UTAH GEOLOGICAL SURVEY
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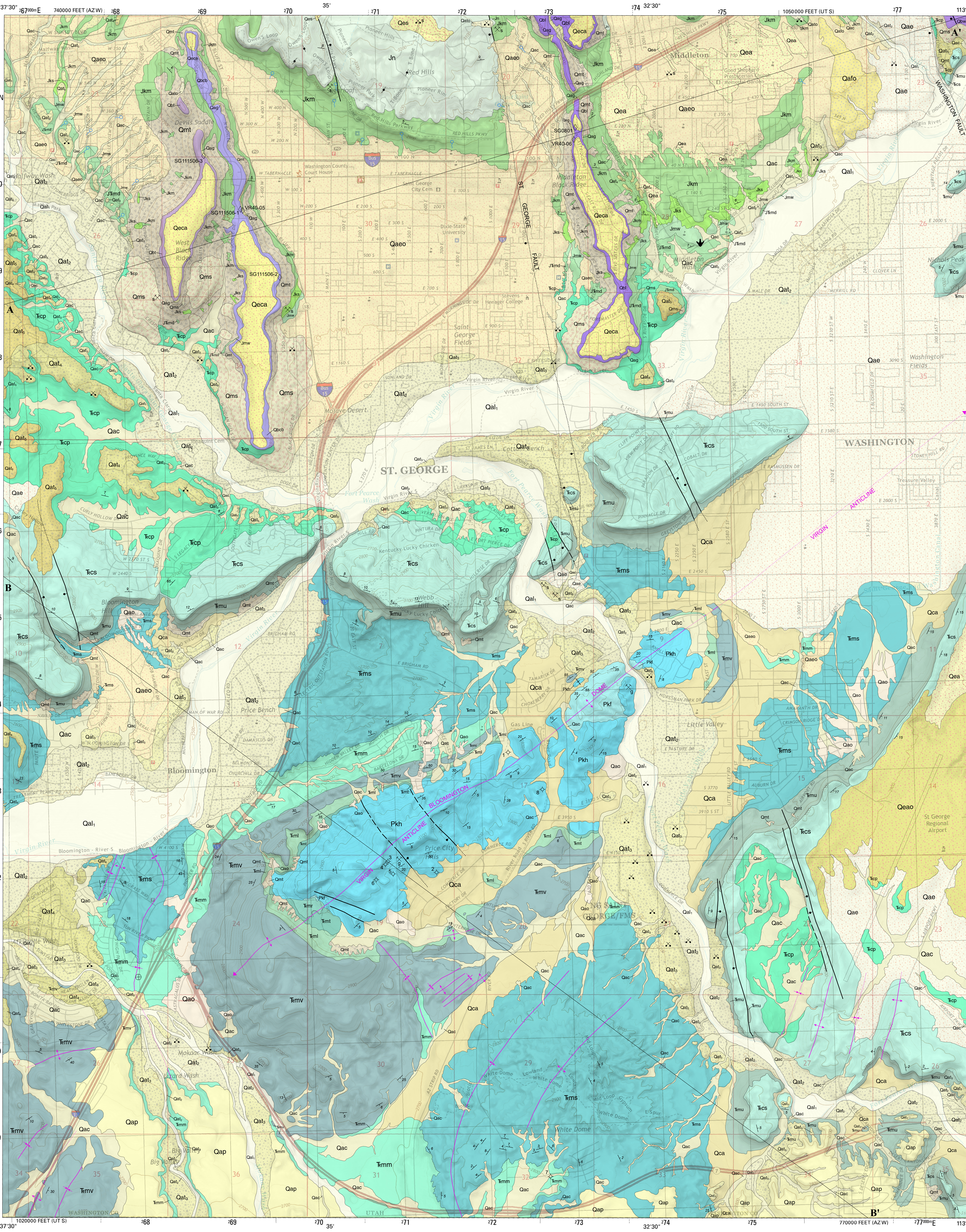

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In 2021, through U.S. Geological Survey cooperative agreement G20AC00389 (2020) funding, the UGS compiled the geologic map into a new GIS database and Geologic Map Schema (GeMS). During this project the UGS made minor changes to the geologic map based on recent geologic studies in the area (see Errata Sheet at back of text booklet).

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

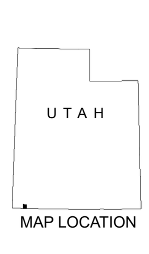
CONTOUR INTERVAL 20 FEET

APPROXIMATE MEAN DECLINATION, 2022

GEOLOGIC MAP OF THE ST. GEORGE 7.5' QUADRANGLE, WASHINGTON COUNTY, UTAH
(GIS reproduction of UGS M-251DM [2011])

by
Janice M. Hayden and Grant C. Willis

2022



MAP LOCATION

Field work 1994–96, 2009
Base from USGS US Topo, St. George 7.5' Quadrangle (2020)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927

Project Manager: Robert F. Biek
GIS and Cartography: Lori J. Steadman, Jay C. Hill, Kent D. Brown, and J. Buck Ehler

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https://doi.org/10.34191/M-291DR

1	2	3
4		5
6	7	8

1. Santa Clara
2. Washington
3. Harrisburg Junction
4. White Hills
5. Washington Dome
6. Purgatory Canyon
7. Lizard Point
8. Yellowhorse Flat

ADJOINING 7.5' QUADRANGLE NAMES

UTAH GEOLOGICAL SURVEY
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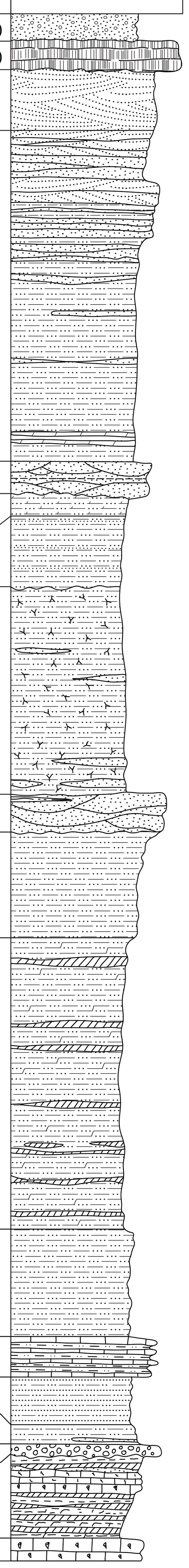
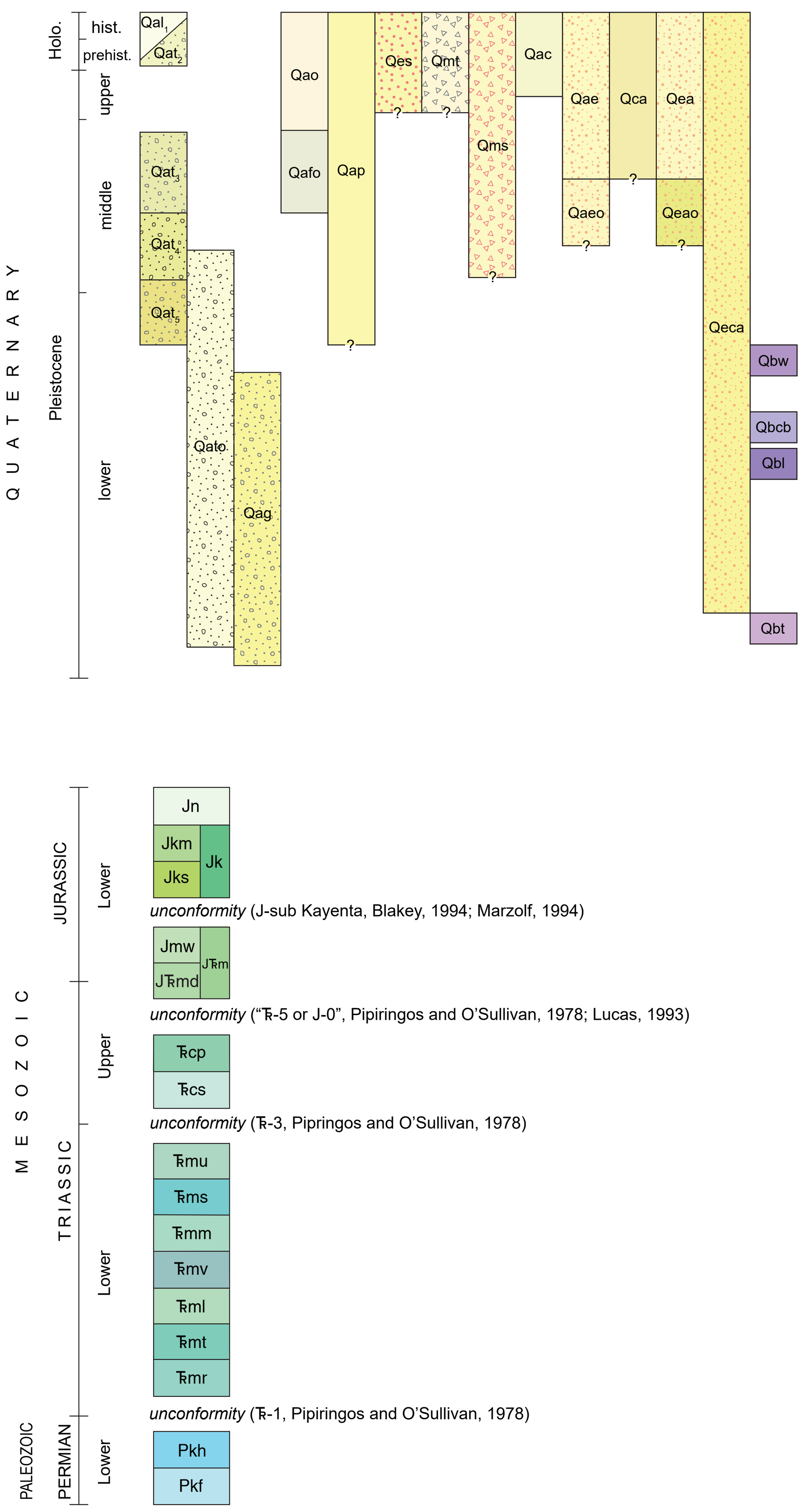
STRATIGRAPHIC COLUMN

