

**GEOLOGIC MAP OF THE HILDALE QUADRANGLE,  
WASHINGTON AND KANE COUNTIES, UTAH  
AND MOHAVE COUNTY, ARIZONA**

by  
**Edward G. Sable**  
U. S. Geological Survey  
**1995**

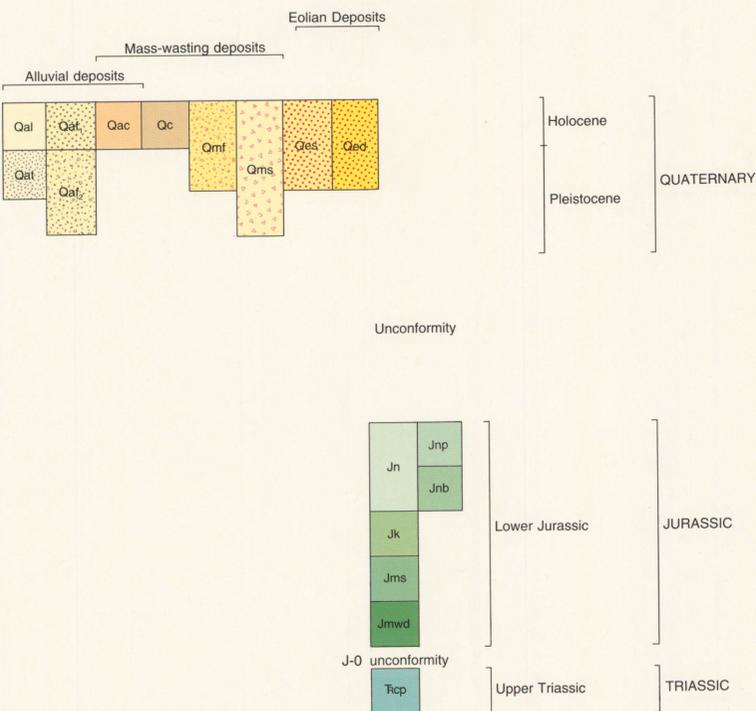
Base map from U.S. Geological Survey  
Hildale 7.5' Quadrangle, 1980

Geology mapped in 1985, 1986 and 1989  
Lori J. Douglas, Cartographer

DESCRIPTION OF MAP UNITS

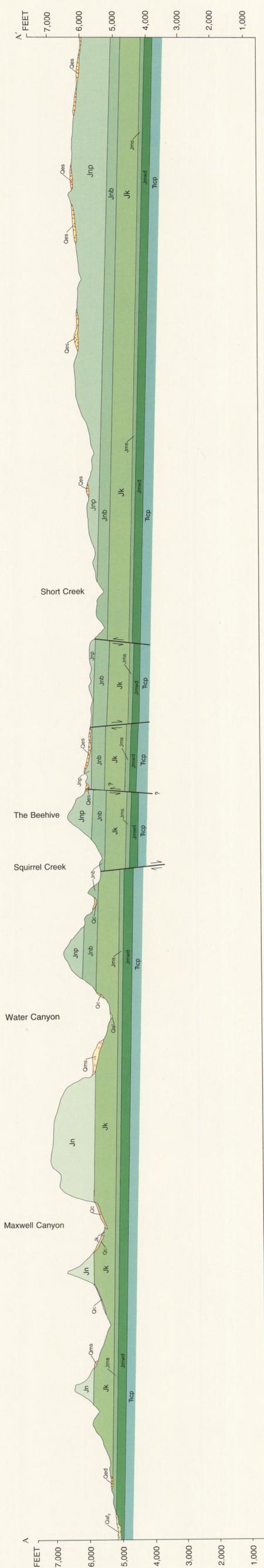
- Qal** Stream alluvium (Holocene) - Mostly sand with scattered pebbles and cobbles and few boulders of sandstone, unfossilized wood and man-made debris in vicinity of Hildale. Lesser amounts of interbedded mud and silt. Generally reddish brown to pale brown; sand mostly fine to medium, well stratified, cross-bedded. Probably less than 10 feet (3 m) thick along South Creek, Broad Hollow, and Cottonwood Canyon; possibly 100 feet (30 m) or more thick along Short Creek. Includes low terraces to about 5 feet (1.5 m) above current stream levels.
- Qat** Terrace alluvium (Pleistocene) - Sand and gravel, reddish brown, tabular bedded to fluvial cross-bedded; contains mostly matrix-supported, pebble-sized, subrounded clasts of sandstone, but includes cobbles and boulders as much as 1.5 feet (0.5 m) in diameter; unit fines upward. Exposed deposits are about 6 to 8 feet (2-2.4 m) thick along Broad Hollow and Cottonwood Canyon, as much as 20 feet (6 m) thick along South Creek, and as much as 80 feet (24 m) thick along Short Creek.
- Qaf** Young fan alluvium (Holocene) - Sand like that in unit Qal but crudely bedded; contains scattered pebbles and cobbles of sandstone and "ironstone" (iron-oxide-cemented sandstone and siltstone), distributed on sloping fan-like surfaces that are well developed along Broad Hollow, where the deposits overlie unit Qac, less common in the high-walled canyons of other main drainages. Estimated to be 2 to 20 feet (0.6-6 m) thick.
- Qaf** Old fan alluvium or pediment surface deposits (Pleistocene?) - Locally derived reddish-brown silt and sand and matrix-supported pebble- to cobble-size gravel lenses and rare subangular boulders; stabilized by low vegetation, locally covered by eolian sand; forms moderately dissected low-angle surfaces that slope away from valley walls; few feet to more than 25 feet (8 m) thick.
- Qac** Mixed alluvium and colluvium (Holocene) - Mostly reddish-brown to light-brown sand eroded from the Navajo Sandstone and reworked by sheet flow and wind. Contains few pebbles and silt to clay admixtures, relatively smooth surfaces are generally low angle, planar to curving, but without morphology characteristic of fan deposits. Deposits thicken downslope toward stream channels and interfinger with fluvial and other mass-wasting deposits. Contains unmapped small bedrock areas. Thickness possibly as much as 20 feet (6 m).
- Qc** Colluvium (Holocene) - Mostly pebble- to boulder-sized debris, unsorted, sand- to clay-size fractions; masks bedrock on steep slopes largely below Navajo Sandstone and Springdale Sandstone Member of Moenave Formation. Includes massive blocks of sandstone as much as 30 feet (9 m) in diameter and some talus. Deposits range from crudely sheet-like to linear gully fills, commonly modified by sheet flow. Thickness 2 to 30 feet (0.6-9 m).
- Qmf** Debris-flow and rock-slide deposit (Holocene to Pleistocene?) - Locally derived rubble of unsorted sand, sandstone, silt and clay, reddish brown to reddish orange, matrix- and clast-supported, generally present as narrow lobate forms, commonly unstable. Thickness 2 to 20 feet (0.6-5 m).
- Qms** Landslide debris (Holocene to Pleistocene) - Chaotic mixture of clay- to sand-matrix-supported clasts ranging from granule-size to angular blocks of Navajo Sandstone many hundreds of feet long. Characterized by modified scarps, Toreva-like blocks, and disturbed bedrock with contorted bedding and steep dips. Thickness may be as much as or more than 100 feet (30 m). Unit where exposed along South Creek drainages is part of a larger slide complex that extends northward beyond quadrangle boundary. Petrified Forest Member of Chinle Formation is the main unstable bedrock unit underlying the landslide complex.
- Qes** Eolian sand, sheet-flow deposits, and residuum, undivided (Holocene and Pleistocene?) - Sand, fine to medium, and minor silt, orange, pink, and yellowish gray; occurs as veneer of mostly stabilized sheet sand and irregular fillings in bedrock hollows and along intermittent drainages mostly in upland areas. Grades downslope to alluvium. Locally includes small unmapped outcrops of bedrock. Thickness 1 to 5 feet (0.3-1.5 m).
- Qed** Eolian sand in dunes and dune ramps (Holocene and Pleistocene?) - Sand as above deposited in dunes and dune ramps flanking steep slopes and cliffs. Locally consists of older, stabilized deposits and younger, active deposits. As much as 50 feet (15 m) thick.
- Jnp** Navajo Sandstone (Lower Jurassic) - Sandstone, generally light brown on fresh surfaces, weathers to a variety of brown, orange, gray, red, and pink hues; quartzose; well sorted, mostly fine to medium grained, moderately friable, mostly massive, with sweeping high-angle, wedge-planar to tabular-planar, tangential cross-beds in sets 5 to 30 feet (1.5-9 m) thick of probable eolian origin. Cement is mostly calcareous and siliceous with lesser iron and manganese oxides. The "pink or vermilion" unit (Jnp), in which cross-bed sets are thick and conspicuous, commonly weathers to curving surfaces, "bosses" and rounded ledges. Basal 200 to 400 feet (61-122 m) "gray and reddish-brown" unit (Jnb) is resistant, ledge-forming, composed of minor planar sandstone interbeds of probable fluvial origin and cross-bed sets generally thinner than those in unit Jnp. Distinction between Jnp and Jnb units is unclear in western part of quadrangle (undifferentiated unit Jn), as well as in the adjoining Smithsonian Butte quadrangle (Moore and Sable, 1992) to the west.
- Jn** Navajo Sandstone (Lower Jurassic) - Sandstone, generally light brown on fresh surfaces, weathers to a variety of brown, orange, gray, red, and pink hues; quartzose; well sorted, mostly fine to medium grained, moderately friable, mostly massive, with sweeping high-angle, wedge-planar to tabular-planar, tangential cross-beds in sets 5 to 30 feet (1.5-9 m) thick of probable eolian origin. Cement is mostly calcareous and siliceous with lesser iron and manganese oxides. The "pink or vermilion" unit (Jnp), in which cross-bed sets are thick and conspicuous, commonly weathers to curving surfaces, "bosses" and rounded ledges. Basal 200 to 400 feet (61-122 m) "gray and reddish-brown" unit (Jnb) is resistant, ledge-forming, composed of minor planar sandstone interbeds of probable fluvial origin and cross-bed sets generally thinner than those in unit Jnp. Distinction between Jnp and Jnb units is unclear in western part of quadrangle (undifferentiated unit Jn), as well as in the adjoining Smithsonian Butte quadrangle (Moore and Sable, 1992) to the west.
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- Jk** Kayenta Formation (Lower Jurassic) - Siltstone, sandstone, mudstone and shale, reddish orange to pale red; sandstone is quartzose, silty, and very fine grained. Bedding is broadly lenticular, some sandstone units contain trough cross-beds with features that suggest point-bar forms. Mudstones are variegated; some beds in lower part of formation resemble those in the Chinle Formation (below), being slippery and unstable when wet. Sandstone units about 30 feet (6 m) thick in middle and lower part of formation exhibit eolian-type cross-beds; may be correlative with Lamb Point Tongue of the Navajo Sandstone. Coarsens upward; uppermost 50 to 100 feet (15-30 m) is largely cliff- or ledge-forming sandstone and siltstone. About 600 to 630 feet (183-192 m) thick.
- Jms** Springdale Sandstone Member - Sandstone, pale red to light brown, quartzose, weathers grayish orange, blocky to flaggy, generally tabular bedded, but with some lenticular beds and trough cross-bedding. Characterized by intermittent lenses a few inches thick of intraformational conglomeratic sandstone and conglomerate with 0.1 to 2 inches (0.2-5 cm) claystone clasts. Uppermost beds tabular, locally stained to moderate yellow hue. Resistant quartz-cemented cliff-former, about 115 to 125 feet (35-38 m) thick.
- Jmw** Whitmore Point and Dinosaur Canyon Members, undivided - Whitmore Point Member is slope-forming, pale-red and light-greenish-gray siltstone and claystone and interbedded minor pale-red sandstone, about 50 to 60 feet (15-18 m) thick. Dinosaur Canyon Member is slope- and ledge-forming, ripple-marked, reddish-brown and light-greenish-gray siltstone and mudstone and lesser very-fine-grained quartzose sandstone. About 200 feet (61 m) thick.
- Jcp** Chinle Formation (Upper Triassic) - Two members are present in the map area, the Petrified Forest Member and underlying Shinarump Member, but the Shinarump is not exposed. Total thickness of Chinle is more than 450 feet (137 m) thick.
- Jcp** Petrified Forest Member - Varicolored (gray, red, purple, brown) slope- and badlands-forming, tabular-bedded clay shale and clay with volcanically derived clay minerals and minor gray fluvial sandstone and conglomerate. Unstable when wet; contributes to mass movement of overlying units. Upper contact is an erosional unconformity. Only upper, roughly 150 to 200 feet (46-61 m) are exposed in the quadrangle. Total thickness in adjoining Smithsonian Butte quadrangle is about 380 feet (116 m) (Moore and Sable, 1992).

