GEOLOGIC MAP OF THE SHIVWITS QUADRANGLE, WASHINGTON COUNTY, UTAH

by
Lehi F. Hintze and Becky J. Hammond

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Lehi F. Hintze[1] *and Becky J. Hammond*[2]

ABSTRACT

This quadrangle straddles the Colorado Plateau-Basin and Range boundary and its western two-thirds includes features that are transitional between the two provinces. The oldest exposed rock is the Early Cambrian Tapeats Quartzite, which is overlain by nearly 4,000 feet (1,220 m) of Cambrian dolomite, limestone, and shale. Ordovician and Silurian strata are absent here. Middle and late Paleozoic marine strata are present in the following thicknesses: Devonian, 700 feet (215 m); Mississippian, 700 feet (215 m); Pennsylvanian, 1,600 feet (490 m); Permian, 3,300 feet (1,000 m). A substantial period of erosion intervened before deposition of the marine Lower Triassic Moenkopi Formation, which is about 1,800 feet (550 m) thick. Another hiatus ensued before the non-marine Upper Triassic Chinle Formation, about 800 feet (250 m) thick, was deposited. Succeeding Jurassic strata include the Moenave Formation, 500 feet (150 m) thick, the Kayenta Formation, 1,700 feet (520 m) thick, the Navajo Sandstone, about 2,000 feet (600 m) thick, and a few feet of the marine Carmel Formation. Locally, the Paleozoic and Mesozoic strata are structurally attenuated. The figures given above are maximums. Quaternary and Tertiary deposits are mostly surficial materials of alluvial, colluvial, mass-movement, or eolian origin, aggregating a few hundred feet at most in thickness. The most noteworthy Quaternary-Tertiary unit is the Gunlock Basalt, 1.6 million years old.

Structures in the quadrangle include folds and thrust faults formed during Laramide compression in Late Cretaceous-Paleocene time, and extensional faults formed during late Cenozoic basin-and-range uplift and extension. The principal Cenozoic faults appear to include a component of left-lateral displacement as well as down-to-the-west normal displacement.

Geological deposits of major economic significance have not been identified in the quadrangle. Minor amounts of sand and gravel, wonderstone, and fossil wood of poor quality have been produced. Water resources in the quadrangle furnish the city of St. George with 40 percent of its culinary water. Because no one lives in the quadrangle, such geologic hazards as there are, principally from floods or possible earthquakes, are only a threat to travelers on the lightly used roads in the area. Caution is, however, advised for future developers to be aware of possible foundation problems from expansive soils or flooding problems in certain areas within the quadrangle.

INTRODUCTION

This quadrangle includes the westernmost part of Utah's "red rock country" and the east side of the Beaver Dam Mountains. The magnificent sequence of sedimentary rocks exposed in this map area is composed of Paleozoic marine carbonate rocks more than 2 miles (3.2 km) thick, overlain by more than a mile (1.6 km) of mostly non-marine, Mesozoic, multicolored sandstone and shale. These are, in turn, locally capped by a 1.6 million-year-old basalt flow and a few hundred feet of Quaternary stream- and wind-laid deposits. The Paleozoic and Mesozoic strata are folded into a broad north-trending syncline and some smaller folds of similar orientation. These folds are cut by north-trending faults that mostly exhibit a combination of down-to-the-west vertical displacement and left-lateral horizontal offset.

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The east edge of the quadrangle lies about 10 miles (16 km) west of St. George. The quadrangle is crossed by U.S. Highway 91. The quadrangle takes its name from an old Shivwits Indian settlement, now abandoned. The new Shivwits village is located in the adjacent Santa Clara quadrangle, a mile (1.6 km) to the east of the old settlement. The Shivwits-Paiute Indian Reservation includes more than half of the Shivwits quadrangle, extending northward for 6 miles (10 km) and westward for 5 miles (8 km) from the southeast corner of the map.

The quadrangle lies within the zone of transition between the Colorado Plateau and Basin and Range physiographic provinces and includes structural features typical of both. Compressional deformation of late Mesozoic to early Cenozoic age was followed by late Cenozoic extensional normal faulting which apparently included a component of left-lateral horizontal movement.

The first geologic map of the Shivwits quadrangle is that of Reber (1951), who included this map area as part of his thesis on the Beaver Dam Mountains. Cook (1960) incorporated Reber's mapping in his geologic atlas map of Washington County. Hintze (1985) presented a geologic map showing, for the first time, subdivisions of major stratigraphic formations into members as a result of field work by students of the Brigham Young University geology field course, which operated in the area between 1981 and 1985. Hintze (1986) summarized the regional stratigraphy and structure of the Beaver Dam Mountains as displayed on six quadrangles, of which the Shivwits quadrangle is one. Hammond (1988) studied the Grand Wash-Reef Reservoir-Gunlock fault zone as shown on parts of the Shivwits and Jarvis Peak quadrangles by analyzing the results of detailed mapping and slickenside orientation measurements. Houser and others (1988) evaluated about 2 square miles (5.2 km^2) in the northeast corner of the quadrangle as part of their mineral potential report for the Red Mountain Wilderness Study Area. Hammond (1991) mapped the adjacent Jarvis Peak quadrangle and gave a detailed account of its stratigraphy, structure, economic geology, and other aspects.

For this report, Hintze is mostly responsible for lithologic and stratigraphic descriptions, and for compilation of the geologic map, except for that part mapped in detail by Hammond (1988). The authors collaborated on the discussion of structure and other aspects of the geology.

STRATIGRAPHY

Paleozoic strata aggregating nearly 11,000 feet (3,400 m) thick are exposed in the quadrangle and include shallow-water marine deposits of all Paleozoic periods except Ordovician and Silurian. If thin Ordovician and Silurian marine deposits were ever present within the map area, they were removed by erosion before Devonian deposits were laid down. The Paleozoic rocks are mostly dolomite and limestone and are overlain by Triassic and Jurassic deposits that are nearly 6,000 feet (1,800 m) thick. The Lower Triassic strata are mostly shallow-marine, near-shore mudstone, sabkha (evaporitic tidal flat) gypsum, and dolomite; a few hundred feet of open-water marine limestone and shale are present near the bottom of the Lower Triassic sequence. Upper Triassic deposits were laid down in meandering rivers and low-relief areas some distance from the ocean, and include a substantial increment of bentonitic ash derived from distant volcanos. Earliest Jurassic deposits are mostly red beds laid down in meandering stream systems on topography of low relief. Stream deposition was overwhelmed later in Jurassic time by eolian sands of the Navajo Sandstone. Marine conditions returned in Middle Jurassic time as evidenced by the Carmel Formation, a very small exposure of which is present near the northeast corner of the quadrangle. Younger Mesozoic strata have been eroded from the quadrangle.

Only the latest part of Cenozoic time is represented by deposits in the map area. The Gunlock Basalt, dated at 1.6 million years, straddles the Quaternary-Tertiary time boundary. Alluvial gravels of a paleo-Santa Clara River locally underlie the basalt. The age of the basalt provides a reference for evaluation of rates of denudation of the area during Quaternary time, movement on the Gunlock fault, and rates of accumulation of surficial alluvium, colluvium, caliche, and eolian sand.

Cambrian

Tapeats Quartzite (Ct)

The Tapeats Quartzite is a dark-reddish-orange to orange quartzite containing a few thin layers of pebble conglomerate and sandstone. It ranges from thin bedded to very thick bedded, contains some cross-bedded layers, and generally forms ledges. The top of this formation barely enters the southwest corner of the quadrangle as part of an outcrop that extends for 12 miles (19.3 km) along the west side of the Beaver Dam Mountains. The unit is tectonically attenuated along much of its exposed length but is believed to display a complete unbroken section in the northwest corner of the adjacent Jarvis Peak quadrangle where Hammond (1991) reported it to be about 1,300 feet (400 m) thick. It rests unconformably on Precambrian gneiss and schist where exposed in adjacent quadrangles in the Beaver Dam Mountains.

Bright Angel Shale (Cba)

This formation consists of olive-green micaceous shale, siltstone, sandstone, and quartzite; it includes a pale-brown-weathering, ledge-forming dolomite bed, about 10 feet (3 m) thick, 125 feet (38 m) above its base, and a thin limestone bed near its top. Both top and basal contacts of the Bright Angel Shale are gradational. It is unfossiliferous. Its best exposures are in the Jarvis Peak quadrangle in section 34, T. 42 S., R. 18 W. along a jeep road which follows the strike valley developed on the shale which is 250 feet (76 m) thick here. In other locations in the Beaver Dam Mountains the Bright Angel Shale is tectonically thinned or absent because of faulting along bedding surfaces.

Bonanza King Formation (Cbk)

This formation is pervasively brecciated where exposed in this quadrangle (figure 1). The one area in the Beaver Dam

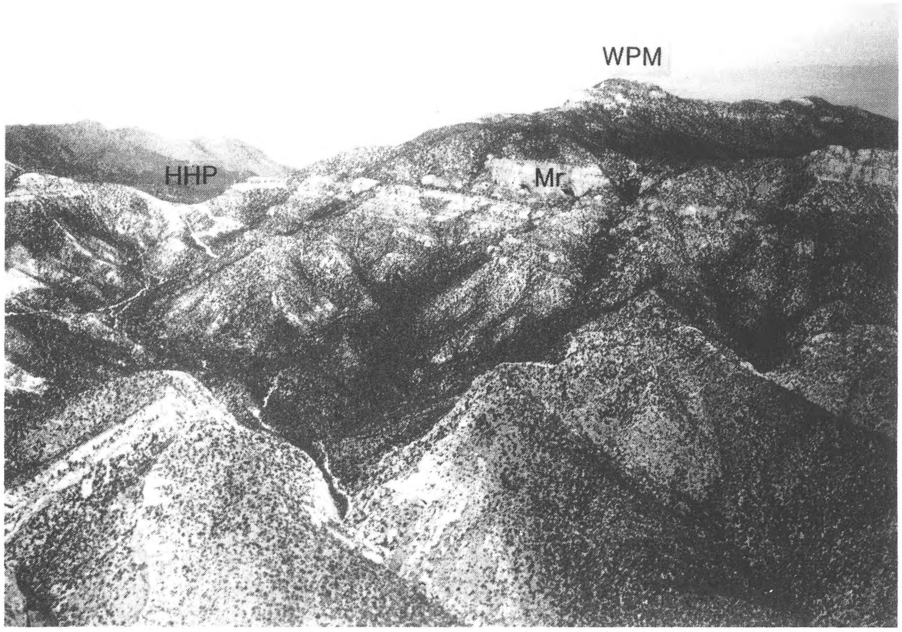

Figure 1. *Aerial view, looking northwestward, of the Hell Hole Pass area. West Mountain Peak (WMP), the high point, lies just west of the Shivwits quadrangle. The road over Hell Hole Pass (HHP), on the left side of the photograph, is on Cambrian dolomite. The cliffs with two caves at its base, below the skyline and slightly left of West Mountain Peak, is Mississippian Redwall Limestone (Mr). The same formation, dipping steeply, forms the sawtooth ridges in the lower third of the picture. The Jackson Wash-Pahcoon Flat fault lies between these ridges and the lower terrain on the near side of Hell Hole Pass.*

Mountains where this formation is relatively intact is on the ridge north of Horse Canyon in the West Mountain Peak quadrangle (Hintze, 1985, 1986). There, the formation is mostly medium- to light-brownish-gray, fine- to medium-grained, medium- to thick-bedded dolomite. Many beds are mottled light- to medium-gray and other beds contain abundant light-gray to white "twiggy bodies" or short, thin, irregular tubular structures which are a few tenths of an inch in length. The lowest 300 feet (90 m) includes some bluish-gray, silty limestone beds. The upper half of the formation includes numerous thin beds of light-gray, laminated boundstone typical of upper Middle Cambrian rocks in western Utah and eastern Nevada. No fossils have been obtained from any part of the formation in the Beaver Dam Mountains, but Steed (1980) reported a Late Cambrian trilobite, *Crepicephalus* sp. from the top of this formation in the Virgin Gorge, 10 miles (16 km) south of this area. Measurements along the north side of Horse Canyon in the West Mountain Peak quadrangle gave a thickness of 2,600 feet (800 m). Elsewhere in the range the formation is structurally attenuated. Brecciation accompanied the thinning, and the dolomite was commonly reduced to gravel-sized rubble which was partially reconsolidated. Bedding features were generally destroyed, and individual major fault or shear zones are seldom identifiable in exposures.

Nopah Dolomite (Cn)

Hazzard (1937) named the Nopah Formation for this unit composed of predominantly dolomitic rocks in southeastern California and western Nevada. Because it is also predominantly dolomite in the Beaver Dam Mountains, we herein call it the Nopah Dolomite, following the practice of naming stratigraphic units for their predominant lithology as recommended by Hansen (1991, p. 47).

This formation is so faulted and brecciated in this quadrangle that it, like the Bonanza King Formation, is best described from exposures in the adjacent West Mountain Peak quadrangle. There it is a light-brownish-gray, medium- to fine-grained, medium- to thick-bedded, ledge- and cliff-forming dolomite. It lacks the light-gray dolomitic boundstone that is common in part of the Bonanza King Formation, but contains, in its upper part, algal stromatolites that are as much as 8 inches (20 cm) in diameter and 20 inches (50 cm) long. Nopah Dolomite locally contains small tubular structures and mottled zones that suggest bioturbation during deposition. The Nopah Dolomite was measured north of Horse Canyon in the West Mountain Peak quadrangle (Hintze, 1985, 1986) where it is 1,380 feet (420 m) thick. It has a similar thickness in this quadrangle. It lies beneath a regional unconformity above which Ordovician and Silurian strata are missing (Hintze, 1988).

Devonian

Muddy Peak Dolomite (Dm)

Longwell (1921) named the Muddy Peak Limestone in the Muddy Mountains of southeastern Nevada. Because this stratigraphic unit is mostly dolomite in the Beaver Mountains, we herein call it the Muddy Peak Dolomite, following the practice of changing lithologic designation to accord with the local exposures as recommended by Hansen (1991, p. 47).