Eratherm	System	Series	Formation	Member	Symbol	Thickness feet (meters)	Lithology
CEN.	Quat.	Pleist-Recent	unconsolidated surficial deposits			0–100 (0–30)	
			basaltic lava flows			10–80 (3–24)	
MESOZOIC	Jurassic	Lower	Navajo Sandstone		Jn	200+ (60+)	cross-beds
			Kayenta Formation	main body	Jkm	810 (247)	dinosaur tracks
				Springdale Sandstone Mbr.	Jks	115 (35)	*J sub Kayenta unconformity*
			Moenave Formation	Whitmore Point Member	Jmw	55 (17)	*Semionotus kanabensis*
	Triassic	Upper		Dinosaur Canyon Member	JŦmd	185 (55)	dinosaur tracks; *Ŧ-5 or J-0 unconformity*
			Chinle Formation	Petrified Forest Member	Ŧcp	700 (215)	swelling clays; landslides; petrified wood
				Shinarump Conglomerate Mbr.	Ŧcs	5–200 (1.5–60)	"picture stone"; *Ŧ-3 unconformity*
		Lower	Moenkopi Formation	upper red member	Ŧmu	360–400 (110–120)	
				Shnabkaib Member	Ŧms	900–1000 (270–300)	"bacon striped"; ledgy slope
				middle red member	Ŧmm	350–375 (107–114)	
				Virgin Limestone Mbr.	Ŧmv	25–225 (8–70)	gray ledges
				lower red member	Ŧml	25–300 (8–90)	
				Timpoweap Mbr.	Ŧmt	10–110 (3–32)	
				Rock Canyon Cg.	Ŧmr	0–38 (0–12)	*Ŧ-1 unconformity*
PALEOZOIC	Permian	Lower	Kaibab Formation	Harrisburg Member	Pkh	0–300 (0–90)	gypsum; brachiopods
				Fossil Mtn Mbr.	Pkf	70+ (20+)	"black-banded" cliff



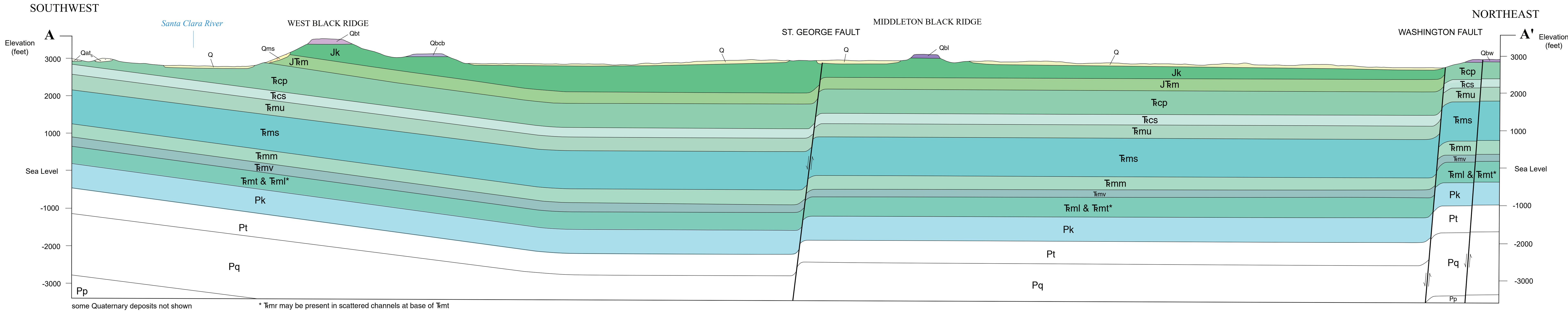
CORRELATION OF MAP UNITS

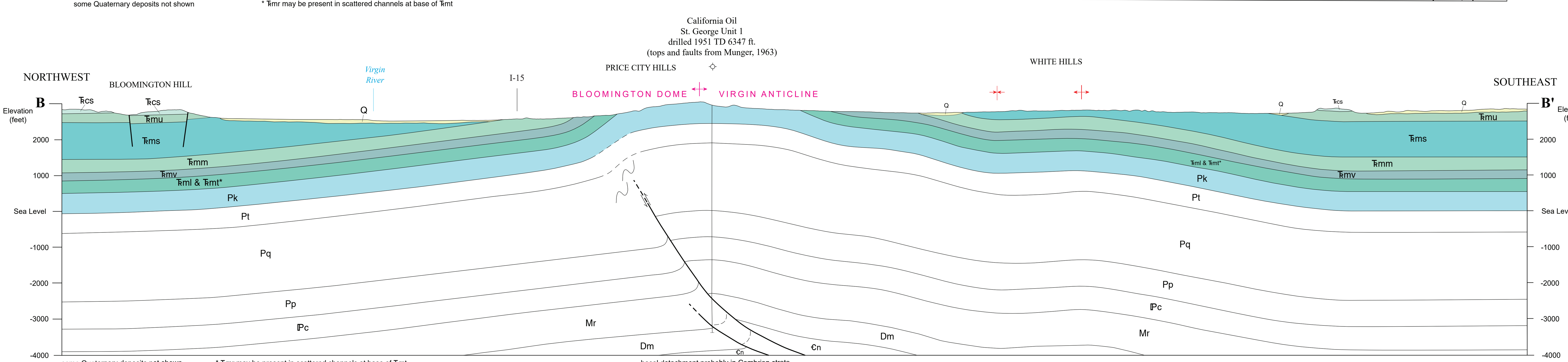


GEOLOGIC SYMBOLS

- Contact
- High-angle normal fault – dashed where approximately located, dotted where concealed, bar and ball on down-thrown side
- Axial trace of folds – dotted where concealed, arrows on trace show direction of plunge
  - Anticline
  - Syncline
- Strike and dip of bedding
  - inclined
  - horizontal
- Joint
- Excavation pit
  - Gravel
  - Sand
- Quarry
  - Gypsum
  - Dimension stone
- Dinosaur track site
- Petroleum exploration drill hole – dry and abandoned, numbers refer to table 1 [in text]
- Spring
- Sample location
- Changes in position of river channels from historic aerial photographs (shown in GIS files only, not on map)

January 2005 flooding caused the Santa Clara River to swell from normal discharge of 6 ft³/s to 6200 ft³/s (0.17 to 175 m³/s). Flooding destroyed homes and infrastructure. Before and after flooding photos provided by Cory Cram of Washington County Water Conservancy District and Jon Fuller of J.E. Fuller and Associates. Dashed yellow line shows cut bank position.





GEOLOGIC MAP OF THE ST. GEORGE 7.5' QUADRANGLE, WASHINGTON COUNTY, UTAH
(GIS reproduction of UGS M-251DM [2011])

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MAP 291DR
(GIS reproduction of UGS Map 251DM [2011])
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2022

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Cover photo: *View to north from flank of Bloomington Dome. Moenkopi Formation beds dip northwest in foreground. Cuesta with towers is capped by Shinarump Conglomerate Member of Chinle Formation. Pine Valley Mountains in distance.*

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MAP 291DR
(GIS reproduction of UGS Map 251DM [2011])
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2022

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SETTING AND STRUCTURE

The St. George quadrangle in southwestern Utah is located in the transition zone between the Basin and Range Province to the west and the Colorado Plateau Province to the east and contains structural elements of both (Hamblin, 1970b; Hintze, 1986). The transition zone coincides with the leading edge of the Late Cretaceous-Paleocene Sevier orogenic thrust belt, and rocks in the quadrangle are involved in minor detachments in front of the main thrust belt. A basal detachment is postulated in underlying Cambrian strata. The rocks have been compressed into the broad, poorly defined, north-northeast trending St. George syncline (axis is poorly constrained and not shown on map) (Cordova, 1978; called the Pine Valley Mountain syncline in some publications, e.g. Hintze, 1986). The syncline is best indicated on the map by the change in strike of the Shinarump Conglomerate cliffs, steep dip (probably because of compression in the synclinal trough) of the Petrified Forest Member of the Chinle Formation north of the Virgin anticline, and the northeast-trending Virgin anticline (much tighter than the syncline), which includes Bloomington, Washington, and Harrisburg domes. Bloomington dome, the southern-most dome of the Virgin anticline, is in the center of the quadrangle. Data from the California Company #1 drill hole shows that the core of the dome is cut by one or more faults with about 900 feet [275 m] of stratigraphic duplication (Munger, 1963) that we interpret as a backthrust with vergence opposite the direction of regional southeast-directed thrusting (cross section B-B').The transition zone is also part of the active southern segment of the Intermountain Seismic Belt, which coincides with the boundary between relatively thin crust and lithosphere of the Basin and Range Province and thicker, more stable crust of the Colorado Plateau Province (Arabasz and Julander, 1986). The zone consists of a series of down-to-the-west normal faults that step down from the Colorado Plateau into the Basin and Range Province. The quadrangle sits on an intermediate structural block bounded on the west by the Grand Wash-Gunlock fault, with a stratigraphic displacement of about 3000 feet (900 m) near Gunlock and about 1500 feet (450 m) near the Utah-Arizona border (Hintze, 1986), and bounded on the east by the Hurricane fault, with offset of 3600 to 4900 feet (1100–1500 m); the block is also cut by smaller faults, including the Washington and St. George faults.

The Permian Kaibab Formation, with about 370 feet (110 m) exposed, crops out in the center of Bloomington dome and is the oldest unit in the quadrangle. The Triassic Moenkopi Formation, which unconformably overlies canyons and ridges eroded into the Kaibab Formation, is attenuated over Bloomington dome, and varies greatly in thickness from about 2400 feet (730 m) to 1800 feet (550 m). The Triassic Chinle Formation, also exposed on both limbs of the Virgin anticline, averages 800 feet (245 m) thick. A Jurassic section consisting of the Moenave Formation, 270 feet (70 m) thick, the Kayenta Formation, 925 feet (280 m) thick, and the basal 200 feet (60 m) of the Navajo Sandstone, is exposed on the north limb of the anticline.

Four Quaternary sequences of basalt flowed down stream drainages from vents north of the quadrangle. Because of continued regional uplift and subsequent erosion of adjacent sedimentary rocks, these flows now cap ridges, forming inverted valleys. Uplift and downcutting are also documented by incised alluvial-terrace deposits with thick calcic soil (indicating relatively old age) along the Virgin and Santa Clara Rivers and their tributaries, and by other elevated alluvial surfaces.

