Dark-gray, thin- to thick-bedded, fossiliferous limestone (lime mudstone [micrite] to wackestone); containing black chert nodules, particularly at top; ledge and cliff forming; exposed on flanks of concealed syncline, with top not exposed, in the Monte Cristo Peak quadrangle and to the east in the Dairy Ridge quadrangle (Coogan, 2006a). To the south in the Causey Dam area, about 830-foot (275 m) thickness was reported by Mullens (1969), excluding basal silty limestone (unit MDcl), and is likely based on Laraway's (1958) measurements of about 825 feet (252 m) of Lodgepole along the South Fork Ogden River; about 790 feet (240 meters) of Lodgepole-equivalent strata (Henderson Canyon Formation) were measured by Webster and others (1987) near Causey Reservoir. Queried where isolated outcrop was not field checked.

The Henderson Canyon name was introduced because the type Lodgepole is overlain by the Mission Canyon Limestone and the Delle phosphatic beds are not present (Sando and Dutro, 1974). So with the Delle marking the boundary between the Deseret and Gardison, this unit may better be called Gardison Limestone or Henderson Canyon Formation. Further, the Mission Canyon contains strata that are time equivalent to the Osagean(?) Delle, and the Mission Canyon Limestone at north Georgetown Canyon, Idaho (Sando and others, 1981), likely contains the upper Chinese wall that underlies the Delle phosphate beds near Logan, Utah, where the wall is in what is mapped as the Lodgepole Limestone. This may be why the reported Osagean and Kinderhookian ages for the Mission Canyon (see for example Sandberg and Gutschick, 1984; Sando and Bamber, 1985; Poole and Sandberg, 1991) overlap with the Lodgepole age (early Osagean and Kinderhookian) in northern Utah. The northern Utah age is based on fossils found on the Willard thrust sheet in the Bear River Range and the Wellsville Mountains (see following paragraph).

The Lodgepole as used here is Kinderhookian and possibly early Osagean in age, depending on the Kinderhookian-Osagean boundary relative to the lower boundary of the *Gnathodus typicus* conodont zone; age here based on fossil conodonts (upper and lower *Siphonodella isostichia – S. crenulata* zones), crinoids, and corals found in the Bear River Range in northern Utah (Sandberg and Gutschick, 1979) and near Brigham City in the Wellsville Mountains (Oviatt, 1986).

MISSISSIPPIAN AND DEVONIAN

MDcl **Cottonwood Canyon Member of Lodgepole Limestone(?) and Leatham Formation** (Lower Mississippian and Upper Devonian, Kinderhookian and Famennian) – Poorly exposed recess or a slope of dark-colored shale, siltstone, and thin-bedded silty to shaly limestone 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; Mullens, 1969, silty limestone) (see also Sandberg and Poole, 1977; Sandberg and Gutschick, 1979); to south in 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, as much as 70 feet (20 m) thick, that is probably the Cottonwood Canyon-Leatham interval, although he typically mapped the recess as part of the Beirdneau Formation. This recessive interval was previously placed in both the Beirdneau and Lodgepole Formations and likely includes both the Cottonwood Canyon Member of the Lodgepole Limestone of Sandberg and Gutschick (1979) and the Leatham Formation (see also Holland, 1952; Benson, 1965); hence the Lower Mississippian (Kinderhookian) age reported for the Upper Devonian (Famennian) (Sandberg and Gutschick, 1979) Leatham at the type section in Leatham Hollow (see Holland, 1952, p. 1719–1720).

The recessive interval was not noted on the leading edge of the Willard thrust sheet by Coogan (2006a, 2000b); but, the characteristic recess is distinct and was mapped by Jon K. King (2008, Utah Geological Survey) in Wheat Grass Canyon in the southeast part of the Monte Cristo Peak quadrangle and in the Causey Dam quadrangle. Well data from the Birch Creek fold belt (see Utah DOGM), east of the Willard thrust sheet, indicate the shaly Cottonwood Canyon Member of Madison/Lodgepole and Leatham Formations 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 (Coogan and King, 2016). The limited thickness means MDcl is the line between Ml and Du on figure 2.

DEVONIAN

Descriptions modified from Coogan (2006a, 2000b). Thickness estimates near Causey Dam are from King using outcrop pattern, dip, and topography in various locations. Devonian stage subdivisions are not noted due to the lack of fossils and age uncertainty.

Du **Devonian, undivided** – Only used on figure 2.

Db **Beirdneau Sandstone** (Upper Devonian) – Tan, reddish-tan and yellowish-gray, dolomitic to calcareous sandstone and siltstone, and silty to sandy dolomite and limestone; contact ledge "limestone" 10 to 20 feet (3–6 m) thick at top, distinct below Leatham recessive zone in Wheat Grass Canyon, Causey Dam quadrangle (see above); in Causey Dam quadrangle locally contains distinctive beds of intraformational conglomerate consisting of small red fragments of siltstone and sandstone in silty limestone matrix, and scattered halite molds in fine-grained rock (Mullens, 1969); exposed on flanks of syncline on east margin of Monte Cristo Peak quadrangle; the map thickness in the Monte Cristo Peak quadrangle is about that noted to the south in the Causey Dam quadrangle, 400 to 500 feet (120–150 m) (Mullens, 1969) or about 550 feet (170 m) (Three Forks of Laraway, 1958 minus Leatham), rather than the approximately 245 feet (77 m) reported by Smith (1965) in the Monte Cristo Peak area. Thicknesses to the east are not known because the base of the Beirdneau is not exposed in the Dairy Ridge quadrangle and the unit is structurally thickened in the Horse Ridge quadrangle (Coogan, 2006a, 2000b); to the west the Beirdneau may be eroded away in the Sharp Mountain area (Hafen, 1961); farther west the Beirdneau is missing at the unconformity between the Lodgepole Limestone and Hyrum Dolomite in the western James Peak quadrangle (Rauzi, 1979); to the northwest, the Beirdneau is about 700 to 1100 feet (210–335 m) thick, apparently thinning to the south (after Brooks, 1954; Mullens and Izett, 1964; Three Forks of Benson, 1965; Williams, 1971). The Beirdneau thins rapidly to the south and west over the Stansbury uplift (compare to Rigby, 1959) and may not have been present on the uplift in the Sharp Mountain quadrangle, but the next oldest unit is on a ridge top and the Beirdneau removal could post-date the Stansbury uplift. Referred to as the "upper" Jefferson member or Three Forks Formation by some previous workers.

Dh **Hyrum Dolomite** (Upper and Middle Devonian) – Dark- to medium-brownish-gray, coarsely crystalline dolomite; weathers distinctive chocolate-brown color and is typically darker-colored and more resistant than silty and sandy overlying Beirdneau and underlying Water Canyon Formations; the map thickness in the Monte Cristo Peak quadrangle is similar to the 400 to 500 feet (120–150 m) thickness to the south in the Causey Dam quadrangle (Jefferson of Laraway, 1958; Mullens, 1969) rather than the reported 221 foot (67 m) thickness in the Monte Cristo Peak area (Smith, 1965). Hyrum strata are 500 to 675 feet (150–205 m) thick to the east in the Horse and Dairy Ridge quadrangles on the leading margin of the Willard thrust sheet (Coogan, 2006a, 2000b); to the west Hyrum strata are eroded in the Sharp Mountain area (Hafen, 1961) and are absent at the unconformity in the James Peak quadrangle (Coogan and King, 2016); to the northwest the Hyrum is 930 to 980 feet (280–300 m) thick along the Blacksmith Fork River (after Mullens and Izett, 1964; Eliason, 1969; Williams, 1971). The Hyrum is thinnest in the Mantua quadrangle and directly to the north (0 to 400 feet [0–120 m] thick) (King and others, 2018). The Hyrum seems to thin to the west and south over the Stansbury uplift (compare to Rigby, 1959). This unit is "lower" Jefferson member of some previous workers.

