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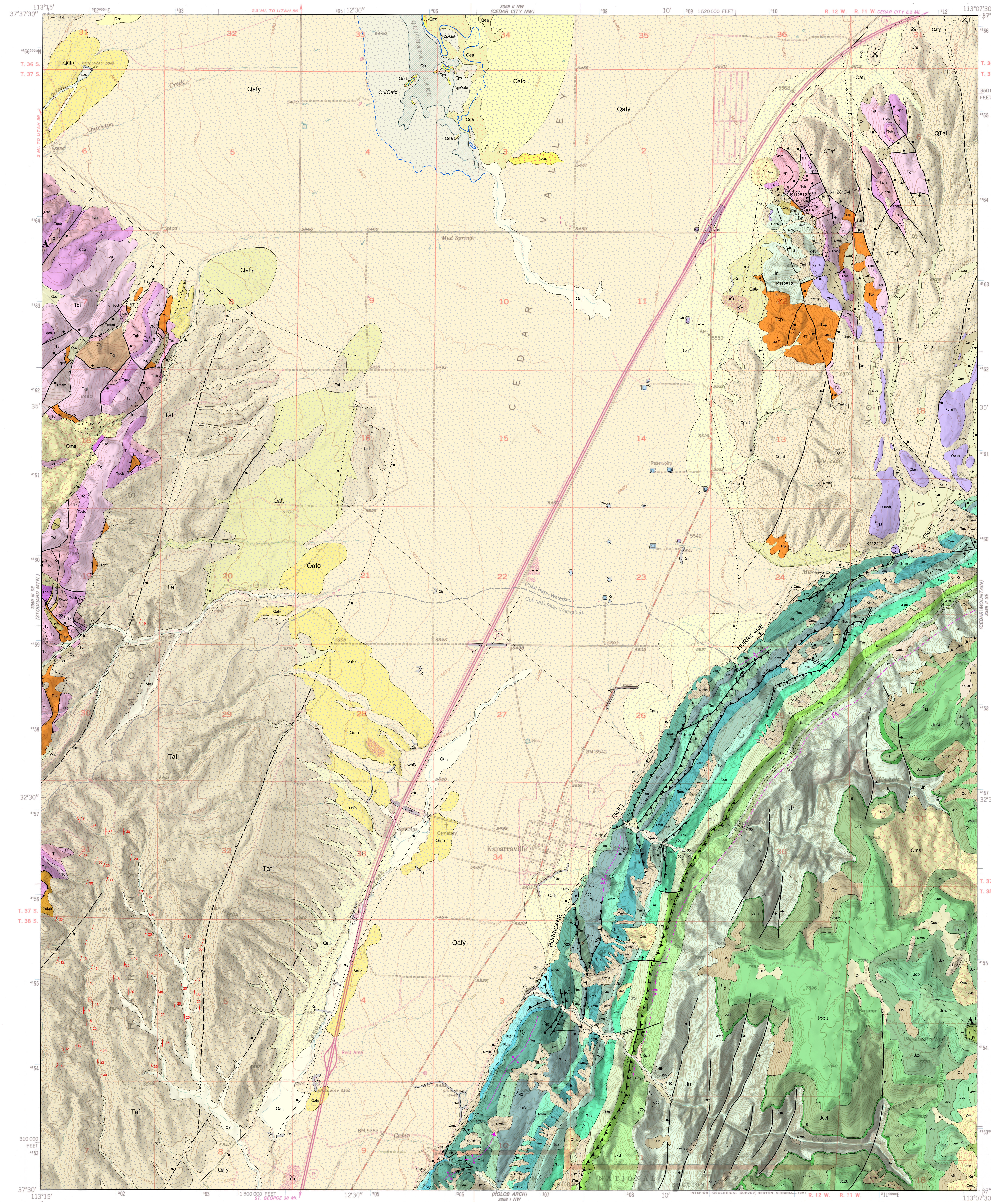

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

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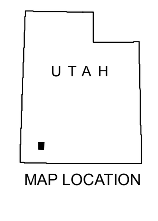
Geology intended for use at 1:24,000 scale.



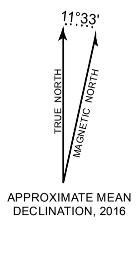
MAP LOCATION

GEOLOGIC MAP OF THE KANARRAVILLE QUADRANGLE, IRON COUNTY, UTAH

by

Robert F. Biek and Janice M. Hayden

2016



APPROXIMATE MEAN DECLINATION, 2016

Base from USGS Kanarraville 7.5' Quadrangle (1978)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Grant C. Willis
GIS and Cartography: Jay C. Hill, Kent D. Brown, and J. Buck Ehler

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P.O. Box 146100, Salt Lake City, UT 84114-6100
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geology.utah.gov

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

1	2	3
4		5
6	7	8

1. Desert Mound
2. Cedar City NW
3. Cedar City
4. Stoddard Mtn.
5. Cedar Mountain
6. New Harmony
7. Kolob Arch
8. Kolob Reservoir

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 978-1557919304

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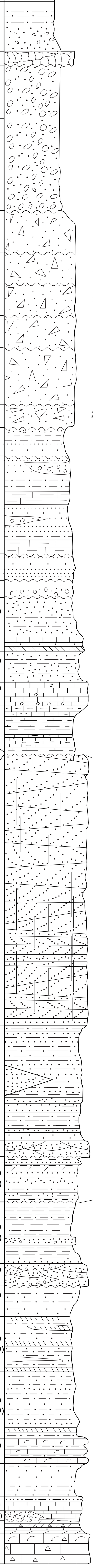
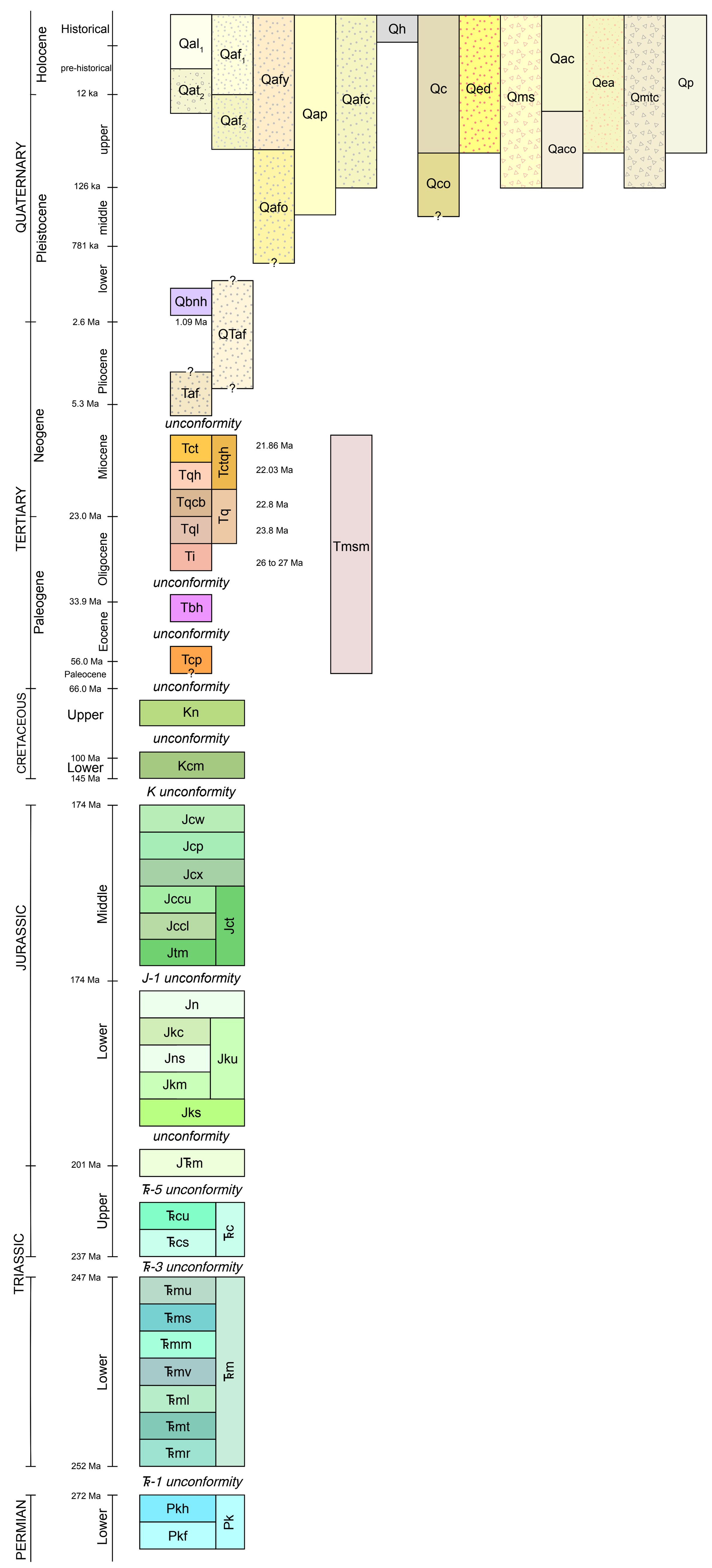
LITHOLOGIC COLUMN

