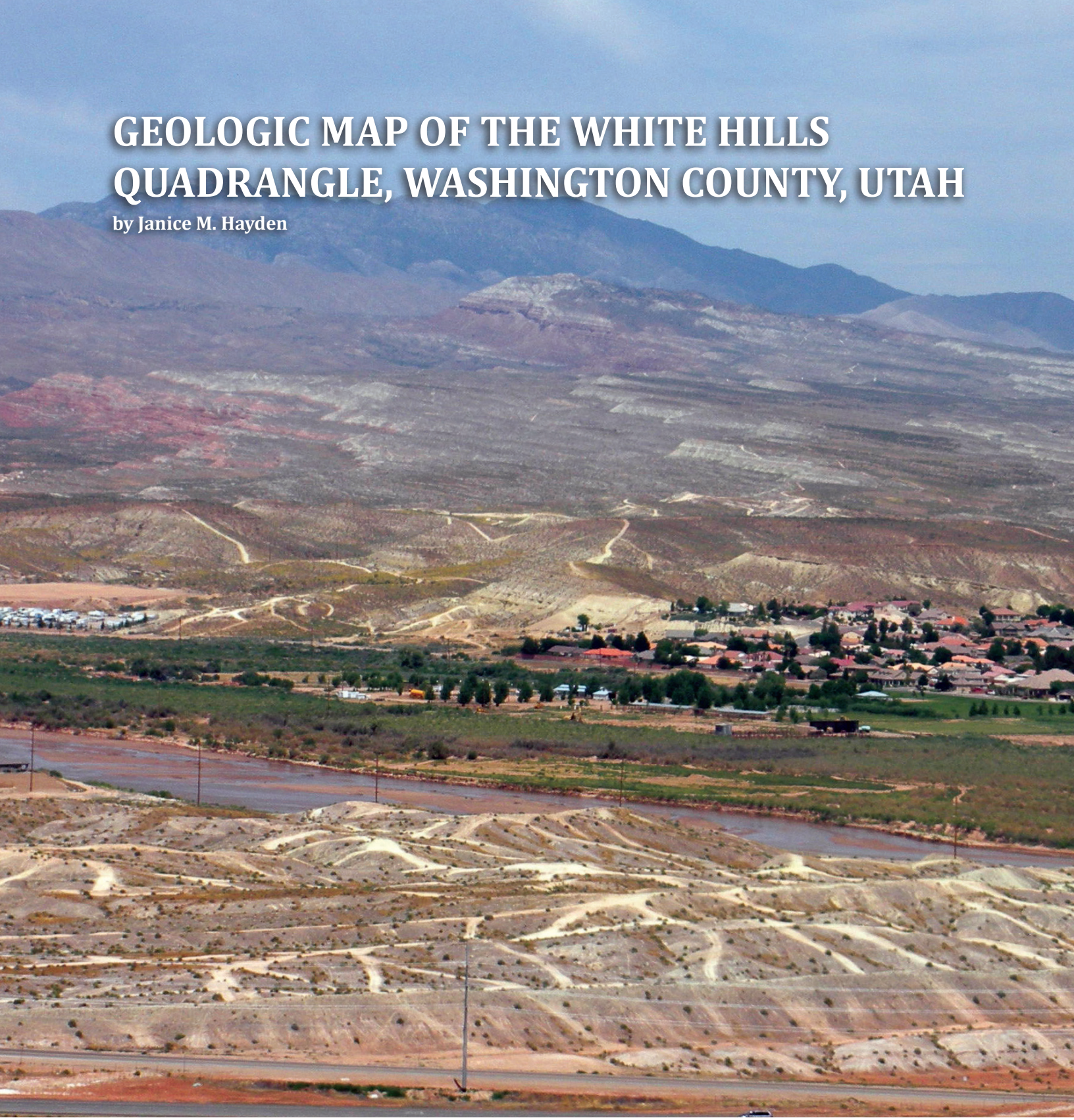
# GEOLOGIC MAP OF THE WHITE HILLS QUADRANGLE, WASHINGTON COUNTY, UTAH

by Janice M. Hayden



MAP 250DM
UTAH GEOLOGICAL SURVEY
*a division of*
UTAH DEPARTMENT OF NATURAL RESOURCES
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**by Janice M. Hayden**

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***Cover photo:*** *View to northwest from Bloomington Dome to gently northeast-dipping Shnabkaib Member of the Moenkopi Formation in the White Hills. Beaver Dam Mountains are in the background.*

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# GEOLOGIC MAP OF THE WHITE HILLS QUADRANGLE,WASHINGTON COUNTY, UTAH

## INTRODUCTION

The White Hills 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. The quadrangle is known locally for its scenic panoramas and recreational opportunities. It sits on the west edge of an intermediate structural block bounded by down-to-the-west faults, the Grand Wash–Gunlock fault to the west and the Hurricane fault to the east, although the block is cut by other smaller faults, including the Washington fault and the St. George fault. The transition zone coincides with the leading edge of the Late Cretaceous Sevier orogenic thrust belt and involves folds and minor detachments in front of the main thrust belt. A basal detachment is postulated in underlying, tectonically weak Cambrian shale. The rocks above the detachment have been compressed into the very broad, poorly defined, north-northeast trending St. George syncline and the much tighter Virgin anticline. The St. George syncline (also called the Pine Valley Mountain syncline in some publications, for example Hintze [1986]) has a poorly constrained fold axis just east of the study area in the St. George quadrangle (Hayden and Willis, 2011). East of the syncline, the Virgin anticline includes the Bloomington, Washington, and Harrisburg domes. The regional dip is to the northeast at five to ten degrees, and strata in the White Hills quadrangle average seven degrees. Tilting is probably the result of the combination of Sevier-age folding and later Basin and Range faulting. Erosion results in a series of impressive cuestas and strike valleys.