Dwc **Water Canyon Formation** (Lower Devonian) – Thin- to medium-bedded, reddish-tan and gray siltstone and very light-gray to light-tannish-gray weathering, very thick-bedded to thinly laminated, at least locally sandy, finely crystalline, typically medium-gray dolomite with some limestone; forms light-colored to orangish-hued slopes; contains fragments of fossil fish plates (Mullens, 1969); the map thickness in the Monte Cristo Peak quadrangle is similar to the 100 to 250 feet (30–75 m) thickness, increasing northward, noted to the south in the Causey Dam quadrangle (Laraway, 1958; Mullens, 1969; Coogan and King, 2016). Smith (1965) reported 296 feet (90 m) of Water Canyon in the Monte Cristo Peak area, but his reported thickness for the overlying Hyrum is too low (see Hyrum) and some Hyrum strata may have been included in his Water Canyon unit. To the east on the leading edge of the Willard thrust sheet, the Water Canyon is an estimated 200 feet (60 m) thick in the Curtis Ridge quadrangle (see Hansen, 1964) and 100 to 150 feet (30–45 m) thick farther south in the Dairy Ridge and Horse Ridge quadrangles (Coogan, 2006a, 2000b). To the west the Water Canyon is 460 feet (140 m) thick in the Sharp Mountain area (Hafen, 1961), which is about what I mapped in this area and it is about 400 feet (120 m) thick in the Mantua quadrangle (Coogan and King, 2016). To the northwest in the Bear River Range, the Water Canyon is about 600 feet (180 m) thick near Logan (see Taylor, 1963; Williams and Taylor, 1964). So the Water Canyon thins to the east and apparently irregularly to the south, probably over the Tooele arch (see Hintze, 1959), or due to erosion during the Late Devonian Stansbury uplift (see Rigby, 1959). However, the uplift is complicated, possibly due to paleotopography, because farther to the northwest near the Blacksmith Fork River the Water Canyon thins to 230 to 320 feet (70–100 m) (after Brooks, 1954; Taylor, 1963; Williams and Taylor, 1964; Mullens and Izett, 1964; Benson, 1965) and yet is ~1200 feet (365 m) thick still farther west in the Mount Pisgah quadrangle (King and others, 2018), and to the north in the Bear River Range is about 600 feet (180 m) thick near Logan (see Taylor, 1963; Williams and Taylor, 1964).

SILURIAN AND ORDOVICIAN

SOlf **Laketown and Fish Haven Dolomites, undivided** (subsurface only) – Combined unit used on figure 2.

Sl **Laketown Dolomite** (Silurian and Ordovician) – Dark- to light-gray, thick- to very thick-bedded, cliff-forming dolomite; locally cherty with irregular blebs, stringers, and layers of chert at various horizons; conodonts and sparse poorly preserved corals reported by Mullens (1969) in the Causey Dam quadrangle; the lower contact is mapped here as the bottom of the non-resistant basal Laketown beds above the resistant Fish Haven, a contact that appears to be what Williams (1948, 1958) mapped in the Bear River Range. The Laketown thickness in the Monte Cristo Peak quadrangle appears to be like that to the east where the Laketown is about 500 feet (150 m) thick in the northwest Dairy Ridge quadrangle (Coogan, 2006a). To the south near Causey Dam, Jon K. King (Utah Geological Survey, verbal communication, 2008) estimated (from dip, topography and outcrop pattern) that the Laketown is about 400 to 600 feet (120–180 m) thick, and is 490 feet (149 m) thick based on Laraway's (1958) measurements (his Laketown plus units 2 and 3 of his Fish Haven) and a non-resistant basal Laketown contact. The combined Laketown and Fish Haven are 530 to 650 feet (160–200 m) thick in the Causey Dam area (Mullens, 1969). To the west the Laketown is reportedly 1240 feet (380 m) thick near Sharp Mountain (Hafen, 1961). Farther west the Laketown of this report is about 1100 feet (335 m) thick. In a measured section east of Mantua Reservoir, probably in the Mount Pisgah quadrangle, Gunn (1965, p. 205) reported the Laketown was 973 feet (300 m) thick, and using my Laketown-Fish Haven contact, his Fish Haven units 3 and 2 (30 and 66 feet [9 and 20 m] thick) would be in our Laketown (for a total of 1072 feet [327 m] thick), leaving 166 feet (50 m) of Fish Haven (his unit 1 of Fish Haven). Other reported thicknesses for the Laketown may include part of the underlying Fish Haven Dolomite, because a different contact was used than the one on the Monte Cristo Peak quadrangle map. Williams (1948) measured 1510 feet (460 m) near Logan and his contacts appear to be the same as mine. In summary, the Laketown thins to the south and apparently to the east, probably over the Tooele arch (see Hintze, 1959), but may be influenced by erosion over the Stansbury uplift (see Rigby, 1959).

ORDOVICIAN

Ofh **Fish Haven Dolomite** (Upper Ordovician, Cincinnatian, possibly Richmondian) – Dark-gray, thick- to very thick-bedded dolomite with white chert as stringers and small nodules; commonly has dull-medium-gray to light-gray mottling on weathered surfaces; forms resistant ridge where distinguishable from recessive dolomite at the base of the overlying Laketown Dolomite; 123 feet (38 m) thick in the Monte Cristo Peak area (Smith, 1965), with minor variation in adjacent quadrangles: 125 feet (38 m) thick to the west in the Sharp Mountain quadrangle (Hafen, 1961), likely 135 feet (41 m) thick to the south in the Causey Dam quadrangle (after Laraway, 1958, unit 1), 128 feet (39 m) thick to the northeast in the Curtis Ridge quadrangle (Hansen, 1964), and about 100 feet (30 m) thick to the east in the northwest Dairy Ridge quadrangle (Coogan, 2006a). Northwest of the Monte Cristo Peak area,

the Fish Haven is likely about 180 feet (55 m) thick near Brigham City (after Jensen and King, 1996), 170 feet (50 m) near Mantua (Gunn, 1965, p. 205, Fish Haven unit 1), and 140 feet (43 m) thick in Blacksmith Fork Canyon (Mecham, 1973). Therefore, the Fish Haven thins to the south, but is about as thick off the Willard thrust sheet at Ogden Canyon (see Sorensen and Crittenden, 1972, 1974) as on the Willard thrust sheet.

The Fish Haven unconformably overlies the Garden City Formation because the entire Swan Peak Formation is missing in the Monte Cristo Peak area (Ross, 1949), to the south near Causey Dam (Laraway, 1958; Mullens, 1969), and to the east in the Curtis Ridge, Dairy Ridge, and Horse Ridge quadrangles (Hansen, 1964; Coogan, 2006a, 2000b). Elsewhere the Fish Haven unconformably overlies shale in the lower Swan Peak Formation; about 20 feet (6 m) of recessive-weathering siltstone and shale (lower Swan Peak) is present to the west near Sharp Mountain (Hafen, 1961) and more Swan Peak is present farther west (see Ross, 1951; Ezell, 1953; Francis, 1972). In the Monte Cristo Peak quadrangle, the shale below the Fish Haven was placed in the upper Garden City Formation by Ross (1949) and Smith (1965) on the basis of paleontological evidence cited by Ross (1949). The Swan Peak Formation is missing over the Tooele Arch on the southeast part of Willard thrust sheet (see Hintze, 1959).