SYSTEM	SERIES	FORMATION	MEMBER	SYMBOL	THICKNESS feet (meters)	REMARKS
QUATERNARY	Holocene	Surficial deposits		Q	0–200+ (0–60+)	
QUATERNARY	Pleistocene	North Hills lava flow		Qbnh	10–20 (3–6)	1.1 Ma
QUATERNARY / TERTIARY	Pleistocene / Pliocene	Basin-fill deposits		QTaf	800+ (245+)	
TERTIARY	Pliocene / Miocene	Basin-fill deposits		Taf	2000+ (600+)	
TERTIARY	Miocene	megabreccia of Stoddard Mtn. gravity slide		Tmsm	500 (150)	
TERTIARY	Miocene	Volcanic rocks of Comanche Canyon - ash flow tuff mbr.		Tct (Tctqh)	150 (45)	21.86 Ma
TERTIARY	Miocene	Harmony Hills Tuff		Tqh (Tctqh)	200 (60)	22.03 Ma
TERTIARY	Miocene	Bauers Tuff Mbr. of Condor Canyon Fm.		Tqcb (Tq)	50–220 (15–67)	22.8 Ma
TERTIARY	Oligocene	Leach Canyon Formation		Tql (Tq)	400+ (120+)	23.8 Ma
TERTIARY	Oligocene	Isom Formation		Ti	0–60 (0–18)	26-27 Ma
TERTIARY	Eocene	Brian Head Formation		Tbh	100+ (30+)	
TERTIARY	Eocene ? Paleocene	pink member of the Claron Formation		Tcp	800+ (245+)	
CRET.	Upper	Naturita Formation		Kn	150+ (45+)	formerly Dakota Fm.
CRET.	Lower	Cedar Mountain Formation		Kcm	25 (8)	*K unconformity*
JURASSIC	Middle	Carmel Formation	Winsor Member	Jcw	150–200 (45–60)	
JURASSIC	Middle	Carmel Formation	Paria River Member	Jcp	120–150 (37–45)	"chippy" limestone alabaster gypsum
JURASSIC	Middle	Carmel Formation	Crystal Creek Member	Jcx	200–250 (60–75)	
JURASSIC	Middle	Carmel Formation	Co-op Creek Limestone Member, upper	Jccu (Jct)	150–200 (45–60)	sparsely vegetated *Isocrinus sp.*
JURASSIC	Middle	Carmel Formation	Co-op Creek Limestone Member, lower	Jccl (Jct)	350 (105)	well vegetated
JURASSIC	Middle	Temple Cap Fm.	Manganese Wash Mbr.	Jtm (Jct)	3–30 (1–9)	red marker; *J-1 unconformity*
JURASSIC	Lower	Navajo Sandstone		Jn	1800–2000 (550–600)	vertical cliffs; large, sweeping cross beds; transition zone; planar bedded, sabkha environment
JURASSIC	Lower	Kayenta Formation	upper unit: Cedar City Tongue of Kayenta Formation	Jkc (Jku)	200–300 (60–90); Jku 700–800 (215–240)	
JURASSIC	Lower	Kayenta Formation	upper unit: Shurtz Ss Tongue of Navajo Ss	Jns (Jku)	0–100 (0–30)	Jns thins southward
JURASSIC	Lower	Kayenta Formation	upper unit: main body of Kayenta Formation	Jkm (Jku)	400–500 (120–150)	
JURASSIC	Lower	Kayenta Formation	Springdale Sandstone Member	Jks	100–150 (30–45)	prominent cliff former; *unconformity*
JURASSIC / TRIASSIC	Lower	Moenave Formation		JTRm	300–500 (90–150)	no fish scales found; uniform reddish brown; *TR-5 unconformity*
TRIASSIC	Upper	Chinle Formation	upper unit	TRcu (TRc)	300–400 (90–120)	limestone nodules at top; variegated, brightly colored; numerous landslides; white pebbly sandstone; petrified wood
TRIASSIC	Upper	Chinle Formation	Shinarump Member	TRcs (TRc)	100–200 (30–60)	prominent cliff former; *TR-3 unconformity*
TRIASSIC	Lower	Moenkopi Formation	upper red member	TRmu (TRm)	200–250 (60–75)	
TRIASSIC	Lower	Moenkopi Formation	Shnabkaib Member	TRms (TRm)	400–500 (120–150)	"bacon striped"; gypsum
TRIASSIC	Lower	Moenkopi Formation	middle red member	TRmm (TRm)	400–500 (120–150)	gypsum
TRIASSIC	Lower	Moenkopi Formation	Virgin Limestone Member	TRmv (TRm)	150–200 (45–60)	three limestone ledges
TRIASSIC	Lower	Moenkopi Formation	lower red member	TRml (TRm)	250 (75)	
TRIASSIC	Lower	Moenkopi Formation	Timpoweap Mbr.	TRmt (TRm)	120 (37)	
TRIASSIC	Lower	Moenkopi Formation	Rock Canyon Conglomerate Mbr	TRmr (TRm)	0–90 (0–27)	*TR-1 unconformity*
PERMIAN	Lower	Kaibab Formation	Harrisburg Member	Pkh (Pk)	100 (30)	
PERMIAN	Lower	Kaibab Formation	Fossil Mountain Member	Pkf (Pk)	200+ (60+)	brachiopods "black banded"

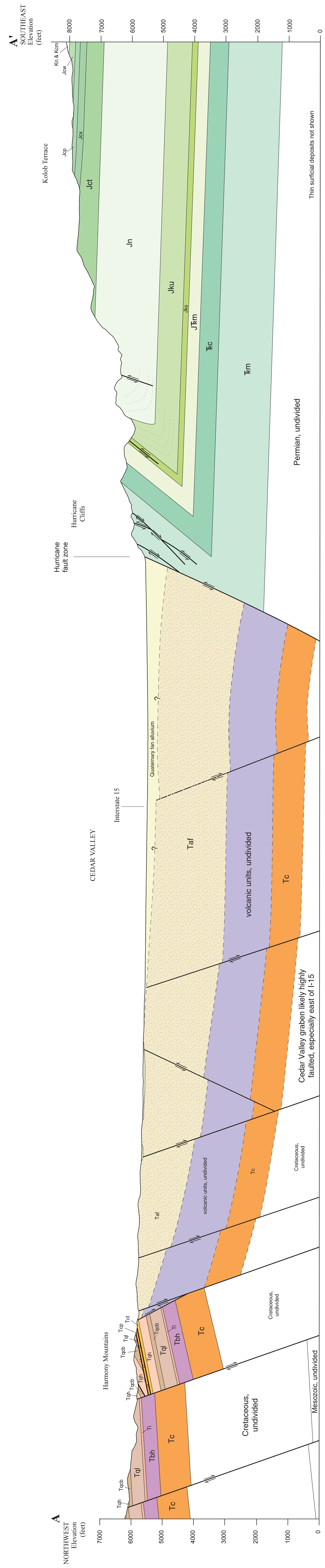


CORRELATION OF MAP UNITS



MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault – dashed where approximately located, dotted where concealed; bar and ball on down-thrown side where known
- Thrust fault – dashed where approximately located, dotted where concealed; saw teeth on upper plate
- Oblique-slip fault
- Gravity slide fault, dotted where concealed; barbs on upper plate
- Anticline, dashed where approximately located, dotted where concealed
- Syncline, dashed where approximately located, dotted where concealed
- Overturned anticline, dashed where approximately located, dotted where concealed
- Overturned syncline, dashed where approximately located, dotted where concealed
- Landslide main scarp
- Great Basin and Colorado River hydrologic boundary
- Shoreline, Holocene, dashed where approximately located
- 50 Strike and dip of inclined bedding
- 30 Approximate strike and dip of inclined bedding
- Strike of vertical bedding
- 21 Strike and dip of overturned bedding
- 25 Strike and dip of inclined bedding, determined photogrammetrically
- 25 Strike and dip of overturned bedding, determined photogrammetrically
- 18 Strike and dip of inclined bedding (from Averitt, 1967), unit Taf in southwest corner of quadrangle
- Sand and gravel pit
- K112412-1 Sample location and number (Biek and Knudsen, in prep.)



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by Robert F. Biek and Janice M. Hayden

MAP 276DM
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SCALE: 1:24,000

Cover photo: *Unusual spheroidal weathering of the North Hills lava flow.*

ISBN: 978-1-55791-930-4

MAP 276DM
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2016

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DESCRIPTION OF MAP UNITS

QUATERNARY

Human-derived deposits

Qh **Artificial fill** (Historical) – Artificial fill used to create stock ponds, retention structures, and highway fill; consists of engineered fill and general borrow material; fill should be anticipated in all areas with human impact, many of which are shown on the topographic base map; 0 to 30 feet (0–9 m) thick.

Alluvial deposits

Qal_1 **Stream alluvium** (Holocene) – Stratified, moderately to well-sorted clay, silt, sand, and gravel in active, major drainages; locally includes alluvial-fan and colluvial deposits too small to map separately, as well as alluvial-terrace deposits as much as 10 feet (3 m) above modern channels; probably less than 30 feet (9 m) thick.

Qat_2 **Stream-terrace alluvium** (Holocene to upper Pleistocene) – Stratified, moderately to well-sorted sand, silt, and pebble to boulder gravel that forms level to gently sloping surfaces 10 to 30 feet (3–9 m) above modern drainages; deposited primarily in a stream-channel environment; may include deposits of fan alluvium and colluvium too small to map separately; as much as 30 feet (9 m) thick.

Qaf_1 **Young fan alluvium** (Holocene) – Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment containing subangular to subrounded clasts deposited principally by debris flows and debris floods at the mouths of active drainages; locally, the master stream may be deeply entrenched; equivalent to the upper part of younger fan alluvium (Qafy), but differentiated because Qaf_1 typically forms smaller, isolated fans with a steeper gradient; typically less than 30 feet (9 m) thick, but larger, coalesced deposits may exceed several tens of feet thick.

Qaf_2 **Middle fan alluvium** (Holocene to upper Pleistocene) – Similar in composition and morphology to young fan alluvium (Qaf_1), but forms mostly inactive surfaces incised by younger stream and fan deposits; deposited principally by debris flows and debris floods at the mouths of modern drainages; equivalent to the older, lower part of young and middle fan alluvium (Qafy); exposed thickness as much as several tens of feet.

Qafy **Younger fan alluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited by streams, debris flows, and debris floods on alluvial fans; forms both active depositional surfaces and low-level inactive surfaces incised by small streams that are undivided here; includes alluvium and colluvium along upslope edges of the fans; mapped where fan alluvium spills out from smaller drainages of the Hurricane Cliffs, North Hills, and Harmony Mountains; small, isolated deposits are typically less than a few tens of feet thick, but larger, coalesced deposits are much thicker and form the upper part of basin-fill deposits.

Rowley and others (2008) briefly summarized evidence for a late Pleistocene shallow lake, first suggested by Thomas and Taylor (1946), that may have occupied parts of Cedar Valley. The lake may have been separated into northern and southern parts by a low divide at an elevation of about 5500 feet (1675 m) northeast of Iron Springs gap northwest of Cedar City. The northern lake is thought to have overtopped its valley threshold and spilled northwest into Lake Bonneville through Mud Spring Canyon northwest of Rush Lake (its modern remnant) at the northwest margin of the valley. The southern lake apparently spilled northwest through Iron Springs gap. This southern lake, in central and southern Cedar Valley, was no more than a few tens of feet deep at its modern remnant, Quichapa Lake. Because of the lake's limited depth, shorelines are poorly developed or not preserved, having been concealed by younger fan alluvium as mapped here. Still, one intriguing feature suggestive of such a lake is the large underfit valley that drains Iron Springs gap, now occupied by the normally dry Iron Springs Creek (Rowley and others, 2008; Knudsen and Biek, 2014); a similar underfit valley marks the outlet of the Rush Lake part of the basin.