Several normal faults displace rocks in the St. George quadrangle. Only two north-trending faults have more than a few tens of feet of offset. The Washington fault offsets strata about 750 feet (230 m) where it crosses the northeast corner of the quadrangle. The St. George fault offsets strata about 400 feet (120 m) and cuts across the north-central part of the quadrangle. Both of these are considered late Cenozoic extensional faults, but neither offsets exposed surficial deposits in the quadrangle. Most other faults in the quadrangle trend north-northwest, roughly perpendicular to the Virgin anticline. These small faults generally developed in pairs, forming grabens, and may be related to formation of the folds or to basin-and-range faulting.

GEOLOGIC RESOURCES

Geologic resources that have been produced from the quadrangle include water, gravel, sand, roadfill, riprap, gypsum, and stone; potential exists for other resources. Water resources are increasingly important as population grows and development continues. The Utah Geological Survey website at geology.utah.gov provides additional information on geologic resources in the area.

Gravel, Sand, Roadfill, and Riprap

Gravel, sand, road fill, and riprap are in high demand in the St. George area because of rapid growth. Primary deposits in the quadrangle are near the Santa Clara River, Fort

Pearce Wash, and Atkinville Wash. Several terrace-gravel deposits are present along the Virgin River, but they are smaller than the Santa Clara terraces because the meandering Virgin River removed most older deposits. Many gravel deposits are cemented with thick calcic soil (caliche). Most active pits are in the lowest (youngest) terrace deposits, which contain less carbonate.

Several large terrace remnants are present on the Chinle Formation dip-slope north of the Santa Clara River near the western edge of the quadrangle and a few large pits have been excavated in the deposits. The gravel has less silt and clay than most other deposits in the quadrangle but is strongly cemented with caliche. Several deposits have been covered by construction and are no longer accessible.

Most active gravel pits in the quadrangle are along Fort Pearce Wash. The gravel deposits locally exceed 100 feet (30 m) in thickness where they overlie the Shnabkaib Member of the Moenkopi Formation. We hypothesize that fresh water from Fort Pearce Wash dissolved gypsum in the Shnabkaib, causing local subsidence that was then filled with gravel. The gravel contains a large percentage of silt and clay compared to the river terrace gravels, but has less caliche. Some gravel is present along Atkinville Wash in the southern part of the quadrangle; however, the deposits are typically less than 10 feet (3 m) thick and contain large percentages of fine-grained materials. Minor gravel resources are also present in surficial deposits in the northern part of the quadrangle.

Roadfill has been acquired from several surficial deposits in the quadrangle. Large boulders from basalt and Shinarump Conglomerate talus are used as riprap along the rivers and washes. Several pits have been opened adjacent to the basalt-capped ridges. However, like the gravel, many of these sources are being blocked by construction. Sand for local uses has been obtained from eolian sand deposits near the northern edge of the quadrangle.

Building Stone

Blocks of sandstone from the Kayenta Formation were quarried from near the north edge of the quadrangle in section 19, T. 42 S., R. 15 W. by early settlers to construct the walls of the LDS (Mormon) temple and tabernacle, and several other historic buildings. Flagstone and crushed stone for landscaping and retaining walls have been quarried from the Kayenta Formation in the SW 1/4 section 17, T. 42 S., R. 15 W., where the rock has been fractured by the St. George fault. Early settlers excavated basalt from a slump block in the NE 1/4 section 35, T. 42 S., R. 16 W. for the foundation of the Mormon temple. Slumping created many fractures, allowing for easy removal of the blocks. Large rock-fall blocks of Shinarump Conglomerate excavated during construction of homes on hillsides are reused to build retaining walls.

Ornamental Stone

Petrified wood from the Petrified Forest Member of the Chinle Formation is used to construct monuments, decorate rock gardens and fireplace mantles, and sell as curiosities. "Picture rock" or "landscape stone" from the Shinarump Conglomerate Member of the Chinle Formation is polished into spheres, coasters, and clock bases, and is cut into slabs that are mounted in picture frames. Picture rock is well-cemented sandstone with extensive Liesegang banding that imparts alternating light-brown, dark-brown, and orangish-brown swirls, bands, and other patterns in the rock. In cut pieces these complexly intertwined bands resemble landscape silhouettes. Currently, no quarries for this stone are active within the quadrangle, but several outcrops exist.

Gypsum

An inactive gypsum quarry is located in NW1/4 NW1/4 section 19, T. 43 S., R. 15 W. on the south side of the Price City Hills where gypsum was mined from the Harrisburg Member of the Kaibab Formation. The gypsum is pale gray to white with bands of clay and limestone. Thicknesses vary due to secondary flowage, but outcrops are typically 10 to 30 feet (3–9 m) thick. The Shnabkaib Member of the Moenkopi Formation also has bedded gypsum, but beds are thin and contain abundant claystone and sandstone.

Metals

No metal mines or mineralization are known in the St. George quadrangle. However, the Springdale Sandstone Member of the Moenave Formation, which is exposed in the quadrangle, produced more than 7 million ounces (220,000 kg) of silver prior to 1900 at the Silver Reef mining district near Leeds, Utah, about 15 miles (24 km) northeast of St. George (James and Newman, 1986; Proctor and Brimhall, 1986; Biek and Rohrer, 2006). Significant copper and uranium concentrations, and minor gold, are also present in the Springdale Sandstone at Silver Reef. In the St. George quadrangle, the sandstone is exposed along the northeast-trending Virgin anticline, a setting similar to the Silver Reef district. Anomalously high concentrations of silver are present in the Springdale Sandstone well beyond the boundaries of the Silver Reef mining district, but no ore deposits have been reported to date.

Oil and Natural Gas

Oil and natural gas have not been produced from the St. George quadrangle; however, oil has been produced from the Virgin oil field, 20 miles (32 km) northeast of St. George. Production from 1907 to 1963 was 195,000 barrels (31,000 m^3) of oil from 30 wells, although over 200 wells were drilled (Eppinger and others, 1990). Oil was derived from a sandstone and vuggy limestone interval 1 to 8 feet (0.3–2.4 m) thick in the uppermost part of the Timpoweap Member of the Triassic Moenkopi Formation, with minor production from the Pennsylvanian Callville Limestone. The brown to black oil from the Virgin field ranges from 22° to 32° API, and has a mixed paraffin-asphalt base (Heylmun, 1993). The field lies in a small synclinal pocket near the axis of a broad, low-relief anticline that plunges gently northward. After erosion caused the reservoir pressure to dissipate, the oil drained into small synclinal pockets on the nose. The accumulations were also controlled by local porosity and fracturing (Heylmun, 1993). The Timpoweap Member flanks the Bloomington dome in the St. George quadrangle, but no shows of oil or asphaltic material have been found (Eppinger and others, 1990). Of eight wells with records drilled on Bloomington dome, only three penetrated more than 1000 feet (300 m) (table 1). The deepest well, California Oil Co. #1, penetrated 6347 feet (1923 m) of strata and bottomed 95 feet (29 m) below the top of the Devonian Muddy Peak Dolomite, after repeating the Mississippian Redwall Limestone (Munger, 1963). Drill stem tests recovered only mud and fresh water; no oil shows were noted.

Geothermal Resources

The quadrangle is in an area with geothermal potential (Mabey and Budding, 1985; Budding and Sommer, 1986; Blackett and Wakefield, 2004; also see Utah Geological Survey website at geology.utah.gov/emp/geothermal/index.htm [accessed May 25, 2011]). Several late Quaternary basalt vents are in the area; however, basalt ascends through relatively small pipes from depths of several miles. No hot springs are known in the quadrangle, but hot springs are present within 30 miles (48 km). A well

Table 1. *Oil and gas exploration wells drilled in the St. George 7.5' quadrangle.*

No.	Location (Sec.-T.R.)	Operator and Well Name	Completion Date	Total Depth (feet)	Formtion at TD	API Well Number
1.	NESENW 17-43S-15W	Escalante Exploration (Mid American) Escalante 1	05/04/31	2532	Queantoweap Sandstone	43-053-20528
2.	NENE 19-43S-15W	Uzona Oil Co Uzona 1A	10/10/27	43	Kaibab Formation	43-053-20538
3.	NWNWNE 19-43S-15W	California Oil St. George Unit 1	09/22/51	6347	Muddy Peak Dolomite	43-053-10214
4.	NWNWNE 19-43S-15W	Arrowhead Petroleum Arrowhead 1	06/06/36	4114	Callville Limestone	43-053-20534
5.	NENW 19-43S-15W	Uzona Oil Co Uzona 1	08/01/27	265	Kaibab Formation	43-053-20536
6.	NENW 19-43S-15W	Uzona Oil Co Bloomington 1	02/01/28	625	Kaibab Formation?	unknown
7.	NESWNE 32-43S-15W	Escalante Exploration Escalante 1	03/05/35	969	Kaibab Formation	43-053-20540
8.	CNNWNE 17-43S-15W	unlabeled standpipe identification unknown				unknown
9.	NWSWSE 17-43S-15W location in state records seems unreasonable - not shown on map	Uzona Oil Government 1	03/15/27	387	Kaibab Formation	43-053-20530
10.	"SWSE 17-43S-15W location in state records seems unreasonable - not shown on map	Utah Parks Pet Government 1	00/00/28	50	Kaibab Formation	43-053-20532

drilled near the cinder cone in Big Sand flats north of the quadrangle may have encountered steam at about 900 feet (270 m) (Pete Tolman, verbal communication, 1995), but no actual testing has been reported.

Water

Water is of great importance in the St. George area since the population is rapidly increasing and much of the valley receives less than 8 inches (20 cm) of precipitation per year (Cordova and others, 1972; Cordova, 1978; Clyde, 1987; Horrocks-Carollo Engineers, 1993; Utah Division of Water Resources, 1993; Hurlow, 1998). Water resources of the map area are discussed in Hurlow (1998); additional resources and links are available at geology.utah.gov/utahgeo/water/index.htm.

Cordova and others (1972), Sandberg and Sultz (1985), and Hurlow (1998) summarized flow data on the three main perennial streams in the quadrangle and reported on surface-water quality in the central Virgin River basin. The Virgin River, with an average local annual flow of 145,600 acre-feet (179 hectares^3), flows diagonally across the quadrangle. The Santa Clara River enters the quadrangle near the northwest border and flows into the Virgin River near the center of the quadrangle. It has an average annual flow of 14,600 acre-feet (18 hectares^3) as measured just west of the quadrangle. Fort Pearce Wash, with an estimated average annual flow of 2000 acre-feet (2.5 hectares^3), enters the quadrangle near the southeast corner and also flows into the Virgin River. A few creeks in the northern part of the quadrangle have small perennial spring-fed flows.