The gently dipping strata are locally folded into small anticlines and synclines, the more chaotic of which were caused by dissolution of gypsum beds. Many breccia pipes and linear collapse structures create synclines that are subparallel to the regional dip. Several small normal faults displace rocks only a few feet and are considered products of local dissolution rather than deep-seated structures. Caves form along joints and small-displacement faults in massive Permian limestone with limited, perhaps very deep, dissolution.

The Virgin River flows westward along the south edge of the quadrangle, exposing only the upper 150 feet (45 m) of the Permian Queantoweap Sandstone and the 550-foot-thick (165 m) Toroweap Formation in the river gorge. The Permian Kaibab Formation covers the southwest third of the quadrangle, with a thickness that varies from 600 feet (180 m) to 100 feet (30 m) because of subaerial erosion during the time of the major Permian-Triassic unconformity. The Triassic section includes the Moenkopi Formation, which unconformably overlies this paleotopography and thus varies greatly in thickness from 1925 feet (580 m) to 2375 feet (715 m), and the Chinle Formation, which averages 800 feet (245 m) thick. The Jurassic Moenave Formation, 240 feet (70 m) thick, is poorly exposed in the northwest corner of the quadrangle.

Only the south end of the Quaternary Santa Clara basalt flow reached the quadrangle as it flowed down stream drainages from the north. This erosion-resistant basalt is beginning to form an inverted valley because of continued regional uplift and subsequent erosion of adjacent sedimentary rocks. Uplift and downcutting are also documented by incised alluvial-terrace deposits with thick calcic soil (indicating relatively old age) along the Santa Clara and Virgin Rivers and their tributaries.

Economic resources include gravel from alluvial terrace deposits and stone. Gypsum and uranium claims have been staked but have not been quarried or mined within the quadrangle. Water resources are increasingly important as the population grows and development continues along the eastern and northern edges of the area. Flooding; slope failures, including rock falls, landslides, and slumps; expansive, soluble, and collapsible rock and soil; earthquakes; volcanic eruptions; and radon are of concern as development increases (see Solomon, 1992a, b; Lund and others, 2008).

## DESCRIPTION OF MAP UNITS

### QUATERNARY/TERTIARY

#### 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 southern portion of the quadrangle, and along the Santa Clara River, which cuts across the northeast corner of the quadrangle; also mapped along Curly Hollow and Cottonwood 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 Virgin River and Santa Clara drainage basins in January 2005 caused the Virgin River, which has an average annual flow of 145,600 acre-feet (179 hectometer$^3$) (Cordova and others, 1972; Sandberg and Sultz, 1985), to swell from a January mean discharge 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 14,600 acre-feet (18 hectometers$^3$), to swell from 6 feet$^3$/second to 6200 feet$^3$/second (0.17 to 175 m$^3$/s). The resulting flood caused $140 million in damage to local infrastructure and $85 million to personal property, including damaging or destroying 28 homes (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 digital 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 with basalt-boulder levees (not mapped) that protected property during a similar flooding event in December 2010.

$Qat_2$–$Qat_7$ **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 present floodplains; clasts are well-rounded and, along the Santa Clara and Virgin Rivers and their major tributaries, 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 Curly Hollow and Cottonwood Washes; most extensive near the Santa Clara River in the northeast portion of the quadrangle where the river has progressively shifted northeast down the dip slope of the resistant Shinarump Conglomerate by 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, but leaving several high terrace deposits on the walls of the Virgin River Gorge; thickness of terraces varies from 0 to about 80 feet (0–24 m); 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), level 6 deposits are 190 to 270 feet (55–80 m), and level 7 deposits are 270 to 350 feet (80–105 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 cutting and filling cycles (decades to a few hundred years) of the "modern" river. They showed that the river cycles through episodes 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 north of the quadrangle and the airport portion of the Cedar Bench lava flow just east of the quadrangle (called "airport flow" in some older publications), is about 190 feet/million years (60 m/myr)(Willis and Biek, 2001).

Circular cone-like collapse features as much as 80 feet (25 m) across and 60 feet (20 m) deep are present in $Qat_3$ deposits next to the Virgin River in and near Big Round Valley. They are probably associated with dissolution of underlying evaporites and/or carbonates, or perhaps breccia pipes at depth, rather than river piping of sediment since they are up to 20 feet (6 m) lower than the base of the river channel.

Qato **Older alluvial-terrace deposits** (Holocene to middle Pleistocene)—Gravel- to cobble-size clasts in a muddy to coarse sand matrix; form small, isolated outcrops of poorly sorted, indurated conglomerate that cannot be directly correlated to the current drainages; terraces are 20 to 50 feet (6–15 m) higher than current drainages; 0 to 20 feet (0–6 m) thick.

