Inverted Topography in St. George, Washington County, Utah

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Utah Geosites
2019

Utah Geological Association Publication 48

M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors

Cover Image: *Photo looking west-northwest at the higher West Black Ridge, capped by the 2.3 million year old Twin Peaks lava flow, behind the lower "old airport ridge," capped by the 1.2 million-year-old Cedar Bench lava flow.*

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Utah Geosites showcases some of Utah's spectacular geology, both little-known localities and sites seen by visitors to Utah's many national and state parks and monuments. The geosites reflect the interests of the many volunteers who wrote to share some of their favorite geologic sites. The list is eclectic and far from complete, and we hope that additional geosites will be added in the coming years. The Utah Geological Survey also maintains a list of geosites https://geology.utah.gov/apps/geosights/index.htm.

We thank the many authors for their geosite contributions, Utah Geological Association members who make annual UGA publications possible, and the American Association of Petroleum Geologists—Rocky Mountain Section Foundation for a generous grant for desktop publishing of these geosite papers.

Design and desktop publishing by Jenny Erickson, Graphic Designer, dutchiedesign.com, Salt Lake City, Utah.

Suggested citation for this geosite:

Hayden , J., 2022, Inverted topography in St. George, Washington County, Utah: Utah Geological Association Publication, v. 1, p. 1-11., doi: 10.31711/ugap.v1i1.99.

Presidents Message

I have had the pleasure of working with many different geologists from all around the world. As I have traveled around Utah for work and pleasure, many times I have observed vehicles parked alongside the road with many people climbing around an outcrop or walking up a trail in a canyon. Whether these people are from Utah or from another state or country, they all are quick to mention to me how wonderful our geology is here in Utah.

Utah is at the junction of several different geological provinces. We have the Basin and Range to the west and the Central Utah Hingeline and Thrust Belt down the middle. The Uinta Mountains have outcrops of some of the oldest sedimentary rock in Utah. Utah also has its share of young cinder cones and basaltic lava flows, and ancient laccoliths, stratovolcanoes, and plutonic rocks. The general public comes to Utah to experience our wonderful scenic geology throughout our state and national parks. Driving between our national and state parks is a breathtaking experience.

The "Utah Geosites" has been a great undertaking by many people. I wanted to involve as many people as we could in preparing this guidebook. We have had great response from authors that visit or work here in the state. Several authors have more than one site that they consider unique and want to share with the rest of us. I wanted to make the guidebook usable by geologists wanting to see outcrops and to the informed general public. The articles are well written and the editorial work on this guidebook has been top quality.

I would like to personally thank Mark Milligan, Bob Biek, and Paul Inkenbrandt for their editorial work on this guidebook. This guidebook could not have happened without their support. I would like to thank Jenny Erickson for doing the great desktop publishing and the many authors and reviewers that helped prepare the articles. Your work has been outstanding and will certainly showcase the many great places and geology of Utah. Last, but not least, Thank you to the American Association of Petroleum Geologists, Rocky Mountain Section Foundation for their financial support for this publication.

Guidebook 48 will hopefully be a dynamic document with the potential to add additional "geosites" in the future. I hope more authors will volunteer articles on their favorite sites. I would like to fill the map with locations so that a person or family looking at the map or articles will see a great location to read about and visit. Enjoy Guidebook 48 and enjoy the geology of Utah.

Peter J. Nielsen
2019 UGA President

INTRODUCTION

Washington County, Utah has several classic examples of inverted topography, where now topographically high ridges are capped by basalt that once flowed as lava down low stream drainages. This paper focuses on the ridges that trend north-south on either side of downtown St. George (figures 1 and 2).

The City of St. George boasts three of these ridges. West Black Ridge capped by the Twin Peaks lava flow, and "old airport ridge" capped by the Cedar Bench lava flow are both located to the west of downtown. Middleton Black Ridge capped by the Lava Ridge lava flow is located to the east of downtown. The two lower elevation ridges are now being covered with homes, some of which have spectacular views. These ridges also remain a favorite place from which to view firework displays during city celebrations and events. Visiting the water tank on the Red Hills, north of downtown offers an excellent perspective from which to view these ridges.