The Virgin River controls base level in the quadrangle and the unconfined potentiometric surface slopes toward the river from both the north and the south (Cordova and others, 1972; Cordova, 1978; Clyde, 1987; Hurlow, 1998). Important aquifers in the quadrangle are in the Moenkopi, Chinle, Moenave, Kayenta, and Navajo Formations, and in thin unconsolidated deposits. Of these, the Navajo aquifer (which includes the upper part of the Kayenta Formation) is the most important. Regionally, it consists of about 2000 feet (610 m) of porous, well-sorted, fine- to medium-grained sandstone, but only the lower few hundred feet extend into the northern part of the quadrangle. The primary recharge area for the Navajo aquifer is limited to the Navajo outcrop area (Freethey, 1993) since the overlying Temple Cap and Carmel Formations form an impervious barrier that seals the Navajo from surface waters. Recharge is from precipitation on the Navajo and from streams crossing the Navajo that originate in the Pine Valley and Bull Valley Mountains to the north and northwest. Wells in the Navajo aquifer north and northwest of the quadrangle are a major source of domestic water for the area (Horrocks-Carollo Engineers, 1993; Hurlow, 1998). Several small springs issue near the top of the Kayenta Formation in the northern part of the quadrangle. The gradational Navajo-Kayenta contact separates underlying, low-porosity, muddy siltstone and sandstone from overlying, porous sandstone and forms the base of the Navajo aquifer. The springs issue where south-flowing water "spills" over this natural threshold. The spring water is primarily used for irrigation. Many small springs are also present in sandy intervals in the lower and middle parts of the Kayenta Formation and in the Dinosaur Canyon Member of the Moenave Formation. In general, water is fresh and of high quality in the Navajo and Kayenta aquifers, but has higher total dissolved solids ranging up to salty in older formations. Water quality in unconsolidated sediment aquifers varies considerably depending upon local conditions.

GEOLOGIC HAZARDS

Geologic hazards have caused significant damage to roads and structures in the St. George area, and concern increases as development continues. Flooding; slope failures, including rock falls and landslides; expandable, soluble, and collapsible rock and soil; earthquakes; volcanic eruptions; and radon are of primary concern. Geologic hazards in the area are shown on a series of maps and discussed in detail in Lund and others (2008); also see Biek and others (2009, 2010). The Utah Geological Survey website at geology.utah.gov/utahgeo/hazards/index.htm also provides additional information and resources on geologic hazards.

DESCRIPTION OF MAP UNITS

QUATERNARY

Alluvial deposits

Qal_1 **Stream alluvium** (Holocene) – Stratified, moderately to well-sorted clay, silt, sand, and gravel deposits in large, active drainages; mapped along the Virgin River, which flows diagonally to the southwest across the center of the quadrangle, and the Santa Clara River, which flows southeast from the west edge of the quadrangle; also mapped along Cotton Mill Creek, and Fort Pearce and Atkinville Washes; includes alluvial-fan and colluvial deposits too small to map separately, and alluvial-terrace deposits as much as 10 feet (3 m) above modern channels; estimated 0 to 80 feet (0–24 m) thick.

A heavy rain-on-snow event in the upper elevations of the St. George basin in January 2005 caused the Virgin River, which has an average annual flow of 200 feet^3/second (5.6 m^3/s) (Cordova and others, 1972; Sandberg and Sultz, 1985), to swell from a January mean flow of 274 feet^3/second to 19,600 feet^3/second (8 to 555 m^3/s), and the Santa Clara River, which has an average annual flow of 20 feet^3/second (0.6 m^3/s) to swell from 6 feet^3/second to 6200 feet^3/second (0.17 to 175 m^3/s), creating a flood that caused $140 million in damage to local infrastructure and $85 million to personal property, including damaging or destroying 28 homes (photos, plate 2) (Wilkowske and others, 2006). Much of the damage was due to erosion of Qat_2 terrace deposits, but lateral river-channel migration also undercut the edges of some Qat_3 terrace deposits. Overlay maps that accompany GIS data for this quadrangle show river courses from photos taken in 2006, 1983, 1978, and 1960 to illustrate this lateral migration. In 2005, local officials lined river banks adjacent to developed property with basalt-boulder levees (not mapped) that protected property during a similar flooding event in December 2010.

Qat_2-Qat_5

Alluvial-terrace deposits (Holocene to lower Pleistocene) – Moderately to well-sorted sand, silt, and pebble to boulder gravel that forms level to gently sloping surfaces at several levels above the present river and stream floodplains; clasts are well-rounded and many are exotic to the quadrangle, indicating a source several miles upstream; important local source of sand and gravel; most terraces have a calcic soil (caliche) layer or horizon that is thicker in older deposits (as much as Stage VI carbonate development—see description of stages in Birkeland and others, 1991); deposited primarily in stream-channel and floodplain environments along the Virgin and Santa Clara Rivers and Fort Pearce and Atkinville Washes; most extensive near the Santa Clara River where the river has progressively shifted northeast down the dip slope of the resistant Shinarump Conglomerate by preferentially cutting into the overlying non-resistant Petrified Forest Member and leaving "stairstep" terrace deposits; in contrast, the Virgin River has meandered back and forth near its present channel, cutting away many older terraces; thickness varies from 0 to about 80 feet (0–24 m); deposits may exceed 100 feet (30 m) thick in an area near Fort Pearce Wash where terraces overlie the gypsiferous Shnabkaib Member of the Moenkopi Formation; subscript denotes height above active drainages: level 2 deposits are 10 to 30 feet (3–9 m) above the present drainage, level 3 deposits are 30 to 90 feet (9–25 m), level 4 deposits are 90 to 140 feet (25–40 m), level 5 deposits are 140 to 190 feet (40–55 m) above modern drainages

Hereford and others (1996), working upstream on Virgin River deposits near the town of Rockville, determined that terrace deposits less than about 30 feet (9 m) above the active river channel (mapped as Qal_1 and Qat_2) are late Holocene in age (probably less than 1000 years old) and are related to short-term (decades to a few hundred years) changes from cutting to filling in the "modern" river. They showed that the river cycles through periods of incision and backfilling of a few tens of feet with associated channel widening, meander shifts, and channel narrowing that are controlled primarily by short-term changes in climate and in the frequency, intensity, and duration of major storms. They also estimated that older river-terrace deposits, mapped as $Qat_{3,4,5\ etc.}$, are late Pleistocene and older. Although these older deposits have not been dated directly, their ages can be estimated using long-term incision rates determined from the age of basaltic lava flows and relative height of the flows above the current drainage level, combined with the amount of soil development and degree of lithification (Willis and Biek, 2001; Biek and others, 2009). The long-term downcutting rate along the Santa Clara River, using the Gunlock lava flow just northwest of the quadrangle and projecting the Cedar Bench lava flow (called Airport flow in some preceding publications; i.e. Willis and Biek, 2001), is about 190 feet/million years (60 m/myr).

Qato **Older Alluvial-terrace deposits** (middle to lower Pleistocene) – Gravel- to cobble-size clasts in a muddy to coarse sand matrix; forms small, isolated outcrops of poorly sorted, indurated conglomerate that cannot be directly correlated to the current drainages or numbered deposits; preserved near the northern edge of the quadrangle; a terrace deposit on the north end of West Black Ridge, standing about 400 feet (120 m) above the current drainages, is bracketed in elevation and thus in age between the Twin Peaks and Cedar Bench lava flows; several smaller nearby terraces, briefly exposed during construction of homes in the W1/2 section 24, T. 42 S., R. 16 W., were deposited at slightly lower levels as streams cut down from the level of Twin Peaks flow to that of the Cedar Bench flow; a quarried terrace deposit overlies the St. George fault in NW1/4 section 20, T. 42 S., R. 15 W., west of Middleton Black Ridge, about 200 feet (60 m) above current drainages at about the same elevation as the Lava Ridge lava flow; and a terrace deposit in the NE1/4 NW1/4 section 22, T. 42 S., R. 15 W., near the north edge of the quadrangle, is an estimated 120 feet (36 m) above present drainages at the elevation of Qat_4 deposits, which correlates up slope with an old surface in the Washington quadrangle (Willis and Hayden, in press); 0 to 20 feet (0–6 m) thick.

Qag **Alluvial gravel beneath lava flows** (lower Pleistocene) – Poorly to moderately sorted, clay- to boulder-size, stream-deposited sediment exposed as small, isolated outcrops beneath lava flows; most clasts are well-rounded cobbles and small boulders exotic to the quadrangle, including igneous rocks derived from the Pine Valley Mountains; slightly older than the lava flows that cover them; best exposures typically in road cuts; gravel deposits too thin to map are also exposed between two flows of the Middleton Black Ridge lava flows (Hamblin and Best, 1970); thickness varies from 0 to 20 feet (0–6 m).

Qao **Older alluvial deposits** (Holocene to middle Pleistocene) – Moderately sorted, clay- to boulder-sized, mostly locally derived deposits that form remnants of older alluvial deposits associated with minor drainages; parts next to cliffs may still be receiving limited sediment; locally includes small, poorly sorted alluvial-fan, slope wash, and minor talus deposits; 10 to 30 feet (3–10 m) higher than, and dissected by, minor drainages; 0 to 10 feet (0–3 m) thick.

Qafo **Older alluvial-fan deposits** (middle Pleistocene) – Poorly to moderately well-sorted, clay- to small boulder-sized alluvial-fan deposits with a thick calcic soil (caliche) and rounded basalt and sedimentary clasts; covers part of an inclined surface about 60 feet (18 m) above the current drainages that correlates with level-3 terrace deposits that slope southward toward the Virgin River near Washington in the northeast part of the quadrangle (E1/2 section 32, T. 42 S., R. 15 W.); thickness varies from 0 to 20 feet (0–6 m).

Qap **Pediment-mantle deposits** (Holocene to lower Pleistocene) – Poorly sorted, gravel- to small boulder-sized, indurated conglomerate caps broad northward-sloping bench in the south part of the quadrangle; subangular- to rounded-clasts include small boulders of petrified wood presumably derived from the Petrified Forest Member of the Chinle Formation, small rounded boulders of basalt derived from older flows south of the quadrangle, and limestone; has thick calcic soil (caliche) cap (as much as Stage VI carbonate development); thickness increases southward from 0 to 80 feet (0–24 m).