Although Devonian strata in the Beaver Dam Mountains are mostly dolomite, and somewhat similar to the underlying Cambrian rocks, certain distinctive lithologies are unique to the Devonian sequence. The lower 520 feet (160 m) is silty, fine-grained, light-olive to pale-yellowish-gray, thin- to medium-bedded dolomite. Reddish-brown-weathering sandy dolomite beds, a few feet thick, also occur in this lower part of the sequence. The lower sequence also includes a few thin pelletoidal beds near the top; small, hemispherical stromatoporoids, usually grossly silicified, are present in some layers; and sparse biohermal mounds include crinoid debris and scattered coral, gastropod, and brachiopod fragments. A few ledge-forming sandstone beds, as much as 6 feet (2 m) thick, occur at the top of this interval. The upper 160 feet (50 m) of the Muddy Peak Dolomite is composed mostly of medium-gray, medium-crystalline, massive dolomite that contains scattered chert nodules and sandy laminae. It also includes some distinctive dark-brownish-gray, coarse-grained dolomite beds.

In parts of the Beaver Dam Mountains it is possible to map two informal subdivisions of the Muddy Peak Dolomite (Hintze, 1985, 1986), but in this quadrangle the faulting and cliff-forming exposures make mapping these subdivisions impractical. The Muddy Peak Dolomite is 680 feet (210 m) thick as measured in Horse Canyon in the adjacent West Mountain Peak quadrangle (Hintze 1985, 1986). Devonian strata in the southwest part of the Shivwits quadrangle are probably locally tectonically attenuated.

Mississippian

Redwall Limestone (Mr)

This is a cliff-forming, massive, medium- to dark-gray limestone that contains a conspicuously cherty zone between 60 (18 m) and 150 (46 m) feet above its base. The upper part of the Redwall is a bioclastic limestone that contains horn corals, colonial corals, brachiopods, and gastropods. Steed (1980) measured 615 feet (190 m) of Redwall Limestone in the Virgin River Gorge, 10 miles (16 km) south of this quadrangle. The Redwall appears to be 700 to 800 feet (215 to 250 m) thick in this quadrangle as determined by map measurements. The Redwall Limestone has responded somewhat differently to tectonism than the dolomitic formations underneath it. It behaves more plastically and, where brecciated, reconsolidates into massive, cliff-forming limestone.

Pennsylvanian

Callville Limestone (IPc)

The Callville Limestone is a medium-gray limestone that is medium to thick bedded, commonly cherty, and cylically interbedded with orange-weathering, calcareous siltstone or sandstone and light-gray dolomite that becomes more common in the upper third of the formation. The cyclic bedding is reflected in a characteristic pattern of weathering to a "stair-step" ledge-slope topography similar to that of the Pakoon Dolomite described below. This weathering pattern renders these formations easily recognizable from a distance. Most of the stair-step ledges are less than 6 feet (1.8 m) high, so the Callville does not form the massive cliffs that are typical of the underlying Redwall Limestone. Callville Limestone is generally fossiliferous, bearing corals, brachiopods, and bryozoans throughout. Poorly preserved fusulinids occur in some beds and Chaetetes "hair coral" is common in the upper part. Hintze (1986) measured 1,520 feet (465 m) of Callville Limestone on Utah Hill in the adjacent Jarvis Peak quadrangle. In the Shivwits quadrangle map, measurements indicate that the Callville Limestone is about 1,600 feet (490 m) thick. The attenuation and brecciation that affect older Palezoic strata appear to fade out in the upper Paleozoic and Mesozoic rocks. This may partly be the result of the interbedding of clastic and carbonate layers in upper Paleozoic strata that permit slippage to occur along bedding surfaces without much deformation.

Permian

Pakoon Dolomite (Pp)

McNair (1951) named the Pakoon Limestone for a dolomitic limestone unit in northwestern Arizona. To emphasize the dolomitic composition of these strata in the Beaver Dam Mountains, we herein call it the Pakoon Dolomite, following the recommendation of Hansen (1991, p. 47) to designate the predominant lithology in the name of the unit.

This formation is predominantly light-gray, medium- to thick-bedded, fine-grained dolomite that weathers to light-brownish-gray, cyclic step-ledges, slopes, and low cliffs. The boundary between it and the Callville Limestone is distinguished by use of dilute hydrochloric acid which indicates the change from limestone to dolomite. The Pakoon Dolomite is commonly cherty like the Callville, but it is sparsely fossiliferous. Bryozoans and fusulinids occur mostly in thin limestone beds in the upper third of the formation, and they identify its age as Wolfcampian (Hintze, 1988). The formation ranges between 600 and 800 feet (180 and 240 m) thick in this quadrangle.

Queantoweap Sandstone (Pq)

In this quadrangle the Queantoweap Sandstone is a fairly uniform, very-pale-orange to grayish-orange-pink, thin- to thick-bedded, fine- to medium-grained, tightly to loosely cemented sandstone that makes a readily identifiable map unit in the field. It ranges between 1,400 (425 m) and 1,800 feet (550 m) thick in the map area; the variation in thickness is at least partly caused by tectonic attenuation, particularly west of the Jackson Wash-Pahcoon Flat fault.

Toroweap Formation

Nielson (1981, 1986) studied the Toroweap and Kaibab Formations in this area and we follow his nomenclature for subdividing the two units. The Toroweap Formation has three members, named in ascending order: Seligman, Brady Canyon, and Woods Ranch. Nielson (1981) described six detailed measured sections of these stratigraphic units within this quadrangle. The alternating resistant - recessive nature of the formation shows on figure 2.

Seligman Member (Pts) –This member consists of gypsiferous siltstone, with minor white gypsum and light-olive-gray, fine-grained sandstone. It generally forms a covered slope and is

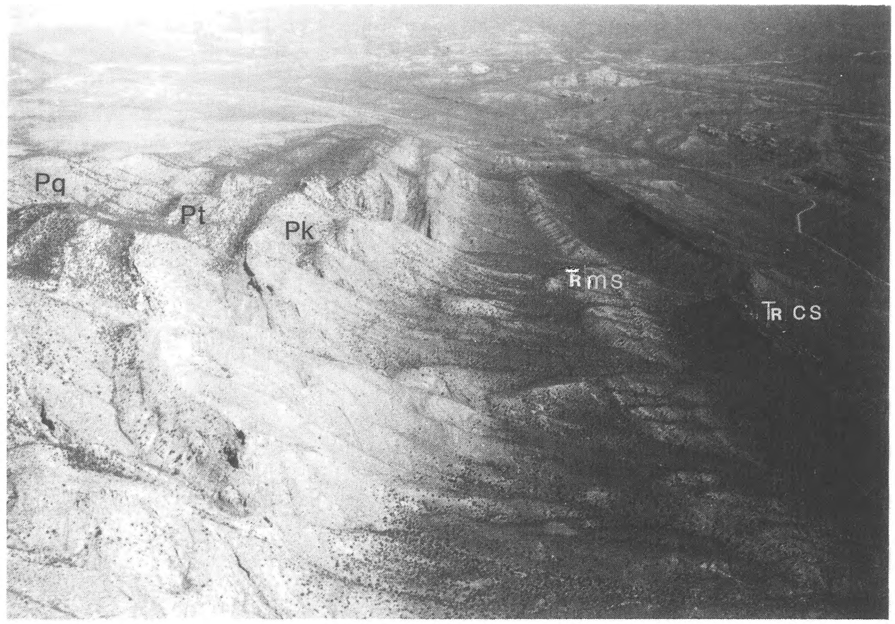

Figure 2. *Aerial view looking northward along the west flank of the Shivwits syncline. Ridges along the left side are Permian Queantoweap (Pq), Toroweap (Pt), and Kaibab (Pk) Formations showing their alternating recessive and resistant topographic expression. The central valley-forming units are members of the Moenkopi Formation. The Shnabkaib Member (TRms) forms the light-colored outcrops. The sharp ridge on the right side of the view is formed by the Shinarump Member of the Chinle Formation (TRcs). The Motoqua road near the right edge of the picture generally follows the recessive middle member of the Kayenta Formation.*

commonly attenuated as judged by thickness variations. Thickness of this unit in the quadrangle, as measured by Nielson (1981), ranges between 70 (20 m) and 200 feet (60 m).

Brady Canyon Member (Ptb) – This member consists of light-gray, fine- to medium-grained, massive limestone that contains reddish-orange chert nodules that constitute about 10 percent of the rock. Brachiopod, gastropod, coral, crinoid, and sponge fragments are common. This member closely resembles the Fossil Mountain Member of the Kaibab Formation and forms prominent cliffs. Its thickness ranges from 215 to 420 feet (65 to 130 m) as measured within this quadrangle by Nielson (1981). The larger number may represent tectonic thickening; a thickness of about 260 feet (80 m) is typical in the quadrangle.

Woods Ranch Member (Ptw) – This member forms an easily traceable strike-valley between the resistant Brady Canyon and Fossil Mountain Members. The lower half to two-thirds of the member is mostly gypsiferous siltstone and gypsum that is recessive and very poorly exposed. The upper part of the member is mostly thin-bedded, gray limestone with a few light-gray dolomite beds that show as marker beds on aerial photographs. Nielson (1981) described detailed measured sections of this member at six locations spaced a mile or two apart along its principal line of outcrop in the quadrangle. His thicknesses ranged from 143 to 349 feet (43 to 107 m). Average thickness is about 260 feet (80 m). Some of the upper limestone beds that were placed within this member by Nielson (1981) may have been included on the present map within the lower part of the Fossil Mountain Member of the Kaibab Formation.

Kaibab Formation

Nomenclature used here follows Nielson (1981, 1986) who traced the history of nomenclature and presented six detailed measured sections of the formation as exposed within this quadrangle. Two members are recognized within the Kaibab Formation, the cliff-forming Fossil Mountain Member at its base, and the less resistant, gypsum-bearing Harrisburg Member above.

Fossil Mountain Member (Pkf) – This member is an abundantly fossiliferous, yellowish-gray, fine- to medium-grained, cherty limestone. Its silicified fossils include brachiopods, crinoids, bryozoans, and corals. This member forms a prominent cliff in the quadrangle between the less-resistant gypsiferous units above and below and generally forms a cap rock or dipslope. Chert makes up about 20 percent of the rock and occurs as irregularly bedded nodules and masses. The chert is reddish-brown, brown, and black and its abundance makes the Fossil Mountain Member recognizable from a distance because of its black-banded appearance. Detailed measured sections by Nielson (1981) show the Fossil Mountain Member to be between 230 and 260 feet (70 and 80 m) thick in this quadrangle.

Harrisburg Member (Pkh) – The Harrisburg Member consists of interbedded laminated gypsum, gypsiferous siltstone, fossiliferous limestone, and thin-bedded dolomite. Chert occurs as pinkish-orange to reddish-brown nodules that make up 10 to 30 percent of the limestone and dolomite beds in the upper half of the member. Because of the long time interval between Harrisburg deposition and deposition of the overlying Moenkopi Formation (some 20 million years including Late Permian and some of Early Triassic time), the Harrisburg underwent subaerial erosion and was completely removed in some places and is only partially present in most sections. Pre-Triassic erosion even cut down into the underlying Fossil Mountain Member and created a post-Harrisburg topographic relief estimated at 600 feet (180 m) in places (Nielson, 1981). This variation in the present thickness of the Harrisburg Member shows plainly in the northwest quarter of the geologic map where the Harrisburg dips steeply and its map width reflects its preserved thickness.

During the pre-Triassic erosional interval, the Harrisburg carbonate beds were commonly reduced to a cherty rubble that formed on the paleosurface by erosion and solution collapse of gypsum beds in the lower part of the Harrisburg. No Harrisburg section in this quadrangle has escaped the weathering and erosional effects of the long interval of time between the end of Harrisburg deposition and the inception of deposition in Early Triassic time. Jenson (1986) showed two measured sections of the Harrisburg Member in this quadrangle; one was 30 feet (9 m) and the other 300 feet (90 m) thick. Nielson's (1981) measured thicknesses of the Harrisburg in this quadrangle range between 80 and 310 feet (25 and 95 m).

Triassic

Moenkopi Formation

The Moenkopi Formation was mapped using the five-member subdivisions of Stewart and others (1972b). Jenson (1986) studied paleoenvironments of the Harrisburg Member of the Kaibab Formation and the lower two-thirds of the Moenkopi Formation and measured two sections of these rocks within the Shivwits quadrangle, as noted below, and six sections in nearby locations. The Moenkopi Formation generally forms low topography as shown on figure 2.

Lower red member (Ꞧml) – This member is composed mostly of reddish-brown calcareous or dolomitic siltstone and mudstone. Thin beds of gypsum are common, particularly in the middle of the member. Locally, very thin beds of limestone and dolomite are interlayered with the siltstone and gypsum. Small-scale cross bedding and ripple marks are common in siltstone layers. The member is nonresistant and generally poorly exposed. It pinches out abruptly on the flanks of paleohills that developed on underlying Permian strata. Thickness of the lower red member ranges from 0 to 160 feet (50 m) (Jenson, 1986) in this quadrangle.

Virgin Limestone Member (Ꞧmv) – Limestone makes up only about 25 percent of this member, but the limestone forms three distinctive sharp ledges or low cliffs near the base, middle, and top that make the member easily identifiable in the field and on aerial photographs. The basal limestone is 6 to 15 feet (1.8-4.6 m) thick and contains abundant five-sided echinoderm fragments. The middle limestone is variable in thickness and position within the member. The upper limestone bed is 10 to 20 feet (3-6 m) thick. The limestones are yellowish brown to medium gray and composed of pelloids, ooids, intraclasts, and shell fragments usually in a micritic matrix.

Most of the Virgin Member is made up of recessive, yellowish-brown-weathering marine mudstone and siltstone. Lenticular chert occurs locally in the limestone beds but has neither the form, abundance, or color of chert beds in the Harrisburg Member against which the lower Virgin Member is juxtaposed where the lower red member is absent. Fossils include echinoid debris, pelecypods, gastropods, brachiopods, and ostracodes. These are found both in limestone and in mudstone beds.

The best exposures of the Virgin Member are in the southeast corner of the quadrangle. Elsewhere, the member is discontinously, and generally incompletely, exposed on the steeply dipping west flank of the Shivwits syncline. Jenson (1986) measured two sections of the Virgin Limestone Member in the quadrangle that were 210 and 250 feet (64 and 76 m) thick.