CORRELATION OF MAP UNITS



MAP SYMBOLS

- Contact - Dashed where approximate or inferred. Contact of Quaternary units approximate.
- High-Angle Fault - Bar and ball on downthrown block; dashed where approximately located or inferred; dotted where concealed; queried where inferred
- Joint in Navajo Sandstone
- Linear Feature Observed on Aerial Photographs - May be fault or joint trace.
- Structure Contour - Datum, top of Moenave Formation; extrapolated where land surface is below datum; contour interval 100 feet.
- Dominant Dip Direction of Cross-beds in Navajo Sandstone
- Top of Prominent Sandstone Units in Kayenta Formation - Probably includes Lamb Point Tongue of Navajo Sandstone.
- Scarp - At head of slump, torea block, or landslide; queried where inferred; hachures indicate direction of movement.
- Direction and Degree of Slope of Alluvial Fan or Pediment Surface
- Coherent Slide Block of Navajo Sandstone



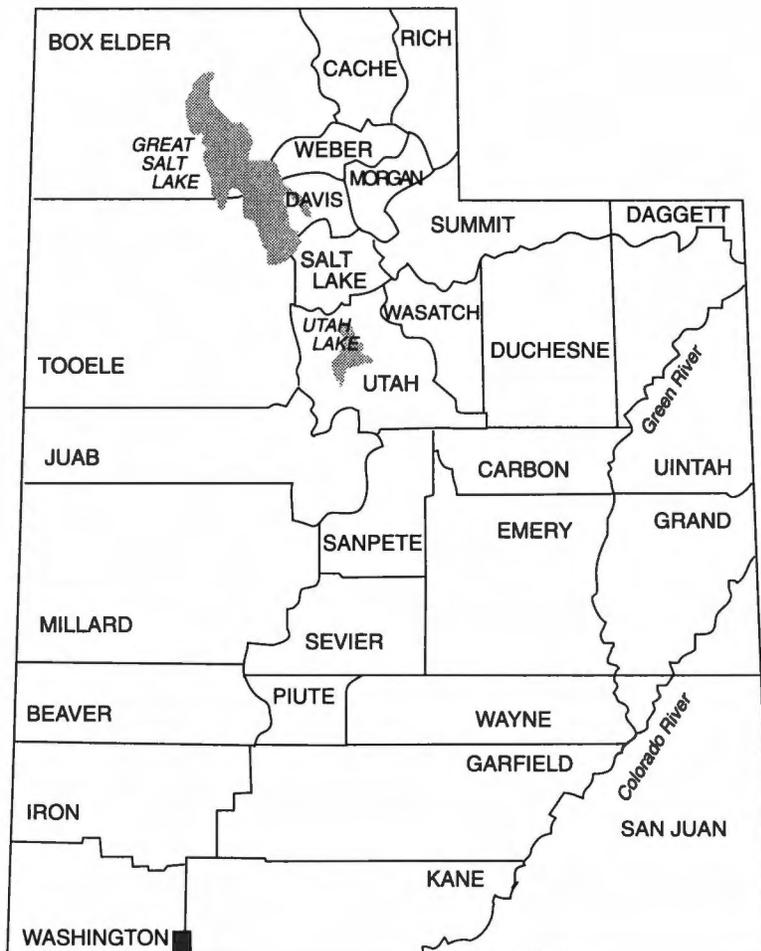
PERIOD	EPOCH	FORMATION	MEMBER	SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY	
JURASSIC	Lower Jurassic	Navajo Sandstone	"pink" or "vermillion" unit	Jnp	1465+ (447+)		
			"gray and reddish-brown" unit	Jnb			
	Lower Jurassic	Kayenta Formation		Jk	600-630 (183-192)		
			Springdale Sandstone Member	Jms	115-125 (35-38)		
			Whitmore Point Member	Jmw	50 (15)	350+	
	Lower Jurassic	Moenave Formation	Dinosaur Canyon Member	Jmw	200± (61±)	107+	
				Jcp	380+ (116+)	450± (137±)	
	TRIASSIC	Upper Triassic	Chinle Formation	Petrified Forest Member	Jcp	380+ (116+)	450± (137±)
				Shinarump Member	Jcp		7-3
		Middle (?) and Lower Triassic	Moenkopi Formation	upper red member			
Shnabkaib Member							
middle red member					1200-1350 (365-411)		
Virgin Limestone Member							
Middle (?) and Lower Triassic	Moenkopi Formation	lower red member					
		Timpowep Member					
PERMIAN	Lower Permian		Kaibab Limestone				

SURFACE UNITS

SUBSURFACE UNITS

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by  
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Denver



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*U.S. Geological Survey, Denver*