Qafc **Coalesced fan alluvium of Cedar Valley** (Holocene to upper Pleistocene) – Similar to younger fan alluvium (Qafy) but forms large, coalesced fans of Cedar Valley; typically exhibits a lower overall slope than younger fan alluvium; forms active depositional surfaces and was deposited principally as debris flows and debris floods; thickness uncertain, but Hurlow (2002) showed that Quaternary and Neogene basin fill is in excess of 1500 feet (460 m) thick near Quichapa Lake in southern Cedar Valley; only the uppermost part of this basin fill is included in map unit Qafc, which we assume to be in excess of several tens of feet thick.

Qap **Pediment alluvium** (Holocene to middle Pleistocene?) – Poorly sorted silt and sand and subangular to rounded, small boulder gravel partially covering gently sloping and deeply dissected erosional surfaces cut into upper Tertiary fan alluvium (Taf) in the northwest corner of the map area; deposited principally as debris flows, debris floods, and as ephemeral stream channel deposits; 0 to 30 feet (0–9 m) thick.

Qafo **Older fan alluvium** (Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with moderately developed calcic soils (caliche); forms broad, gently sloping, incised surfaces in Cedar Valley; deposited principally as debris flows and debris floods; exposed thickness as much as several tens of feet.

Colluvial deposits

Qc **Colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited principally by slope wash and soil creep on moderate slopes and in shallow depressions; locally includes talus and alluvial deposits too small to map separately; typically less than 20 feet (6 m) thick.

Qco **Older colluvium** (upper to middle Pleistocene) – Similar to colluvium but deeply incised by modern drainages; deposit in the south-central part of section 1, T. 37 S., R. 12 W. includes large basalt blocks of the North Hills lava flow; typically less than 40 feet (12 m) thick.

Eolian deposits

Qed **Eolian dune sand** (Holocene to upper Pleistocene) – Well-sorted silt and fine-grained sand; deposited in small dunes, now largely stabilized by vegetation, downwind of Quichapa Lake; as much as about 15 feet (5 m) thick.

Mass-movement deposits

Qms **Landslides** (Holocene to upper Pleistocene) – Extremely poorly sorted, clay- to boulder-size, chaotic debris with large blocks of rotated strata that form chaotic, hummocky surfaces; form primarily on steep slopes of the Carmel and Brian Head Formations; slide masses involve overlying bedrock formations and talus and commonly exhibit soil creep; evidence of historical movement is locally common; undivided as to inferred age because even landslides having subdued morphology (suggesting that they are older, weathered, and have not experienced recent large-scale movement) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar may show that many slopes, particularly those developed on the Carmel Formation, host surficial deposits that reveal evidence of creep or shallow landsliding; understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations; thickness of these deposits is highly variable, but is generally 30 to 100 feet (9–30 m).

Mixed-environment deposits

Qac **Alluvium and colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.

Qaco **Older alluvium and colluvium** (upper Pleistocene) – Similar to mixed alluvium and colluvium (Qac), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6–9 m) thick.

Qea **Eolian and alluvial fine-grained deposits** (Holocene to upper Pleistocene) – Moderately to well-sorted, yellowish-brown silt and fine-grained sand deposited by wind and locally reworked by sheetwash and ephemeral streams near Quichapa Lake; probably less than 20 feet (6 m) thick.

Qmtc **Talus and colluvium** (Holocene to upper Pleistocene) – Poorly sorted, angular to subangular, cobble- to boulder-size and finer-grained interstitial sediment deposited principally by rockfall and slope wash on steep slopes throughout the quadrangle; includes minor alluvial sediment at the bottom of washes and locally contains small landslides; generally less than 30 feet (9 m) thick.

Playa deposits

Qp **Playa deposits** (Holocene to upper Pleistocene) – Calcareous, saline, and gypsiferous, light-gray and yellowish-brown clay, silt, and fine-grained sand deposited on the flat playa floor of Quichapa Lake; locally includes small dunes of eolian silt and fine-grained sand; thickness uncertain, but probably at least several tens of feet thick.

Quichapa Lake is a terminal playa lake that prehistorically received most of its runoff from the Shurtz Creek drainage east of the map area, but that now also receives runoff diverted from the Coal Creek drainage east of Cedar City. It lies atop a distinct sub-basin within Cedar Valley thought to have formed in response to early development and subsequent linkage of once discrete fault segments of the Hurricane and related fault zones (Hurlow, 2002). We infer that a playa has occupied this area intermittently throughout the Pleistocene, but deposits at and near the surface are doubtless Holocene in age.

Stacked-unit deposits

Qp/Qafc

Playa deposits over coalesced fan alluvium of Cedar Valley (Holocene/Holocene to upper Pleistocene) – Thin (generally less than 1 foot thick [0.3 m]) accumulations of clay, silt, and locally dried mats of filamentous algae over low-relief alluvial-fan deposits (Qafc); deposited during high lake levels, including several flood events in historical time (Lips, 2010); extent of Qp/Qafc corresponds to the approximate high-stand shoreline established during a 2005 flood event.

Basaltic lava flow

Qbnh North Hills lava flow (lower Pleistocene) – Dark-greenish-gray to brownish-black basalt with small phenocrysts of clinopyroxene and olivine; preserved as faulted remnants that overlie Quaternary and late Tertiary fan alluvium (QTaf) of the North Hills; we suspect, as did Anderson and Mehnert (1979), that the North Hills flow erupted from one or more vents at Pine Spring Knoll or Co-op Knoll in the central Cedar Mountain 7.5′ quadrangle adjacent on the east, but that correlation has not yet been confirmed; sample IHH273-1 from the south end of the North Hills yielded a K-Ar age of 1.09 ± 0.34 Ma (Anderson and Mehnert, 1979), concordant with the 1.06 ± 0.28 Ma Pine Spring Knoll flow complex mentioned above (Anderson and Mehnert, 1979, sample C-311-34); Knudsen (2014) reported an $^{40}Ar/^{39}Ar$ age of 1.12 ± 0.08 Ma for the similar Cross Hollow Hills lava flow immediately northeast of this quadrangle; typically about 20 feet (6 m) thick but may be thicker where it fills paleotopography eroded into underlying basin-fill deposits.

The North Hills lava flow is near the northern edge of the Western Grand Canyon basaltic field, which extends across the southwest part of the Colorado Plateau and adjacent High Plateaus transition zone with the Basin and Range Province in southwest Utah, northeast Arizona, and adjacent Nevada (Hamblin, 1963, 1970, 1987; Best and Brimhall, 1970, 1974; Best and others, 1980; Smith and others, 1999; Johnson and others, 2010). This volcanic field contains hundreds of relatively small-volume, widely scattered, mostly basaltic lava flows and cinder cones that range in age from Miocene to Holocene. In southwestern Utah, basalts are synchronous with basin-range deformation and are part of mostly small, bimodal (basalt and high-silica rhyolite) eruptive centers (Christiansen and Lipman, 1972; Rowley and Dixon, 2001). The oldest basaltic lava flows in southwestern Utah are about 17 Ma (basalt of Harrison Peak; Biek and others, 2009). The youngest dated lava flow in southwest Utah is the 32,600 ± 300 cal yr B.P. (27,270 ± 250 ^{14}C yr B.P.) Santa Clara basaltic lava flow (Willis and others, 2006; Biek and others, 2009; Willis and Hayden, 2015), but the Dry Valley and Panguitch Lake lava flows south of Panguitch Lake may be younger still (Biek and others, 2015).

unconformity

QUATERNARY-TERTIARY

QTaf **Quaternary and late Tertiary fan alluvium** (Pleistocene? to Pliocene?) – Rare exposures show these deposits to be poorly sorted, poorly to moderately lithified, clay to large boulder-size debris with a muddy and sandy, reddish-brown matrix; clasts are mostly subangular to subrounded regional ash-flow tuffs, quartz monzonite porphyry, Claron Formation, Upper Cretaceous sandstone and oyster coquina, Carmel limestone, and Lower Jurassic sandstone; clasts also include rounded quartzite and limestone cobbles and boulders recycled from the Grand Castle Formation, Drip Tank Conglomerate Member of the Straight Cliffs Formation, and Claron Formation; locally, clasts of one lithology—typically Navajo Sandstone, Claron Formation, or quartz monzonite porphyry—dominate the deposits; megaboulders of quartz monzonite porphyry—probably derived from the Pine Valley laccolith (Averitt, 1962; Anderson and Mehnert, 1979; Biek and others, 2009)—and regional ash-flow tuffs as much as 10 to 15 feet (3–5 m) in diameter are locally common; Averitt (1967) interpreted parts of this map unit as Claron Formation or regional ash-flow tuffs, but volcanic clasts weathering out of his "Claron" hillsides and wildly disparate flow foliations in ash-flow tuff megaboulders clearly show this to be younger transported material; at least 800 feet (240 m) thick in the North Hills.

Anderson and Mehnert (1979) interpreted a westerly source for the North Hills deposits, inferred that they were deposited principally as debris flows given the great size of their common boulders, and constrained their age to younger than about 20 Ma and older than about 1 Ma (the age of dated underlying Harmony Hills Tuff and apparently overlying basaltic lava flows). However, the presence of locally abundant Lower Jurassic sandstone clasts is problematic given that this interval is not exposed west of Cedar Valley, and thus the North Hills deposits likely represent basin-fill material derived from both the west and east.

TERTIARY

Taf **Late Tertiary fan alluvium** (Pliocene to Miocene) – Poorly to moderately lithified, mostly reddish-brown, fine- to medium-grained sandstone, siltstone, and lesser conglomerate nearly everywhere covered by colluvium; conglomerate clasts—similar in lithologic diversity (or locally in lack of diversity) and size to those observed in QTaf at the North Hills—weather out and accumulate at the surface, giving the impression of an overall coarser deposit than in fact exists; additionally, some of this pebble to boulder lag may represent remnants of coarser pediment-mantle deposits that may have once covered the eastern flank of the Harmony Mountains; mapped by Averitt (1967) as two units of Miocene(?) alluvium, but we see no significant difference between his upper and lower units, and we find that the resistant conglomerate ledges in his lower unit are nothing more than small, discontinuous exposures; Hurlow (1998) postulated deposition primarily by debris flows from the west, and Rowley and others (2008) suggested that these older basin-fill deposits resulted from erosion of rapidly emplaced intrusions of the Iron Axis; the fine-grained nature of many of the deposits suggests at least local deposition in a distal fan setting; Hurlow (1998) described three informal units having a total thickness of 1500 feet (450 m) whereas Rowley and others (2008) reported a maximum thickness of 2000 feet (600 m), both in the greater Cedar Valley area; map patterns here show an incomplete section at least 2000 feet (600 m) thick on the east flank of the Harmony Mountains.