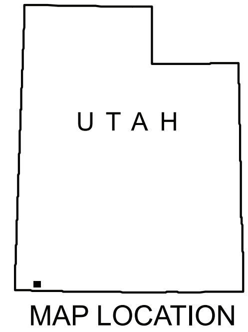
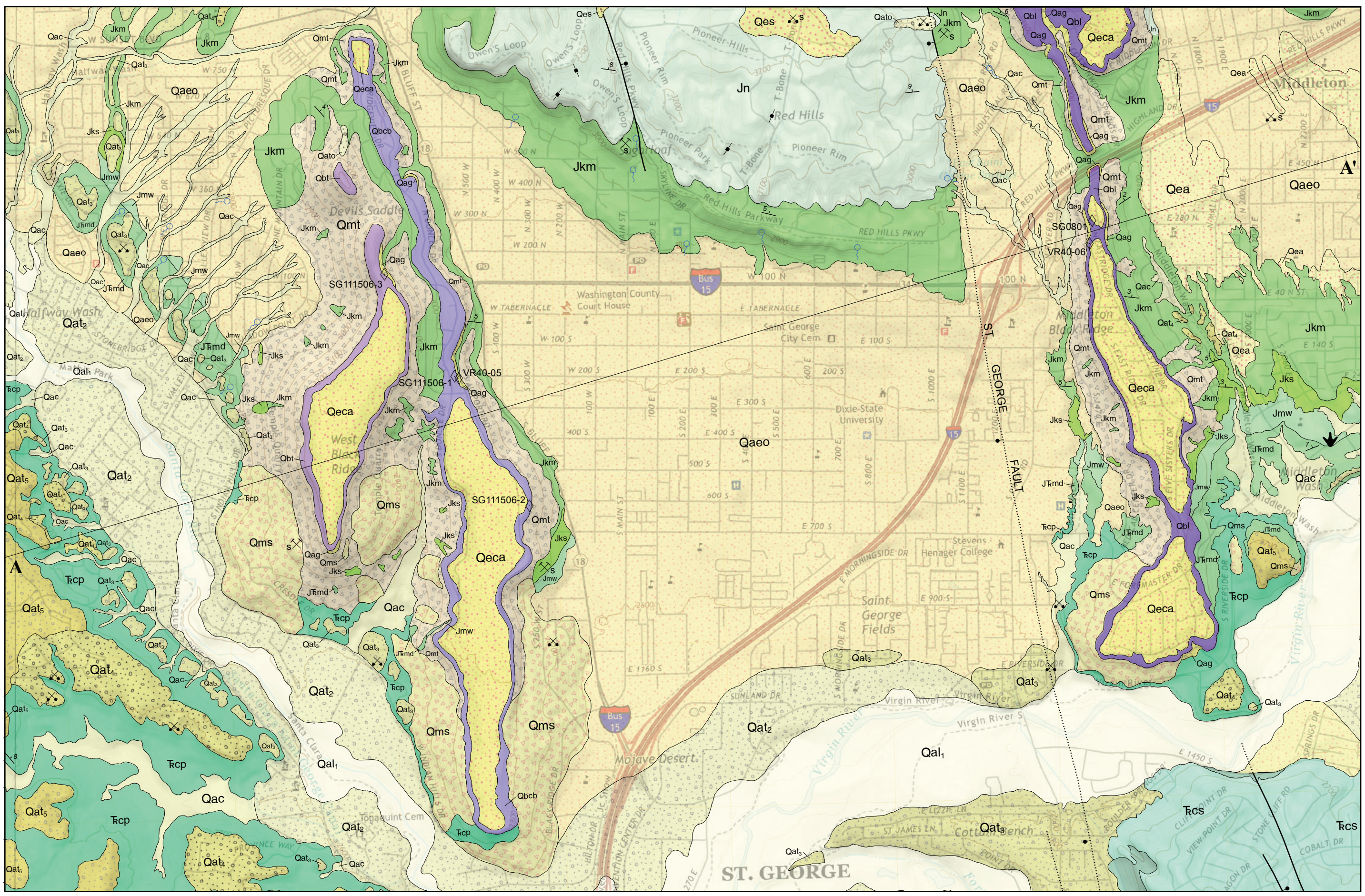
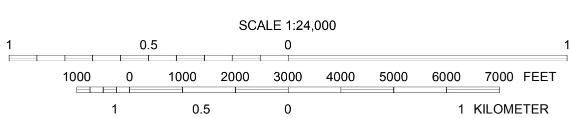


Figure 1. Map showing inverted valleys in St. George, Washington County, Utah.