Qao **Older alluvial deposits** (Holocene to middle

Pleistocene)—Moderately sorted, clay- to gravel-sized, locally derived deposits that are remnants of older alluvium associated with minor drainages; deposits are 10 to 30 feet (3–10 m) higher than, and dissected by, minor drainages; 0 to 10 feet (0–3 m) thick.

**Colluvial Deposits**

Qc **Colluvial deposits** (Holocene to middle Pleistocene)—Poorly sorted, angular to rounded blocks up to a few feet in diameter in a muddy to sandy matrix; deposited by sheet wash and slope-creep on moderate slopes within the quadrangle; only the larger deposits are mapped; gradational with, and locally includes eolian, talus, debris-flow and alluvial deposits too small to map separately; 0 to 20 feet (0–6 m) thick.

**Artificial deposits**

**Artificial fill** (Historical)—Artificial fill (from human activity) used to create small dams, road base, dikes, etc., 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 fill 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 thicker.

**Mass-Movement Deposits**

Qmt **Talus deposits** (Holocene to middle 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 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; 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.

Qmso **Old landslide deposits** (lower Pleistocene)—Extremely poorly sorted, boulder- to clay-sized, chaotic debris with angular blocks up to 30 feet (9 m) in diameter; caps several knolls of the Shnabkaib Member of the Moenkopi Formation in the northwest corner of the quadrangle that are about 400 feet (120 m) above nearby washes; primarily derived from the Shinarump Conglomerate Member of the Chinle Formation, the nearest outcrop of which is about 0.5 mile (0.8 km) to the southeast at a lower elevation; apparently these blocks slid from, and are the remnants of, Shinarump Conglomerate outcrops once exposed farther west than they are now; similar deposits were mapped in quadrangles to the west and northwest by Hammond (1991) and Hintze and Hammond (1994) as old, high-level, alluvial gravel; however, Hintze (personal communication, April 16, 1997) agreed that they are more fittingly described as chaotic landslide deposits rather than bedded alluvial deposits; 20 to 80 feet (6–24 m) thick.

**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; gradational with colluvial deposits farther upslope; 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; Qaeo deposits are older with a more developed calcic soil (caliche) horizon; mapped in the northeast corner of the quadrangle and adjacent St. George and Santa Clara quadrangles (Hayden and Willis, 2011; Willis and Hayden, in preparation) where they form broad, sloping benches dissected by current drainages; typically 0 to 30 feet (0–9 m) thick, but may thicken locally.

Qacg **Gypcrete and alluvial gravel** (Holocene to middle Pleistocene)—Pale-gray to pinkish-gray, punky, gypsiferous silt and clay and gypsum deposits collectively referred to as gypcrete; basal part locally includes poorly to moderately stratified, moderately sorted, lenticular channel deposits of silt- to small boulder-size sediment; probably eroded from the Shnabkaib Member of the Moenkopi Formation, which contains abundant gypsum; additional deposits of gypcrete have developed on the Shnabkaib itself, but are difficult to map as a separate unit; similar in appearance to a thick calcic soil (caliche) layer; forms a resistant bed that caps a sloping irregular surface cut

across the Shnabkaib and upper red members of the Moenkopi Formation at the mouth of Box Canyon in the north-central part of the quadrangle; 0 to 5 feet (0–1.5 m) thick.

**Basaltic lava flow**

Qbs **Santa Clara lava flow** (upper Pleistocene)—Dark-brownish-black to black subalkaline basalt; contains abundant small olivine phenocrysts in an aphanitic groundmass; jagged (aa texture) upper surface with an iridescent sheen locally present on protected surfaces; a few poorly developed lava tubes, some collapsed, are locally present, although none are known within the quadrangle; pedogenic carbonate coats joints in some road cuts; erupted from a vent at a cinder cone near Diamond Valley near the head of Snow Canyon along Highway 18 north of the quadrangle and flowed westward, spreading out and cascading southward into Snow Canyon through several gaps in the sandstone, thus creating the popular scenery of Snow Canyon State Park; only the distal end of the flow is present in the northeast corner of the White Hills quadrangle; flow base is several feet above the Santa Clara River, which exposes stream sediments beneath the flow in places; radiocarbon age of 32,600 ± 300 calendar years (27,270 ± 250 $^{14}$C yr B.P.) from charcoal in loose sand just underneath the flow (Willis and others, 2006), and the sand itself yielded an optically stimulated luminescence (OSL) age of about 40,000 calendar years (Biek and others, 2009; Biek and others, 2011), suggesting that the sand is part of older mixed alluvial and eolian deposits adjacent to the ancestral Snow Canyon wash that existed before emplacement of the flow; forms the youngest flow in the St. George basin, along with the nearby and chemically similar Diamond Valley lava flow; generally 10 to 30 feet (3–10 m) thick, but thickens to as much as 60 feet (18 m) where it fills washes and gullies north of the quadrangle.

*unconformity*

**JURASSIC/TRIASSIC**

**Moenave Formation**

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 is 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 the northeast corner of the quadrangle; 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; Milner and Kirkland, 2006); only the lower 20 feet (6 m) is exposed, but the complete thickness is 55 feet (15 m) in the St. George quadrangle to the east (Kirkland and Milner, 2006; Hayden and Willis, 2011).