Tctqh **Ash-flow tuff member of the volcanic rocks of Comanche Canyon, and Harmony Hills Tuff, undivided** (lower Miocene) – Mapped at the west edge of the quadrangle, west of Kanarraville, where the two highly faulted and fractured units appear to be part of the Stoddard Mountain gravity slide.

Tctcp **Ash-flow tuff member of the volcanic rocks of Comanche Canyon, and pink member of the Claron Formation, undivided** (lower Miocene and Paleocene-Eocene) – Mapped at the west edge of the quadrangle northwest of Kanarraville where thin slivers of the two units appear to be part of the Stoddard Mountain gravity slide; there, the pink member is poorly exposed pebbly conglomerate identified by its distinctive suite of clasts.

Tmsm **Megabreccia of the Stoddard Mountain gravity slide** (lower Miocene) – A chaotic mixture of Claron, Brian Head, Leach Canyon, Bauers Tuff Member, and Harmony Hills Tuff mapped in the northeast part of the Harmony Mountains; appears to both overlie and locally include Comanche Canyon tuff; interpreted as gravity-slide breccia derived from catastrophic failure of the east flank of the Stoddard Mountain intrusion; map patterns suggest that the breccia may be as much as 500 feet (150 m) thick.

Tct **Volcanic rocks of Comanche Canyon, ash-flow tuff member** (lower Miocene) – White to light-gray, unwelded, crystal-rich, dacitic ash-flow tuff with abundant resistant fragments of quartz monzonite porphyry; contains rare but conspicuous reddish-brown sandstone lithic fragments (possibly of slightly metamorphosed Iron Springs Formation [Rowley and others, 2008]) and even less common fragments of the Bauers Tuff Member of the Condor Canyon Formation; locally cavernous weathering; non-resistant matrix and resistant angular quartz monzonite clasts make it appear similar to an autobrecciated ash-flow tuff; unconformably overlain by basin-fill deposits (Taf); erupted from the east side of the Stoddard Mountain laccolith in the adjacent Stoddard Mountain quadrangle (Rowley and others, 2008); $^{40}Ar/^{39}Ar$ age is 21.86 ± 0.09 Ma (Rowley and others, 2008); incomplete thickness at the west edge of the map area, where it was previously mapped as a local tuff within the Claron Formation by Averitt (1967), is several tens of feet, and newly identified but incomplete exposures in the North Hills are about 150 feet (45 m) thick; Rowley and others (2008) reported that collectively, lava flows and ash-flow tuff are as much as about 160 feet (50 m) thick in the Stoddard Mountain area.

Quichapa Group (lower Miocene to upper Oligocene) – Consists of three regionally distinctive ash-flow tuffs: in ascending order, the Leach Canyon Formation, Condor Canyon Formation, and Harmony Hills Tuff (Mackin, 1960; Williams, 1967; Anderson and Rowley, 1975; Rowley and others, 1995). The Leach Canyon Formation likely erupted from the Caliente caldera complex (Williams, 1967), the two-member Condor Canyon Formation clearly erupted, at least in part, from the west (Clover Creek caldera) part of the Caliente caldera complex (Rowley and others, 1995), and the Harmony Hills Tuff likely erupted from the eastern Bull Valley Mountains (Rowley and others, 1995).

Tqh **Harmony Hills Tuff** (lower Miocene) – Resistant, pale-pink to grayish-orange-pink, crystal-rich, moderately welded, dacitic ash-flow tuff; contains about 50% phenocrysts of plagioclase (63%), biotite (16%), hornblende (9%), quartz (7%), pyroxene (5%), and sanidine (trace) (Williams, 1967); weathers to rounded outcrops and glittery, sandy soils; disconformably overlies the Bauers Tuff Member; yielded an $^{40}Ar/^{39}Ar$ plateau age of 22.03 ± 0.15 Ma (Cornell and others, 2001); probably about 200 feet (60 m) thick in this map area, but thicknesses are difficult to estimate due to poor, structurally complicated exposures—Averitt (1967) estimated thickness as 300 to 350 feet (90–110 m) in this map area; Knudsen and Biek (2014) reported that the tuff is as much as 200 feet (60 m) thick in the nearby Eightmile Hills, similar to the 180 to 250 feet (55–75 m) reported there by Mackin and others (1976).

In this map area, the best exposures of Harmony Hills Tuff are in section 6, T. 37 S., R. 12 W. at the north end of the Harmony Mountains. Elsewhere in the Harmony Mountains and North Hills, the member is preserved in highly faulted blocks and weathers to rubble-covered slopes unconformably overlain by basin-fill deposits or by the Comanche Canyon tuff member. The source of the Harmony Hills Tuff is unknown, but thickness isopachs are centered on Bull Valley (Williams, 1967), suggesting that it was derived from the eastern Bull Valley Mountains, probably from an early, much more voluminous eruptive phase of the Bull Valley/Hardscrabble Hollow/Big Mountain intrusive arch as suggested by Blank (1959), Williams (1967), and Rowley and others (1995, 2008). Consistent with this interpretation is the fact that its age is nearly identical to those intrusions.

Tq **Bauers Tuff Member of Condor Canyon Formation and Leach Canyon Formation, undivided** (lower Miocene and upper Oligocene) – Mapped in the northeast part of the Harmony Mountains where these ash-flow tuffs are highly fractured and heavily iron stained.

Tqcb **Bauers Tuff Member of Condor Canyon Formation** (lower Miocene) – Resistant, light-brownish-gray to pinkish-gray, densely welded, rhyolitic ash-flow tuff; contains about 10 to 20% phenocrysts of plagioclase (40–70%), sanidine (25–50%), biotite (2–10%), Fe-Ti oxides (1–8%), and pyroxene (<3%), but lacks quartz phenocrysts (Rowley and others, 1995); bronze-colored biotite and light-gray flattened lenticules are conspicuous in the upper, vapor-phase part of the tuff, and a basal vitrophyre 10 to 20 feet (3–6 m) thick is normally present; typically forms a more resistant ledge between slightly less resistant Leach Canyon and Harmony Hills tuffs; weathers to form grussy soils; disconformably overlies the Leach Canyon Formation; about 220 feet (67 m) thick at the north end of the Harmony Mountains and about 50 feet (15 m) thick at the north end of the North Hills, but elsewhere thickness is difficult to estimate due to poor, structurally complicated exposures—Averitt (1967) estimated thickness in this map area as 170 to 250 feet (50–75 m); Knudsen and Biek (2014) reported that the tuff is about 150 feet (45 m) thick in the nearby Eightmile Hills, similar to the 100 to 180 feet (30–55 m) reported there by Mackin and others (1976).

In this map area, the best exposures of the Bauers Tuff Member are in the SW ¼ section 6 and the NW ¼ section 7, T. 37 S., R. 12 W. at the north end of the Harmony Mountains. Excellent exposures are also present in the North Hills in a drainage on the southwest flank of hill 6233 in the SE ¼ section 1, T. 37 S., R. 12 W. Elsewhere in the Harmony Mountains and North Hills, the member is preserved in highly faulted blocks and weathers to rubble-covered slopes unconformably overlain by basin-fill deposits.

The Bauers Tuff Member erupted from the northwest part (Clover Creek caldera) of the Caliente caldera complex and covered an area of at least 8900 square miles (23,000 km^2) (Best and others, 1989b; Rowley and others, 1995) with an estimated volume of 740 mi^3 (3200 km^3) (Best and others, 2013). The preferred $^{40}Ar/^{39}Ar$ age of the Bauers Tuff Member is 22.7 Ma (Best and others, 1989a) or 22.8 Ma (Rowley and others, 1995), which is also the $^{40}Ar/^{39}Ar$ age of its intracaldera intrusion exposed just north of Caliente, Nevada (Rowley and others, 1994b). Fleck and others (1975) reported a K-Ar age (corrected according to Dalrymple, 1979) of 22.7 ± 0.6 Ma (plagioclase) for Bauers Tuff Member on the Markagunt Plateau.

Tql **Leach Canyon Formation** (upper Oligocene) – Grayish-orange-pink to pinkish-gray, poorly welded, crystal-rich rhyolite tuff that contains abundant white or light-pink collapsed pumice fragments and several percent lithic clasts, many of which are reddish brown; contains 25 to 35% phenocrysts of plagioclase, slightly less but subequal amounts of quartz and sanidine, and minor biotite, hornblende, Fe-Ti oxides, and a trace of pyroxene; typically disconformably overlies the Isom Formation in the greater Cedar Valley area and locally in the Harmony Mountains in this map area; elsewhere in the map area, it apparently unconformably overlies either poorly exposed Brian Head or Claron strata—likely, Isom or Brian Head strata are missing not because of a local unconformity but rather due to structural truncation by gravity sliding; about 200 feet (60 m) thick in the North Hills and an incomplete section in the northern Harmony Mountains at the west edge of the map area is probably about 400 feet (120 m) thick; the Leach Canyon Formation is 150 to 300 feet (45–90 m) thick in the Eightmile Hills (Knudsen and Biek, 2014).

In this map area, the best exposures of Leach Canyon are in section 7, T. 37 S., R. 12 W. at the north end of the Harmony Mountains. Elsewhere in the Harmony Mountains and North Hills, Leach Canyon is preserved in highly faulted blocks and weathers to rubble-covered slopes; in an apparent gravity slide block in the north-central part of section 18, T.37 S., R. 12 W. in the Harmony Mountains, it is locally heavily iron stained.

The Leach Canyon Formation is widely agreed to be about 23.8 Ma (Best and others, 1993; Rowley and others, 1995; Biek and others, 2015). Its source is unknown, but is probably the Caliente caldera complex because isopachs show that the formation thickens toward the complex (Williams, 1967; Rowley and others, 1995). The total volume of the Leach Canyon is estimated to be 830 mi^3 (3600 km^3), representing the largest eruption of the Caliente caldera complex (Best and others, 2013).