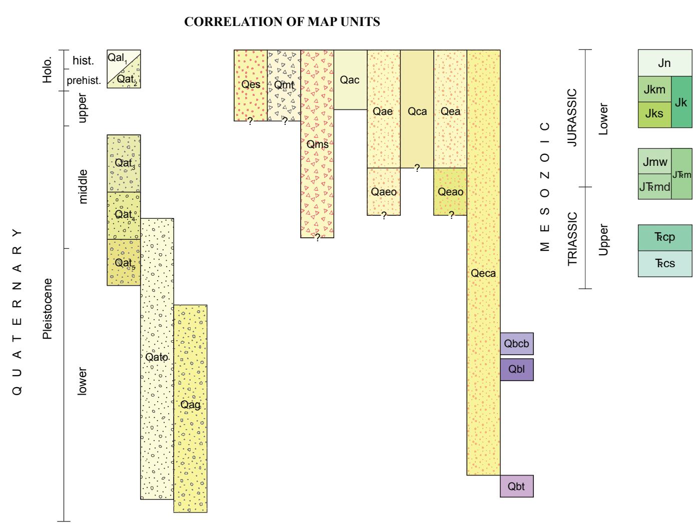


Figure 2. Geologic map of the downtown St. George area (from Hayden and Willis, 2011). Note the north-south trending ridges both east and west of downtown that are capped by lava that flowed down stream valleys but, because of subsequent downcutting and erosion, now cap ridges, forming classic examples of inverted topography or "inverted valleys." The sedimentary bedrock that comprise the ridges underneath the lava flows strikes generally east to west-northwest, just opposite that of the ridges, with northeastward tilting rock layers getting progressively younger from south to north. A significant portion of the map area is covered by recent Quaternary sediments. See figure 4 for A-A' cross section and figure 8 for a partial stratigraphic column with unit names.

LOCATION

Traveling on I-15, use Exit 8 to access St. George Boulevard. Travel west to 1000 East then turn right to go north up the hill for one block. Turn left onto Red Hills Parkway and proceed 0.5 miles (0.8 km) before turning left into a parking lot. Just to the west of the parking lot you'll see a large water tank built in 1948 with stairs and a railing. Community dances were held atop the tank on Friday and Saturday nights for many years (Washington County Historical Society, website). Should you miss pulling in to this first parking lot that is on the side of the stairs, another parking lot is located just to the west of the water tank. You can see the view from the parking lots, but it is more fun to climb to the top of the water tank, which is perched atop the Red Hills with a view down onto the city center. Look left and right for a great view of the inverted topography ridges that flank downtown St. George.

GPS location: 37°06'46.07"N 113°34'22.70"W.
Elevation: 3020 feet (921 meters) above mean sea level on top of the tank.

INVERTED VALLEYS AND BASALTIC LAVA FLOWS

The concept of inverted topography in the St. George area was first described in detail by Hamblin (1963, 1970, 1987) and Hamblin and others (1981). Typically, the lava flowed down the bottom of stream valleys and cooled, forming a hard surface (figure 3). 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 form the valley floors now cap the ridges. Because 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).

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 side of active faults (figure 4). The eastern Middleton Black Ridge (Lava Ridge lava flow) has comparably greater inversion that do those flows to the west. This anomaly is because the ridges are on the opposite sides of the St. George fault, a late Cenozoic extensional, down-to-the-west fault