## ABSTRACT

Field mapping supplemented by aerial photograph interpretation has delineated exposures of four bedrock formations ranging from Triassic to Jurassic in age, consisting of seven map units, and ten informal surficial units of known or inferred Quaternary age in the scenic Hildale quadrangle. Only the uppermost part of the Petrified Forest Member of the Chinle Formation (Upper Triassic), variegated claystone about 150 feet (46 m) thick, is exposed in the quadrangle. The Moenave Formation (Lower Jurassic), about 350 feet (107 m) thick, consists of (in ascending order) the Dinosaur Canyon Member, mostly red-hued siltstone and mudstone and lesser sandstone, 200(?) feet (61? m) thick; the Whitmore Point Member, 50 to 60 feet (15 -18 m) of pale-red to greenish-gray siltstone and clay-stone; and the Springdale Sandstone Member, a cliff-forming, pale-red to light-brown sandstone 115 to 125 feet (35-38 m) thick. The Kayenta Formation (Lower Jurassic), is a coarsening-upwards unit of mostly reddish-orange- to moderate-red-hued siltstone, mudstone, and sandstone and minor limestone, 600 to 630 feet (183-192 m) thick. As mapped, it includes beds of eolian sandstone probably equivalent to the Lamb Point Tongue of the Navajo Sandstone. The overlying Navajo Sandstone (Lower Jurassic) exhibits an incomplete local thickness of as much as 1,300 feet (396 m) and a total incomplete thickness of about 1,465 feet (447 m). It consists predominantly of highly cross-bedded sandstone of various hues of pink, gray, buff, and red, and is divided informally into a lower gray or reddish-brown unit

and an upper pink or vermilion unit in the eastern part of the quadrangle. Elsewhere the Navajo is undivided. A prominent feature of the Navajo is the large-scale, steep cross-bedding of probable eolian origin, which generally dips south-southwest to west-southwest in this area.

Unconsolidated to poorly consolidated surficial deposits are of local origin, and include those of alluvial, eolian, colluvial (mass wasting), and weathering processes. Alluvial deposits of Holocene and probable Pleistocene ages include fan deposits along several drainages and sand and gravel terrace deposits of probable Pleistocene age along South Creek and Short Creek, where terrace surfaces are as much as 20 and 80 feet (6 and 24 m), respectively, above present stream levels. Younger stream deposits include sand and gravel in present stream channels and those of modern and recent floodplain deposits generally less than 5 feet (1.5 m) above present streams. Mass-wasting colluvial deposits include deposits from slope wash and downslope creep; a unit of local flow, slide, and talus debris; and a complex unit of heterogeneous mud- to gigantic boulder-sized debris of landslide, mudflow, and debris-flow origin chaotically distributed on slopes below the Navajo Sandstone. Slippage occurred mostly in and on the Petrified Forest Member of the Chinle Formation and to a lesser extent on the Kayenta Formation. Some hillsides are formed by Toreva blocks. Eolian deposits of sand and silt derived largely from the Navajo Sandstone include sheet-like or generally smooth-surfaced, formless deposits and dune-ramp deposits of lobate form which have encroached on steep hillsides and cliffs. Mixed alluvial, colluvial, eolian depos-

its, and weathered residuum are mapped together locally where the dominant type of deposit is uncertain.

Structure in the Hildale quadrangle consists of a homocline dipping northeast to east-northeast with regional dip of generally less than 2 degrees; it is cut by a few steeply dipping extensional faults of probably less than 300-feet (91 m) displacement. Well-developed joints form dominant roughly unidirectional sets striking north-northwest to northwest and north-northeast to northeast, as well as enigmatic semi-radial and semi-arcuate patterns that may be perturbations along faults.

No known mineral or fuel resource exploitation or subsurface exploration has occurred in the quadrangle, most of which lies within the Canaan Mountain Wilderness Study Area which has been appraised as having moderate resource potential for petroleum and low potential for various metals, coal, and geothermal energy. Sand and gravel for construction use are present along Short Creek. The Navajo Sandstone has limited potential for use in some industrial applications and for decorative and souvenir purposes.

Interpretation of gravity and aeromagnetic geophysical data indicates no known significant local anomalies. A gravity low at Canaan Mountain appears to be due to thick Navajo Sandstone. The area lies on the west flank of a basement magnetic low; readings within the quadrangle are -380 to -130 nanoteslas.

Earthquakes of Richter magnitudes 2.0 and greater have been recorded east and west of the quadrangle; a 1992 earthquake (M 5.8) resulted in structural damage due to landslide at Springdale, 5 miles (8 km) north of the quadrangle. Surface-water potential is limited; two essentially perennial streams of low volume flow through the quadrangle. Ground-water potential is considered good.

## INTRODUCTION

The Hildale quadrangle (plate 1 and figure 1), named from the town of Hildale in its southwest corner, straddles the boundary between Washington and Kane Counties, Utah, along the Arizona border. It is the southwesternmost quadrangle in the Kanab 30' x 60' (1:100,000 scale) quadrangle. A narrow strip about 50 to 150 feet (15-46 m) wide lies along the southern margin of the quadrangle in Mohave County, Arizona. The quadrangle, which lies 1 mile (1.6 km) south of Zion National Park, is bounded by Springdale East, Elephant Butte (Sable and Doelling, 1990) and Smithsonian Butte (Moore and Sable, 1992) quadrangles on the north, east, and west, respectively. The area is located within the Colorado Plateaus physiographic province, and is mostly characterized by rolling upland surfaces that average roughly 6,500 feet (1,980 m) altitude along the divide between the north-flowing Virgin River tributaries and the south-flowing streams of Short Creek and Cottonwood Canyon. Canaan Mountain and South Mountain rise 1,700 to 2,500 feet (518-762 m) above the main drainages; they consist of sandstone bedrock and sand. Lowland areas along South and Short Creeks and Cottonwood Canyon consist of steep slopes and ledges mostly covered by rock and soil debris, above which rise the precipitous Vermilion Cliffs. The highest point is 7,175 feet

(2,187 m) above mean sea level on Canaan Mountain, the lowest is less than 4,200 feet (1,280 m) along South Creek. Over 90 percent of the area is administered by federal and state agencies; land in the vicinity of Hildale and Short Creek is privately owned. The town of Hildale (1,009 population in 1990) is situated mostly on a high alluvial terrace about 30 to 50 feet (9 to 15 m) above Short Creek (figure 2). Principal public and private access routes into the quadrangle are secondary roads and trails leading from Utah Highway 59 that crosses the southwest corner of the map area; and trails along and near Broad Hollow, accessible from a county road southeast of the quadrangle, called the "sand dunes" road because it passes through Coral Pink Sand Dunes State Park 14 miles (22 km) east of the Hildale quadrangle. Most of the quadrangle is accessible only by foot or horseback, and most unimproved vehicle trails are accessible only to four-wheel drive or specialized terrain vehicles because of soft, deep sand.