Ti **Isom Formation** (upper Oligocene) – Medium-gray, crystal-poor, densely welded, trachydacitic ash-flow tuff, typically having distinctive rheomorphic features including flow folds, elongated vesicles, and flow breccias and thus commonly known as a tufflava (Mackin, 1960; Anderson and Rowley, 2002); small (1–3 mm) euhedral crystals constitute 10 to 15% or less of the rock and are mostly plagioclase (90%) and minor pyroxene and Fe-Ti oxides set in a devitrified-glass groundmass; exhibits pronounced subhorizontal lamination or platiness, which Mackin (1960) called "lenticules" that locally are dark reddish brown to dusky red; base not exposed, but unit ranges from 0 to about 60 feet (0–18 m) thick in this map area; Mackin and others (1976) reported that the Hole-in-the-Wall Member is 10 to 60 feet (3–18 m) and the Baldhills Tuff Member is 250 to 350 feet (75–110 m) thick at Eightmile Hills, similar to that reported by Knudsen and Biek (2014).

In this map area, the Isom Formation is thin and poorly exposed in the Harmony Mountains and is absent in the North Hills. At its type area in the Iron Springs district north of the map area, Mackin (1960) defined three members, a lower unnamed member, the Baldhills Tuff Member, and the upper Hole-in-the-Wall Tuff Member; Rowley and others (1975) redefined the Baldhills Tuff Member to include Mackin's lower unnamed member and noted that the Baldhills consists of at least six cooling units. Both members, the thick Baldhills and the thin overlying Hole-in-the-Wall, are present to the north at Eightmile Hills (Mackin and others, 1976; Knudsen and Biek, 2014), but we are uncertain which member may be present in this map area.

Regionally, many outcrops of all cooling units in the Isom Formation reveal secondary flow characteristics, including flow breccias, contorted flow layering, and linear vesicles such that the unit was considered a lava flow until Mackin (1960) mapped its widespread distribution (300 cubic miles [1300 km^3] today spread over an area of 9500 square miles [25,000 km^2] [Best and others, 1989a]) and found evidence of glass shards, thus showing its true ash-flow tuff nature. For that reason, the Isom is commonly referred to as a tufflava, also called a rheomorphic ignimbrite, an ash-flow tuff that was sufficiently hot to move with laminar flow as a coherent ductile mass—see, for example, Anderson and Rowley (1975, 2002), Andrews and Branney (2005), and Geissman and others (2010).

The Isom Formation is about 26 to 27 Ma on the basis of many $^{40}Ar/^{39}Ar$ and K-Ar ages (Best and others, 1989b; Rowley and others, 1994a). Its source is unknown, but isopach maps and pumice distribution suggest that the Isom was derived from late-stage eruptions of the 27–32 Ma Indian Peak caldera complex that straddles the Utah-Nevada border, possibly in an area now concealed by the western Escalante Desert (Rowley and others, 1979; Best and others, 1989a, 1989b). Estimated crystallization temperature and pressure of phenocrysts of the Isom is 950°C and < 2 kbar (Best and others, 1993), and this relatively high temperature is supported by its degree of welding and secondary flow features.

unconformity

Brian Head Formation (lower Oligocene to middle Eocene) – The Brian Head Formation is the oldest widespread Tertiary volcaniclastic unit in the region. Immediately north of the map area in the Eightmile Hills, it disconformably overlies a non-volcaniclastic pebbly conglomerate likely equivalent to the conglomerate at Boat Mesa (Knudsen and Biek, 2014). Sable and Maldonado (1997) designated a type section at Brian Head peak, 20 miles (32 km) east-northeast of the map area, and divided the Brian Head Formation into three informal units, ascending: (1) a thin, nontuffaceous sandstone and conglomerate, (2) a volcaniclastic unit that has minor but conspicuous limestone and chalcedony, and (3) a volcanic unit, locally present in the northern Markagunt Plateau but not at the type section, characterized by volcanic mudflow breccia, mafic lava flows, volcaniclastic sandstone and conglomerate, and ash-flow tuff. Only their middle volcaniclastic unit is present in the map area.

Biek and others (2015) summarized radiometric ages for the formation that show it to be about 37 to 33 Ma; regionally it is disconformably overlain by the 30 Ma Wah Wah Springs Formation or, as in the Eightmile Hills area to the north, by the 26 to 27 Ma Isom Formation. In this map area it is involved in a gravity slide shed off the Stoddard Mountain intrusion. Eaton and others (1999) and Korth and Eaton (2004) reported on Duchesnean (middle Eocene) vertebrate fossils in lower Brian Head strata of the Sevier Plateau. The Brian Head Formation is thus early Oligocene to latest middle Eocene.

Tbh **Middle volcaniclastic unit** – White to light-gray volcaniclastic mudstone, siltstone, silty sandstone, sandstone, conglomerate, volcanic ash, micritic limestone, and multi-hued chalcedony; exceptionally poorly exposed in this map area; sandstone is commonly bioturbated with pencil-size root or burrow casts that weather out in relief; conglomerate clasts are quartzite, limestone, and chert—surprisingly, clasts of intermediate-composition volcanic rocks are virtually absent; chalcedony is various shades of white, gray, yellow, red, black, and brown, typically has a white weathering rind, is commonly highly brecciated and resilicified, typically occurs in beds 1 to 3 feet (0.3–1 m) thick but locally as much as 8 feet (2.5 m) thick, is locally stained by manganese oxides, and likely resulted from silicification of limestone beds (Maldonado, 1995; Sable and Maldonado, 1997; Schinkel, 2012); chalcedony is almost always highly fractured, but some is useful for lapidary purposes (Strong, 1984); because of abundant bentonitic clay derived from weathered volcanic ash, this unit weathers to strongly swelling soils (unlike the underlying Claron Formation) and regionally forms large landslide complexes (for example, on the nearby Markagunt Plateau [Biek and others, 2015]); deposited in low-relief fluvial, floodplain, and lacustrine environments in which large amounts of volcanic ash accumulated (Sable and Maldonado, 1997); about 500 feet (150 m) thick at its type section on Brian Head peak (Sable and Maldonado, 1997; Rowley and others, 2013; Biek and others, 2015), but only about 100 feet (30 m) are exposed in this map area.

Tcp **Pink member of the Claron Formation** (Eocene to Paleocene?) – Varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, and grayish-pink sandy and micritic limestone, calcite-cemented sandstone, calcareous mudstone, and conglomerate that weather to colluvium-covered slopes; well exposed only where it overlies Navajo Sandstone in the North Hills, otherwise very poorly exposed in this map area, but the formation's presence is betrayed by its distinctive colors and lithologies. Limestone is poorly bedded, microcrystalline, generally sandy with 2 to 20% fine-grained quartz sand, and is locally argillaceous; it represents calcic paleosols—fluvial and floodplain deposits greatly modified by bioturbation and pedogenic processes (Mullett and others, 1988a, 1988b; Mullett, 1989; Mullett and Wells, 1990). Sandstone is thick-bedded, fine- to coarse-grained, calcareous, locally cross-bedded quartz arenite. Mudstone is generally moderate reddish orange, silty, calcareous, contains calcareous nodules, and weathers to earthy, steep slopes between ledges of sandstone and limestone. Pebbly conglomerate forms lenticular beds typically 5 to 15 feet (2–5 m) thick containing rounded quartzite, limestone, and chert pebbles and cobbles. Regionally, the Claron is unconformably overlain by the conglomerate at Boat Mesa (Knudsen and Biek, 2014; Biek and others, 2015), but in this map area, incomplete, fault-bounded exposures are unconformably overlain by late Tertiary basin-fill deposits.

In the North Hills, Claron strata overlie the Navajo Sandstone and both formations dip moderately to steeply west-southwest. Anderson and Mehnert (1979) were the first to show that their mutual contact is disconformable, not an angular unconformity as envisioned by Threet (1963) nor faulted as envisioned by Averitt (1967). We agree that no pronounced angular unconformity exists, as it does just north of Cedar City (Averitt and Threet, 1973; Knudsen, 2014), although it is difficult to precisely ascertain Navajo attitudes given its massive cross-bedding. An incomplete section of the pink member is about 800 feet (245 m) thick in the North Hills. Only limited Claron exposures are present on the east flank of the Harmony Mountains; the apparent absence of Brian Head strata in sections 18 and 19, T. 37 S., R. 12 W. suggests that the entire volcanic section there is part of a gravity slide.

Claron Formation strata are among the most visually arresting rocks in southwestern Utah, prominently displayed at Cedar Breaks National Monument and

Bryce Canyon National Park among other places, but because the formation lacks a type section and was named for incomplete, fault-bounded exposures in the Iron Springs mining district (Leith and Harder, 1908), the nomenclatural history of these rocks is complicated as described by Biek and others (2015). The formation contains two informal members—an upper white member not present in this map area and the lower pink member—and as now defined it lacks volcanic clasts or ash-flow or ash-fall tuff. Claron strata were deposited in fluvial, floodplain, and lacustrine environments of an intermontaine basin bounded by Laramide uplifts; the pink member is almost wholly fluviatile and the white member is both lacustrine and fluviatile (Goldstrand, 1990, 1991, 1992, 1994; Bown and others, 1997). Anderson and Dinter (2010) and Biek and others (2015) showed that east-vergent, Sevier-age compressional deformation continued into early Claron time in the High Plateaus of southwestern Utah. The age of the white member is well constrained as late middle Eocene (Duchesnean Land Mammal Age) based on sparse vertebrate fossils and constraining U-Pb zircon ages of overlying strata (Biek and others, 2015 and references therein), but the maximum age of the mostly nonfossiliferous pink member is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994). Biek and others (2015) noted that the lower part of the pink member is likely Paleocene in age, but given its paucity of datable materials, could not rule out the possibility that it is latest Cretaceous.

unconformity

CRETACEOUS

Kn **Naturita Formation (formerly Dakota Formation)** (Upper Cretaceous) – Interbedded, slope- and ledge-forming sandstone, siltstone, and mudstone poorly exposed at the southeast edge of the map area; in this map area, represents floodplain and river environments, whereas the upper part, on the nearby Kolob Plateau and in Cedar Canyon, represents estuarine, lagoonal, and swamp environments of a coastal plain (Gustason, 1989; Eaton and others, 2001; Laurin and Sageman, 2001a, 2001b; Tibert and others, 2003); smectitic clays make these strata highly susceptible to landsliding; they are the culprit in landslides that recently damaged Utah Highway 14 in nearby Cedar Canyon (Lund and others, 2012); formation forms the lower part of the Gray Cliffs step of the Grand Staircase (Gregory, 1950); only the basal 150 feet (45 m) is in the map area, but the complete formation is 1300 to 1400 feet (400–425 m) thick on the Markagunt Plateau where it was mapped as the Dakota Formation (Biek and others, 2015).

