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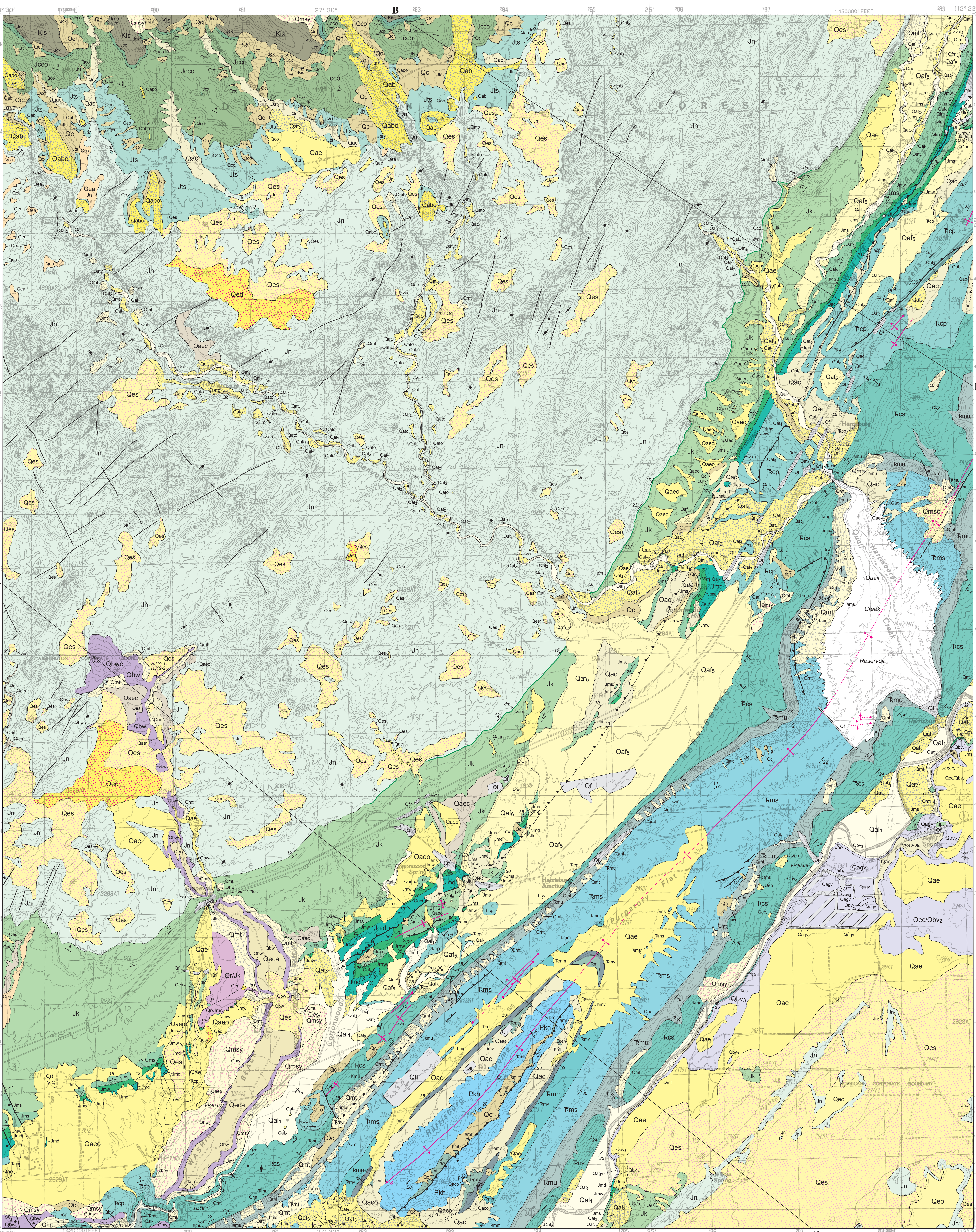
STATEMAP Agreement No. 1434-HQ-96-AG-01521



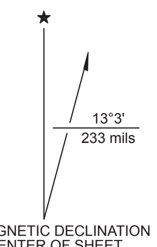
Base from U.S. Geological Survey,
Harrisburg Junction 7.5' provisional quadrangle, 1986

Field work by author in 1997-98
Grant C. Willis, Project Manager
Kent Brown and James Parker, Cartographers

SCALE 1:24,000

1 MILE | 1000 FEET | 1 KILOMETER

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL



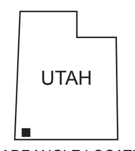
2002 MAGNETIC DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE HARRISBURG JUNCTION 7.5' QUADRANGLE WASHINGTON COUNTY, UTAH

by

Robert F. Biek

2003



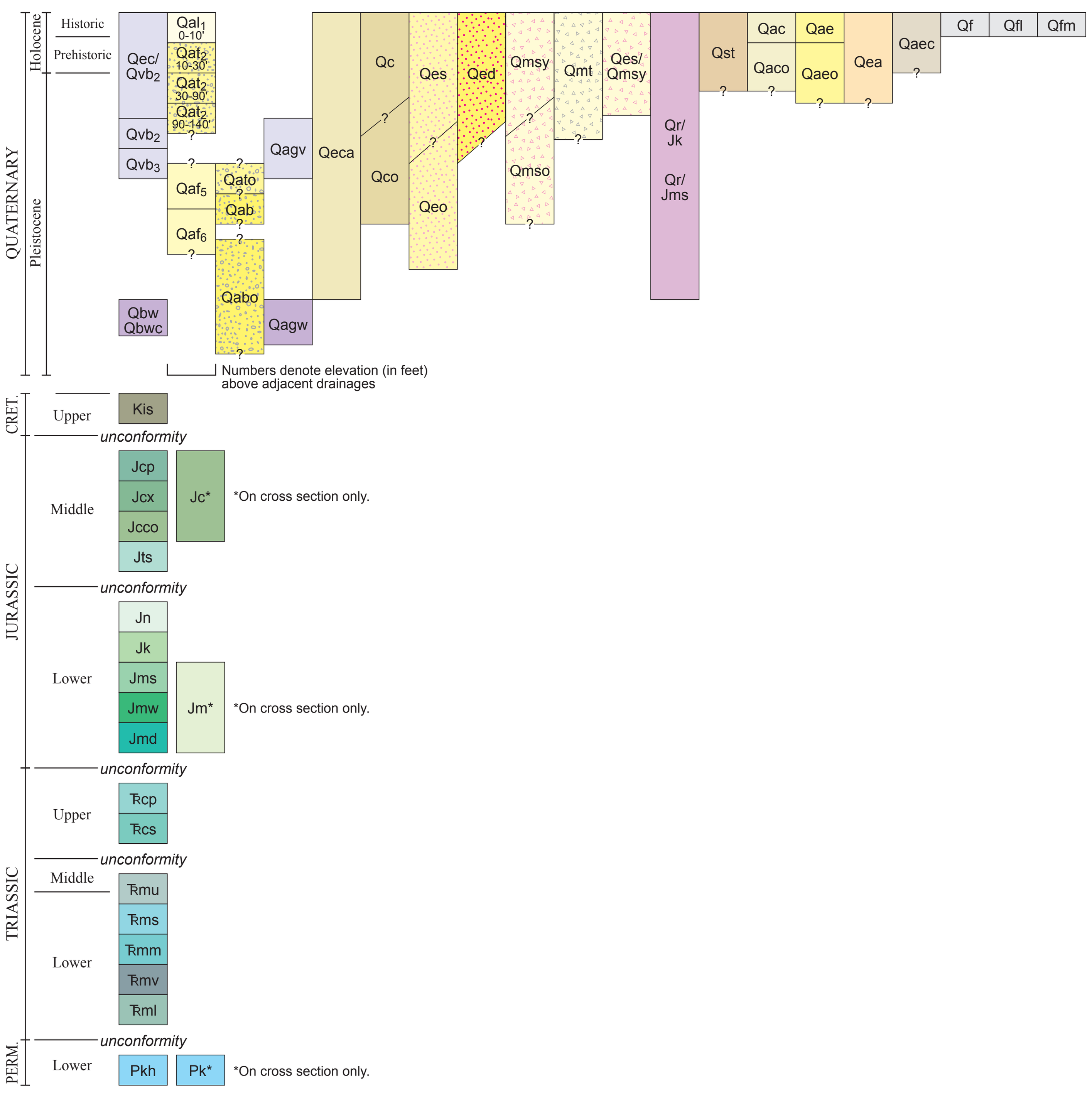
QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1. Saddle Mountain
2. Signal Peak
3. Pintura
4. Washington
5. Hurricane
6. St. George
7. Washington Dome
8. The Divide