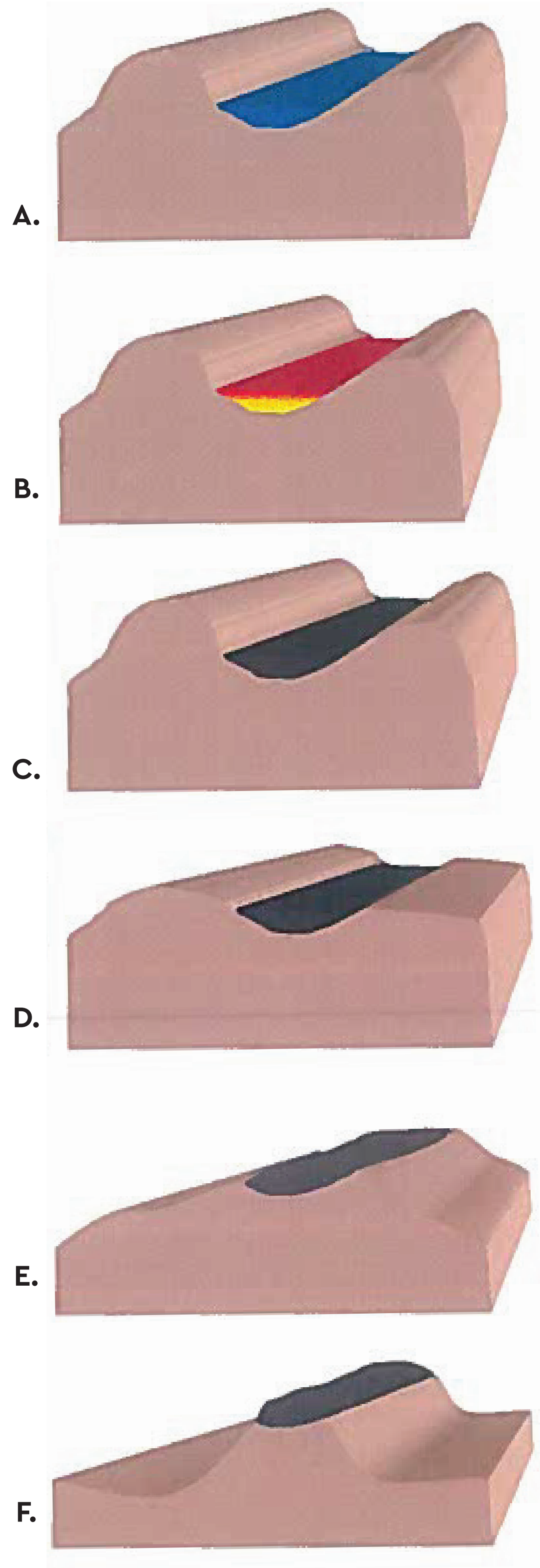


*Figure 3. Diagrams showing the sequential development of inverted topography (created by Jerry D. Harris, Dixie State University). **A)** Water flows down a stream valley. **B)** A cinder cone erupts upstream, filling the stream valley with lava. **C)** The lava cools and hardens into a basaltic rock that is more resistant to weathering and erosion than the sedimentary bedrock it rests on. **D)** Streams downcut and erode along the edges of the flow. **E-F)** What used to be the valley floor now caps a ridge, creating a classic example of inverted topography.*

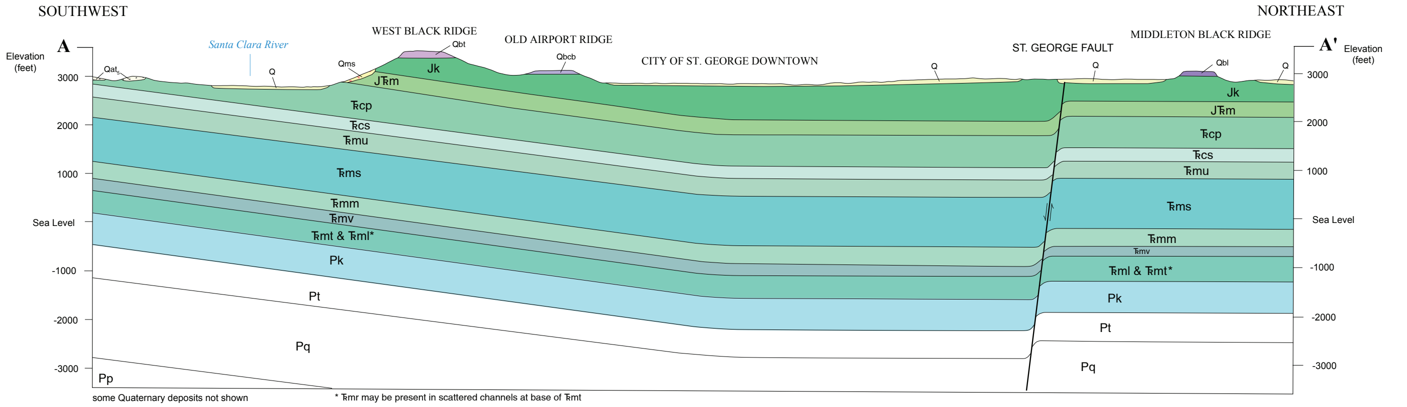


Figure 4. Cross-section showing the three, north-south trending inverted topography ridges that bracket downtown St. George. Generally, the higher the ridge is above the current drainage, the older the capping lava flow. However, note that when comparing ridges on different structural blocks, the higher elevation block commonly weathers and erodes at a faster rate than the block that has been dropped down by normal faulting. The St. George fault separates Middleton Black Ridge (Lava Ridge lava flow, east of downtown) from West Black Ridge (Twin Peaks lava flow) and "old airport ridge" (Cedar Bench lava flow) on the west side of downtown. Older rock units that are not exposed at the surface in the map area are shown on the cross-section. (From Hayden and Willis, 2011.)

that offsets strata about 400 feet (120 m) but does not offset exposed surficial deposits (Hayden and Willis, 2011). The comparably greater topographic inversion of this middle-aged flow (of the three flows) 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, 1970, 1987).

Hamblin (1963, 1970, 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) all 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.

Twin Peaks Lava Flow of West Black Ridge

The oldest of the three lava flows is the lower Pleistocene Twin Peaks lava flow (Qbt) which caps West Black Ridge above the Dixie State University "D." It is dark-gray basaltic trachyandesite with large plagioclase and quartz, and small olivine and clinopyroxene phenocrysts (Hayden and Willis, 2011). It has strong columnar jointing and weathers to large, angular, blocky rubble. There are two cooling units that are 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) to the north, and it is now considered the southernmost part of the Twin Peaks lava flow (Biek and others, 2009).

The flow yielded radiometric K-Ar ages of 2.3 $\pm$ 0.1 million years (Ma) (Best and others, 1980) and 2.24 $\pm$ 0.11 Ma (Hamblin and others, 1981), and an $^{40}Ar/^{39}Ar$ age of 2.34 $\pm$ 0.02 Ma (Biek and others, 2009). It is 20 to 80 feet (6-24 m) thick.