Ogc **Garden City Formation** (Lower Ordovician) – Gray- to tan-weathering, dark-gray to gray, thin- to medium-bedded, silty limestone, with less resistant, tan to yellowish-weathering, wavy, silty to argillaceous laminae to inch-scale layers that are more abundant in lower part; intraformational, flat-pebble conglomerate present in lower half; ledge forming; chert near top of unit (black nodules and stringers) and in lowermost part; forms resistant ridges; at least locally fossiliferous (see Mullens, 1969); an estimated 1185 feet (360 m) thick north of the Monte Cristo Peak quadrangle (Ross, 1949), and reportedly about 500 feet (150 m) thick in the Causey Dam quadrangle (Mullens, 1969), but its base is not exposed. To the east the Garden City appears to thin southward from 1280 feet (390 m) thick in a composite section in the Curtis Ridge quadrangle (Hansen, 1964) to about 1050 feet (320 m) thick along Sugar Pine Creek in the Dairy Ridge quadrangle and to about 700 feet (215 m) thick in the southern Horse Ridge quadrangle (Coogan, 2006a, 2000b), but Garden City strata are commonly structurally thickened in these quadrangles on the leading margin of the Willard thrust sheet (Coogan, 2006a, 2000b). These data indicate the Garden City thins to south over the Tooele arch (see Hintze, 1959).

ORDOVICIAN AND CAMBRIAN

Csc **St. Charles Formation** (Lower Ordovician and Upper Cambrian) – Mostly dark-gray, medium- to thick-bedded dolomite; contains subordinate medium-gray dolomite and limestone; all with tan-weathering mottling and recesses of crude laminae to inch-scale layers of sandstone and siltstone; overall gray to tan weathering and ledge forming; uppermost part contains light-colored, typically pink, chert; lower part is less resistant, light-gray, tannish-gray weathering, thin-bedded, silty and sandy limestone and dolomite, and silty shale, with Worm Creek Quartzite Member locally. The St. Charles Formation is 723 feet (220 m) thick, including the Worm Creek, in the Monte Cristo Peak area (Smith, 1965) and to the west is 970 feet (295 m) thick, including the Worm Creek, in the Sharp Mountain quadrangle (Hafen, 1961). To the south near Causey Dam, the entire St. Charles appears to be about 650 feet (200 m) thick (including Worm Creek) (after mapping of Mullens, 1969). To the east on the leading margin of the Willard thrust sheet, the St. Charles thins southward from 700 feet (215 m) thick along Sugar Pine Creek in the Dairy Ridge quadrangle, with about 75 feet (25 m) of Worm Creek, to about 500 feet (150 m) thick in the Horse Ridge quadrangle, with no Worm Creek (Coogan, 2006a, 2000b). The St. Charles may thin to the south and east over the Tooele arch (see Hintze, 1959).

Csw **Worm Creek Member** (Upper Cambrian) – Tannish-gray, medium-bedded, cross-bedded quartzite interbedded with and overlain by poorly resistant light-tannish-gray, thin-bedded, silty carbonate (limestone and dolomite) and shale; thickness uncertain.

Regionally, the member has been inconsistently mapped; some geologists have only mapped and reported the quartzite portion of the member (see for example Ezell, 1953 versus Hafen, 1961), ignoring other lithologies (poorly resistant carbonate, clastic sedimentary rocks, and shale) and placing the contact at the top of the quartzite, that is at least locally absent (Haynie, 1957). This has led to problems with the presence or absence of the member as well as thicknesses, and makes the information on the Worm Creek in the Monte Cristo Peak area and the following information suspect.

To the south the Worm Creek is reportedly about 50 feet (15 m) thick in the Causey Dam quadrangle (Rigo, 1968, aided by Mullens; Mullens, 1969), but a thin (<100 feet [30 m]) non-resistant zone is present at the base of the St.

Charles Formation on the nose of the Knighton anticline in the Causey Dam quadrangle, and is likely the Worm Creek Member (Jon K. King, unpublished mapping in 2008, Utah Geological Survey). To the west the Worm Creek is about 90 feet (27 m) thick in the Sharp Mountain quadrangle (Hafen, 1961), and to the east on the leading margin of the Willard thrust sheet, it thins southward from about 75 feet (25 m) thick in the northern Dairy Ridge quadrangle to 10 feet (3 m) and then to nothing in the Horse Ridge quadrangle (Coogan, 2006a, 2000b).

CAMBRIAN

Descriptions largely from Coogan (2006a, 2000b).

Cn **Nounan Formation** (Upper Cambrian) – Medium-gray, very thick- to thick-bedded dolomite with subordinate dark-gray, medium- to thick-bedded dolomite that weathers very dark gray; typically cliff forming; regionally some light to medium gray and tan-weathering, variably sandy and silty dolomite and lesser limestone in upper part; all with crude laminae to partings and mottling of sandstone and siltstone that weather tan or reddish; thickness not known because base not exposed in Monte Cristo Peak quadrangle. Reportedly 1145 feet (350 m) thick to the west at Sharp Mountain (Hafen, 1961) and reportedly about 630 feet (190 m) thick (Mullens, 1969) to the south in the Causey Dam quadrangle; possibly the "average" of 571 and 696 feet (174 and 210 m) measured by Rigo (1968, aided by Mullens) and Gardiner (1974), respectively, on Baldy Ridge in the Causey Dam quadrangle. Gardiner's (1974) thickness more closely matches Mullens' (1969) mapped thickness. To the east on the leading margin of the Willard thrust sheet the Nounan thins southward from 1025 feet (312.5 m) thick in the Curtis Ridge quadrangle (Hansen, 1964) to 800 feet (245 m) thick in Sugar Pine Canyon (Creek) in the Dairy Ridge quadrangle (Gardiner, 1974; Coogan, 2006a) to 675 feet (205 m) thick in the Horse Ridge quadrangle (Coogan, 2006b). In summary, the Nounan thins to the south and east over the Tooele arch (see Hintze, 1959).

The Cambrian Bloomington, Blacksmith, Ute, and Langston Formations are covered by the Wasatch Formation in the Monte Cristo Peak quadrangle and are present between the Nounan outcrops on the east and Geertsen Canyon outcrops to the west, so map unit symbols shown below are used on figure 2. Descriptions of these units are included to help with identifications if they are penetrated by well bores.

Cbo **Bloomington Formation** (Middle Cambrian) (subsurface only) – Olive to tan shale and gray, nodular limestone; 600 feet (180 m) thick to west near Sharp Mountain (Hafen, 1961), and 650 feet (200 m) thick to south near Causey Dam (Mullens, 1969); a report of 918-foot (280 m) thickness in the Baldy Ridge section (Rigo, 1968, aided by Mullens) in the Causey Dam quadrangle may be faulted strata, but on the leading margin of the Willard thrust sheet northeast of Baldy Ridge the Bloomington is about 935 feet (285 m) thick in the Dairy Ridge quadrangle, thickening to more than twice as thick, 1550 feet (470 m), to the south (east of Baldy Ridge) in the Horse Ridge quadrangle (Coogan, 2006a, 2000b). West of the map area in the Wellsville Mountains, shale members are Middle Cambrian (*Bolaspidella* zone) in age (Oviatt, 1986; Jensen and King, 1996, table 2). The Bloomington is divisible into distinct members (descending):

Calls Fort Shale Member (Middle Cambrian) – Brown-weathering, slope-forming, olive-gray to tan-gray, thin-bedded shale and micaceous argillite with minor, thin-bedded, dark-gray, silty limestone; *Bolaspidella* sp. trilobite fossils reported by Rigo (1968, USGS No. 5965-CO) in the Causey Dam quadrangle. As exposed to the east of the map area 75 to 125 feet (25–40 m) thick on the leading edge of the Willard thrust sheet in Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a, 2000b), and to the south in the Causey Dam quadrangle 100 to 120 feet (30–35 m) thick (Coogan and King, 2016), with 90 feet (27 m) reported by Rigo (1968, aided by Mullens) and about 30 feet (9 m) of slope-forming capping shale reported by Mullens (1969). Mullens (1969) upper member includes the Calls Fort Shale and middle limestone members.