The name Dakota Formation has long been used in Utah for marginal marine sedimentary deposits of an overall transgressive sequence of Cenomanian age below the Tropic Shale (e.g., Nichols, 1997; Eaton, 2009). Carpenter (2014) reviewed the historical legacy of the name Dakota and eloquently argued for its abandonment in Utah because: (1) this interval in Utah was separated from type Dakota of the Great Plains by the Western Interior Seaway (thus there is no physical stratigraphic continuity across the basin), and (2) this interval in Utah had its source in east-flowing streams tapping the Sevier orogenic belt, whereas the type Dakota was derived from west-flowing streams draining the North American craton (thus they represent completely different source areas). We follow Carpenter's (2014) recommendation to rename this interval the Naturita Formation of Young (1960, 1965).

Kcm **Cedar Mountain Formation** (Cretaceous, Cenomanian to Albian) − Poorly exposed but assumed to be present at the southeast edge of the map area, as it is to the south at Horse Ranch Mountain (Biek, 2007a), to the southeast on the Kolob Plateau (Biek, 2007b), and to the northeast on the Markagunt Plateau (Biek and others, 2015). In this area, Cedar Mountain strata consist of a thin pebble conglomerate overlain by brightly colored variegated mudstone; mudstone is gray, purplish-red, and reddish-brown—distinctly different from the gray and yellowish-brown hues of overlying Naturita strata; clay is smectitic and weathers to "popcorn-like" soils. Basal conglomerate forms a grayish-brown ledge with subrounded to rounded, pebble- to small-cobble-size quartzite, chert, and limestone clasts; entire formation is about 60 feet (18 m) thick in Cedar Canyon, and the conglomerate ranges from less than one foot (0.3 m) to about 10 feet (3 m) thick (Biek and others, 2015; Knudsen, 2014); formation thickness here is probably similar to its 20- to 25-foot thickness (6–8 m) at Horse Ranch Mountain.

Except for the thin conglomerate ledge at its base, the formation weathers to generally poorly exposed slopes covered with debris from the overlying Naturita Formation. The upper contact is poorly exposed and corresponds to a color and lithologic change from comparatively brightly colored smectitic mudstone below to gray and light-yellowish-brown mudstone and fine-grained sandstone above, but regionally the Cedar Mountain Formation is unconformably overlain by the Naturita Formation (see, for example, Kirkland and others, 1997). Volcanic ash from correlative strata on the Kolob Plateau yielded a single-crystal $^{40}Ar/^{39}Ar$ age of 97.9 ± 0.5 Ma (Cenomanian) on sanidine (Biek and Hylland, 2007), yet pollen analyses indicate an Albian or older age (Doelling and Davis, 1989; Hylland, 2010), and Dyman and others (2002) obtained an $^{40}Ar/^{39}Ar$ age of 101.7 ± 0.42 Ma (latest Albian) on slightly older basal Cedar Mountain strata near Gunlock, Utah. Additionally, palynomorphs from a thin mudstone interval, including rare occurrences of *Trilobosporites humilis* and possibly *Pseudoceratium regium*, collected in Cedar Canyon immediately to the west of the map area (NW1/4 NW1/4 SE1/4 section 17, T. 36 S., R. 10 W., Cedar City 7.5′ quadrangle), suggest a late Albian age for this horizon (Mike Hylland, Utah Geological Survey, unpublished data, November 9, 2001). The Cedar Mountain Formation was deposited in a floodplain environment of a broad coastal plain (Tschudy and others, 1984; Cifelli and others 1997; Kirkland and others, 1997; Kirkland and Madsen, 2007). This interval was previously mapped as the lower part of the Dakota Formation, but the lithology, age, and stratigraphic position of these beds suggest correlation to the Cedar Mountain Formation (Biek, 2007b; Biek and Hylland, 2007; Biek and others, 2009; Hylland, 2010). Specifically, the mudstone interval appears to be time-correlative with the Mussentuchit Member of the Cedar Mountain Formation of central and eastern Utah.

The basal conglomerate is part of the relatively thin but widespread Lower Cretaceous gravels that once formed a broad alluvial plain over most of the Western Interior. As noted in the classic paper by Heller and Paola (1989), the distribution of these gravels is believed to reflect regional thermal uplift associated with Jurassic-Cretaceous magmatism in the hinterland, immediately prior to onset of thrusting in the Sevier orogenic belt and creation of sediment-trapping foredeep and backbulge basins. Detrital zircon studies of Hunt and others (2011) showed that the clasts were largely derived from Ordovician to Devonian strata in the Sevier thrust belt, and they suggested correlation with the Short Canyon Conglomerate of central Utah (Doelling and Kuehne, 2013).

Cretaceous (K) unconformity. No rocks of late Middle Jurassic to middle Early Cretaceous age are preserved in southwest Utah. During this time, the back-bulge basin that developed in front of the Sevier orogenic belt had migrated eastward, and much of western Utah was a forebulge high, a broad, gentle uplift that was high enough to undergo a prolonged period of modest erosion (see, for example, Willis, 1999). In this area, this 60-million-year-long gap in the rock record is commonly marked by a bleached zone at the top of the Winsor Member of the Carmel Formation. The Cretaceous unconformity cuts down section to the west, where, on the south flank of the Pine Valley Mountains, first Winsor, then Paria River, and finally Crystal Creek strata are completely eroded away, so that at Gunlock the Cedar Mountain Formation rests upon the Co-op Creek Limestone, the lower member of the Carmel Formation (Biek and others, 2009).

JURASSIC

Carmel Formation

Nomenclature of the Carmel Formation follows that of Doelling and Davis (1989), Sprinkel and others (2011a), and Doelling and others (2013). The Carmel Formation was deposited in a shallow inland sea of a back-bulge basin, and together with the underlying Temple Cap Formation, provides the first clear record of the effects of the Sevier orogeny in southwestern Utah (Sprinkel and others, 2011a). Middle Jurassic age is from Imlay (1980), Sprinkel and others (2011a), and Doelling and others (2013). Kowallis and others (2001) and Sprinkel and others (2011a) reported no significant time gap between the Temple Cap and Carmel Formations and could not find evidence for the J-2 unconformity of Pipiringos and O'Sullivan (1978), suggesting that the J-2 may not exist or is a very short hiatus in southern Utah.

Jcw **Winsor Member** (Middle Jurassic, Callovian to Bathonian) – Dusky yellow to yellowish-gray, very fine to medium-grained, friable sandstone and minor pinkish-gray to pale-pink siltstone; poorly cemented and typically poorly exposed, weathering to steep vegetated slopes; upper contact is at the base of a thin pebble conglomerate, which marks the Cretaceous unconformity; Sprinkel and others (2011a) reported that the Winsor Member is about 164 to 162 Ma in southwest Utah; deposited on a broad, sandy mudflat during the second major regression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); about 150 to 200 feet (45–60 m) thick.

Jcp **Paria River Member** (Middle Jurassic, Bathonian) – Pinkish-gray to pale-pink siltstone and very thin bedded, yellowish-gray to grayish-orange-pink limestone and micritic limestone that overlies a basal, thick-bedded, white, alabaster gypsum bed 5 to 12 feet (1.5–4 m) thick; limestone weathers to small chips and plates and locally contains casts and molds of small pelecypod fossils; basal gypsum forms ledge whereas the overlying layers form a steep slope; upper conformable contact is sharp and planar and is drawn at the base of yellowish-gray, very fine to medium-grained, friable sandstone and minor pinkish-gray to pale-pink siltstone, above the chippy-weathering limestone of the Paria River Member; zircon from an ash near the base of the member in south-central Utah is 165.9 ± 0.51 Ma (Sprinkel and others, 2011a); deposited in shallow-marine and coastal-sabkha environments during the second major transgression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); 120 to 150 feet (37–45 m) thick.

Jcx **Crystal Creek Member** (Middle Jurassic, Bathonian) – Interbedded, thin- to medium-bedded, pale- to moderate-reddish-brown gypsiferous siltstone, pinkish-gray mudstone, very fine to medium-grained sandstone, and gypsum; typically poorly exposed, forming vegetated slopes; upper conformable contact is sharp but broadly undulating at the base of a thick gypsum bed of the Paria River Member above alternating, pale- to moderate-reddish-brown Crystal Creek siltstone; Kowallis and others (2001) reported two $^{40}Ar/^{39}Ar$ ages of 167 to 166 million years old for altered volcanic ash beds, likely derived from a magmatic arc in what is now southern California and western Nevada, within the member near Gunlock, about 50 miles (80 km) south of the quadrangle; deposited in coastal-sabkha and tidal-flat environments during the first major regression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); 200 to 250 feet (60–75 m) thick.

Co-op Creek Limestone Member (Middle Jurassic) − Light-olive-gray to light-gray, thin- to medium-bedded, micritic limestone and sandy limestone interbedded with mostly light-gray, thinly laminated to thin-bedded, micritic limestone, calcareous shale, platy limestone, and very fine to fine-grained sandstone; locally contains *Isocrinus* sp. crinoid columnals, pelecypods, and gastropods, especially in the upper beds; Kowallis and others (2001) reported several $^{40}Ar/^{39}Ar$ ages of 168 to 167 million years old for altered volcanic ash beds, likely derived from a magmatic arc in what is now southern California and western Nevada, within the lower part of the member in southwest Utah; Sprinkel and others (2011a) obtained radiometric ages of 169.2 ± 0.51 and 169.9 ± 0.49 Ma from sanidine in ash samples near the base of the member; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983).

Jccu **Upper unit** − Light-olive-gray to light-gray, thin- to medium-bedded, micritic limestone and sandy limestone; forms steep, sparsely vegetated, ledgy slopes and small cliffs; upper conformable contact is sharp and drawn at the base of reddish-brown gypsiferous siltstone and mudstone; 150 to 200 feet (45–60 m) thick.

Jccl **Lower unit** − Mostly light-gray, thinly laminated to thin-bedded, micritic limestone, calcareous shale, platy limestone, and very fine to fine-grained sandstone; forms steep vegetated slopes; gradational contact with upper unit is placed at the subtle change of slope and a conspicuous decrease in vegetation; about 350 feet (105 m) thick.

Jct **Co-op Creek Limestone Member of the Carmel Formation and the Manganese Wash Member of the Temple Cap Formation** – Used only on cross section.