JTRmd **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), but here is poorly exposed in the northeast corner of the quadrangle where it has been 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 not exposed in this quadrangle, but regionally 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 in the St. George quadrangle to the east (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

TRcp **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; although not exposed in this quadrangle, regionally, a 6-inch-thick (15 cm) pebble to small-cobble conglomerate is within the first few feet of the base; clasts in the conglomerate 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; mudstone and claystone weather to a "popcorn" surface with abundant mudcracks due to expansive clays, causing 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 River in the northeast corner of the quadrangle adjacent to the more resistant cliffs of the Shinarump Conglomerate Member; well exposed where protected from erosion by stream-terrace deposits; lower contact with the Shinarump Conglomerate Member of the Chinle Formation is not exposed in this quadrangle; regionally, it is placed at the base of a 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, with a significant portion of the sediment supplied by volcanic ash (Stewart and others, 1972a; 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 in the St. George quadrangle to the east where both upper and lower contacts are 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.

TRcs **Shinarump Conglomerate Member** (Upper Triassic)—Varies from a grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone with locally well-developed limonite bands ("picture stone" or "landscape rock"), to a moderate-brown, pebbly conglomerate with subrounded clasts of quartz, quartzite, and chert; 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; 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 South Hills and Bloomington Hill that stretches northwest-southeast across the northeast one-third of the quadrangle; along the northern edge of the quadrangle, conglomerate is overlain by a sandstone ledge separated by a few feet of brownish-gray to grayish-purple benton-

itic shale; 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, 1972a; Dubiel, 1994); ranges from 50 to 200 feet (15–60 m) thick within map area.

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

**Moenkopi Formation**

Ꞧmu **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; well exposed as a steep, ledgy slope with at least one prominent sandstone ledge beneath the resistant ledge formed by the Shinarump Conglomerate in the northeast one-third of the quadrangle; where the basal sandstone is thicker, weathering and slope retreat of overlying units is slowed, creating resistant points on the cuestas that form the South Hills and Bloomington Hill; conformable lower contact is gradational and drawn where reddish-brown mudstone of the upper red member grades into greenish-gray, gypsiferous siltstone of the Shnabkaib Member; deposited in tidal-flat and coastal-plain environments (Stewart and others, 1972b; Dubiel, 1994); measured 363 feet (111 m) thick just east of the map area.

Ꞧms **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 portion slightly more resistant to erosion than the upper portion, which is gypsiferous, weathers to a powdery soil, and forms a strike valley; gypsum dissolution causes local settlement, collapse, and piping; well exposed in the northwest part of the quadrangle where it forms the southeast-trending White Hills; 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 below; deposited on a broad coastal shelf of low relief in a variety of supratidal, intertidal, and subtidal environments (Stewart and others, 1972b; Lambert, 1984); measured 996 feet (302 m) thick just east of the map area.

Ꞧmm **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 a strike valley occupied by Curly Hollow Wash; best exposures are in the northwest portion of the quadrangle, but the map unit is commonly covered by 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, 1972b; Dubiel, 1994); measured 372 feet (113 m) thick just east of the map area.

Ꞧmv **Virgin Limestone Member** (Lower Triassic)—Five distinct medium-gray to yellowish-brown shallow-marine limestone ledges, each 3 to 15 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; 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 a few feet below upper limestone; mudstone intervals commonly contain expansive clays; forms well-exposed series of resistant ridges that trend northwest-southeast across the quadrangle; slight thickening and thinning of beds is traceable through the unit and small faults, obvious with the displacement of a resistant bed, are associated with folding and collapse caused by the solution of gypsum and thus are considered surface structures rather than deep-seated faults; this is the oldest Moenkopi unit not depositionally affected by paleotopography associated with the Permian-Triassic unconformity; lower conformable contact with lower red member placed at the base of the lowest limestone bed, although locally the basal limestone sits directly on the Harrisburg Member of the Kaibab Formation; deposited in a variety of shallow-marine environments (Stewart and others, 1972b; Dubiel, 1994); total thickness is 200 feet (60 m) measured within the map area.

Ꞧml **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 slope beneath the more resistant basal ledge of the Virgin Limestone Member; 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, but the lower red member locally unconformably rests on, or pinches out against, the Harrisburg Member of the Kaibab Formation; 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, 1972b; Dubiel, 1994); thickness varies considerably from 0 to 200 feet (0–60 m) because of stratigraphic thinning over paleohills of the Kaibab Formation.

Ŧmt **Timpoweap Member** (Lower Triassic)—Upper portion consists of dark-yellowish-orange and moderate-reddish-brown, thin- to very thin bedded, calcareous sandstone and siltstone with thin, medium-gray limestone beds and medium- to coarse-grained lenticular sandstone near the base; upper beds generally fine upward; 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, thin- to thick-bedded limestone and cherty limestone that weathers light-brown, and which may include pebble and gravel-sized clasts; lower conformable and gradational contact with the Rock Canyon Conglomerate Member, where present, is placed at the top of conglomerate beds; but more commonly, member rests unconformably on the Harrisburg or Fossil Mountain Member of the Kaibab Formation; deposited in a shallow-marine environment (Nielson and Johnson, 1979; Dubiel, 1994); varies from 0 to 100 feet (0–30 m) thick due to deposition over paleotopography.