Middle limestone member (Middle Cambrian) – Dark-gray to medium-gray, thick- to thin-bedded argillaceous limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; contains subordinate olive-gray and tan-gray, thin-bedded shale and micaceous argillite; typically ridge and cliff former between less resistant shale members; in exposures to east on leading edge of Willard thrust sheet, thickens southward from 425 feet (130 m) along Sugar Pine Creek in the Dairy Ridge quadrangle, to 850 feet (260 m) along Sawmill Canyon in the Horse Ridge quadrangle (Coogan, 2006a, 2000b); to south 548 feet (167 m) thick at the Baldy Ridge section (Rigo, 1968, aided by Mullens) in the Causey Dam or Horse Ridge quadrangle, but may be faulted, because it is about 400 feet (120 m) thick on the flanks of Baldy and Knighton Ridges (Coogan and King, 2016). Given smaller thicknesses in adjacent quadrangles, may be structurally thickened in the Horse Ridge quadrangle.

Hodges Shale Member (Middle Cambrian) – Brown-weathering, slope-forming, olive-gray to tan-gray, thin-bedded shale and micaceous argillite, and thin- to thick-bedded, dark-gray to medium-gray limestone with tan-, yellow-, and red-weathering, wavy, silty layers and partings; typically vegetated slope former; in exposures to east along leading edge of Willard thrust sheet, thickens southward from 410 feet (125 m) along Sugar Pine Creek in the Dairy Ridge quadrangle, to 600 feet (180 m) along Sawmill Canyon in the Horse Ridge quadrangle (Coogan, 2006a, 2000b). To the south the Hodges is about 300 feet (90 m) thick on a flank of Baldy Ridge (Coogan and King, 2016), and reportedly 281 feet (86 m) thick at the Baldy Ridge section (Rigo, 1968, aided by Mullens) in the Causey Dam or Horse Ridge quadrangle; the lower Bloomington of Mullens (1969) in the Causey Dam quadrangle is likely the Hodges Shale, and it is about 250 feet (75 m) thick (see Mullens, 1969).

Cbk **Blacksmith Formation** (Middle Cambrian) (subsurface only) – Medium-gray, very thick- to thick-bedded, coarsely crystalline dolomite and dolomitic limestone with tan-weathering, irregular silty partings to layers; weathers to a lighter gray; forms cliffs and ridges; 409-foot (125 m) thickness reported to the west in the Sharp Mountain area (Hafen, 1961). To the east the Blacksmith on the leading edge of the Willard thrust sheet thickens southward from 600 feet (180 m) along Sugar Pine Creek in the Dairy Ridge quadrangle, to about 760 feet (230 m) in the northwestern Horse Ridge quadrangle (Coogan, 2006a, 2000b). To the south the Blacksmith is about 500 feet (150 m) thick near Causey Dam (Mullens, 1969), with a 530-foot (161 m) thickness reported at the Baldy Ridge section (Rigo, 1968, aided by Mullens) in the Causey Dam or Horse Ridge quadrangle. The Blacksmith thickness southwest of Monte Cristo Peak and west of Sharp Mountain is uncertain (see Coogan and King, 2016). But, the Blacksmith to the northwest is about 475 feet (144 m) thick in the Porcupine Reservoir quadrangle (Rigo, 1968; Hay, 1982), about 450 feet (137 m) thick near the Blacksmith Fork River (Deiss, 1938, p. 1112–1113; Maxey, 1958, p. 672), and 410 feet (125 m) thick in Blacksmith Fork Canyon (Hay, 1982).

Cu **Ute Formation** (Middle Cambrian) (subsurface only) – Gray, thick-bedded limestone and minor medium-bedded, gray to light-gray dolomite above and below interbedded, thin-bedded, gray to dark-gray limestone with tan-, yellowish-tan-, and reddish-tan-weathering, wavy, silty layers and partings and olive-gray to tan-gray, thin-bedded shale and micaceous argillite; mostly slope and thin ledge former; base less resistant (more argillaceous) than underlying Langston Formation; *Zacanthoides, Kootenia, Bathyuriscus*, and *Peronopsis* sp. trilobite fossils reported by Rigo (1968, USGS No. 5960-CO) in the Causey Dam quadrangle, but these trilobite species have long age ranges, hence are not age diagnostic (see Robison, 1976). Deiss (1938) and Berry (1989) reported *Ehmaniella* sp. trilobites northwest of the map area near the Blacksmith Fork River, making the Ute Middle Cambrian (see Robison, 1976). The Ute is reportedly 1090 feet (330 m) thick to the west in the Sharp Mountain area (Hafen, 1961), but this thickness is suspect since the Ute is thinner to the north, east, and west. King suspects that Hafen (1961) used dips that were too steep (~30 degrees versus ~16.5 degrees shown on his map near his measured section) so the Ute thickness is about 620 feet (190 m) where he measured it. North of the map area in the Hardware Ranch quadrangle, Deputy (1984) measured 681 feet (207.6 m) of Ute. To the east on the leading margin of the Willard thrust sheet, the Ute is about 450 feet (137 m) thick in the Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a, 2000b) and 515 feet (157 m) thick at the Baldy Ridge section (Rigo, 1968) in the Horse Ridge quadrangle. To the west of Sharp Mountain, the Ute is reportedly 600 to 700 feet (180–210 m) thick (see Ezell, 1953; Crittenden, 1972; Deputy, 1984), and although an 840-foot (256 m) thickness was reported in the Porcupine Reservoir area (Rigo, 1968), the Ute only looks to be about 600 feet (180 m) thick on Porcupine Reservoir map of Berry (1989).

The thickest Ute may be near the South Fork of Wolf Creek in the Huntsville quadrangle. I estimate the Ute there is ~1000 feet (300 m) thick, 1150 feet (350 m) thick if the dip is steeper, while King (Utah Geological Survey) estimates the Ute is ~1100 feet (335 m) thick, based on my map thicknesses of the Blacksmith and Hodges units near the South Fork of Wolf Creek, and his higher Langston-Ute contact. Rigo (1968) reported 1370 feet (418 m) of Ute near the South Fork of Wolf Creek, but his contacts were not used when mapping the area (see Coogan and King, 2016).

In the Browns Hole quadrangle south of Wolf Creek and southwest of the Monte Cristo Peak quadrangle, about 700 feet (210 m) of mixed shale and limestone was shown by Crittenden (1972) and his depiction was likely derived from the 659 feet (201 m) of Ute reported by Laraway (1958) along the South Fork of Ogden River in the Browns Hole quadrangle; this is about what Laraway (1958) mapped. Also, Crittenden (1972) did not map the Ute-Blacksmith contact; further, see problems in Coogan and King (2016) about the Ute and Blacksmith Formations.

Cl **Langston Formation** (Middle Cambrian) (subsurface only) – Upper part is brown-weathering, gray, sandy dolomite and limestone that weathers to ledges and cliffs; middle part is yellowish- to reddish-brown and gray weathering,

greenish-gray, silty shale and lesser interbedded gray laminated to very thin-bedded, silty limestone (Spence Shale Member); thin lower part is light-brown weathering, ledge-forming, gray limestone and dolomite, locally with poorly indurated tan, dolomitic sandstone at base (Naomi Peak Member) (after Coogan, 2006a, 2000b; King and others, 2018); conformably overlies Geertsen Canyon Quartzite. Designated "Formation" rather than "Dolomite" due to the varied lithologies.