Eolian Deposits

Qes **Eolian sand deposits** (Holocene to upper Pleistocene) – Well- to very well sorted, fine- to very fine grained, well-rounded, mostly quartz sand; derived from weathering of the Navajo Sandstone and the Kayenta Formation, which it now covers; accumulates in irregular hummocky mounds on the lee side of ridges along the top of the Red Hills; locally forms poorly developed dunes; well exposed in a sand pit near northern edge of quadrangle; thickness varies from 0 to 50 feet (0–15 m).

Artificial deposits

Artificial fill (Historical) – Artificial fill (from human activity) emplaced in small dams, road base, dikes, and other projects; and large excavated and disturbed areas; are extensive throughout the quadrangle. They have not been mapped to avoid obscuring natural geologic relationships and because they change with each new construction project. The fill ranges from engineered and compacted deposits to general borrow materials, and should be anticipated in all areas with human impact, many of which are shown on the topographic base map. Deposits are generally 0 to 20 feet (0–6 m) thick, but locally are thicker.

Mass-Movement Deposits

Qmt **Talus deposits** (Holocene to upper Pleistocene) – Very poorly sorted, angular boulders with minor fine-grained interstitial sediment that has accumulated on and at the base of steep slopes; consists mostly of basalt blocks that roll down slopes as the supporting softer red beds of the Kayenta and Moenave Formations erode, blocks of the Shinarump Conglomerate Member of the Chinle Formation that accumulate on the upper red member of the Moenkopi Formation, and blocks from the Virgin Limestone Member that rest on the lower red member; boulders are commonly used as riprap along rivers and washes; only large deposits are mapped, but talus boulders are common on and at the base of all steep slopes in the quadrangle; 0 to 10 feet (0–3 m) thick.

Qms **Landslide deposits** (Holocene to middle Pleistocene) – Extremely poorly sorted, clay- to boulder-sized, chaotic debris with blocks of rotated strata up to several hundred feet across that form chaotic, hummocky mounds; form primarily on steep slopes capped by basalt flows; basal detachments are in the Petrified Forest Member of the Chinle Formation; common where the Petrified Forest Member forms bluffs held up by gravel-terrace deposits along the Virgin and Santa Clara Rivers and on unstable slopes at the southern ends of the black ridges; slide masses involve overlying bedrock formations, talus, and basalt; evidence of historical movement is common in several areas in mapped deposits, and is suspected in others, including in other map units conducive to sliding; construction activity induced two slumps in Green Valley (Christenson, 1992); Temple Trail is slightly displaced in a few places, indicating historical movement; thickness of these deposits is highly variable, but is generally 10 to 40 feet (3–12 m).

A semi-coherent slump block of basalt and sandstone at the south end of West Black Ridge, in and near the NE1/4 section 35, T. 42 S., R. 16 W., slid about 330 feet (100 m) (prehistoric movement), opening joints in the basalt and forming 5- to 10-foot-diameter (1.5–3-m) blocks. Early settlers quarried the blocks of basalt, slung them under wagons, hauled them along Temple Trail to the marshy site of the St. George LDS (Mormon) temple, and pounded them into the ground with the town cannon to form the footings for the temple (DeMille, 1976).

Mixed-Environment Deposits

Qac **Mixed alluvial and colluvial deposits** (Holocene to upper Pleistocene) – Poorly to moderately sorted clay- to boulder-sized sediment mapped in minor drainages; alluvium is transported along washes during heavy rainstorms, whereas colluvium is derived from side slopes; include stream alluvial deposits (Qal_1) and alluvial terrace deposits (Qat_2) too small to map separately; 0 to 10 feet (0–3 m) thick.

Qae, Qaeo

Mixed alluvial and eolian deposits (Holocene to middle Pleistocene) – Moderately to well-sorted, clay- to sand-sized sediment of alluvial origin that locally includes abundant eolian sand and minor gravel; generally finer-grained than other surficial deposits, consisting primarily of silt- and clay-sized particles in the Washington fields area (Christenson and Deen, 1983); deposited on broad, gentle slopes; Qae deposits are younger with minor calcic soil (caliche) development, whereas Qaeo deposits are older, with a thicker calcic soil horizon, and are more dissected by minor drainages; typically 0 to 30 feet (0–9 m) thick, but may thicken locally.

Qca **Mixed colluvial and alluvial deposits** (Holocene to middle Pleistocene) – Poorly sorted, clay- to boulder-sized, angular to rounded sediment deposited on broad, moderate slopes that lack well-defined drainage patterns, mainly by debris flow, slope-creep, and sheet wash processes; locally dissected by minor washes; include talus, eolian sand, and alluvial deposits too small to map separately; 0 to 30 feet (0–18 m) thick.

Qea, Qeao

Mixed eolian and alluvial deposits (Holocene to middle Pleistocene) – Well-sorted eolian sand locally reworked by alluvial processes; locally include minor alluvial clay to gravel deposits; contain thick calcic soil (caliche) horizon (stage II-IV in Qea deposits, stage V-VI in Qeao deposits); thick calcic soils form a resistant caprock that protects surfaces from erosion, such as the elevated surface of the St. George City airport site in the southeast part of the quadrangle; 0 to 20 feet (0–6 m) thick.

Qeca **Eolian and alluvial deposits with thick calcic soil on lava flows** (Holocene to lower Pleistocene) – Eolian clay, silt, sand, and alluvial gravel with very thick calcic soil (caliche) deposited on lava flows; calcic soil is up to stage VI with more advanced stage (exhibiting laminar layers and platy structures with multiple generations of incipient brecciation and recementation, and pisoliths) on older flows; deposited by streams that reestablished on top of lava flows that filled and hardened bottoms of canyons and valleys; generally, streams eventually shifted to flanks of flows and continued to incise in more-easily eroded Jurassic sedimentary rock; eolian sand, silt, and clay continued to accumulate on the flows, allowing thick calcic soils to develop; thickness varies from 0 to 15 feet (0–5 m).

Basaltic Lava Flows

Basaltic lava flows cap four prominent mesas in the quadrangle, creating classic examples of inverted topography first described in detail by Hamblin (1963, 1970a, 1987) and Hamblin and others (1981): West Black Ridge (Twin Peaks lava flow), "airport ridge" (Cedar Bench lava flow), Middleton Black Ridge (Lava Ridge lava flow), and Washington Black Ridge (Washington lava flow). Typically, the lava flowed down the bottom of valleys, forming a hard surface. Streams commonly re-established on top of the flows, as evidenced by thin gravel deposits, before slipping to the sides of the flows to preferentially erode the softer sedimentary bedrock. Continued downcutting then left the resistant lava flows isolated as elevated, sinuous ridges, called inverted valleys; thus, flows that used to be the valley floors now cap the ridges. Since most small basaltic volcanoes are monocyclic, meaning that each vent produces only one eruptive cycle that may last less than a year to a few tens of years, the resistant flows document the local drainage pattern as it existed when the flow erupted (in contrast, flows from a single eruptive cycle may consist of several pulses of lava, called cooling units, that can be confused as separate flows.)

Isotopic ages for these lava flows and their heights above major drainages provide a means for calculating long-term incision rates for major rivers and streams in the St. George area (Willis and Biek, 2001). The calculations reconfirm and expand on many of the findings of Hamblin and others (1981), who similarly documented incision rates in the St. George basin. However, the old axiom that "the higher the lava flow is above the current drainage, the older it is" is only valid when comparing flows on the same part of the same structural block. For example, the lower reaches of Middleton and Washington Black Ridges, capped by the Lava Ridge and Washington lava flows, respectively, are classic inverted valleys. The two flows are about 5 miles (8 km) apart and both flowed into a well-graded stretch of the ancestral Virgin River, but they are on different structural blocks separated by the Washington fault. The Washington flow stands about twice as high above the present Virgin River as the Lava Ridge flow, yet $^{40}Ar/^{39}Ar$ ages show that it is about 500,000 years younger than the Lava Ridge flow (Biek and others, 2009). The greater topographic inversion of the younger flow is directly attributable to its position on the footwall (upthrown part) of a separate, relatively more elevated structural block. Thus, position on structural blocks is important when estimating relative ages of lava flows based on the amount of "topographic inversion" ("stage" designations of Hamblin, 1963, 1970a, 1987).

Flows consist of multiple cooling units that range from a few feet to a few tens of feet thick, each unit representing a pulse of magma separated by enough time for cooling, but not significant weathering, to occur. However, the cap on the northeast portion of Middleton Black Ridge is composed of at least three flows (Hamblin and Best, 1970) that are separated by alluvial gravel layers that indicate the presence of a more significant break between the flows.

Hamblin (1963, 1970a, 1987), Best and others (1966, 1980), Lowder (1973), Leeman, (1974), Best and Brimhall (1970, 1974), Hamblin and others (1981), Nelson and Tingey (1997), Nusbaum and others (1997), Smith and others (1999), Downing (2000), and Biek and others (2009) described lava flows in the greater St. George area, their tectonic setting, and their petrogenesis, and proposed that the geochemical variability between individual lava flows could be explained by their derivation from the partial melting of compositionally heterogeneous lithospheric mantle, and by fractional crystallization. Raw data for whole-rock groundmass concentrate $^{40}Ar/^{39}Ar$ ages and major and trace-element geochemistry for these lava flows are in Biek and Ehler (2007), which is available on the Utah Geological Survey Web site geology.utah.gov/online/analytical_data.htm. Rock names are derived from the total alkali vs. silica diagram of LeBas and others (1986).

Qbw **Washington lava flow** (lower Pleistocene) – Medium- to dark-gray to dark-greenish-gray, fine-grained basanite to picrobasalt with a uniform seriate texture and abundant clinopyroxene and olivine phenocrysts that range in size from about 0.1 inch (3 mm) down to groundmass; groundmass is plagioclase and titaniferous magnetite (Best and Brimhall, 1974); forms strongly jointed ledge in northeast corner of quadrangle; erupted from a vent at a cinder cone about 5 miles (8 km) north-northeast of the quadrangle; flow is offset 20 to 30 feet (6–9 m) by splays of Washington fault, with additional slumping and settling due to movement of the underlying weak, clay-rich Petrified Forest Member of the Chinle Formation; three cooling units are exposed in the quadrangle to the east (Biek, 2003); quarried for building stone northeast of the quadrangle; yielded $^{40}Ar/^{39}Ar$ ages of 0.87 ± 0.04 and 0.98 ± 0.02 Ma (Biek, 2003), which fits well with regional incision rates (Willis and Biek, 2001); an anomalously old K-Ar age of 1.7 ± 0.1 Ma reported in Best and others (1980) is not reliable; 15 to 25 feet (5–8 m) thick within the quadrangle.