ADJOINING 7.5' QUADRANGLE NAMES

CORRELATION OF GEOLOGIC UNITS



LITHOLOGIC COLUMN

SYSTEM AND SERIES		FORMATION	MEMBER	SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY
QUATERNARY		surficial deposits		Q	0-160 (0-50)	
QUATERNARY		basalt flows		Qbv-,Qbw	0-100 (0-30)	
CRET.	UPPER	Iron Springs Formation		Kis	250+ (75+)	
JURASSIC	MIDDLE	Carmel Formation	Paria River Member	Jcp	0-28 (0-9)	Platy limestone
JURASSIC	MIDDLE	Carmel Formation	Crystal Creek Mbr	Jcx	48-144 (15-44)	Red jasper, oyster-shell coquina
JURASSIC	MIDDLE	Carmel Formation	Co-op Creek Limestone Member	Jcco	285-342 (87-104)	*Pentacrinus* sp.
JURASSIC	MIDDLE	Temple Cap Formation	Sinawava Member	Jts	187 (57)	Gypsum
JURASSIC	LOWER	Navajo Sandstone		Jn	2,300 (700)	High-angle cross beds; Transition zone
JURASSIC	LOWER	Kayenta Formation		Jk	925 (282)	Dolomite marker
JURASSIC	LOWER	Moenave Formation	Springdale Ss Mbr	Jms	120-164 (36-50)	Silver Reef mining district
JURASSIC	LOWER	Moenave Formation	Whitmore Point Mbr	Jmw	64-125 (19-38)	*Semionotus kanabensis*
JURASSIC	LOWER	Moenave Formation	Dinosaur Canyon Member	Jmd	163 (50)	
TRIASSIC	UPPER	Chinle Formation	Petrified Forest Member	Ꞧcp	400-450 (120-135)	Swelling, brightly colored clays
TRIASSIC	UPPER	Chinle Formation	Shinarump Conglomerate Mbr	Ꞧcs	104-165 (32-50)	"Picture stone"
TRIASSIC	M.	Moenkopi Formation	upper red member	Ꞧmu	397 (120)	"Purgatory sandstone"
TRIASSIC	LOWER	Moenkopi Formation	Shnabkaib Member	Ꞧms	600-700 (180-210)	Gypsum; "Bacon striped"
TRIASSIC	LOWER	Moenkopi Formation	middle red member	Ꞧmm	400-500 (120-150)	
TRIASSIC	LOWER	Moenkopi Formation	Virgin Limestone Mbr	Ꞧmv	85 (26)	3 limestone ledges
TRIASSIC	LOWER	Moenkopi Formation	lower red member	Ꞧml	150-200 (45-60)	
PERMIAN	LOWER	Kaibab Formation	Harrisburg Member	Pkh	250+ (75+)	Gypsum; "Medial limestone"

DESCRIPTION OF GEOLOGIC UNITS

QUATERNARY

Alluvial deposits

Qal$_1$ Stream deposits - Moderately to well-sorted sand, silt, clay and pebble to boulder gravel; includes river-channel, flood-plain, local small alluvial-fan and colluvial deposits, and minor terraces up to 10 feet (3 m) above current base level; 0 to 40 feet (0-12 m) thick.

Qat$_{2,3,4}$ Stream-terrace deposits - Moderately to well-sorted sand, silt, and pebble to boulder gravel that forms level to gently sloping surfaces above, and restricted to, modern drainages; level 2 deposits are about 10 to 30 feet (3-9 m), level 3 deposits are about 30 to 90 feet (9-27 m), and level 4 deposits are about 90 to 140 feet (27-43 m) above adjacent drainages; deposited principally in river-channel and flood-plain environments; truncates older alluvial-fan deposits (Qaf$_5$ and Qaf$_6$); 0 to 20 feet (0-6 m) thick.

Qato Older alluvial-terrace deposits - Moderately sorted sand to boulder deposits that form isolated, level to gently sloping surfaces above, and restricted to, modern drainages; clasts are predominantly from Pine Valley intrusive complex; boulders are highly weathered such that outer rind easily disaggregates into constituent grains; represent channel deposits probably correlative with Qaf$_5$; generally found from 120 to 200 feet (37-60 m) above nearby drainages; about 0 to 30 feet (0-9 m) thick.

Qaf$_{5,6}$ Older alluvial-fan deposits - Poorly to moderately sorted sand to boulder deposits with common clasts in excess of 10 feet (3 m) in diameter; clasts are predominantly from Pine Valley intrusive complex; boulders are highly weathered such that outer rind easily disaggregates into constituent grains; forms broad, deeply dissected surfaces along the west side of the Virgin anticline; Qaf$_5$ deposits are generally found from 40 to 100 feet (12-30 m) and Qaf$_6$ deposits from 120 to 200 feet (36-60 m) above modern drainages; about 0 to 30 feet (0-9 m) thick.

Qab, Qabo Alluvial-boulder deposits - Very poorly to moderately sorted sand to boulder deposits with common clasts in excess of 10 feet (3 m) in diameter; clasts are predominantly from Pine Valley intrusive complex; boulders are highly weathered such that outer rind easily disaggregates into constituent grains; basal portion of many deposits contains a more varied suite of clasts, including Carmel limestone, and reworked quartzite and pebbly conglomerate cobbles and sandstone from the Iron Springs Formation; caps ridges and fills drainages that trend radially away from Pine Valley Mountains; deposited by alluvial and debris-flow processes; Qab lies up to about 200 feet (60 m) above nearby drainages, Qabo up to about 400 feet (120 m); 0 to 160 feet (0-50 m) thick.

Artificial deposits

Qf Artificial fill - Fill used to create roadbeds, dams and retaining ponds, and building foundations; consists of engineered fill and general borrow material; although only a few deposits are mapped, fill should be anticipated in all developed areas, many of which are shown on the topographic base map; thickness variable.

Qfl Landfill deposits - Common trash and general borrow material; thickness variable.

Qfm Mine-dump deposits - Waste rock from mining; thickness variable.

Colluvial deposits

Qc,Qco Colluvial deposits - Poorly to moderately sorted, clay- to boulder-size, locally derived sediment deposited on moderate slopes; deposited by slopewash and soil creep; locally includes talus, alluvial, and eolian deposits; older colluvial deposits (Qco) form incised, largely inactive surfaces; 0 to 30 feet (0-9 m) thick.

Eolian Deposits

Qes Eolian sand deposits - Well- to very well-sorted, very fine- to medium-grained, well-rounded, frosted quartz sand; derived principally from the Navajo and Kayenta Formations; underlain by thick pedogenic carbonate in most areas; deposited as an irregular blanket from 0 to 30 feet (0-9 m) thick.

Qed Eolian dune sand deposits - Well- to very well-sorted, very fine- to medium-grained, well-rounded, frosted quartz sand; derived principally from the Navajo and Kayenta Formations; forms small dunes on Qes deposits; 0 to 15 feet (0-5 m) thick.

Qeo Older eolian sand and caliche deposits - Pedogenic carbonate with lesser eolian sand; forms planar surfaces covered with caliche and sparse eolian sand, except in sections 2 and 11, T. 42 S., R. 14 W. where it consists of very rough weathering, pale-red, stage IV-V pedogenic carbonate 2 to 5 feet (0.6-1.5 m) thick; 0 to 10 feet (0-3 m) thick.

Mass-movement deposits

Qmsy, Qmso Landslide deposits - Very poorly sorted, clay- to boulder-size, locally derived material deposited principally by rotational slump processes; commonly characterized by hummocky topography, numerous subdued internal scarps, and chaotic bedding attitudes; an older, deeply dissected landslide deposit (Qmso) is at the north end of Quail Creek Reservoir; slip surfaces are in the Petrified Forest Member of the Chinle Formation, the Shnabkaib and upper red members of the Moenkopi Formation, and the Carmel Formation; the slides themselves incorporate these units and overlying formations and surficial deposits; block-glide detachments, with failure at or near the top of the upper red member of the Moenkopi Formation, are present along Shinarump cuesta in section 10, T. 42 S., R. 14 W.; thickness highly variable.

Qmt Talus deposits - Very poorly sorted, angular boulders and lesser fine-grained interstitial sediments; locally derived material deposited by rock-fall processes on and at the base of steep slopes; locally includes, and is gradational with, colluvial deposits; about 0 to 20 feet (0-6 m) thick.