Northwest of the map area, 410 feet (125 m) of Langston was measured along the upper Blacksmith Fork River in the Hardware Ranch quadrangle by Buterbaugh (1982). West of Monte Cristo Peak the Langston is 270 feet (80 m) thick in the Sharp Mountain area (Hafen, 1961) and to the east on the leading margin of the Willard thrust sheet it is about 200 to 250 feet (60–75 m) thick in the Horse Ridge and Dairy Ridge quadrangles (Coogan, 2006a, 2000b). To the southwest of the map area near Browns Hole, the 170 feet (50 m) of dolomite reported by Crittenden (1972, his entire Langston) is likely only the basal dolomite of the Langston Formation. Laraway (1958) probably measured 120 feet (37 m) of this basal dolomite and 298 feet (91 m) of Langston along the South Fork Ogden River in the Browns Hole quadrangle. Laraway's (1958) reported 398-foot (121 m) Langston thickness is likely an addition error, since he measured and mapped about 300 feet (90 m) of Langston. Near the South Fork of Wolf Creek in the Huntsville quadrangle, the Langston is about 300 feet (90 m) thick (my calculations), but King used a higher contact on our map (Coogan and King, 2016), making the Langston about 390 feet (120 m) thick. West of Sharp Mountain the Langston is about 400 to 460 feet (120–140 m) thick (see Ezell, 1953; Maxey, 1958; Rigo, 1968; Buterbaugh, 1982).

CAMBRIAN AND PROTEROZOIC

Cgc **Geertsen Canyon Quartzite** (Middle and Lower Cambrian and possibly Neoproterozoic) – In exposures west of the map area, mostly buff (off-white and tan) quartzite with pebble conglomerate beds; weathered quartzite outcrops darker than fresh surfaces; regionally some brown-weathering micaceous argillite interbeds, with *Skolithus* tubes, common at top, pebble to cobble conglomerate lenses in middle part of quartzite, and basal, very coarse-grained arkose (arkosic to feldspathic quartzite) locally; to the southwest near Huntsville, the total thickness is about 4200 feet (1280 m), including upper argillite about 375 feet (114 m) thick and basal arkose about 300 to 400 feet (90–120 m) thick (Crittenden and others, 1971); to the east on the leading margin of the Willard thrust sheet the Geertsen Canyon is thinner, an estimated 3200 feet (975 m) total thickness (Coogan, 2006a, 2000b). Top and base are not exposed in the Monte Cristo Peak quadrangle. Called Prospect Mountain and Pioche (argillite at top) by some previous workers. To the east, the Geertsen Canyon may be divided into different members, although the informal members to the west and east are based on conglomerate lenses near the member contact and a feldspathic lower member (see Crittenden and others, 1971; Coogan, 2006a, 2000b).

To the east, the contact between members is partly based on purplish color of upper part of lower member, so the contact may shift in the quartzite (Coogan, 2006a, 2000b). The upper member is incompletely exposed, so the thickness is uncertain, while the lower member is about 600 to 1300 feet (180–400 m) thick, thickening northward in the Dairy Ridge quadrangle. The upper member is tan, white, and light-gray, medium- to coarse-grained, cross-bedded, thick-bedded quartzite, with base marked by resistant, light-colored quartzite with quartz-pebble conglomerate containing white and pink quartz and rare jasper clasts. The lower member is typically conglomeratic and feldspathic and contains a purplish upper part and a light-colored lower part (Coogan, 2006a, 2000b).

PROTEROZOIC

Older Proterozoic strata are likely present in the Monte Cristo Peak quadrangle below a thick section of hard quartzite of the Geertsen Canyon Quartzite (see figure 2). These strata are described here, although reaching them by borehole would likely be expensive. These strata are exposed to the east in the Dairy Ridge quadrangle, to the southwest in the Browns Hole and Huntsville quadrangles, and to the west in the James Peak quadrangle, all on the Willard thrust sheet; for more detailed descriptions from these areas see Crittenden and others (1971), Crittenden (1972), Coogan (2006a, 2000b), and Coogan and King (2016).

Zb **Browns Hole Formation** (Neoproterozoic) (subsurface only) – In exposures to the east brownish to purplish red (hematitic), mostly volcanic meta-sandstone with some argillite (Coogan, 2006a), and to the west metamorphosed, intermediate-composition (basaltic andesite to trachytic) lava flows, fragmental(?) volcanic rocks, and volcanic-clast sedimentary rocks (Crittenden and others, 1971; Crittenden, 1972; Blau, 1975; Crittenden and Sorensen, 1985); volcanic material and clast size decreases to south and east, so mostly volcanic meta-sandstone with some

argillite near South Fork Ogden River and on leading margin of Willard thrust sheet (Coogan, 2006a); hornblende K-Ar dated at 570 ± 7 Ma (580 Ma corrected) from a trachyte cobble in Huntsville quadrangle (Crittenden and Wallace, 1973; Sorensen and Crittenden, 1979). To the east on figure 2 shown as line between Cgc and Zm-Zcc because Browns Hole is only 20 to 200 feet (6–60 m) thick in exposures on the leading edge of the Willard thrust sheet in the Dairy Ridge quadrangle (Coogan, 2006a); about 180 to 460 feet (55–140 m) thick to the west and south (Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979).

Upper or terra-cotta-colored quartzite member to south and west is not distinctly red or terra-cotta colored despite previous descriptions (see Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979). Much of the reddish-orange color seems to be along fault zones and be "bleeding" from the underlying hematitic Browns Hole. The upper unit is a lighter colored (white to pale gray), almost vitreous quartzite with an upper contact at beds that are less resistant and the overlying quartzite is placed in Geertsen Canyon Quartzite; beds higher in Geertsen Canyon are just as resistant. Unlike the basal Geertsen Canyon, the quartzite is not feldspathic or conglomeratic; this with the local absence of the upper quartzite unit implies the Geertsen Canyon Quartzite at least locally unconformably overlies the Browns Hole Formation; it is 0 to 285 feet (0–85 m) thick and is not present on the leading margin of the Willard thrust sheet (Coogan, 2006a, 2000b) and locally to the west.

Zm **Mutual Formation** (Neoproterozoic) (subsurface only) – Typically purplish (grayish-red to purplish-gray), thick-bedded quartzite with pebble conglomerate lenses; also reddish-gray, pink, tan, and light-gray in color and typically weathers to darker shades than, but at least locally indistinguishable from, the Geertsen Canyon Quartzite; locally feldspathic; contains argillite beds and, in the James Peak quadrangle, a locally mappable medial argillite unit like that reported in Idaho by Link and others (1987); to the west the Mutual is 435 to 1200 feet (130–370 m) thick in Browns Hole quadrangle (Crittenden, 1972) and is thinnest near the South Fork of Ogden River (Dr. Adolph Yonkee, Weber State University, verbal communication, 2006); thicker to northwest, up to 2600 feet (800 m) thick in Huntsville and James Peak quadrangles (Crittenden and others, 1971; Blau, 1975). May be as little as 300 feet (90 m) thick south of the South Fork of Ogden River (Coogan and King, 2016), and absent or thin on the leading edge of the Willard thrust sheet; therefore, thins to south and east.

To the east, undivided Mutual(?) and Caddy Canyon Formations (Zm?-Zcc) are shown on figure 2 because the Inkom Formation is missing and the undivided unit has characteristics of both formations in the Dairy Ridge quadrangle (see Coogan, 2006a); total exposed thickness of the undivided unit is about 725 to 1300 feet (220–400 m), with the base truncated by Willard thrust fault where queried Papoose Creek (Zpc? of Coogan and King, 2016; Zkc? of Coogan, 2006a) not exposed.

Zi? **Inkom Formation** (Neoproterozoic) (subsurface only) – Only present in west part of figure 2; absent on leading edge of Willard thrust sheet in east part of figure 2 (see Coogan, 2006a, 2000b); queried because location of "pinch out" not known. In exposures to the west the Inkom is gray to reddish-gray weathering, poorly resistant, psammite and argillite, with gray-weathering meta-tuff lenses in lower part; olive-gray to light-green, thin-bedded to laminated, micaceous meta-siltstone, argillite, and quartzite (meta-sandstone); 360 to 450 feet (110–140 m) thick in James Peak and Huntsville quadrangles (Crittenden and others, 1971; Blau, 1975); lower greenish-weathering part missing near South Fork of Ogden River and Inkom is less than 200 feet (60 m) thick.