Middle red member (Ꞧmm) – This member consists of pale-reddish-brown, laminated or thinly bedded siltstone and mudstone with very thin interbeds and vein stringers of white or greenish-gray gypsum. The gypsum makes up about 20 percent of the member. The middle red member is nonresistant and weathers to red soil. Basal contact of the middle red member is taken at the first appearance of red beds above the highest limestone beds of the Virgin Limestone. The contact with the overlying Shnabkaib is gradational; the lowest gypsum bed thicker than 5 feet (1.5 m) was mapped as basal Shnabkaib. The middle red member is unfossiliferous and ranges in thickness from 300 to 350 feet (90 to 107 m), thinning northwestward. Best exposures of the middle red member are near the Apex Mine road in the southeast corner of the quadrangle.

Shnabkaib Member (Ꞧms) – This is the thickest member of the Moenkopi Formation and generally shows on aerial photographs in conspicuously lighter shades than other map units. It consists mostly of light-gray to pale-red gypsiferous mudstone and siltstone containing interbeds of thin-bedded, light-gray dolomite and lesser limestone that is generally unfossiliferous. The Shnabkaib Member was deposited in a near-shore marine sabkha (evaporitic tidal flat) environment in contrast with the more normal marine environment represented by the Virgin Limestone Member. The Shnabkaib Member forms ledge-slope topography and is more resistant than the red members bounding it. In about the middle of the member some light-gray, sandy, dolomitic limestone beds hold up a cuesta that occurs throughout the area. The upper 400 feet (120 m) of Shnabkaib is made of gypsum intercalated with mudstone and thin beds of dolomite. The gypsum weathers to powdery soil that looks like dirty snow. It is well displayed at the junction of U.S. Highway 91 and the Apex Mine road. In this quadrangle, the best exposures of the Shnabkaib Member are in the southeast part, north and south of Wittwer Canyon, where the beds dip gently northeastward. The Shnabkaib Member ranges between 800 to 870 feet (240 to 260 m) in thickness in the quadrangle.

Upper red member (Ꞧmu) – The upper red member consists mainly of reddish-brown, thin-bedded siltstone. A massive, pale-reddish-orange sandstone ledge occurs near the top. Thin gypsum beds are present, but make up less than 1 percent of the member. Ripple marks are common in the siltstone. The member is well exposed along both flanks of the Shivwits syncline where it is 500 feet (150 m) thick.

Chinle Formation

This formation is Late Triassic in age and is separated from the underlying Moenkopi Formation by an unconformity that represents all of Middle Triassic time (about 10 million years). The Chinle Formation represents non-marine floodplain and local lake-basin deposition. Members as mapped follow subdivisions used by Stewart and others (1972a).

Shinarump Conglomerate Member (TRcs) – This member consists of orangish-brown conglomerate, gritstone, and sandstone, and forms a resistant, dark-brown ledge or caprock (figure 2). It represents stream-channel deposition and thus its thickness and lithology vary considerably within short distances along its outcrop. Chert-pebble and cobble conglomerate forms the lower part of the member. It is commonly overlain by salt-and-pepper gritty sandstone, and/or medium-grained, light-brown sandstone. The latter has well-developed limonite banding and is called "wonderstone" or "picturestone" in rock shops. Fossil wood is common, mostly as fragments, but some as logs as much as a few feet long. Along the west flank of the Shivwits syncline, the Shinarump Conglomerate Member is made up of three parts not mapped separately: a basal resistant conglomerate 45 feet (14 m) thick; a middle gritty, salt-and-pepper sandstone 170 feet (52 m) thick that contains 40 feet (12 m) of wonderstone at its base; and an upper resistant, ledge-forming chert-pebble conglomerate. The Shinarump totals 255 feet (78 m) in thickness here, but it is as thin as 60 feet (20 m) thick at other locations in this quadrangle.

In some places the lower part of the overlying Petrified Forest Member includes conglomerate and sandstone beds similar to those of the Shinarump Member. These are ordinarily separated from the top of the Shinarump by purplish bentonitic clay typical of the Petrified Forest Member, in which case, the contact is drawn at the base of the clay. However, because of the nature of channel deposition, the Shinarump and basal Petrified Forest channel deposits merge in some places and have been mapped together as Shinarump. Such is the case in the thin Shinarump outcrop above the Santa Clara Bench Canal along the east edge of the quadrangle near old Shivwits. At the north edge of the quadrangle the Shinarump Member is separated from a substantial sandstone bed in the lower Petrified Forest Member by 20 feet (6 m) of bentonitic clay that makes a strike valley followed by a jeep road.

Petrified Forest Member (TRcp) – This member is made up of mudstone, siltstone, and some sandstone that together produce varicolored exposures ranging from white to purplish red, orangish red, and greenish gray. Fossil wood is common but not as abundant as in the Shinarump Conglomerate Member. Some mudstones contain bentonitic clays, derived from volcanic ash, that make this member prone to mass movement. Hummocky slump topography is well developed east of the Gunlock fault south of the Santa Clara Bench where the slumped Petrified Forest Member is mostly covered with talus blocks of basalt. The best exposures of the member are west of the road to Motoqua in the north-central part of the map area where the unit is 650 to 700 feet (200-215 m) thick.

Jurassic

Moenave Formation

We follow Wilson and Stewart (1967) in recognizing three members of this formation as described below. Hintze (1986) reviewed the rationale for assigning a Jurassic age to the Moenave. The Whitmore Point Member of the Moenave contains lacustrine fish and palynomorph fossils that are the only age-diagnostic materials so far recovered from the thick, nonmarine, red-bed sequence that overlies the Upper Triassic Chinle Formation over a broad area in Utah and Arizona. Hence the Moenave Formation is a key unit for assigning the ages of a large body of sedimentary deposits.

Dinosaur Canyon Member (Jmd) – This member consists of dark-reddish-brown siltstone and thin-bedded sandstone. It resembles the red beds of the overlying lower and middle Kayenta Formation. Its contact with the Chinle Formation is placed at the color change where the purplish or greenish bentonitic shale of the Chinle is overlain by the dark-reddish-brown beds of the Dinosaur Canyon Member. The member was measured in the central part of section 29, T. 41 S., R. 17 W. where it is 275 feet (85 m) thick.

Whitmore Point Member (Jmw) – This recessive member is mostly gray to reddish-gray siltstone and claystone with a few thin beds of dolomitic limestone that contain algal structures and other fossil fragments. The Whitmore Point Member is well exposed on the east limb of the Shivwits syncline 0.5 mile (0.8 km) north of Camp Spring where we measured its thickness to be 55 feet (17 m). A mile (1.6 km) to the west, on the west limb of the syncline, we measured it to be 80 feet (25 m) thick.

Springdale Sandstone Member (Jms) – This member is a light-brownish-gray, fine- to medium-grained sandstone that forms ledges and small cliffs. Near its middle it locally includes a recessive siltstone bed as much as 15 feet (5 m) thick. The Springdale Member is the silver-bearing host rock in the old Silver Reef mining district at Leeds north of St. George (Proctor, 1953). At its type locality at Springdale near Zion National Park, it forms a conspicuous reddish-brown ledge. In this quadrangle the Springdale Sandstone Member is 55 feet (17 m) thick in section 29, T. 41 S., R. 17 W., and 180 feet (55 m) thick a mile (1.6 km) to the west in section 30. It is well exposed near Pahcoon Spring (figure 3).

Kayenta Formation

Wilson and Stewart (1967, p. 16) described the Kayenta Formation in the Leeds-St. George area as consisting of two parts. There the lower part, about 600 feet (185 m) thick, is a slope-forming series of interbedded, pale-reddish-brown sandstone and siltstone. The upper part, about 400 feet (120 m) thick, is mostly orangish-brown sandstone that forms cliffs. The upper Kayenta cliff-forming sandstones are similar to the Navajo Sandstone except that the horizontal bedding in the Kayenta Formation, produced by fluvial processes, differs from the large-scale, eolian cross-bedding of the Navajo.

In the Beaver Dam Mountains area, the Kayenta Formation is about 1,700 feet (520 m) thick and is divided into three members, a lower mudstone and lacustrine member, a middle dark-red sandstone and siltstone member, and an upper pink cliff-forming sandstone member.

Lower member (Jkl) – This member is mostly reddish-brown mudstone and siltstone, but near its top it includes several thin

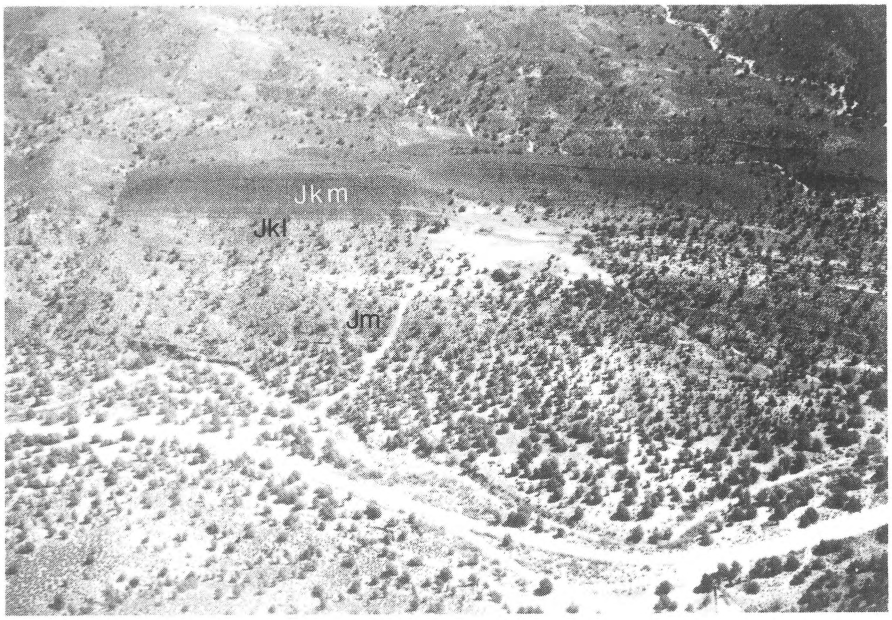

Figure 3. Aerial view looking eastward at Pahcoon Spring, the treeless area near the photo center. Pahcoon Spring emerges from a fault with small displacement which shows in the offset of the low, dark ridges at the base of the middle member of the Kayenta Formation (Jkm) just beyond the spring. The thin white beds directly below Jkm are in the lower member of the Kayenta Formation (Jkl). The Motoqua road is on alluvium at the bottom of the picture. The small road to the spring crosses low outcrops of the Moenave Formation (Jm).

but resistant beds of very-light-gray, laminated dolomite interpreted by Larsen and others (1986) to be of lacustrine origin. Talus slabs of this white dolomite show up against the darker reddish siltstone very prominently on aerial photographs as a white band, making it an easily identifiable marker horizon. The lower member is 150 to 180 feet (46 to 55 m) thick in this quadrangle.

Middle member (Jkm) – This member consists of interbedded siltstone, sandstone, and shale red beds that were deposited on broad floodplains. Dinosaur tracks have been found in this unit near Pahcoon Spring (Hintze, 1986). Color of individual beds in the member ranges from orangish brown through reddish brown, to dark reddish brown but the overall aspect of the unit darkens westward from its exposures near St. George . On the west limb of the Shivwits syncline, the middle member exhibits the darkest red color of any sedimentary unit in the quadrangle. It also increases in resistance to erosion westward; on the east side of the quadrangle it is the slope-forming unit along the base of the Red Mountains. But on the west flank of the Shivwits syncline it becomes increasingly resistant westward forming a dark-red ridge in the adjacent quadrangles to the northwest. The increased resistance reflects an increase in sandstone over siltstone, and this westward coarsening of the clastics suggests that their source lay to the west. The middle member is about 800 feet (240 m) thick in this quadrangle.

Upper member (Jku) – This is a pale-red sandstone with thin interbeds of reddish-brown mudstone and siltstone. It was stream deposited, as shown by planar bedding in the mudstone and siltstone beds and small-scale cross-bedding in some sandstone layers. It forms prominent ledges and cliffs on the flanks and nose of the Shivwits syncline. On the Red Mountains, it forms the horizontally bedded lower part of the sandstone cliffs. The member is about 700 feet (215 m) thick in this quadrangle.

Navajo Sandstone (Jn)

This famous formation forms the top part of the Red Mountains east of the Gunlock fault and the trough of the Shivwits syncline west of the fault. It is characterized by conspicuous cross-bedding and jointing. Calcareous cement provides various degrees of coherence, so that in places the formation breaks down to form pink Quaternary dune sand. The Navajo Sandstone is grayish orange to pale reddish brown and composed quite uniformly of medium-size quartz grains. The top of the formation is not exposed in this quadrangle. Map measurements in the Shivwits syncline in the adjacent Gunlock quadrangle and in the Red Mountains area directly east of the Shivwits quadrangle indicate that the Navajo Sandstone is between 2,000 and 2,500 feet (610 and 760 m) thick.

Carmel Formation (Jc)

This formation is extensively exposed in the Gunlock quadrangle directly north of our map area where it was recently described by Nielson (1990). In the Shivwits quadrangle, the Carmel is limited to a very small exposure of limy shale and thin-bedded limestone in a stream cutbank near the northeast corner of the map area.

Quaternary and Tertiary

Only the very latest part of Tertiary time is represented by stratigraphic units in this quadrangle. Basis for the age assignment is a 1.6 Ma K-Ar age for the Gunlock Basalt reported by Best and others (1980) for a basalt sample from section 8, T. 41 S., R. 17 W. Because the latest calibration of the Cenozoic time scale by Berggren and others (1985) places the Quaternary-Tertiary boundary at 1.6 million years, the basalt straddles the time boundary. Alluvial and other kinds of surficial deposits in the map area that appear to have been formed about the same time as the basalt, as judged by their height above the present stream valley bottoms, or by their position relative to other topographic features, are also assigned a latest Tertiary and early Quaternary age. Deposits that are accumulating on present land surfaces are judged to be the youngest, and those that occupy topographic positions intermediate between the presently accumulating deposits and the higher-level deposits that are now being removed by erosion are thought to be early Holocene or Pleistocene in age as indicated schematically on the "Correlation of Quaternary and Tertiary Map Units" chart on plate 2.

