GEOLOGIC MAP OF THE DIVIDE QUADRANGLE, WASHINGTON COUNTY, UTAH

by

Janice M. Hayden

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through Statemap Agreement No. 98HQAG2067.

ISBN 1-55791-597-0

MAP 197
Utah Geological Survey
a division of
2004 Utah Department of Natural Resources

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ABSTRACT

The Divide quadrangle in southwest Utah is bisected north-south by the Hurricane fault zone. The east half of the quadrangle is part of the Colorado Plateau whereas the west half is part of the transition zone that leads into the Basin and Range Province farther west. In the footwall of the Hurricane fault zone, the Hurricane Cliffs expose just over 1,000 feet (300 m) of Permian rocks, including the upper part of the Queantoweap Sandstone and the Toroweap and Kaibab Formations. The Triassic Moenkopi Formation unconformably overlies paleotopography eroded into the Kaibab Formation and is about 1,700 feet (515 m) thick. The Moenkopi is unconformably overlain by the Chinle Formation, which averages 725 feet (220 m) thick. These two Triassic formations form Little Creek Mountain along the east edge of the quadrangle; they are also partially exposed in Warner Valley in the southwest part of the quadrangle. Slivers of Triassic rocks are also present in the Hurricane fault zone. Jurassic strata exposed in the quadrangle consist of the Moenave Formation, 400 feet (120 m) thick; the Kayenta Formation, 900 feet (270 m) thick; and the basal 1,000 feet (300 m) of the Navajo Sandstone. Normal faults repeat the Moenave Formation several times in Warner Valley. The Kayenta Formation and Navajo Sandstone comprise Sand Mountain in the northwest part of the quadrangle.

Five Quaternary basaltic flows are in the quadrangle. Two flows lie west of the Hurricane fault (Ivans Knoll and Grass Valley), and two flows lie east of the fault (Gould Wash and The Divide). The fifth flow (Remnants) straddles and is offset by the fault. Because of continued erosion, the older flows typically cap ridges and form inverted valleys. Alluvial-terrace deposits and other elevated alluvial surfaces capped by thick pedogenic carbonate also document relative uplift and downcutting in the quadrangle.

Many normal faults are in The Divide quadrangle, but only three have more than a few tens of feet of displacement. The largest is the down-to-the-west Hurricane fault zone, which has about 5,000 feet (1,500 m) of displacement near the south end of the quadrangle. Most of the displacement along the fault zone occurred during Quaternary time. Displacement across the Hurricane fault zone increases northward to at least 6,000 feet (1,800 m) near the north end of the quadrangle. Farther west, the Warner Valley fault also cuts Quaternary deposits, and has about 1,800 feet (545 m) of stratigraphic separation.

Geologic resources in The Divide quadrangle include gravel from alluvial-fan deposits, sand, and stone. Exploration for gypsum, petroleum, uranium, and paleoplacer deposits of precious metals has been undertaken in the quadrangle. Water resources are increasingly important as population growth continues in the area. Geologic hazards in the quadrangle include earthquakes; floods and debris flows; slope failures, including rock falls and landslides; expansive, soluble, and collapsible rock and soil; blowing sand; and radon.

INTRODUCTION

The Divide quadrangle is in south-central Washington County in southwestern Utah (figure 1). This area, nicknamed "Utah's Dixie," is one of the fastest growing areas in the state and many geologic concerns are arising as the population increases. Water supplies are limited. Construction materials, particularly gravel, are in short supply. Expansive, soluble, and collapsible soil and rock which can cause damage to buildings, roads, and other structures are present and need to be recognized by planners and builders. Other potential geologic hazards include earthquakes, blowing sand, flooding, debris flows, slope failures, radon, and volcanic eruptions.

Maximum topographic relief is about 2,930 feet (888 m) from the top of Little Creek Mountain at 5,912 feet (1,792 m) above sea level to the northwest corner of the quadrangle at Sand Hollow Reservoir at about 3,060 feet (933 m). Little Creek Mountain is an extensive mesa that rises above the bench developed on top of the Hurricane Cliffs; the cliffs bisect the quadrangle and create a formidable barrier that trends north-south. Warner Valley and Sand Mountain lie west of the Hurricane Cliffs. The Hurricane fault zone, a major, active, down-to-the-west normal fault, lies at the base of the cliffs.

The Divide quadrangle receives about 8 inches (20 cm) of precipitation annually (Cordova and others, 1972). Natural vegetation includes sparse grasses, sagebrush, creosote bush, and several varieties of cactus and yucca. The Virgin River lowland, which includes the western part of The Divide quadrangle, has the lowest elevation, warmest climate, and the longest growing season in Utah.

Geologic investigations in the region started early, beginning with the Wheeler Survey in 1871 and 1872 (Wheel-

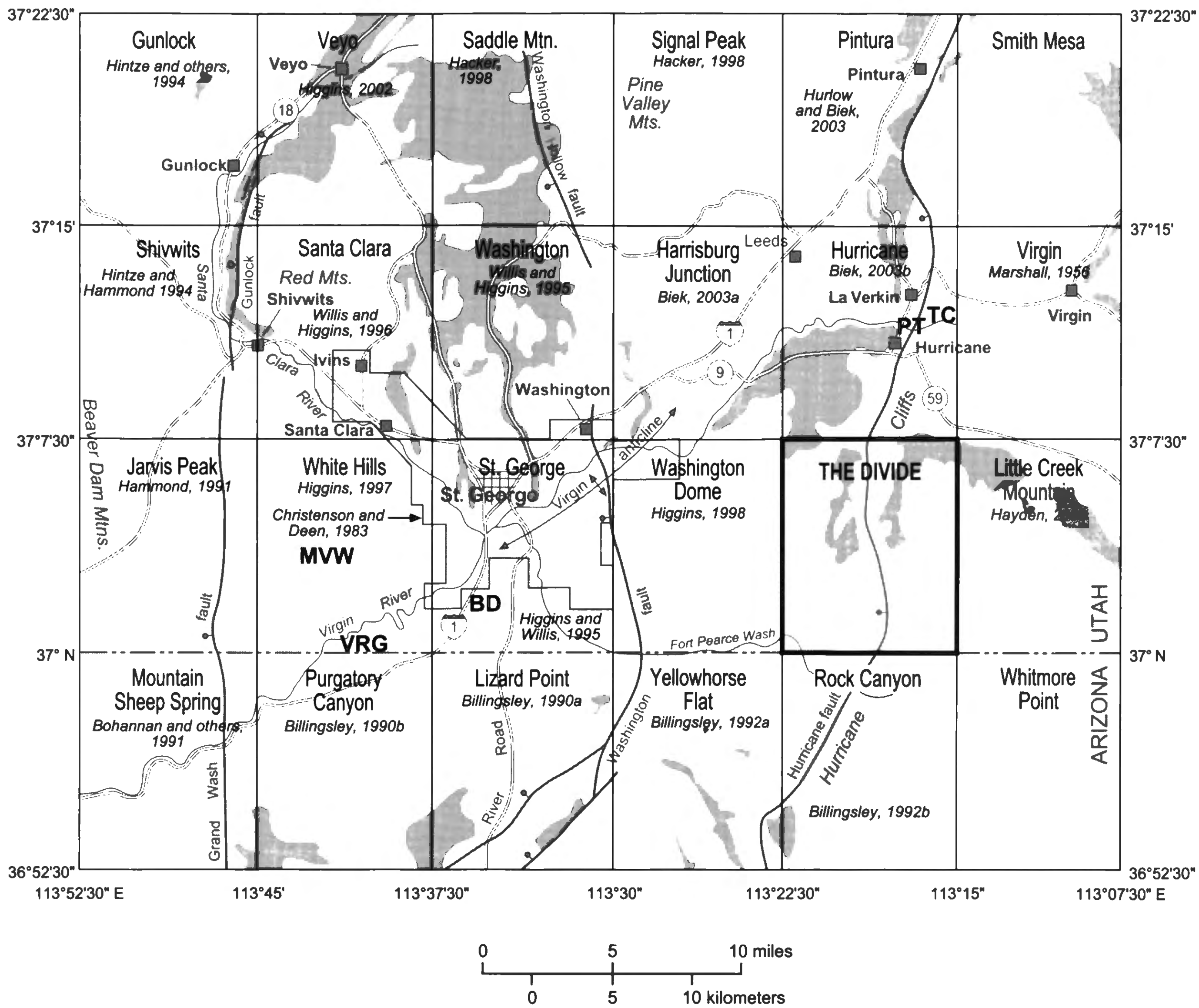


Figure 1. Location of The Divide and surrounding 7.5' quadrangles, and major geographic and geologic features; basalt flows are shaded. MVW = Mountain Valley Wash, VRG = Virgin River Gorge, BD = Bloomington dome, TC = Timpoweap Canyon, and PT = Pah Tempe Hot Springs.

er, 1886). The area was also visited by J.W. Powell in 1873 (Powell, 1875), and by G.K. Gilbert, who worked with the Wheeler Survey. Gregory (1950) gave a thorough history of the early exploration of the region. Dobbin (1939) produced a small-scale geologic map of the greater St. George area that focused on structural geology. Gardner's (1941) report of the Hurricane fault zone in southwestern Utah and northwestern Arizona included a 1:320,000-scale geologic map. Gregory (1950) mapped the Zion Canyon area (1:125,000) and established many of the geologic names in use today in this region. Marshall (1956) made photogeologic maps of the Little Creek Mountain quadrangle to the east and the Virgin quadrangle to the northeast, both at a scale of 1:24,000. Cook (1960) completed a map of Washington County (1:125,000). Eppinger and others (1990) compiled a 1:250,000-scale map of the Cedar City 1°x 2° quadrangle, which includes The Divide quadrangle. Published 1:24,000-scale geologic maps for surrounding quadrangles are shown on figure 1. Many topical studies have addressed the structure, stratigraphy, volcanism, hazards, and economic and water resources of the area.

DESCRIPTION OF MAP UNITS

Over 5,500 feet (1,680 m) of Lower Permian to Middle Jurassic sedimentary strata are exposed in The Divide quadrangle. They were deposited in a variety of shallow-marine, tidal-flat, sabkha, sand-desert, coastal-plain, river, and lake environments reminiscent of the modern Caribbean Sea, Gulf Coast coastal plain, Sahara desert, and coastal Arabian Peninsula, among other places. Hintze (1993), Biek and others (2000), and Higgins (2000) provided popular narrative histories of these units.

The oldest rocks exposed in The Divide quadrangle are the Early Permian Queantoweap Sandstone, Toroweap Formation, and Kaibab Formation. They form the Hurricane Cliffs that trend north-south through the quadrangle (figure 2). East of the cliffs, the Early Triassic Moenkopi Formation and the capping Shinarump Conglomerate Member of the Late Triassic Chinle Formation comprise Little Creek Mountain. With the exception of the Petrified Forest Member of the Chinle Formation, which underlies much of Warner Valley (figure 3), and a pod-shaped horst of Triassic rocks in east Warner Valley, all exposed sedimentary rocks west of the Hurricane Cliffs are Jurassic in age. This includes the Early Jurassic Moenave Formation, which is repeated several times by faulting in Warner Valley, and the Kayenta Formation and Navajo Sandstone, which form Sand Mountain.

Sea-level fluctuations influenced deposition of Permian and Mesozoic strata in the region. Vail and others (1977), Mitchum (1977), and Van Wagoner and others (1990) recognized major cycles in the depositional record that are divisible into first-order megasequences through fifth-order parasequences, according to duration and extent of the cycle. Figures 4 and 5 summarize strata in The Divide quadrangle and their relationship to sea-level fluctuations.

Five Quaternary basaltic lava flows or groups of flows cover part of the north half of the quadrangle. The Ivans knoll and Gould Wash flows erupted from cinder cones just north and east of the quadrangle, respectively. The cinder cone associated with the Grass Valley flow and two cinder cones associated with The Divide flow are well preserved within the quadrangle. The Remnants flow, which is contained completely within the quadrangle, no longer has a well-formed cinder cone; however, the cone was probably immediately east of the Hurricane Cliffs between the "Three Brothers," which are the northern three of the five hills capped by this flow (figure 3). Three levels of gravel terraces, two levels of alluvial-fan deposits, and a variety of alluvial, colluvial, eolian, and mass-movement deposits are also present in the quadrangle.

Permian

Permian strata exposed in the quadrangle include the upper portion of the Queantoweap Sandstone, the Toroweap Formation, and the Kaibab Formation. Outcrops of these units are confined to the Hurricane Cliffs, which were created by displacement and differential erosion along the Hurricane fault.

Queantoweap Sandstone (Pq)

In The Divide quadrangle, the Queantoweap Sandstone is a pale-yellow to grayish-pink, calcareous, thick-bedded, fine-grained sandstone that locally forms a steep, ledgy slope at the base of the Hurricane Cliffs. Billingsley (1997) measured a section of 1,020 feet (311 m) in the Hurricane Cliffs, just south of the Utah-Arizona border, that is equivalent to the Queantoweap Sandstone of southwestern Utah, but only the upper 75 feet (23 m) is exposed in The Divide quadrangle. The Queantoweap Sandstone in Utah (Hintze, 1986a, b;

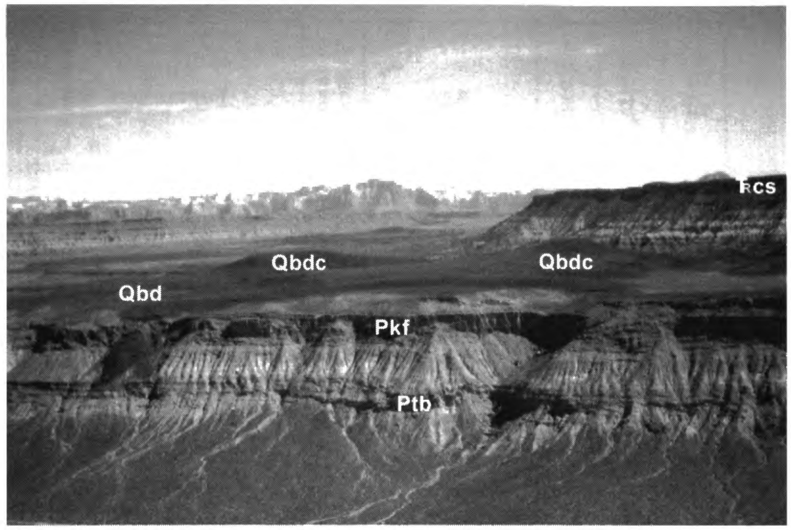


Figure 2. Oblique aerial view northeast to the Hurricane Cliffs, with Zion National Park on the skyline. The lowest prominent cliff is the Brady Canyon Member (Ptb) of the Toroweap Formation; the upper cliff is the Fossil Mountain Member (Pkf) of the Kaibab Formation. Little Creek Mountain, which exposes a complete section of the Moenkopi Formation on the right side of the photograph, is capped by the Shinarump Conglomerate Member (Ћcs) of the Chinle Formation. Both cinder cones (Qbdc) of The Divide flow (Qbd) are visible in the middle of the photo; the flow cascaded over the Hurricane Cliffs and now rests at the top of the Brady Canyon Member of the Toroweap Formation.

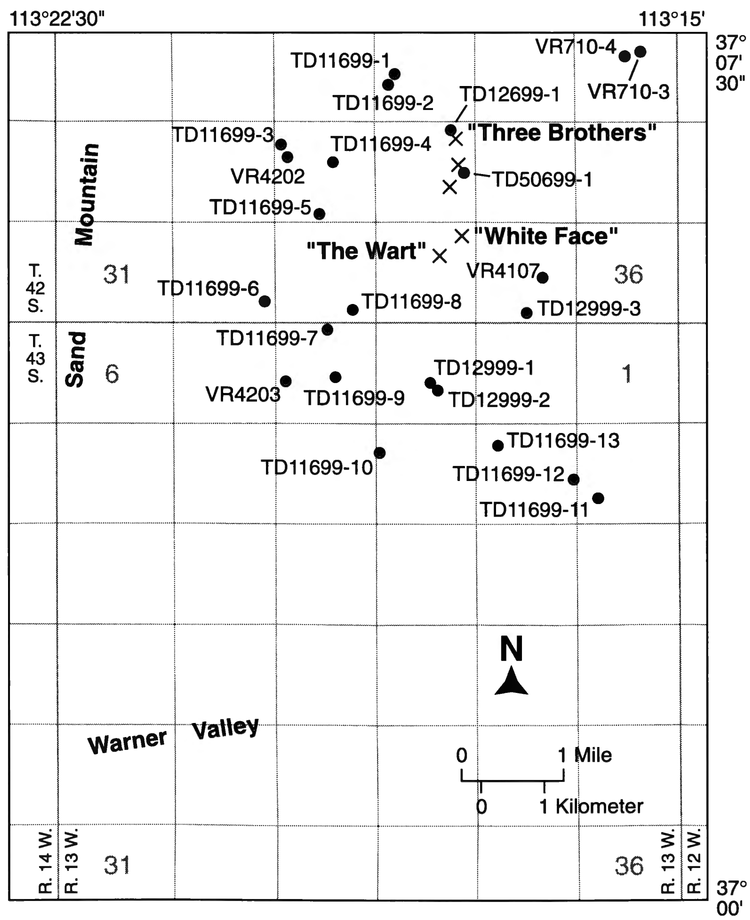
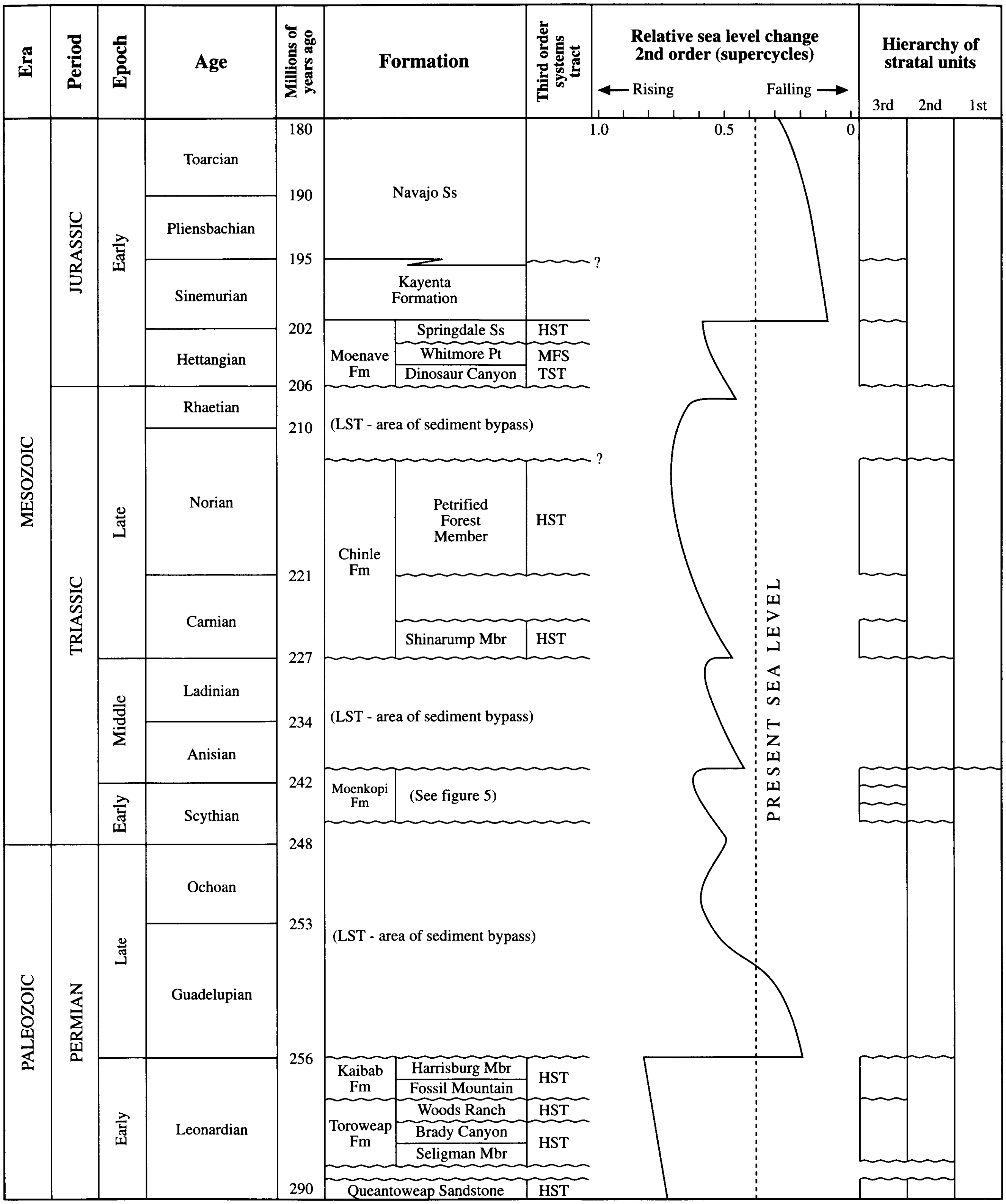


Figure 3. The Divide quadrangle showing selected geographic features and basalt sample locations (for more detail see plate 1).



HST = highstand systems tract. MFS = maximum flooding stage. TST = transgressive systems tract. LST = lowstand systems tract.

Figure 4. *Strata in The Divide quadrangle and their relationship to sea-level fluctuations. Vail and others (1977) divided the interval represented by strata exposed in the quadrangle into eight second-order supercycles, five of which are found within the quadrangle. The St. George area underwent erosion and/or sediment bypass during three of the second-order sequences, so sea-level fluctuations during the Late Permian, Middle Triassic, and earliest Jurassic (shown by the sea-level curve) are not represented by rock in the quadrangle. The five documented second-order cycles are further divided into 11 third-order cycles that reflect smaller relative changes in sea level. Systems tracts are listed for the third-order cycles. Modified from Vail and others (1977), Hintze (1993), and Dubiel (1994). Time scale from Hanson (1991). Vertical scale is based on time of deposition, not on strata thickness.*

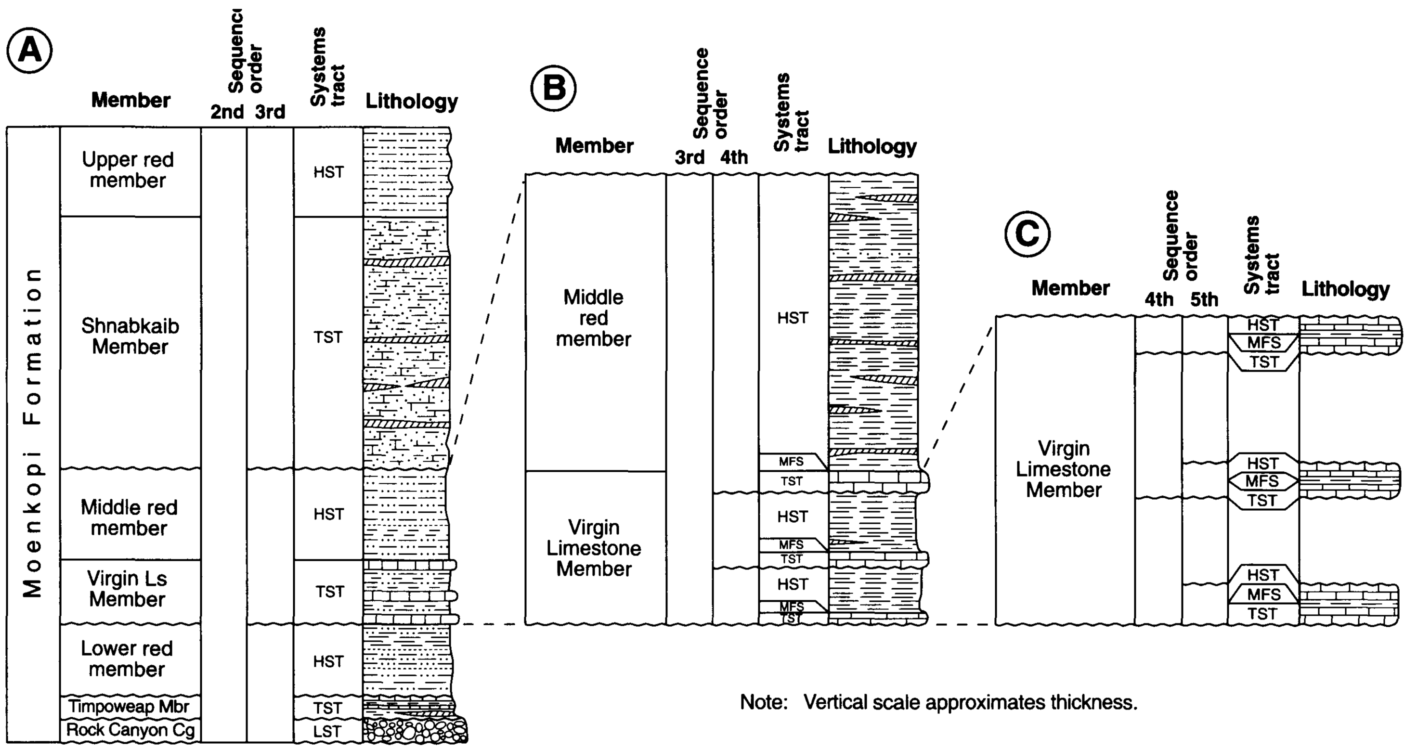


Figure 5. *(A) The second-order sequence of the Moenkopi Formation is divided into three third-order sequences indicating three smaller transgressive-regressive sequences. (B) Similarly, the third-order sequence of the Virgin Limestone and middle red member is divided into three fourth-order sequences with transgressive system tracts (TST) of the limestone ledges separated from the muddy siltstone interbeds of the highstand systems tract (HST) by a maximum flooding surface (MFS). (C) Each limestone ledge is itself a fifth-order parasequence. The lower portion of each ledge is finer, more muddy, and non-fossiliferous, signifying a transgressive systems tract (TST), while the upper portion is a coarser wackestone with birdseye structures and fossils, signifying a highstand system tract (HST). The two portions are typically divided by a thin dark-grayish-brown shale, indicative of a maximum flooding surface. Modified from Vail and others (1977), Hintze (1993), Dubiel (1994), and additional work in this project.*

Higgins, 1997) extends into northwest Arizona and southeastern Nevada where the lower portion is variously known as either the Queantoweap Sandstone or Esplanade Sandstone, and the upper portion as the Hermit Formation (Billingsley, 1992b), Hermit Shale (McNair, 1951; McKee, 1975, 1982; Rowland, 1987), or Coconino(?) Sandstone (McKee, 1934). On the geologic map of the adjacent Rock Canyon quadrangle, Billingsley (1992b) referred to the upper 760 to 800 feet (230-245 m) of red and white, ledge- and slope-forming sandstone and siltstone as the sandstone facies of the Hermit Shale. In his stratigraphic study of the area, Billingsley (1997) suggested that because the clastic sequence apparently becomes a white, low-angle, cross-bedded sandstone in southwestern Utah, the entire sequence in The Divide quadrangle should be mapped as Queantoweap Sandstone. The Queantoweap Sandstone is Early Permian (Wolfcampian) in age and was deposited in a shallow-marine environment (Billingsley, 1997). The unconformable upper contact corresponds to a break in slope at the base of the Seligman Member of the Toroweap Formation.