Zcc **Caddy Canyon Quartzite** (Neoproterozoic) (subsurface only) – To west, mostly vitreous, almost white quartzite; colors vary and are tan, light gray, pinkish gray, greenish gray, and purplish gray, and typically lighter shades than the Geertsen Canyon Quartzite; 1500 feet (460 m) thick near the South Fork of Ogden River (Coogan and King, 2006) increasing northward to 2500 feet (760 m) thick near Geertsen Canyon in the Huntsville quadrangle (Crittenden and others, 1971; Crittenden, 1972), but this thickness likely includes 600 feet (180 m) of Papoose Creek Formation or mixed Papoose Creek–Caddy Canyon strata; thinner, 725 to 1300 feet (220–400 m) thick, and less vitreous on leading edge of Willard thrust sheet (Coogan, 2006a, 2006b).

The lower contact with the Kelley Canyon Formation is gradational with interbedded brownish-gray quartzite and argillite, reportedly over a few tens to 200 feet (3–60 m) (see Crittenden and others, 1971). Where thick, this gradational-transitional zone is what was mapped as the Papoose Creek Formation by Coogan and King (2016). Near geographical Geertsen Canyon, this transition zone is 600 feet (180 m) thick but was mapped with and included in the Caddy Canyon Quartzite by Crittenden and others (1971, figure 7) and was shown in the Caddy Canyon and Kelley Canyon Formations by Crittenden (1972, see lithologic column).

Interbedded gray quartzite (like Caddy Canyon) and reddish- and greenish-gray argillite (like Kelley Canyon) was mapped as Zpc? in the Dairy Ridge quadrangle by Coogan and King (2016); it is up to about 300 feet (90 m) thick, with its base truncated by the Willard thrust (see Zkc? of Coogan, 2006a). Other exposed Neoproterozoic units thin to the east, so this may be the entire Papoose Creek thickness.

Zkc **Kelley Canyon Formation** (Neoproterozoic) (subsurface only) – In exposures to the west, dark-gray to black, gray to olive-gray-weathering argillite to phyllite, with rare meta-carbonate; grades into overlying Caddy Canyon quartzite with increasing quartzite; gradational strata mapped as Papoose Creek Formation (Zpc) by Coogan and King (2016); silvery gray weathering reportedly characteristic (Sorensen and Crittenden, 1976), but silvery looking due to micas in phyllite rather than being a weathering characteristic; reportedly 2000 feet (600 m) thick near Huntsville (Crittenden and others, 1971, figure 7), but only shown as about 1600 feet (500 m) thick to Papoose Creek transition zone by Crittenden (1972).

Still older Proterozoic strata are not exposed on the leading edge of the Willard thrust sheet, and may or may not be present in subsurface in the Monte Cristo Peak quadrangle. Because figure 2 is diagrammatic, the Willard thrust fault may ramp upward and truncate these older units west of the location shown on figure 2, and they may not be present in the Monte Cristo Peak quadrangle.

Zmc **Maple Canyon Formation** (Neoproterozoic) (subsurface, if present) – Upper conglomerate member includes: green to greenish-gray feldspathic quartzite; light-gray, coarse-grained quartzite to gritty to pebble to small cobble meta-conglomerate, with dark-gray meta-graywacke matrix; olive-gray, laminated argillite with silvery phyllite; and light-gray quartzite to meta-conglomerate; total thickness 60 to 500 feet (18–150 m), but 200 feet (60 m) on average (Crittenden and others, 1971). Lower (green arkose) member includes greenish-gray, fine-grained, feldspathic meta-sandstone with argillite partings and local, lenticular quartzite as much as 200 feet (60 m) thick; lower member 500 to 1000 feet (150–300 m) thick (Crittenden and others, 1971); about 1000 feet (300 m) total formation thickness. Members are actually lithosomes.

ZYp **Formation of Perry Canyon, undivided** (Neoproterozoic and possibly Mesoproterozoic) (subsurface, if present) – Argillite to meta-graywacke upper unit, middle meta-diamictite, and basal slate, argillite, and meta-sandstone; locally includes meta-igneous rocks; phyllitic. Members are likely lithosomes; total thickness likely less than 2000 feet (600 m) (Coogan and King, 2016).

Graywacke (siltstone or sandstone) member includes olive-green to greenish-gray to brown to medium to dark-gray slate to argillite to phyllite to micaceous meta-siltstone and meta-graywacke to quartzose meta-sandstone, in variable proportions such that unit looks like both the "greywacke-sandstone" and "mudstone" members of previous workers; rare meta-gritstone and meta-diamictite (conglomerate?); locally schistose; reportedly 3000 feet (900 m) thick (after Crittenden and Sorensen, 1985), but apparently estimated on dip slope and actual thickness is only about 1000 feet (300 m) between Ogden Canyon and North Ogden divide (Coogan and King, 2016); may be gradational into "mudstone" member. Lower argillite of Maple Canyon Formation (Zmca on Huntsville and Browns Hole quadrangle maps of Sorensen and Crittenden, 1979, and Crittenden, 1972) is actually part of this Perry Canyon member.

Diamictite member includes gray to dark-gray meta-diamictite containing pebble- to boulder-size quartzite and granitoid (quartzo-feldspathic gneiss) clasts in very dark-gray sandy (up to granule size) to micaceous argillite matrix; local meta-pillow lava and meta-limestone at and near base, and local altered intrusive diorite; reportedly up to 1650 feet (500 m) thick (after Crittenden and Sorensen, 1985), but apparently estimated on dip slope and actual thickness only about 200 to 400 feet (60–120 m) (Coogan and King, 2016).

"Mudstone" member includes black non-foliated argillite and slate, and sandy argillite; grades laterally into black chloritoid schist that contains scattered pyrite cubes; locally contains lenses of pebbly meta-diamictite (conglomerate?); reportedly 1650 to 3300 feet (500–1000 m) thick (after Crittenden and Sorensen, 1985), but appears to be about 1000 to 1800 feet (300–550 m) thick in Wasatch Range (Coogan and King, 2016); relationship with diamictite member uncertain, but Dr. Adolph Yonkee (Weber State University, February 2, 2011, email) puts the mudstone member at the base of the formation of Perry Canyon, and noted that due to overturned folding, only one diamictite unit is present rather than two (see Crittenden and others, 1983).