Temple Cap Formation

Jtm **Manganese Wash Member** (Middle Jurassic) − Moderate-reddish-brown mudstone, siltstone, and very fine grained, gypsiferous, silty sandstone; poorly exposed in a narrow bench at the top of massive Navajo Sandstone cliffs; clay particles weathered from the member locally stain the upper cliffs of Navajo Sandstone; poorly exposed upper conformable contact corresponds to the base of light-gray shale and limestone beds of the Co-op Creek Member of the Carmel Formation; based on $^{40}Ar/^{39}Ar$ ages of sanidine and biotite, and U-Pb zircon ages, the preferred age of Temple Cap strata is 172.9 ± 0.6 to 170.2 ± 0.5 Ma (Sprinkel and others, 2011a); deposited in coastal-sabkha and tidal-flat environments, with volcanic ash derived from a magmatic arc in what is now southern California and western Nevada (Blakey, 1994; Peterson, 1994); about 3 to 30 feet (1–9 m) thick.

Regional stratigraphic studies (Sprinkel and others, 2011a) redefined the Temple Cap Formation to include the Sinawava, White Throne, and Esplin Point Members; where White Throne strata are missing, similar strata of the Sinawava and Esplin Point Members are now known as the Manganese Wash Member. In areas to the south-southeast, Willis and Hylland (2002) and Biek (2007b) originally inferred that the White Throne Member was erosionally truncated beneath the J-2 unconformity in this area, west of what is now the transition zone between the Colorado Plateau and Basin and Range Province. But because Sprinkel and others (2011a) found evidence that a significant unconformity does not exist between Temple Cap and Carmel strata, we now think that the White Throne Member was simply not deposited.

J-1 unconformity. The J-1 unconformity of Pipiringos and O'Sullivan (1978) formed prior to 173 million years ago in southwest Utah (Sprinkel and others, 2011a).

Navajo Sandstone and Kayenta Formation

Jn **Navajo Sandstone** (Lower Jurassic) – Light-gray to pale-orange in upper part and moderate-reddish-orange to moderate-reddish-brown in the lower part, massively cross-bedded, moderately well-cemented sandstone with well-rounded, fine- to medium-grained, frosted quartz sand grains; locally contains ironstone bands and concretions called "Moki marbles"; forms spectacular, sheer cliffs and is locally prominently jointed; upper, unconformable contact is sharp and planar and corresponds to a prominent break in slope, with cliff-forming, cross-bedded sandstone below and poorly exposed reddish-brown mudstone of the Temple Cap Formation above; forms the White Cliffs step of the Grand Staircase (Gregory, 1950); the Navajo Sandstone is the main aquifer for much of the region (Heilweil and others, 2002; Rowley and Dixon, 2004); deposited in a vast coastal and inland dune field with prevailing winds principally from the north, and with rare interdunal ephemeral playa lakes (Blakey, 1994; Peterson, 1994); part of one of the world's largest coastal and inland paleodune fields (Milligan, 2012), and correlative in part with the Nugget Sandstone of northern Utah and Wyoming and the Aztec Sandstone of southern Nevada and adjacent areas (see, for example, Kocurek and Dott, 1983; Riggs and others, 1993; Sprinkel and others, 2011b); the lower few hundred feet is characterized by planar sandstone beds and represents deposition in a sand-dominated sabkha environment (Tuesink, 1989; Sansom, 1992); originally, much of the sand may have been carried to the area by a transcontinental river system that eroded Grenvillian-age (about 1.0 to 1.3 billion-year-old) crust that was involved in the Appalachian orogeny of eastern North America (Dickinson and Gehrels, 2003, 2009a, 2009b; Rahl and others, 2003; Reiners and others, 2005); map unit includes areas of weathered sandstone regolith and Quaternary eolian sand too small to map separately; total thickness in this area is 1800 to 2000 feet (550–600 m).

Jku **Upper unit of the Kayenta Formation** (Lower Jurassic) – Reddish-brown to moderate-reddish-brown to pale-red siltstone and mudstone interbedded with very fine to fine-grained sandstone with planar, low-angle, and ripple cross-stratification; includes minor intraformational pebble conglomerate and thin beds of light-gray limestone; lower part weathers to a poorly exposed slope, upper part to ledgy slope and small cliffs; upper conformable and gradational contact is placed at the break in slope at the top of the thin siltstone and sandstone beds and below the very thick bedded, cliff-forming sandstone of the Navajo Sandstone; mapped where Shurtz Tongue of the Navajo Sandstone is not present to separate similar strata of the Cedar City Tongue and main body of the Kayenta Formation, and also used on cross section; deposited in distal river, playa, and minor lacustrine environments (Tuesink, 1989; Sansom, 1992; Blakey, 1994; Peterson, 1994); about 800 feet (240 m) thick.

Jkc **Cedar City Tongue of Kayenta Formation** (Lower Jurassic) – Interbedded pale-reddish-brown siltstone, mudstone, and very fine grained, very thin bedded to laminated, quartz sandstone that forms ledgy slopes; deposited in distal river, playa, and minor lacustrine environments (Tuesink, 1989; Blakey, 1994; Peterson, 1994); type section located two miles (3 km) east of Cedar City, northeast of the quadrangle (Averitt and others, 1955); conformably lies between the Navajo Sandstone and, where present, the Shurtz Sandstone Tongue of the Navajo Sandstone with sharp upper and lower contacts; upper contact is placed where the thin, interbedded siltstone, mudstone, and sandstone below give way to the massively cross-bedded sandstone of the Navajo Sandstone; where the Shurtz Sandstone is not present, the Cedar City Tongue is combined with the main body of the Kayenta Formation and mapped as the upper unit of the Kayenta Formation; thickens southward from 425 feet (130 m) near the mouth of Cedar Canyon (Knudsen, 2014) to 720 feet (220 m) along Shurtz Creek, east of the map area (Averitt and others, 1955), but is only 200 to 300 feet (60–90 m) thick in this map area, likely a result of structural thinning on the east flank of the Kanarra anticline.

Jns **Shurtz Sandstone Tongue of the Navajo Sandstone** (Lower Jurassic) – Similar to the lower part of the Navajo Sandstone with its planar bedding and few large-scale cross-beds; upper conformable contact is placed where thick, cliff-forming sandstone beds give way to thinner bedded siltstone and sandstone; springs are common at the lower contact with the main body of the Kayenta Formation; deposited in an eolian erg and sabkha environment (Tuesink, 1989; Blakey, 1994; Peterson, 1994); type section is at Shurtz Creek, just east of the map area where it is about 60 feet (20 m) thick (Averitt, 1962); it is unusually thick in Cedar Canyon (Knudsen, 2014) and appears to pinchout southward in this map area just south of Kanarra Creek.

Jkm **Main body of Kayenta Formation** (Lower Jurassic) – Reddish-brown to moderate-reddish-brown to pale-red siltstone and mudstone interbedded with very fine to fine-grained sandstone; includes minor intraformational pebble conglomerate and thin beds of light-gray limestone; forms ledgy slope; upper contact is placed at the top of the thinner bedded ledgy slope at the base of the sandstone cliff of the Shurtz Sandstone Tongue; where the Shurtz Tongue is not present, this main body is combined with the Cedar City Tongue above and mapped as the upper unit of the Kayenta Formation; deposited in distal river, playa, and minor lacustrine environments (Tuesink, 1989; Blakey, 1994; Peterson, 1994); about 290 feet (88 m) thick in Cedar Canyon (Knudsen, 2014); map patterns suggest that the unit is about 400 to 500 feet (120–150 m) thick in this map area.

Jks **Springdale Sandstone Member of the Kayenta Formation** (Lower Jurassic) – Mostly pale-reddish-purple to pale-reddish-brown, moderately sorted, fine- to medium-grained, medium- to very thick bedded sandstone with planar and low-angle cross-stratification, and minor, thin, discontinuous lenses of intraformational conglomerate and thin interbeds of moderate-reddish-brown or greenish-gray mudstone and siltstone; has large lenticular and wedge-shaped, low-angle, medium- to large-scale cross-bedding; secondary color banding that varies from concordant to discordant to cross-beds is common in the sandstone; weathers to rounded cliffs and ledges and contains locally abundant petrified and carbonized fossil plant remains; conformable upper contact is placed at the top of a sandstone cliff, below the slope of interbedded siltstone and mudstone of the main body or upper unit of the Kayenta Formation; deposited in braided-stream and minor floodplain environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998); Knudsen (2014) reported that the member is about 135 feet (40 m) thick in Cedar Canyon, similar to the 100 to 150 feet (30–45 m) estimated thickness in this map area.

J-sub Kayenta unconformity of Blakey (1994) and Marzolf (1994), who proposed a major regional unconformity at the base of the Springdale Sandstone, thus restricting the Moenave Formation to the Dinosaur Canyon and Whitmore Point Members. Subsequent work by Lucas and Heckert (2001), Molina-Garza and others (2003), and Lucas and Tanner (2007) also suggested that the Springdale Sandstone is more closely related to, and should be made the basal member of, the Kayenta Formation.

JURASSIC AND TRIASSIC

JTRm **Moenave Formation** (Lower Jurassic to Upper Triassic) – Regionally divided into two members, but not mapped separately here because of the thinness and lack of fossil fish scales characteristic of the upper member. Upper formational contact corresponds to a major regional unconformity (Blakey, 1994; Marzolf, 1994) and is placed at the base of the thick- to very thick bedded sandstone ledge of the Springdale Sandstone Member of the Kayenta Formation. Knudsen (2014) reported that the formation is about 375 feet (115 m) thick in Cedar Canyon, but map patterns suggest that it ranges from 300 to 500 feet (90-150 m) thick in this map area, likely due to structural thickening on the east limb of the Kanarra anticline. **Whitmore Point Member** (Lower Jurassic): interbedded, pale-reddish-brown, greenish-gray, and grayish-red mudstone and claystone, with thin-bedded, moderate-reddish-brown, very fine to fine-grained sandstone and siltstone; siltstone is commonly thin bedded to laminated in lenticular or wedge-shaped beds; claystone is generally flat bedded; contains thin, bioturbated, cherty, very light gray to yellowish-gray dolomitic limestone beds with algal structures, some altered to jasper; forms poorly exposed ledgy slope; conformable and gradational lower contact with the Dinosaur Canyon Member is placed at the base of the lowest light-gray, thin-bedded, dolomitic limestone; deposited in low-energy lacustrine and fluvial environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998). **Dinosaur Canyon Member** (Lower Jurassic to Upper Triassic): uniformly colored, interbedded, generally thin-bedded, moderate-reddish-brown to moderate-reddish-orange, very fine to fine-grained sandstone, very fine grained silty sandstone, and lesser siltstone and mudstone; ripple marks and mud cracks are common; forms ledgy slope; deposited on broad floodplain that was locally shallowly flooded (fluvial mud flat) (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998).