Toroweap Formation

The Early Permian Toroweap Formation – which consists of sediment deposited during shallow sea regression, transgression, and subsequent regression (Rawson and Turner-Peterson, 1979; Sorauf and Billingsley, 1991) – is exposed only along the Hurricane Cliffs. It was mapped using nomenclature defined by Nielson (1981, 1986) that divides the formation into three members: Seligman Member, Brady Canyon Member, and Woods Ranch Member.

Seligman Member (Pts): The Seligman Member forms a poorly exposed slope near the base of the Hurricane Cliffs. It consists of a lower pale-yellowish-brown, fine-grained sandstone; a middle interbedded yellowish-gray, calcareous, very fine-grained sandstone and grayish-yellow, gypsiferous, calcareous siltstone; and an upper medium-gray, thin-bedded, sandy limestone. The conformable upper contact with the Brady Canyon Member corresponds to the base of a light-gray, cherty limestone cliff. The Seligman Member is 115 feet (36 m) thick near the south edge of the quadrangle. Biek (2003b) estimated a thickness of 30 to 50 feet (9-15 m) to the north and Billingsley (1992b) reported a thickness of 100 to 200 feet (30-60 m) to the south along the Hurricane Cliffs.

Brady Canyon Member (Ptb): The Brady Canyon Member consists of medium-light-gray to dark-gray, medium- to coarse-grained, thick-bedded, fossiliferous limestone with reddish-brown, rounded chert nodules. The limestone contains abundant poorly preserved crinoid stems and disarticulated brachiopods, as well as coral and sponge fragments; it is slightly dolomitic near its base and top. It forms the prominent, lower cliff along the Hurricane Cliffs and is 200 feet (60 m) thick. The upper unconformable contact corresponds to the top of a massive cliff where the gypsiferous slope of the Woods Ranch Member begins.

Woods Ranch Member (Ptw): The slope-forming Woods Ranch Member is commonly covered with talus. It is gray-

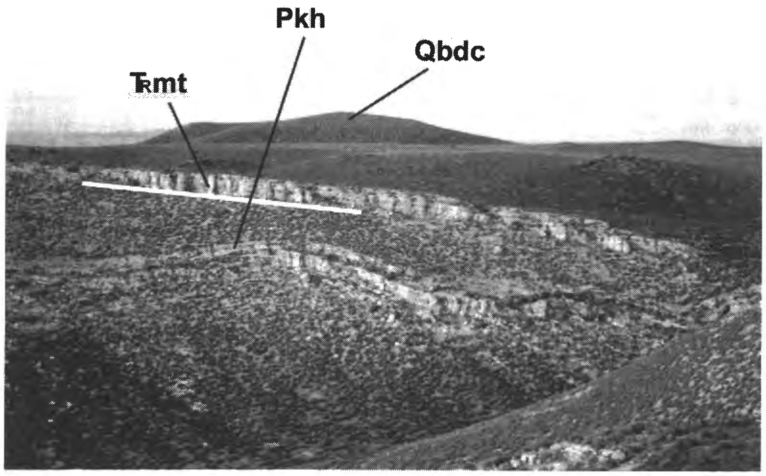


Figure 6. View northeast to the contact between the undulating layers of the Harrisburg Member of the Kaibab Formation (Pkh) below, and the straight layers of the Timpoweap Member of the Moenkopi Formation (TRmt) above, in the NE1/4NE1/4 section 10, T. 43 S., R. 13 W. Note the northernmost cinder cone of The Divide flow (Qbdc) that caps the ridge.

ish-pink to very-pale-orange, very thick-bedded gypsum with interbeds of light-brownish-gray siltstone, pale-red shale, and yellowish-gray to light-gray, laminated to thin-bedded dolomite and limestone. Bedding is distorted from dissolution of gypsum. This member is about 320 feet (98 m) thick. The upper contact with the Fossil Mountain Member of the Kaibab Formation is unconformable and channel erosion into the Woods Ranch Member produced local relief of as much as 12 feet (3 m). The upper contact is at the base of the massive cliff of the overlying Fossil Mountain Member of the Kaibab Formation.

Kaibab Formation

The Kaibab Formation (late Early Permian [Leonardian]) consists of sediment deposited by a transgressive, then regressive shallow sea (McKee, 1938; Rawson and Turner-Peterson, 1979; Nielson, 1981). It is divided into two members after Nielson (1981) and Sorauf and Billingsley (1991): the Fossil Mountain Member and Harrisburg Member.

Fossil Mountain Member (Pkf): The Fossil Mountain Member forms the upper prominent limestone cliff of the Hurricane Cliffs. It consists of yellowish-gray, abundantly fossiliferous, cherty limestone that contains silicified fossils, including corals, brachiopods, crinoids, and bryozoans. Outcrops commonly appear black-banded because of reddish-brown and black chert that forms irregularly bedded nodules. Total thickness is 300 feet (90 m). The upper contact with the Harrisburg Member is conformable and is drawn at the base of the first thick gypsum bed, just above the top of the massive cliff.

Harrisburg Member (Pkh): The Harrisburg Member, named for a type section at Harrisburg Dome just northwest of the quadrangle (Reeside and Bassler, 1921; Sorauf, 1962), is exposed near the top of the Hurricane Cliffs. Because Sorauf's type section is incomplete, Nielson (1981, 1986) established two reference sections that illustrate the rapid east-west facies changes of the Harrisburg Member. One section, west of the quadrangle in Mountain Valley Wash (MVW, figure 1), is typical of western exposures. A second section, north of the quadrangle in Timpoweap Canyon (TC, figure 1), is typical of eastern facies along the Hurricane Cliffs, including those of The Divide quadrangle. In The Divide quadrangle, the Harrisburg Member is light-gray, fossiliferous, sandy, fine- to medium-grained limestone interbedded with red and gray gypsiferous siltstone and sandstone, and gray gypsum beds several feet thick. Dissolution of interbedded gypsum has locally distorted the member. It forms a slope with limestone ledges. Beds of cherty limestone, sandy limestone, and chert, informally referred to as the "medial limestone" (Nielson, 1981), form a resistant low cliff about 30 feet (10 m) high near the middle of the member.

Post-depositional, subaerial erosion removed several hundred feet of strata during Late Permian and Early Triassic time and completely removed the Harrisburg Member from the southwest part of the Price City Hills in the Bloomington dome portion of the Virgin anticline about 10 miles (16 km) west of the quadrangle (Higgins and Willis, 1995) (figure 1). In the Beaver Dam Mountains farther to the west, Jenson (1984) and Higgins (1997) described karst topography having more than 500 feet (150 m) of relief that formed during this 15-million-year period of erosion (Nielson, 1981; Sorauf and Billingsley, 1991). In The Divide quadrangle, only part of the Harrisburg Member was removed. Channels, some as deep as 170 feet (50 m), are filled with the Rock Canyon Conglomerate Member of the Moenkopi Formation and younger strata. Elsewhere, the Harrisburg Member is overlain by the Timpoweap Member of the Moenkopi Formation (figure 6). The upper contact, which is poorly exposed, highly variable, and unconformable, is locally difficult to follow where Rock Canyon strata are not well developed.

Thickness of the Harrisburg Member ranges from 30 to 175 feet (9-53 m) in the quadrangle. Nielson (1981) measured 280 feet (85 m) near the southwest end of the Price City Hills in Bloomington dome and an incomplete section of 185 feet (56 m) near the northeast end of Bloomington dome, both to the southwest. Biek (2003a) described an incomplete section 250 feet (75 m) thick at Harrisburg Dome to the northeast, and a varying thickness from 100 to 160 feet (30-50 m) just to the north in the Hurricane quadrangle (Biek, 2003b).

Triassic

The Lower to Middle Triassic Moenkopi and Upper Triassic Chinle Formations are separated by an unconformity of about 10 million years (figure 4). These formations record two major second-order supercycles of Vail and others (1977) separated by a smaller rise and subsequent fall of sea level during Middle Triassic time (Paull and Paull, 1994).

Moenkopi Formation

The Moenkopi Formation is divided into seven members after Reeside and Bassler (1921) and Stewart and others (1972b) and is about 1,700 feet (515 m) thick in The Divide quadrangle. The Moenkopi Formation is Early to Middle Triassic (late Scythian to early Anisian) in age (Dubiel, 1994). It records a series of marine transgressions and regressions on a very gently sloping continental shelf, where sea-level changes of several feet translated into shoreline changes of tens of miles (Morales, 1987; Blakey, 1989; Dubiel, 1994).

Rock Canyon Conglomerate Member (TRmr): Although Nielson (1991) proposed that this member be elevated to formation status, Hintze (1993) and other subsequent authors still treat it as a member of the Moenkopi Formation. I agree that it is most appropriate as a member of the Moenkopi Formation. Channel conglomerates of the Rock Canyon Conglomerate Member fill paleocanyons eroded into the Kaibab Formation. Along much of the contact, the channel conglomerate is not present and a thin, regolithic breccia up to 10 feet (3 m) thick separates the Harrisburg Member of the Kaibab Formation from the Timpoweap Member of the Moenkopi Formation.

The Rock Canyon Conglomerate Member is composed of yellowish-gray to light-olive-gray, poorly to moderately sorted conglomerate with angular to subrounded clasts. Thick beds, some of which are lenticular and indurated, form a cliff. The basal layers include limestone rip-up clasts and blocks eroded from the Harrisburg Member as large as 14 inches (35 cm) in diameter. Rounding in the conglomerate varies from mostly angular in the lower part to subangular to subrounded toward the top. Clasts are pebble to cobble size and composed primarily of chert weathered from the Kaibab Formation. The conglomerate is mostly clast supported but, where matrix supported, the matrix is commonly limestone and locally coarse-grained sandstone. The Rock Canyon Conglomerate grades upward into calcareous, gritty, pebble conglomerate that is poorly sorted and includes some sandstone and yellowish-gray, sandy limestone lenses. The upper contact is conformable and gradational with dark-yellowish-orange to light-pinkish-gray, gritty siltstone beds of the Timpoweap Member. Thickness ranges from 0 to 130 feet (0-40 m).

Timpoweap Member (TRmt): The Timpoweap Member is extensively exposed at top of the Hurricane Cliffs. The member was named by Gregory (1950) for Timpoweap canyon, which is just north of the quadrangle (figure 1), but the type sections northeast of the quadrangle were not designated until 1979 (Nielson and Johnson, 1979). The Timpoweap Member forms a resistant ledge and bench on top of the channel-fill conglomerate or regolithic breccia of the Rock Canyon Conglomerate Member.

The lower part of the Timpoweap Member is light-gray to grayish-orange, thin- to thick-bedded limestone and cherty limestone that weathers light-brown, commonly with a meringue-like surface of protruding chert blebs. These lower beds contain ammonites, gastropods, and brachiopods. Locally, euhedral pyrite crystals up to 1/4 inch (1 cm) across are also present. The upper part of the member is grayish-orange, thin- to thick-bedded, slightly calcareous, very fine-grained sandstone with thin-bedded siltstone and mudstone intervals that weather yellowish-brown. An oil seep issues from these beds at the top of the Hurricane Cliffs just west of "White Face" and "The Wart," which are the two southernmost hills capped by the Remnants flow in the center of the N1/2 section 34, T. 42 S., R. 13 W. (figure 3, plate 1). Other oil seeps are known in the area (Blakey, 1979; Biek, 2003b). The upper contact with the lower red member is gradational and conformable and corresponds to the top of the highest yellowish-brown siltstone, sandstone, and limestone interval, above which lies reddish-brown siltstone and mudstone of the lower red member. This contact is covered by Quaternary alluvial deposits across most of the quadrangle, but is well exposed in a few draws near the hills capped by the Remnants flow. The Timpoweap Member ranges from about 50 to 125 feet (15-37 m) thick.

Lower red member (TRml): The lower red member consists of interbedded siltstone, mudstone, and sandstone that form a slope beneath the more resistant ledges of the Virgin Limestone Member. It is generally well exposed except for near the lower contact. The siltstone and mudstone are moderate-reddish-brown, generally calcareous, commonly ripple marked, and exhibit small-scale cross-bedding. Thin siltstone and mudstone beds are both interbedded with and crossed by stringers and thin veinlets of gypsum. The sandstone is reddish brown, calcareous, very fine grained, and thinly bedded. The unconformable upper contact with the Virgin Limestone Member corresponds to the base of the lowest limestone ledge. The lower red member is about 200 feet (60 m) thick in the quadrangle.

Virgin Limestone Member (TRmv): The Virgin Limestone Member forms a prominent bench along the flank of Little Creek Mountain on the east edge of the quadrangle. It consists of three distinct, resistant, medium-gray to yellowish-brown, marine limestone ledges, each 5 to 10 feet (1.5-3 m) thick, except in the SE1/4SE1/4 section 14, T. 43 S., R. 13 W. where the lower limestone reaches a thickness of 40 feet (12 m). These limestone beds are interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum. The limestone contains five-sided crinoid columnals. *Composita* brachiopods (Billingsley, 1992a) are present in the upper portion of the lowest limestone bed. They seem especially common where the ledge thickens.

The Virgin Limestone Member is generally 75 feet (23 m) thick, except where the lower limestone thickens. The upper contact with the middle red member corresponds to the top of the highest limestone ledge.

Middle red member (TRmm): The middle red member forms a slope at the base of Little Creek Mountain, and is also exposed in a horst west of the Hurricane fault zone in the south-central part of the quadrangle. It is composed of interbedded, moderate-red to moderate-reddish-brown siltstone, mudstone, and very fine-grained, thin-bedded sandstone. Very thin interbeds and veinlets of gypsum that vary in color from greenish-gray to white are locally common. Several ledge-forming gypsum beds are present near the base of the member. The upper contact corresponds to the base of predominantly light-gray, unfossiliferous, dolomitic limestone beds of the Shnabkaib Member, which overlie moderate-red siltstone of the middle red member. The middle red member is 360 feet (110 m) thick.

Shnabkaib Member (TRms): The Shnabkaib Member is extensively exposed midway up the slope of Little Creek Mountain, and is also exposed in a horst west of the Hurricane fault zone in the south-central part of the quadrangle. It consists of light-gray to pale-red gypsiferous siltstone with several thin interbeds of unfossiliferous, dolomitic limestone near the base. The alternating resistant and nonresistant beds form ledge-slope topography and make the lower portion slightly more resistant to erosion than the upper portion. The gypsiferous upper portion weathers into a powdery soil and generally forms a valley except where it is held up by more resistant overlying units. Alternating light and dark colors give this member a "bacon-striped" appearance. The upper contact is gradational and is placed where the greenish-gray gypsiferous siltstone of the Shnabkaib Member grades into reddish-brown mudstone of the upper red member. This member is 375 feet (115 m) thick.

Upper red member (TRmu): The upper red member of the Moenkopi Formation is generally well exposed, although locally it is covered by talus. It forms a steep slope with at least one prominent sandstone ledge beneath the resistant ledge of the Shinarump Conglomerate Member of the Chinle Formation, which caps Little Creek Mountain; it is also exposed in the horst west of the Hurricane fault. The upper red member consists of moderate-reddish-brown, thin-bedded siltstone and very fine-grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers. Ripple marks are common in the siltstone. The upper contact is unconformable, representing approximately 10 million years of Middle Triassic time (Dubiel, 1994), and is mapped at the base of the first coarse-grained, thick-bedded, pale-yellowish-brown conglomeratic sandstone that fills shallow paleovalleys eroded into the upper red member. The upper red member is estimated to be 425 feet (130 m) thick.

Moenkopi Formation, undivided (TRm): Numerous fault blocks along the Hurricane fault zone contain steeply west-dipping Moenkopi strata. These Moenkopi beds are undivided due to structural complexity and difficulty in identifying individual members.

Chinle Formation

In The Divide quadrangle, the Chinle Formation consists of the Shinarump Conglomerate and Petrified Forest Members. The Chinle Formation averages 725 feet (220 m) thick, but varies due to changes in thickness of the basal Shinarump Conglomerate Member. The Chinle is Late Triassic in age (Stewart and others, 1972a) based primarily on vertebrate and plant remains. Dubiel (1994) assigned it to the early Carnian to late Norian with an unconformity of several million years separating the two members.

The Shinarump Conglomerate Member comprises sediments shed off the ancestral Uncompahgre highlands to the east and a magmatic arc near the continental margin to the southwest (Blakey and others, 1993). The basal Shinarump was deposited in the lowest parts of paleovalleys cut into the upper red member of the Moenkopi Formation (Dubiel, 1994). The Petrified Forest Member's fluvial systems mimicked paleoflow of the Shinarump system except that Petrified Forest streams were of much higher sinuosity as evidenced by abundant flood-plain mudstone (Dubiel, 1994). Abundant bentonitic mudstone in the Petrified Forest Member indicates that volcanic ash formed a significant component of the sediment supply, most of which was derived from the magmatic arc at the continental margin to the southwest (Blakey and others, 1993).

Shinarump Conglomerate Member (TRcs): The Shinarump Conglomerate is resistant, moderate-brown, chert-pebble conglomerate grading to a grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone that caps Little Creek Mountain; Shinarump strata also cap the north end of the Warner Valley horst. It weathers dark brown to moderate yellowish brown. It is mostly thick to very thick bedded with both planar and low-angle cross-stratification, although thin, platy beds are present locally. In some areas, the more coarsely grained sandstone contains fragments of poorly preserved petrified wood that is commonly replaced in part by iron-manganese oxides. Locally, the finer grained sandstone has well-developed Liesegang bands of limonite that give rise to the nicknames of "picture rock" or "landscape stone" (Bugden, 1993).

The Shinarump Conglomerate Member was deposited in braided-stream channels that backfilled paleotopography; it ranges from 75 to 165 feet (23-50 m) thick in The Divide quadrangle. The upper contact is unconformable (Dubiel, 1994) and corresponds to the base of the first variegated, bentonitic shale of the Petrified Forest Member. Unlike areas to the northwest (Biek, 2003a, 2003b) and west (Willis and Higgins, 1996), no Shinarump-like sandstone beds are in the lower Petrified Forest Member in The Divide quadrangle.

Petrified Forest Member (TRcp): The Petrified Forest Member of the Chinle Formation is exposed in the southwest corner of the quadrangle. It consists of light-brownish-gray to grayish-red-purple bentonitic shale and siltstone with several lenticular interbeds of pale-yellowish-brown, cross-bedded, thick-bedded, resistant sandstone up to 10 feet (3 m) thick. Shaly beds weather to a "popcorn" surface due to swelling and shrinking of bentonitic clay. These swelling clays are responsible for many foundation problems in the region as well as landsliding. Petrified wood, typically well silicified and brightly colored, is common. Although the member is usually covered by Quaternary deposits, it is well exposed where it is protected from erosion by older alluvial deposits. The upper contact corresponds to the top of the highest purplish-gray shale and the base of reddish-brown siltstone of the Dinosaur Canyon Member of the Moenave Formation. This contact is unconformable and represents a gap of about 10 million years (Dubiel, 1994). Within the quadrangle, the Petrified Forest Member is about 600 feet (185 m) thick as estimated from map relationships, but it is only 400 feet (120 m) thick to the north in the adjacent Hurricane quadrangle (Stewart and others, 1972a; Biek, 2003b).

Jurassic

Moenave Formation

Miller and others (1989) assigned the Moenave Formation to the Lower Jurassic rather than the Upper Triassic largely because of the presence of fish scales from the holostean fish, *Semionotus kanabensis* (Hesse, 1935; Schaeffer and Dunkle, 1950). The fish fossils were originally thought to be restricted to the Triassic and so conflicted with palynomorphs from the Whitmore Point Member that indicate the unit is Early Jurassic (Peterson and others, 1977; Imlay, 1980). Olsen and Padian (1986) later found that *Semionotus kanabensis* is not age diagnostic, which resolved the long-standing debate on the age of the Early Jurassic Moenave, Kayenta, and Navajo Formations. Lucas and Hechert (2001) also assigned Moenave strata to the Early Jurassic. The Moenave Formation is divided into three members: in ascending order, the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone Members. The formation is 400 feet (120 m) thick in The Divide quadrangle.

Dinosaur Canyon Member (Jmd): A complete section of the Dinosaur Canyon Member is exposed in several areas of Warner Valley. It comprises interbedded, ledge- and slope-forming, moderate-reddish-brown siltstone and very fine-grained, thin-bedded, pale-reddish-brown to grayish-red sandstone and mudstone. Planar, low-angle, and ripple cross-stratification are common. Isolated outcrops are difficult to distinguish from the Kayenta Formation. The upper contact is conformable and is placed between the highest reddish-brown sandstone of the Dinosaur Canyon Member and the base of a 6-inch-thick (15 cm), light-gray dolomitic limestone with algal structures that weathers to mottled colors of yellowish-gray, white, and grayish-orange-pink with dark-reddish-brown chert nodules. The Dinosaur Canyon Member is 200 feet (60 m) thick.

Whitmore Point Member (Jmw): This member is also well exposed in several areas of Warner Valley. It comprises pale-red-purple to greenish-gray claystone interbedded with pale-brown to pale-red, thin-bedded siltstone. Several 2- to 6-inch-thick (5-15 cm) beds of light-greenish-gray, dolomitic limestone contain algal structures and fossil fish scales of *Semionotus kanabensis* (Hesse, 1935; Schaeffer and Dunkle, 1950). Unlike in the St. George quadrangle to the west, about 5 feet (2 m) of red beds that look like the Dinosaur Canyon Member are above the basal light-gray dolomitic limestone with algal structures (Higgins and Willis, 1995). These beds are assigned to the Whitmore Point Member. The unconformable upper contact corresponds to the base of the massive, cross-bedded Springdale Sandstone Member (see, for example, Peterson, 1994). The Whitmore Point Member is 80 feet (24 m) thick.

Springdale Sandstone Member (Jms): The Springdale Sandstone Member of the Moenave Formation is best exposed along the west side of the quadrangle in Warner Valley. It is pale-reddish-brown to grayish-yellow, medium- to very thick-bedded, fine- to medium-grained, cross-bedded, ledge-forming sandstone with interbedded light-purple-gray siltstone near the middle. The sandstone weathers to pale pink, pinkish gray, yellowish gray, and pale reddish purple and forms rounded cliffs and ledges that commonly have Liesegang banding. Some of the sandstone beds are characterized by small, resistant, 0.1-inch-diameter (2 mm) concretions that give weathered surfaces a pimply appearance. In some areas the member also includes minor, thin, discontinuous lenses of intraformational conglomerate with mudstone rip-up clasts. Poorly preserved petrified wood is locally abundant. The upper contact corresponds to the top of very thick-bedded sandstone and the base of slope-forming mudstone and claystone of the Kayenta Formation.