Mixed-environment deposits

Qac, Qaco Alluvial and colluvial deposits - Poorly to moderately sorted, clay- to boulder-size, locally derived sediments deposited in swales and small drainages; gradational with alluvial and colluvial deposits; older deposits (Qaco) form incised, inactive surfaces up to about 20 feet (6 m) above modern drainages; generally less than 20 feet (6 m) thick.

Qae, Qaeo Alluvial and eolian deposits - Poorly to moderately sorted, clay- to boulder-size sediments, with well-sorted eolian sand and reworked eolian sand; younger (Qae) deposits are in modern channels and broad depressions and are gradational and correlative with Qal$_1$, Qes, and Qea deposits; older (Qaeo) deposits commonly have well-developed pedogenic carbonate, are locally gypsiferous, and form incised, inactive, gently sloping surfaces about 20 feet (6 m) above modern drainages; Qaeo deposits are correlative with level 2 and 3 stream-terrace deposits; generally less than 30 feet (9 m) thick.

Qea Eolian and alluvial deposits - Well-sorted eolian sand and reworked eolian sand and lesser clay- to pebble-size alluvial sediments, normally with a thick pedogenic carbonate; forms planar, gently sloping surface that is correlative and gradational with mixed alluvial and eolian deposits; generally less than about 20 feet (6 m) thick.

Qaec Alluvial, eolian, and colluvial deposits - Poorly to moderately sorted, clay- to small boulder-size sediments, with well-sorted eolian sand and reworked eolian sand and a significant component of colluvium; deposited in modern channels; gradational and correlative with modern alluvial, colluvial, and eolian deposits; generally less than 20 feet (6 m) thick.

Qeca Eolian and alluvial deposits with thick carbonate soil on basalt flow - Eolian clay, silt, and sand that overlies alluvial gravel; includes stage V pedogenic carbonate up to several feet thick; overlies the Washington basalt flow; 0 to 10 (0-3 m) thick.

Spring deposits

Qst Spring deposits - Light-gray to brownish-gray, porous, calcareous tufa characterized by a sponge-like network of vesicles; exposed in trench northeast of Washington; thickness uncertain.

Stacked-unit deposits

Qr/Jk, Qr/Jms Residual deposits - Angular cobble- to boulder-size basalt clasts apparently let down by erosion of underlying beds; forms a thin blocky surface that drapes over and mostly conceals Springdale Sandstone (Qr/Jms) and Kayenta (Qr/Jk) strata west of Washington Black Ridge.

Qes/Qmsy Eolian sand over landslide deposits - Eolian sand that drapes over and mostly conceals landslide deposits along the east side of Washington Black Ridge.

Basalt flows and related deposits

Qbv$_{2,3}$, Qec/Qbv$_2$, Qagv Volcano Mountain flows and associated deposits - Dark-gray to grayish-black, very fine-grained, alkali olivine basalt with sparse olivine phenocrysts; subscript denotes relative elevation and age, with 3 lower and older and 2 higher and younger; source was Volcano Mountain (section 5, T. 42 S., R. 13 W.), the youngest flow of which yielded an $^{40}Ar/^{39}Ar$ age of 258 ± 24 ka (Sanchez, 1995); Qbv$_3$ is about 40 feet (12 m) thick, except where it thins at its southern margin; Qbv$_2$ is 30 to 45 feet (9-14 m) thick. Qec/Qbv$_2$ denotes partial cover of eolian sand and pedogenic carbonate up to about 3 feet (1m) thick. Qagv denotes moderately sorted, moderately to well-cemented, pebble to cobble gravel of the ancestral Virgin River that contains rounded quartzite, limestone, and basalt clasts and which both overlies and underlies the Qbv$_3$ flow; 0 to 20 feet (0-6 m) thick.

Qbw, Qbwc, Qagw Washington flow, cinder cone, and associated deposits - Medium- to dark-gray, very fine-grained, alkali olivine basalt (Qbw) with abundant clinopyroxene and olivine phenocrysts (petrographically classified as an ankaramite; chemically as a basinite to picrobasalt); consists of up to four flow units; margins eroded; prominent columnar jointing; caps a prominent ridge and has a relatively constant thickness of about 25 to 35 feet (8-11 m) along its length, except near its source where it reaches up to about 100 feet (30 m) thick; source is a highly dissected cinder cone (Qbwc); yielded $^{40}Ar/^{39}Ar$ ages of 0.87 ± 0.04 and 0.98 ± 0.02 Ma; Qagw denotes moderately sorted, moderately to well-cemented, pebble to cobble gravel of the ancestral Virgin River that contains rounded quartzite, limestone, and basalt clasts that both overlies and underlies the flow – it is probably less than 15 feet (5 m) thick.

unconformity

CRETACEOUS

Kis Iron Springs Formation - Interbedded, ledge-forming, mildly calcareous, cross-bedded, fine- to medium-grained sandstone and less resistant, poorly exposed sandstone, siltstone, and mudstone; the formation is variously colored grayish orange, pale yellowish orange, dark yellowish orange, white, and pale reddish brown, and is commonly heavily stained by iron-manganese oxides; Liesegang banding is common; deposited in braided-stream and flood-plain environments; only about the lower 250 feet (75 m) of the formation is exposed in the quadrangle, but the formation is about 3,500 to 4,000 feet (1,070-1,220 m) thick in the area.

unconformity (K)

JURASSIC

Carmel Formation

Jc Carmel Formation, undivided - Shown on cross section only.

Jcp Paria River Member - Yellowish-gray to light-olive-gray, thin- to medium-bedded, platy weathering, ledge-forming limestone and lithographic limestone; contains sparse bivalve fossils; deposited in a shallow-marine environment; forms an eastward-thickening wedge, 0 to 28 feet (0-9 m) thick, preserved beneath the K unconformity.

Jcx Crystal Creek Member - Laterally variable sequence of mostly slope-forming, interbedded, generally thin-bedded, pale- to moderate-reddish-brown mudstone, siltstone, very fine-grained sandstone, and gypsum; contains local thin interbeds of yellowish-gray to light-olive-gray mudstone with abundant fine- to coarse-sand-size biotite flakes; moderate-reddish-brown blebby jasper is common in the lower part of the member; uppermost strata consist of variously colored white, grayish-orange-pink, light-brown, and dark-yellowish-orange, very fine- to medium-grained sandstone and minor mudstone and siltstone that is about 10 feet (3 m) thick at the western quadrangle boundary but that reaches up to 73 feet (22 m) thick east of Big Hollow; deposited in a variety of shallow-marine, shoreline, and sabkha environments; forms an eastward-thickening wedge across quadrangle, preserved beneath K unconformity, ranging from 48 to 144 feet (15-44 m) thick.

Jcco Co-op Creek Limestone Member - Laterally variable sequence of interbedded, generally thin-bedded mudstone, siltstone, limestone, and, especially in the lower portion, lesser gypsum and very fine- to fine-grained sandstone; the lower portion of the member weathers to a pale yellowish gray, while the upper portion weathers to distinctly darker yellowish-brown hues; both form steep ledgy slopes; upper portion abundantly fossiliferous with *Pentacrinus* sp. columnals, bivalves, mollusks, and local oyster coquina; upper contact marked by a resistant, 6-inch-thick (15 cm), yellowish-gray to greenish-gray, silicified mudstone with abundant moderate-reddish-brown blebby jasper and medium-sand-size biotite flakes; deposited in a variety of shallow-marine, shoreline, and sabkha environments; thickens eastward across the quadrangle, from 285 feet (87 m) at western quadrangle boundary to 342 feet (104 m) thick at northern edge.

Temple Cap Formation

Jts Sinawava Member - Interbedded, moderate-reddish-brown mudstone, siltstone, very fine-grained silty sandstone, and lesser gypsum; a ledge-forming, pinkish-gray to light-greenish-gray, calcareous, medium- to coarse-grained, locally pebbly sandstone that may correspond to the J-2 unconformity is present about one-third the way up the section; forms conspicuous bright-red and gray slopes that weather to soft, gypsiferous soils; contains numerous, thin, greenish-gray mudstone (altered volcanic ash) beds with common biotite; gypsum is white to gray to pink and both bedded and nodular in beds up to about 10 feet (3 m) thick; contains several zones of thin, white to pinkish-gray chert nodules that may be silicified bentonite; 187 feet (57 m) thick.

unconformity (J-1)

Jn Navajo Sandstone - Moderate-reddish-orange to moderate-orange-pink, massively cross-bedded, poorly to moderately well-cemented, well-rounded, fine- to medium-grained, frosted quartz sandstone; locally very pale orange to yellowish gray, especially in upper part; forms bold cliffs; lower 300 feet (90 m) forms transition zone characterized by planar bedded, very fine- to fine-grained sandstone and fine-grained silty sandstone with thin siltstone interbeds, and less common but resistant cross-stratified sandstone; wavy bedding, dark flaser-like laminae, and soft-sediment-deformation features, including flame and load structures, are common in transition zone; deposited in a vast coastal and inland dune field, transition zone represents deposition in a sabkha environment; about 2,300 feet (700 m) thick.