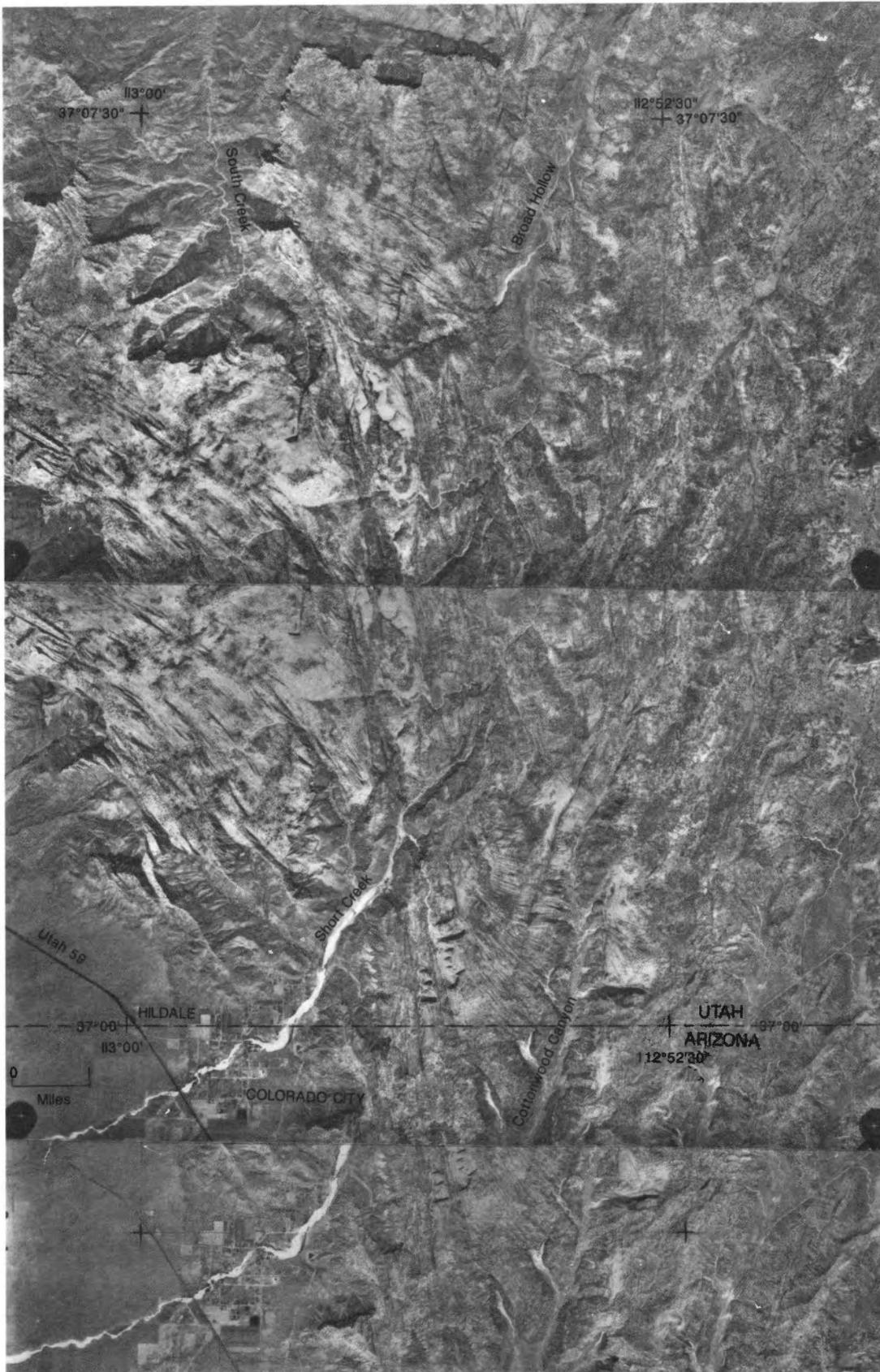
The upland surfaces of Canaan and South Mountains trend northeast across the quadrangle (figure 3). Short Creek, in the southwestern part, and South Creek, in the northwestern part, are the two main drainages. Streams in Broad Hollow and Cottonwood Canyon in the northeastern and southeastern areas are ephemeral. The upland surfaces are used for winter grazing of cattle, and several springs and seeps, which issue from the Navajo Sandstone, are used by local ranchers for their livestock. Most of the area was set aside as part of the U.S. Bureau of Land Management's Canaan Mountain Wilderness Study Area and was investigated for mineral resources by the U.S. Geological Survey and the U.S. Bureau of Mines (Van Loenen and others, 1988). Farm produce and forage crops are grown along Short Creek in and near Hildale. The Hildale irrigation and culinary water supply is obtained from springs in Water and Maxwell Canyons and from wells.

There has been little geologic work in the Hildale quadrangle prior to investigations of the wilderness study area mentioned above, which consisted of geologic mapping concurrent with sampling and analysis of stream sediments and bedrock, and regional geophysical investigations. Previously published geologic maps have been of small scale (Gregory, 1950; Hintze, 1963, 1980) or photogeologic interpretation (Pillmore, 1956). Part of the quadrangle was mapped by Sable in 1985 and 1986 as part of the USGS investigation of the Canaan Mountain Wilderness Study Area, and the remainder by Sable in 1989, supplemented by interpretation of vertical aerial photographs. The photographs included black-and-white photography at 1:33,200 scale flown for U.S. government agencies and color photography at 1:24,000 scale obtained from Intrasearch, a private organization.

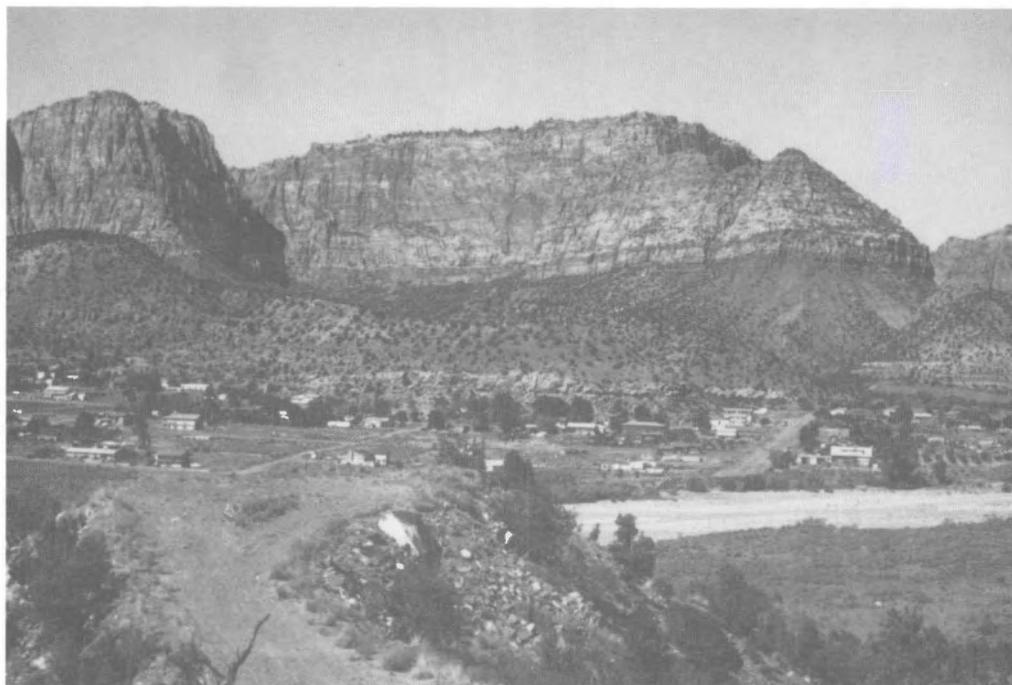
## STRATIGRAPHY

### Mesozoic Rocks

Mesozoic rocks in the subsurface of the quadrangle in descending order are the Upper Triassic Chinle Formation, which consists of the lower part of the Petrified Forest Member, mostly varicolored claystone containing volcanically derived clay min-



**Figure 1.** Aerial photograph stereotriplet of Hildale quadrangle and adjoining areas. Prominent fracture patterns in the Navajo Sandstone reflect multidirectional stress fields. U.S. Geological Survey VERE photographs 2-17, 2-18, 2-19, flown August 28, 1978. Scale and boundaries are approximate.



**Figure 2.** Part of town of Hildale, Utah, looking north. Cliffs of Navajo Sandstone form a scenic background and overlie slope-forming Kayenta Formation mostly covered by debris. Low cliffs of Springdale Sandstone Member of the Moenave Formation are above buildings. Short Creek in right middle foreground. Photograph taken in 1987.



**Figure 3.** Oblique aerial view of southern part of Hildale quadrangle looking southeast. Precipitous cliffs and low-relief upland surfaces cut in Navajo Sandstone dominate the area. Low cliffs of Springdale Sandstone Member of Moenave Formation in lower foreground. Short Creek valley at upper right. Photograph taken in 1985.

erals and fluvial channel-fill sandstone; and the underlying Shinarump Member, gray cross-bedded fluvial sandstone, conglomerate, and minor shale, which overlies the Moenkopi Formation (Lower and Middle Triassic). These units are well exposed in the Springdale West and Virgin quadrangles northwest of the Hildale quadrangle. Members of the Moenkopi are, in descending order, the upper red member, composed of red mudstone, siltstone, and sandstone; the Shnabkaib Member, similar to the upper red member but containing abundant gypsum and gypsiferous mudstone; the middle red member, similar to the upper red member but with less sandstone; the Virgin Limestone Member, in part fossiliferous limestone interbedded with marine shale; the lower red member, similar to the middle red member; and the Timpoweap Member, largely sandy limestone, limy sandstone, and minor sedimentary breccia and conglomerate. The base of the Moenkopi, which overlies the Kaibab Limestone (Lower Permian), coincides with the Tr-1 unconformity of Pippingos and O'Sullivan (1978). Thicknesses of the subsurface Mesozoic units shown on the columnar section (plate 2) are extrapolated from nearby areas.

About 2,500 feet (762 m) of Upper Triassic and Lower Jurassic sedimentary rocks are exposed in the Hildale quadrangle. The Upper Triassic rocks consist of the upper part of the Petrified Forest Member of the Chinle Formation. Lower Jurassic rocks (ascending) are the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone Members of the Moenave Formation, the Kayenta Formation, and the Navajo Sandstone. Large areas of bedrock are veneered by unconsolidated Quaternary deposits of alluvial, eolian, mass-wasting, and weathering origin.

## Triassic Rocks

### Chinle Formation (Upper Triassic) (T<sub>cp</sub>)

The Chinle Formation consists of two members in this part of southwestern Utah, the Petrified Forest Member and the underlying Shinarump Member (Gregory, 1916; Gregory and Williams, 1947). Only the upper part of the Petrified Forest Member is exposed in the Hildale quadrangle. The exposures along South Creek and its tributaries are largely mud covered. They consist of varicolored (gray, red, purple, brown) claystone and clay containing volcanically derived swelling clay minerals, minor siltstone lenses, and minor slumped sandstone. Float of pebble-conglomerate clasts, mostly well-rounded quartzite and chert, silicified wood fragments, and manganiferous limy nodules are present on badlands-like slopes along South Creek. Rare bedrock exposures exhibit low-angle and contorted bedding, the result of creep and sliding of these and overlying rocks and debris into the valley. No continuous exposures or distinct upper contact of the unit were seen, and the incomplete thickness of the exposed upper part of the member is estimated to be 150 to 200 feet (46-61 m). In the Smithsonian Butte quadrangle, adjoining the Hildale quadrangle to the west, the total thickness of the member is estimated to be 380 feet (116 m).