Qbcb **Cedar Bench lava flow** (lower Pleistocene) – Dark-greenish-gray to brownish-black trachybasalt with small phenocrysts of clinopyroxene and olivine; prevalent columnar jointing; strongly weathered along joints, forming a mottled texture; previously called Airport lava flow (Willis and Biek, 2001) but, because of similar geochemistry, is now considered the southern extension of the Cedar Bench lava flow (Biek and others, 2009); two cooling units are well exposed along the southeast edge of the flow; erupted from vents at two overlapping cinder cones about 10 miles (16 km) north of St. George; yielded an $^{40}Ar/^{39}Ar$ plateau age of 1.23 ± 0.01 Ma (Biek and others, 2009), which fits well with regional downcutting rates (Willis and Biek, 2001); a younger K-Ar age of 1.07 ± 0.04 Ma reported by Hamblin and others (1981) is not reliable; typically 10 to 30 feet (3–9 m) thick.

Qbl **Lava Ridge lava flow** (lower Pleistocene) – Moderate- to dark-gray to dark-brownish-gray basaltic trachyandesite with prominent euhedral plagioclase phenocrysts up to 0.4 inch (1 cm) wide, common quartz and pyroxene phenocrysts, and small olivine phenocrysts; moderately jointed; previously called Middleton lava flow (Willis and Biek, 2001) but petrographic and limited geochemical data suggests it is the southern extension of the Lava Ridge lava flow (Biek and others, 2009); consists of three flows near the north edge of the quadrangle in a road cut on Middleton Drive near the intersection with Red Rock Road in NE1/4 NE1/4 section 20, T. 42 S., R. 15 W. (Hamblin and Best, 1970) where the more mafic oldest flow, about 5 feet (1.5 m) thick, overlies alluvial gravel deposited on bedrock; it is overlain by another well-developed alluvial gravel, a lava flow about 20 feet (6 m) thick, another gravel, and then an upper lava flow about 15 feet (4.5 m) thick; a nearby roadcut on Interstate 15 reveals that only the upper flow continues south, capping Middleton Black Ridge; forms a two-mile-long (3.2 km), straight, narrow inverted valley where the flow was confined in a narrow channel, and a broad "foot" where it entered the more open channel of the ancestral Virgin River; erupted from a group of heavily weathered cinder cones on Lava Ridge, about 8 miles (13 km) north of the quadrangle (Willis and Hayden, in press); from Middleton Black Ridge, the upper flow yielded a K-Ar age of 1.5 ± 0.1 Ma (Best and others, 1980) and an $^{40}Ar/^{39}Ar$ age of 1.41 ± 0.01 Ma (Biek and others, 2009) the lower two flows are probably about the same age; generally 20 to 40 feet (6–12 m) thick.

Qbt **Twin Peaks lava flow** (lower Pleistocene) – Dark-gray to dark-brownish-gray basaltic trachyandesite with large plagioclase and quartz, and small olivine and clinopyroxene phenocrysts; strong columnar jointing; weathers to large, angular, blocky rubble; two cooling units well exposed; geochemistry suggests that this flow, previously called West Black Ridge lava flow (Willis and Biek, 2001), erupted from vents at extensively eroded cinder cones at Twin Peaks, about 8 miles (13 km) north of the quadrangle, and it is now considered the southernmost part of the Twin Peaks lava flow (Biek and others, 2009); caps the inverted valley of West Black Ridge where the flow yielded K-Ar ages of 2.3 ± 0.1 Ma (Best and others, 1980) and 2.24 ± 0.11 Ma (Hamblin and others, 1981), and an $^{40}Ar/^{39}Ar$ age of 2.34 ± 0.02 Ma (Biek and others, 2009); 20 to 80 feet (6–24 m) thick.

unconformity

JURASSIC

Jn **Navajo Sandstone** (Lower Jurassic) – Moderate-reddish-orange to moderate-reddish-brown, massively cross-bedded, moderately well-cemented sandstone with well-rounded, fine- to medium-grained, frosted quartz sand grains; locally common ironstone bands and concretions; strongly jointed in two main joints sets; generally north-northeast-trending joints are parallel, high-angle, typically open; northwest-trending joints are commonly brecciated and strongly cemented with siliceous and calcareous cement that is more resistant than the host rock and therefore stands out in relief; forms the White Cliffs step of the Grand Staircase (Gregory, 1950); mapped as the cliffs and slopes of the upper portion of the Red Hills; formation is principal aquifer in the area (Clyde, 1987; Hurlow, 1998; Heilweil and others, 2000, 2002; Rowley and Dixon, 2004; Rowley and others, 2004); springs commonly develop at lower contact with the Kayenta Formation; deposited in a vast coastal and inland dune field with prevailing winds principally from the north, and in rare interdunal ephemeral lakes and playas (Blakey, 1994; Peterson, 1994); much of the sand may originally have been transported to areas north and northwest of Utah via a transcontinental river system that tapped Grenvillian-age (about 1.0 to 1.3 billion-year-old) crust involved in Appalachian orogenesis of eastern North America (Dickinson and Gehrels, 2003, 2009; Rahl and others, 2003; Reiners and others, 2005); lower contact is drawn where massively bedded, vertically jointed sandstone gives way to thinner bedded siltstone and sandstone of the Kayenta Formation, although a transition zone between the two formations that reaches its maximum thickness of about 300 feet (100 m) in the Red Cliffs area northeast of the quadrangle can make the contact difficult to pick; map unit includes small areas of weathered sandstone regolith and Quaternary eolian sand that may be blown into crude dune form; only lower 200 feet (60 m) is present in the quadrangle, but total thickness in this area is 1800 to 2000 feet (550–600 m).

Jk **Kayenta Formation** (Lower Jurassic) – Main body and Springdale Sandstone Member combined on cross section only.

Jkm **Main body** (Lower Jurassic) – Reddish-brown to moderate-reddish-brown to pale-red, thin-bedded siltstone and mudstone interbedded with very fine to fine-grained, planer to lenticular, mottled sandstone with climbing ripple marks; sericite common on some bedding surfaces; upper surface of sandstone ledges is commonly bioturbated; includes minor intraformational pebble conglomerate near the base and three thin beds of light-pinkish-gray to light-olive-gray, micritic limestone at 85 feet (26 m), 105 feet (31 m), and 110 feet (33 m) above the base; 2-foot-thick (0.6 m), light-gray siltstone marker bed about 30 feet (9 m) below the top extends across the quadrangle; generally coarsens upward; forms steep, ledgy slope to ledgy cliff that is mostly covered by talus; commonly strongly jointed; quarried from Red Hills by early settlers for building stone; best exposed by construction and roadcuts along Bluff Street, in the drainage on the east side of Middleton Black Ridge, and at the base of Red Hills along the northern edge of the quadrangle; lower contact with the Springdale Sandstone Member is conformable and gradational and is placed at the base of laterally continuous, thin-bedded, reddish-brown, fine-grained silty sandstone that overlies the Springdale cliff; deposited in distal river, playa, and minor lacustrine environments (Tuesink, 1989; Blakey, 1994; Peterson, 1994); 810 feet (247 m) thick just east of Middleton Black Ridge (based on combined measurements in washes and I-15 roadcuts).

Jks **Springdale Sandstone Member** (Lower Jurassic) – Mostly pale-reddish-brown to pale-grayish-yellow, moderately sorted, fine- to medium-grained, medium- to very thick bedded, ledge- to small-cliff-forming sandstone, 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; contains locally abundant petrified and carbonized fossil plant remains; theropod tracks common in upper horizon known as the Springdale megatracksite (Lucas and others, 2005; Hamblin and others, 2006); produced silver at the Silver Reef mining district 15 miles (24 km) to the northeast (James and Newman, 1986; Proctor and Shirts, 1991; Biek and Rohrer, 2006), and has local copper and uranium mineralization (James and Newman, 1986); resistant to erosion and forms isolated outcrops that protrude from beneath basalt talus along the slopes of the black ridges and is completely exposed in washes east and west of Middleton Black Ridge; unconformable lower contact with the Whitmore Point Member of the Moenave Formation is placed at the base of massive, sandstone cliff and above a slope of interbedded mudstone and claystone; deposited in braided-stream and minor flood-plain environments (Clemmensen and others, 1989; Blakley, 1994; Peterson, 1994; DeCourten, 1998; and Lucas and Tanner, 2006); 115 feet (35 m) thick east of Middleton Black Ridge, in the SE1/4 SE1/4 NW1/4 section 28, T. 42 S., R. 15 W.

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 the Kayenta Formation.

JURASSIC/TRIASSIC

Moenave Formation

JTRm **Moenave Formation** (Lower Jurassic to Upper Triassic) – Whitmore Point and Dinosaur Canyon Members combined on cross section only.

Jmw **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 and very light gray to yellowish-gray, dolomitic limestone; siltstone commonly thin bedded to laminated in lenticular or wedge-shaped beds; claystone is generally flat bedded and weathers into an expansive soil; contains several 2- to 6-inch-thick (5–15 cm), bioturbated, cherty, dolomitic limestone beds with algal structures, some altered to jasper, and fossil fish scales, likely of semionotid fish (Milner and Kirkland, 2006); nonresistant and poorly exposed in excavations along Bluff Street, in drainages next to Middleton Black Ridge, and beneath a few protective stream terraces now largely removed by construction along Riverside Drive; this construction area, now called the St. George Dinosaur Discovery Site at Johnson Farm, revealed exceptionally well-preserved theropod tracks (*Eubrontes* and *Grallator*) near the base of the member, including swim tracks (Kirkland and Milner, 2006; Milner and others, 2006), and a variety of invertebrate (Lucas and Milner, 2006), trace (Lucas and others, 2006), and plant (Tidwell and Ash, 2006) fossils; lower, conformable contact is placed at a pronounced break in slope at the base of the lowest light-gray, thin-bedded, dolomitic limestone and above the thicker bedded sandstone and siltstone ledges of the Dinosaur Canyon Member; deposited in low-energy lacustrine and fluvial environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998; and Milner and Kirkland, 2006); measured 55 feet (17 m) thick in the drainage east of Middleton Black Ridge in the NE1/4 NE1/4 SE1/4 section 28, T. 42 S., R. 15 W.