In the NW1/4NW1/4SW1/4 section 33, T. 43 S., R. 13 W., the beds just above the Springdale/Kayenta contact are composed of pale-reddish-purple to greenish-gray claystone interbedded with pale-brown to pale-red, thin-bedded siltstone that appear identical to the Whitmore Point Member. These beds also include fossil fish scales, probably of *Semionotus kanabensis*. I mapped this 10-foot-thick (3 m) interval as part of the Kayenta Formation, thus including Whitmore Point-like beds in the lower Kayenta. These beds probably indicate a brief return to Whitmore Point-like depositional conditions at the close of Springdale time. The Springdale Sandstone Member is 120 feet (36 m) thick.

Kayenta Formation (Jk)

The Kayenta Formation displays a general coarsening-upward sequence. Because of its transitional nature, the upper contact with the Navajo Sandstone is not consistently described in the literature. In southwest Utah, generally west of the Hurricane fault, this transition zone can be several hundred feet thick (Tuesink, 1989; Sansom, 1992). Hintze and Hammond (1994) divided the Kayenta Formation into three members in the Shivwits quadrangle and placed the upper contact above the uppermost fluvial sequence, thus including a significant amount of eolian sand in the upper Kayenta. In this and the adjacent Washington Dome quadrangles, I place the contact above the major break in topography created by the fluvial siltstone beds below the first major eolian sandstone, above which the sequence remains predominantly eolian (Higgins, 1998). This is consistent with Doelling and Davis (1989), Willis and Higgins (1995), Moore and Sable (2001), and Biek (2003a). As a result, much of what Hintze and Hammond (1994) placed in their upper Kayenta member is herein included in the Navajo Sandstone.

The upper contact with the Navajo Sandstone is difficult to trace across the quadrangle, especially with complications created by faulting at the southeast corner of Sand Mountain. It corresponds to the top of the topographic break created by planar beds of siltstone and sandstone. Above this break the sandstone is slightly lighter in color and very thick bedded with large-scale eolian cross-beds, above which the transitional sequence remains predominantly eolian. Dividing the remaining Kayenta beds into two members with a lower member extending to the top of a few thin dolomite beds that are roughly 100 feet (30 m) above the base works reasonably well to the west (Higgins and Willis, 1995); however, in The Divide quadrangle, the dolomite beds are more randomly located and do not provide a suitable horizon for dividing the formation. The Kayenta Formation is late Pliensbachian to early Toarcian (Early Jurassic) in age (Imlay, 1980). Total thickness of the formation in The Divide quadrangle is 900 feet (270 m).

The Kayenta Formation forms the base of Sand Mountain just north of Warner Valley in the southwest part of the quadrangle, and is also exposed in the hanging wall adjacent to the Hurricane fault zone. The lower slope-forming unit consists of interbedded, pale-reddish-brown to moderate-reddish-brown, thin-bedded siltstone; very fine-grained, moderately well-sorted, thin-bedded, planar to lenticular sandstone with climbing ripple marks; and moderate-purplish-red mudstone that has sericite on some bedding surfaces. The thin sandstone layers generally pinch out laterally and are typically calcareous. Their upper surface is locally bioturbated and mottled, varying in color from light greenish gray to moderate reddish brown. Dinosaur footprints in the northwest corner of section 30, T. 43 S., R. 13 W. are in these lower beds, several feet above the top of the Springdale Sandstone Member of the Moenave Formation. Previous publications (for example, Miller and others, 1989) and the interpretive sign at the track site incorrectly state that these footprints are in the Moenave Formation. Local beds of thinly laminated, light-pinkish-gray to light-olive-gray, micritic dolomite weather in blocky chips. Intervals toward the middle of the formation commonly weather to punky, gypsiferous soil, although gypsum beds are seldom exposed.

The upper, coarser grained part of the formation comprises most of the cliff face along the south side of Sand Mountain. It consists of moderate-reddish-brown siltstone and pale-reddish-brown to light-purplish-red mudstone with interbedded pale-reddish-brown to pale-red sandstone. Planar bedding of the mudstone and siltstone layers, along with the small-scale cross-bedding of the sandstone, indicates distal alluvial, tidal-flat, or playa deposition. The mudstone and siltstone are generally slope forming, but the very fine-grained, usually calcareous sandstone forms thin ledges in the lower portion that thicken to small cliffs near the top.

Navajo Sandstone (Jn)

The Navajo Sandstone is the youngest Mesozoic formation exposed in the quadrangle. Although it is about 2,000 feet (600 m) thick in southwest Utah, only the lower 1,000 feet (300 m) is exposed in The Divide quadrangle. It forms the uppermost portion of the Sand Mountain cliff face. The Navajo Sandstone contains a basal transition zone characterized by resistant, very thick-bedded, cross-bedded sandstone separated by planar bedded, silty, fine-grained sandstone with thin mudstone interbeds. In addition to wavy bedding and dark flaser-like laminae, the transition zone contains soft-sediment deformation features such as diapiric and load structures, and bioturbation (Sansom, 1992). Except in the basal transition zone, this cross-bedded, eolian sandstone is pale to moderate reddish brown and consists of fine- to medium-grained, well-rounded, well-sorted, frosted quartz grains. It weathers to sand that accumulates on outcrops and adjacent low areas. Locally, the sand is blown into dune form.

Quaternary

Basaltic Flows

The five Quaternary basaltic flows present in The Divide quadrangle are part of the western Grand Canyon basaltic field (Hamblin and Best, 1970), a large area of late Tertiary to Holocene basaltic volcanism in northwestern Arizona and southwestern Utah (Hamblin, 1970a; Best and Brimhall, 1974). Because flows are resistant to erosion and are erupted over a relatively short period of time, they are useful in evaluating rates of local tectonic and geomorphic development (Willis and Biek, in press). Erupting flows generally coursed their way down pre-existing stream channels or valleys before solidifying. Thereafter, erosion proceeded more rapidly in the adjacent, softer sedimentary rocks that originally channeled the flow. Eventually, erosion produced sinuous basalt-capped ridges or "inverted valleys" (Hamblin, 1970a, 1987; Hamblin and others, 1981). Typically, the oldest inverted valleys are now at the highest elevations above present drainages. Because downcutting has been the dominant geomorphic process on the Colorado Plateau during the late Cenozoic, the relative height above modern drainages provides a way of estimating the relative age of the flows, and, coupled with radiometric dating, allows determination of a downcutting rate for the area. Hamblin and others (1981) calculated a downcutting rate of 300 feet (90 m) per million years for the structural block that includes the west half of The Divide quadrangle, west of the Hurricane fault zone. Based on dated basalt flows that entered the channel of the ancestral Virgin River, Willis and Biek (in press) reported long-term incision rates of 1,245 feet (380 m) per million years and 360 feet (110 m) per million years for the areas east and west of the Hurricane fault, respectively.

Hamblin (1970a, 1987) mapped flows in the region as stages I to IV, based on the amount of topographic inversion and erosion of the flows. Stage I are high remnants that bear no apparent relation to the present topography, whereas stage IV are very young flows with little or no topographic inversion. However, this system is only valid for comparisions within a large structural block (Willis and Biek, in press). Flows that cross and are offset by the Hurricane fault zone, such as the Remnants flow, illustrate that the amount of downcutting is largely a function of the amount and rate of relative uplift. Thus, near areas having a complex downcutting history, the geomorphic stage designations can be misleading.

Sanchez (1995) and Smith and others (1999) studied the composition and evolutionary history of the flows in the Hurricane volcanic field, which includes four of the five flows within The Divide quadrangle, as well as theoretical aspects of mantle properties beneath the Basin and Range/Colorado Plateau transition zone. They classified these volcanic rocks as low-silica basinite, basinite, and alkali basalt. Sanchez (1995) and Smith and others (1999) also discussed the trace element geochemistry for these rocks and suggested that they represent magmas that had an oceanic island basalt (OIB)-like garnet-free source, but that show variable amounts of mixing with lithospheric mantle. The primitive geochemistry of the low-silica basinite and basinite suggests that they rose rapidly from a site of partial melting to the surface. Sanchez (1995) showed that the geochemical variation among the basalts of the greater Hurricane area cannot be due to simple fractional crystallization of a single magma, similar to the findings of Best and Brimhall (1974), who studied basaltic rocks of the western Grand Canyon region.

The location of vents in the Hurricane volcanic field seems to be controlled by joints instead of faults (Sanchez, 1995). Sanchez indicated that cone alignments match local joint maxima data of Lefebvre (1961). He also showed that most cones in the area are monocyclic (single event) and monogenetic (single source), meaning that most erupted from a single source over a relatively short time span (probably less than 100 years).

Several flows in The Divide quadrangle consist of more than one cooling unit (cooling units are lava pulses from the same eruption separated by short time intervals, whereas flows are from different eruptions and are separated by enough time for weathering to take place). Some basaltic flows, like the Remnants flow, may be composed of multiple flows. All of the flows are partly covered by a veneer of eolian sand and pedogenic carbonate, herein mapped as stacked-unit deposits. Cinder cones are denoted using the flow symbol followed by a "c."

Gould Wash flow (Qbgw): The Gould Wash flow, whose source is a cinder cone 3 miles (5 km) east of The Divide quadrangle, cuts across the northeast corner of the quadrangle. This dark-gray, very fine-grained olivine basalt has abundant olivine phenocrysts up to 0.05 inch (1 mm) in size, the only recognizable mineral in hand sample. Geochemically, the flow is classified as a basalt on the TAS diagram of Le Bas and others (1986) (figure 7; appendix; see also Biek,

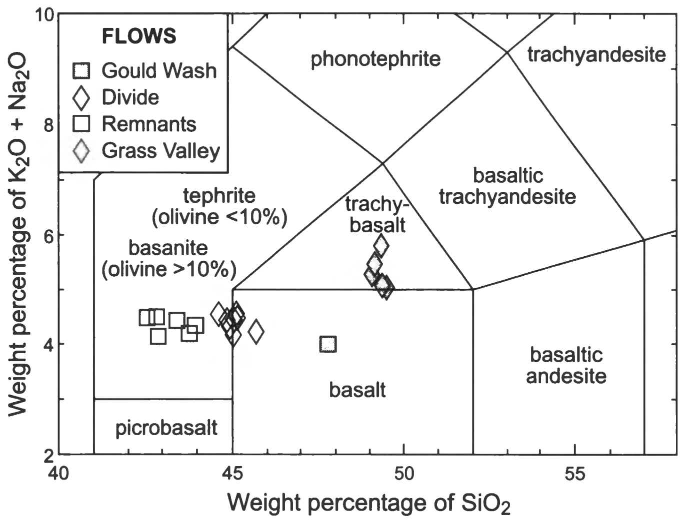


Figure 7. Geochemical classification of basaltic rocks in The Divide quadrangle using the scheme of Le Bas and others (1986). See appendix for analytical data.

2003b). Downing (2000) reported an $^{40}Ar/^{39}Ar$ age of 0.278 ± 0.018 Ma for this flow. The Gould Wash flow is generally 20 to 30 feet (6-9 m) thick and in The Divide quadrangle is only a few feet above adjacent streams.

The Divide flow and cinder cones (Qbd, Qbdc): The Divide flow (Qbd) is dark gray and very fine grained with phenocrysts of olivine. It is classified as borderline basalt to basanite on the TAS diagram of Le Bas and others (1986), according to geochemical data from 14 samples collected by Sanchez (1995) and eight additional samples for this report (figure 7, appendix). The flow still has a relatively fresh surface morphology even though a sample taken from near where the flow cascaded over the Hurricane Cliffs in the SW1/4SE1/4 section 3, T. 43 S., R. 13 W. yielded an $^{40}Ar/^{39}Ar$ age of 0.41 ± 0.08 Ma. The lava cascade itself consists of two flow remnants: a large one on the front of the cliff and a smaller one in a small drainage just to the south (figure 8). Both remnants are isolated from the rest of the flow by a massive cliff of the Fossil Mountain Member of the Kaibab Formation. Similarly, the cascade abruptly ends at the top of the Brady Canyon cliff, 300 feet (90 m) above the current level of the alluvial fan and 400 feet (120 m) below the top of the Hurricane Cliffs. Both the thickness and eroded nature of the end of the cascade indicate that it probably once extended farther downhill than its present terminus. Any lava that may have reached the down-dropped side of the Hurricane fault is now covered by alluvium and talus. Thus, about 400,000 years ago, relief on the Hurricane Cliffs was at least 400 feet (120 m).

Figure 8. View northeast to The Divide flow cascade over the Hurricane Cliffs in the SW1/4SE1/4 section 3, T. 43 S., R. 13 W. Fossil Mountain (Pkf), Woods Ranch (Ptw), Brady Canyon (Ptb), and Seligman (Pts) strata are visible.

Two cinder cones (Qbdc) are associated with The Divide flow. Volcanic bombs up to 6 feet (2 m) in diameter and agglutinate are present near the summit of the southernmost of the two cones. The way the bombs are stretched suggests that they flowed downslope after impact (Sanchez, 1995). The cones are extensively eroded along their east flanks by intermittent flow in a north-draining wash.

Two dikes, mapped as one outcrop, strike north-south in the SW1/4SW1/4 section12, T. 43 S., R. 13 W. The northern dike starts about 0.6 mile (1 km) south and a little east of the southern cinder cone. It extends about 1,300 feet (400 m) and is 5 feet (1.5 m) wide. This dike includes abundant xenoliths of Moenkopi Formation red beds up to 1 inch by 2 inches (3 x 5 cm), presumably from the middle red member that surrounds it. Continuing south but beginning about 30 feet (10 m) to the east from the end of the first dike, a second dike extends another 650 feet (200 m) but is only 2 feet (0.6 m) wide. Sanchez (1995) interpreted the dikes to be conduits for the two cones. The eastern extent of the southern isolated outcrops of the flow are higher in elevation than the cinder cones, so the dikes were likely a partial source of the flow.

Ivans knoll flow (Qbi): The Ivans Knoll flow extends from the north into the northwest corner of The Divide quadrangle. Just north of the quadrangle are small cinder deposits of a deeply eroded source area for this flow (Sanchez, 1995; Biek, 2003b). The edge of the flow is eroded, typically exposing two flow units underlain by Navajo Sandstone. It forms a well-exposed, resistant ridge north of Sand Hollow Draw that stands about 200 feet (60 m) above local drainages.

Geochemical analyses of 16 samples reported by Sanchez (1995) and Biek (2003b) classify the Ivans Knoll flow as a basalt on the TAS diagram of Le Bas and others (1986). In hand sample, the flow is a medium-gray, fine- to medium-grained olivine basalt, with olivine phenocrysts up to about 0.1 inch (3 mm) in size. Olivine is the only recognizable mineral in hand sample. The Ivans Knoll flow yielded $^{40}Ar/^{39}Ar$ ages of 0.97 ± 0.07 Ma and 1.03 ± 0.02 Ma (Biek, 2003b). The flow also yielded a normal paleomagnetic signature (Mike Hozik, Stockton College, verbal communication, 1999), fortuitously recording the short-lived Jamarillo magnetic reversal event. Within The Divide quadrangle, the Ivans Knoll flow is 15 to 25 feet (5-8 m) thick.

Remnants flow (Qbr): The Remnants flow is the only flow within the quadrangle that is present on both the hanging wall and footwall of the Hurricane fault. The portion of the flow that lies on the higher footwall is eroded into five remnants: the northern three overlie the lower red member of the Moenkopi Formation and are known as the "Three Brothers;" "White Face," to the south, is named for an underlying ledge of Virgin Limestone; the southernmost basalt-capped butte is called "The Wart" and also overlies the lower red member (figure 3). Although geomorphically it appears to be an outlier of the Remnants flow, the flow that caps Mollies Nipple erupted from Ivans knoll (Biek, 2003b). These remnants are approximately 350 feet (100 m) higher than the surrounding topography at the top of the Hurricane Cliffs. The portion of the flow west of the Hurricane fault, however, is partly buried by Quaternary sediment (figure 9), as evidenced by the gravel pit operation along the north edge of the flow.

The geochemistry of Sanchez's (1995) two "White Face" samples and one from "The Wart" classifies this flow as a low-silica basanite on the TAS diagram of Le Bas and others (1986), as do the seven samples collected for this report (five from west of the fault and two from the "Three Brothers") (figure 7, appendix). The Remnants flow yielded $^{40}Ar/^{39}Ar$ ages of 1.06 ± 0.03 Ma, 0.94 ± 0.04 Ma, and 1.47 ± 0.34 Ma. The latter age, reported in Lund and others (2001), is from the same location as the first age and may be anomalous. Based on the large amount of scoria, the vent for this flow is probably just west of, and perhaps includes, the southern two of the "Three Brothers." At least three flow units are present on the middle of the "Three Brothers," but in most places only one is obvious. This dark-brownish-black to dark-gray, medium-grained olivine basalt is approximately 40 feet (12 m) thick.

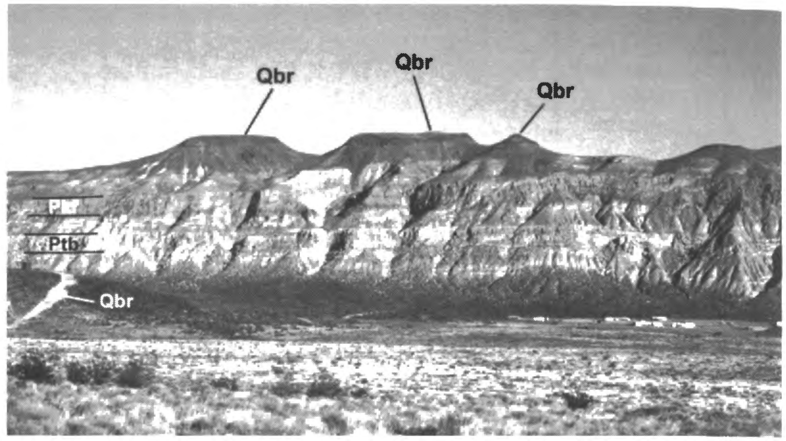


Figure 9. View east to the "Three Brothers," which are capped by the Remnants flow (Qbr) (sections 27 and 28, T. 42 S., R. 13 W.). Cliff-forming cherty limestone of the Brady Canyon Member (Ptb) of the Toroweap Formation and the Fossil Mountain Member (Pkf) of the Kaibab Formation are visible in the Hurricane Cliffs. The portion of the Remnants flow in the valley is partly buried by alluvial-fan deposits shed from the cliffs.

Grass Valley flow and cinder cone (Qbgv, Qbgvc): The Grass Valley flow is a very dark-gray, fine- to medium-grained olivine basalt. Geochemical data from 12 samples collected by Sanchez (1995) and six for this report classify this flow as a trachybasalt to borderline basalt on the TAS diagram of Le Bas and others (1986) (figure 7, appendix). The flow has been offset, down to the northwest, by two northeast-trending faults. The southernmost of the two faults has offset the flow approximately 20 feet (6 m) while the northernmost has a minimum offset of 150 feet (45 m) with alluvial and eolian sediment covering the down-dropped block next to the fault. Additionally, from some perspectives the entire flow appears tilted toward the east into the Hurricane fault; however, part of this apparent tilt may be due to the paleotopography on the Navajo Sandstone over which the basalt flowed. The partially eroded Grass Valley cinder cone (Qbgvc) has a 10-foot-thick (3 m) flow that probably cooled in a lava lake; two dikes, about 10 feet (3 m) wide, radiate from its center (Sanchez, 1995). Based on degree of incision and comparison with other dated flows in the area, the Grass Valley flow is probably about 200,000 to 300,000 years old.

Alluvial Deposits

Alluvial-fan deposits (Qafy, Qafo): Alluvial-fan deposits include poorly to moderately sorted, boulder- to clay-size sediment at the base of the Hurricane Cliffs and locally at the mouth of active drainages. Younger alluvial-fan deposits (Qafy) form active depositional surfaces, whereas older alluvial-fan deposits (Qafo) are deeply dissected. Alluvial-fan deposits vary from 0 to about 50 feet (0-15 m) thick, but may be somewhat thicker adjacent to the Hurricane Cliffs.

Stream-terrace deposits (Qat_2, Qat_3): Higher-level stream-terrace deposits (Qat_3) consist of well-rounded, pebble- to cobble-size clasts in a muddy- to coarse-sand matrix that form a moderately sorted, indurated, pedogenic carbonate-cemented conglomerate 30 to 90 feet (9-27 m) above the modern flood plain of Fort Pearce Wash. Using an approximate downcutting rate of 360 feet (110 m) per million years (Willis and Biek, in press) for this structural block, level 3 deposits are estimated to be 80,000 to 270,000 years old. The thickness of level 3 stream-terrace deposits ranges from 0 to about 40 feet (0-12 m). Level 2 stream-terrace deposits (Qat_2) are adjacent to and dissected by modern drainages and are 10 to 30 feet (3-9 m) above active channels. They are 0 to 20 feet (0-6 m) thick.

Stream deposits (Qal_1): Stream deposits are moderately to well-sorted, clay to fine gravel in the larger, active drainages, including Fort Pearce Wash and its tributaries. Stream deposits include sediment in, and up to 10 feet (3 m) above, current channels and are 0 to 10 feet (0-3 m) thick.

Colluvial Deposits (Qc)

Colluvial deposits are poorly sorted, angular to rounded blocks in a muddy to sandy matrix and are deposited principally by sheet wash and soil creep on moderate slopes. Plate 1 shows only the larger deposits. Locally, this unit includes eolian, talus, and debris-flow and alluvial deposits too small to map separately. Thickness of these deposits ranges from 0 to 20 feet (0-6 m).

Eolian Deposits

Caliche and eolian-sand deposits (Qeo): These deposits form planar surfaces covered with thick pedogenic calcium carbonate (stage IV carbonate of Birkeland and others, 1991) and lesser amounts of eolian sand. These deposits locally cap the Navajo Sandstone of Sand Mountain, where they form planar surfaces of higher elevation than the surrounding sandstone. Thickness is generally 0 to 10 feet (0-3 m).

Eolian-dune-sand deposits (Qed): These deposits consist of well- to very well-sorted, very-fine- to medium-grained, well-rounded, usually frosted, mostly quartz sand blown into dune form on Sand Mountain and in Warner Valley. The sand is derived primarily from weathering of the Navajo Sandstone. Some of the transverse dunes in the main dune field on Sand Mountain, just west of the quadrangle, are 40 feet (12 m) high. Thickness ranges from 0 to 40 feet (0-12 m).

Eolian-sand deposits (Qes): These deposits consist of well- to very well-sorted, very fine- to medium-grained, well-rounded, usually frosted, mostly quartz sand that has accumulated in irregular hummocky mounds on the lee side of ridges, as well as on Sand Mountain and in Warner Valley. In many areas, the sand is partially stabilized by sparse vegetation. Most of the sand was derived from weathering of the Navajo Sandstone and Kayenta Formation. Locally, it forms poorly developed dunes. Thickness ranges from 0 to 50 feet (0-15 m).

Mass-Movement Deposits

Landslide deposits (Qms): Several landslide deposits are present near the east side of the quadrangle along the southwest edge of Little Creek Mountain. The deposits consist of very poorly sorted debris ranging in size from clay to blocks several feet across, and form chaotic, hummocky mounds. Slip surfaces are in the middle red member of the Moenkopi Formation. The landslides involve overlying bedrock formations and talus. The thickness of these deposits is highly variable.

Talus deposits (Qmt): Talus deposits are very poorly sorted, angular boulders with minor fine-grained interstitial sediments that have accumulated on and at the base of steep slopes. Most talus deposits consist of blocks of basalt that roll down slopes created as the underlying softer sedimentary beds erode. Similarly, blocks of the Shinarump Conglomerate Member of the Chinle Formation accumulate as talus on the upper red member of the Moenkopi Formation and blocks of Kayenta Formation and Navajo Sandstone rest on the lower slopes of Sand Mountain. Along the Hurricane Cliffs, blocks of the Fossil Mountain Member of the Kaibab Formation and the Brady Canyon Member of the Toroweap Formation also collect on steep slopes. Plate 1 shows only the larger deposits, but talus is common on all steep slopes in the quadrangle. Thickness ranges from 0 to 20 feet (0-6 m).

Mixed-Environment Deposits

Mixed alluvial and colluvial deposits (Qac, Qaco): These deposits are poorly to moderately sorted, clay- to boulder-sized sediment in minor drainages throughout the quadrangle. Alluvial deposits are transported along washes during heavy rainstorms, mixing with colluvial sediment derived from side slopes along the washes. Qaco deposits are higher than and are dissected by modern drainages. In some areas, the younger mixed alluvial and colluvial deposits (Qac) are derived from Qaco. Qac and Qaco deposits are gradational with colluvial deposits (Qc) and locally include stream deposits and level 2 stream-terrace deposits (Qal_1, Qat_2) too small to map separately. Mixed alluvial and colluvial deposits vary in thickness from 0 to 10 feet (0-3 m).