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 rounded chert and minor limestone clasts derived from the Harrisburg Member of the Kaibab Formation; deposited in paleocanyons; typically 0 to several tens of feet thick, but locally as much as about 150 feet (45 m) thick; and (2) thin-bedded, very angular to sub-angular limestone clasts and brecciated blocks weathered from Harrisburg Member that probably formed as a regolith deposit on Harrisburg strata (Nielson, 1981); locally cemented with sparry calcite; about 3 to 10 feet (1–3 m) thick. Both types grade upward to calcareous, gritty, pebble conglomerate with coarse-grained sandstone lenses; have thick, locally lenticular bedding; are cliff forming; and unconformably rest on either the resistant limestone ledges of the Harrisburg Member of the Kaibab Formation where only the upper gypsum layers were eroded during the Permian-Triassic unconformity, or the Fossil Mountain Member of the Kaibab Formation where the Harrisburg Member was completely removed by erosion; 0 to 150 feet (0–45 m) thick.

*unconformity*, Ŧ-1 of Pipiringos and O'Sullivan (1978). Because of a worldwide drop in sea level (Vail and others, 1977), several hundred feet of post-depositional, subaerial erosion occurred during Late Permian and Early Triassic time that completely removed the Harrisburg Member of the Kaibab Formation in several places along paleochannels, some as deep as 500 feet (150 m) within the quadrangle. Jenson (1984) described karst topography in the region with more than 590 feet (180 m) of relief that formed during this 15-million-year period of erosion.

**PERMIAN**

**Kaibab Formation**

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 part of the member, referred to as the "medial limestone" by Nielson (1981); dissolution of interbedded gypsum locally distorts bedding; many large collapse structures and/or breccia pipes exist, which may have begun forming during Mississippian time (Wenrich and others, 1986; Wenrich and Huntoon, 1989) as there is slight thickening of beds traceable up through the lower members of the Moenkopi Formation; this thickening is particularly noticeable in the siltstone beds of the Virgin Limestone Member; several of these thickened features have northeast-southwest linear orientations that are shown on the map as small synclines; Harrisburg Member forms slope with limestone ledges; unusually well exposed across the quadrangle; lower conformable contact is placed at the base of the lowest thick gypsum bed, just above the top of the massive Fossil Mountain limestone cliff; deposited in shallow-marine and sabkha environments (McKee, 1938; Nielson, 1981, 1986; Sorauf and Billingsly, 1991); thickness varies greatly due to subaerial erosion asso-

ciated with the Permian-Triassic unconformity; 0 to 300 feet (0–90 m) thick.

Pkf **Fossil Mountain Member** (Lower Permian)—Yellowish-gray, abundantly fossiliferous, cherty limestone that forms a prominent cliff; silicified fossils include corals, brachiopods, crinoids, and bryozoans; reddish-brown and black chert forms irregularly bedded nodules and causes the outcrop to appear black-banded; prominent, northwest-trending, high-angle joints are common; Bloomington Cave, one of several caves in the area, has a surveyed depth of 240 feet (73 m) and length of 7136 feet (2176 m) and formed along a north-trending fracture with the cave dipping westward at 65° likely with very little, or perhaps very deep, dissolution (Kyle Voyles, BLM Cave Coordinator, personal communication, August 26, 2009); forms rimrock of the Virgin River Gorge and is extensively exposed over the southwest one-third of the quadrangle; lower unconformable contact drawn at the base of the massive limestone cliff, above the gypsiferous slope of the Woods Ranch Member of the Toroweap Formation; deposited in a shallow-marine environment (McKee, 1938; Nielson, 1981, 1986; Sorauf and Billingsley, 1991); total thickness calculated as 300 feet (90 m), at least 200 feet (60 m) of which has been locally removed by channel erosion and subsequently filled in with the Rock Canyon Conglomerate Member and/or Timpoweap Member of the Moenkopi Formation.

*unconformity*, P-k of Blakey (1996)

**Toroweap Formation**

Pt **Toroweap Formation**—undivided on cross section

Ptw **Woods Ranch Member** (Lower Permian)—Grayish-pink to very pale orange massive gypsum with interbeds of light-brownish-gray siltstone and pale-red shale; forms slope, commonly covered with talus; beds distorted from dissolution of gypsum; contains three principal gypsum beds, each 20 to 50 feet (6–15 m) thick (Hintze, 1986); upper surface, the P-k unconformity, has local relief of as much as 12 feet (3 m) because of channel erosion (see also Billingsley and Workman, 2000); lower contact corresponds to a sharp break in slope, with slope-forming, gypsiferous siltstone and thin limestone beds above and cliff-forming cherty limestone below; deposited in a variety of shallow-marine and sabkha environments (McKee, 1938; Rawson and Turner-Peterson, 1979, 1980; Nielson, 1981, 1986); measured 200 feet (60 m) thick within the quadrangle.