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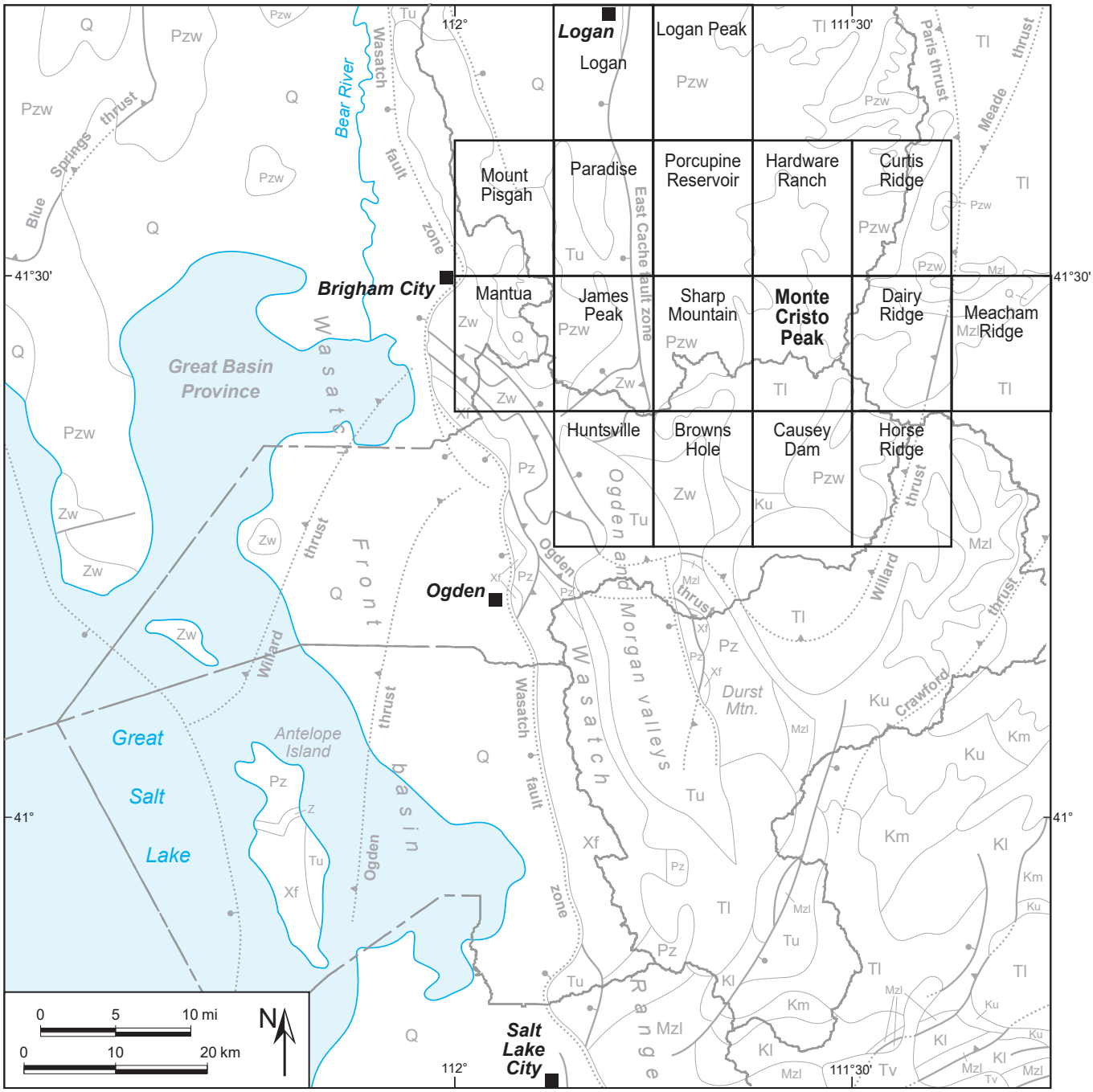


Figure 1. Generalized geologic map (modified from Yonkee and others, 1997) showing Monte Cristo Peak quadrangle (in bold) and quadrangles referred to in text.

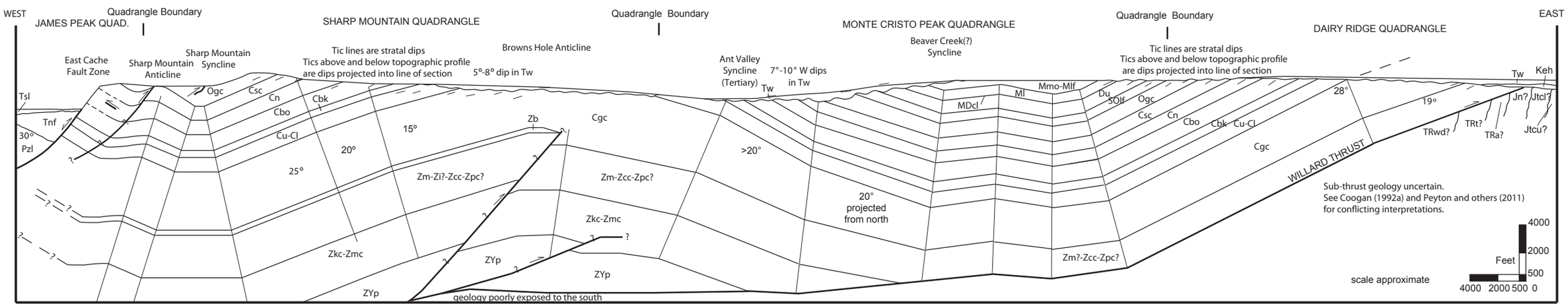


Figure 2. Diagrammatic cross section through the Willard thrust sheet across the southern Bear River Range, crossing the James Peak, Sharp Mountain, Monte Cristo Peak and Dairy Ridge equadrangles, Cache, Rich, and Weber Counties. Modified from Dr. Adolph Yonkee (Weber State University), email communication July 18, 2011, sketch. Scale approximate.

Unit symbols	Unit
Tsl	Salt Lake Formation
Tnf	Norwood and Fowkes Formations
Tw	Wasatch Formation
Keh	Hams Fork Member of Evanston Formation
Jtcu?	Upper Twin Creek Limestone
Jtcl?	Lower Twin Creek Limestone
Jn?	Nugget Sandstone
TRa?	Ankarah Formation
TRt?	Thaynes Formation
TRwd?	Woodside and Dinwoody Formations
Mmo-Mlf	Monroe Canyon and Little Flat Formations
Ml	Lodgepole Limestone
MDcl	Cottonwood Canyon Mbr of Lodgepole Limestone(?) and Leatham Formation
Du	Devonian rocks, undivided
Pzl	Lower Paleozoic rocks, potential units listed below
SOlf	Laketown and Fish Haven Dolomites
Ogc	Garden City Formation
Csc	St. Charles Formation
Cn	Nounan Formation
Cbo	Bloomington Formation
Cbk	Blacksmith Formation
Cu-Cl	Ute and Langston Formations
Cgc	Geertsen Canyon Quartzite
Zb	Browns Hole Formation
Zm	Mutual Formation
Zi?	Inkom Formation?
Zcc	Caddy Canyon Quartzite
Zpc?	Papoose Creek Formation?
Zkc	Kelley Canyon Formation
Zmc	Maple Canyon Formation
ZYp	Formation of Perry Canyon

MAP SYMBOLS

Monte Cristo Peak

Contact, dashed where approximately located or gradational, dotted where concealed

Fault, dashed where approximately located, dotted where concealed, sense of movement unknown

57 ?

Normal fault, bar and ball on down thrown side, dashed where approximately located, dotted where concealed, queried where existence uncertain; arrow and number indicate photogrammetric dip on fault

Lineament (fold axis or fault), bar and ball on downslope side

Edge of fluvial(?) surface

Anticline hinge zone trace, dashed where approximately located, dotted where concealed

? Syncline hinge zone trace, dashed where approximately located (very approximate for broad syncline in unit Tw), dotted where concealed, queried where uncertain and concealed, arrow shows plunge

Monocline (flexure) hinge zone trace, dashed where approximately located, dotted where concealed