In the descriptions below, the Quaternary and Tertiary map units are grouped as follows: volcanic rocks, alluvial deposits, colluvial deposits, mass-movement deposits, eolian deposits, and caliche soil.

Volcanic Rocks

Gunlock Basalt (QTb) – Basalt flows that cap the inverted valley (a former valley that has become a ridge) just east of the Santa Clara River (figure 4) were described by Embree (1970) who recognized that several successive flows issued from the source area near the town of Veyo. The oldest flow is the one that extends into this quadrangle. It has been dated by Best and others (1980) at 1.6 ± 0.1 Ma. The basalt is brownish black, locally vesicular, and contains olivine phenocrysts. It generally rests on alluvial gravel of the paleo-Santa Clara River about 300 feet (90 m) above the present river elevation. The pre-basalt river followed a zone of weakness created by the Gunlock fault. Consequently, the paleo-river gravels and the basalt generally conceal the fault. The east edge of the Gunlock Basalt laps out against alluvial and colluvial deposits along the base of the Red Mountains; its western edge is an erosional escarpment. Thickness of the basalt ranges from 0 to 30 feet (0-9.2 m).

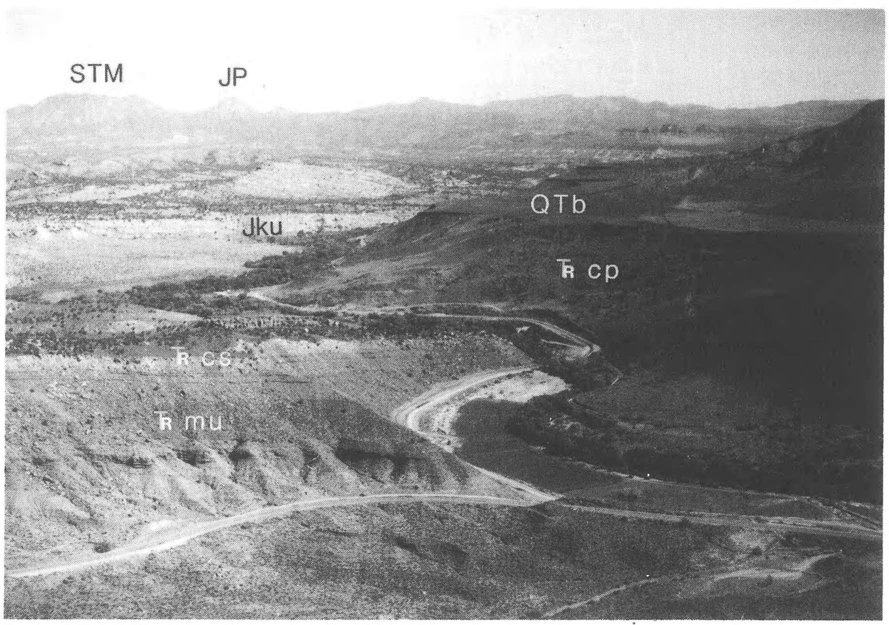

Figure 4. Aerial view looking northward along the Santa Clara River valley from the road junction of U.S. Highway 91 and the road that follows the river valley toward Gunlock. The Gunlock Basalt (QTb) caps the dark bench in the right half of the picture. Square Top Mountain (STM) and Jackson Peak (JP) are on the left skyline. The light-colored hill below and to the right of Jackson Peak exposes the upper member of the Kayenta Formation (Jku) on the axis of the Shivwits syncline. Slumped ground in the right center of the picture is underlain by Petrified Forest Member of the Chinle Formation (Ћcp), here covered with talus blocks of Gunlock Basalt. Outcrops above the highway in the lower left corner are the upper red member of the Moenkopi Formation (Ћmu) capped by the Shinarump Conglomerate Member of the Chinle Formation (Ћcs) which forms the dip slope.

Alluvial Deposits

High-level alluvial gravel (QTag) – This unit includes not only the paleo-Santa Clara River gravel beneath the Gunlock Basalt, but also other high-level gravel deposited by smaller paleostreams about the same time as the Santa Clara gravels, as judged by their elevations above present drainages. The high-level alluvium beneath the Gunlock Basalt contains a mixture of clasts derived from local sources, such as alluvial fans on the Red Mountains, and distant sources tens of miles upstream as evidenced by the presence of volcanic clasts. Most of the clasts are rounded, well-traveled cobbles and boulders of igneous rocks exposed in the Bull Valley and Pine Valley Mountains. Some of the locally derived clasts are large slabs of sandstone, apparently dumped into the paleo-river system by cloudburst floods.

The large area of high-level alluvium along the north-central map border (figure 5) is made up mostly of Permian quartzite and carbonate rocks derived from the Square Top Mountain area some 10 miles (16 km) to the north. Volcanic clasts are lacking. The high-level alluvial gravel in the central and south-central part of the quadrangle is mostly cherty carbonate clasts derived from upper Paleozoic carbonate rocks exposed on the east side of the Beaver Dam Mountains. Sparse volcanic clasts suggest some connection with the paleo-Santa Clara River system. Because these unconsolidated gravels are more resistant than some bedrock formations, the gravels commonly form a caprock on ridges. Maximum thickness of the high-level alluvial gravel in this quadrangle is about 100 feet (30 m).

Older alluvium and colluvium, undivided (QTac) – The largest area underlain by this deposit covers Pahcoon Flat and nearby areas in the northwest part of the quadrangle. There the deposits are poorly sorted, angular to subangular materials of local derivation, largely soil covered, and may include mudflow or debris-flow

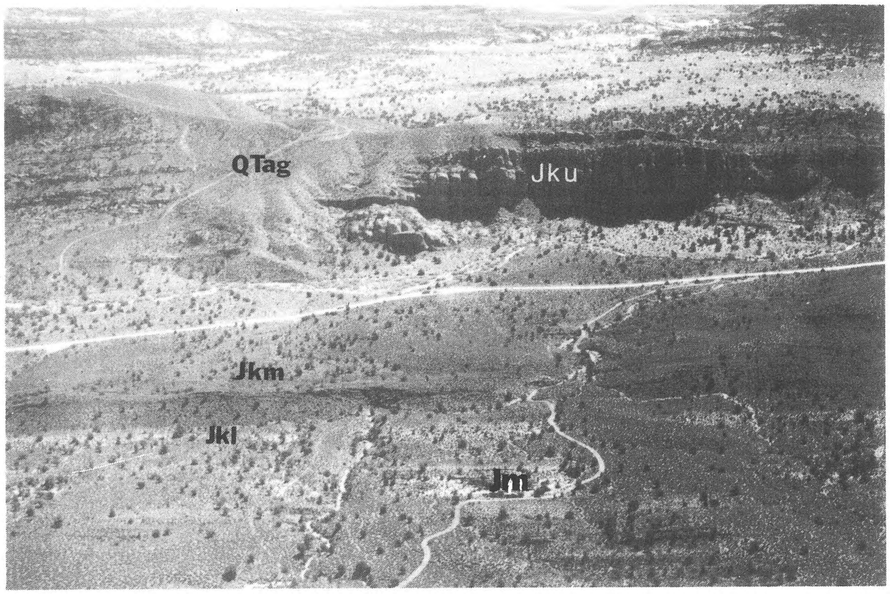

Figure 5. Aerial view looking eastward showing Pahcoon Spring Wash and the road to Motoqua running across the photo midline. Cliffs are the upper member of the Kayenta Formation (Jku) which is unconformably overlain by high-level alluvial gravel (QTag) which has provided a path for the jeep road to surmount the cliffs. The main road follows the middle member of the Kayenta Formation (Jkm), and the thin, lower member (Jkl) makes the light-colored horizon directly below Jkm. Beds in the immediate foreground belong to the Moenave Formation (Jm).

materials. Thickness is variable because the topography upon which these deposits accumulated had a hundred or more feet of relief. Gullies at the south edge of Pahcoon Flat expose a thickness of more than 50 feet (15 m) of this material. A much smaller area mapped as QTac is on the west flank of the Red Mountains where alluvial-colluvial deposits both underlie and overlie the Gunlock Basalt.

Terrace gravel (Qat_2) – Gravel deposits that lie above present floodplain levels have formed along the Santa Clara River and Pahcoon Spring Wash. No effort was made to map each terrace level separately, so this map unit includes all gravels intermediate between the high-level alluvial gravels and those of the present streams. Thickness and areal extent of these deposits is not great. Maximum thickness is about 50 feet (15 m), but most deposits are less than 20 feet (6 m) thick.

Recent alluvium (Qal_1) – Recent alluvium has been shown separately from colluvium only along the courses of major streams: the Santa Clara River, Pahcoon Spring Wash, Wittwer Canyon, and the unnamed stream that U.S. Highway 91 follows in the south-central part of the quadrangle. Santa Clara River gravels have the greatest heterogeneity of clast composition and include a large proportion of igneous rock clasts from the Gunlock Basalt and earlier Tertiary igneous rocks exposed upstream in the Bull Valley and Pine Valley Mountains. Igneous clasts are sparse to absent along other major stream courses in the map area. Mostly locally derived clasts are represented. Thickness of gravel deposits is locally more than 20 feet (6 m) as shown in the abandoned gravel pits along U.S. Highway 91 in section 7, T. 42 S., R. 17 W.

Alluvium and colluvium, undivided (Qac) – Alluvial deposits of minor alluvial fans merge with colluvial (slope wash) materials in the valley bottoms and sideslopes of most minor drainages in the map area. The deposits consist of soils and angular or subangular rock fragments, and are commonly poorly sorted and unstratified. They range in thickness from 0 to 25 feet (0-8 m).

Mass-Movement Deposits

Older colluvium (QTmc) – These deposits are restricted to the northeast flank of the ridge of Permian and Triassic formations that intersects the northwest corner of the quadrangle. The deposits are mostly made up of gravel-size chert fragments which have weathered from the Harrisburg Member of the Kaibab Formation. The chert fragments are embedded in a caliche-rich soil. This older colluvium has been preserved because this part of the strike ridge lies on a drainage divide where erosion is minimized. Thickness of the deposit is probably less than 30 feet (9 m).

Older slump and landslide deposits (QTms) – The map area contains several masses of semicoherent rocks that have slumped or slid from adjacent outcrops. Most are associated either with gypsum beds in the Harrisburg Member of the Kaibab Formation or with bentonitic clay beds in the Chinle Formation. All of the large examples occur on the west limb of the Shivwits syncline. Harrisburg-related slumps are prominently exposed at the watergap where U.S. Highway 91 cuts across steeply tilted Permian rocks. A similar mass is present in the same stratigraphic position near the north edge of the quadrangle adjacent to the Pahcoon Flat road. Two large, displaced masses of Shinarump Conglomerate and/or basal Petrified Forest sandstone beds are present on the west limb of the syncline in the central part of the quadrangle; much smaller slumped blocks of Shinarump are found on the east limb of the syncline near the Santa Clara River. In the center of the quadrangle at its south edge a large mass of Queantoweap Sandstone has become detached and moved downslope, apparently having been undercut by the river.

Although we have no sure way of determining when these mass movements occurred, we believe that their position relative to other surficial deposits suggests that some may be about the same age as the high-level alluvial gravel (QTag).

Colluvium (Qmc) – Colluvium consists of slope-wash deposits of angular and subangular debris of widely variable clast size. Although colluvial and alluvial deposits together are shown as Qac, the map unit Qmc is used for colluvium on sidehills away from stream channels where these deposits have undergone little transport, and that mainly by downhill creep. These deposits are generally less than 20 feet (6 m) thick.

Talus (Qmt) – Talus consists of rock-fall debris and is shown on the map only where that debris has accumulated to such a degree that it completely conceals the underlying bedrock. In this quadrangle it is located chiefly below the west side of the Gunlock Basalt, where the talus is composed of large basalt blocks, and on the east side of the Reef Reservoir fault where the talus is derived from the Fossil Mountain Member of the Kaibab Formation. Thickness of accumulation may be as much as 20 feet (6 m) locally.

Slumped masses (Qms) – Slumped masses are present northeast of the Santa Clara River along the east side of the quadrangle where the Gunlock Basalt is underlain by the Petrified Forest Member of the Chinle Formation. Bentonitic clay contained in the Triassic beds has promoted slumping, producing hummocky topography on both sides of the basalt caprock. Limited exposures of this unit in roadcuts show disturbed bedding.

Eolian Deposits

Sand deposits (Qe) – Areas of sand deposition are closely associated with outcrops of Navajo Sandstone, which readily breaks down to loose sand. The sand is pink, fine-grained, uncemented, and ordinarily not well organized into dunes. Thickness ranges up to 30 feet locally.

Sand dunes (Qed) – Some sand has formed crude longitudinal dunes. Thickness of dune sand may be as much as 50 feet (15 m).

Mixed eolian and alluvial deposits (Qea) –Santa Clara Bench, an alluvial apron, is largely covered with pink sand derived from the Kayenta and Navajo formations in the Red Mountains. But these sand deposits also include rounded sandstone pebbles and cobbles washed down and across the bench. The proportion of alluvial clasts increases rapidly in the direction of the Red Mountains source area. Thickness of the mixed eolian and alluvial deposits on the Santa Clara Bench ranges from zero where resistant bedrock protrudes through the deposits to an estimated 40 feet (12 m) where underlain by the easily erodible Petrified Forest Member.

Mixed eolian and colluvial deposits (Qec) – Along the west base of the Red Mountains angular colluvial materials are intermixed with wind-blown sand. Thickness of this deposit may be as much as 30 feet (9 m).

Caliche soil deposits (Qca) – Caliche soil, as much as 3 feet (1 m) thick locally, has accumulated on the top of the Gunlock Basalt. The caliche is light gray, irregularly laminated, and breaks up into irregular tabular fragments. Light tones of the caliche show up prominently on aerial photographs in contrast to the darker tones of the basalt. The material within which the caliche soil horizon developed consists mostly of eolian dust. This has been leached, by weathering and soil-forming processes, to form the secondary carbonate-cemented material that constitutes the caliche.

Because caliche forms slowly, its thickness gives a crude indication of how long it has taken to develop (Machette, 1985). The thickness of the caliche soil on top of the Gunlock Basalt is consistent with the amount of time that has passed since deposition of the basalt.