Mixed alluvial and eolian deposits (Qae, Qaeo): These deposits consist of moderately to well-sorted clay- to sand-sized sediment of alluvial origin that locally includes abundant eolian sand and minor gravel. The younger deposits (Qae) are in large, open, nearly flat areas east of the Hurricane Cliffs and in Grass Valley, are generally finer grained than other surficial deposits, and have minor pedogenic carbonate (caliche) development. Older, deeply incised deposits (Qaeo) are restricted to Gould Wash in the northeast corner of the quadrangle. The deposits are typically 0 to 30 feet (0-9 m) thick, but locally may be thicker.

Mixed eolian and alluvial deposits (Qea): These deposits are composed mostly of well-sorted eolian sand locally reworked by alluvial processes, and locally include alluvial clay- to gravel-size sediment and an incipient pedogenic carbonate horizon. These deposits flank Sand Mountain in Warner Valley. An 1,800-foot-long (550 m) Quaternary fault scarp on the Warner Valley fault offsets these deposits about 9 feet (3 m). The scarp trends north-northeast from the NE1/4NW1/4 section 28, to SE1/4SW1/4 section 21, T. 43 S., R. 13 W. These deposits are typically 0 to 20 feet (0-6 m) thick.

Stacked-Unit Deposits

Eolian sand and pedogenic carbonate over basalt flows (Qec/Qbgw, Qec/Qbd, Qec/Qbi, Qec/Qbr, Qec/Qbgv): Each basaltic flow in The Divide quadrangle is partly concealed by eolian sand and pedogenic carbonate (up to stage V of Birkeland and others, 1991). These deposits are discontinuous and generally less than 3 feet (1 m) thick.

Artificial-Fill Deposits (Qf)

Artificial fill used for dams and levees consists of engineered fill and general borrow material. Although plate 1 shows only a few deposits, fill may be present in all developed areas, many of which are shown on the topographic base map. Thickness is highly variable.

STRUCTURE

Regional Setting

The Divide quadrangle straddles the boundary between the Colorado Plateau and the transition zone with the Basin and Range Province (Hamblin, 1970b; Hintze, 1986a). The Colorado Plateau, relatively coherent and tectonically stable, is underlain by generally subhorizontal sedimentary strata that are locally disrupted by early Tertiary Laramide basement-block uplifts, Oligocene/Miocene igneous intrusions, and late Tertiary to Quaternary normal faults. The Basin and Range Province is characterized by roughly east-west extensional tectonics that created north-south-trending horsts and grabens and widespread igneous activity. Both provinces have experienced broad regional uplift.

The transition zone roughly coincides with the leading edge of the Late Cretaceous to early Tertiary Sevier orogenic thrust belt. Rocks in the area are deformed by folds and minor faults in front of the main thrust belt, and Davis (1999) postulated a basal detachment in underlying Cambrian strata. At the frontal portion of most thrust belts, a detachment at depth transfers the waning displacement of the thrust belt through a triangle zone characterized by a reverse fault that helps create an anticline commonly tens of miles in length (see, for example, Willis, 1999); development of the fold effectively uses up the remaining displacement of the thrust belt. In this area, the basal detachment is believed to lie within the Cambrian Bright Angel Shale and the frontal fold is the Virgin anticline, whose axis is just west of the western quadrangle boundary.

The transition zone is also part of the active southern segment of the Intermountain seismic belt, which coincides with the boundary between relatively thin lithosphere of the Basin and Range Province and thicker, more stable lithosphere of the Colorado Plateau (Arabasz and Julander, 1986). The zone consists of a series of down-to-the-west normal faults that step down from the Colorado Plateau into the Basin and Range Province. The greater St. George area lies on an intermediate block between two major fault zones. The block is bounded on its eastern edge by the Hurricane fault zone and on its western edge by the Grand Wash-Gunlock fault zone (figure 1); The Divide quadrangle straddles the eastern edge of this block. Displacement on the Hurricane fault zone increases to the north (Hamblin, 1970b) whereas displacement on the Grand Wash-Gunlock fault zone increases to the south (Hintze, 1986b). Schramm (1994) postulated that a displacement transfer zone lies between these faults, in which decreasing slip on one fault is compensated for by increasing slip on another. This type of transfer zone could account for the relatively wide width of the transition zone in southwestern Utah.

Strata between the Hurricane and Grand Wash-Gunlock fault zones, including the west half of The Divide quadrangle, have a regional dip of 5 to 10 degrees to the northeast. Three northeast-trending folds occupy this structural block: the broad St. George syncline, the axis of which underlies St. George City; the much tighter Virgin anticline, the axis of which is approximately 5 miles (8 km) west of The Divide quadrangle; and the broad Sand Mountain syncline, whose east limb is included within The Divide quadrangle. East of the Sand Mountain syncline, folding and faulting in east Warner Valley and along the Hurricane fault create more complex features. Rocks east of the Hurricane fault dip about 10 degrees eastward near the fault, but their dip decreases to about 2 degrees along the east edge of the quadrangle.

Folds

Sand Mountain Syncline

Strata of Sand Mountain and western Warner Valley, just west of the quadrangle, define a very broad syncline. The fold is best expressed by a gradual change in strike of the Kayenta Formation around the south and west edges of Sand Mountain. The axis trends northeast but is not well defined because the fold is so broad and because of the massive nature of the Navajo Sandstone. Only the east limb of the Sand Mountain syncline is included in The Divide quadrangle.

Warner Valley Dome

The Warner Valley dome is near the south edge of the quadrangle in east Warner Valley about 1.5 miles (2.4 km) west of the Hurricane fault zone. The dome is cut by and bounded on both sides by normal faults that create a pod-shaped horst of Triassic rocks; however, not all of the folding is easily attributed to faulting and the formation of the horst. It is probable that the dome formed during the Sevier orogeny, similar to the Virgin anticline, and was subsequently cut and modified by normal faults.

The Warner Valley dome was drilled as a petroleum prospect in 1960 by Intex Oil Co. The Skyline No. 1 well, spudded in the middle red member of the Moenkopi Formation, reached a total depth of 3,006 feet (917 m). No oil or gas shows were reported.

Normal Faults

Hurricane Fault Zone

The Hurricane fault zone is a major, active, steeply west-dipping normal fault system that stretches at least 155 miles (250 km) from south of the Grand Canyon to north of Cedar City. The total stratigraphic separation generally increases northward along the fault from less than 200 feet (60 m) south of the Grand Canyon (Hamblin, 1970b) to 8,265 feet (2,520 m) near Toquerville (Stewart and Taylor, 1996). The Hurricane fault zone has been called a normal dip-slip fault (Huntington and Goldthwait, 1904; Gardner, 1941; Cook, 1960; Averitt, 1962; Hamblin, 1965, 1970b; Kurie, 1966; and Stewart and Taylor, 1996), a reverse fault (Lovejoy, 1964), and even a fault zone with a significant component of left-lateral slip (Moody and Hill, 1956; Anderson and Barnhard, 1993). However, recent studies in the greater Hurricane area (Schramm, 1994; Stewart and Taylor, 1996; Biek, 2003b; Hurlow and Biek, 2003) show that Pliocene to Quaternary displacement on the Hurricane fault zone is normal dip slip, locally with a small component of right-lateral slip.

Because of the great length of the Hurricane fault, it almost certainly ruptures in segments (Stewart and others, 1997; Lund and Everitt, 1998; Lund and others, 2001). The greatest number and best preserved scarps, at the north end of the fault zone, indicate that the most recent faulting on the Hurricane fault zone in Utah occurred in the latest Pleistocene or early Holocene (Lund and Everitt, 1998; Lund and others, 2001). Lund and Everitt (1998) postulated that multiple surface-faulting earthquakes have occurred in the late Quaternary along most, if not all, of the Utah portion of the fault zone.

Lund and others (2001) calculated a slip rate based on the Remnants flow, which is displaced about 1,445 feet (440 m) by the Hurricane fault. I obtained an $^{40}Ar/^{39}Ar$ age of 0.94 ± 0.04 Ma for the flow on the footwall and 1.06 ± 0.03 for the flow on the hanging wall. Lund and others (2001) obtained an $^{40}Ar/^{39}Ar$ age of 1.47 ± 0.34 Ma for the same hanging-wall basalt flow, although the reason for the age discrepancy remains unclear. Based on the nearly concordant ages determined in this study, they calculated a long-term slip rate of 0.02 inches/year (0.44 mm/yr) for this portion of the fault.

The Divide flow, which cascaded over the Hurricane Cliffs, yielded an $^{40}Ar/^{39}Ar$ age of 0.41 ± 0.08 Ma from the top of the cascade in the SW1/4SE1/4 section 3, T. 43 S., R. 13 W. The cascade abruptly ends at the top of the Brady Canyon Member of the Toroweap Formation, 300 feet (90 m) above the current level of the adjacent alluvial fan. Both the thickness and the eroded nature of the end of the cascade indicate that it probably once extended beyond its current limit of 400 feet (120 m) downslope from the top of the cliffs. Thus about 400,000 years ago, the Hurricane Cliffs were at least 400 feet (120 m) high, thereby providing a minimum slip rate of approximately 0.009 inches/year (0.23 mm/yr) for the past 400,000 years.

North from the Utah/Arizona border, the Hurricane fault zone strikes N30°E for 1.5 miles (2.4 km) to the mouth of a large, unnamed drainage. Along this section, the fault zone is about 1,600 feet (490 m) wide and includes as many as six mappable faults. A fault plane in bedrock about 10 feet (3 m) high is in the NE1/4 section 34, T. 43 S., R. 13 W., where the Brady Canyon Member of the Toroweap Formation is juxtaposed against a nearly vertical section of the Virgin Limestone Member and red beds of the Moenkopi Formation that have been caught in the fault zone between the Permian rocks and the Jurassic Kayenta Formation. Additionally, Lund and Everitt (1998) identified possible isolated, colluvium-mantled, bedrock-cored scarps as much as 20 feet (6 m) high in the SW1/4 and NE1/4 section 34 indicative of recurrent surface-faulting earthquakes during the late Quaternary; however, stream-terrace deposits (Qat_3) at the mouth of the large, unnamed drainage to the north (sections 26 and 27) are not displaced, possibly indicating an absence of Holocene surface-fault rupture on this portion of the fault. Just north of this drainage, cross section A-A′ shows 4,800 feet (1460 m) of displacement across the Hurricane fault zone (figure 10).

From the large, unnamed drainage described above, the Hurricane fault zone trends N20°W for 5.25 miles (8.45 km), veers to N20°E for 0.5 mile (0.8 km), and continues nearly due north for an additional almost 2 miles (3 km) to the north edge of the quadrangle. The base of the Hurricane Cliffs is covered by alluvial-fan and other Quaternary deposits so that all hanging-wall bedrock exposures but one are 0.2 to 2 miles (0.3-3 km) to the west. Even so, Moenkopi Formation red beds are smeared in the fault zone near the base of the cliffs. There is only one place, about 0.75 mile (1.2 km) north of the large, unnamed drainage in section 26, where the rocks on both sides of the fault zone are not covered. There, the fault zone is almost 0.5 mile (0.8 km) wide; most of the displacement takes place along a fault in the middle of the zone. Westward from the Woods Ranch Member of the Toroweap Formation exposed in the Hurricane Cliffs, these normal faults drop rock sequentially down-to-the-west beginning with the Fossil Mountain Member of the Kaibab Formation, the Rock Canyon Conglomerate and Timpoweap Members of the Moenkopi Formation, the Moenkopi red beds and Petrified Forest Member of the Chinle Formation that are partially covered by Quaternary alluvial deposits, and finally the Kayenta Formation. Continuing to the west, an antithetic fault is also within the Kayenta Formation. The only other instructive exposure of the Hurricane fault in The Divide quadrangle is nearly 4 miles (6.4 km) to the north, in the SW1/4 section 34, T. 42 S., R. 13 W., where the Brady Canyon Member of the Toroweap Formation is in fault contact with Moenkopi red beds, which are in turn in fault contact with the Petrified Forest Member. Alluvial-fan deposits there are not faulted (Lund and Everitt, 1998), suggesting that no Holocene surface rupture has occurred on this portion of the fault.

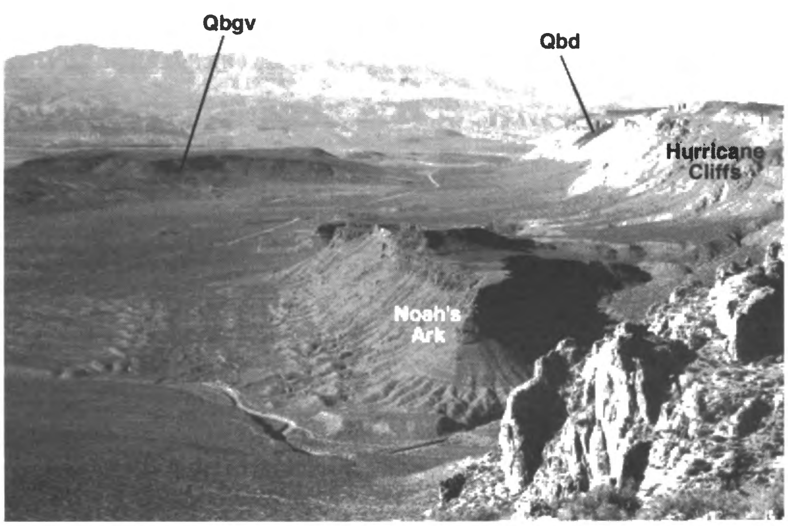


Figure 10. *The Hurricane fault is at the base of the Hurricane Cliffs, east of the Jurassic Kayenta Formation exposed at "Noah's Ark." Photo taken looking north from the SE1/4NE1/4 section 34, T. 43 S., R. 13 W., roughly perpendicular to cross section A-A′. The Grass Valley flow (Qbgv) is visible in the middle left, and the Pine Valley Mountains form the skyline. The basalt cascade of The Divide flow (Qbd) is visible atop the Hurricane Cliffs in the distance.*

Warner Valley Fault

The Warner Valley fault bounds the west side of the Warner Valley dome and is a normal fault with down-to-the-west displacement. This fault juxtaposes the Kayenta Formation against the Shnabkaib Member of the Moenkopi Formation, indicating 1,800 feet (550 m) of stratigraphic separation at cross section A-A′ (plate 2). Displacement decreases southward, where the fault dies out in northern Arizona, and northward where it becomes buried by alluvial-fan deposits. From the southern map boundary, the scarp trends generally north to section 28, T. 43 S., R. 13 W., where it turns to the north-northeast. It probably connects with or is en echelon with the Hurricane fault zone. A Quaternary fault scarp on the Warner Valley fault is 1,800 feet (550 m) long and offsets mixed alluvial and eolian sediments (Qae) about 9 feet (3 m).

Other Normal Faults

The east side of the Warner Valley dome is cut and bounded by a normal fault with down-to-the-east displacement, forming a pod-shaped horst with the Warner Valley fault. This unnamed fault has an offset of about 1,000 feet (300 m) at cross section A-A′ (plate 2). The fault is antithetic to the Hurricane fault zone.

Numerous other normal faults exist, mostly in the southwest quadrant of the quadrangle. The Navajo Sandstone and Kayenta Formation on the southeast corner of Sand Mountain are broken by several sets of northeast-trending faults that form small grabens. These faults accommodate monoclinal flexure, variously called "down bending" (Gardner, 1941) and "reverse drag" (Hamblin, 1965), toward the Hurricane fault zone. Some of these faults probably extend south into Warner Valley, where they are covered by Quaternary sediments; some faults may extend north through the Grass Valley flow, but if present, they are poorly expressed. Other small faults with minor offsets are within the pod-shaped horst of Triassic rocks and east of the horst toward the Hurricane Cliffs. Additionally, several faults cut basalt flows on the hanging wall of the Hurricane fault zone.

Joints and Fractures

All competent bedrock units in the quadrangle are fractured, but the most prominent joints are in the massive sandstone beds of the upper part of the Kayenta Formation and the Navajo Sandstone at Sand Mountain, and in the Shinarump Conglomerate Member of the Chinle Formation that caps Little Creek Mountain. The joints in the Shinarump Conglomerate Member are generally spaced from a few feet to a few tens of feet and form a conjugate set subparallel to the strike and dip of bedding. The joints control the Liesegang banding of iron-manganese oxides, which commonly form "picture stone."

Willis and Higgins (1995) recognized three main types of joints in the extensive exposures of Navajo Sandstone of the Washington quadrangle to the northwest; two of these are prominent in The Divide quadrangle at Sand Mountain. The first type form a very prominent joint pattern of generally parallel, high-angle, open joints that trend north. Spacing is generally uniform over large areas although there are local areas of higher joint density. In several areas these joints form a conjugate set with northwest-trending joints. Joints in this category are generally not healed or recemented and in many areas are differentially weathered, forming straight, narrow gaps in the rock a few inches to several feet wide and locally more than 50 feet (15 m) deep.

The second type of joints are less pervasive, but show up as prominent features on aerial photographs. These joints are widely spaced, high-angle, parallel joints that mostly trend northeast. They are distinguished by strong siliceous and calcareous recementation that is generally more resistant than the country rock, causing them to weather to prominent linear ridges. Some brecciation is generally near the fracture and in a few cases cross-beds in the sandstone are offset up to a few feet.

ECONOMIC GEOLOGY

A variety of geologic resources have been developed in The Divide quadrangle. Gravel, sand, road fill, and riprap are currently in high demand because of rapid development of the region. Stone is used for construction and ornamental purposes. The quadrangle has also been explored for gypsum, petroleum, uranium, and paleoplacer deposits of precious metals. However, none of these potential resources are currently being developed. The Springdale Sandstone Member of the Moenave Formation, host to the silver, copper, and uranium mineralization in the Silver Reef mining district, is present in the quadrangle.

Gravel, Road Fill, Riprap, and Sand

Gravel, essential for construction, is presently the most important geologic resource in The Divide quadrangle. The best deposits are in alluvial fans associated with the Hurricane Cliffs and stream-terrace deposits along Fort Pearce Wash. The largest active pit is at the north edge of the quadrangle in alluvial-fan deposits. Some older gravel deposits are cemented with thick pedogenic carbonate (caliche). Most active pits are in young deposits that contain less carbonate.

Road fill was also acquired from deposits mapped as Qea and Qaco. Large talus boulders from the Shinarump Conglomerate and basalt flows are used as riprap, especially along the base of artificial-fill deposits. Sand for local use has been obtained from eolian sand deposits (Qes) near Fort Pearce Wash and in north Warner Valley.

Building Stone

Blocks of Kayenta Formation sandstone are taken from the talus in the east end of Warner Valley at the base of "Noah's Ark." The blocks are used for landscaping and retaining walls (Larry Gore, Bureau of Land Management, verbal communication, May 27, 1999). No rock quarries for building stone are present in The Divide quadrangle. However, outcrops of flagstone in the Timpoweap Member of the Moenkopi Formation and Kayenta Formation are extensive.

Ornamental Stone

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

Gypsum

The Woods Ranch Member of the Toroweap Formation and the Harrisburg Member of the Kaibab Formation locally contain gypsum, but typically as impure beds and gypsiferous mudstone of unknown economic importance. They could provide small blocks of massive gypsum (alabaster) for sculpting. Thicknesses of these gypsum intervals vary due to secondary flowage, but outcrops are typically 10 to 30 feet (3-9 m) thick. The Shnabkaib Member of the Moenkopi Formation also has bedded gypsum, but beds are thin and contain abundant claystone and sandstone contaminants. No gypsum has been mined from the quadrangle.

Metals

In his reconnaissance examination of copper-uranium deposits west of the Colorado River for the U.S. Atomic Energy Commission, Everhart (1950) included the "Fort Pearce deposit in a Chinle sandstone" (Petrified Forest Member) as a source of uranium. This deposit, near the southwest corner of the quadrangle just south of the north line of section 31, T. 43 S., R. 13 W., is also included in subsequent work by Finch (1967), which was also prepared partly on behalf of the Atomic Energy Commission. A mine shaft is about 10 feet (3 m) deep and is kept open by a timber stockwork. Two other uranium prospects in Petrified Forest strata are along the south border of the quadrangle in the SE1/4 section 31, T. 43 S., R. 13 W. (plate 1).

Finch and others (1987) included the east half of the quadrangle in an area with possible deep-seated, solution-collapse breccia pipes that could be potential hosts for economic deposits of copper and uranium minerals (see also Wenrich, 1985). Pipes formed in the deeply buried Mississippian Redwall Limestone provide the proper lithotectonic setting for such mineralization (Wenrich and Sutphin, 1989). Such deep-seated structures cannot be distinguished with certainty by the surface appearance of overlying strata, which commonly exhibit shallow collapse structures caused by the removal of gypsum (Wenrich and others, 1986; Wenrich and Huntoon, 1989). The only way the potential of such pipes can be evaluated is by deep drilling. In the early 1980s, Uranereuz USA, Inc., of Reno, Nevada drilled several reported breccia pipes for uranium just north of the quadrangle, but test results are not available. I mapped no breccia pipes or shallow collapse features in The Divide quadrangle.

The Springdale Sandstone Member of the Moenave Formation, which is extensively exposed in the quadrangle, produced more than 7 million ounces (220,000 kg) of silver prior to 1910 in the Silver Reef mining district near Leeds, Utah, about 8 miles (13 km) north of the quadrangle (Proctor and Brimhall, 1986; Biek, 2003a, 2003b; Biek and Rohrer, in press). Proctor and Shirts (1991) provided an excellent account of the discovery, disbelief, rediscovery, and development of this unusual mineral occurrence. Anomalous concentrations of silver are present in the Springdale Sandstone well beyond the boundaries of the mining district and some gold has been reported, but none of ore grade (Proctor and Brimhall, 1986). Locally, significant copper and uranium concentrations are also present in the Springdale Sandstone at Silver Reef (James and Newman, 1986). In The Divide quadrangle, the Springdale Sandstone is exposed in Warner Valley where it is repeated several times by normal faulting.

Claims have been staked for paleoplacer deposits of precious metals from the red beds of the Moenkopi Formation around the base of Little Creek Mountain. The Little Creek Venture Company staked claims in the middle red member of the Moenkopi Formation in the SW1/4 section 12, T. 43 S., R. 13 W. and the lower red member in the NE1/4 section 25, T. 43 S., R. 13 W. Master Petroleum of Bryon, Texas reportedly staked similar claims (Larry Gore, Bureau of Land Management, verbal communication, May 27, 1999).

Oil and Natural Gas

No oil or gas has been produced from The Divide quadrangle. The nearest production was from the Virgin oil field, which was first developed in 1907, about 7 miles (11 km) northeast of the quadrangle, adjacent to Zion National Park. Production through 1963 was 195,000 barrels (31,000 m^3) of oil from 30 wells, although over 200 wells were drilled (Eppinger and others, 1990). Oil was derived from a sandstone and vuggy limestone interval 1 to 8 feet (0.3-2.4 m) thick in the uppermost part of the Timpoweap Member of the Triassic Moenkopi Formation, with minor production from the Pennsylvanian Callville Limestone. The brown to black oil from the Virgin field ranges from 22° to 32° API gravity and has a mixed paraffin-asphalt base (Heylmun, 1993). The field lies in a small synclinal pocket near the axis of a broad, low-relief anticline that plunges gently northward. After erosion caused the reservoir pressure to dissipate, the oil drained from the anticline into small synclinal pockets on the nose. The accumulations were also controlled by local porosity and fracturing (Heylmun, 1993).

Table 1 summarizes the four petroleum exploration wells in The Divide quadrangle; each is plugged and abandoned. Only one of these, the Dawn Petroleum Federal 1, reported

Table 1. *Wildcat wells in The Divide quadrangle. From Utah Division of Oil, Gas and Mining. Formation tops not independently verified.*

Well	**So. Penn USL Knowles Skyline No.1**	**Federal 1**	**Federal No. 1**	**Glen Coluas No. 1**
API Number	4305310602	4305310302	4305320044	4305310635
Location	NW1/4NE1/4 sec. 28 T. 43 S., R. 13 W.	SW1/4SW1/4 sec. 31 T. 43 S, R. 12 W.	SW1/4SW1/4 sec. 14 T. 43 S., R. 13 W.	NE1/4NE1/4NE1/4 sec. 25
Date Drilled	1960	1962	1966	1964
Company	Intex Oil Co.	Dawn Petroleum, Inc.	Devereax Co.	K-T Petroleum Co.
Total Depth feet (m)	3,006 (917)	1,353 (413)	6,000 (1,829)	6,260 (1,909)
Formation Tops feet (m)	Toroweap Fm. 905 (276)	Kaibab Fm. 150 (46)	Coconino Ss. 996 (304)	Coconino Ss. 1,170 (357)
	Coconino Ss. 1,425 (435)	Coconino Ss. 950 (290)	Pakoon 2,030 (619)	Pakoon Dolomite 2,505 (764)
	Pakoon Dolomite 2,745 (837)		Mississippian 3,130 (954)	Mississippian 3,570 (1,088)
				Devonian 4,535 (1,383)

oil shows, probably from the Fossil Mountain Member of the Kaibab Formation between a depth of 835 and 880 (255-268 m) feet. Records of the Oil, Gas and Mining Division, Utah Department of Natural Resources, show that an additional well, the Virgin Federal No. 3 in the NW1/4NW1/4NW1/4 section 36, T. 42 S., R. 13 W., was permitted but apparently never drilled.