Jk Kayenta Formation - Interbedded, thin- to medium-bedded, moderate-reddish-brown to moderate-reddish-orange siltstone, fine-grained sandstone, and mudstone with planar, low-angle, and ripple cross-stratification; contains several poorly exposed, 1- to 5-inch-thick (2.5-12.5 cm), light-olive-gray weathering, light-gray dolomite beds; lower part weathers to poorly exposed, commonly gypsiferous slopes, upper part to ledges and small cliffs; upper contact locally marked by a 3- to 8-inch-thick (7-20 cm), light-gray limy dolomite bed (dm); deposited in fluvial, distal fluvial/playa, and minor lacustrine environments; 925 feet (282 m) thick.

Moenave Formation

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

Jms Springdale Sandstone Member - Medium- to very thick-bedded, fine-grained or rarely medium-grained sandstone, with planar and low-angle cross-stratification, and minor, thin, discontinuous lenses of intraformational conglomerate and thin interbeds of moderate-reddish-brown or greenish-gray mudstone and siltstone; weathers to rounded cliffs and ledges; contains locally abundant petrified and carbonized fossil plant remains; host to ore deposits of the Silver Reef mining district; deposited in braided-stream and minor flood-plain environments; 120 to 164 feet (36-50 m) thick.

Jmw Whitmore Point Member - Interbedded, pale-red-purple, greenish-gray, and blackish-red mudstone and claystone, lesser moderate-reddish-brown very fine- to fine-grained sandstone and siltstone, and uncommon dark-yellowish-orange micaceous siltstone and very pale-orange, very fine- to fine-grained sandstone; weathers to poorly exposed, brightly colored slopes; contains several 3- to 18-inch-thick (8-46 cm), bioturbated, cherty, dolomitic limestone beds with algal structures and fossil fish scales of *Semionotus kanabensis* (Hesse, 1935; Schaeffer and Dunkle, 1950); the dolomitic limestones vary in color from light greenish gray to very light gray and yellowish gray, and weather to mottled colors of pale yellowish orange, white, yellowish gray, and pinkish gray, commonly with green copper-carbonate stains; lower 25 feet (7.5 m) consists of moderate-reddish-brown sandstone similar to that of the Dinosaur Canyon Member; deposited in flood-plain and lacustrine environments; 64 to 125 feet (19-38 m) thick.

Jmd Dinosaur Canyon Member - Interbedded, generally thin-bedded, moderate-reddish-brown to moderate-reddish-orange, very fine- to fine-grained sandstone, very fine grained silty sandstone, and lesser siltstone and mudstone with planar, low-angle, and ripple cross-stratification; slope forming; deposited in river and flood-plain environments; 163 feet (50 m) thick.

unconformity (J-0)

TRIASSIC

Chinle Formation

Ꞧcp Petrified Forest Member - Varicolored mudstone, claystone, siltstone, lesser sandstone and pebbly sandstone, and minor chert and nodular limestone; lower part contains Shinarump-like sandstone and pebbly sandstone lenses up to 40 feet (12 m) thick; swelling mudstones and claystones are common throughout and although typically poorly exposed, their bright colors of various shades of purple, grayish red, dark reddish brown, light greenish gray, brownish gray, olive gray, and similar hues locally show through to the surface; mudstones weather to a "popcorn" surface and are responsible for numerous foundation problems in the area; commonly forms slumps, especially along steep hillsides; contains petrified wood, commonly well silicified and brightly colored, especially in the upper part of the member; deposited in a variety of fluvial, flood-plain, and lacustrine environments; about 400 to 450 feet (120-135 m) thick.

Ꞧcs Shinarump Conglomerate Member - Laterally and vertically variable sequence of cliff-forming, fine- to very coarse-grained sandstone, pebbly sandstone, and lesser pebbly conglomerate; clasts are subrounded quartz, quartzite, and chert; mostly thick to very thick bedded with both planar and low-angle cross-stratification, although thin, platy beds with ripple cross-stratification are present locally; predominantly pale- to dark-yellowish orange, but pale-red, grayish-red, very pale-orange, and pale-yellow-brown hues are common; heavily stained by iron-manganese oxides, locally forming "picture stone;" strongly jointed with common slickensides; contains poorly preserved petrified wood and plant fragments, commonly replaced in part by iron-manganese oxides; forms a prominent cuesta along both flanks of the Virgin anticline; variable thickness, from about 104 to 165 feet (32-50 m) thick, probably due to paleotopography and deposition in braided-stream channels.

unconformity (Ꞧ-3)

Moenkopi Formation

Ꞧmu Upper red member - Interbedded, mostly thin- to medium-bedded, moderate-reddish-orange to moderate-reddish-brown siltstone, mudstone, and very fine- to fine-grained sandstone with planar, low-angle, and ripple cross-stratification; well-preserved ripple marks are common; forms ledgy slopes and cliffs; includes a prominent, medium- to very thick-bedded, commonly cliff-forming, 108-foot-thick (33 m), pale-yellowish-orange to grayish-orange, fine-grained sandstone (the Purgatory sandstone) with both planar and low-angle cross-stratification and local Liesegang banding; deposited in tidal-flat and coastal-plain environments; 397 feet (120 m) thick.

Ꞧms Shnabkaib Member - Forms "bacon striped," ledgy slopes of laminated to thin-bedded, gypsiferous, pale-red to moderate-reddish-brown mudstone and siltstone, resistant, white to greenish-gray gypsum and lesser thin, laminated, light-gray dolomite beds; gypsum is present as laterally continuous, massive beds, finely laminated, commonly silty or muddy beds, and nodular intervals that range from less than one inch to about 9 feet (0.01-3 m) thick; gypsum also present as secondary cavity fillings and cross-cutting veins; weathers to soft, punky, gypsiferous soils; deposited in a variety of supratidal, intertidal, and subtidal environments on a broad, coastal shelf of very low relief; about 600 to 700 feet (180-210 m) thick.

Ꞧmm Middle red member - Interbedded, laminated to thin-bedded, moderate-reddish-brown to moderate-reddish-orange siltstone, mudstone, and very fine-grained sandstone; white to greenish-gray gypsum beds and veins are common, and the lower part contains several thick, ledge-forming gypsum beds; very poorly exposed in the core of the Virgin anticline; deposited in a tidal-flat environment; about 400 to 500 feet (120-150 m) thick.

Ꞧmv Virgin Limestone Member - Very pale-orange to yellowish-gray, finely crystalline limestone and silty limestone, light-gray to light-olive-gray, coarsely crystalline, fossiliferous limestone with locally abundant circular and five-sided crinoid columnals, gastropods, and brachiopods, and siltstone and mudstone; along the southwestern flank of Harrisburg Dome, includes three limestone ledges separated by poorly exposed mudstone slopes; elsewhere, only the thicker, lower limestone is exposed; forms a low, prominent cuesta that encloses all but the southern end of Harrisburg Dome; deposited in a variety of shallow-marine environments; about 85 feet (26 m) thick.

Ꞧml Lower red member - Interbedded, laminated to thin-bedded, moderate-reddish-brown mudstone and siltstone with local, thin, laminated, light-olive-gray gypsum beds and veinlets; poorly exposed in a strike valley around Harrisburg Dome; deposited in a tidal-flat environment; about 150 to 200 feet (45-60 m) thick.

unconformity (Ꞧ-1)

PERMIAN

Kaibab Formation

Pk Kaibab Formation, undivided - shown in cross section only.

Pkh Harrisburg Member - Laterally variable sequence of interbedded, medium- to very thick-bedded, laminated and massive gypsum, gypsiferous mudstone, and lesser laminated limestone and cherty limestone breccia above a medial limestone. The medial limestone includes medium-gray cherty limestone breccia and coarsely crystalline limestone; laminated, thin-bedded, brown-weathering, medium-gray, slightly fetid limestone; grayish-orange-pink intraformational limestone conglomerate; grayish-orange-pink to pinkish-gray oncolitic limestone; and fine- to medium-crystalline limestone, with abundant light-brown to moderate-reddish-brown weathering, light-gray chert nodules and lenticular beds with sparse silicified fenestrae bryozoans. Deposited in a complex sequence of shallow-marine and sabkha environments; only about the upper 250 feet (75 m) is exposed in the quadrangle.