JŦmd **Dinosaur Canyon Member** (Lower Jurassic to Upper Triassic) – 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 with laminated cross-beds; uniformly colored; ripple marks and mud cracks common; forms ledgy slope; regionally forms the base of Vermilion Cliffs step of the Grand Staircase (Gregory, 1950); is poorly exposed in the northern part of the quadrangle in excavations below basalt talus near the south end of Middleton and West Black Ridges, in stream drainages on either side of the ridges, and where protected from erosion by overlying stream-terrace deposits, although several outcrops have recently been removed by construction; regionally, a thin chert pebble conglomerate marks the base of the unit, but in this area it is more common to have a 1.5- to 2-foot-thick (0.5–0.6 m) gypsum bed with local chert pebbles; unconformable lower contact is placed at the base of a chert pebble conglomerate or gypsum bed where recognized, otherwise it is placed at a prominent color and lithology change from reddish-brown siltstone above to pale-greenish-gray mudstone of the Petrified Forest Member of the Chinle Formation below; deposited on broad, low floodplain that was locally shallowly flooded (fluvial mud flat) (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; and DeCourten, 1998); 185 feet (55 m) thick (Kirkland and Milner, 2006).

unconformity, originally called the J-0 unconformity by Pipiringos and O'Sullivan (1978), who thought it was at the Jurassic-Triassic boundary; however, evidence now shows that the Jurassic-Triassic boundary is within the Dinosaur Canyon Member of the Moenave Formation; thus this unconformity is within Upper Triassic strata suggesting that it may be the TR-5 unconformity of Lucas (1993) (Molina-Garza and others, 2003; Kirkland and Milner, 2006; Lucas and Tanner, 2007).

TRIASSIC

Chinle Formation

Ŧcp **Petrified Forest Member** (Upper Triassic) – Highly variegated, light-brownish-gray, pale-greenish-gray, to grayish-red-purple, bentonitic shale, mudstone, siltstone, and claystone, with several lenticular interbeds of pale-yellowish-brown, cross-bedded, resistant sandstone up to 10 feet (3 m) thick; pebble to small-cobble conglomerate near base; clasts are primarily chert and quartzite; contains minor chert, nodular limestone, very thin coal seams and lenses as much as 0.5 inch (1 cm) thick, and locally abundant, brightly colored fossilized wood; shale and mudstone weather to a "popcorn" surface with abundant mudcracks due to expansive clays and cause road and building foundation problems; weathers to badland topography; prone to landsliding along steep hillsides; local primary source for radon (Solomon, 1992a, b); forms well-developed strike valley of the Santa Clara and Virgin Rivers adjacent to the more resistant cliffs of the Shinarump Conglomerate Member; well exposed only where protected from erosion by stream terrace deposits and in road cuts along the south edges of Middleton and West Black Ridges; lower contact with the Shinarump Conglomerate Member is placed at the base of the purplish-gray clay slope and above a prominent sandstone and conglomerate ledge; deposited in lacustrine, floodplain, and fluvial environments of a back-arc basin formed inland of a magmatic arc associated with a subduction zone along the west coast of North America and a significant portion of sediment was supplied by volcanic ash (Stewart and others, 1972b; Dickinson and others, 1983; Blakey and others, 1993; Lucas, 1993; Dubiel, 1994; DeCourten, 1998; Lucas and Tanner, 2007); 700 feet (215 m) thick as estimated from map relationships where both upper and lower contact is exposed.

Working in Petrified Forest National Park in Arizona, Billingsley (1985) divided the Petrified Forest Member into upper and lower members separated by the Sonsela Sandstone bed. Heckert and Lucas (2002) expanded the Sonsela term to include three major packages of rock (including the original sandstone bed), upgraded it to a member, proposed an unconformable surface at the base, and renamed the underlying bentonitic beds Blue Mesa Member and the overlying bentonitic beds Painted Desert Member. Woody (2006) doubted the existence of a single unconformable surface at the base of the Sonsela Member and retained the name Petrified Forest Member for the upper beds. Martz and Parker (2010) agreed that the base of the expanded Sonsela Member consists of discontinuous lenses of sandstone and conglomerate that are complexly interbedded with the Blue Mesa Member as five major packages of rock. Discontinuous sandstone and conglomerate beds are locally present in southwestern Utah, but evidence is not conclusive if these sandstone and conglomerate beds represent the Sonsela Member, thereby making the underlying bentonitic beds the Blue Mesa Member, or if they are simply sandstones within the Petrified Forest Member, as currently mapped. Therefore, these members have not yet been established in southwest Utah and the entire package of strata is herein mapped as Petrified Forest Member; individual sandstone beds are not mapped separately because of poor, discontinuous exposures.

₸cs **Shinarump Conglomerate 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"), grading to moderate-brown, pebbly conglomerate with subrounded clasts of quartz, quartzite, and chert; conglomerate well developed in the southeast corner of the quadrangle; mostly thick- to very thick bedded with both planar bedding and low-angle cross-stratification, although thin, platy beds with ripple cross-stratification occur locally; strongly jointed with common slickensides on multiple surfaces; weathering along major northeast-trending joints forms repeated straight, narrow gaps in the rock a few inches to several feet wide and locally more than 50 feet (15 m) deep; contains poorly preserved petrified wood, commonly replaced in part by iron-manganese oxides; forms a dark-brown to moderate-yellowish-brown resistant ledge to small cliff above the Moenkopi Formation, thus capping the Chocolate Cliffs step of the Grand Staircase (Gregory, 1950); forms the cuesta of Bloomington and Webb Hills that stretches east-west across the middle of the quadrangle as the north limb of the Virgin anticline, and the cuesta in the southeast quadrant of the quadrangle that forms the south limb; lower unconformable contact is drawn at the base of the Shinarump cliff, above the slope-forming, reddish-brown siltstone of the upper red member of the Moenkopi Formation; variable in composition and thickness because it represents stream-channel deposition over Late Triassic paleotopography (Stewart and others, 1972b; Dubiel, 1994); measured thickness variations may also be due in part to unmapped slumping or sliding of blocks on the steeply dipping north limb of the Virgin anticline, such as at Webb Hill, similar to those described by Hintze and Hammond (1994) in the Shivwits quadrangle northwest of the study area; slickensides with multi-directional lineations at the base of the sandstone indicate that it commonly slides on the upper red member of the Moenkopi Formation; ranges from 5 to 200 feet (1.5–60 m) thick.

unconformity, TR-3 of Pipiringos and O'Sullivan (1978)

Moenkopi Formation

₸mu **Upper red member** (Lower Triassic) – Moderate-reddish-brown to moderate-reddish-orange, thin- to medium-bedded siltstone and very fine grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers; ripple marks common in the siltstone; locally includes 20-foot-thick (6 m) fine-grained, resistant sandstone near base; where the basal sandstone is thickened, the weathering and slope retreat of overlying units is slowed, creating resistant points on the cuestas that form Webb and Bloomington Hills; well exposed along both the north and south flanks of the Virgin anticline as a steep slope with at least one prominent sandstone ledge beneath the resistant caprock of Shinarump Conglomerate; conformable lower contact is gradational and drawn where the reddish-brown mudstone of the upper red member grades into the greenish-gray, gypsiferous siltstone of the Shnabkaib Member; deposited in tidal-flat and coastal-plain environments (Stewart and others, 1972a; Dubiel, 1994); 360 to 400 feet (110–120 m) measured 363 feet (111 m) thick on the south side of Webb Hill in the SW1/4 NW1/4 NE1/4 section 7, T. 43 S., R. 15 W.

₸ms **Shnabkaib Member** (Lower Triassic) – Light-gray to pale-red gypsiferous siltstone with several thin interbeds of dolomitic, unfossiliferous limestone near the base; alternating light- and dark-colored strata create a "bacon-striped" appearance; resistant limestone and nonresistant siltstone beds form ledge-slope topography, thus making the lower part slightly more resistant to erosion than the upper part; upper part is very gypsiferous, weathers to a powdery soil, and forms a strike valley; gypsum dissolution causes local settlement, collapse, and piping; well exposed between the Price City Hills and Webb Hill near the center of the quadrangle and in the White Hills near the south edge; probably youngest layer to have structural closure around the north end of Bloomington dome beneath valley alluvium; conformable and gradational lower contact is placed where the predominantly light-gray, unfossiliferous, dolomitic limestone beds that mark the base of the Shnabkaib Member are underlain by the moderate-red siltstone of the middle red member; deposited on a broad coastal shelf of low relief in a variety of supratidal, intertidal, and subtidal environments (Stewart and others, 1972a; Lambert, 1984); 900 to 1000 feet (270–300 m) thick; measured 996 feet (302 m) in the E1/2 section 7, T. 43 S., R 15 W.

Ћmm **Middle red member** (Lower Triassic) – Interbedded 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; best exposed along the northwest side of Bloomington dome and next to the White Hills near the south edge of the quadrangle where the member forms low reddish-colored hills; commonly covered with stream terrace gravels; conformable lower contact is placed at the top of the highest limestone ledge of the Virgin Limestone Member; deposited in a tidal-flat environment (Stewart and others, 1972a; Dubiel, 1994); 350 to 375 feet (107–114 m) thick; measured 372 feet (113 m) along the northeast side of Bloomington dome in the NW1/4 NE1/4 section 18, T. 43 S., R. 15 W.