STRUCTURE

Regional Setting

The Shivwits quadrangle lies on the boundary between the Basin and Range and the Colorado Plateau physiographic provinces. The Grand Wash fault, shown on figures 6 and 7, traditionally marks the west edge of the Colorado Plateau south of the quadrangle. The Gunlock fault marks the boundary within the quadrangle. East of the Gunlock fault, the Red Mountains, a block of gently tilted strata, are typical of Colorado Plateau geology. West of the Gunlock fault, the folding and faulting of the Beaver Dam Mountains are transitional between typical basin-and-range structures, found west of the Virgin-Beaver Dam Mountains fault (VDBMF on figure 6), and Colorado Plateau features east of the Gunlock and Grand Wash faults.

Geologic structures in this area were formed mostly during two widely separated times by two different kinds of forces. The earlier folds and faults in the region were formed by southeasterly directed horizontal compression during Late Cretaceous and Paleocene time between 70 to 60 million years ago. A 40-million-year interval followed during which no major deformation occurred in this area. Less than 20 million years ago the broad area that is now the Basin and Range Province began to be uplifted and stretched in an east-west direction, producing north-south normal faults and other extensional features. Extension was most active between about 15 and 5 million years ago, at which point the intensity of uplift and extension began to taper off, continuing less actively to today (Lucchita, 1990).

Some geologists, for example, Wernicke and others (1988), infer that attenuation of strata occurs solely with regional extension. And while it is true that attenuation does represent stretching out or smearing out of beds, the phenomenon can be produced either along an extensional low-angle normal fault, or along a compressional thrust fault. Attenuation, by itself, does not identify the regional motivating force as either extensional or compressional; it shows only that structural sheets have moved past one another, smearing and stretching rocks between the overriding and underlying plates. Other structural clues must be used to differentiate regional extension and compression.

Structures believed to have formed during the earlier compressional period are described first, followed by discussion of the later extensional structures.

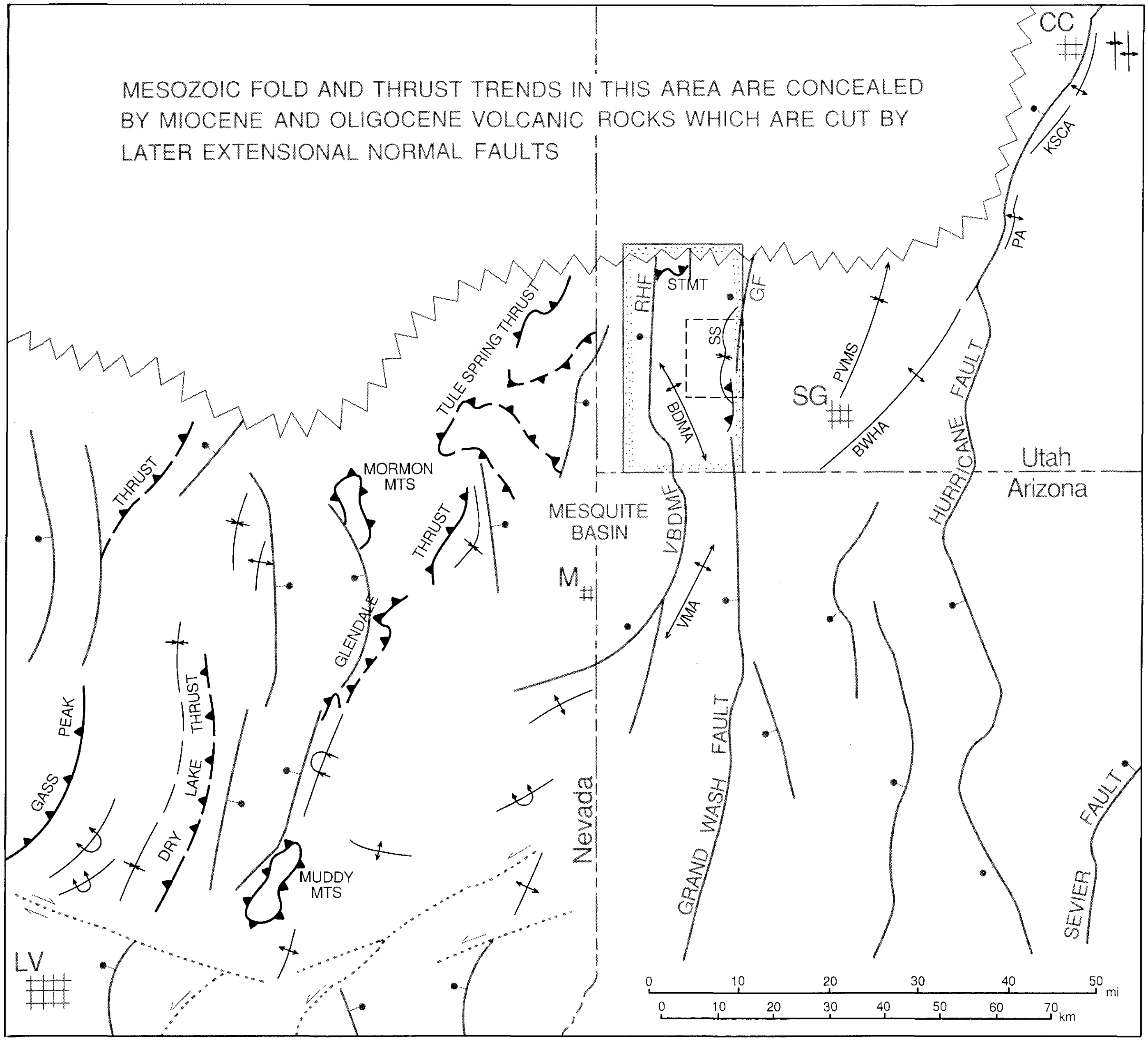

Figure 6. *Selected structural features in the area between Cedar City, Utah and Las Vegas, Nevada. Mesozoic folds and thrusts are shown in black, late Cenozoic normal and strike-slip faults are in gray. Stippled box shows area of six 7.5-minute quadrangles that cover the Beaver Dam Mountains. The Shivwits quadrangle is outlined by black dashed line. Town names are: LV-Las Vegas, M-Mesquite, SG-St. George, CC-Cedar City. Abbrevations for structural features: VMA-Virgin Mountains anticline, VBDMF-Virgin-Beaver Dam Mountains fault, BDMA-Beaver Dam Mountains anticline, RHF-Red Hollow fault, STMT-Square To Mountain thrust, SS-Shivwits syncline, GF-Gunlock fault, PVMS-Pine Valley Mountains syncline, BWHA-Bloomington-Washington-Harrisburg anticline (sometimes called Virgin anticline), PA-Pintura anticline, KSCA-Kanarraville-Shurtz Creek-Cedar City anticline. Structural features in Nevada are from Stewart (1980).*

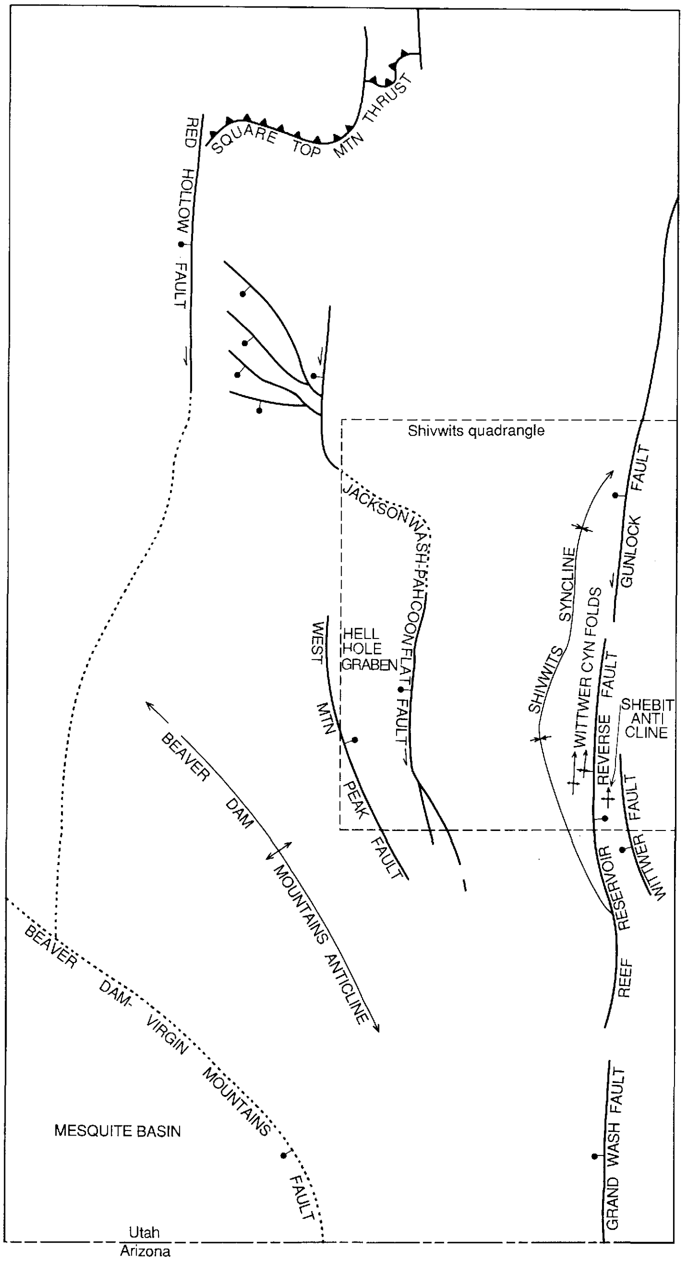

Figure 7. *Beaver Dam Mountains area shown on figure 6, enlarged to show names of features mentioned in this paper. Area of Shivwits quadrangle shown by dashed line. Area of this map is outlined on figure 6.*

Late Cretaceous-Paleocene Compressional Structures

The western United States was subjected to compression from the west and northwest beginning in Early Cretaceous time when mountains formed during the Sevier orogeny (Armstrong, 1968; Hintze, 1988) arose in eastern Nevada and northwestern Utah. Streams draining the east side of the Sevier orogenic belt deposited great amounts of sediment in the Cretaceous foreland basin, which extended from Utah's southwestern corner to the northeast. The Cretaceous Iron Springs Formation exposed in the Gunlock quadrangle directly north of the Shivwitts quadrangle (Hintze, 1986) is a Sevier orogenic deposit. Early Sevier structural deformation all lay to the west in eastern Nevada and western Utah. As time went on, deformation moved progressively eastward and culminated in the faults, monoclinal folds, and anticlinal uplifts of the Laramide orogeny that characterize the Colorado Plateau and Rocky Mountains (Hintze, 1988). The Beaver Dam Mountains anticline, the Shivwits syncline, the Wittwer Canyon folds, and the Shebit anticline, discussed below, are believed by us to have formed during the Laramide orogeny in latest Cretaceous and Paleocene time. In addition, the Reef Reservoir reverse fault, and the folds and faults in Devonian and Mississippian rocks in the Hell Hole Basin area at the south edge of the map area, are probably of Laramide age. This quadrangle does not include the Cretaceous and Tertiary strata that date the time of compression. These strata are exposed in the Motoqua and Gunlock quadrangles just north of this quadrangle and are described by Hintze (1986).

Beaver Dam Mountains Anticline

Paleozoic strata in the southwest part of the quadrangle lie on the northeast flank of the large Beaver Dam Mountains anticline as shown on the regional map (figure 6) by Hintze (1986). That part of the anticlinal flank that lies west of the Jackson Wash-Pahcoon Flat fault has been downdropped and moved to the south and west along that fault during Cenozoic extension.

Smith and others (1987) and Wernicke and Axen (1988) interpreted the Beaver Dam Mountains anticline as part of a broad arcuate zone of uplift resulting from isostatic adjustment to late Tertiary denudation. This interpretation was challenged vigorously by Carpenter and others (1989) on the basis of seismic-reflection data and a cross section extending westward from the Beaver Dam Mountains to the Tule Spring Hills. We reject the isostatic uplift explanation for the Beaver Dam Mountains anticline on the basis of the lack of other examples of anticlines being formed in the Great Basin along major normal faults and their associated uplifts.

Shivwits Syncline

This is the largest structural feature in the quadrangle (figure 8). It plunges northward at about 10 degrees, which is about the same as the plunge of the much broader Pine Valley Mountains syncline to the east (see figure 6). The angle of dip is similar on its two flanks in the south half of the quadrangle where a comparison can be made. The most puzzling aspect of the fold is that its axial trace appears to veer eastward into the Gunlock fault, but does not reappear east of the fault anywhere that can be observed. We interpret the Gunlock fault to be an oblique-slip fault, left-lateral and down to the west. It is possible that the axial trace of the syncline is present east of the Gunlock fault and north of this quadrangle. Inspection of the geologic map of Washington County (Cook, 1960) shows that Cenozoic basalt flows cover the area where the syncline might be present. The eastern limb of the Shivwits syncline is also cut by the Reef

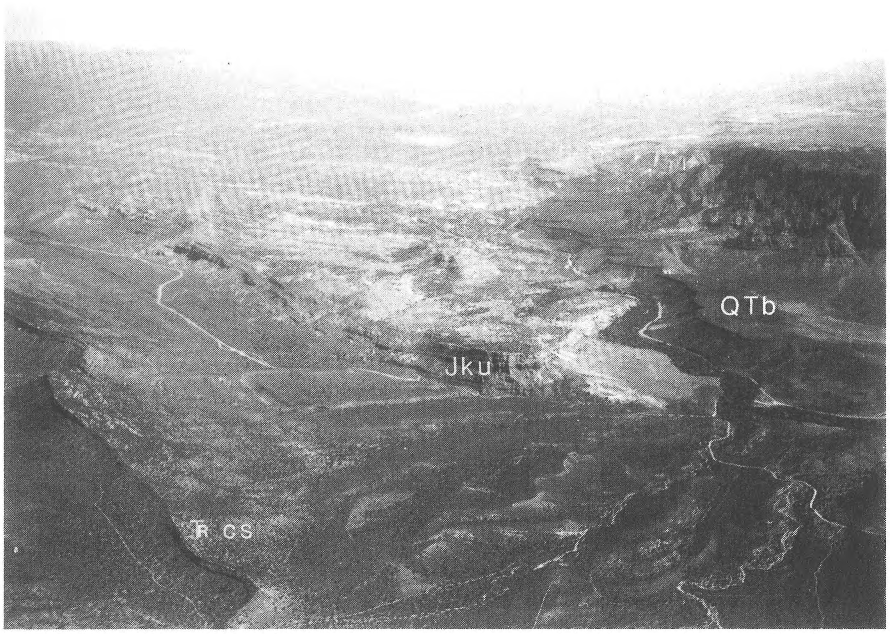

Figure 8. *Aerial view looking northward along the axis of the Shivwits syncline. The prominent cliff in the center of the photo is formed by the upper member of the Kayenta Formation (Jku). The Gunlock Basalt (QTb) largely conceals the Gunlock fault. In the 1.6 million years since the basalt flowed down the Santa Clara paleovalley, the river has shifted to the west and cut its valley more than 300 feet (90 m) lower into the Mesozoic bedrock units. The Shinarump Member of the Chinle Formation (TRcs) makes the sinuous hogback on the left side of the photo.*