Subsurface Units

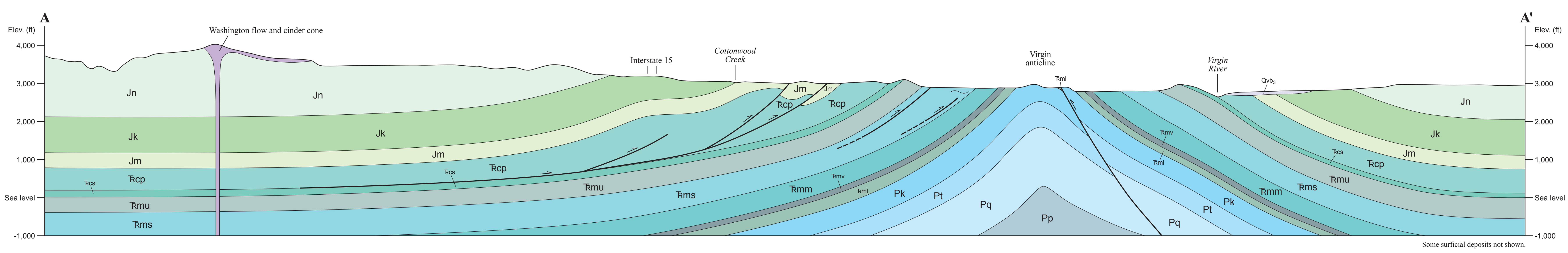
Pt Toroweap Formation - Shown on cross section only.

Pq Queantoweap Sandstone -Shown on cross section only.

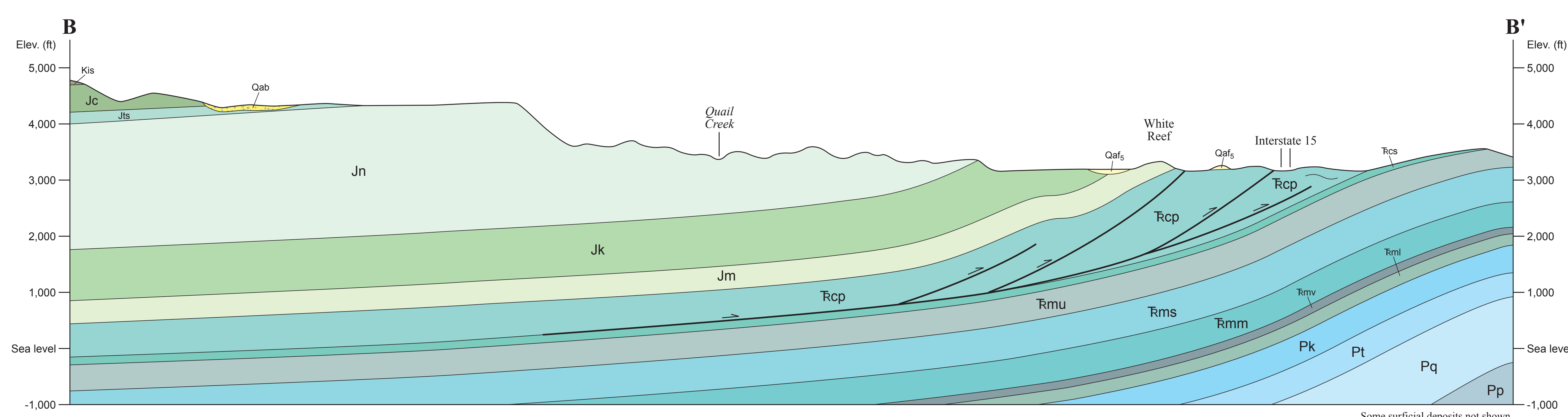
Pp Pakoon Dolomite -Shown on cross section only.

GEOLOGIC SYMBOLS

- Contact
- dm — Kayenta Formation dolomite marker bed
- High-angle normal fault - dashed where approximate, dotted where concealed; bar and ball on down-thrown side
- Thrust or reverse fault - dotted where concealed; teeth on upper plate
- Tear fault - arrows show direction of relative movement
- Fault - displacement unknown
- Prominent joint
- 8 — Anticline - with direction and degree of plunge; dotted where concealed
- Syncline - with direction of plunge; dotted where concealed
- 40 — Strike and dip of inclined bedding
- Strike of near vertical joint
- Pit - sand and gravel (no letter), sand (s), clay (cl)
- Quarry - gypsum (g), building or ornamental stone (s)
- Prospect - gypsum (g), metals (no letter)
- Spring
- Volcanic vent
- Petroleum exploration drill hole - plugged and abandoned
- VR40-08 — Sample location and number



Some surficial deposits not shown.



Some surficial deposits not shown.

GEOLOGIC MAP OF THE HARRISBURG JUNCTION QUADRANGLE, WASHINGTON COUNTY, UTAH

by

Robert F. Biek

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GEOLOGIC MAP OF THE HARRISBURG JUNCTION QUADRANGLE, WASHINGTON COUNTY, UTAH

by

Robert F. Biek

ABSTRACT

The Harrisburg Junction quadrangle lies in the transition zone between the Colorado Plateau and Basin and Range physiographic provinces. Stratigraphic units ranging in age from the Early Permian Harrisburg Member of the Kaibab Formation to the Late Cretaceous Iron Springs Formation and totaling about 8,200 feet (2,500 m) thick are exposed in the quadrangle. Three Pleistocene basaltic lava flows, one Pleistocene cinder cone, and a variety of Quaternary deposits are also present.

The quadrangle lies on an intermediate structural block bounded on the east by the Hurricane fault and on the west by the Gunlock and Grand Wash faults. The dominant structural feature in the mapped area, the Virgin anticline, trends northeast through the quadrangle. The oldest strata exposed in the quadrangle are in the core of the anticline, at Harrisburg Dome. The dome itself is cut by an east-dipping reverse fault that placed the Lower Permian Harrisburg Member of the Kaibab Formation over the lower red member of the Lower Triassic Moenkopi Formation. Several west-dipping, Sevier-age thrust faults repeat Triassic and Jurassic strata on the northwest flank of the anticline. Jurassic and Cretaceous strata in the northwest portion of the quadrangle dip gently to the north under the southern flank of the Pine Valley Mountains.

Primary geologic resources in the quadrangle include sand and gravel, gypsum, building and ornamental stone, and clay. The Silver Reef mining district, which includes the northeast portion of the quadrangle, produced approximately 8 million ounces (226,800,000 g) of silver prior to 1910, and small amounts of gold, silver, copper, and uranium oxide between 1949 and 1968. The Navajo Sandstone, Kayenta Formation, and, locally, unconsolidated Quaternary deposits are important ground-water sources in this arid region. The principal geologic hazards in the quadrangle include earthquakes, landslides, rock falls, problem soil and rock, flash floods, debris flows, and radon.

INTRODUCTION

The Harrisburg Junction quadrangle straddles the Interstate 15 corridor in central Washington County and covers an area of about 60 square miles (156 km^2) between Washington City and the Town of Leeds (figure 1). This area is part of the burgeoning retirement, retail, and vacation center of southwestern Utah, affectionately known as "Utah's Dixie." Once populated by a few hardy pioneers sent south from Salt Lake City to grow cotton, the region's population grew by 140 percent from 1980 to 1995 and it continues to be among the fastest growing areas in the state. An important concern is that this new development is encroaching into geologically hazardous areas. Geologic hazards present in the quadrangle include earthquakes, landslides and rock falls, expansive and collapsible soil and rock, and other hazards. Rapid development also puts pressure on the region's natural resources – especially scarce gravel and water resources, silver and other metals, and even open space. This geologic map and report contain much of the basic geologic information needed to address these and other issues. The report also contains a detailed discussion of the geologic structure and stratigraphy of the quadrangle. I hope that this report and map will prompt further field inspection and more detailed mapping of geologically hazardous areas and interesting geologic sites.

The Harrisburg Junction quadrangle lies in the transition zone between the Colorado Plateau and Basin and Range physiographic provinces. Strata in the quadrangle, although folded into the northeast-trending Virgin anticline, are generally characteristic of the generally flat-lying strata of the Colorado Plateau. The quadrangle also lies on an intermediate structural block bounded on the east by the Hurricane fault and on the west by the Gunlock and Grand Wash faults. Several small high-angle normal faults, splays of the Washington fault zone, displace a 900,000-year-old basaltic lava flow that caps the southern end of Washington Black Ridge. The dominant structural feature of the quadrangle, the Virgin anticline with associated west-dipping thrust faults on its northwest limb, formed during the Late Cretaceous as one of the frontal folds of the Sevier orogenic belt.