Ptb **Brady Canyon Member** (Lower Permian)—Medium-light-gray to dark-gray, medium- to coarse-grained, thick-bedded, fossiliferous limestone with reddish-brown chert nodules and ribbon chert; contains abundant poorly-preserved crinoid stems, disarticulated brachiopods, and coral and sponge fragments; forms prominent gray cliff in Virgin River Gorge; lower conformable contact corresponds to a sharp break in slope, with cliff-forming cherty limestone above and slope-forming, thin-bedded sandstone below; deposited in a shallow-marine environment (McKee, 1938; Rawson and Turner-Peterson, 1979, 1980; Nielson, 1981, 1986); measured 250 feet (75 m) thick within the quadrangle.

Pts **Seligman Member** (Lower Permian)—Consists of three parts: upper part is medium-gray, thin-bedded, sandy limestone; middle part is interbedded yellowish-gray, calcareous, very fine grained sandstone and grayish-yellow, calcareous, gypsiferous siltstone and minor gypsum; and basal part is pale-yellowish-brown, fine-grained sandstone; aragonite and calcite have replaced much of the gypsum (Nielson, 1986); forms recess in cliff of Virgin River Gorge; lower unconformable contact corresponds to a subtle break in slope, with slope- and ledge-forming, planar-bedded sandstone and gypsiferous, sandy siltstone above and ledge- and cliff-forming cross-bedded sandstone below; deposited in shallow-marine and beach environments (McKee, 1938; Rawson and Turner-Peterson, 1979, 1980; Nielson, 1981, 1986); measured 100 feet (30 m) thick within the quadrangle.

*unconformity*, P-tw of Blakey (1996)

Pq **Queantoweap Sandstone** (Lower Permian)—Pale-yellow to grayish-pink, cross-bedded, thick-bedded, fine- to medium-grained, calcareous sandstone; upper half stratigraphically equivalent to the Hermit Shale of northwest Arizona and southeast Nevada and the lower half is stratigraphically equivalent to the Esplanade Sandstone of northwest Arizona (Blakey, 1996; Billingsley, 1997); forms steep slope in Virgin River Gorge; deposited in shallow-marine, beach, and dune environments (Nielson, 1981; Johansen, 1988); only the upper 150 feet (45 m) of the 1400- to 2000-foot-thick (425–600 m) unit is exposed in the quadrangle (Hintze and Hammond, 1994; Hintze and others, 1994).

Subsurface Units

Pp **Pakoon Dolomite**—Cross section only. Thickness from Hammond (1991).

**PENNSYLVANIAN**

ℙc **Callville Limestone**—Cross section only. Thickness from Hammond (1991).

**MISSISSIPPIAN**

Mr **Redwall Limestone**—Cross section only. Thickness from 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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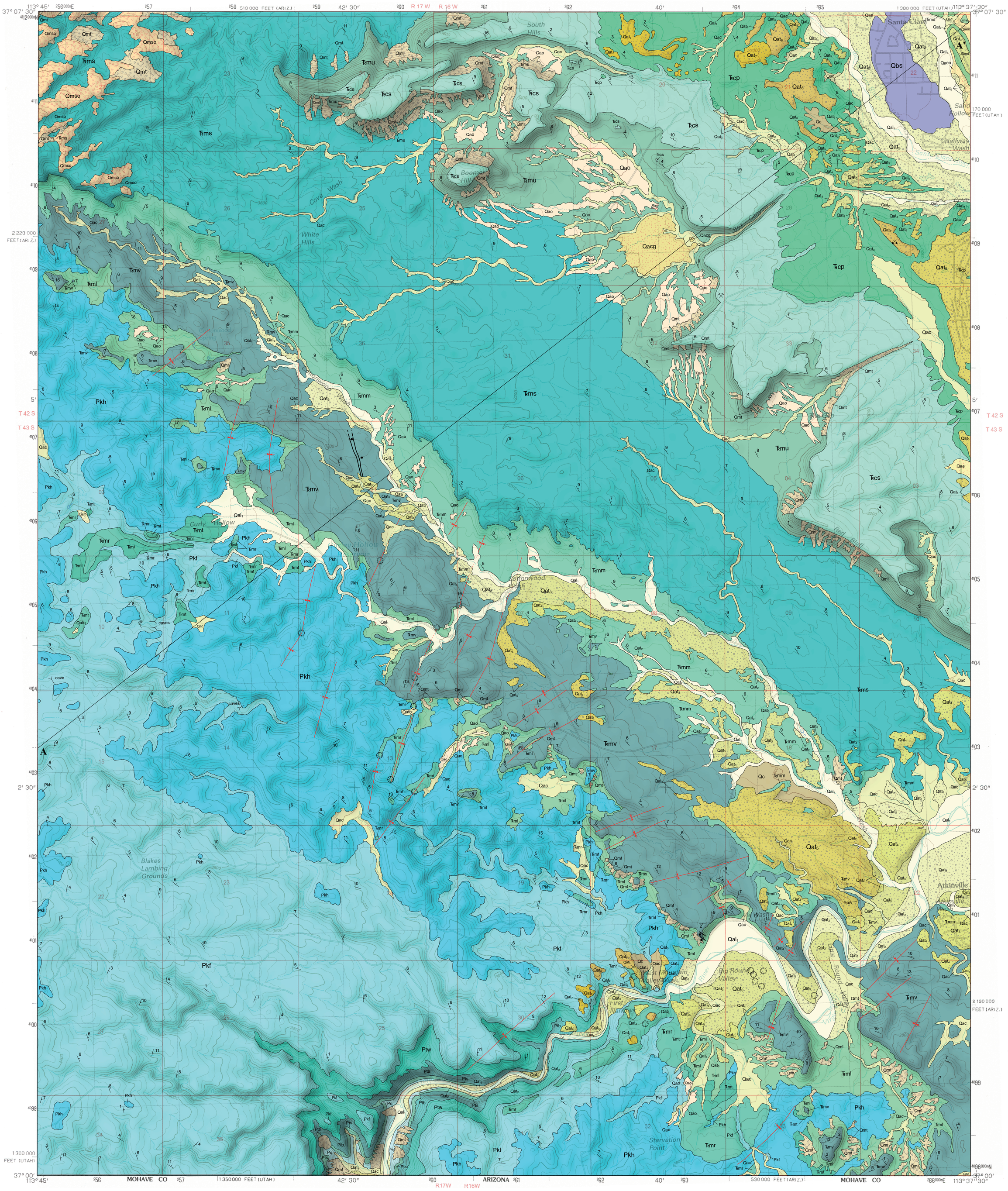