This flow, accessible to pioneers because of a landslide at the southern tip of West Black Ridge, was quarried and pounded into the ground with a pile driver fashioned from an old cannon to make the foundation for the Church of Jesus Christ of Latter-Day Saints St. George Temple, a process taking two years. The remnants of the road and quarry can be visited by taking an easy 2 mile (3.2 km) round-trip hike that begins at the city park located at the top of "old airport ridge" after continuing west on St. George Boulevard (figure 5). (Trailhead: 37°06'10.2"N 113°35'45.2"W)

Figure 5. Photo looking west-northwest at the higher West Black Ridge, capped by the 2.3 million year old Twin Peaks lava flow, behind the lower "old airport ridge," capped by the 1.2 million-year-old Cedar Bench lava flow. These flows are quite young. Comparing the 4.5 billion-year-old age of Earth to the length of a football field, where one inch on the field represents 1.25 million years, these two flows occurred about two- and then one-inch shy of the endzone. Note the "D" on the slope between the two flows. Both lava flows are partially covered by sediment deposited by eolian, colluvial and alluvial processes (Qeca, figure 2). Much of the ridge slope is covered by rockfall blocks as talus deposits (Qmt, figure 2), but the Triassic-Jurassic sedimentary layers are exposed by roadcuts along Bluff Street and in drainages, and get progressively younger going left to right in the photo. Note that Petrified Forest Member of the Chile Formation underlies the south (left) end of both ridges, creating landslides (Qms, figure 2) that include the lava flows. Photo taken Aug, 24, 2018.

Lava Ridge Lava Flow of Middleton Black Ridge

The middle-aged of the three flows is the lower Pleistocene Lava Ridge flow (Qbl) that caps Middleton Black Ridge east of downtown (figure 6). It is a moderately jointed, dark-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 (Hayden and Willis, 2011). It was previously called Middleton lava flow (Willis and Biek, 2001), but petrographic and limited geochemical data suggest it is the southern extension of the Lava Ridge flow (Biek and others, 2009). It consists of three flows in a road cut on Middleton Drive near the intersection with Red Rock Road (37°07'16.26"N 113°33'02.96"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 and forming 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 (figure 7). It erupted from a group of heavily weathered cinder cones on Lava Ridge, about 8 miles (13 km) north of St. George.

Figure 6. Photo looking north-northwest at the northern part of Middleton Black Ridge, which is capped by the 1.4 million-year-old Lava Ridge flow. Like the other two lava flows, this one is partially covered by sediment (Qeca, figure 2). Talus (Qmt, figure 2) covers much of the slope of the ridge and the Jurassic-Triassic section is best exposed along roadcuts and in drainages. I-15 cuts through the flow near middle of photo. Photo taken Mar. 1, 2007 by Jerry D. Harris.

Samples taken from the upper flow on Middleton Black Ridge yielded a radiometric K-Ar age of 1.5 $\pm$ 0.1 Ma (Best and others, 1980) and an $^{40}Ar/^{39}Ar$ age of 1.41 $\pm$ 0.01 Ma (Biek and others, 2009). The lower two flows are probably about the same age. It is generally 20 to 40 feet (6-12 m) thick.

Cedar Bench Lava Flow of "Old Airport Ridge"

The youngest of the three lava flows included here is the lower Pleistocene Cedar Bench lava flow (Qbcb) that caps "old airport ridge" below the Dixie State University "D" to the west of downtown. It is a brownish-black trachybasalt with small phenocrysts of clinopyroxene and olivine. It has prevalent columnar jointing and is strongly weathered along joints, forming a mottled texture (Hayden and Willis, 2011). Previously called the Airport lava flow (Willis and Biek, 2001), it is now considered the southern extension of the Cedar Bench lava flow because of similar geochemistry (Biek and others, 2009). Two cooling units are well exposed along the southeast edge of the flow, which erupted from vents at two overlapping cinder cones about 10 miles (16 km) north of St. George.

The rock yielded a radiometric $^{40}Ar/^{39}Ar$ plateau age of 1.23 $\pm$ 0.01 Ma (Biek and others, 2009), which fits well with regional downcutting rates (Willis and Biek, 2001). The flow is typically 10 to 30 feet (3-9 m) thick. These three lava flows sit atop lower Pleistocene, poorly to moderately sorted, clay- to boulder-size, stream-deposited gravel (Qag) with mostly well-rounded cobbles and small boulders that are exotic to the quadrangle, including igneous rocks derived from the Pine Valley Mountains. These alluvial gravels are best exposed in road cuts.