The greater St. George area, including the Harrisburg Junction quadrangle, has been the focus of numerous topical geological investigations, many of which are cited elsewhere in this report. Previous geologic maps of the area include that of Bassler and Reeside (1921), who prepared a simplified, 1:62,500-scale geologic map of Harrisburg Dome in their study of oil prospects in Washington County. Dobbin (1939) prepared a small-scale geologic map for his study of the structural geology of the St. George basin. Proctor (1948,

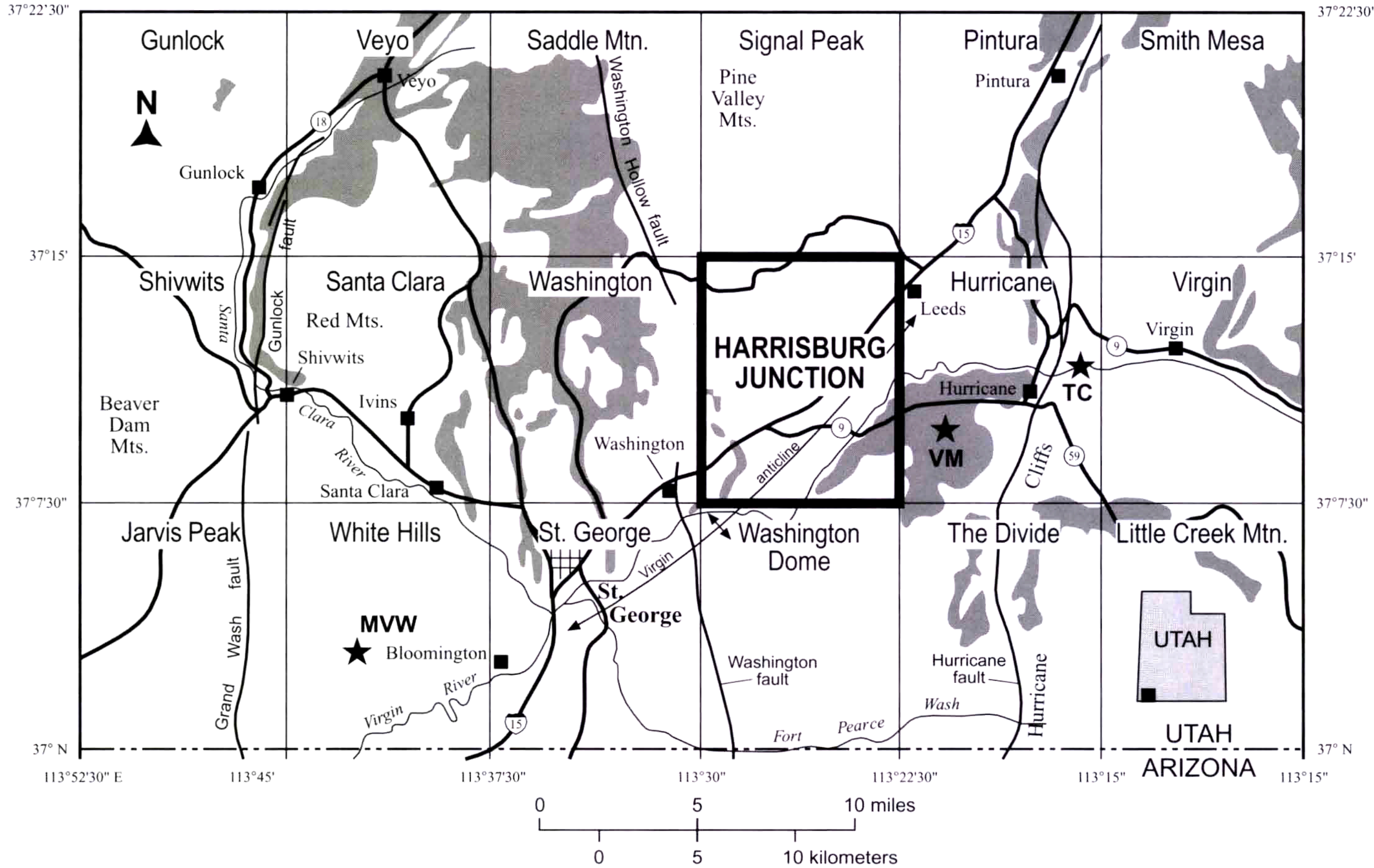

***Figure 1.** Location of the Harrisburg Junction and surrounding 7.5' quadrangles, with major geographic and geologic features; basalt flows are shaded. VM = Volcano Mountain and Ivan's Knoll; MVW = Mountain Valley Wash; TC = Timpoweap Canyon.*

1953) provided detailed geologic maps of the Silver Reef mining district. Cook (1957) mapped the Pine Valley Mountains, and later expanded that study to map the geology of Washington County at 1:125,000 (Cook, 1960). Haynes (1983) mapped geomorphic features of a portion of the Virgin River basin between Hurricane and Washington. Christenson and Deen (1983) mapped the surficial geology of the greater St. George area (1:31,250), including the southwestern corner of the Harrisburg Junction quadrangle, for their engineering-geology report. Budding and Sommer (1986) published a 1:62,500-scale geologic map, modified from unpublished maps of W.K. Hamblin, of portions of the Hurricane and St. George 15-minute quadrangles. In their assessment of the mineral resource potential of the Cottonwood Canyon Wilderness Study Area, Houser and others (1988) produced a simplified 1:24,000-scale geologic map of the northwestern portion of the Harrisburg Junction quadrangle and adjacent areas. Noweir (1990) provided a sketch map of a portion of Harrisburg Dome in his study of the geology of the overthrust belt of southwestern Utah. Eppinger and others (1990) produced a 1:250,000-scale geologic map of the Cedar City 1° x 2° quadrangle, which includes the Harrisburg Junction quadrangle. Hacker (1998) mapped the Signal Peak and Saddle Mountain quadrangles to the north and northwest.

Geologic maps (1:24,000 scale) and reports are available for the following 7.5′ quadrangles in the area (figure 1): Gunlock (Hintze and others, 1994), Hurricane (Biek, 2002), Jarvis Peak (Hammond, 1991), Pintura (Hurlow and Biek, 2000), Santa Clara (Willis and Higgins, 1996), St. George (Higgins and Willis, 1995), Shivwits (Hintze and Hammond, 1994), The Divide (Higgins, 2000), Washington (Willis and Higgins, 1995), Washington Dome (Higgins, 1998), and the White Hills (Higgins, 1997). Most of the 1:24,000-scale geologic maps that border the Harrisburg Junction quadrangle were completed as part of a multi-year project by the Utah Geological Survey (UGS) to produce detailed geologic maps of the rapidly growing St. George basin. This geologic map is part of that effort and was jointly funded through a cooperative agreement between the UGS and the U.S. Geological Survey under the National Geologic Mapping Act of 1992.

STRATIGRAPHY

About 8,200 feet (2,500 m) of Lower Permian to Upper Cretaceous sedimentary strata are exposed in the Harrisburg Junction quadrangle, and they provide a record of changing environmental conditions through 275 million years of geologic time. These rocks 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 (1999, 2000), and Biek and others (2000) provided popular narrative histories of these units.

The oldest exposed rocks in the quadrangle, the Early Permian Harrisburg Member of the Kaibab Formation, form the core of the Virgin anticline at Harrisburg Dome. Strata become progressively younger across the limbs of the anticline, and the youngest sedimentary strata in the quadrangle, the Late Cretaceous Iron Springs Formation, are exposed on the flank of the Pine Valley Mountains. Three Pleistocene basaltic lava flows, erupted from one vent in the quadrangle and a second vent to the east near Hurricane, and a variety of Quaternary deposits are also present.

Permian

Kaibab Formation

The Kaibab Formation consists of two members, the Fossil Mountain Member and the overlying Harrisburg Member (Nielson, 1981; Sorauf and Billingsly, 1991). Only the Harrisburg Member is exposed in the Harrisburg Junction quadrangle. The Kaibab Formation is late Early Permian (Leonardian) in age (King, 1930; McKee, 1938; Rawson and Turner-Peterson, 1979; Sorauf and Billingsly, 1991).