## Jurassic Rocks

### Moenave Formation (Lower Jurassic) (J<sub>mwd</sub>, J<sub>ms</sub>)

The Moenave Formation (Harshbarger and others, 1957), more than 300 feet (91 m) thick, consists of three members in ascending order: the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone Members.

Strata of the Dinosaur Canyon Member of the Lower Jurassic Moenave Formation are poorly to moderately resistant, slope- and ledge-forming, reddish-orange and reddish-brown siltstone and mudstone and lesser amounts of sandstone, minor claystone, and conglomerate. The member, here mapped with the overlying Whitmore Point Member (map unit J<sub>mwd</sub>), is exposed in the southwestern and northwestern parts of the quadrangle. This map unit is largely debris covered, and no continuously exposed section is known in this quadrangle. Its thickness, based on map measurements and estimates along South Creek, is about 200 feet (61 m). Resistant sandstone and siltstone ledge-forming units are mostly less than 5 feet (1.5 m) thick and are tabular-bedded but contain internal cross-bedding features of fluvial origin. The depositional environment is interpreted to be that of an arid floodplain with overbank and shallow channel-fill deposits.

The Whitmore Point Member of the Moenave Formation overlies the Dinosaur Canyon with apparent conformity and gradation. Best exposures in the quadrangle are in minor drainages on the west side and west of Hildale, along the Canaan Mountain front. There, the member consists of 50 feet (15 m) of pale-red to light-greenish-gray claystone, reddish-brown to gray siltstone, and quartzose sandstone beds that are generally thin and tabular bedded but in part cross-bedded and ripple marked. Concentrations of irregular pebble-sized red chert and claystone pebbles were seen in float in the middle part of the unit, apparently derived from the weathered bedrock. The uppermost beds consist of 5 feet (1.5 m) of dusky-red clay capped by 1 foot (0.3 m) of greenish-gray sandstone. The contact of the Whitmore Point with the overlying Springdale Sandstone Member appears to be conformable but abrupt; regionally, the two members are reported to intertongue west of Johnson Canyon, about 25 miles (40 km) east of the Hildale quadrangle (Doelling and Davis, 1989, p. 43). Depositional environments of the Whitmore Point Member were probably mostly floodplain and lacustrine; no distinctive channel-fill sandstone was seen, the sandstone beds being thin and tabular.

The Springdale Sandstone Member (map unit J<sub>ms</sub>) crops out as a distinctive pale-red to light-brown, cliff-forming unit in the southwestern and northwestern parts of the quadrangle (figure 3); it is 115 to 125 feet (35-38 m) thick. Fresh surfaces are light to very light gray; the sandstone is generally fine- to very fine-grained, silty, moderately to well indurated with calcite cement, is partly micaceous, and contains lenses of claystone-pebble conglomerate and rare silicified logs. Trough and tabular cross-bedding are common; they grade upward to tabular horizontal bedding. The thin lenses of red and gray, matrix-supported claystone-pebble conglomerate are distinctive features of the member. Viscous-flow features and vertical sand fillings are present. Uppermost beds west of Hildale are tabular and have a distinctive yellow color. Depositional environments, judging

from current features, point bar-like features, and channel geometry, were fluvial; the considerable lateral extent of sandstone beds and paucity of clay material may indicate a braided stream system.

No diagnostic fossils were noted in the Moenave in the Hildale quadrangle, but the formation is considered Early Jurassic in age on the basis of organic remains found in other areas; they include palynomorphs (Peterson and Pippingos, 1979; Im-lay, 1980, p. 97) and dinosaur scutes (Padian, 1989). The base of the Moenave Formation corresponds with the J-0 unconformity of Pippingos and O'Sullivan (1978).

#### Kayenta Formation (Lower Jurassic) (Jk)

The Kayenta Formation (Baker and others, 1936), exposed in the southwestern and northwestern parts of the Hildale quadrangle mainly along Short Creek and South Creek, is a vivid reddish-orange to moderate-red, moderately steep slope- and ledge-forming unit about 600 to 630 feet (183-192 m) thick (figure 2). It consists mostly of siltstone and mudstone, lesser sandstone and claystone, thin limestone beds in the upper part, and minor thin claystone conglomerate. Sandstone comprises about 25 percent of the unit, is pinkish gray, very fine grained, quartzose, with cement of carbonate, iron oxide, and clay. Prominent ledge-forming sandstone units are present about 150 to 200 feet (46 to 61 m) and 400 feet (122 m) above the base of the Kayenta; their intermittent outcrop character may represent actual lensing or may be due to rubble cover. The sandstone is pinkish gray to gray, fine grained, and exhibits eolian-type planar and tangential cross-bedding that dips southwestward. One of the lower of these sandstone units may represent the Lamb Point Tongue of the Navajo Sandstone. In addition to slope-ledge exposures, the sandstone unit is exposed along the west side of Maxwell Canyon about 40 feet (12 m) above the stream 0.5 mile (0.3 km) above the mouth. Mud cracks and ripple marks are present in Kayenta mudstone and siltstone; small-scale cross-bedding is characteristic of many sandstone beds. The Kayenta Formation coarsens upwards; cliff-forming, red-weathering sandstone and siltstone beds make up more than 80 percent of the upper 50 to 100 feet (15-30 m). The Kayenta was deposited largely by streams, but eolian and lacustrine playa(?) environments are also represented. No recognizable organic remains were seen in the Kayenta in the Hildale quadrangle, although dinosaur tracks are present in the Kayenta in Zion National Park, north of the Hildale quadrangle (Hamilton, 1984, p. 81).

The Tenney Canyon Tongue of the uppermost Kayenta (Averitt and others, 1955) is recognized as that stratigraphic interval between the Lamb Point Tongue of the Navajo and the main body of the Navajo Sandstone. The exact interval of the Tenney Canyon is not known in the Hildale quadrangle because the position

and unequivocal identification of the Lamb Point Tongue are uncertain.

#### Navajo Sandstone (Lower Jurassic) (Jn, Jnb, Jnp)

Exposures of the Navajo Sandstone cover the largest part of the Hildale quadrangle (figure 3). The lower, roughly 800 to 1,000 feet (244-305 m) of the formation rises as steep-walled cliffs of massive sandstone above the slopes and lowlands on the underlying rock units. Its relative resistance to erosion has been attributed to a higher proportion of carbonate cement than in younger (and higher) sandstone beds of the formation (Doelling and Davis, 1989, p. 49). The uplands above the cliffs are relatively smooth, rolling topographic features expressed as sandstone bosses, knolls, mounds, ledges, and low cliffs that protrude through generally featureless sand-covered areas. The Navajo is almost entirely sandstone that ranges from pale to moderate reddish brown, light brown, and a variety of common colors such as tan, gray, white, buff, and salmon. The sandstone is more than 90 percent quartz grains that are mostly fine, subround to subangular, generally well sorted, frosted, but range from very fine to coarse. Cement is of carbonate, silica, iron oxides, and probably manganese oxides. No green or highly vivid red or yellow colorations like those used for decorative or artistic purposes were seen in the quadrangle. Minor, thin interbeds of reddish-brown mudstone and siltstone between cross-bedded sandstone are uncommon except in the lowest approximately 100 feet (30 m).

A characteristic feature of the Navajo is the sets of cross beds of probable eolian origin as much as 30 feet (9 m) thick that are most pronounced and thickest in the middle and upper parts of the formation (figure 4). Cross beds range from tangential to tabular, and planar beds are tabular or wedge-shaped as seen in three-dimensional view. Cross-bed directional readings were taken in many places, but were not systematic; the method was



Figure 4. Cross bedding in Navajo Sandstone along Broad Hollow. View to northwest. Hill in background composed of pink unit of Navajo. Photograph taken in 1985.

to view a large outcrop or group of outcrops and determine the average dominant direction in a semiquantitative manner. Some bimodal cross-bedding directions are present in the area, but the predominant dip directions are southwest (ranges of S. 25° W. to S. 70° W.), with dips of 15 to 27 degrees. Penecontemporaneous contorted bedding is not common but is a locally prominent feature of the Navajo; it has commonly been attributed to slump down oversteepened dune faces (for example, McKee, 1979, p. 213-214).