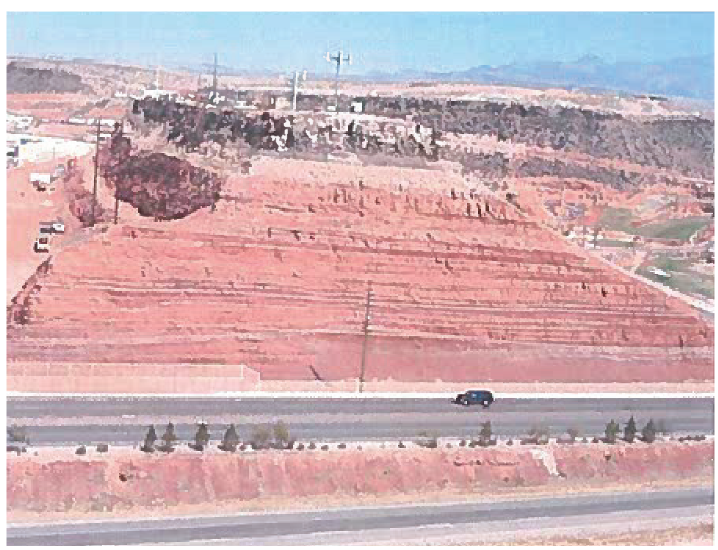


Figure 7. Photo looking north at the I-15 roadcut showing the red beds of the Early Jurassic-age main body of the Kayenta Formation (Jkm) below, separated from the black Lava Ridge lava flow (Qbl) above, by a tan layer of stream gravel (Qag), indicating that the lava flowed down an ancestral stream valley. Photo taken Aug. 26, 2006 by Jerry D. Harris.

Stratigraphy

These three lava flows unconformably overlie Triassic to Jurassic age sedimentary rocks that were tilted to the northeast as part of the broadly folded St. George syncline, a down-arched fold of rock layers (figure 8). The fold axis runs under downtown, through the south end of "old airport ridge," and continues over the ridge to the south-southwest. There is a profound change in the direction of strike of these sedimentary rocks from west-southwest on the east side of town, to northwest on the west side of town, This change is shown nicely by the bend in the ridge of the Shinarump Conglomerate member of the Chinle Formation (TRcs).

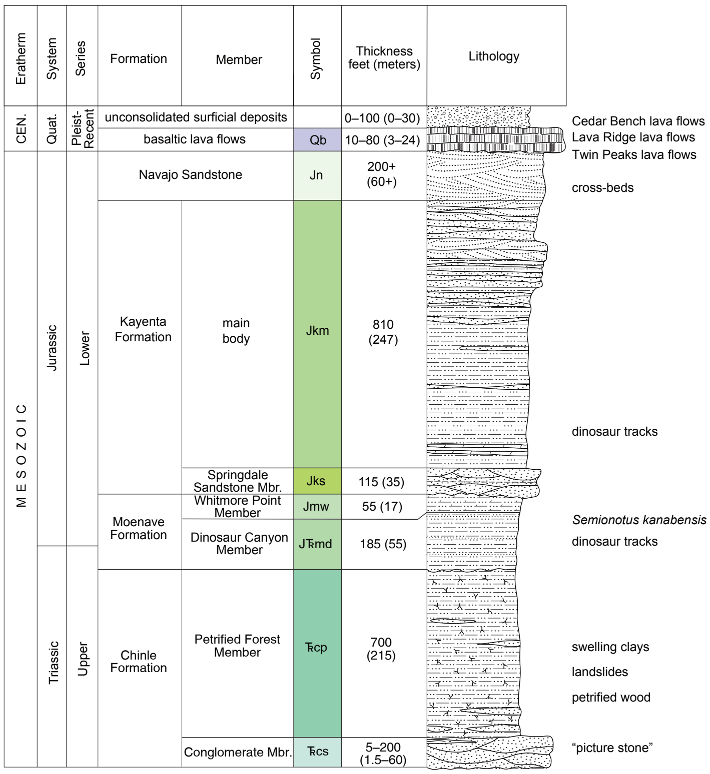


Figure 8: Stratigraphic column showing the exposed rock layers within the map area. (From Hayden and Willis, 2011.)

Triassic Chinle Formation, Shinarump Conglomerate Member

The Upper Triassic Chinle Formation (TRc) covers the southern portion of the geologic map (Figure 2). The Shinarump Conglomerate Member (TRcs), shown in the southeast corner, is a yellowish-brown, medium- to coarse-grained sandstone with locally well-developed limonite bands ("picture stone" or "landscape rock"), grading to brown pebbly conglomerate with subrounded clasts of quartz, quartzite, and chert (Hayden and Willis, 2011). It is 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, it contains poorly preserved petrified wood, commonly replaced in part by iron-manganese oxides. Regionally it caps the Chocolate Cliffs step of the Grand Staircase (Gregory, 1950) and is variable in composition and thickness because it represents braided stream-channel deposition over Late Triassic paleotopography (Stewart and others, 1972b; Dubiel, 1994). It ranges from 5 to 200 feet (1.5-60 m) thick.