35 Bearing and plunge of minor fold

Mass-movement scarp

Strike and dip of bedding

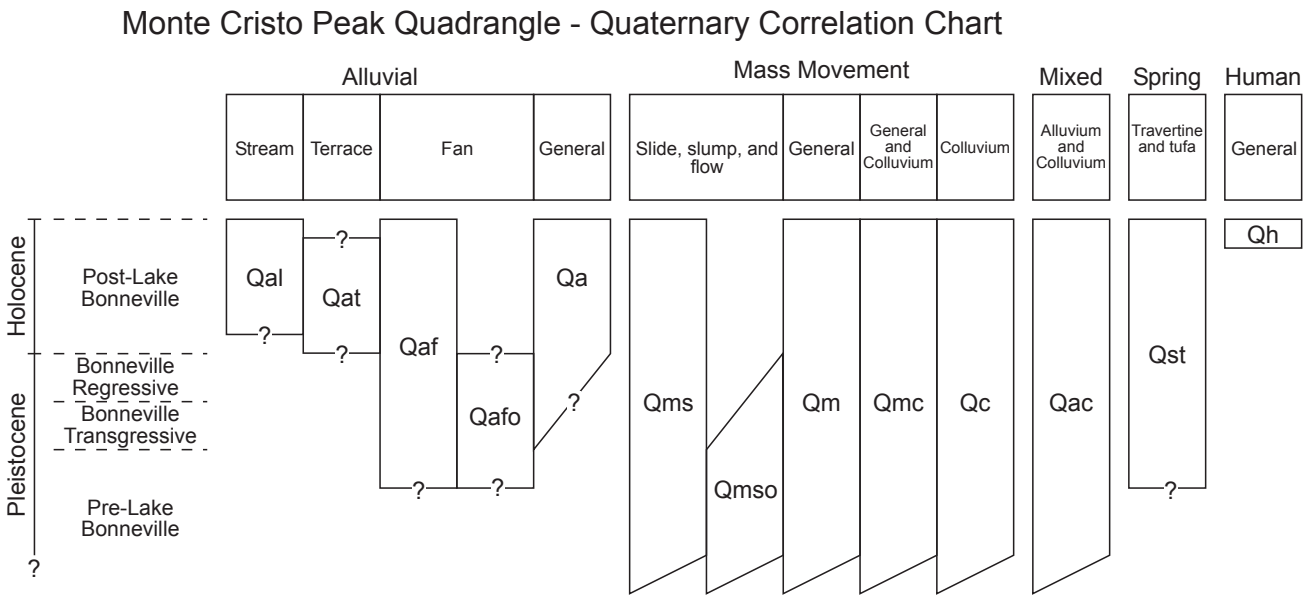
75 Upright

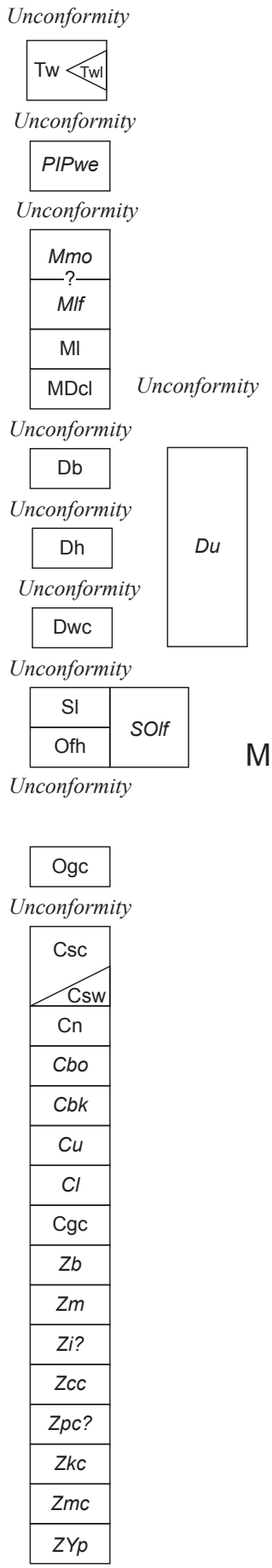
15 5 Photogrammetric, upright, basal Wasatch Formation in red

80 Strike and dip of joint

Sinkhole

Spring


Monte Cristo Peak Quadrangle - Quaternary Correlation Chart
Alluvial
Mass Movement
Mixed
Spring
Human
Stream
Terrace
Fan
General
Slide, slump, and flow
General
General and Colluvium
Colluvium
Alluvium and Colluvium
Travertine and tufa
General
Holocene
Pleistocene
Post-Lake Bonneville
Bonneville Regressive
Bonneville Transgressive
Pre-Lake Bonneville
Qal
Qat
Qaf
Qafo
Qa
Qh
Qms
Qmso
Qm
Qmc
Qc
Qac
Qst



MONTE CRISTO PEAK QUADRANGLE
(WILLARD THRUST SHEET)

Units symbols shown in italics only used in subsurface (figure 2) or only present in subsurface

LITHOLOGIC COLUMN - MONTE CRISTO PEAK QUADRANGLE

AGE	UNIT SYMBOL	GEOLOGIC UNIT		THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q	Q- various	Alluvial and lake deposits		0-500	0-150	
TERT	Tw	Wasatch Formation		0-1300	0-400	Twl - limestone, 0-300 ft (0-90 m)
						MAJOR UNCONFORMITY
IP.P.	*PIPwe*	Wells Formation		400?	120?	Covered, exposed to south
MISSISSIPPIAN	*Mmo*	Monroe Canyon Limestone		<1000?	<300?	Likely present in subsurface
	Mlf	Little Flat Formation		800?	245?	Thicker to south Delle Phosphatic Member
	Ml	Lodgepole (Gardison) Limestone		790-900	240-275	Top not exposed Fossiliferous MDcl - Cottonwood Canyon Mbr. and Leatham Formation
?						
DEV	Db	Beirdneau Sandstone		245-500	75-150	Db absent to west
	Dh	Hyrum Dolomite		400-675	120-205	Thinner to south
	Dwc	Water Canyon Formation		100-300	30-90	Thicker to west
S	Sl	Laketown Dolomite		500-600	150-180	2x thicker to west
?						
ORD	Ofh	Fish Haven Dolomite		100-135	30-40	UNCONFORMITY
	Ogc	Garden City Formation		est 800-1200	est 245-365	Swan Peak Fm. missing Thins to east and south Intraformational conglomerate
?						
CAMBRIAN	Csc	St. Charles Formation		700-900	215-275	
	Csw	Worm Creek Member		0-90	0-27	Quartzite locally
	Cn	Nounan Formation		800-1145	245-350	Thins to east and south Base not exposed Intraformational conglomerate
	Cbo	Bloomington Formation	Calls Fort Shale Member	75-125	25-40	Covered, exposed to east and to west
			Middle limestone member	425-550	130-165	
			Hodges Shale Member	250-600	75-180	
	Cbk	Blacksmith Formation		400-760	120-230	Limestone locally Thicker to east
	Cu	Ute Formation		450-700	140-215	Thicker to west
	Cl	Langston Formation		200-270	60-80	Top not exposed
	Cgc	Brigham Group	Geertsen Canyon Quartzite	3200-4200	975-1280	Thinner to east
?						Browns Hole quartzite mbr. locally distinct from Geertsen Canyon Quartzite
				0-150	0-45	
	Zb		Browns Hole Formation	20-460	6-140	Thinner and volcanic sandstone to east
PROTEROZOIC	*Zm*		Mutual Formation	435-2600	130-790	Purple to pink Cross-bedded Some argillite Some feldspar locally
	Zi?		Inkom Formation	0-450	0-140	Not present to east
	Zcc		Caddy Canyon Quartzite	1500-2500	460-760	To east, Mutual and Caddy Canyon Quartzites (Zm?c) 725-1300 ft (220-400 m) thick 2500 ft includes 600 ft transition zone of Papoose Creek Fm (Zpc) into Zkc
	Zkc	Kelley Canyon Formation		2000?	640?	Argillitic to phyllitic
	Zmc	Maple Canyon Formation	Conglomerate member	60-500	20-150	Covered, exposed to east in Dairy Ridge quadrangle and to west in James Peak quadrangle
			Green arkose member	500-1000	150-300	Thin limestone locally
	ZYp	Formation of Perry Canyon	Graywacke member	1000	300	Exposed to west
			Diamictite member	200-400	60-120	
			"Mudstone" member	1000-1800	300-550	

Unit symbols in italics=not exposed Diagram is schematic - no fixed thickness scale