Subdivisions of the Navajo were described as early as the late 1800s. They were made largely on the basis of color and bedding feature characteristics and topographic expression (see Doelling and Davis, 1989, for historic discussion). Although the colors cross the bedding planes in places and are probably not positionally significant, they nevertheless indicate differences in cement composition and, within an area of several quadrangles, do, on a gross scale, approximate bedding. Three informal units were delineated on the geologic map of The Barracks quadrangle (Sable and Doelling, 1993), just northeast of the Hildale quadrangle. They have been named, in ascending order, the gray and reddish-brown unit (Jnb), the pink or vermilion unit (Jnp), and the upper white unit (Jnw). In the Hildale quadrangle, the lower two units are reasonably well defined along Cottonwood Wash and upper Short Creek, but in South Creek drainages, in the southwesternmost part of the Hildale quadrangle, and in the adjoining Smithsonian Butte quadrangle (Moore and Sable, 1992) to the west, the two units could not be differentiated and the Navajo is not divided. There, beds in the lowermost part of the Navajo are similar to those in the pink unit. Although speculative, the possibility exists that the pink unit of the Navajo is in overlap relationship with the underlying gray and reddish-brown unit. It would thus represent southwestward-transgressing beds of an eolian "sand sea" that extended beyond the distal edge of the earlier mixed eolian and fluvial deposits.

A maximum thickness of the incomplete Navajo Sandstone of 1,465 feet (447 m) was calculated by cross-section measurement, using a regional dip of 2 degrees. Of this, the lowest, gray and reddish-brown unit, characterized by interbedded, strongly eolian-type cross-bedded, gray sandstone and more or less tabular reddish-brown to brown sandstone is as much as about 400 feet (122 m) thick. The contact between the underlying Kayenta and the Navajo is drawn at the base of the lowest thick sandstone bed exhibiting eolian-type cross bedding. This placement may differ from that of some other workers who place the contact lower, at the base of red, cliff-forming sandstones above slope-forming, less resistant Kayenta beds; the difference is about 100 feet (30 m) in the Hildale quadrangle. The pink unit, more than 1,065 feet (325 m) thick, consists almost entirely of eolian-type cross-bedded sandstone as previously described. Compared with the gray and reddish-brown unit, the pink unit exhibits lighter pink and gray colors, thicker cross-bed sets in which the cross beds are strongly accentuated by weathering, and relatively rare tabular sandstone beds.

In The Barracks quadrangle (Sable and Doelling, 1993), the complete thickness of the Navajo Sandstone is about 1,650 feet (503 m). There, the uppermost, white unit is about 400 to 600 feet (122-183 m) thick. Similarly, the white unit is about 400 feet (122 m) thick about 2 miles (3.2 km) east of the Hildale

quadrangle in the Elephant Butte quadrangle (Sable and Doelling, 1990). The white unit as defined elsewhere is not, however, present in the Hildale quadrangle although, on an equal interval basis, its equivalent should be present in the upper 300 feet (90 m) or so of the Navajo there. Thus, the lower boundary of the white unit seems meaningless as even an approximation of a sedimentary interface.

## Quaternary Rocks

Ten units of surficial, relatively unconsolidated deposits were mapped in the Hildale quadrangle. They fall under three genetic types resulting from alluvial, eolian, and mass-wasting processes modified in part by weathering. Some mapped units include two or more genetic types, such as the unit "mixed alluvium and colluvium" (map unit Qac). Parts of some surficial deposits may be as old as late Tertiary age, however, the map symbols reflect their dominant Quaternary aspect.

Alluvium includes fluvial (stream) deposits. These are divided on the basis of relative age as determined by their geomorphology and position relative to modern stream levels. Current river-channel and floodplain deposits, the most recent fluvial sediments, are mapped as Qal. They are characterized by their fresh appearance and relatively sparse vegetation cover, and consist of locally derived pale-orange to reddish-brown sand and gravel from bedrock formations, including pebble- to boulder-sized, mostly subangular clasts of sandstone as well as man-made debris. Older stream deposits (Qat) at higher levels, through which current streams have downcut, exhibit gently sloping terrace surfaces, the tops of which are a few feet to as much as 80 feet (24 m) above present stream levels, such as the terrace at the junction of Water and Maxwell Canyons with Short Creek. These well-exposed deposits consist of reddish-brown, crudely to well-bedded, mostly cross-bedded sand and gravel of mostly pebbles but with cobbles and boulders as much as 1.5 feet (0.5 m) in diameter. Sand and gravel with incorporated blocks of mass-wasting debris near the forks of South Creek form a single terrace deposit 6 to 8 feet (2-3 m) above stream level.

Younger alluvial-fan deposits (Qaf<sub>1</sub>) are well developed along Broad Hollow; they consist of largely structureless sand from Navajo Sandstone sources, with intermixed pebbles and cobbles of sandstone. Older alluvial-fan or pediment deposits (Qaf<sub>2</sub>) at the southwestern corner of the quadrangle occur as erosional remnants of an extensive fan apron, currently inactive, that bordered the southwestern side of Canaan Mountain. They are characterized by smooth, sloping bajada-like surfaces and are composed of fine sand and gravel of pebble to cobble size, in part mantled by wind-blown sand. Similar remnants are present high on the west wall of South Creek, but appear to have slumped towards the creek, as indicated by fractured surfaces, and, in one location, a reversal of surface slope dip. Mixed alluvial and colluvial deposits (Qac), such as those along Broad Hollow in the northeastern part of the quadrangle, are mostly sand with incorporated talus, slump blocks of sandstone, and soil-creep deposits; these also contain varied amounts of intermixed and, in part, overlying eolian sand and silt.

Eolian (wind-blown) deposits consist of two geomorphic forms of wind-blown sand and silt. Sheet-like relatively formless deposits (Qes) are commonly thin (a few feet), have smooth surfaces, and are found as surface veneer or infillings of topographic depressions. These are mostly stabilized by low plant cover such as grasses and sagebrush; some are currently active as shown by their lack of plant cover and fresh ripple-marked surfaces (figure 5). Dune-ramp or dune-apron sand deposits (Qed) include stabilized and fresh lobate deposits that have encroached onto steep hillsides, such as those 1.5 miles (2.4 km) north-northeast of Hildale, west of Short Creek. Commonly orange pink to grayish orange, they contrast vividly with the underlying slopes. They include minor rockfall debris. Most of the eolian sand is of local origin, the major source being the Navajo Sandstone. Height of individual sand ramps is as much as 200 feet (61 m); thickness of the sand is difficult to estimate, but may be as much as 50 feet (15 m).

Mass-wasting (gravity-induced) processes include colluvium, debris-flow deposits, and larger landslide complexes. Colluvium (Qc) is a general term for a loose mass of soil and/or rock fragments reworked and deposited by rainwash, slope wash, or slow continuous downslope creep. As mapped in this area, the unit also includes local incorporated talus debris which has



**Figure 5.** Photograph along Old Shunesburg Trail at Broad Hollow showing windblown sand cover. The trail served as a pioneer mail route to settlements west of the area.

fallen or rolled downslope. Debris-flow deposits (Qmf) are relatively small lobate debris-flow and muddy avalanche rubble mostly below Navajo Sandstone cliffs, including talus deposits in some places. Landslide, mudflow, and debris-flow materials are also present in large slide complexes (Qms). These heterogeneous, very poorly sorted, unlayered masses of debris contain clay-sized to very large angular boulder-sized fragments as much as tens of feet in diameter including a few gigantic blocks of Navajo Sandstone mapped as allochthonous blocks surrounded by debris (figure 6). This unit includes numerous smaller slides of varying ages as well as Toreva blocks (bedrock which has been detached from its parent body as a homogeneous mass and rotated as it slid downslope), and is especially well developed along South Creek where it is part of a much larger slide complex exposed in adjoining quadrangles north and northwest of the Hildale quadrangle. Comparison of aerial photographs of 1:62,500 scale taken in 1953 with those of 1:24,000 scale taken in 1983 failed to reveal evidence of movement of or within these debris-slide complexes in that time interval, although minor movements too small to be recognized may have occurred. Smaller slide complexes are also present along Short Creek and its tributaries and are well developed in the area of Maxwell Canyon.

Bedrock units upon which debris-slide deposits are well developed are the Petrified Forest Member of the Chinle Formation and the Kayenta Formation, both containing claystone and mudstone that are plastic and unstable when wet. Just north of the Hildale quadrangle, the Petrified Forest Member underlying the debris complex along South Creek exhibits high and irregular dips, folds, and shear zones that are anomalous to the bedrock structure of the area. The complex has also caused a pronounced constriction of the channel of South Creek. Furthermore, these debris deposits lie along a zone of such deposits about 30 miles (48 km) long that extends north-northwest along the west side of Zion National Park, subparallel to a series of faults of small to moderate displacement. Whether displacements along these faults provided the energy to initiate landsliding and debris fall is not known. On September 2, 1992, however, ground shaking during an earthquake located southeast of St. George, Utah, about 28 miles (45 km) west of the Hildale quadrangle caused a slope failure with resultant structural damage in the town of Springdale, about 5 miles (8 km) north of the Hildale quadrangle.