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SCALE 1:24,000

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1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

MAP LOCATION

# GEOLOGIC MAP OF THE WHITE HILLS QUADRANGLE, WASHINGTON COUNTY, UTAH

by

**Janice M. Hayden**

**2011**

APPROXIMATE MEAN DECLINATION, 2011

Base from U.S. Geological Survey White Hills 7.5' Quadrangle (2011)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Fieldwork: 1994–96, 2009
Project Manager: Robert F. Biek
GIS and Cartography: Jay C. Hill, Kent D. Brown and J. Buck Ehler

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| 6 | 7 | 8 |

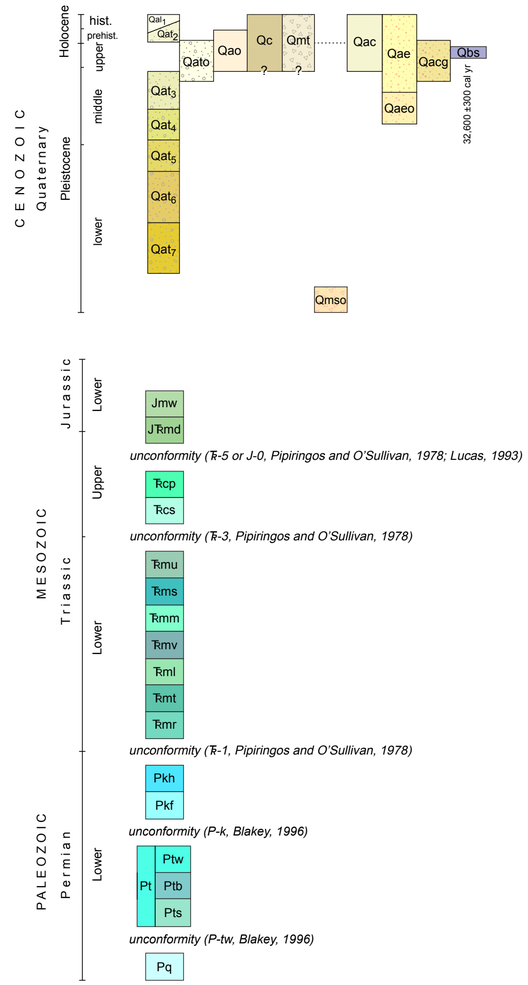
1. Shivwits
2. Santa Clara
3. Washington
4. Jarvis Peak
5. St. George
6. Mountain Sheep Spring
7. Purgatory Canyon
8. Lizard Point