Triassic Chinle Formation, Petrified Forest Member

The Petrified Forest Member (TRcp) of the Chinle Formation consists of highly variegated, light-brownish-gray, pale-greenish-gray, to grayish-red-purple, smectitic (swelling) shale, mudstone, siltstone, and claystone, with several lenticular interbeds of yellowish-brown, cross-bedded, resistant sandstone up to 10 feet (3 m) thick. There is a pebble to small-cobble conglomerate near the base with primarily chert and quartzite clasts. It also 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 (Hayden and Willis, 2011).

Shale and mudstone layers of the Petrified Forest Member weather to a "popcorn" surface with abundant mudcracks due to expansive clays that cause road and building foundation problems. It weathers to badland topography and is prone to landsliding along steep hillsides. It is also the local primary source of radon gas (Solomon, 1992a, 1992b). It forms the well-developed strike valley of the Santa Clara and Virgin Rivers. It is 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. Where underlain by Petrified Forest beds, the lava flow capped ridges commonly exhibit a series of steps created by landslides.

The Petrified Forest Member was 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. A significant portion of its 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). It is 700 feet (215 m) thick.

Moenave Formation, Dinosaur Canyon Member

The Lower Jurassic Moenave Formation (JTRm) trends across the middle of the map area. The Dinosaur Canyon Member (JTRmd) is interbedded, generally thin-bedded, reddish-brown, very fine to fine-grained sandstone, very fine grained silty sandstone, and lesser siltstone and mudstone with laminated cross-beds with common ripple marks and mud cracks that forms a ledgy slope (Hayden and Willis, 2011). Regionally it forms the base of Vermilion Cliffs step of the Grand Staircase (Gregory, 1950). It is locally exposed 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. Several outcrops exposed by construction have revealed plant fossils (Tidwell and Ash, 2006). It was deposited on a broad, low floodplain that was locally shallowly flooded (fluvial mud flat) (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998). It is 185 feet (55 m) thick (Kirkland and Milner, 2006).

Moenave Formation, Whitmore Point Member

The Whitmore Point Member (Jmw) is an interbedded, pale-reddish-brown, greenish-gray, and grayish-red mudstone and claystone, with thin-bedded, reddish-brown, very fine to fine-grained sandstone and siltstone. It also includes yellowish-gray, dolomitic limestone that includes 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 (Hayden and Willis, 2011), likely of semionotid fish (Milner and Kirkland, 2006). It is 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. The nearby St. George Dinosaur Discovery Site at Johnson Farm (Harris and Milner, 2016) revealed exceptionally well-preserved theropod tracks (three-toed dinosaur tracks called *Eubrontes* and *Grallator*) near the base of the member. The site also includes swim tracks (Kirkland and Milner, 2006; Milner and others, 2006), other trace fossils (Lucas and others, 2006), and a variety of invertebrate fossils (Lucas and Milner, 2006). Note the dinosaur footprint symbol near the east edge of the geologic map (Fig. 2) for the location of the museum along Riverside Drive, which is definitely worth a visit. The member was deposited in low-energy lacustrine and fluvial environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998; and Milner and Kirkland, 2006) and is 55 feet (17 m) thick.

Kayenta Formation, Springdale Sandstone Member

The Lower Jurassic Kayenta Formation (Jk) fills much of the northern portion of the map area beneath the lava flows and is well exposed at the base of the Red Hills. The lower, Springdale Sandstone Member (Jks) is mostly grayish-yellow, moderately sorted, fine- to medium-grained, medium- to very thick bedded, ledge- to small-cliff-forming sandstone, with minor, thin, discontinuous lenses of intraformational conglomerate and thin interbeds of reddish-brown or greenish-gray mudstone and siltstone (Hayden and Willis, 2011). It contains locally abundant petrified and carbonized fossil plant remains. Theropod dinosaur tracks are common in upper horizon, known as the Springdale megatracksite (Lucas and others, 2005; Hamblin and others, 2006). The sandstone 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). It is resistant to erosion and forms isolated outcrops that protrude from beneath basalt talus along the slopes of the basalt-capped ridges and is completely exposed in washes east and west of Middleton Black Ridge. It was deposited in braided-stream and minor floodplain environments (Clemmensen and others, 1989; Blakley, 1994; Peterson, 1994; DeCourten, 1998; Lucas and Tanner, 2006). It is 115 feet (35 m) thick.