## STRUCTURE

Folding in the Hildale quadrangle consists of a homocline dipping gently northeast to east-northeast where the dip rarely exceeds 2 degrees. The highest structural area is therefore in the southwestern part of the map area. The datum for structural contours where they can be reasonably determined is the top of the Springdale Sandstone Member of the Moenave Formation; the northeastern part of the quadrangle does not show structural contours because no reliable structure horizon is known in the thick Navajo Sandstone. No lesser folds are known although there may be some minor ones along faults.

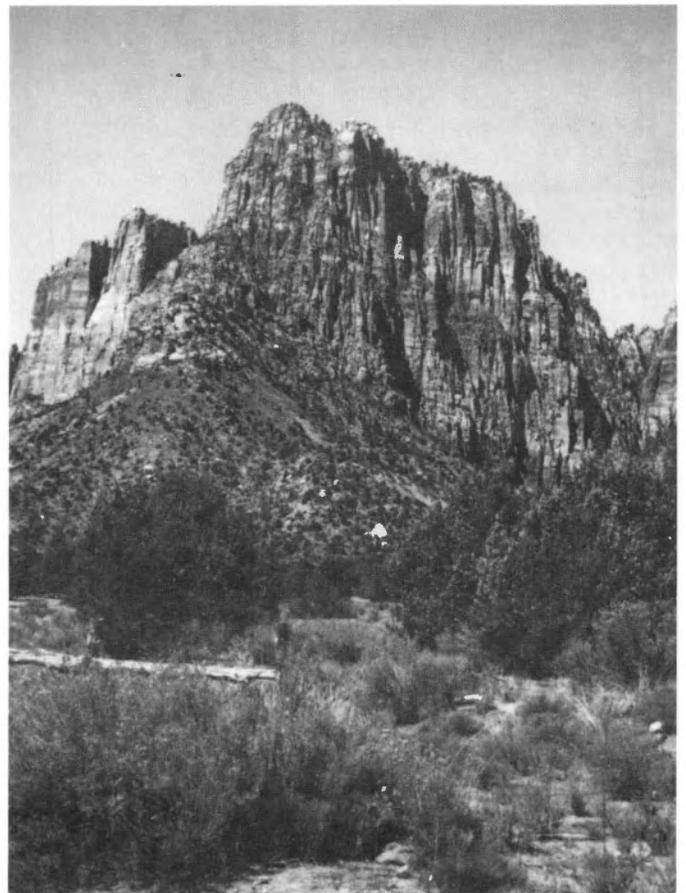


*Figure 6. Slide debris on hillside in vicinity of Hildale. Larger blocks shown are 2 to 3 feet (1 m) in diameter; elsewhere blocks are as much as tens of feet and, rarely, hundreds of feet in diameter. Photograph taken 1986.*

The few mapped faults, including inferred faults, are of north-northeast and north-northwest trends. They appear to be very steeply dipping, but no fault planes were seen. Maximum vertical displacement of the known fault along Squirrel Creek is about 200 feet (61 m). The known and inferred faults appear to be mostly downthrown to the east. This is in contrast to the displacement of the major fault zones of the region; the Hurricane fault zone 16 miles (26 km) west of the Hildale quadrangle and the Sevier fault zone 9 miles (14 km) to the east are both downdropped to the west.

A complex pattern is represented by conspicuous joint sets in the Navajo Sandstone and to lesser extent in sandstone and siltstone of older units (figures 1 and 7). The joints are extremely steep to vertical. Selected joints that indicate major trends are shown on the geologic map; they are only a few of the thousands visible in the field and on aerial photographs. Many joints locally control surface drainage trends and are also probable important factors in the control of ground-water movement.

In the western and northwestern parts of the quadrangle, especially west of Squirrel Creek, two prominent joint sets are exposed in the Navajo Sandstone. Large, widely spaced joints with prominent, long traces strike north-northwest to northwest and appear to belong to a single curving set that strikes N. 20° W. to N. 50° W. in the northwestern quadrant of the quadrangle. The other joint set consists of north-northeast- to northeast-striking joints that are more closely spaced and shorter. Because of the large difference in apparent trace lengths, one might surmise that the north-northeast-striking set is the younger of the two, but this interpretation is not certain. The north-northwest- to northwest-trending joint set is also prominent and apparently curving in the central and north-central part of the map area east of Squirrel Creek. If the northwest-trending curved pattern of joint traces represents a single curved set of joints rather than two interfering sets, this may reflect curved stress trajectories in perturbations in



*Figure 7. Highly fractured Navajo Sandstone exposed northwest of Hildale, Utah. Photograph taken in 1987.*

the vicinity of the fault as described for other areas by Rawnsley and others (1992). The joints, therefore, would postdate the fault, and would not require major displacement along it. Conversely, if the curved patterns represent oroclinal bending of sets with originally rectilinear traces, such a model would require a 30 degree bend about a vertical axis northwest of Short Creek and would imply a large component of right lateral slip along the Squirrel Creek fault.

The puzzling semi-radial joint pattern in the southeast quadrant of the area east of Squirrel Creek appears to be a fanning of the northwest-striking joint set, and may also be related to perturbations along the fault. The joints appear to converge on a focal area at the junction of Short and Squirrel Creeks. The convergence, if real, suggests that parts of the fault were "locked," and parts were active. Thus the joints would postdate or be approximately synchronous with faulting. Other less likely explanations for the radial joint pattern is that it may reflect local subsurface vertical uplifts, but neither gravity nor magnetic patterns show anomalies there, although control used in these geophysical studies is not closely spaced (Van Loenen and others, 1988, p. A13-A14). A remote possibility is that the fractures may reflect subsurface collapse features such as those that mark locations of breccia "pipes" of the southwestern United States (Sulphin and Wenrich, 1989). However, no sagging of bedding in this vicinity was seen, and this possibility thus seems unlikely.

Areas of Navajo Sandstone outcrops which contain numerous prominent joints alternate with areas in which jointing is sparse or absent. One such area of few joints is the elongate, oval-shaped area east of Squirrel Creek. That area is less than 1 mile (1.6 km) wide and extends to about 3 miles (5 km) north of "The Beehive." This may represent a minor graben that escaped stresses that resulted in the closely spaced joints on either of its margins. Other similar north-trending, fracture-free areas occur within and without the quadrangle in roughly anastomosing patterns, as shown on aerial photographic indexes of the region.

## ECONOMIC GEOLOGY

There are no known mines, prospects, or identified mineral resources in the Hildale quadrangle, and the area is not included in any mining district. The nearest mining district is the Silver Reef (Harrisburg) district, about 20 miles (32 km) west of the quadrangle, which yielded mainly silver between 1875 and 1910, and later produced minor amounts of copper, uranium, and vanadium, all from the Springdale Sandstone Member of the Moenave Formation. No indications of commercial-grade metallization have been recognized in the Springdale Sandstone in this quadrangle, however. What appear to be bulldozed prospect trails are present along the west valley wall of South Creek just north of the Hildale quadrangle; they are believed to have been associated with uranium prospecting.

Small amounts of gold and other precious metals have long been known to occur in clay and claystone of the Petrified Forest

Member of the Chinle Formation over a large region (Gregory, 1950), but attempts at economic recovery have not been successful. A prospect mine 2.8 miles (4.5 km) west of the Hildale quadrangle was reported by Moore and Sable (1992); analysis of three samples indicates that the precious metal content of these is subcommercial. The U.S. Bureau of Mines and the U.S. Geological Survey analyzed stream sediment, heavy mineral concentrate, and bedrock samples in the proposed Canaan Mountain Wilderness Study Area, within which the major part of the Hildale quadrangle lies. The results were reported by Van Loenen and others (1988), and in detail by Adrian and others (1988) and Kreidler (1986). No gold was detected in the Petrified Forest Member; silver, platinum, and palladium were detected but of such low values that economic recovery is not considered feasible. Uranium values are also subcommercial, and surface scintillometer surveys indicate only background values of radioactivity. Manganese-rich limestone nodules are present in the Petrified Forest Member, but they are sparse and constitute a very small volume.

The Navajo Sandstone might be utilized for several industrial applications such as foundry, fracturing, and abrasive sand. A few samples of the sandstone from the Navajo and Navajo-derived sand dunes from other areas have been tested for glass sand as reported by Doelling and Davis (1989, p. 137-138); impurities appear to make it unsuitable for any use except common colored container glass. Colored sand from the Navajo, the result of intergranular cement coloration, has been used for decorative and souvenir purposes, but the supply from accessible sources, such as a small mine north of Kanab, Utah, seems to be currently adequate. Iron-oxide concretions, used as curio souvenirs, are common in the Navajo Sandstone in many areas, and are locally present in the study area.