TR-5 unconformity (Pipiringos and O'Sullivan, 1978)

TRIASSIC

Chinle Formation

TRc **Chinle Formation, undivided** – Used on cross section only.

TRcu **Upper unit** (Upper Triassic) – Highly variegated, light-brownish-gray, pale-greenish-gray, to grayish-purple smectitic mudstone, claystone, and siltstone, with resistant, thick-bedded sandstone and pebble- to small-cobble conglomerate near base; clasts are primarily chert and quartzite; contains minor thin beds of chert, nodular limestone, and very thin coal seams and lenses as much as 0.5 inch (1 cm) thick; mudstone weathers to a "popcorn" surface due to expansive clays and regionally causes road and building foundation problems; contains locally abundant, brightly colored fossilized wood; weathers to badland topography and is prone to landsliding, especially along steep hillsides; upper contact corresponds to a color change between the purplish mudstone below and the moderate-reddish-brown, fine-grained sandstone above and is typically marked by a thin chert-pebble conglomerate; most of our upper unit is the Petrified Forest Member, which regionally is divided into three parts in ascending order: the smectitic Blue Mesa unit, the pebbly sandstone of the Sonsela unit, and the smectitic Painted Desert unit (Lucas, 1993), but which are undivided here; strata equivalent to the light-gray, fine-grained sandstone of the Monitor Butte Member may be present at the base of the map unit, whereas limestone-nodule-bearing swelling mudstone of the Owl Rock Member may be present at the top of the map unit; deposited in lacustrine, floodplain, and braided-stream environments of a back-arc basin formed inland of a magmatic arc associated with a subduction zone along the west coast of North America (Stewart and others, 1972a; Lucas, 1993; Dubiel, 1994; DeCourten, 1998); about 300 to 400 feet (90–120 m) thick.

Ʀcs **Shinarump Member** (Upper Triassic) – Grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone with locally well-developed limonite bands (“picture stone” or “landscape rock”) and moderate-brown pebble conglomerate with subrounded clasts of quartz, quartzite, and chert; mostly thick to very thick bedded with both planar and low-angle cross-stratification; contains locally abundant, poorly preserved petrified wood; upper contact is placed between the yellowish-brown sandstone and pebbly sandstone of the Shinarump below and the base of the varicolored smectitic mudstone beds of the upper unit; variable in composition and thickness because it represents stream-channel deposition over Late Triassic paleotopography (Stewart and others, 1972a; Lucas, 1993; Dubiel, 1994; DeCourten, 1998); Knudsen (2014) described unusual facies changes in lower Chinle strata near Cedar City and reported that Shinarump strata there are 30 to 50 feet (9–15 m) thick and are underlain by several tens of feet of Petrified Forest-like mudstone; this lower mudstone unit extends southward to Kolob Canyons, but is not mapped separately here due to poor exposure; Shinarump strata can thus be directly traced from the Zion Canyon area to Cedar City, but it is only in the northern extent of its outcrop belt where we find it underlain by Petrified Forest-like mudstone; in this map area, the Shinarump generally ranges from 100 to 200 feet (30–60 m) thick.

TR-3 unconformity (Pipiringos and O’Sullivan, 1978), a widespread episode of erosion across the western U.S. that spans about 10 Ma during late Middle and early Late Triassic time (e.g., Kirkland and others, 2014).

Moenkopi Formation

Ʀm **Moenkopi Formation, undivided** (Lower Triassic) – Used on cross section only.

Ʀmu **Upper red member** (Lower Triassic) – Moderate-reddish-brown, thin-bedded siltstone and very fine grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers; ripple marks are common in the siltstone; forms a steep slope with a few sandstone ledges, which are more abundant towards the top of the unit; upper unconformable contact is based on the lithologic change between ledges of moderate-reddish-brown siltstone and sandstone of the upper red member and the overlying cliff of moderate-yellowish-brown sandstone and pebble conglomerate of the Shinarump Member; contact shows minor channeling at the base of the Shinarump; deposited in coastal-plain and tidal-flat environments (Stewart and others, 1972b; Dubiel, 1994); Knudsen (2014) reported that the member is about 400 feet (120 m) thick in Cedar Canyon, but map patterns here show it to be about 200 to 250 feet (60–75 m) thick.

Ʀms **Shnabkaib Member** (Lower Triassic) – Light-gray to pale-red, gypsiferous siltstone with bedded gypsum and several thin interbeds of dolomitic, unfossiliferous limestone near the base; upper part is very gypsiferous and weathers to a powdery soil commonly covered by microbiotic crust; forms ledge-slope “bacon-striped” topography; gypsum also present as cross-cutting veins and cavity fillings; upper, gradational contact, marked by a prominent color change and lesser slope change, corresponds to the top of the highest light-colored, thick gypsum bed, above which are steeper slopes of laminated to thin-bedded, moderate-reddish-brown siltstone and sandstone of the upper red member; deposited on broad coastal shelf of very low relief where minor fluctuations in sea level produced interbedding of evaporites and red beds (Stewart and others, 1972b; Dubiel, 1994); about 400 to 500 feet (120–150 m) thick; the member thickens southward from 320 feet (98 m) thick in Cedar Canyon (Knudsen, 2014) to about 450 feet (135 m) near Kolob Canyons (Biek, 2007a).

Ʀmm **Middle red member** (Lower Triassic) – Moderate-red to moderate-reddish-brown siltstone, mudstone, and thin-bedded, very fine grained sandstone with thin interbeds and veinlets of greenish-gray to white gypsum; forms slope with several ledge-forming gypsum beds near base; upper contact is placed at the base of the first thick gypsum bed where the moderate-reddish-brown siltstone below gives way to banded, greenish-gray gypsum and pale-red siltstone above; deposited in tidal-flat environment (Stewart and others, 1972b; Dubiel, 1994); the member thickens to the south from 410 feet (128 m) thick in Cedar Canyon (Knudsen, 2014), to about 400 to 500 feet (120–150 m) thick in this map area, and about 550 feet (170 m) thick near Kolob Canyons (Biek, 2007a).

Ꞧmv **Virgin Limestone Member** (Lower Triassic) – Three distinct medium-gray to yellowish-brown limestone ledges interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum; limestone beds are typically 5 to 10 feet (1.5–3 m) thick and locally contain abundant circular and five-sided crinoid columnals and brachiopods; upper contact corresponds to the top of the highest limestone bed; deposited in shallow-marine environment (Stewart and others, 1972b; Dubiel,1994); about 150 to 200 feet (45–60 m) thick.

Ꞧml **Lower red member** (Lower Triassic) – Moderate-reddish-brown, laminated to thin-bedded siltstone, mudstone, and fine-grained, slope-forming sandstone; generally calcareous and has interbeds and stringers of gypsum; ripple marks and small-scale cross-beds are common in the siltstone; query indicates uncertain correlation of fault sliver at the entrance to Spring Creek canyon; upper contact corresponds to the color change from moderate-reddish-brown siltstone of the lower red member to moderate-yellowish-brown, muddy siltstone, usually about 3 feet (1 m) thick, which underlies the base of the first limestone ledge of the Virgin Limestone Member; deposited in tidal-flat environment (Stewart and others, 1972b; Dubiel, 1994); about 250 feet (75 m) thick.

Ꞧmt **Timpoweap Member** (Lower Triassic) – Lower part is light-gray to grayish-orange, thin- to thick-bedded limestone and cherty limestone, locally with gastropods and brachiopods, that weathers light-brown with a rough, "meringue-like" surface due to blebs of chert; upper part is grayish-orange, thin- to thick-bedded, slightly calcareous, very fine grained sandstone with thin-bedded siltstone and mudstone; member overall weathers yellowish-brown and forms ledges or low cliff that locally caps the Hurricane Cliffs; upper contact placed at the color change from grayish-orange sandstone of the Timpoweap Member below to the moderate-reddish-brown siltstone of the lower red member above; deposited in north-trending shallow-marine trough, filling paleotopography on top of the Kaibab Formation or the Rock Canyon Conglomerate Member of the Moenkopi Formation (Nielson and Johnson, 1979; Nielson, 1981; Dubiel, 1994); thickness approximately 120 feet (37 m).

Ꞧmr **Rock Canyon Conglomerate Member** (Lower Triassic) – Consists of two main rock types: (1) a pebble to cobble, clast-supported conglomerate with subrounded to rounded chert and minor limestone clasts derived from Harrisburg strata, which was deposited as channel fill in paleovalleys (Nielson, 1991), and (2) a thin breccia or regolith deposit (Nielson, 1991) on Harrisburg strata; upper gradational contact is placed at the base of the first laterally extensive yellowish-brown limestone of the Timpoweap Member; 0 to 90 feet (0–27 m) thick.

TR-1 unconformity (Pipiringos and O'Sullivan, 1978). In southwestern Utah, this unconformity spans 10 to 20 million years during Late Permian and Early Triassic time (Nielson, 1981, 1991; Sorauf and Billingsley, 1991).

PERMIAN

Kaibab Formation

Pk **Kaibab Formation, undivided** – Used on cross section only.

Pkh **Harrisburg Member** (Lower Permian) – Laterally variable, thin- to very thick bedded gypsum, gypsiferous mudstone, and limestone, some of which contains chert; mostly slope-forming, but includes a resistant cliff- and ledge-forming medial white chert and limestone interval; upper unconformable contact with the Rock Canyon Conglomerate Member of the Moenkopi Formation is typically within a ledge or cliff-forming interval and is difficult to identify where the conglomeratic facies is missing; deposited in sabkha and shallow-marine environments (McKee, 1938; Nielson, 1986; Sorauf and Billingsly, 1991); about 100 feet (30 m) thick (Nielson, 1981).

Pkf **Fossil Mountain Member** (Lower Permian) – Laterally uniform, light-gray, thick- to very thick bedded, planar-bedded, cherty limestone and fossiliferous limestone that forms a prominent cliff; whole silicified brachiopods are abundant near top of member; "black-banded" due to abundant reddish-brown, brown, and black chert; upper conformable contact drawn at the break in slope between the limestone cliff of Fossil Mountain Member and the overlying gypsiferous mudstone and gypsum slope of the Harrisburg Member; deposited in shallow-marine environment (McKee, 1938; Nielson, 1986; Sorauf and Billingsly, 1991); 200 to 250 feet (60–75 m) thick in the Kolob Arch quadrangle to the south (Biek, 2007a), but only the upper 200 feet (60 m) are exposed in this map area.

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