A hydrocarbon tar sand deposit, described in records of the Energy and Minerals Resources Program of the Utah Geological Survey, is between the top of the Hurricane Cliffs and the southern two basalt-capped hills of "White Face" and "The Wart" in the NE1/4 section 34, T. 42 S., R. 13 W. The location is also included in the compilation of surface and shallow oil-impregnated rocks and shallow oil fields in the United States by Ball Associates Ltd. (1965) and on Ritzma's (1979) map of oil-impregnated rock deposits of Utah. The asphalt-like seep is in the Timpoweap Member of the Moenkopi Formation, which was the primary producing interval in the Virgin oil field (Blakey, 1974, 1977, 1979).

Geothermal Resources

The Divide quadrangle is in an area having geothermal potential (Mabey and Budding, 1985; Budding and Sommer, 1986; Blackett and Wakefield, 2002). Quaternary basalt vents in the region, some as young as about 10,000 years, could be an indicator of geothermal potential. However, basalts are believed to ascend through relatively small pipes from depths of several miles (Budding and Sommer, 1986). The hydrothermal alteration of, and emplacement of minerals into, the Permian Harrisburg Member of the Kaibab Formation along the Virgin anticline just west of the quadrangle may be another indicator of geothermal potential (Higgins, 1998). No hot springs are known in the quadrangle, but hot springs are present 4 miles (6 km) to the north. The highest recorded spring water temperature in the area is 108°F (42°C) at Pah Tempe Hot Springs between Hurricane and LaVerkin (Budding and Sommer, 1986).

WATER RESOURCES

Water is of great importance in the St. George Basin since the population is rapidly increasing and much of the area receives only 10 to 12 inches (25-30 cm) of precipitation per year (Cordova and others, 1972; Cordova, 1978; Clyde, 1987; Horrocks-Carollo Engineers, 1993; Utah Division of Water Resources, 1993). Water availability and use for the Kanab Creek/Virgin River Basin is summarized in the 1993 State Water Plan (Utah Division of Water Resources, 1993), as is development, regulatory, and other issues that relate to water management in the area. A cooperative study by the Utah Geological Survey (Hurlow, 1998) and the U.S. Geological Survey Water Resources Division (Heilweil and others, 2000) evaluated major aquifers and hydrogeology of the central Virgin River basin.

Surface Water

Cordova and others (1972) and Sandberg and Sultz (1985) summarized flow data on perennial streams in the area and reported on surface-water quality in the upper Virgin River basin; however, no perennial streams flow across The Divide quadrangle. Fort Pearce Wash cuts across the southwest corner of the quadrangle. It has an estimated average annual flow of 2,000 acre-feet (2,500,000 m^3) but is dry most of the year, as are Gould Wash, Frog Hollow, and Workman Wash that cut across the northeast corner of the quadrangle. Many catchment ponds have been constructed to pool runoff water, particularly in the east half of the quadrangle. The few perennial springs in the quadrangle flow for short distances down their drainages before sinking into the alluvium.

The east half of the 960 acre (390 hectare) Sand Hollow Reservoir is in the northwest corner of the quadrangle on Sand Mountain. It is operated by the Washington County Water Conservancy District as an off-line reservoir. Virgin River water is pumped into it during peak runoff months and then allowed to re-enter Quail Creek Reservoir by gravity flow during the summer months. An estimated 10,000 acre-feet (12,000,000 m^3) will be utilized from the 28,000 acre-foot (35,000,000 m^3) reservoir annually, with an additional 5,000 acre-feet (6,000,000 m^3) recovered by several down-gradient wells in the Navajo Sandstone as ground water is recharged by the reservoir (Washington County Water Conservancy District, 1997).

Ground Water

The Virgin River controls base level in the quadrangle and the unconfined potentiometric surface slopes northwest toward the river (Cordova and others, 1972; Cordova, 1978; Clyde, 1987). Important aquifers in the quadrangle include the Shinarump Conglomerate Member of the Chinle Formation; the Moenave, Kayenta, and Navajo Formations; and thin unconsolidated deposits (Cordova and others, 1972; Clyde, 1987). Of these, the Navajo aquifer is the most important. Regionally, it consists of about 2,000 feet (600 m) of porous, well-sorted, fine- to medium-grained sandstone, but ground water is best transmitted through the formation along fractures (Cordova, 1978; Hurlow, 1998; Heilweil and others, 2000). Only the lower 1,000 feet (300 m) of Navajo Sandstone is exposed in the northwest part of the quadrangle. Regionally, the primary recharge area for the Navajo aquifer is limited to the Navajo Sandstone outcrop area (Heilweil and others, 2000) since the overlying Temple Cap and Carmel Formations form an impervious barrier that effectively seals the Navajo from surface waters. Recharge is from precipitation on the Navajo Sandstone and from streams that cross the Navajo. Wells in the Navajo aquifer north and northwest of the quadrangle are a major source of domestic water for the area (Horrocks-Carollo Engineers, 1993; Willis and Higgins, 1996). No perennial streams cross the Navajo aquifer in The Divide quadrangle, so the only recharge currently comes from precipitation; however, Sand Hollow Reservoir is expected to recharge the Navajo aquifer at a rate of 6 to 15 cubic feet per second (cfs) (0.18-0.45 m^3/s) or 4,500 to 11,000 acre-feet (5,500,000-14,000,000 m^3) annually, under full reservoir conditions. Six to ten wells down gradient from the reservoir are expected to recover 5,000 acre-feet (6,000,000 m^3) of ground water annually, which will be fed into the St. George City water system

(Washington County Water Conservancy District, 1997).

Due to the isolation of the Navajo aquifer at Sand Mountain from potential recharge areas other than precipitation, virtually no springs are in the northwest quadrant of the quadrangle. Springs along the contact between the upper part of the Kayenta Formation and the Navajo Sandstone are common to the west of the quadrangle on the opposite limb of the Virgin anticline where south-flowing water "spills" over this natural threshold (Higgins and Willis, 1995). Only one named spring, Swett Spring, is in The Divide quadrangle. Located at the base of Little Creek Mountain in the SE1/4 section 24, T. 43 S., R. 13 W., it generally flows at a rate of 0.016 cfs (0.0005 m^3/s) from the Virgin Limestone Member of the Moenkopi Formation. A few other small springs provide water for limited use. The spring water is primarily used for stock watering.

Water quality for many of the springs and wells in the quadrangle is reported in Cordova and others (1972), Cordova (1978), Clyde (1987), and Freethey (1993). In general, water is fresh and of high quality in the Navajo aquifer, but older formations generally have a higher total dissolved solids content. Water quality in unconsolidated aquifers varies considerably depending upon local conditions.

GEOLOGIC HAZARDS

The Divide quadrangle is in a tectonically active area with several faults capable of generating large earthquakes. The quadrangle contains many steep slopes with landslide and rock-fall hazards. It includes formations that contain expansive, soluble, or compactible sediments that may cause foundation problems, and radon-producing minerals, which may create a health hazard. Flash floods and debris flows are also of concern, as is the potential for damage by blowing sand. The possibility of volcanic hazards from either local or distant sources is slight.

Earthquakes

The Divide quadrangle is within the Intermountain seismic belt and the area has experienced several historical earthquakes of magnitude 4 or greater (Christenson and Deen, 1983; Anderson and Christenson, 1989; Christenson and Nava, 1992; Hecker, 1993). Historical earthquakes have not exceeded magnitude 6.5 in southwest Utah; however, geological studies indicate that faults in the region could produce earthquakes of magnitude 7 to 7.5 (Arabasz and others, 1992; Lund and others, 2001). The largest historical earthquake was an estimated magnitude 6.3 event in 1902 with an epicenter about 20 miles (32 km) north-northwest of the quadrangle near the Pine Valley Mountains (Arabasz and others, 1979; Christenson and Deen, 1983). The most recent large earthquake was a magnitude M_L 5.8 event on September 2, 1992, with an epicenter 5 miles (8 km) west of The Divide quadrangle (Pechmann and others, 1995). Ground shaking was strongly felt in the St. George and Washington City areas and caused minor damage as far as 95 miles (153 km) from the epicenter (Olig, 1995). Seismologic data indicate that the earthquake originated at a depth of 9 miles (15 km) and was caused by dominantly normal faulting on a north-south-trending fault (Pechmann and others, 1995). Distribution of the limited aftershocks implies a west-dipping slip plane, possibly coincident with the Hurricane fault (Pechmann and others, 1995). Ground accelerations in the St. George and Washington City areas were not measured, so an empirical relationship (Campbell, 1987) was used to estimate a peak horizontal ground acceleration (PHA) of 0.21 g for the area (Black and others, 1994). Ground shaking triggered landslides that destroyed homes and utilities in Springdale, 27 miles (44 km) east of the epicenter, and caused liquefaction, lateral spreads, and sand blows in poorly graded sand along the Virgin River (Black and Christenson, 1993; Black, 1994; Black and others, 1994). It also caused a change in flow of Pah Tempe Hot Springs near Hurricane and triggered many rock falls, at least two of which caused property damage (Black and others, 1995). No surface rupture was reported from the 1992 event (Black and Christenson, 1993). Total losses from direct damage, response costs, and lost property values approached $1 million, but this value is likely a minimum (Carey, 1995).

Three large fault zones in the area have documented Quaternary movement and a few smaller faults have possible Quaternary movement (Christenson and Deen, 1983; Anderson and Christenson, 1989; Hecker, 1993; Lund and Everitt, 1998; Lund and others, 2001). Six sites along the Utah portion of the Hurricane fault have scarps that cut unconsolidated deposits; the youngest sediment displaced is latest Pleistocene or early Holocene in age (Lund and Everitt, 1998). The Warner Valley fault displaces unconsolidated sediment near the center of the southern part of the quadrangle about 9 feet (3 m) in a north-south-trending scarp that is 1,800 feet (550 m) long. The Washington fault also trends north-south about 5 miles (8 km) west of the quadrangle (figure 1). It displaces 10,000- to 25,000-year-old Quaternary sediments 11.5 feet (3.5 m) in the NW1/4 section 13, T. 43 S., R. 15 W. (Anderson and Christenson, 1989), as well as the 900,000-year-old Washington basalt flow about 20 feet (6 m) (Higgins, 1998). The Grand Wash, Reef Reservoir, and Gunlock faults lie about 22 miles (35 km) west of the quadrangle (figure 1) (Hammond, 1991; Hintze and Hammond, 1994; Hintze and others, 1994).

Future earthquakes in the area could generate ground-shaking and related hazards such as surface fault rupture, slope failure, liquefaction, flooding, and tectonic subsidence (Christenson and Nava, 1992). Poorly consolidated sediment, such as is present in parts of The Divide quadrangle, can amplify ground motions relative to sites on bedrock, thereby increasing the potential for damage. Flooding may result from failure of nearby dams; diversion or destruction of canals, aqueducts, water lines, or streams; increased ground-water discharge; seiches (large waves) in reservoirs; or tectonic subsidence in areas of shallow ground water or around reservoirs. Fault movement sufficient to cause surface rupture would likely damage many structures in the surrounding area, especially older, unreinforced masonry buildings, and may rupture underground utilities. Rock falls caused by ground shaking are of increasing concern as development encroaches on steep slopes capped by basalt flows and resistant bedrock units. To address earthquake ground shaking, buildings should be constructed in accordance with seismic provisions of the International Building Code (2000).

Slope Failures

Many ridges and benches bounded by steep slopes in the quadrangle have landslide and rock-fall hazards. The stability of natural slopes is dependent on lithology, ground-water conditions, and attitude of bedding or jointing (Christenson and Deen, 1983). The most common causes of slope destabilization include loss of support at the base of the slope because of stream erosion or excavations for construction, increased pore pressure by adding water or increasing the load, ground shaking resulting from earthquakes, and strong vibrations caused by construction.

Landslides

Slip surfaces of landslides within the quadrangle develop primarily in the middle red member of the Moenkopi Formation along the south edge of Little Creek Mountain. The landslides involve overlying bedrock units of the Moenkopi Formation and talus. Most of the large landslides along the south edge of Little Creek Mountain probably last moved during Pleistocene time when conditions were wetter than they are today (Christenson, 1992). Potential exists for landslides to develop in the clay-rich Petrified Forest Member of the Chinle Formation exposed throughout much of Warner Valley. The clay absorbs moisture and forms a weak, pasty substance that is prone to slumping (Harty, 1992).

Rock Falls

Rock falls are common in the quadrangle as evidenced by abundant rock debris both on and at the base of steep slopes. Rock falls happen naturally as less resistant rock layers are eroded from beneath more resistant, fractured rock. They may also be triggered by earthquake ground shaking. Human activities that artificially increase the slope of a hillside, introduce significant moisture to hilltops, or add substantial weight to the edge of hilltops also increase the potential for rock falls. Buildings constructed at the top of steep slopes are at risk from damage by rock falls as their foundations are undermined, and those constructed on or at the base of slopes are at risk because of potential impact.

Steep slopes capped by basalt, Navajo Sandstone, Shinarump Conglomerate Member of the Chinle Formation, and the Kaibab and Toroweap Formations have the greatest potential for rock fall. Rock falls from basalt-capped ridges are particularly dangerous since the basalts are dense, jointed, and form equidimensional blocks that roll well and do not break up during descent. Major rock-fall hazards involving the Kayenta Formation and Navajo Sandstone exist around the south edge of Sand Mountain, and around Little Creek Mountain, which is capped by the Shinarump Conglomerate Member of the Chinle Formation. Massive sandstone beds of these units have intersecting joints, making it common for blocks to detach and roll. Several blocks fell from these cliffs during the 1992 St. George earthquake (Christenson and Nava, 1992). Also, massive limestone boulders from the Kaibab and Toroweap Formations roll down the steep face of the Hurricane Cliffs.

As the development of subdivisions and other structures continues, the probability of damage from rock falls increases. Although a rock-fall hazard exists near the base of all slopes, site-specific investigations indicate that the local degree of hazard varies significantly and is dependent upon several variables. These include distance of the site from the base of the slope, nature and stability of slope debris, local protection provided by previous rock-fall blocks, and the presence of erosional gullying in the slope that may deflect falling rocks (Christenson, 1992).

Problem Soil and Rock

Although development within the quadrangle is currently minimal, several highly publicized incidents of structural damage in the area due to problem soil and rock have increased public awareness of such potential problems. Hurricane City officials, responding to the concern, now require site evaluations and laboratory reports for new subdivisions. Hazards are of three types: expansive soil and rock, soluble soil and rock, and collapsible or compressible soil.

Expansive Soil and Rock

Bentonitic clay from altered volcanic ash in the mudstone and shale intervals of the Petrified Forest Member of the Chinle Formation (locally known as "blue clay"), which swells when moistened, is responsible for most of the expansive soil and rock problems in the area. In The Divide quadrangle, the Petrified Forest Member covers extensive areas, including much of Warner Valley. In swell tests using a 60-pounds-per-square-foot (psf) (293 kg/m^2) surcharge load, expansion greater than 12 percent is classified as critical (Rick Chestnut, Kleinfelder, verbal communication, May 28, 1998). Clay from the Petrified Forest Member is highly variable but typically swells 15 to 20 percent and some samples have tested as high as 38 percent. Based on Atterburg-limits test results, the clay is classified as CH soil, or a "lean to fat clay," with a plasticity index of 15 to 30 and liquid limit of 30 to 55. Even in some tests that apply pressures of 3,000 to 5,000 psf (14,650-24,417 kg/m^2), the clay can still swell 2 to 5 percent (Rick Chestnut, Kleinfelder, verbal communication, May 28, 1998). Thick overburden or other measures are necessary to protect a structure from this amount of swelling.

The Shnabkaib Member of the Moenkopi Formation, which is well exposed in east Warner Valley and near the base of Little Creek Mountain, also has expansive clays. To a lesser degree, mudstone intervals in the Virgin Limestone Member and the three red members of the Moenkopi Formation, as well as the Whitmore Point Member of the Moenave Formation, can create problems due to expansion (Christenson and Deen, 1983). In addition, easily eroded, fine-grained soil with moderate swell potential (4 to 8 percent) is common on flat to very gentle slopes on flood plains, alluvial lowlands, and benches (Christenson and Deen, 1983).

Common signs of expansive soils are cracked foundations, heaving and cracking of floor slabs and walls, and failure of wastewater disposal systems (Mulvey, 1992). Expansive soils can also damage sidewalks, roads, porches, garages, driveway and patio slabs, and underground utilities. Damage can happen quickly; Thompson (1992) found an average time lapse of two years and seven months from construction to repairs in similar settings in the Denver, Colorado area.

Soluble Soil and Rock

Soluble soil and rock – which contain minerals that dissolve when exposed to water – are common in the quadrangle. These include gypsiferous deposits, weathered limestone, and pedogenic and ground-water-deposited calcium carbonate (Christenson, 1992). The Shnabkaib Member, and to a lesser degree, the red members of the Moenkopi Formation and the lower part of the Kayenta Formation, are subject to settlement, collapse, piping, and local heaving problems due to dissolution of gypsum (Christenson and Deen, 1983). Piping may also affect the Petrified Forest Member of the Chinle Formation. Solubility tests run by Kleinfelder on the Shnabkaib Member show an average of 3 to 8 percent of the sample is dissolvable (Rick Chestnut, Kleinfelder, verbal communication, May 28, 1998). As development continues, weathered limestone and gypsum of the Kaibab and Toroweap Formations could present a similar problem.

Pedogenic carbonates developed in terrace gravel and older geomorphic surfaces are common in the quadrangle and impede water percolation if undisturbed. However, construction may fracture the seal and increase weathering (Christenson, 1992). Honeycomb gypsum and solution cavities as much as 2 feet (0.6 m) wide are sometimes encountered in the area during excavation (Dave Black, Black, Miller and Associates, verbal communication, 1995).

Collapsible and Compressible Soil

Hydrocompaction, which causes subsidence, may present a problem in certain geologically young sediments present in the quadrangle (Mulvey, 1992). Subsidence happens in loose, dry, low-density deposits that decrease in volume or collapse when they are saturated or loaded for the first time since deposition (Costa and Baker, 1986). To measure collapsibility, a sample is weighted with 1,000 psf (4,883 kg/m^2) and then saturated with water. The percent of volume change, which averages 2 to 6 percent in the region, is then calculated (Rick Chestnut, Kleinfelder, verbal communication, May 28, 1998). Debris flow deposits that accumulate on alluvial fans at the mouths of drainages may contain collapsible soils. Some of these areas are currently being subdivided in The Divide quadrangle. Other low-density deposits, such as eolian silt and sand, mainly derived from the upper portion of the Kayenta Formation and the Navajo Sandstone, are commonly poorly consolidated and require compaction prior to construction.

Blowing Sand

As development continues, blowing sand may become a genuine concern in the area. Currently, blowing sand causes the migration of sand dunes that must be periodically removed from the Warner Valley road in order to keep the road passable. The development of facilities around Sand Hollow Reservoir will require special efforts to keep sand from encroaching into unwanted areas such as ball fields, camping areas, and the paved road to the off-highway vehicle (OHV) staging area.

Flooding and Debris Flows

Floods are probably the most frequent and consistently destructive natural hazard in the area. Most of the historical record of flooding published by the Utah Division of Comprehensive Emergency Management (1981) was summarized by Christenson and Deen (1983). The high flood hazard results from the complex interaction of the area's rugged topography and seasonal weather patterns (Lund, 1992). Flooding within the quadrangle is influenced by snow melt and storms in the region. Although the conditions that cause flooding are not controllable, the relative hazard posed by flooding is generally manageable with wise planning that encourages preservation of natural flood plains and discourages channelization and development within the 100-year flood plain.

Fort Pearce Wash and its tributaries provide drainage for the southern part of The Divide quadrangle, whereas Gould Wash and its tributaries drain the northeastern part. Any water on Sand Mountain usually does not flow very far northward, but may flow into Sand Hollow Reservoir. Locally, levees and dams were built on many smaller drainages to inhibit flooding of farmland and Hurricane City; however, most of these structures are not designed to adequately provide protection for subdivisions or more extensive development.

Debris flows are poorly sorted masses of clay- to boulder-sized sediment that flow in a muddy slurry and are deposited on alluvial fans. They commonly develop during or after a cloudburst storm as colluvium, stream-channel alluvium, and other loose deposits become saturated with water and flow down gullies and washes. Development along the base of the Hurricane Cliffs increases the potential for damage from debris flows on alluvial fans as runoff drains the area above the cliffs after a storm.

Radon

Radon gas is derived primarily from the decay of uranium-238 (Solomon, 1992a). Alpha particles, emitted by atoms as they decay, are the main danger. If radon gas is inhaled, these particles can cause serious damage to sensitive cells, eventually causing lung cancer (Wilbraham and others, 1990). The U.S. Environmental Protection Agency (EPA) estimated that 8,000 to 40,000 Americans die each year from lung cancer caused by long-term radon inhalation (Schmidt and others, 1990).

Radon can enter homes and offices built on soil and rock rich in uranium through porous building materials, cracks in basement floors, walls or slabs, or other openings below grade. If the home is well insulated, the gas may be trapped inside and inhaled by the occupants. Because radon gas is colorless, odorless, and causes no pain when it is inhaled, most people are never aware of its presence.

Indoor-radon levels measured in the southern St. George basin during a 1988 statewide survey conducted by the Utah Division of Radiation Control (UDRC) indicated local high radon levels (Sprinkel and Solomon, 1990). A map of potential radon hazards in Utah shows The Divide quadrangle as having a moderate radon-hazard potential, which could result in an indoor radon concentration of 4 to 10 picocuries per liter (pCi/L) of air (Solomon, 1992a; Black, 1993), well above the action level of 4 pCi/L specified by the EPA and U.S. Department of Health and Human Services (1986). Above this level, hazard-reduction procedures are recommended. The average ambient outdoor radon level is 0.2 pCi/L (Monroe and Wicander,1998).

The primary geologic prerequisite for elevated indoor-radon levels is uranium in the soil around building foundations. Solomon (1992b) measured uranium levels in the southern St. George basin using gamma-ray spectrometry and found that high uranium levels originate from three distinct sources. A local primary source where levels were highest (up to 6.7 parts per million [ppm]) is the tuffaceous, fine-grained rock and residual bentonitic soil of the Petrified Forest Member of the Chinle Formation, which is extensively exposed in The Divide quadrangle. Levels were also high (up to 3.4 ppm) in granular soils of the Virgin River flood plain, which are derived in part from Miocene intrusive igneous rocks eroded from the Pine Valley Mountains to the north, but which are not present in The Divide quadrangle (Cook, 1957). Secondary uranium mobilization, suggested by high uranium/thorium ratios, has also resulted in uranium enrichment in local areas of rock and soil.

Two important geologic factors inhibit the ability of radon to migrate into buildings: shallow ground-water levels, since pore water effectively traps radon, and impermeable soil, since there must be soil pathways through which the gas can migrate. Solomon (1992b) contoured a map of the southern St. George basin showing depth to ground water using well data from Cordova and others (1972), and a map of soil permeability using data from a soil survey made by Mortensen and others (1977). He then used a combination of all three factors (uranium concentration, ground-water level, and soil permeability) to derive a map showing the relative potential for elevated indoor-radon levels in the southern St. George basin.

Solomon's map, which ends just west of The Divide quadrangle, indicated that the most extensive areas of high-hazard potential are in the small hills underlain by the Petrified Forest Member of the Chinle Formation and in the alluvial deposits of the Virgin River flood plain. The factor common to areas of high-hazard potential is a uranium level greater than 3 ppm. Permeability varies considerably in these areas, from relatively high in the flood plain to relatively low in the shale of the Petrified Forest Member, but ground water is nowhere less than 10 feet (3 m) deep (Solomon, 1992b). The area of the adjacent Washington Dome quadrangle that was included in his study was of moderate radon-hazard potential.

Because many non-geologic factors influence indoor-radon levels, a quantitative relationship between geologic factors and indoor-radon levels does not exist. However, relative hazard potential can be used to prioritize indoor testing and to evaluate the need for radon-resistant new construction (Solomon, 1996).

Volcanism

Volcanic hazards in the area are of two main types: ash and lava flows from local sources, and wind-blown ash from distant sources (Mabey, 1985; Bugden, 1992). Only hazards from local sources are discussed here. While volcanic activity in southwest Utah during mid-Cenozoic time (mostly 10 to 30 million years ago) was characterized by violent eruptions of large volumes of felsic pyroclastic material, late Cenozoic (past few million years) eruptions resulted in smaller mafic cinder cones and basalts. The most recent basalt flow in the area, the Santa Clara flow, is 15 miles (24 km) west of the quadrangle. Luedke and Smith (1978) indicated this flow is less than 1,000 years old. However, Willis and Higgins (1996) believe it is 10,000 to 20,000 years old based on downcutting next to the flow and weathering of the basalt. Such relatively young flows and regional geothermal activity suggest that additional eruptions may occur. Future eruptions can be expected to follow a similar pattern, producing relatively small cinder cones and slow-moving flows that follow topographic lows. Flows from future eruptions would likely follow drainages into populated areas. Eruptions would likely be preceded by earthquake swarms, which could provide some advance notice of an impending eruption. Hazards from future eruptions include damage and injuries from molten lava, explosively ejected cinders and volcanic gas, blockage of transportation corridors and rivers, disruption of utilities, and fires (Mabey, 1985).