Petrified wood, used in the lapidary industry, is common in many areas in the Petrified Forest Member of the Chinle Formation. Although large amounts were not seen in this quadrangle, more may be present along South Creek near the northern boundary of the quadrangle. Gravel and sand has been exploited locally along Short Creek for construction in the Hildale-Colorado City area.

Petroleum potential of the region was reported by Molenaar and Sandberg (1983). Much of the Hildale quadrangle has been under oil and gas leases in the past, but it is not known by the author what areas may now be under lease. As of January 1987, most of the leases in the Canaan Mountain Wilderness Study Area had been cancelled; no drilling or other known active exploration activity had taken place prior to this. The Virgin oil field, about 17 miles (27 km) northwest of the quadrangle, produced about 201,000 barrels between 1907 and 1970 (Stowe, 1972, p. 23) from Lower Triassic and possibly Permian rocks. These rocks are estimated to be about 2,000 feet (610 m) below the top of the Springdale Sandstone Member of the Moenave Formation in the quadrangle. No surface evidence of oil and gas was seen.

In summary, the Canaan Mountain Wilderness Study Area, of which the Hildale quadrangle is part, is estimated to have a moderate resource potential for oil and gas and geothermal energy, and a low resource potential for coal and manganese (Van Loenen and others, 1988).

## GEOPHYSICS

Aeromagnetic and gravity data for the Canaan Mountain Wilderness Study Area were reported by Van Loenen and others (1988, p. A13-A14 and figs. 5 and 6). Gravity readings in the Hildale quadrangle indicate a low of more than -186 milligals. The anomaly appears to be due to the thick Navajo Sandstone which makes up Canaan Mountain, and thus is of shallow origin. The quadrangle lies on the west flank of a basement magnetic low of more than -430 nanoteslas (nT) 3 miles (5 km) east of the quadrangle, with values that increase from about -380 nT along the eastern boundary to -130 nT at the northwestern corner of the quadrangle. These values appear to be due to magnetic sources in the underlying basement rocks.

## WATER RESOURCES

Water resources in the Hildale quadrangle consist of limited surface water and numerous springs and wells. South Creek, in the northwestern part of the Hildale quadrangle, and Short Creek, in the southwestern part, are perennial streams, although not always throughflowing; ponds remain in the deeper parts of the channels and are connected by drainage through the stream bed during dry periods. South Creek, when seen by the author in mid-summer of 1986 was throughflowing, fed by springs in the uppermost reaches of its east fork. Streams in Broad Hollow and Cottonwood Canyon are ephemeral. According to Price (1983), theoretical mean annual run-off of surface water is less than one inch, and the main discharge of major streams in the region, such as the Virgin River, is in April and May. Seven springs are shown within the quadrangle by Price (1982), who also reported that sustained yields of wells in the general area are 50 to 500 gallons per minute (3.1-31 l/sec), with local yields as much as 500 to 2,000 gallons per minute (31-126 l/sec). The Navajo Sandstone is considered the best aquifer in the region (Cordova, 1981), but wells in the quadrangle produce from underlying units.

The following information was obtained from Mr. Joe Jessup, well driller, Hildale, Utah (oral communication, May 19, 1993). Water supplies for the town of Hildale are obtained from springs in Water and Maxwell Canyons and from wells in alluvial sand in the Short Creek valley and sandstone of the Shinarump Member of the Chinle Formation. Water supply from the springs amounts to cumulative production of 400 gallons per minute and 1,050 gallons per minute (25-66 l/sec) for irrigation and culinary purposes, respectively. Cumulative peak production from wells is about 1,100 and 3,000 gallons per minute (70-190 l/sec) for culinary and irrigation use, respectively. Depths to sand aquifers are more than 100 feet (30 m) and from about 200 to 700 feet (61-213 m) to the bedrock aquifer depending on well location relative to the northeast dip of the aquifer. About 15 to 20 gallons per minute (9-12 l/sec) are obtained from the Shinarump Member from scattered wells in the lowlands west of Canaan Mountain.

## GEOLOGIC HAZARDS

The potential for flooding, eolian, and mass-movement processes is generally low in the Hildale quadrangle. Sporadic torrential rainfall from summer storms can fill drainages to capacity, with resultant flooding that damages roads, trails, and artificial catchment basins, and causes and exacerbates gullying. According to local residents, a cloudburst on Canaan Mountain in the early 1980s resulted in large amounts of sand being washed into drainages, obliterating parts of roads and trails. As a result, for example, deep, soft sand made the upper reaches of the main drainage in Broad Hollow impassable to a four-wheel drive vehicle in 1986. To a lesser extent in this quadrangle, windstorms often blow sand across roads and trails so that loss of vehicle traction can result, but this is not as serious a problem as in the Elephant Butte and The Barracks quadrangles farther east.

Swelling clay in the Petrified Forest Member of the Chinle Formation, and to a lesser extent in the Kayenta Formation, results in unstable slopes, creep, and local landslides, as evidenced by chaotic debris, scarp-like features, bedding contortion, and the presence of Toreva blocks. The southern part of a very large mass-movement complex that covers about 5.7 square miles (14.8 km<sup>2</sup>) lies along South Creek, which, just north of the quadrangle, is constricted by encroachment of the creek banks in which complex structure in the Petrified Forest Member is exposed. Smaller areas of debris and displaced bedrock also adjoin Short Creek. These appear to be the result of slip on the underlying Kayenta Formation. Evidences of smaller landslides and rock falls are common along the steep slopes and cliffs in and below the Navajo Sandstone. Whether the debris concentrations, roughly aligned with a series of intermittent north-northwest-striking faults that extend along the western boundary of Zion National Park, are due to movement along these faults is conjectural.

Several earthquake epicenters have been recorded in or along the borders of the Hildale quadrangle as shown on the recent earthquake map of Utah (Goter, 1991). They include one quake of Richter magnitude 5.0-5.9, between 1884 and 1974, and five quakes of magnitudes 2.0 to 3.9 between 1975 and 1989. From 1950 through 1986, 33 seismic events with Richter magnitudes of 2.0 and greater have also been plotted along Long Valley and near Kanab, east of the Hildale quadrangle. All the larger events were felt in the region with the greatest of these being about magnitude 5.5 (Arabasz and others, 1979; University of Utah Seismology Catalog, 1986). Some of these events may have been associated with the Sevier and Kanab Creek fault zones located about 9 and 19 miles (14 and 29 km) east of the Hildale quadrangle. On September 2, 1992, the epicenter of an earthquake of Richter magnitude 5.8 was located about 5 miles (8 km) southeast of St. George, Utah, 28 miles (45 km) west of Hildale quadrangle (Arabasz and others, 1992). A resultant landslide at Springdale, Utah about 5 miles (8 km) north of the quadrangle boundary damaged several structures there (Black, 1992; Pearthree and Wallace, 1992; Black and Christenson, 1993). Placement of man-made structures in or near already emplaced slide complexes should be carefully considered and, at least in part, avoided. In addition, because slope instability encroaching on South Creek has the potential for damming the

stream should more rapid mass movement occur, there is the possibility that structures downstream of these areas would be vulnerable to flooding.

Another potential geologic hazard, that of radon gas accumulations within buildings, is considered to be generally moderate throughout the quadrangle (Black, 1993).

## SCENIC POTENTIAL

The picturesque Vermilion Cliffs, an expression largely of the lower part of the Navajo Sandstone, are exposed along South and Short Creeks and make a scenic backdrop to the town of Hildale. The upland surfaces on the Navajo Sandstone make for a serene landscape, interrupted sporadically by concentrations of trees and bushes. The area has a desert climate but receives enough precipitation, about 12 inches (30.5 cm) per year, to support ponderosa pine and juniper in the uplands, and sagebrush, maple, and pinon pine at lower altitudes. Wildlife reported by local residents include mule deer, many small animals such as jack rabbits and cottontail rabbits, snakes, lizards, scorpions, and occasional mountain lions. Views from the rimrock of the upland areas are spectacular; to the north rise the towers and cliffs of Zion National Park, below lies the deep Parunuweap Canyon of the East Fork of the Virgin River and to the south extend vast areas of desert, the "Arizona Strip," broken by sandstone-capped mesas and buttes. A U.S. Bureau of Land Management trail, with the trailhead along a service road about 2.5 miles (4 km) northwest of the quadrangle, leads to the northwest boundary of the quadrangle above South Creek and affords scenic views to the north, northeast, and northwest, as

well as across the South Creek valley to the precipitous cliffs that surround its headwaters. The uplands expose large areas of "slickrock," barren, planar to rounded flat-lying rock surfaces broken by joints and small pinnacles. A trailhead identifying the "Canaan Mountain Primitive Area" at the confluence of Short Creek and Water Canyon leads to a foot and horse trail which ascends to the uplands via Squirrel Creek. The Beehive, a unique, rounded erosional feature in the Navajo Sandstone between Squirrel and Short Creeks, can best be viewed from the highlands to the east and west.

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