Kayenta Formation, Main Body

The main body of the Kayenta Formation (Jkm) is reddish-brown, thin-bedded siltstone and mudstone interbedded with very fine to fine-grained, planer to lenticular, mottled sandstone with climbing ripple marks (Hayden and Willis, 2011). The upper surface of sandstone ledges is commonly bioturbated. It forms a steep, ledgy slope to ledgy cliff that is mostly covered by talus but is 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 map. The top of the formation is close to Red Hills Parkway, the road you took to reach the view from the water tank. The main body of the Kayenta was deposited in distal river, playa, and minor lacustrine environments (Tuesink, 1989; Blakey, 1994; Peterson, 1994). It is 810 feet (247 m) thick.

This member was quarried from the Red Hills by early settlers for the stone used to build the St. George Temple, Tabernacle, Historic Courthouse, Washington Cottonmill and many other buildings. A 0.6 mile (1 km) round-trip trail to the quarry begins at the north end of 700 West and goes along the edge of Red Hills Golf Course.

Navajo Sandstone

The Lower Jurassic Navajo Sandstone (Jn) is a reddish-orange, massively cross-bedded, moderately well-cemented sandstone with well-rounded, fine- to medium-grained, frosted quartz sand grains and locally common ironstone bands and concretions (Hayden and Willis, 2011). It forms the cliffs and slopes of the upper portion of the Red Hills. It is strongly jointed in two main joints sets: generally north-northeast-trending joints that are parallel, high-angle, and typically open, and northwest-trending joints that are commonly brecciated and strongly cemented. These joints are prominent in the outcrops on the north side of Red Hills Parkway in the area of "Dixie" rock. A local favorite just up the one-way road from the Red Hills Desert Garden parking lot is known as "the crack."

Regionally this sandstone forms the White Cliffs step of the Grand Staircase (Gregory, 1950), although it does not happen to be white locally. The formation is also the principal aquifer in the area (Clyde, 1987; Hurlow, 1998; Heilweil and others, 2000, 2002; Rowley and Dixon, 2004) and springs are common at the lower contact with the Kayenta Formation. The sand was 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). Only the lower 200 feet (60 m) is present in the area shown on figure 2, but the Navajo's total thickness is 1800 to 2000 feet (550-600 m) in Snow Canyon State Park.

Quaternary Age Sediments

Much of the map area is covered by Quaternary-age sediment deposited by several agents of gradation: streams, wind, debris flows, and landslides. Landslides (Qms) and broken blocks of rock called talus

(Qmt) that cover many bedrock slopes are deposited as gravity pulls them down the hillsides. Piles of unconsolidated sand are deposited by wind (eolian) processes (Qes). Stream systems deposit alluvial sediment in the active channel of the Virgin and Santa Clara rivers (Qal_1), and old stream deposits are preserved as terraces ($Qat_{2\text{-}5}$) at higher elevations than current drainages. Some much older terraces (Qato) are not connected to present drainages. There are also units deposited by a combination of processes, such as both alluvial and colluvial (Qac) in minor drainage dissected areas, and both alluvial and eolian (Qea and Qae) in mostly broad, flat areas. The valley underneath downtown is an older alluvial and eolian surface (Qaeo), while the sediment covering part of the top of the lava flows is deposited by a combination of eolian, colluvial, and alluvial processes (Qeca).

SUMMARY

When trying to understand landscape development, it is helpful to know that whatever landscape you are seeing is DUE for a change. DUE stands for deposition, uplift, and erosion. Although these processes are not mutually exclusive, with one ending before another one can begin, it is meaningful to consider one at a time. Rock layers must be made through deposition before they can experience either uplift or erosion. Said in a different way, once the rock layers are deposited, they are subjected to (1) Earth's internal energy, which drives plate tectonics that roughens up the surface of the Earth (uplift), and (2) external energy, which powers the hydrologic cycle that smooths the surface (erosion). The modern landscape you see is a result of that interaction. Usually, to shift regimes from deposition to erosion, base level must lower in some way. In southwest Utah this is commonly achieved by uplifting of rock layers, by, for example, movement on major faults. Once there is any topographic relief, erosion begins.

The inverted topography of these three basalt-capped ridges can be viewed as experiencing this simplified sequence twice. First, the Triassic-Jurassic sedimentary rock was deposited (along with younger sedimentary rock that was subsequently removed), then the area experienced compression that tilted the rock (St. George syncline); subsequent relative uplift allowed stream channels to be eroded into the layers. Much later, the area experienced deposition, but this time lava flows filled the stream valleys, and the area elevations were adjusted by tension (extension) that created normal faults (St. George fault). Now, with this most recent period of predominantly downcutting and erosion, the lava flows that filled the stream valleys instead cap the ridges, thus inverting the topography and giving the ridges the landform name of "inverted valleys" or "inverted topography." As you look out on the ridges and the valley of downtown St. George from the vantage point of the water tank on the Red Hills, it can be quite a mind-expanding experience to think of how different the topography looked not so very long ago. But then again, many concepts in geology are mind-expanding. Now go take a closer look.

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