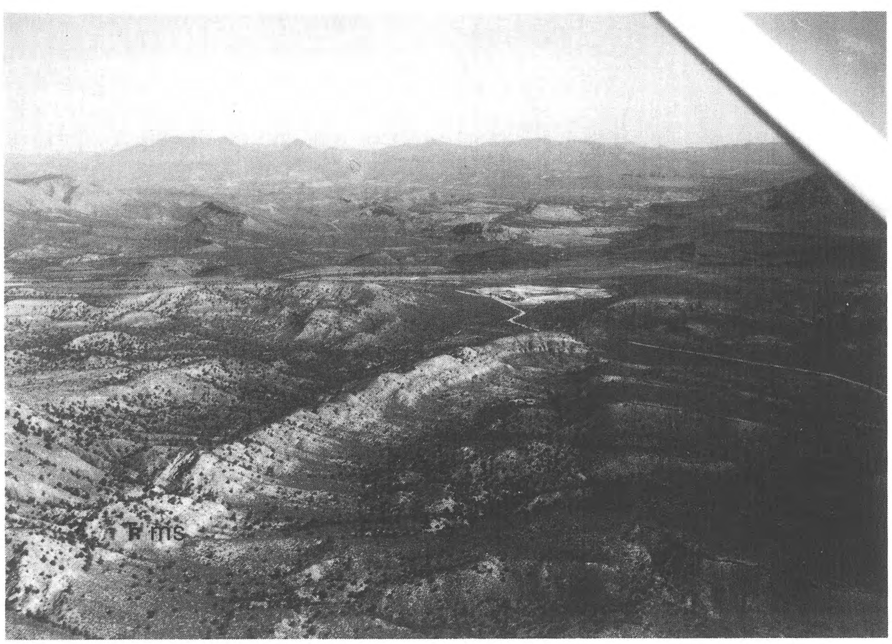

Figure 9. *Aerial view looking northward along the Wittwer fault. Lightest patch to the right of the road near the photo center is the Apex Mill site. Light-colored ridge that runs from the lower left corner of the photo toward the photo center is the Shnabkaib Member of the Moenkopi Formation (TRms), exposed on the west side of the faulted Shebit anticline.*

Reservoir reverse fault. The axis of the syncline is cut at a 45 degree angle by the Reef Reservoir fault about a mile (1.6 km) south of this quadrangle in the Jarvis Peak quadrangle (Hammond, 1991). These relations suggest that the Shivwits syncline is a compressive structure that existed before its displacement by the Gunlock and Reef Reservoir faults.

Wittwer Canyon Folds

In the southeast part of the quadrangle, directly west of the Reef Reservoir fault, a small, tight, north-plunging anticline and adjacent syncline extend from Wittwer Canyon northward for about 2 miles (3 km) to the Apex Mill area. Hammond (1988) measured 25 slickenlines on small fault surfaces near a short, southeastward-striking tear fault (her locality 7) that terminates at the Reef Reservoir fault. She found the fault dips to be moderately steep to vertical, and the rakes at moderate to low angles; movement was dominantly strike-slip. We believe that the geometry of these structures suggests that the Wittwer Canyon folds and the small strike-slip faults have a common origin as Late Cretaceous-Paleocene compressional structures.

Shebit Anticline

This fold parallels the Wittwer Canyon folds to the east on the east side of the Reef Reservoir fault, and is similar in shape and length to the Wittwer Canyon anticline. The east flank of the Shebit anticline is cut by the Wittwer fault (Hammond, 1988) along its entire length, and structure east of the fault does not match that on the west side (figure 9). We regard it as likely that the Wittwer fault is an oblique-slip, left-lateral fault and that the Shebit anticline has been displaced southward at least half a mile (0.8 km) along the fault. We interpret the Shebit anticline, like the Wittwer Canyon folds and the Shivwits syncline, to have initially been formed as a Late Cretaceous-Paleocene compressive structure.

Reef Reservoir Fault

This fault extends for more than 10 miles (16 km) along the east side of the Shivwits and Jarvis Peak quadrangles. It was mapped in detail by Hammond (1988, 1991) who concluded that the Reef Reservoir fault probably formed as a reverse fault in response to compressional stress, but has been reactivated during late Cenozoic time. The fault plane is exposed only in one location near Wittwer Canyon, where beds of the Shnabkaib and middle red members of the Moenkopi Formation are juxtaposed against the Chinle Formation. Down-to-the-east stratigraphic offset is about 1,400 feet (425 m), and the fault dips steeply westward. Apparent displacement decreases abruptly to the north.

Hell Hole Basin Folds and Faults

Mississippian and Devonian rocks in Hell Hole Basin, in the southwest part of the quadrangle and the northwest part of the Jarvis Peak quadrangle, are tectonically juxtaposed along the south end of the Jackson Wash-Pahcoon Flat fault. Hammond (1991) noted that in this area the Devonian Muddy Peak Formation has been overturned and moved eastward over the Mississippian Redwall Limestone. Also, the Redwall Limestone has been moved over itself in this area. At its north end, the Jackson Wash-Pahcoon Flat fault appears to be a low-angle, down-to-the-west, normal fault that probably has left-lateral oblique slip. The block west of the fault has moved down and to the south. In the southern part of the quadrangle the dip of the fault steepens as it approaches the area where apparent thrusts and folds occur. We interpret the faults and folds to be Late Cretaceous-Paleocene compressive structures that have been cut by the extensional Jackson Wash-Pahcoon Flat fault during late Cenozoic time.

Late Cenozoic Extensional Structures

Age of Faulting

Regional studies show that widespread uplift and extensional spreading affected the western United States beginning about 15 million years ago (Stewart, 1978; Hintze, 1988). Interpretation of the geology in this quadrangle adds nothing new to this generalization. The only Cenozoic rock that bears on the age of Cenozoic normal faulting is the Gunlock Basalt, dated at 1.6 million years. The basalt covers the Gunlock fault, showing that almost all of the displacement on the fault occurred before 1.6 million years. Since that time, a small amount of movement on the fault has cut the basalt, displacing the east side relatively upwards about 20 feet (6 m). The fault scarp on the basalt has been modified by erosion to a gentle slope, suggesting that the latest movement on the Gunlock fault occurred many thousands of years ago. Anderson and Christenson (1989) estimated that the last movement on the Gunlock fault was early to middle Pleistocene.

Left-lateral Oblique Slip on Extensional Faults

Map relationships of faulted folds in the quadrangle are more readily explained if, in addition to the predominantly down-to-the-west normal fault movement, a left-lateral oblique slip component is added. Hammond (1988) measured more than 300 slickenside orientations along the Grand Wash-Reef Reservoir-Gunlock fault zone and concluded that the slickensides indicate oblique movement along the larger faults that she studied. Left-lateral movement on faults has been observed by Anderson and Barnhard (1992) in central Utah, in the same area where Arabasz and Julander (1986) have described earthquake movements having a strike-slip component. Anderson and Christenson (1989) reported left-lateral oblique slip on the Sevier fault in south-central Utah.

The amount of left-lateral offset on extensional faults appears to be greater than the vertical movement and may amount to more than 2 miles (3.2 km) along the Gunlock and Jackson Wash-Pahcoon Flat faults, based on comparison of comparable features across the fault zone.

Gunlock Fault

The Gunlock fault extends from a mile (1.6 km) west of the old Shivwits townsite, northward for 10 miles (16 km), to 2 miles (3 km) north of the town of Gunlock. Its maximum down-to-the-west stratigraphic offset is near the north end in the Gunlock quadrangle, where moderately dipping Cretaceous strata on the west limb of the Shivwits syncline are juxtaposed against gently dipping Jurassic Navajo Sandstone. Stratigraphic offset diminishes to zero at the south end of the fault. If, as we suspect, the Gunlock fault shares Cenozoic left-lateral movement with the Reef Reservoir fault, the apparent normal-sense stratigraphic offset is more a reflection of the displacement of Late Cretaceous-Paleocene fold structures than it is a measure of vertical displacement along a normal fault. As noted above under the "Age of Faulting" section, the Gunlock fault has not broken the surface for many thousand years.

Wittwer Fault

This fault has only a few hundred feet (100 m) of stratigraphic displacement, but it juxtaposes the north-plunging, considerably faulted Shebit anticline against virtually unfaulted rocks to the east (figure 8). We suggest that the Shebit anticline is a Late Cretaceous-Paleocene compressive structure that has been offset by down-to-the-west, left-lateral displacement on the Wittwer fault in late Cenozoic time. Lateral offset is estimated at about 0.5 mile (0.8 km). The relatively soft, poorly consolidated rocks of the Moenkopi Formation, which the fault cuts, are not conducive to preservation of slickenlines. Hence, no studies of direction of movement along the fault have been made.

Reef Reservoir Fault

This fault lies about 0.5 mile (0.8 km) west of the Wittwer fault which it parallels, forming a graben. Hammond (1991) concluded that the Reef Reservoir fault probably formed initially as a reverse fault in response to compressional stresses, but was reactivated during the late Cenozoic. Hammond (1988) measured 140 slickenside orientations along small fault surfaces along the length of the Reef Reservoir fault in the Jarvis Peak quadrangle, and found that rake values varied considerably, but most are less than 45 degrees, indicating strike-slip movement. The Reef Reservoir fault aligns with the Gunlock fault. We suggest that both of these faults share an important component of late Cenozoic, left-lateral, strike-slip movement that has offset earlier-formed folds and faults.

Jackson Wash-Pahcoon Flat Fault

This important fault cuts the west limb of the Shivwits syncline, which it appears to downdrop to the west and displace to the south. We interpret the fault as a late Cenozoic extensional structure with a large component of left-lateral displacement. In section 27, just south of Pahcoon Flat, the fault dips 35 degrees westward. Two miles (3 km) south it dips 45 degrees westward; farther south it becomes steeper. The Cenozoic movement may be reactivation on a thrust fault that formed during Late Cretaceous to Paleocene eastward compression. Northeast of Pahcoon Flat, the Permian strata in the footwall are overturned westward and the amount of overturning increases towards the fault trace. The overturning is related to the development of an asymmetrical anticline during the compression. This anticline was cut by the thrust fault penecontemporaneously with folding. Near the south edge of the map area the fault also cuts fold and fault structures which formed during the Late Cretaceous to Paleocene period of compression.

Cambrian dolomites in the Hell Hole Basin area are pervasively brecciated and attenuated. We suggest that this is the brittle response of the dolomite to both the earlier compressional folding and faulting and to the later extensional displacement.

Hell Hole Graben

Paleozoic strata west of the Jackson Wash-Pahcoon Flat fault are cut by several down-to-the-northeast normal faults, the largest of which lies just east of Hell Hole Pass. Taken together with the Jackson Wash-Pahcoon Flat fault, this largest fault defines a graben. Displacement on these faults is small compared to that on the Jackson Wash-Pahcoon Flat fault to which they may be antithetic.

Clastic Dikes

Clastic dikes are associated with movement along the Gunlock and Wittwer faults. Six clastic dikes were mapped in the quadrangle by Hammond (1988). Five of these dikes are located near Camp Spring along the Gunlock fault and one is located approximately 1 mile (1.6 km) south of the Apex Mill along the Wittwer fault. An additional dike is located near the Gunlock fault on the line between sections 16 and 17, T. 41 S., R. 17 W. The clastic dikes are interpreted as having been injected up along the fault planes concurrent with faulting.

The dikes trend from N. 6° E. to N. 60° W. and are vertical to steeply dipping. The dikes intrude mudstone units of the Virgin Limestone, upper red, and middle red members of the Moenkopi Formation and the upper member of the Kayenta Formation. They are more resistant than the country rock and usually form small ridges. The host rock walls are sharp at the dike contact and pieces of country rock are included within the dike.

The dikes are composed of a fine-grained, moderately sorted quartz sandstone which ranges from very-pale-orange to grayish-orange to dark-yellowish-orange. The orange stain is due to the presence of iron oxides, which locally form networks of intersecting veinlets. The sandstone is well cemented with silica and iron oxide in varying proportions. The grains are 99 percent quartz, equant, frosted, and subrounded to rounded.

The source for the material in the dikes mapped by Hammond (1988) is probably the Permian Queantoweap Sandstone. It is suggested that movement along the Gunlock and Wittwer faults opened fissures along the faults, which were quickly intruded, and perhaps enlarged, by fluidized clastic material. Fluids could have been trapped under the impermeable gypsum and shale units of the Kaibab and Toroweap Formations creating abnormally high water pressures in, and dilation of, the Queantoweap Sandstone. Fissuring may have released the pressure and injected liquefied sand into the Triassic strata above. It is also possible that a pressure pulse associated with an earthquake caused the dilation and subsequent injection.

ECONOMIC GEOLOGY

Nonmetals

The largest economic mineral product produced from the quadrangle has been sand and gravel from a pit in stream alluvium adjacent to U.S. Highway 91 in section 7, T. 42 S., R. 17 W. Operations at the pit ceased a few years ago when the readily available alluvial gravels were depleted and alternative sources were located closer to St. George.

A small amount of "wonderstone," an ornamental sandstone of interest to rock collectors, was mined from a small quarry in the Shinarump Member of the Chinle Formation by Mr. Milton Holt of Gunlock, Utah. His quarry is located in section 13, T. 41 S., R. 18 W.; access to the quarry is limited to foot travel. Petrified wood occurs in the Chinle Formation throughout the quadrangle, but none of it is of rock-polishing quality.