Harrisburg Member (Pkh): Reeside and Bassler (1921) named the Harrisburg Gypsiferous Member for exposures along the southeast side of Harrisburg Dome; Sorauf (1962) later renamed it simply the Harrisburg Member. Because Sorauf's type section does not contain a complete section of the Harrisburg Member, Nielson (1981, 1986) established two reference sections. One section, typical of eastern facies along the Hurricane Cliffs, is in Timpoweap Canyon (figure 1). A second section, typical of western exposures, including those of Harrisburg Dome, is in Mountain Valley Wash, southwest of Bloomington (figure 1). These reference sections illustrate the rapid east-west facies changes characteristic of the Harrisburg Member.

The Harrisburg Member consists of slope- and ledge-forming, interbedded gypsum, gypsiferous mudstone, and minor thin-bedded limestone and cherty limestone that overlie a medial limestone interval. Harrisburg strata form the tightly folded core of Harrisburg Dome where only the upper part of the member, above and including the medial limestone interval, is exposed (figure 2). A wide variety of rock types are present along the crest and flanks of the dome, but because of poor exposures and tight folding, relations among them are unclear. The best exposures are in the east-dipping cuesta immediately east of the dome's axial surface.

On the northeast side of Harrisburg Dome, in the SE1/4SE1/4SW1/4 section 9, T. 42 S., R. 14 W., the east-dipping cuesta is capped by about 30 feet (9 m) of very rough-weathering, thick- to very thick-bedded, cherty limestone breccia that overlies very coarsely crystalline limestone that

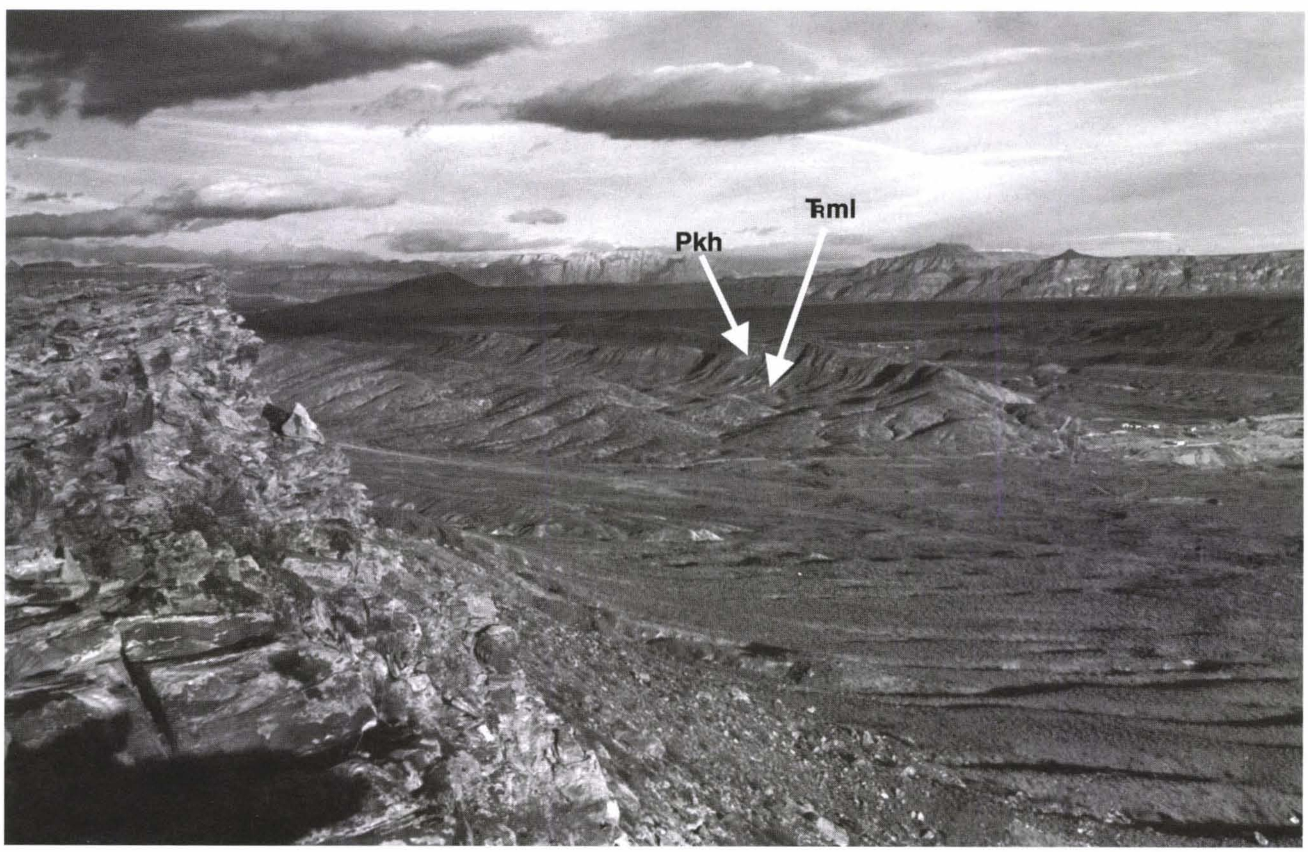

Figure 2. *View northeast to Harrisburg Dome, in the core of the Virgin anticline; photo taken from the NW1/4 section 19, T. 42 S., R. 14 W. The lower red member of the Moenkopi Formation (₸ml) is exposed in the east-dipping cuesta immediately east of the dome's axial surface. The cuesta itself is capped by Harrisburg Member (Pkh) strata that are in fault contact with the lower red member.*

lacks chert. This carbonate sequence corresponds to the medial limestone described by Nielson (1981). The chert forms very coarse sand- to pebble-size angular fragments in both clast- and matrix-supported limestone breccias. The chert is white to light gray, but weathers moderate yellowish brown with iron-manganese stains. The host limestone is pale red to moderate orange pink and weathers grayish orange pink to light brownish gray; I found no fossils in these beds. These limestones and cherty limestones are in fault contact with the lower red member of the Moenkopi Formation, which here consists of about 30 feet (9 m) of pale- to dark-yellowish-orange mudstone and siltstone underlain by about 40 feet (12 m) of moderate- to dark-reddish-brown gypsiferous mudstone and siltstone. Like Noweir (1990), I interpret the fault as a steeply east-dipping axial backthrust.

When traced southwest, to the NE1/4SW1/4 section 17, T. 42 S., R. 14 W., these limestones appear thinner and more cherty, with both thin-bedded and nodular chert. There, the limestones are underlain by about 50 feet (15 m) of additional Harrisburg Member strata that consist of interbedded, laminated and structureless gypsum and lesser thin-bedded, laminated limestone. About 200 feet (60 m) of the lower red member of the Moenkopi Formation is exposed below the Harrisburg Member. The upper 20 feet (6 m) of the lower red member is yellowish-orange gypsiferous mudstone and siltstone, similar to exposures of the same unit to the northeast (figure 3).

In addition to the cherty limestone breccia and coarsely crystalline limestone described above, other limestone varieties in the medial limestone interval are apparent along the crest of Harrisburg Dome. These include a brown-weathering, medium-gray, slightly fetid limestone in thin, laminated beds; a grayish-orange-pink intraformational limestone conglomerate; and a grayish-orange-pink to pinkish-gray oncolitic limestone. Similarly colored fine- to medium-grained limestone – with abundant light-brown- to moderate-reddish-brown-weathering, light-gray chert nodules and lenticular beds – is common. Locally, silicified fenestrate bryozoans are found in these beds.

Outcrop patterns suggest that gypsiferous strata that normally overlie the medial limestone interval were partially removed by erosion associated with the Permian-Triassic unconformity. Poorly exposed and contorted gypsum and gray gypsiferous mudstones, which lie stratigraphically above the medial limestones, form the bulk of exposures along the southern flanks of the dome. These strata are largely missing near the center of the Harrisburg Dome in the NW1/4 section 16, T. 42 S., R. 14 W., and are only locally preserved along the dome's northern end. This apparent overall northward thinning of gypsiferous strata above the medial limestone interval may be due in part to structural thinning of incompetent beds, but is likely mostly a result of pre-Moenkopi erosion. To the southwest, in the St. George and White Hills quadrangles, Higgins and Willis (1995) and Higgins (1997) documented in excess of 600 feet (180 m) of pre-Moenkopi erosion that locally removed the entire Harrisburg Member. Biek (2002) reported up to 80 feet (24 m) of erosional relief on the Harrisburg Member in the adjacent Hurricane quadrangle.