SCENIC AND RECREATIONAL RESOURCES

The Divide quadrangle is in the "red rock" country of southwest Utah and is surrounded by buttes and mesas of red sandstone. Many are capped by black basalt, creating a striking visual contrast. The quadrangle is also near the lowest elevation in the state and has the warmest climate. The combination of the striking scenery and warm climate make the area a popular recreation and retirement destination. It is near several popular recreation sites, including Snow Canyon State Park and Zion National Park.

Sand Mountain is the most popular area for year-round off-highway vehicle (OHV) use in Washington County. The sand dunes are low, rounded hills that provide a challenge for novice to intermediate riders. The newly completed Sand Hollow Reservoir provides water-based recreation such as boating and fishing. Recreation facilities at Sand Hollow Reservoir include three camping areas, one group picnic activity area, a day-use parking area, a marina flanked by two beaches, and a paved road to an OHV staging area. Views from this area of the Pine Valley Mountains and Virgin anticline to the north and the cliffs of Zion National Park to the east are stunning.

Dinosaur footprints and trackways, near the west edge of the quadrangle in Warner Valley in the northwest corner of section 30, T. 43 S., R. 13 W., were discovered in May 1982 by Gary Delsignore of Cedar City. At that time, 161 separate prints representing 23 trackways were identified as *Grallator*, a coelurosaurid, and *Eubrontes*, a possible plateosaurid (Miller and others, 1989). They are actually within the lower part of the Kayenta Formation, not in the Moenave Formation as stated on an interpretative sign at the site. The BLM placed a metal diversion structure in the wash to keep runoff and debris from destroying or covering a portion of the tracks.

History enthusiasts enjoy following the route of the historical Honeymoon Trail, which crosses the quadrangle and was commonly used by couples coming from settlements in Arizona to be married in the St. George Temple. This trail traverses the southern part of the quadrangle, winding down off of the Hurricane Cliffs just to the south of the quadrangle boundary and then continuing west through Warner Valley. Views in all directions from the top of the Hurricane Cliffs are captivating.

ACKNOWLEDGMENTS

Thanks to my mentor Lehi F. Hintze (Brigham Young University) for sharing his expertise during many hours in the field. This study has benefitted from numerous field trips and discussions with Spencer J. Reber, Ward O. Abbott, Charles D. Snow, and Cliff Phillips. Bob Biek of the Utah Geological Survey (UGS) and Larry Gore of the Bureau of Land Management were particularly helpful in collecting samples and in the preparation of this report. Lehi Hintze, Bob Biek (UGS), Hellmut Doelling (UGS), Mike Hylland (UGS), and Grant Willis (UGS) reviewed the report and offered valuable advice; Bob Blackett, Sandy Eldredge, Hugh Hurlow, and Bill Lund, each with the UGS, also reviewed parts of the report. Bob Biek edited the report and plates 1 and 2. Morgan Jensen with the Washington County Water Conservation District provided information concerning plans for Sand Hollow Reservoir. Dave Black of Black, Miller and Associates, and Rick Chestnut of Kleinfelder, contributed their knowledge of the geologic hazards in the area. John S. Hayden provided assistance with fieldwork. Brandon Darrington and Amy Higgins helped measure sections. Special thanks to my brother, Harold D. Mitchell, who donated flying time so that I could obtain photographs of the quadrangle.

REFERENCES

Anderson, R.E., and Barnhard, T.P., 1993, Heterogeneous Neogene strain and its bearing on horizontal extension and vertical contraction at the margin of the extensional orogen, Mormon Mountains area, Nevada and Utah: U.S. Geological Survey Bulletin 2011, 43 p.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p.

Arabasz, W.J., and Julander, D.R., 1986, Geometry of seismically active faults and crustal deformation within the Basin and Range – Colorado Plateau transition in Utah: Geological Society of America Special Paper 208, p. 43-74.

Arabasz, W.J., Pechmann, J.C., and Nava, S.J., 1992, The St. George (Washington County), Utah, earthquake of September 2, 1992: University of Utah Seismograph Stations Preliminary Earthquake Report, 12:00 MDT, September 6, 1992, 6 p.

Arabasz, W.J., Smith, R.B., and Richins, W.D., 1979, Earthquake studies in Utah 1850-1978: University of Utah Seismograph Stations and Department of Geology and Geophysics Special Publication, 552 p.

Averitt, Paul, 1962, Geology and coal resources of the Cedar Mountain quadrangle, Iron County, Utah: U.S. Geological Survey Professional Paper 389, 72 p.

Ball Associates Ltd., compilers, 1965, Surface and shallow oil-impregnated rocks and shallow oil fields in the United States: U.S. Bureau of Mines Monograph 12, Interstate Oil Compact Commission, Oklahoma City, 375 p.

Best, M.G., and Brimhall, W.H., 1974, Late Cenozoic alkalic basaltic magmas in the western Colorado Plateaus and the Basin and Range transition zone, U.S.A., and their bearing on mantle dynamics: Geological Society of America Bulletin, v. 85, no. 11, p. 1,677-1,690.

Biek, R.F., 2003a, Geologic map of the Harrisburg Junction quadrangle, Washington County, Utah: Utah Geological Survey Map 191, 42 p., scale 1:24,000.

—2003b, Geologic map of the Hurricane quadrangle, Washington County, Utah: Utah Geological Survey Map 187, 61 p., scale 1:24,000.

Biek, R.F., and Rohrer, J.C., in press, Geology, mining history, and reclamation of the Silver Reef mining district, Washington County, Utah, *in* Gloyn, R.W., Park, G.M., and Spangler, Larry, editors, Mining camps of Utah: Utah Geological Association Publication 31.

Biek, R.F., Willis, G.C., Hylland, M.D., and Doelling, H.H., 2000, Geology of Zion National Park, Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 107-138.

Billingsley, G.H., 1990a, Geologic map of the Lizard Point quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-643, scale 1:24,000.

—1990b, Geologic map of the Purgatory Canyon quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 90-540, scale 1:24,000.

—1992a, Geologic map of the Yellowhorse Flat quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-442, scale 1:24,000.

—1992b, Geologic map of the Rock Canyon quadrangle, northern Mohave County, Arizona: U.S. Geological Survey Open-File Report 92-449, scale 1:24,000.

—1997, The Permian clastic sedimentary rocks of northwestern Arizona: U.S. Geological Survey Bulletin 2153-F, p. 108-124.

Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey, Miscellaneous Publication 91-3, 63 p.

Black, B.D., 1993, The radon-hazard potential map of Utah: Utah Geological Survey Map 149, 12 p., 1:1,000,000.

—1994, The Springdale landslide, Washington County, Utah, *in* Blackett, R.E., and Moore, J.N., editors, Cenozoic geology and geothermal systems of southwestern Utah: Utah Geological Association Publication 23, p. 195-201.

Black, B.D., and Christenson, G.E., 1993, Magnitude 5.8 St. George earthquake: Utah Geological Survey, Survey Notes, v. 25, no. 3-4, p. 25-29.

Black, B.D., Mulvey, W.E., Lowe, Mike, and Solomon, B.J., 1994, Investigation of geologic effects associated with the September 2, 1992, St. George earthquake, Washington County, Utah, *in* Mayes, B.H., and Wakefield, S.I., compilers, Technical reports for 1992-1993, Applied Geology Program: Utah Geological Survey Report of Investigation 224, p. 66-81.

—1995, Geologic effects, *in* Christenson, G.E., editor, The September 2, 1992 ML 5.8 St. George earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p. 2-11.

Blackett, R.E., and Wakefield, S.I., 2002, Geothermal resources of Utah, a digital atlas of Utah's geothermal resources: Utah Geological Survey Open-File Report 397, CD-ROM.

Blakey, R.C., 1974, Stratigraphic and depositional analysis of the Moenkopi Formation: Utah Geological and Mineralogical Survey Bulletin 104, 81 p.

—1977, Petroliferous lithosomes in the Moenkopi Formation, southern Utah: Utah Geology, v. 4, no. 2, p. 67-84.

—1979, Oil impregnated carbonate rocks of the Timpoweap Member, Moenkopi Formation, Hurricane Cliffs area, Utah and Arizona: Utah Geology, v. 6, no. 1, p. 45-54.

—1989, Triassic and Jurassic geology of the southern Colorado Plateau, *in* Jenny, J.P., and Reynolds, S.J., editors, Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 369-396.

Blakey, R.C., Basham, E.L., and Cook, M.J., 1993, Early and Middle Triassic paleogeography of the Colorado Plateau and vicinity, *in* Morales, Michael, editor, Aspects of Mesozoic geology and palenotology of the Colorado Plateau: Museum of Northern Arizona Bulletin 59, p. 13-26.

Bohannan, R.G., Lucchitta, Ivo, and Anderson, R.E., 1991, Geologic map of the Mountain Sheep Spring quadrangle, Mohave County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-2165, scale 1:24,000.

Budding, K.E., and Sommer, S.N., 1986, Low-temperature geothermal assessment of the Santa Clara and Virgin River valleys, Washington County, Utah: Utah Geological and Mineral Survey Special Study 67, 34 p.

Bugden, Miriam, 1992, Volcanic hazards of southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 193-200.

—1993, Geologic resources of Washington County, Utah: Utah Geological Survey Public Information Series 20, 25 p.

Campbell, K.W., 1987, Predicting strong ground motion in Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 87-585, p. L-1 to L-90.

Carey, Robert, 1995, Estimated economic losses, *in* Christenson, G.E., editor, The September 2, 1992 ML 5.8 St. George Earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p. 40.

Christenson, G.E., 1992, Geologic hazards of the St. George area, Washington County, Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 99-107.

Christenson, G.E., and Deen, R.D., 1983, Engineering geology of the St. George area, Washington County, Utah: Utah Geological and Mineral Survey Special Studies 58, 32 p., scale 1:24,000.

Christenson, G.E., and Nava, S.J., 1992, Earthquake hazards of southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 193-200.

Clyde, C.G., 1987, Groundwater resources of the Virgin River basin in Utah: Logan, Utah State University, Utah Water Research Laboratory, 104 p.

Cook, E.F., 1957, Geology of the Pine Valley Mountains, Utah: Utah Geological and Mineral Survey Bulletin 58, 111 p.

—1960, Geologic atlas of Utah – Washington County: Utah Geological and Mineralogical Survey Bulletin 70, 119 p., scale 1:125,000.

Cordova, R.M., 1978, Ground-water conditions in the Navajo Sandstone in the central Virgin River basin, Utah: Utah Division of Water Rights Technical Publication 61, 66 p., scale 1:250,000.

Cordova, R.M., Sandberg, G.W., and McConkie, Wilson, 1972, Ground-water conditions in the central Virgin River basin, Utah: Utah Department of Natural Resources Technical Publication 40, 64 p.

Costa, J.E., and Baker, V.R., 1986, Surficial geology – building with the earth: New York, John R. Wiley and Sons, 498 p.

Davis, G.H., 1999, Structural geology of the Colorado Plateau region of southern Utah with special emphasis on deformation bands: Geological Society of America Special Paper 342, 168 p.

Dobbin, C.E., 1939, Geologic structure of the St. George district, Washington County, Utah: American Association of Petroleum Geologists Bulletin, v. 23, p. 121-144.

Doelling, H.H., and Davis, F.D., 1989, The geology of Kane County, Utah – geology, mineral resources, and geologic hazards, with sections on petroleum and carbon dioxide by C.J. Brandt: Utah Geological Survey Bulletin 124, 192 p., 10 plates, scale 1:100,000.

Downing, R.F., 2000, Imaging the mantle in southwestern Utah using geochemistry and geographic information systems: Las Vegas, University of Nevada, M.S. thesis, 128 p.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography and paleoclimate of the Western Interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, p. 132-168.

Eppinger, R.E., Winkler, G.R., Cookro, T.M., Shubat, M.A., Blank, H.R., Crowley, J.K., Kucks, R.P., and Jones, J.L., 1990, Preliminary assessment of the mineral resources of the Cedar City 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 90-34, 146 p., scale 1:250,000.

Everhart, D.L., 1950, Reconnaissance examinations of copper-uranium deposits west of the Colorado River: U.S. Atomic Energy Commission RMO-659, issued by Technical Information Service, Oak Ridge, TN, 19 p.

Finch, W.I., 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geological Survey Professional Paper 538, 121 p.

Finch, W.I., Sutphin, H.B., Pierson, C.T., McCammon, R.B., and Wenrich, K.J., 1987, The 1987 estimate of undiscovered uranium endowment in solution-collapse breccia pipes in the Grand Canyon region of northern Arizona and adjacent Utah: U.S. Geological Survey Circular 1051, 19 p.

Freethey, G.W., 1993, Maps showing recharge areas and quality of ground water for the Navajo aquifer, western Washington County, Utah: U.S. Geological Survey Water Resources Division Map WRIR 92-4160, scale approximately 1:250,000.

Gardner, L.S., 1941, The Hurricane fault in southwestern Utah and northwestern Arizona: American Journal of Science, v. 239, p. 241-260.

Gregory, H.E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geological Survey Professional Paper 220, 200 p., scale 1:125,000.

Hacker, D.B., 1998, Catastrophic gravity sliding and volcanism associated with the growth of laccoliths – examples from early Miocene hypabyssal intrusions of the Iron Axis magmatic province, Pine Valley Mountains, southwest Utah: Kent State University, Ph.D. dissertation, 258 p., scale, 1:24,000.

Hamblin, W.K.,1965, Origin of "reverse drag" on the downthrown side of normal faults: Geological Society of American Bulletin, v. 76, p. 1,145-1,164.

—1970a, Late Cenozoic basalt flows of the western Grand Canyon, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geology Society Guidebook to the Geology of Utah, no. 23, p. 21-38.

—1970b, Structure of the western Grand Canyon region, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geology Society Guidebook to the Geology of Utah, no. 23, p. 3-20.

—1987, Late Cenozoic volcanism in the St. George basin, Utah: Geological Society of America Centennial Field Guide, Rocky Mountain Section, p. 291-294.

Hamblin, W.K., and Best, M.G., 1970, Road log, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geology Society Guidebook to the Geology of Utah, no. 23, p. 93-154.

Hamblin, W.K., Damon, P.E., and Bull, W.B., 1981, Estimates of vertical crustal strain rates along the western margins of the Colorado Plateau: Geology, v. 9, p. 293-298.

Hammond, B.J., 1991, Geologic map of the Jarvis Peak quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 212, 63 p., scale 1:24,000.

Hansen, W.R., 1991, Suggestions to authors of the reports of the United States Geological Survey, seventh edition: U.S. Geological Survey, 289 p.

Harty, K.M., 1992, Landslide distribution and hazards in southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 109-118.

Hayden, J.M., 2003, Interim geologic map of the Little Creek Mountain quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 417, 2 plates, scale 1:24,000.

Hecker, Suzanne, 1993, Quaternary tectonics of Utah with emphasis on earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 157 p., scale 1:500,000.

Heilweil, V.M., Freethey, G.W., Stolp, B.J., Wilkowske, C.D., and Wilberg, D.E., 2000, Geohydrology and numerical simulation of ground-water flow in the central Virgin River basin of Iron and Washington Counties, Utah: Utah Department of Natural Resources Technical Publication 116, 139 p.

Hesse, C.J., 1935, *Semionotus* cf *gigas* from the Triassic of Zion Park, Utah: American Journal of Science, 5th series, v. 29, p. 526-531.

Heylmun, E.B., 1993, Virgin field, *in* Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22, unpaginated.

Higgins, J.M., 1997, Interim geologic map of the White Hills quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 354, 94 p., scale 1:24,000.

—1998, Interim geologic map of the Washington Dome quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 363, 108 p., scale 1:24,000.

—2000, Geology of Snow Canyon State Park, southwestern Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 479-494.

—2002, Interim geologic map of the Veyo quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 401, 18 p., scale 1:24,000.

Higgins, J.M., and Willis, G.C., 1995, Interim geologic map of the St. George quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 323, 90 p., scale 1:24,000.

Hintze, L.F., 1986a, Stratigraphy and structure of the Beaver Dam Mountains, southwestern Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 1-36.

—1986b, Geologic map of the Beaver Dam Mountains, Washington County, Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, plate 2.

—1993, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 7, 202 p.

Hintze, L.F., Anderson, R.E., and Embree, G.F., 1994, Geologic map of the Motoqua and Gunlock quadrangles, Washington County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2427, 7 p., scale 1:24,000.

Hintze, L.F., and Hammond, B.J., 1994, Geologic map of the Shivwits quadrangle, Washington County, Utah: Utah Geological Survey Map 153, 21 p., scale 1:24,000.

Horrocks-Carollo Engineers, 1993, Culinary water resources study: St. George City Water and Power Department, June 1993, 128 p.

Huntington, E., and Goldthwaite, J.W., 1904, The Hurricane fault zone in the Toquerville district, Utah: Harvard College Museum Comparative Zoology Bulletin, v. 42, p. 199-259.

Hurlow, H.A., 1998, The geology of the central Virgin River basin, southwestern Utah, and its relation to ground-water conditions: Utah Geological Survey Water-Resources Bulletin 26, 53 p., 6 plates, various scales.

Hurlow, H.A., and Biek, R.F., 2003, Geologic map of the Pintura quadrangle, Washington County, Utah: Utah Geological Survey Map 196, 20 p., scale 1:24,000.

Imlay, R.W., 1980, Jurassic paleogeography of the coterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

International Building Code, 2000: Falls Church, Virginia, International Code Council, Inc., 756 p.

James, L.P., and Newman, E.W., 1986, Subsurface character of mineralization at Silver Reef, Utah, and a possible model for ore genesis, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 149-158.

Jenson, John, 1984, Stratigraphy and facies analysis of the upper Kaibab and lower Moenkopi Formations in southwest Washington County, Utah: Brigham Young University Geology Studies, v. 33, pt. 1, p. 21-43.

Kurie, A.E., 1966, Recurrent structural disturbance of the Colorado Plateau margin near Zion National Park, Utah: Geological Society of America Bulletin, v. 77, p. 867-872.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745-750.

Lefebvre, R.H., 1961, Joint patterns in the central part of the Hurricane fault zone, Washington County, Utah: Lawrence, University of Kansas, M.S. thesis, 35 p.

Lovejoy, E.M.P., 1964, The Hurricane fault zone and the Cedar Pocket Canyon-Shebit-Gunlock fault complex, southwestern Utah and northwestern Arizona: Tucson, University of Arizona, Ph.D. dissertation, 195 p.

Lucas, S.G., and Hechert, A.B., 2001, Theropod dinosaurs and the Early Jurassic age of the Moenave Formation, Arizona-Utah, USA: Neves Jahrbuch für Geologic und Paläontologie Mh., Stuttgart, Germany, volume 7, p. 435-448.

Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-1091B, scale 1:100,000.

Lund, W.R., 1992, Flooding in southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 159-163.

Lund, W.R., and Everitt, B.L., 1998, Reconnaissance paleoseismic investigation of the Hurricane fault in southwestern Utah, including the Ash Creek section and most of the Anderson Junction section, *in* Pearthree, P.A., Lund, W.R., Stenner, H.D., and Everitt, B.L., Paleoseismic investigation of the Hurricane fault in southwestern Utah and northwestern Arizona, final project report: U.S. Geological Survey, National Earthquake Hazards Reduction Program, p. 8-48.

Lund, W.R., Pearthree, P.A., Amoroso, Lee, Hozik, M.J., and Hatfield, S.C., 2001, Paleoseismic investigation of earthquake hazard and long-term movement history of the Hurricane fault, southwestern Utah and northwestern Arizona – final technical report: U.S. Geological Survey, National Earthquake Hazards Reduction Program External Research, Program Element I, Panel NI, Award No. 99HQGR0026, 120 p.

Mabey, D.R. 1985, Volcanic hazards: Utah Geological and Mineral Survey, Survey Notes, v. 19, no. 3, p.10-11.

Mabey, D.R., and Budding, K.E., 1985, High-temperature geothermal resources of Utah: Utah Geological Survey Bulletin 123, 64 p.

Marshall, C.H., 1956, Photogeologic map of the Virgin NW [Virgin] quadrangle, Washington County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-149, scale 1:24,000.

McKee, E.D., 1934, The Coconino Sandstone – its history and origin: Carnegie Institution of Washington Publication 440, p. 77-115.

—1938, The environment and history of the Toroweap and Kaibab Formations of northern Arizona and southern Utah: Carnegie Institute of Washington, Publication 492, 268 p.

—1975, The Supai Group – subdivision and nomenclature: U.S. Geological Survey Bulletin 1395-J, p. 1-11.

—1982, The Supai Group of the Grand Canyon: U.S. Geological Survey Professional Paper 1173, 503 p.

McNair, A.H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: American Association of Petroleum Geologists Bulletin, v. 35, no. 3, p. 503-541.

Miller, W.E., Britt, B.B., and Stadtman, K.L., 1989, Tridactyl trackways from the Moenave Formation of southwestern Utah, *in* Gillette, D.D., and Lockley, M.G., editors, Dinosaur tracks and traces: Cambridge University Press, p. 209-215.

Mitchum, R.M., 1977, Seismic stratigraphy and global changes in sea level, part 1 – glossary of terms used in seismic stratigraphy, *in* Payton, C.E., editor, Seismic stratigraphy – applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, p. 205-212.

Monroe, J.S., and Wicander, Reed, 1998, Radon – the silent killer, perspective 8-2, *in* Physical geology – exploring the earth: Belmont, California, Wadsworth Publishing Company, p. 207-208.

Moody, J.D., and Hill, M.J., 1956, Wrench-fault tectonics: Geological Society of America Bulletin, v. 67, p. 1,207-1,246.

Moore, D.W., and Sable, E.G., 2001, Geologic map of the Smithsonian Butte quadrangle, Washington County, Utah: Utah Geological Survey Miscellaneous Publication 01-1, 30 p., scale 1:24,000.

Morales, Michael, 1987, Terrestrial fauna and flora from the Triassic Moenkopi Formation of the southwestern United States, *in* Morales, Michael, and Elliot, D.K., editors, Triassic continental deposits of the American southwest: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 1-19.

Mortensen, V.L., Carley, J.A., Crandall, G.C., Donaldson, K.M., Jr., and Leishman, G.W., 1977, Soil survey of Washington County area, Utah: U.S. Department of Agriculture, Soil Conservation Service, and U.S. Department of the Interior, Bureau of Land Management and National Park Service, in cooperation with Utah Agricultural Experiment Station, 140 p.

Mulvey, W.E., 1992, Engineering geologic problems caused by soil and rock in southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 139-144.

Nielson, R.L., 1981, Depositional environment of the Toroweap and Kaibab Formations of southwestern Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 1,015 p.

—1986, The Toroweap and Kaibab Formations, southwestern Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 37-53.

—1991, Petrology, sedimentology and stratigraphic implications of the Rock Canyon Conglomerate, southwestern Utah: Utah Geological Survey Miscellaneous Publication 91-7, 65 p.

Nielson, R.L., and Johnson, J.L., 1979, The Timpoweap Member of the Moenkopi Formation, Timpoweap Canyon, Utah: Utah Geology, v. 6, no. 1, p. 17-27.

Olig, S.S., 1995, Ground shaking and modified Mercalli intensities, in Christenson, G.E., editor, The September 2, 1992 ML 5.8 St. George Earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p. 12-20.

Olsen, P.E., and Padian, Kevin, 1986, Earliest records of *Batrachopus* from the southwestern United States, and a revision of some early Mesozoic crocodylomorph ichnogenera, *in* Padian, Kevin, editor, The beginning of the age of dinosaurs – faunal changes across the Triassic-Jurassic boundary: Cambridge University Press, p. 260-273.

Paull, R.K., and Paull, R.A., 1994, Lower Triassic transgressive-regressive sequences in the Rocky Mountains, eastern Great Basin, and Colorado Plateau, USA, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, p. 169-180.

Pechmann, J.C., Arabasz, W.J., and Nava, S.J., 1995, Seismology, *in* Christenson, G.E., editor, The September 2, 1992 ML 5.8 St. George Earthquake, Washington County, Utah: Utah Geological Survey Circular 88, p. 1.

Peterson, Fred, 1994, Sand dunes, sabkhas, streams, and shallow seas – Jurassic paleogeography in the southern part of the Western Interior basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 233-272.

Peterson, Fred, Cornet, Bruce, and Turner-Peterson, C.E., 1977, New data on the stratigraphy and age of the Glen Canyon Group (Triassic and Jurassic) in southern Utah and northern Arizona [abstract]: Geological Society of America Abstracts with Programs, v. 9, no. 6, p. 755.