Ћmv **Virgin Limestone Member** (Lower Triassic) – Four distinct medium-gray to yellowish-brown marine limestone ledges, each about 5 feet (1.5 m) thick, interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum; lower part of each limestone is finer-grained, muddy, and non-fossiliferous while the upper part is coarser wackestone with birdseye structures; these two limestone parts are divided by about an inch (2.5 cm) of dark-grayish-brown mudstone; limestone locally contains circular and five-sided crinoid columnals, gastropods, and brachiopods; includes 10-foot-thick (3 m) ledge of light-gray to grayish-orange-pink gypsum near top; mudstone intervals contain expansive clays; forms well exposed series of resistant ridges along the west and south sides of Bloomington dome; lower conformable contact with lower red member placed at the base of the lowest limestone bed; deposited in a variety of shallow-marine environments (Stewart and others, 1972a; Dubiel, 1994); thickness varies from 225 feet (70 m) on the southwest edge of the Price City Hills to an attenuated 25 feet (8 m) along the near-vertical north limb of the asymmetrical Virgin anticline where small bedding plane faults (not mapped due to limited extent) are common (even though overall the member is attenuated in this area, the four key limestone ledges are still present, and even locally thickened due to movement on low-angle reverse faults); measured 134 feet (41 m) thick in SE1/4 SW1/4 SE1/4 section 13 ,T. 43 S., R. 16 W.

Ћml **Lower red member** (Lower Triassic) – Moderate-reddish-brown to dark-yellowish-orange, thin-bedded siltstone, mudstone, and very fine grained sandstone; generally calcareous with interbeds and stringers of gypsum; ripple marks and small-scale cross-beds are common in the siltstone; forms strike valley around the edge of the Price City Hills with best exposures along the north and west sides between the more resistant basal ledge of the Virgin Limestone Member and the Kaibab Formation; lower conformable and gradational contact placed at the base of predominantly light-reddish-brown mudstone and above dark-yellowish-orange, friable sandstone that marks the top of the Timpoweap Member; locally, very thin beds of dark-yellowish-orange siltstone, widely separated by light- to moderate-reddish-brown mudstone and siltstone, are included in the lower red member; deposited in a tidal-flat environment (Stewart and others, 1972a; Dubiel, 1994); thickness varies from 25 to 300 feet (8–90 m), probably due to attenuation faulting, especially in steeply dipping beds on the north side of the Virgin anticline; thickness variations are probably not due to stratigraphic thinning over paleohills of the Kaibab Formation (as is the case to the west in the Beaver Dam Mountains; Jenson, 1984; Hayden, 2011) since the underlying Timpoweap Member, which fills and smooths most paleo-topographic relief, is present everywhere the base is exposed.

Ћmt **Timpoweap Member** (Lower Triassic) – Upper part consists of dark-yellowish-orange and moderate reddish-brown, thin- to very thin bedded, calcareous sandstone and siltstone with typically five 0.25- to 2-inch-thick (0.5–5 cm), medium-gray limestone beds that have medium- to coarse-grained lenticular sandstone near the base; upper beds generally fine upward and are gypsiferous near the top with lenses of gypsum and sandstone; bedded gypsum forms punky surface and weathers to form a slope covered with cryptogamic soil; lower part consists of light-gray to grayish-orange, light-brown-weathering, thin- to thick-bedded limestone and cherty limestone that locally includes pebble and gravel-sized clasts; member is best exposed along the north side of Bloomington dome; generally unconformably overlies limestone and gypsum of the Harrisburg Member of the Kaibab Formation but locally overlies the Rock Canyon Conglomerate Member of the Moenkopi Formation, although exposures are poor; lower conformable and gradational contact with the Rock Canyon Conglomerate Member, where present, is placed at the top of conglomerate beds; deposited in a near-shore shallow-marine environment with abundant clastic input (Nielson and Johnson, 1979; Dubiel, 1994; Lucas and others, 2007); thickness decreases dramatically as the siltstone beds between the limestone intervals thin; Nielson (1981) measured 272 feet (83 m) in the NW1/4 NE1/4 NE1/4 section 24, T. 43 S., R. 15 W., but we only measured 110 feet (32 m) in the same area probably due to using different upper contacts and possibly to local thinning; measured 75 feet (23 m) in the SW1/4 SW1/4 SW1/4 section 18, T. 43 S., R 15 W.; ranges from 10 to 110 feet (3–32 m) thick.

Ŧmr **Rock Canyon Conglomerate Member** (Lower Triassic) – Consists of two main rock types: (1) yellowish-gray to light-olive-gray, pebble to cobble, clast-supported conglomerate, with sub-angular to rounded chert and minor limestone clasts derived from the Harrisburg Member of the Kaibab Formation, grading upward to a limestone or coarse-grained sandstone-matrix-supported conglomerate; deposited in paleocanyons; typically 0 to several tens of feet thick, but as much as about 200 feet (60 m) thick regionally; and (2) thin-bedded, angular to sub-angular, limestone clasts and brecciated blocks as large as 14 inches (35 cm) in diameter from the Harrisburg Member that probably formed as weathered regolith on Harrisburg strata (Nielson, 1981); locally cemented multiple times with sparry calcite; about 3 to 10 feet (1–3 m) thick; both types grade upward to calcareous, gritty, poorly sorted, pebble conglomerate with coarse sandstone lenses; thick, locally lenticular bedding; indurated and cliff forming; only one outcrop mapped in the quadrangle at the southwest end of the Price City Hills; unconformably rests on the Fossil Mountain Member of the Kaibab Formation where the Harrisburg Member was completely removed by erosion; nearby it abuts the Harrisburg Member; lower contact drawn at the base of the conglomerate, above the massive limestone of the Fossil Mountain Member of the Kaibab Formation; measured thickness of 35 feet (11 m) in the NE1/4 SE1/4 NE1/4 section 24, T. 43 S., R. 16 W., whereas is completely cut out in adjacent outcrop; Nielson (1981) measured 38 feet (12 m) nearby.

unconformity, TR-1 of Pipiringos and O'Sullivan (1978). Several hundred vertical feet of subaerial erosion during Late Permian and Early Triassic time completely removed the Harrisburg Member of the Kaibab Formation in some places along channels. Jenson (1984) described karst topography with more than 594 feet (180 m) of relief that formed during this 15-million-year period of erosion in the Beaver Dam Mountains to the west.

PERMIAN

Kaibab Formation

Pk **Kaibab Formation** (Lower Permian) – Harrisburg and Fossil Mountain Members combined on cross section only.

Pkh **Harrisburg Member** (Lower Permian) – Light-gray, fossiliferous, sandy, fine- to medium-grained limestone interbedded with red and gray gypsiferous siltstone, sandstone, and gray gypsum beds up to several feet thick; beds of cherty limestone and sandy limestone about 20 feet (6 m) thick form resistant ledges near the upper middle and were referred to as the "medial limestone" by Nielson (1981); well-exposed in an inactive gypsum quarry on the south side of Price City Hills and an active quarry in the east edge of Bloomington dome; dissolution of interbedded gypsum locally distorts bedding and complicates secondary thrust-related folding in the center of Bloomington dome regionally, the member has many large collapse structures and/or breccia pipes that may have begun forming during Mississippian time (Wenrich and others, 1986; Wenrich and Huntoon, 1989) although none are mapped within this quadrangle; several hundred feet of post-depositional, subaerial erosion during Late Permian to Early Triassic time completely removed the Harrisburg Member from the southwest part of the Price City Hills where the Rock Canyon Conglomerate Member of the Moenkopi Formation is deposited directly on the Fossil Mountain Member of the Kaibab Formation; lower conformable contact is placed at the base of the lowest thick gypsum bed and just above the top of the massive Fossil Mountain Member limestone cliff; deposited in shallow-marine and sabkha environments (McKee, 1938; Nielson, 1981, 1986; Sorauf and Billingsley, 1991); Nielson (1981) measured 280 feet (85 m) near the southwest end of the Price City Hills and an incomplete section of 185 feet (56 m) near the northeast end; thickness varies greatly due to subaerial erosion; 0 to 300 feet (0–90 m) thick.

Pkf **Fossil Mountain Member** (Lower Permian) – Yellowish-gray, abundantly fossiliferous, cherty limestone with silicified fossils that include corals, brachiopods, crinoids, and bryozoans; reddish-brown and black chert forms irregularly bedded nodules and causes the outcrop to appear black-banded; forms a prominent cliff; only upper part exposed in the northeast part of Bloomington dome and in the bottom of a few deep washes along the southwest edge of the Price City Hills; deposited in a shallow-marine environment (McKee, 1938; Nielson, 1981, 1986; Sorauf and Billingsley, 1991); Nielson (1981) measured an incomplete thickness of 68 feet (20 m) in sections 8 and 9, T. 43 S., R. 15 W., near River Road, whereas only uppermost four feet (1.2 m) is exposed beneath the Rock Canyon Member of the Moenkopi Formation in a wash on the southwest side of the dome in and near SE1/4 NE1/4 section 24, T. 43 S., R. 16 W.; up to 300 feet (90 m) thick to the west in the White Hills quadrangle where at least 200 feet (60 m) of unit was locally removed by channel erosion prior to deposition of the Rock Canyon Conglomerate Member and/or Timpoweap Member of the Moenkopi Formation (Hayden, 2011).

Subsurface Units

Pt **Toroweap Formation** – Cross section only; thickness from Munger (1963) and Hayden (in press).

Pq **Queantoweap Sandstone** – Cross section only; thickness from Munger (1963) and Hammond (1991).

Pp **Pakoon Dolomite** – Cross section only; thickness from Munger (1963) and Hammond (1991).

PENNSYLVANIAN

IPc **Callville Limestone** – Cross section only; thickness from Munger (1963) and Hammond (1991).

MISSISSIPPIAN

Mr **Redwall Limestone** – Cross section only; thickness from Munger (1963) and Hammond (1991).

DEVONIAN

Dm **Muddy Peak Dolomite** – Cross section only; thickness from Hammond (1991).

CAMBRIAN

Ꞓn **Nopah Dolomite** – Cross section only; thickness from Hammond (1991).

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Erratum (May 2021)

During compilation into the USGS Geologic Map Schema in 2021, the UGS made the following changes to the geologic map. These changes were based on unpublished geotechnical and research studies conducted in the area after the map was published, as provided by Janice Hayden, original map author and Professor of Geology at Dixie State University, to Grant Willis, UGS Geologic Mapping Program Manager, on February 3, 2021.

Changes made to Geologic Map of the St. George Quadrangle Based on Instructions from Original Lead Author

Change	Latitude North	Longitude West
Moved contact and dinosaur tracksite symbol slightly south	37.102	113.535
Slightly enlarged size of Qms polygon and slightly reduced size of bedrock polygon	37.087	113.589
Extended a mapped fault	37.072	113.620
Extended a mapped fault	37.041	113.578
Extended a mapped fault	37.043	113.572
Added various missing unit labels	–	–