Gypsum claims have been staked in the Woods Ranch Member of the Toroweap Formation in section 11, T. 41 S., R. 18 W., just south of the graded dirt road to Pahcoon Flat. The claims have not been developed. Gypsum also occurs in the Shnabkaib Member of the Moenkopi Formation, but it is generally interbedded with red silt and clay. Dune sand is widespread in the northeast part of the quadrangle, but many sources of dune sand are also available closer to the probable market in St. George.

Metals

Metal exploration in the quadrangle has been concentrated in Paleozoic rocks in the Beaver Dam Mountains, mostly near the Jackson Wash-Pahcoon Flat fault. Principal activity has been in section 3, T. 42 S., R. 18 W. where access roads and small pits and a 600-foot adit are present. An exploratory hole was drilled here in 1988 by Gage Minerals Corporation, but no further development has occurred. Similar exploration has gone on in section 34, T. 41 S., R. 18 W. A small prospect occurs northeast of Camp Spring in section 29, T. 41 S., R. 17 W. The impetus appears to be faint traces of secondary copper minerals, principally malachite and iron oxides that may contain gallium and germanium.

Although preliminary regional assessment of mineral resources in the Cedar City 1° x 2° quadrangle (Eppinger and others, 1990), which includes the Shivwits quadrangle, did not mention any mineral occurrences within the Shivwits quadrangle, the area may have exploration potential. The Apex Mill (figure 10), in this quadrangle, processes ore from the Apex gallium-germanium mine located in the adjacent Jarvis Peak quadrangle (Hammond, 1991). The mine and mill are not operating currently (1993), awaiting higher metal prices.

Because it served as the host rock for mineralization in the Silver Reef mining district near Leeds, the Springdale Sandstone Member of the Moenave Formation may have potential for exploration. It is well exposed in the quadrangle along both flanks of the Shivwits syncline. Because the Silver Reef-type mineralization is related to the abundance of fossil plant debris in the sandstone, Kackstaetter (1990) evaluated the amount of plant material and thus the silver potential of surface exposures of the Springdale Sandstone in this quadrangle and found that there was insufficient plant material in the sandstone to form significant mineralization at the surface here. We are not aware of any drilling program that evaluated the subsurface potential in the quadrangle.

Oil and Gas

There is no record of oil or gas exploration in the quadrangle. The nearest exploratory wells are in the St. George basin to the east, and the Mesquite basin to the west. Many of the formations in the map area have adequate porosity to be good reservoir rocks, but good oil source rocks are scarce in the rock sequence here, and the structures and sedimentary facies relationships are not favorable for oil and gas accumulation.

WATER RESOURCES

The quadrangle is uninhabited at present, and consumptive use of water within the quadrangle is limited to irrigation of 53 acres of river bench land near the abandoned Indian settlement of Shivwits (Utah Division of Water Resources, 1983), well-water used at the Apex Mill, and cattle and wildlife watering at two small springs and along the Santa Clara River. Most of the ground water produced within the quadrangle is piped to St. George (see section on ground water). Therefore, the water resources of the quadrangle are of great interest because of the rapid population growth in the St. George area (Utah Division of Water Resources, 1990a, 1990b).

Surface Water

The only perennial stream in the quadrangle is the Santa Clara River which heads in the Pine Valley Mountains and joins the Virgin River at St. George. Hydrologic records (Utah Division of Water Resources, 1983) show that, from 1942 to 1979, the mean annual flow of the Santa Clara River at the gaging station in the quadrangle was about 16,500 acre feet (20.36 million m^3). Peak flow generally occurs in April. Mean peak flow in April is 3,680 acre feet (4.54 million m^3); but a maximum peak flow of more than 9,000 acre feet (11.1 million m^3) has been recorded during that month.

Two springs are shown on the Shivwits quadrangle topographic map. Pahcoon Spring near the north edge of the map issues from a small fault that cuts the Moenave and Kayenta Formations. Water from the spring feeds a small animal-watering trough throughout the year, and overflows to nourish a small meadow. Camp Spring, 1.3 miles (2 km) west of old Shivwits townsite, generally flows only in the spring and early summer months. A small earth dam has been built to retain its limited flow which mainly waters phreatophytic plants.

Figure 10. Aerial view looking northwestward at the Apex Mill in June 1991. The ponds hold tailings produced in the mill by rock-leaching operations.

Ground Water

The city of St. George currently obtains more than 40 percent of its culinary water from 6 wells located in the northeast part of the quadrangle (plate 1), just west of the Santa Clara River. These wells, known as the Gunlock wells, are located on federal land managed by the Bureau of Land Management, which has granted St. George City the right to maintain these wells in perpetuity. Water rights for these wells are equal to 12 cubic feet (3.2 m^3) per second, 5,400 gallons (20,520 L) per minute, or 8,733 acre feet (10,777,832 m^3) per year (St. George City Water Department, 1990). The wells pump from the Navajo Sandstone aquifer. Well depths range from 340 to 650 feet (104 to 200 m), and the individual pumping capacity for the six wells ranges from 650 to 1,300 gallons (2,470 to 4,940 L) per minute, averaging 950 gallons (3,610 L) per minute. Clyde (1987) summarized ground-water quality for the Virgin River Basin area and showed that the Gunlock wells have low sodium, magnesium, chloride, and sulfate values, and slightly higher calcium and carbonate-bicarbonate values.

A mill was built in section 5, T. 42 S., R. 17 W., in 1985, for processing gallium-germanium ore from the Apex mine located south of the quadrangle. Three widely spaced wells were drilled on the property to furnish water for the mill operations. The wells are from 300 to 400 feet (92 to 122 m) deep, and the aquifer is a limestone bed in the Moenkopi Formation. One well yields 75 gallons (285 L) per minute, a second well yields 100 gallons (380 L) per minute, and the third well is used principally for water-quality sampling (personal communication, Tanara Harlin, geologist, Hecla Mining Company, July, 1991).

GEOLOGIC HAZARDS

Although no one lives in the Shivwits quadrangle, the roads that traverse it carry much daily traffic between St. George and Gunlock, Motoqua, and Littlefield. The most frequent natural hazard is flooding, not only on the Santa Clara River, but also on intermittent streams draining the east side of Beaver Dam Mountains. Records show that floods are most common in August and December, but may also occur in spring months (Utah Division of Water Resources, 1983). Significant flood damage is likely restricted to roads, rendering them temporarily dangerous or impassable.

Landslides and slumps are common in the Chinle Formation. The process is generally a slow one, not life-endangering, but causing damage to roads or building foundations. Most of the mass-movement features shown on the geologic map probably formed during parts of Quaternary time when the climate was generally wetter than today. Certain Permian and Triassic map units include gypsum beds and expansive clays that make them potentially poor foundations for structures. Persons planning major building projects in the quadrangle should prudently check the foundation materials at their proposed sites.

Earthquakes are a possible but infrequent geologic hazard. The Gunlock fault is the only fault in the quadrangle with evidence of Quaternary movement, and thus must be considered capable of generating surface-faulting earthquakes. However, erosional modification of the scarp that cuts the Gunlock basalt suggests that the last surface faulting occurred many thousands of years ago, perhaps in early to middle Pleistocene time (Anderson and Christenson, 1989). This indicates a low likelihood of surface faulting here in the near future. Based on records of historical seismicity and proximity to several large, potentially active faults, Christenson (1987) and Christenson and others (1987) reported that the St. George area is in a moderately active earthquake zone and Uniform Building Code zone 2 (International Conference of Building Officials, 1988). The largest historical earthquakes in nearby areas were an estimated magnitude 6 event in 1902, near Pine Valley, some 15 miles (24 km) northeast of the Shivwits quadrangle (Arabasz and others, 1979), and a magnitude 5.9 event 5 miles (8 km) southeast of St. George (Black and others, 1992). The principal earthquake hazards in the quadrangle in a moderate to large earthquake include ground shaking, landsliding, and rock fall. Failure of the Gunlock Reservoir, which lies directly north of the quadrangle, in an earthquake may initiate major flooding on the Santa Clara River causing severe damage downstream. Persons planning major structures in the Santa Clara River floodplain should consider this as a long-term possibility.

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Plate 1
Utah Geological Survey Map 153
Geologic Map of the Shivwits Quadrangle

Base map from U.S. Geological Survey Shivwits 7.5′ Quadrangle, 1983

Lori J. Douglas, Cartographer

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

13°39′ E
242.6 mils

1994 Magnetic North Declination at center of sheet

QUADRANGLE LOCATION

GEOLOGIC MAP OF THE SHIVWITS QUADRANGLE, WASHINGTON COUNTY, UTAH

by

Lehi F. Hintze
and
Becky J. Hammond

1994

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DESCRIPTION OF MAP UNITS

Qal₁ Recent alluvium - *Sand and gravel deposits of present streams and floodplains.*

Qat₂ Terrace gravel - *Gravel deposits above present floodplain levels of the Santa Clara River and Pahcoon Springs Wash.*

Qac Alluvium and colluvium, undivided - *Sand and gravel deposits that merge with colluvial materials in the valley bottoms and side slopes of minor drainages. Thickness 0-25 feet (0-8 m).*

Qmc Colluvium - *Angular and subangular debris formed by rock weathering and downslope mass movement on sidehills. Generally less than 20 feet (6 m) thick.*

Qmt Talus - *Rock-fall debris that has mostly accumulated on slopes beneath the Gunlock Basalt and the Shinarump Conglomerate Member of the Chinle Formation. May be 20 feet (6 m) thick locally.*

Qms Slumped masses - *Materials that have crept downslope by gravity mass movement. Almost entirely confined to areas underlain by the Petrified Forest Member of the Chinle Formation. Identity of slumped material is shown on map in parentheses.*

Qe Sand deposits - *Loose wind-blown sand that is derived principally from weathering of the Navajo Sandstone. Thickness ranges up to 30 feet (9 m) locally.*

Qed Sand dunes - *Crude longitudinal dunes in areas of general sand accumulation. Thickness of dune sand may be as much as 50 feet (15 m).*

Qea Mixed eolian and alluvial deposits - *Eolian sand deposits that include rounded clasts of alluvial origin. May be as much as 40 feet (12 m) thick.*

Qec Mixed eolian and colluvial deposits - *Angular colluvial materials intermixed with wind-blown sand along the west base of the Red Mountains. Thickness may range up to 30 feet (9 m).*

Qca Caliche soil deposits - *Light gray, irregularly laminated calcareous deposit that breaks down into rough flaky pieces. At least 3 feet (1 m) thick locally on top of the Gunlock Basalt.*

QTb Gunlock Basalt - *Brownish-black, locally vesicular, olivine basalt. Age is 1.6±0.1 Ma. Thickness ranges up to 30 feet (9 m).*

QTag High-level alluvial gravel - *Includes both river gravel beneath the Gunlock Basalt and other gravel that caps hilltops and sideslopes well above the present stream levels. Deposit is unconsolidated and contains a great range of clast sizes, including large boulders. Clast composition shows that deposits are derived from local and distant bedrock units. Maximum thickness is about 100 feet (30 m).*

QTac Older alluvium and colluvium undivided - *Poorly sorted, angular to subangular debris of local derivation that covers Pahcoon Flat and smaller areas of the flank of the Red Mountains. Locally more than 50 feet (15 m) thick.*

QTmc Older colluvium - *Colluvium of chert fragments derived locally from Permian bedrock units. Deposit is preserved on drainage divide where active erosion is minimized. Deposit is less than 30 feet (9 m) thick.*

QTms Older slump and landslide deposits - *Large, semicoherent masses of bedrock that have slumped or slid from adjacent outcrops. Identity of material that makes up the displaced mass is shown on the map in parentheses.*

Jc Carmel Formation - *Limy shale and thin-bedded limestone, exposed only in a small stream cutbank in the northeast corner of the map area.*

Jn Navajo Sandstone - *Pale-reddish-brown to grayish orange, medium-grained, friable quartz sandstone that is conspicuously cross-bedded and jointed. Thickness is between 2,000 and 2,500 feet (610 and 760 m).*

Jku Upper member of the Kayenta Formation - *Pale-red sandstone with thin interbeds of reddish-brown mudstone and siltstone. This unit forms prominent ledges and cliffs above the less-resistant middle member. The upper member is about 700 feet (215 m) thick.*

Jkm Middle member of the Kayenta Formation - *Interbedded siltstone, sandstone, and shale that ranges from orangish-brown to dark reddish-brown. Unit forms silty slopes on the base of the Red Mountains on the east side of the quadrangle, but increases in sand content and resistance to erosion westward across the quadrangle. About 800 feet (240 m) thick.*

Jkl Lower member of the Kayenta Formation - *Mostly reddish-brown mudstone and siltstone, but includes thin, resistant beds of light-gray, laminated dolomite near its top. Member is 150 to 180 feet (46 to 55 m) thick.*

Jms Springdale Sandstone Member of the Moenave Formation - *Light-brownish-gray, fine- to medium-grained sandstone that forms ledges and small cliffs. Locally includes siltstone interbeds. Thickness ranges from 55 to 180 feet (17 to 55 m) in this quadrangle.*

Jmw Whitmore Point Member of the Moenave Formation - *Recessive gray to reddish-gray siltstone and claystone with a few thin beds of dolomitic limestone that contain algal structures and other fossil fragments. Thickness ranges from 55 to 80 feet (17 to 25 m).*

Jmd Dinosaur Canyon Member of the Moenave Formation - *Dark-reddish-brown siltstone and thin-bedded sandstone that closely resembles the redbeds in the lower and middle members of the Kayenta Formation. Member is 275 feet (85 m) thick.*

Ŧcp Petrified Forest Member of the Chinle Formation - *Varicolored bentonitic mudstone, siltstone, and some sandstone that generally forms slopes and slumped areas. About 650-700 feet (200-215 m) thick.*

Ŧcs Shinarump Conglomerate Member of the Chinle Formation - *Orangish-brown conglomerate, gritstone, and sandstone that forms a resistant, dark-brown ledge or caprock. Chert pebble conglomerate commonly forms the lowest part of the unit, and gritstone and sandstone make up the upper part. Fossil wood is common throughout. Unit ranges greatly in thickness from 60 feet to 255 feet (20 to 78 m).*