Powell, J.W., 1875, Exploration of the Colorado River of the west and its tributaries, 1869-1872: Washington, D.C., Smithsonian Institute, 294 p.

Proctor, P.D., and Brimhall, W.H., 1986, Silver Reef mining district, revisited, Washington County, Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 159-177.

Proctor, P.D., and Shirts, M.A., 1991, Silver, sinners, and saints – a history of old Silver Reef, Utah: Provo, Utah, Paulmar, Inc., 224 p.

Rawson, R.R., and Turner-Peterson, C.E., 1979, Marine-carbonate, sabkha, and eolian facies transitions within the Permian Toroweap Formation, northern Arizona, *in* Barrs, D.L., editor, Permianland: Four Corners Geological Society Guidebook, Ninth Field Conference, p. 87-99.

Reeside, J.B., Jr., and Bassler, Harvey, 1921, Stratigraphic sections in southwestern Utah and northwestern Arizona: U.S. Geological Survey Professional Paper 129-D, p. 53-77.

Ritzma, H.R., 1979, Oil-impregnated rock deposits of Utah: Utah Geological and Mineralogical Survey Map 47, 2 sheets, scale 1:1,000,000.

Rowland, S.M., 1987, Paleozoic stratigraphy of Frenchman Mountain, Clark County, Nevada, *in* Hill, M.L., editor, Geological Society of America Centennial Field Guide, Cordilleran Section: Boulder, Colorado, Geological Society of America, p. 53-56.

Sanchez, Alexander, 1995, Mafic volcanism in the Colorado Plateau/Basin-and-Range transition zone, Hurricane, Utah: Las Vegas, University of Nevada, M.S. thesis, 92 p., scale 1:52,000.

Sandburg, G.W., and Sultz, L.G., 1985, Reconnaissance of the quality of surface water in the upper Virgin River basin, Utah, Arizona, and Nevada, 1981-1982: Utah Division of Water Rights Technical Publication 83, 69 p.

Sansom, P.J., 1992, Sedimentology of the Navajo Sandstone, southern Utah, USA: Oxford, England, Department of Earth Sciences at Wolfson College, Ph.D. dissertation, 291 p.

Schaeffer, B., and Dunkle, D.H., 1950, A semionotid fish from the Chinle Formation, with consideration of its relationships: American Museum Novitates, no. 1457, p. 1-29.

Schmidt, Anita, Puskin, J.S., Nelson, Christopher, and Nelson, Neal, 1990, Estimate of annual radon-induced lung cancer deaths – EPA's approach, *in* U.S. Environmental Protection Agency, The 1990 international symposium on radon and radon reduction technology, Atlanta, Georgia – Reprints: Environmental Protection Agency/600/9-90/005a, v. 1, p. II-3.

Schramm, M.E., 1994, Structural analysis of the Hurricane fault in the transition zone between the Basin and Range Province and the Colorado Plateau, Washington County, Utah: Las Vegas, University of Nevada, M.S. thesis, 90 p., scale 1:12,000.

Smith, E.I., Sanchez, Alexander, Walker, J.D., and Wang, Kefa, 1999, Geochemistry of mafic magmas in the Hurricane volcanic field, Utah – implications for small- and large-scale chemical variability of the lithospheric mantle: The Journal of Geology, v. 107, p. 433-448.

Solomon, B.J., 1992a, Geology and the indoor-radon hazard in southwestern Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 164-172.

—1992b, Environmental geophysical survey of radon-hazard areas in the southern St. George basin, Washington County, Utah, *in* Harty, K.M., editor, Engineering and environmental geology of southwestern Utah: Utah Geological Association Publication 21, p. 173-191.

—1996, Radon-hazard potential in the St. George area, Washington County, Utah: Utah Geological Survey Public Information Series 35, 1 p.

Sorauf, J.E., 1962, Structural geology and stratigraphy of Whitmore area, Moenave County, Arizona: Lawrence, Kansas, University of Kansas, Ph.D. dissertation, 361 p.

Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northwest Arizona and southwest Utah: Mountain Geologist, v. 28, no. 1, p. 9-24.

Sprinkel, D.A., and Solomon, B.J., 1990, Radon hazards in Utah: Utah Geological and Mineral Survey Circular 81, 24 p.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

—1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region, with a section on sedimentary petrology by R.A. Cadigan: U.S. Geological Survey Professional Paper 691, 195 p., scale 1:2,500,000.

Stewart, M.E., and Taylor, W.J., 1996, Structural analysis and fault segment boundary identification along the Hurricane fault in southwest Utah: Journal of Structural Geology, v. 18, p. 1,017-1,029.

Stewart, M.E., Taylor, W.J., Pearthree, P.A., Solomon, B.J., and Hurlow, H.A., 1997, Neotectonics, fault segmentation, and seismic hazards along the Hurricane fault in Utah and Arizona – an overview of environmental factors in an actively extending region, *in* Link, P.K., and Kowallis, B.J., editors, Geological Society of America field trip guidebook, 1997 Annual Meeting, Salt Lake City, Utah: Brigham Young University Geology Studies, v. 42, part II, p. 235-254.

Thompson, R.W., 1992, Swell testing as a predictor of structural performance, *in* Wray, W.K., chairman, Seventh International Conference on expansive soils: American Society of Civil Engineers, p. 84-88.

Tuesink, M.F., 1989, Depositional analysis of an eolian-fluvial environment – the intertonguing of the Kayenta Formation and Navajo Sandstone (Jurassic) in southwestern Utah: Flagstaff, Arizona, Northern Arizona University, M.S. thesis, 189 p.

U.S. Environmental Protection Agency and U.S. Department of Health and Human Services, 1986, A citizen's guide to radon: U.S. Environmental Protection Agency Report OPA-86-004, 13 p.

Utah Division of Comprehensive Emergency Management, 1981, History of Utah floods, 1947-1981: Utah Division of Comprehensive Emergency Management, Floodplain Management Status Report, variously paginated.

Utah Division of Water Resources, 1993, Municipal and industrial water diversions and depletions for the Virgin River and Kanab Creek drainage basins: Utah Division of Water Resources, unnumbered report, variously paginated.

Vail, P.R., Mitchum, R.M., Jr., and Thompson, S. III, 1977, Seismic stratigraphy and global changes of sea level, part 4 – global cycles of relative changes of sea level, *in* Payton, C.E., editor, Seismic stratigraphy – applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, p. 83-97.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: American Association of Petroleum Geologists Methods in Exploration Series, no. 7, 55 p.

Washington County Water Conservancy District, 1997, Sand Hollow Reservoir project report: Sacramento, California, Graystone Environmental Planners, Scientists and Engineers, July 1997, variously paginated.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Economic Geology, v. 80, no. 6, p. 1,722-1,735.

Wenrich, K.J., Billingsley, G.H., and Huntoon, P.W., 1986, Breccia pipe and geologic map of the northeastern Hualapai Indian Reservation and vicinity, Arizona: U.S. Geological Survey Open-File Report 86-458-A, 29 p., 2 plates, scale 1:48,000.

Wenrich, K.J., and Huntoon, P.W., 1989, Breccia pipes and associated mineralization in the Grand Canyon region, northern Arizona, *in* Elston, D.P., Billingsley, G.H., and Young, R.A., editors, Geology of Grand Canyon, northern Arizona (with Colorado River guides): Washington, D.C., American Geophysical Union, 28th International Geological Congress field trip guidebook T115/315, p. 212-216.

Wenrich, K.J., and Sutphin, H.B., 1989, Lithotectonic setting necessary for formation of a uranium-rich, solution-collapse breccia-pipe province, Grand Canyon region, Arizona: U.S. Geological Survey Open-File Report 89-0173, 33 p.

Wheeler, G.M., 1886, Geographic report: U.S. Geographic Surveys west of the 100th meridian, report, v. 1.

Wilbraham, A.C., Staley, D.D., Simpson, C.J., Matta, M.S., 1990, Issues in chemical technology: Menlo Park, California, Addison-Wesley Publishing Co, Inc., p. 13-14.

Willis, G.C., 1999, The Utah thrust system – an overview, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 1-9.

Willis, G.C., and Biek, R.F., in press, Quaternary downcutting rates of the Colorado River and major tributaries in the Colorado Plateau, Utah, *in* Young, R.A., editor, The Colorado River – origin and evolution: Grand Canyon Association Monograph.

Willis, G.C., and Higgins, J.M., 1995, Interim geologic map of the Washington quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 324, 113 p., scale 1:24,000.

—1996, Interim geologic map of the Santa Clara quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 339, 87 p., scale 1:24,000.

APPENDIX.

Whole-rock geochemical analyses of basalt flows in The Divide quadrangle.

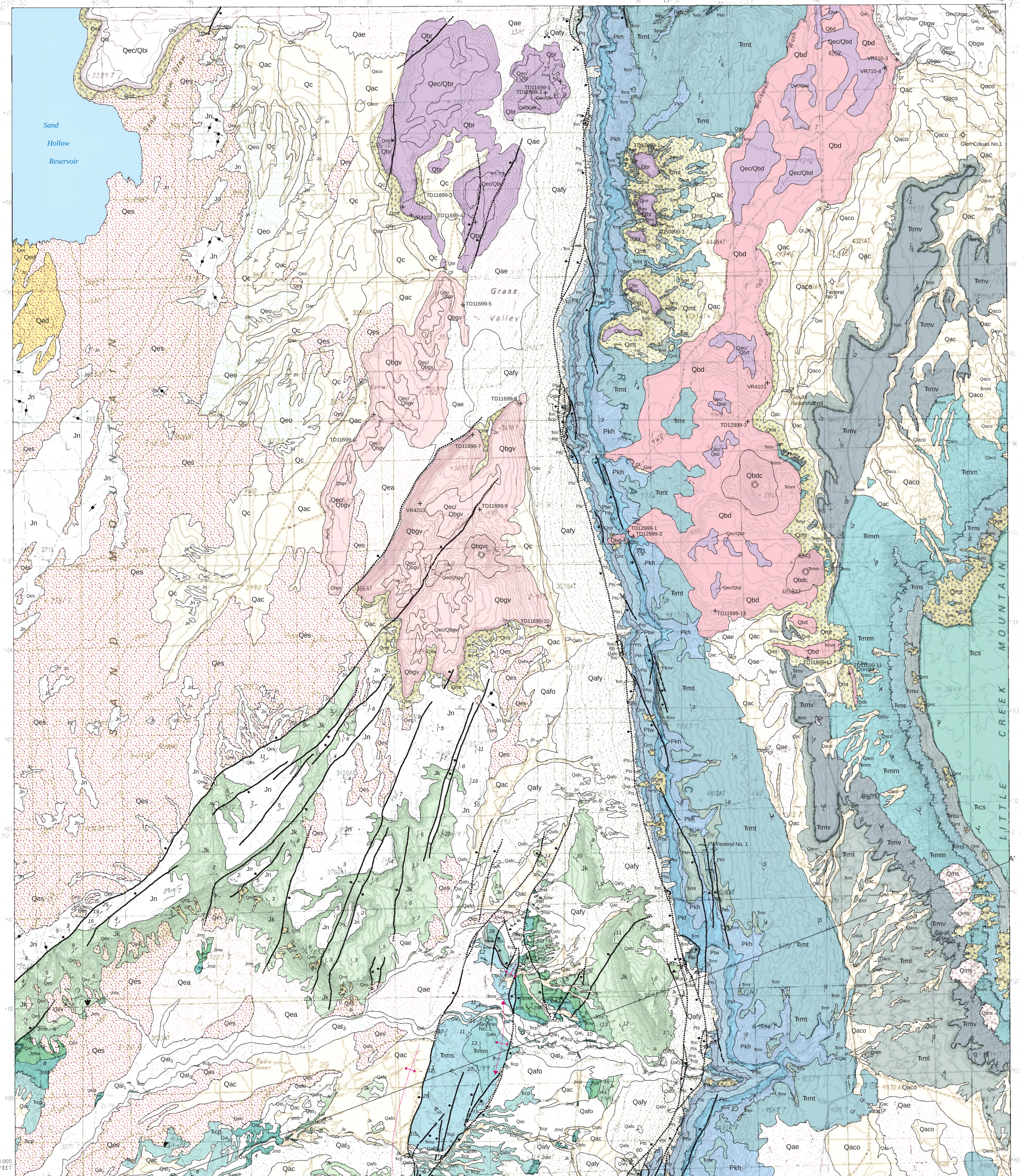
Flow				The Divide			
Symbol	Qbd	Qbd	Qbd	Qbd	Qbd	Qbd	Qbd
Sample No.	VR4107	TD11699-11	TD11699-12	TD11699-13	TD12999-1	TD12999-2	TD12999-3
long (^{0}W)	113.280	113.270	113.275	113.286	113.298	113.298	113.282
lat (^{0}N)	37.087	37.058	37.059	37.064	37.072	37.072	37.083
			X-ray Fluorescence Analyses, wt. %				
Al2O3	10.99	10.53	10.67	11.27	11.32	11.13	10.92
CaO	10.77	10.85	10.73	11.12	10.87	11.00	10.82
Cr2O3	0.03	0.07	0.06	0.05	0.06	0.06	0.05
Fe2O3	13.35	13.23	13.22	12.97	12.94	12.95	13.21
K2O	1.74	1.37	1.41	1.39	1.37	1.46	1.38
MgO	12.27	12.70	12.51	11.61	11.79	11.71	11.75
MnO	0.19	0.18	0.19	0.19	0.18	0.18	0.18
Na2O	2.70	2.69	2.77	2.96	3.08	2.91	2.76
P2O5	0.78	0.74	0.75	0.78	0.81	0.77	0.79
SiO2	43.62	43.97	43.70	43.96	44.12	44.05	44.77
TiO2	2.60	2.51	2.49	2.51	2.45	2.49	2.59
LOI	0.01	0.04	-0.15	-0.16	-0.34	-0.08	0.02
Total	99.05	98.88	98.50	98.81	98.99	98.71	99.24
			ICP-MS, ppm				
Ba	715	682	670	735	707	708	672
Ce		106.5	109.0	110.0	112.0	113.0	110.0
Cs	1	0.3	0.3	0.3	0.4	0.4	0.5
Co		59.0	60.0	54.5	56.0	57.0	57.0
Cu		80	80	75	75	80	75
Dy		6.2	6.1	6.3	6.1	6.2	5.9
Er		2.6	2.6	2.8	2.7	2.8	2.8
Eu		2.8	3.1	2.7	2.9	3.0	3.3
Gd		9.4	9.9	9.4	9.2	9.5	9.1
Ga		19	20	19	19	20	19
Hf	6	6	6	6	6	6	7
Ho		1.0	1.1	1.1	1.1	1.1	1.0
La	55	53.5	57.5	57.5	58.0	58.0	56.5
Pb		20	25	25	15	15	15
Lu		0.3	0.3	0.3	0.3	0.3	0.3
Nd		50.0	51.5	51.5	52.5	53.5	52.0
Ni		335	280	280	310	300	310
Nb	69	59	60	60	62	62	62
Pr		12.2	13.1	13.1	13.1	13.1	12.8
Rb		17.4	18.0	18.0	18.4	18.4	18.2
Sm	20	10.3	10.0	10.0	10.0	9.8	10.2
Ag		1	1	1	1	1	1
Sr	846	772	797	797	790	810	786
Ta	7	3.5	3.5	3.5	4.0	4.0	4.0
Tb		1.2	1.2	1.2	1.3	1.3	1.3
Tl		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Th		7	8	8	8	8	8
Tm		0.4	0.3	0.3	0.3	0.4	0.3
Sn		2	2	2	1	2	2
W		<1	<1	<1	<1	<1	<1
U		2.0	2.0	2.0	2.0	2.0	2.0
V		270	270	270	275	290	270
Yb		2.1	2.2	2.3	2.2	2.4	2.3
Y	27	26.0	26.0	26.0	26.5	27.0	26.5
Zn		130	125	120	120	130	120
Zr	219	236	237	237	239	243	255

Anaylses by ALS Chemex Labs, Inc., Sparks, Nevada.

Sample locations shown on plate 1 and figure 3.

Flow	The Divide			Grass Valley				Gould Wash
Symbol	Qbd	Qbgv	Qbgv	Qbgv	Qbgv	Qbgv	Qbgv	Qbgw
Sample No.	VR710-4	TD11699-5	TD11699-6	TD11699-7	TD11699-8	TD11699-9	TD11699-10	VR-710-3
long (°W)	113.266	113.319	113.33	113.318	113.311	113.316	113.308	113.264
lat (°N)	37.119	37.095	37.085	37.082	37.085	37.074	37.063	37.120
				X-ray Fluorescence Analyses, wt. %				
Al2O3	10.95	15.91	15.73	15.63	15.94	15.71	15.33	13.35
CaO	10.76	8.12	9.05	8.87	9.09	8.93	9.07	10.61
Cr2O3	0.04	0.03	0.03	0.01	0.01	0.01	0.03	0.04
Fe2O3	13.30	10.46	10.10	10.15	10.11	10.07	10.22	11.93
K2O	1.42	1.53	1.36	1.42	1.40	1.29	1.34	0.93
MgO	12.35	7.70	8.04	8.12	7.85	8.25	8.21	10.13
MnO	0.19	0.16	0.16	0.16	0.16	0.16	0.16	0.17
Na2O	2.93	4.10	3.53	3.89	3.73	3.64	3.58	2.99
P2O5	0.74	0.60	0.55	0.56	0.56	0.54	0.54	0.50
SiO2	43.97	48.31	48.44	48.01	47.81	48.23	48.28	46.90
TiO2	2.61	1.90	1.75	1.73	1.70	1.76	1.70	1.67
LOI	<0.01	-0.02	0.15	-0.21	0.43	0.75	-0.08	0.60
Total	99.26	98.82	98.89	98.55	98.79	99.34	98.46	99.82
				ICP-MS, ppm				
Ba	665	426	487	468	480	475	469	696
Ce	106.0	69.5	70.0	71.0	69.0	71.0	68.0	
Cs	0.3	0.1	0.1	0.3	0.1	0.1	0.1	0.1
Co	65.5	36.5	39.5	39.5	42.5	41.0	37.5	
Cu	90	50	55	55	60	65	55	
Dy	5.7	5.2	5.5	5.4	5.5	5.1	5.1	
Er	2.4	3.0	3.2	3.0	3.0	2.9	3.2	
Eu	2.6	2.1	2.2	1.9	1.9	2.1	1.9	
Gd	8.6	6.6	6.8	6.4	6.4	6.6	6.2	
Ga	19	17	18	18	18	14	18	
Hf	6	6	5	6	6	5	5	3
Ho	0.9	1.0	1.1	1.1	1.0	1.1	1.1	
La	53.5	34.0	35.0	35.5	35.5	35.0	34.0	43
Pb	65	30	15	5	15	5	25	
Lu	0.3	0.4	0.4	0.5	0.4	0.4	0.4	
Nd	48.5	34.0	34.5	34.5	33.0	35.0	32.5	
Ni	345	90	135	115	120	145	125	
Nb	64.0	25.0	24.0	24.0	23.0	21.0	23.0	36
Pr	12.5	8.2	8.2	8.2	8.4	8.7	7.8	
Rb	20.2	11.4	12.8	13.4	11.4	13.4	12.8	11
Sm	9.6	6.3	6.5	6.6	6.0	7.0	6.5	
Ag	1	<1	<1	<1	<1	1	<1	
Sr	833	734	690	675	667	719	668	669
Ta	5.0	1.5	1.5	1.5	1.5	1.5	1.5	3
Tb	1.1	1.0	1.0	1.0	0.9	1.0	1.0	
Tl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Th	5	3	4	4	3	5	3	
Tm	0.3	0.4	0.4	0.4	0.4	0.4	0.4	
Sm	2	2	1	1	1	<1	1	
W	<1	<1	<1	<1	<1	<1	<1	
U	1.5	0.5	0.5	1.0	1.0	1.0	1.0	
V	235	175	205	200	200	185	185	
Yb	1.7	2.7	2.8	2.9	2.8	2.7	2.8	
Y	27.5	26.5	26.5	26.5	26.5	26.5	26.0	23
Zn	140	80	85	80	80	105	85	
Zr	239	255	283	246	231	241	236	145

Flow	Remnants						
Symbol	Qbr	Qbr	Qbr	Qbr	Qbr	Qbr	Qbr
Sample No.	TD11699-1	TD11699-2	TD11699-3	TD1699-4	TD11699-1	TD50699-1	VR4202
long (ºW)	113.306	113.308	113.326	113.317	113.297	113.294	113.326
lat (ºN)	37.119	37.118	37.105	37.104	37.110	37.104	37.105
	X-ray Fluorescence Analyses, wt. %						
Al2O3	11.75	11.91	11.86	11.94	11.57	11.54	11.70
CaO	12.76	12.50	12.55	12.29	12.57	12.48	12.04
Cr2O3	0.07	0.10	0.07	0.09	0.07	0.05	0.05
Fe2O3	11.95	11.93	11.63	11.88	12.06	12.08	12.46
K2O	1.23	1.10	0.86	0.86	1.03	1.15	1.34
MgO	12.95	12.51	12.05	12.56	13.67	13.85	13.32
MnO	0.19	0.19	0.19	0.20	0.19	0.19	0.20
Na2O	3.14	3.22	3.35	3.23	3.06	2.90	3.00
P2O5	1.07	1.05	1.08	1.04	1.06	1.04	1.05
SiO2	41.79	42.40	42.60	42.71	42.01	42.00	41.31
TiO2	1.81	1.81	1.78	1.82	1.82	1.81	1.78
LOI	0.08	0.18	0.68	0.07	0.03	0.08	0.01
Total	98.79	98.90	98.70	98.69	99.14	99.17	98.26
	ICP-MS, ppm						
Ba	1915	1880	1910	1905	2100	2140	1930
Ce	193.5	194.5	189.0	195.5	202.0	198.5	
Cs	0.6	0.5	0.7	0.7	0.7	0.6	1
Co	50.5	51.5	48.5	49.5	51.5	55.5	
Cu	80	85	100	80	80	95	
Dy	5.6	5.4	5.4	5.8	5.8	6.2	
Er	2.5	2.6	2.7	2.4	2.6	2.7	
Eu	3.2	3.5	3.2	3.2	3.5	3.6	
Gd	10.0	10.4	9.8	10.1	10.3	10.2	
Ga	18	18	18	18	18	15	
Hf	5	5	5	5	5	5	5
Ho	1.1	1.1	1.0	1.0	1.0	1.0	
La	107.5	106.0	105.0	107.5	111.0	109.0	102
Pb	30	30	25	20	15	30	
Lu	0.4	0.4	0.4	0.4	0.4	0.4	
Nd	76.0	78.0	76.5	78.0	82.5	87.5	
Ni	260	245	260	240	260	310	
Nb	85	82	77	81	82	81	93
Pr	21.0	21.0	20.1	21.0	21.9	23.1	
Rb	16.0	10.8	6.8	9.0	14.8	15.1	13
Sm	12.9	12.3	11.5	12.5	13.0	14.1	
Ag	3	2	2	2	1	3	
Sr	1275	1640	1140	1170	1160	1295	1170
Ta	4.5	4.5	4.5	4.5	4.5	4.5	7
Tb	1.3	1.3	1.3	1.3	1.3	1.3	
Tl	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Th	22	18	18	18	21	12	
Tm	0.4	0.4	0.3	0.4	0.4	0.4	
Sn	1	1	1	1	1	<1	
W	2	1	1	<1	<1	1	
U	4.5	4.0	4.0	5.0	5.0	5.5	
V	290	300	280	300	300	275	
Yb	2.2	2.4	2.2	2.3	2.3	2.2	
Y	27.0	26.5	25.0	25.5	25.5	26.5	26
Zn	110	120	115	105	105	160	
Zr	212	218	208	209	209	239	190



Base map from U.S. Geological Survey
The Divide 7.5' quadrangle, 1986

Cartographer, Lori J. Douglas

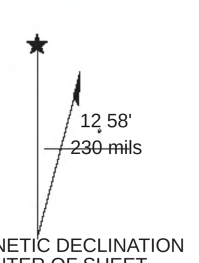
SCALE 1 : 24,000

1 1/2 0 1 MILE

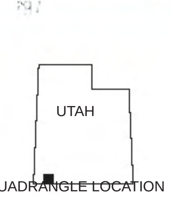
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

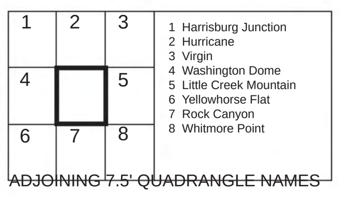
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



2004 MAGNETIC DECLINATION
AT CENTER OF SHEET



QUADRANGLE LOCATION



ADJOINING 7.5' QUADRANGLE NAMES

This geologic map was funded by the Utah Geological Survey and the U. S. Geological Survey, National Cooperative Geologic Mapping Program, through Statemap Agreement No. 98HQAG2067