ADJOINING 7.5' QUADRANGLE NAMES

## STRATIGRAPHIC COLUMN

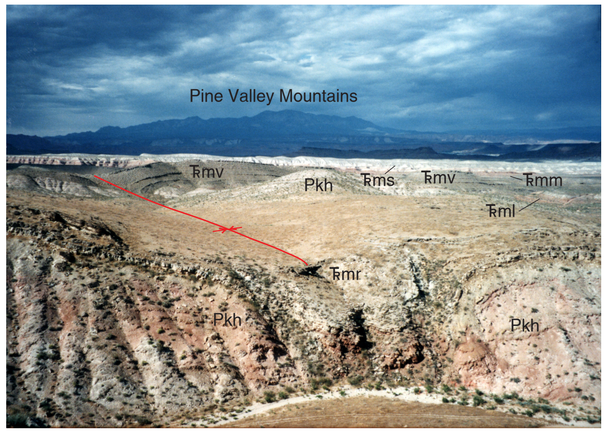
| Erathem | System | Series | Formation | Member | Symbol | Thickness feet (meters) | Lithology | |
|---|---|---|---|---|---|---|---|---|
| CEN. | Quat. | Pleis.-Recent | unconsolidated surficial deposits | | | 0–80 (0–24) | | |
| | | | Santa Clara lava flow | | Qbs | 10–30 (3–10) | | 32,600 ±300 cal yr (27,270 ± 250 $^{14}$C yr B.P.) |
| MESOZOIC | Jurassic | Lower | Moenave Formation | Whitmore Point Member | Jmw | 55 (15) | | semionotid fish scales |
| | | | | Dinosaur Canyon Member | J̶Ꞧmd | 185 (55) | | *Ꞧ-5 or J-0 unconformity* |
| | Triassic | Upper | Chinle Formation | Petrified Forest Member | Ꞧcp | 700 (215) | | swelling clays<br>petrified wood |
| | | | | Shinarump Conglomerate Member | Ꞧcs | 50–200 (15–60) | | "picture stone"<br>*Ꞧ-3 unconformity* |
| | | Lower | Moenkopi Formation | upper red member | Ꞧmu | 363 (111) | | |
| | | | | Shnabkaib Member | Ꞧms | 996 (302) | | "bacon-striped" ledgy slope |
| | | | | middle red member | Ꞧmm | 372 (113) | | |
| | | | | Virgin Limestone Member | Ꞧmv | 200 (60) | | gray ledges |
| | | | | lower red member | Ꞧml | 0–200 (0–60) | | |
| | | | | Timpoweap Mbr. | Ꞧmt | 0–100 (0–30) | | |
| | | | | Rock Canyon Conglomerate Member | Ꞧmr | 0–150 (0–45) | | *Ꞧ-1 unconformity* |
| PALEOZOIC | Permian | Lower | Kaibab Formation | Harrisburg Member | Pkh | 0–300 (0–90) | | gypsum<br>brachiopods |
| | | | | Fossil Mountain Member | Pkf | 100–300 (30–90) | | "black-banded" cliff<br>*P-k unconformity* |
| | | | Toroweap Formation | Woods Ranch Member | Ptw | 200 (60) | | |
| | | | | Brady Canyon Member | Ptb | 250 (75) | | |
| | | | | Seligman Mbr. | Pts | 100 (30) | | *P-tw unconformity* |
| | | | Queantoweap Sandstone | | Pq | 150+ (45+) | | |

## CORRELATION OF MAP UNITS

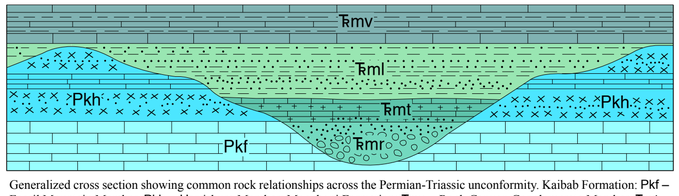



## GEOLOGIC SYMBOLS

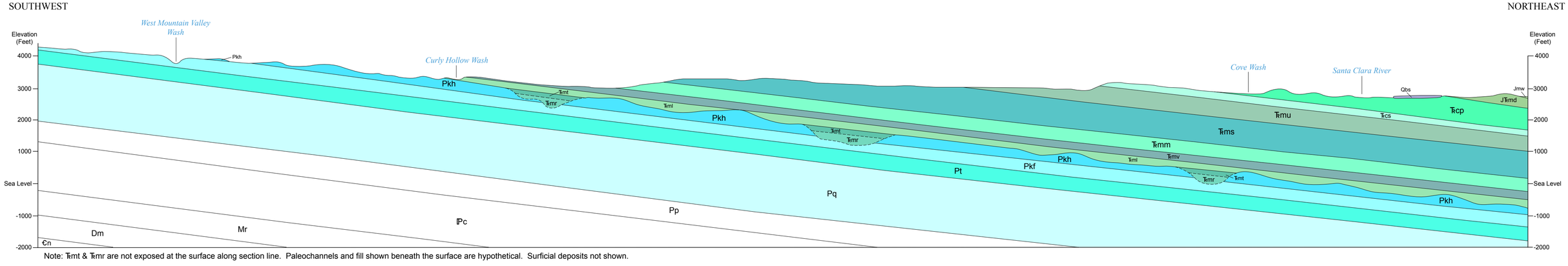
- Contact
- High-angle fault – dashed where approximately located, dotted where concealed, bar and ball on down-thrown side
- Axial trace of syncline – dotted where concealed (anticlines not shown)
- 12 Strike and dip of inclined bedding
- Gravel or road-fill pit
- Quarry
- Spring
- Cave
- Circular collapse structure




Large collapse structure in the Harrisburg Member of the Kaibab Formation (Pkh) associated with a northeast-southwest linear trend that also affects the limestone ledges of the Virgin Limestone Member of the Moenkopi Formation (Ꞧmv). Flat beds of the Rock Canyon Conglomerate Member of the Moenkopi Formation (Ꞧmr) fill the trough of the collapse structure which extends to the base of the hill of Virgin Limestone ledges. Photo looks northeast across West Mountain Valley Wash toward SE ¼ of section 13, T.43S., R.17W. The Pine Valley Mountains are in the background.




Generalized cross section showing common rock relationships across the Permian-Triassic unconformity. Kaibab Formation: Pkf – Fossil Mountain Member, Pkh – Harrisburg Member; Moenkopi Formation: Ꞧmr – Rock Canyon Conglomerate Member, Ꞧmt – Timpoweap Member, Ꞧml – lower red member, Ꞧmv – Virgin Limestone Member.




Note: Ꞧmt & Ꞧmr are not exposed at the surface along section line. Paleochannels and fill shown beneath the surface are hypothetical. Surficial deposits not shown.