Ŧmu Upper red member of the Moenkopi Formation - *Mostly reddish-brown, thin-bedded siltstone and sandstone. Contains minor gypsum. About 500 feet (150 m) thick.*

Ŧms Shnabkaib Member of the Moenkopi Formation - *Mostly light-gray to pale-red gypsiferous mudstone and siltstone with interbeds of thin-bedded, light-gray dolomite and lesser limestone that is unfossiliferous. The member forms ledge and slope topography. Light-gray, dolomitic limestone beds in the middle part to the member form a cuesta throughout the quadrangle. The upper 400 feet (120 m) of the member is about half gypsum that weathers to powdery soil. The member ranges between 800 and 870 feet (240 and 260 m) thick.*

Ŧmm Middle red member of the Moenkopi Formation - *Pale-reddish-brown, thin-bedded siltstone and mudstone with thin interbeds of white to greenish-gray gypsum. Ranges from 300 to 350 feet (90 to 107 m) in thickness, thinning to the northwest.*

Ŧmv Virgin Limestone Member of the Moenkopi Formation - *Mostly recessive, yellowish-brown-weathering, marine mudstone and siltstone, but includes limestone beds that make distinctive sharp ledges of low cliffs at the base, middle, and top of the member. Commonly fossiliferous, bearing brachiopods and five-sided echinoderm fragments. Thickness ranges between 210 and 250 feet (64 and 76 m).*

Ŧml Lower red member of the Moenkopi Formation - *Recessive reddish-brown siltstone and mudstone that commonly includes gypsum beds in the middle of the member. Member was deposited on a hilly paleotopography and pinches out abruptly on the flanks of paleohills. Thickness ranges from 0 to 160 feet (0-50 m),*

Pkh Harrisburg Member of the Kaibab Formation - *Interbedded, laminated gypsum, fossiliferous limestone, gypsiferous siltstone, and thin-bedded dolomite. Pinkish-orange to reddish-brown chert nodules make up 10 to 30 percent of the limestone and dolomite beds in the upper part of the member. During the pre-Triassic erosional interval, the Harrisburg carbonate beds were commonly reduced to a cherty rubble that formed on the paleosurface by erosion and solution collapse of gypsum beds in the lower part of the Harrisburg Member. Map unit ranges between 30 to 310 feet (9 to 95 m) thick.*

Pkf Fossil Mountain Member of the Kaibab Formation - *Abundantly fossiliferous, yellowish-gray, fine- to medium-grained, cherty limestone. Unit forms cliffs that commonly look dark brown to black because of the abundant chert. Thickness ranges from 230 to 260 feet (70 to 80 m).*

Ptw Woods Ranch Member of the Toroweap Formation - *Grayish-orange to yellowish-orange gypsiferous siltstone with thin interbeds of white gypsum and light-gray, fine-grained dolomite. Member is generally recessive. Average thickness is about 260 feet (80 m).*

Ptb Brady Canyon Member of the Toroweap Formation - *Light-gray, fine- to medium-grained, cherty, fossiliferous, massive, cliff-forming limestone. Thickness ranges from 215 to 420 feet (65 to 130 m).*

Pts Seligman Member of the Toroweap Formation - *Gypsiferous siltstone with minor white gypsum and light-olive-gray, fine-grained sandstone. Recessive. Thickness ranges between 70 and 200 feet (20 and 60 m).*

Pq Queantoweap Sandstone - *Light-orange to grayish-pink, fine- to medium-grained, cross bedded sandstone; usually cemented with calcite. Thickness ranges from 1,400 to 1,800 feet (425 to 550 m).*

Pp Pakoon Dolomite - *Light-gray, medium- to thick-bedded, fine-grained dolomite; contains some chert nodules. Gypsum and minor sandstone beds occur in the upper part. Weathers to alternating low ledges and slopes. Ranges between 600 and 800 feet (180 and 240 m) thick.*

₱c Callville Limestone - *Medium-gray limestone, medium to thick bedded, commonly cherty, and cyclically interbedded with orange-weathering, calcareous siltstone or sandstone and light-gray dolomite. Forms ledge-slope topography similar to the Pakoon Dolomite. Thickness about 1,600 feet (490 m).*

Mr Redwall Limestone - *Cliff-forming, massive, medium- to dark-gray limestone that contains a conspicuously cherty zone between 60 and 150 feet (18 and 46 m) above its base. The upper part is a bioclastic limestone. Thickness is about 700 to 800 feet (215 to 250 m).*

Dm Muddy Peak Dolomite - *The lower three-fourths consists of silty, fine-grained, light-olive to pale-yellowish-gray, thin- to medium-bedded, dolomite. The upper fourth includes some quartz sandstone beds and distinctive dark-brownish-gray, coarse-grained dolomite beds. Thickness is 680 feet (210 m).*

Ꞓn Nopah Dolomite - *Fine- to medium-grained, medium- to thick-bedded, light-brownish-gray dolomite. Extensively brecciated in the quadrangle. Thickness in nearby area is 1,380 feet (420 m), but no unfaulted section is present in this quadrangle.*

Ꞓbk Bonanza King Formation - *Medium- to light-brownish-gray, fine- to medium-grained, medium- to thick-bedded dolomite. Many beds are mottled light- to medium-gray. Extensively brecciated. Thickness in nearby area is 2,600 feet (800 m) but no unfaulted section is present in this quadrangle.*

Ꞓba Bright Angel Shale - *Olive-green, micaceous shale, siltstone, sandstone, and quartzite; nonresistant; forms a strike valley. Thickness is 250 feet (76 m).*

Ꞓt Tapeats Quartzite - *Orange to dark-reddish-orange, coarse- to medium-grained quartzite. Includes some gritstone and pebble conglomerate beds. Forms ledges and cliffs. Thickness is 1.300 feet (400 m) in an adjacent quadrangle.*

pꞒ Precambrian gneiss and schist - *Subsurface only. Complex of gneiss, schist, and pegmatite. Dark-gray dioritic gneiss is the most abundant rock type. Pegmatites are common and intrude both the gneiss and the schist.*

MAP SYMBOLS

Contact - Mapped boundary between map units

Fault - Dashed where inferred or approximately located; dotted where covered; ball and bar on downthrown side; dip indicated. Lateral movement indicated by arrows on map, and by **T** (toward) and **A** (away) on cross section

Brittle attenuation in bedding-parallel fault zones - Strata missing or substantially thinned by structural dislocation

Strike and dip of beds - Overturned: tilting has exceeded vertical
Right-side-up: tilting less than vertical

Fold - Trace of axial plane and plunge of axis
Anticline, arrows point in direction of dip and plunge
Syncline, arrows point in direction of dip and plunge

Landslide scarp

Clastic dike

Water well - St. George City water wells indicated by number

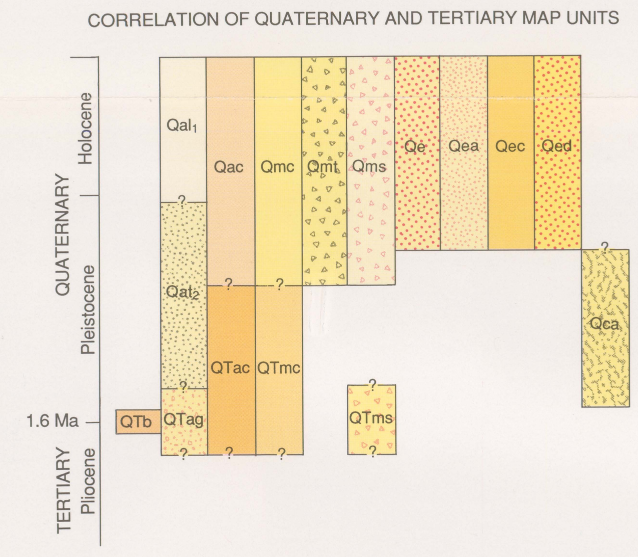
Shaft

Adit

Prospect pit

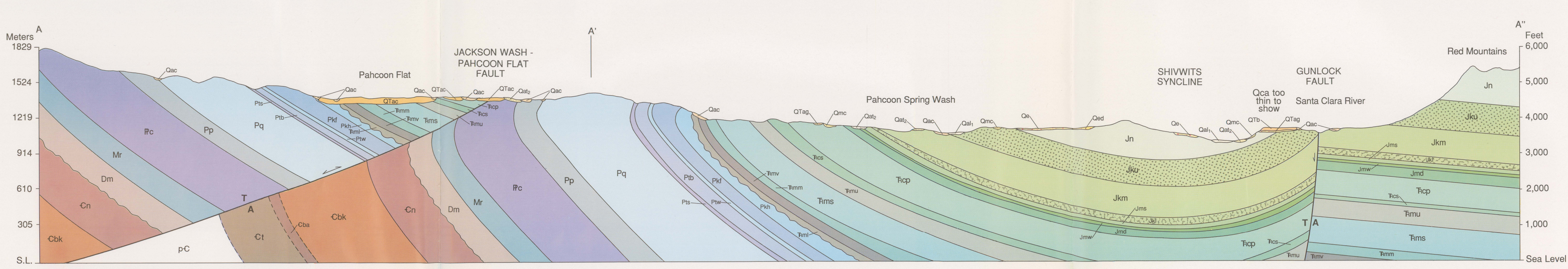
Gravel pit

CORRELATION OF QUATERNARY AND TERTIARY MAP UNITS

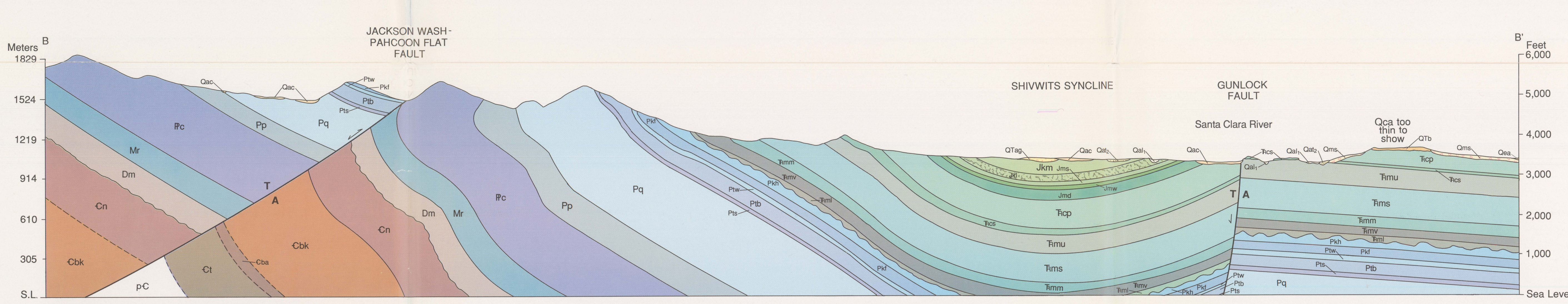


AGE		FORMATION	SYMBOL	THICKNESS (feet)	THICKNESS (meters)	LITHOLOGY
Q - T	Gunlock Basalt		QTb	0-30	0-9	1.6 ma
Q - T	High-level alluvial gravel		QTag	0-100	0-30	UNCONFORMITY
JURASSIC	Carmel Formation		Jc	10+	3+	
JURASSIC	Navajo Sandstone		Jn	2000-2500	610-760	cross-bedded
JURASSIC	Kayenta Formation	Upper member	Jku	700	215	
JURASSIC	Kayenta Formation	Middle member	Jkm	800	240	
JURASSIC	Kayenta Formation	Lower member	Jkl	150-180	46-55	white dolomite beds
JURASSIC	Moenave Formation	Springdale Ss Mbr	Jms	55-180	17-55	
JURASSIC	Moenave Formation	Whitmore Point Mbr	Jmw	55-80	17-25	fossils
JURASSIC	Moenave Formation	Dinosaur Canyon Mbr	Jmd	275	85	
TRIASSIC	Chinle Formation	Petrified Forest Member	Ŧcp	650-700	200-215	slumps
TRIASSIC	Chinle Formation	Shinarump Cg Mbr	Ŧcs	60-255	20-78	
TRIASSIC	Moenkopi Formation	Upper red member	Ŧmu	500	150	
TRIASSIC	Moenkopi Formation	Shnabkaib Member	Ŧms	800-870	240-260	gypsum
TRIASSIC	Moenkopi Formation	Middle red member	Ŧmm	300-350	90-107	
TRIASSIC	Moenkopi Formation	Virgin Member	Ŧmv	210-250	64-76	
TRIASSIC	Moenkopi Formation	Lower red member	Ŧml	0-160	0-50	UNCONFORMITY
PERMIAN	Kaibab Formation	Harrisburg Member	Pkh	30-310	9-95	chert, gypsum
PERMIAN	Kaibab Formation	Fossil Mountain Mbr	Pkf	230-260	70-80	black chert
PERMIAN	Toroweap Formation	Woods Ranch Mbr	Ptw	260 - 870	80 - 260	
PERMIAN	Toroweap Formation	Brady Canyon Mbr	Ptb	215-420	65-130	chert
PERMIAN	Toroweap Formation	Seligman Member	Pts	70-200	20-60	
PERMIAN	Queantoweap Sandstone		Pq	1400-1800	425-550	
PERMIAN	Pakoon Dolomite		Pp	600-800	180-240	
PENNSYLVANIAN	Callville Limestone		₱c	1600	490	
MISS.	Redwall Limestone		Mr	700-800	215-250	chert
DEVON.	Muddy Peak Dolomite		Dm	680	210	UNCONFORMITY
CAMBRIAN	Nopah Dolomite		Ꞓn	1380*	420*	
CAMBRIAN	Bonanza King Formation		Ꞓbk	2600*	800*	banded light and dark gray dolomite
CAMBRIAN	Bright Angel Shale		Ꞓba	250	76	
CAMBRIAN	Tapeats Quartzite		Ꞓt	1300	400	UNCONFORMITY
	Precambrian gneiss & schist		pꞒ	subsurface only		

*attenuated thickness in this quadrangle is less than this.



Strata above the Jackson Wash-Pahcoon Flat fault are locally tectonically attenuated.



Subsurface condition of Precambrian and Cambrian rocks is uncertain. Cambrian strata are locally brecciated and tectonically attenuated.