GEOLOGIC MAP OF THE DIVIDE QUADRANGLE, WASHINGTON COUNTY, UTAH

by

Janice M. Hayden

2004

DESCRIPTION OF MAP UNITS

QUATERNARY

Qal_1 Stream deposits -- *Moderately to well-sorted clay to fine gravel deposits in large active drainages; includes terraces up to 10 feet (3 m) above active channels; 0 to 10 feet (0-3 m) thick.*

Qat_{2-3} Stream-terrace deposits -- *Moderately sorted, well-rounded, pebble- to cobble-size clasts in a muddy to coarse sand matrix. Qat_2 includes deposits adjacent to and dissected by Qal_1; upper surface up to 30 feet (9 m) above active channels; 0 to 20 feet (0-6 m) thick. Qat_3 forms an indurated, pedogenic carbonate-cemented conglomerate; upper surface 30 to 90 feet (9-27 m) above active channels; typically 0 to 40 feet (0-12 m) thick.*

Qafy Younger alluvial-fan deposits -- *Poorly to moderately sorted boulder- to clay-size sediment deposited at the base of the Hurricane Cliffs and locally at the mouths of active drainages; 0 to about 50 feet (0-15 m) thick.*

Qafo Older alluvial-fan deposits -- *Poorly to moderately sorted boulder- to clay-size sediment deposited at the base of the Hurricane Cliffs; forms deeply dissected surfaces; 0 to about 50 feet (0-15 m) thick.*

Qf Artificial-fill deposits -- *Engineered fill and general borrow material used to create small dams; thickness variable.*

Qc Colluvial deposits -- *Poorly sorted, angular to rounded blocks in a muddy to sandy matrix, deposited by sheet wash and soil creep on moderate slopes; only larger deposits mapped, and these locally include eolian, talus, debris-flow, and alluvial deposits too small to map separately; 0 to 20 feet (0-6 m) thick.*

Qes Eolian-sand deposits -- *Well- to very well-sorted, very fine- to medium-grained, well-rounded, usually frosted, mostly quartz sand derived primarily from the Navajo and Kayenta Formations; commonly deposited in irregular hummocky mounds on the lee side of ridges, as well as on Sand Mountain and in Warner Valley; locally forms poorly developed dunes; 0 to 50 feet (0-15 m) thick.*

Qed Eolian-dune-sand deposits -- *Well- to very well-sorted, very fine- to medium-grained, well-rounded, usually frosted, mostly quartz sand in dune form on Sand Mountain; derived primarily from the Navajo Sandstone; 0 to 40 feet (0-12 m) thick.*

Qeo Caliche and eolian-sand deposits -- *Well-developed soil carbonate (Stage IV carbonate of Birkeland and others, 1991) with lesser eolian sand; generally forms planar surfaces on top of the Navajo Sandstone that are covered with nodular caliche and sparse eolian sand; 0 to 10 feet (0-3 m) thick.*

Qmt Talus deposits -- *Very poorly sorted, angular boulders with minor fine-grained interstitial materials; deposited on and at the base of steep slopes; 0 to 20 feet (0-6 m) thick.*

Qms Landslide deposits -- *Very poorly sorted clay- to boulder-size, locally derived debris in chaotic, hummocky mounds; located on steep slopes of Little Creek Mountain below the Shinarump Conglomerate, with slip surfaces in the middle red member of the Moenkopi Formation; thickness highly variable.*

Qae, Qaeo Mixed alluvial and eolian deposits -- *Moderately to well-sorted, clay- to sand-sized alluvial sediment that locally includes abundant eolian sand and minor alluvial gravel; minor pedogenic carbonate development; Qae mapped in small valleys east of the Hurricane Cliffs and in Grass Valley; Qaeo forms deeply dissected deposit in Gould Wash; 0 to 30 feet (0-9 m) thick.*

Qea Mixed eolian and alluvial deposits -- *Well-sorted eolian sand with minor clay- to gravel-size alluvial sediment; locally reworked by alluvial processes; 0 to 20 feet (0-6 m) thick.*

Qac, Qaco Mixed alluvial and colluvial deposits -- *Poorly to moderately sorted clay- to boulder-size sediment in minor drainages; gradational with colluvial deposits; Qac deposits are in active drainages and Qaco deposits are older and are dissected by active drainages; includes minor terraces too small to map separately; 0 to 10 feet (0-3 m) thick.*

Qbgw Gould Wash basalt flow -- *Dark-gray, very fine-grained olivine basalt; abundant olivine phenocrysts; generally 20 to 30 feet (6-9 m) thick; yielded an $^{40}Ar/^{39}Ar$ age of 0.278 ± 0.018 Ma (Downing, 2000); originated at cinder cone to the east in the Little Creek Mountain quadrangle; Qec/Qbgw indicates a veneer of eolian sand and pedogenic carbonate generally less than 3 feet (1 m) thick that partly conceals underlying flow.*

Qbd, Qbdc The Divide basalt flow and cinder cones -- *Dark-gray, very fined-grained olivine basalt to borderline basanite; cascaded over Hurricane Cliffs; north-trending dike in the SW1/4 section 12, T. 43 S., R. 13 W. may have been a partial source of flow; yielded an $^{40}Ar/^{39}Ar$ age of 0.41± 0.08 Ma; Qbdc denotes two partially eroded cinder cones; Qec/Qbd indicates a veneer of eolian sand and pedogenic carbonate generally less than 3 feet (1 m) thick that partly conceals underlying flow.*

Qbi Ivans Knoll basalt flow -- *Medium-gray, fine- to medium-grained olivine basalt; olivine phenocrysts up to about 0.1 inch (3 mm) across; forms highland along northwest edge of quadrangle; erupted from vent to north in the Hurricane quadrangle; 15 to 25 feet (5-8 m) thick; yielded $^{40}Ar/^{39}Ar$ ages of 1.03 ±0.02 Ma and 0.97 ± 0.07 Ma (Biek, 2003b); Qec/Qbi indicates a veneer of eolian sand and pedogenic carbonate generally less than 3 feet (1 m) thick that partly conceals underlying flow.*

Qbr Remnants basalt flow -- *Dark-brownish-black to dark-gray, medium-grained olivine basanite; remnant of deeply eroded cinder cone present near the "Three Brothers"; displaced by the Hurricane fault, and deeply eroded on footwall and partially buried on hanging wall; approximately 40 feet (12 m) thick; yielded $^{40}Ar/^{39}Ar$ ages of 1.06 ± 0.03 Ma and 0.94 ± 0.04 Ma; Qec/Qbr indicates a veneer of eolian sand and pedogenic carbonate generally less than 3 feet (1 m) thick.*

Qbgv, Qbgvc Grass Valley flow and cinder cone -- *Very dark-gray, fine- to medium-grained olivine trachybasalt to borderline basalt; partially eroded cinder cone (Qbgvc) has 10-foot-thick (3 m) lava lake and two 10-foot-wide (3 m) dikes that radiate from the center; Qec/Qbgv indicates a veneer of eolian sand and pedogenic carbonate generally less than 3 feet (1 m) thick that partly conceals underlying flow.*

unconformity

JURASSIC

Jn Navajo Sandstone -- *Pale to moderate-reddish-brown, cross-bedded, poorly to moderately well-cemented, well-rounded, fine- to medium-grained, frosted quartz sandstone; strongly jointed; forms cliff; basal transition zone characterized by very thick-bedded, resistant, cross-bedded sandstone separated by planar-bedded, silty, fine-grained sandstone with thin mudstone interbeds that display wavy bedding, dark flaser-like laminae, soft-sediment deformation features, and bioturbation; about 2,000 feet (600 m) thick, but only basal 1,000 feet (300 m) exposed in the quadrangle.*

Jk Kayenta Formation -- *Interbedded moderate-reddish-brown siltstone, light-purplish-red to pale-reddish-brown mudstone, and pale-reddish-brown to pale-red, fine-grained, planar-bedded, calcareous, slightly mottled sandstone; includes a few thin dolomite beds, punky gypsum intervals, and prominent ledges and cliffs near the top; dinosaur footprints in Warner Valley near base; 900 feet (270 m) thick.*

Moenave Formation

Jm Moenave Formation, undivided - *Shown on cross section only.*

Jms Springdale Sandstone Member -- *Pale-reddish-brown to grayish-yellow, fine- to medium-grained, medium- to very thick-bedded, cross-bedded sandstone with minor, thin, discontinuous lenses of intraformational conglomerate and interbedded light-purple-gray siltstone near the middle; petrified wood is locally abundant; weathers to pale pink, pinkish gray, and pale reddish purple rounded ledges; 120 feet (36 m) thick.*

Jmw Whitmore Point Member -- *Pale-red-purple to greenish-gray claystone interbedded with pale-brown to pale-red, thin-bedded siltstone with several 2- to 6-inch-thick (5-15 cm) beds of light-greenish-gray dolomitic limestone that contain algal structures and fossil fish scales of Semionotus kanabensis (Hesse, 1935; Schaeffer and Dunkle, 1950); nonresistant but locally well exposed; about 80 feet (24 m) thick.*

Jmd Dinosaur Canyon Member -- *Interbedded moderate-reddish-brown siltstone and very fine-grained, thin-bedded, pale-reddish-brown to grayish-red sandstone and mudstone; planar, low-angle, and ripple cross-stratification are common; forms ledgy slopes; 200 feet (60 m) thick.*

unconformity

TRIASSIC

Chinle Formation

TRcp Petrified Forest Member -- *Light-brownish-gray to grayish-red-purple bentonitic shale and siltstone with several lenticular interbeds of pale-yellowish-brown, cross-bedded, thick-bedded, resistant sandstone up to 10 feet (3 m) thick; petrified wood is common; shale weathers to a "popcorn" surface with abundant mudcracks due to swelling and shrinking of bentonitic clay; forms a valley; estimated to be 600 feet (185 m) thick.*

unconformity?

TRcs Shinarump Conglomerate Member -- *Varies from a grayish-orange to moderate-yellowish-brown, medium- to coarse-grained sandstone, with locally well-developed limonite bands ("picture rock" or "landscape stone"), to a moderate-brown, chert-pebble conglomerate; contains poorly preserved petrified wood fragments; forms a dark-brown to moderate-yellowish-brown cap rock above the Moenkopi Formation; variable in composition and thickness because of deposition in a braided-stream environment; 75 to 165 feet (23-50 m) thick.*

unconformity

Moenkopi Formation

TRm Moenkopi Formation, undivided - *Mapped in fault slivers along the Hurricane fault zone.*

TRmu Upper red member -- *Moderate-reddish-brown, thin-bedded siltstone and very fine-grained sandstone with some thin gypsum beds and abundant discordant gypsum stringers; ripple marks common in the siltstone; forms a steep slope with a few sandstone ledges; includes 20-foot-thick (6 m), fine-grained, resistant sandstone near base; 425 feet (130 m) thick.*

TRms Shnabkaib Member -- *Light-gray to pale-red, gypsiferous siltstone with several thin interbeds of dolomitic limestone near the base; upper portion is very gypsiferous and weathers to a powdery soil; forms ledge-slope topography with "bacon-stripe" appearance; 375 feet (115 m) thick.*

TRmm Middle red member -- *Interbedded moderate-red to moderate-reddish-brown siltstone, mudstone, and thin-bedded, very fine-grained sandstone with thin interbeds and veinlets of greenish-gray to white gypsum; forms slope with several ledge-forming gypsum beds near base; 360 feet (110 m) thick.*

TRmv Virgin Limestone Member -- *Three distinct medium-gray to yellowish-brown marine limestone ledges interbedded with nonresistant, moderate-yellowish-brown, muddy siltstone, pale-reddish-brown sandstone, and light-gray to grayish-orange-pink gypsum; limestone beds are usually 5 to 10 feet (1.5-3 m) thick and contain five-sided crinoid columnals and Composita brachiopods; total thickness is generally 75 feet (23 m).*

TRml Lower red member -- *Interbedded, slope-forming, moderate-reddish-brown siltstone, mudstone, and fine-grained, slope-forming sandstone; generally calcareous and has interbeds and stringers of gypsum; ripple marks and small-scale cross-beds are common in the siltstone; 200 feet (60 m) thick.*

TRmt Timpoweap Member -- *Lower part is light-gray to grayish-orange, thin- to thick-bedded limestone and cherty limestone; weathers to a light-brown meringue-like surface due to blebs of chert; contains few ammonites, gastropods, and brachiopods, and uncommon euhedral pyrite crystals up to 1/4 inch (1 cm) across; upper part is grayish-orange, thin- to thick-bedded, slightly calcareous, very fine-grained sandstone with thin-bedded siltstone and mudstone intervals that weathers yellowish-brown; forms a coherent ledge or low cliff; thickness ranges from 50 to 125 feet (15-37 m).*

TRmr Rock Canyon Conglomerate Member -- *Yellowish-gray to light-olive-gray, clast-supported, but grading upward to a matrix-supported, conglomerate with pebble- and cobble-size clasts; basal part contains angular to subangular limestone rip-up clasts and brecciated blocks from the Harrisburg Member of the Kaibab Formation, locally cemented with sparry calcite; rounding increases upward to subrounded, mostly chert clasts near top; thick, locally massive, forms cliff and fills paleocanyons eroded into the Harrisburg Member; 0 to 130 feet (0-40 m) thick.*

unconformity

PERMIAN

Kaibab Formation

Pkh Harrisburg Member -- *Light-gray, fossiliferous, sandy, fine- to medium-grained limestone interbedded with red and gray gypsiferous siltstone, sandstone, and gray gypsum beds several feet thick; beds of cherty limestone, sandy limestone, and chert about 30 feet (9 m) thick form resistant low cliff near middle; beds locally distorted due to dissolution of gypsum; forms slope with limestone ledges; thickness varies greatly due to erosion associated with the Permian-Triassic unconformity; 30 to 175 feet (9-53 m) thick.*

Pkf Fossil Mountain Member -- *Yellowish-gray, abundantly fossiliferous, cherty limestone that forms a prominent cliff; silicified fossils include corals, brachiopods, crinoids, and bryozoans; reddish-brown and black chert forms irregularly bedded nodules and causes the outcrop to appear black-banded; 300 feet (90 m) thick.*

unconformity

Toroweap Formation

Ptw Woods Ranch Member -- *Grayish-pink to very pale-orange, very thick-bedded gypsum with interbeds of light-brownish-gray siltstone, pale-red shale, and yellowish-gray to light-gray, laminated to thin-bedded dolomite and limestone; forms slope, commonly covered with talus; beds distorted from dissolution of gypsum; 320 feet (98 m) thick.*

Ptb Brady Canyon Member -- *Medium-light-gray to dark-gray, medium- to coarse-grained, thick-bedded, fossiliferous limestone with reddish-brown chert nodules; contains locally common brachiopods, crinoids, and corals; forms prominent cliff; 200 feet (60 m) thick.*

Pts Seligman Member -- *Consists of three parts: upper part is medium-gray, thin-bedded, sandy limestone; middle part is interbedded yellowish-gray, calcareous, very fine-grained sandstone and grayish-yellow, gypsiferous, calcareous siltstone; and basal part is pale-yellowish-brown, fine-grained sandstone; 115 feet (36 m) thick.*

unconformity

Pq Queantoweap Sandstone -- *Pale-yellow to grayish-pink, calcareous, thick-bedded, fine-grained sandstone; only the upper 75 feet (23 m) is exposed in the quadrangle, but the formation is about 1,300 feet (400 m) thick in the area.*

Subsurface Units

Pzu Paleozoic, undivided - *Pre-Queantoweap units shown on cross section only.*

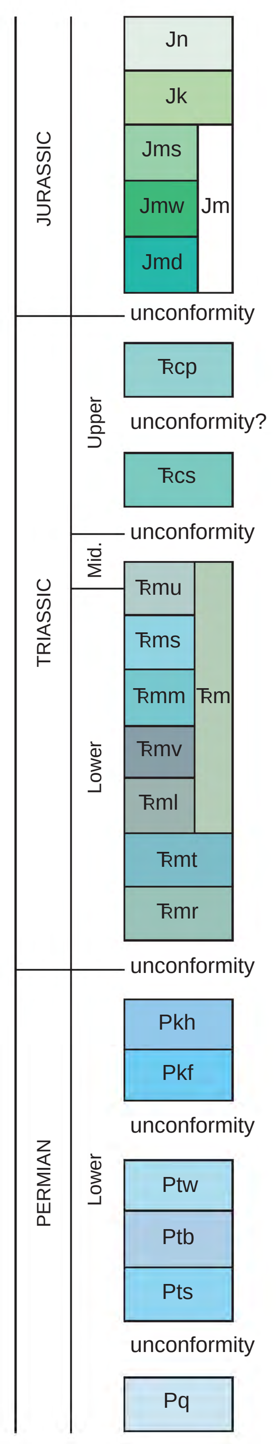
MAP SYMBOLS

- Contact
- High-angle normal fault, dashed where approximately located, dotted where concealed; bar-and-ball on down-thrown side
- Approximate trace of anticline, dotted where concealed; arrows show direction of plunge
- 8 — Strike and dip of inclined bedding from field measurements
- 10 — Approximate strike and dip of inclined bedding determined from photogrammetry
- Strike of vertical joint
- Sand and gravel pit
- X — Uranium prospect
- Mine shaft
- Spring
- oil seep — Oil seep
- Federal No.1 — Oil exploration test hole, plugged and abandoned, with name
- Cinder cone
- Dinosaur footprints
- TD12999-1 — Sample location and number
- A — A' — Line of cross section

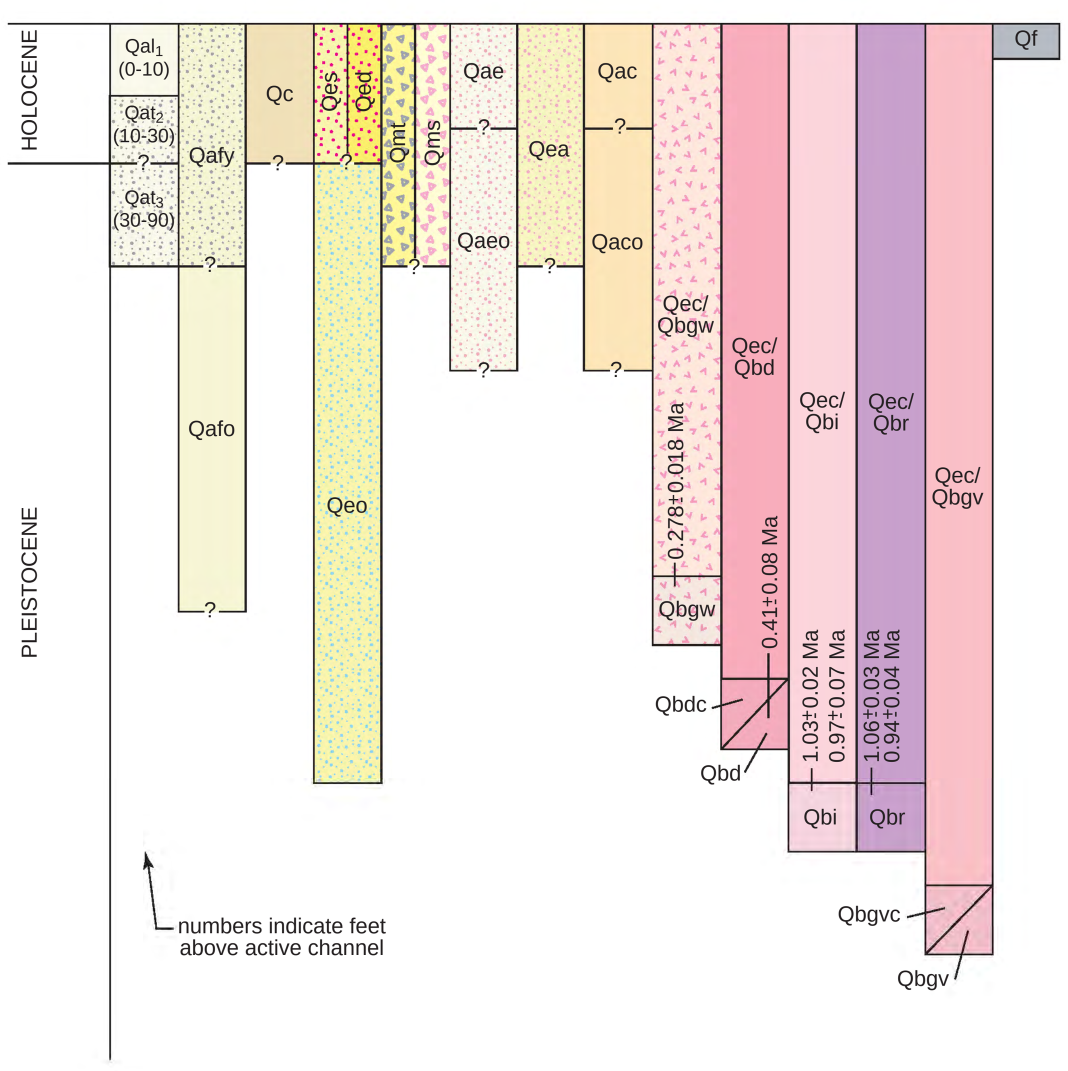
LITHOLOGIC COLUMN

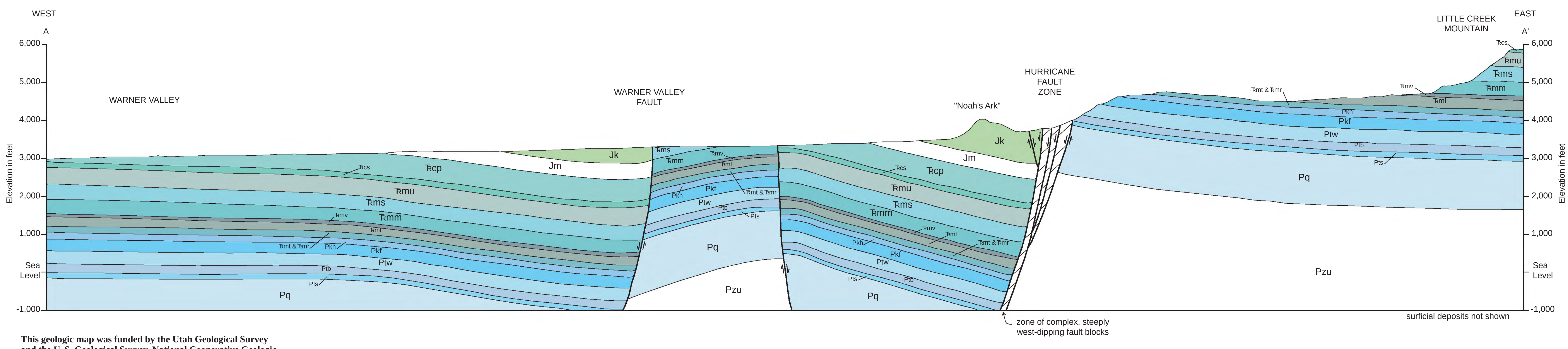
System	Series	Formation	Member	Symbol	Thickness feet (meters)	Lithology
Quaternary		Surficial deposits		Q	0-50 (0-15)	
		Basalt flows		Qb	0-40 (0-12)	
Jurassic	Lower	Navajo Sandstone		Jn	1,000+ (300+)	Sand Mountain; high-angle cross beds; Transition zone
		Kayenta Formation		Jk	900 (270)	
		Moenave Formation	Springdale Sandstone Member	Jms (Jm)	120 (36)	gypsum; petrified wood
			Whitmore Point Member	Jmw (Jm)	80 (24)	*Semionotus kanabensis*
			Dinosaur Canyon Member	Jmd (Jm)	200 (60)	
Triassic	Upper	Chinle Formation	Petrified Forest Member	TRcp	600 (185)	swelling clays; petrified wood
			Shinarump Cgl Mbr	TRcs	75-165 (23-50)	"picture stone"
	Mid. / Lower	Moenkopi Formation	Upper red member	TRmu (TRm)	425 (130)	
			Shnabkaib Member	TRms (TRm)	375 (115)	
			Middle red member	TRmm (TRm)	360 (110)	
			Virgin Ls Mbr	TRmv (TRm)	75 (23)	*Composita* brachiopods; five sided crinoid columnals
			Lower red mbr	TRml (TRm)	200 (60)	
			Timpoweap Mbr	TRmt (TRm)	50-125 (15-37)	oil seep; ammonites
			Rock Canyon Cgl Mbr	TRmr (TRm)	0-130 (0-40)	
Permian	Lower	Kaibab Formation	Harrisburg Mbr	Pkh	30-175 (9-53)	white chert; gypsum; brachiopods
			Fossil Mountain Member	Pkf	300 (90)	"black-banded" chert
		Toroweap Formation	Woods Ranch Member	Ptw	320 (98)	gypsum
			Brady Canyon Member	Ptb	200 (60)	brachiopods
			Seligman Mbr	Pts	115 (36)	
		Queantoweap Sandstone		Pq	75+ (23+)	

CORRELATION OF BEDROCK UNITS



CORRELATION OF QUATERNARY UNITS





This geologic map was funded by the Utah Geological Survey
and the U. S. Geological Survey, National Cooperative Geologic
Mapping Program, through Statemap Agreement No. 98HQAG2067