The incomplete section of Harrisburg strata exposed along the southeastern flank of Harrisburg Dome is about 250 feet (75 m) thick; folding and relatively poor exposures

Figure 3. *View northeast to east-dipping cuesta immediately east of the axial surface of Harrisburg Dome; photo taken from the SW 1/4 section 17, T. 42 S., R. 14 W. An east-dipping reverse fault separates the lower red member of the Moenkopi Formation (Ꞧml) from the Harrisburg Member of the Kaibab Formation (Pkh).*

preclude accurate thickness measurements. Reeside and Bassler (1921) assigned about 270 feet (82 m) of mostly cherty limestones to the Harrisburg Member at Harrisburg Dome. Nielson (1981) measured two partial sections of Harrisburg strata on the Harrisburg Dome. The Harrisburg Member varies from about 100 to 160 feet (30-50 m) thick in the Hurricane quadrangle (Biek, 2002) and from 0 to about 300 feet (0-90 m) thick in the St. George quadrangle to the southwest, in part as a result of pre-Moenkopi erosion (Nielson, 1981; Higgins and Willis, 1995). The Harrisburg Member was deposited in a complex sequence of shallow-marine and sabkha environments (Nielson, 1981, 1986), and is considered to be late Early Permian (Leonardian) in age (Sorauf and Billingsly, 1991).

Triassic

Moenkopi Formation

The Moenkopi Formation in southwestern Utah consists of three transgressive members (the Timpoweap, Virgin Limestone, and Shnabkaib Members), each overlain by an informally named regressive red-bed member (the lower, middle, and upper red members, respectively); the Rock Canyon Conglomerate Member locally forms the base of the Moenkopi Formation (Reeside and Bassler, 1921; Stewart and others, 1972; Dubiel, 1994). The Moenkopi Formation (late Early Triassic to lower Middle Triassic) 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 many miles (Morales, 1987; Blakey, 1989; Dubiel, 1994). The transgressive members generally thicken, and the red bed members thin, from east to west across southwestern Utah. The entire Moenkopi section generally thickens westward.

The Permian-Triassic boundary in southwestern Utah is a major disconformity that represents about 10 to 20 million years of subaerial exposure and erosion (Nielson, 1981; Sorauf and Billingsley, 1991). It is the TR-1 unconformity of Pipiringos and O'Sullivan (1978). Erosion produced an irregular surface having several hundred feet of relief upon which conglomerates and breccias of the Rock Canyon Conglomerate Member were locally deposited in paleocanyons, karst-depressions, and as regolith (Nielson, 1991). The overlying Timpoweap Member was deposited in broader paleovalleys. However, these lower two members of the Moenkopi Formation are not exposed, and may not have been deposited, at Harrisburg Dome, suggesting that this area may have been a paleohigh during Rock Canyon and Timpoweap time.

Due to incomplete exposures and internal deformation, the total thickness of the Moenkopi Formation in the Harrisburg Junction quadrangle is uncertain. It is probably 1,600 to 1,800 feet (495-570 m) thick, significantly less than the 2,035 feet (620 m) reported by Reeside and Bassler (1921) on the south side of Harrisburg Dome. The six upper members of the Moenkopi Formation are about 1,500 feet (460 m) thick at Hurricane Mesa, immediately east of the Hurricane quadrangle (Biek, 2002). Higgins and Willis (1995) reported that in the St. George quadrangle to the southwest, the seven members of the Moenkopi Formation total 2,150 feet (650 m) thick. The five upper members of the Moenkopi Formation in the Washington Dome quadrangle to the south are about 1,900 feet (575 m) thick (Higgins, 1998).

Lower red member (TRml): The lower red member forms a prominent strike valley that encircles Harrisburg Dome, but is almost completely concealed by Quaternary deposits. Isolated exposures of the upper part of the member are in the NE1/4SW1/4 section 9, T. 42 S., R. 14 W., in the SW1/4NE1/4NE1/4 section 9, T. 42 S., R. 14 W., and in several drainages that cut through the east flank of the dome. The best exposures of lower red strata are along the west side of the east-dipping cuesta immediately east of Harrisburg Dome. These exposures show the lower red member consists of interbedded, laminated to thin-bedded, moderate-reddish-brown mudstone and siltstone with local, thin, laminated, light-olive-gray gypsum beds and veinlets; the member is locally irregularly colored yellowish orange. I placed the upper contact of the lower red member at the base of the lowest Virgin limestone bed.

Incomplete exposures make thickness determinations of the lower red member at Harrisburg Dome difficult. Based on outcrop patterns, the member appears to vary from about 150 to 200 feet (45-60 m) thick. The lower red member is about 200 to 250 feet (60-75 m) thick in the Hurricane quadrangle to the east (Biek, 2002). Higgins (1998) reported thickness variations from 25 to 200 feet (8-60 m) at Washington Dome to the south, probably due to fault attenuation. Along the flanks of the Bloomington dome to the southwest, lower red strata are 25 to 300 feet (8-90 m) thick, again probably due to fault attenuation (Higgins and Willis, 1995). In the White Hills quadrangle, Higgins (1997) reported lower red thicknesses that varied from 0 to 200 feet (0-60 m) due to paleotopography. Reeside and Bassler (1921) assigned 335 feet (102 m) to this member at Harrisburg Dome and noted that the lower 60 feet (18 m) consists of yellow gypsiferous shale with thin black limestone beds. Their description suggests that these lower beds may belong to the Timpoweap Member. A few tens of feet of yellowish-brown, silty, gypsiferous beds, and thin-bedded, medium- to coarse-grained, intraformational pebbly sandstone and sandy limestone do overlie typical Harrisburg strata on the southeast flank of the dome; however, I did not observe thin limestones characteristic of the Timpoweap. I assign the silty gypsiferous beds to the lower red member and the underlying limy beds to the Harrisburg Member. The lower red member was probably deposited in a tidal-flat environment, and is unconformably overlain by the transgressive Virgin Limestone Member throughout southwestern Utah (Stewart and others, 1972; Nielson and Johnson, 1979).

Virgin Limestone Member (TRmv): The Virgin Limestone Member forms a low, prominent cuesta that encloses all but the southern end of Harrisburg Dome. The member weathers to three well-exposed limestone ledges and poorly exposed siltstone and mudstone slopes, and is locally concealed by Quaternary deposits, producing an outcrop pattern that thickens and thins irregularly. Along the dome's southwest side, in the SW1/4 section 17, T. 42 S., R. 14 W., three limestone ledges are exposed. The lower ledge is about 8 feet (2.4 m) thick and is overlain by about 50 feet (15 m) of very poorly exposed mudstone and siltstone. The two overlying limestone ledges are each about 2 feet (0.6 m) thick and are separated by about 22 feet (7 m) of similar poorly exposed mudstone strata. Elsewhere, only the lower and, rarely, middle limestone beds are exposed. Virgin limestones vary from very pale-orange to yellowish-gray, finely crystalline limestone and silty limestone, to light-gray to light-olive-gray, coarsely crystalline, fossiliferous limestone with locally abundant circular and five-sided crinoid columnals, gastropods, and brachiopods.

The Virgin Limestone Member is about 85 feet (26 m) thick along the southwestern flank of Harrisburg Dome. In the adjacent Hurricane quadrangle to the east, the Virgin Limestone is about 100 feet (30 m) thick (Biek, 2002). To the south, in the Washington Dome quadrangle, Higgins (1998) reported that undisturbed Virgin strata are 115 feet (35 m) thick. In the St. George quadrangle to the southwest, Higgins and Willis (1995) measured 134 feet (30 m) of Virgin Limestone strata. The member varies considerably in thickness along the flanks of the Bloomington dome due to structural complications. There, Higgins and Willis (1995) reported the Virgin Limestone Member varies from 225 feet (68 m) to an attenuated 25 feet (7.5 m) thick. Reeside and Bassler (1921) assigned 160 feet (49 m) of beds at both Harrisburg and Washington Domes to this member. The Virgin Limestone is conformably overlain by the middle red member (Poborski, 1954; Stewart and others, 1972). I placed the upper contact at the top of the uppermost limestone bed. The Virgin Limestone Member is Early Triassic (early to middle Spathian) in age and was deposited in a shallow-marine environment (Dubiel, 1994).

Middle red member (TRmm): The middle red member forms very poorly exposed slopes in the core of the Virgin anticline. The best exposures are along the southeast side of Harrisburg Dome. Elsewhere, middle red strata are mostly concealed beneath younger mixed alluvial and eolian deposits. The middle red member consists of interbedded, laminated to thin-bedded, moderate-reddish-brown to moderate-reddish-orange siltstone, mudstone, and very fine-grained sandstone. Thin, white to greenish-gray gypsum beds and veins are common. The lower part of the member contains several thick, ledge-forming gypsum beds.

The upper contact of the middle red member appears sharp on aerial photographs and corresponds to a change from moderate-reddish-brown siltstone below to banded, greenish-gray gypsum and pale-red mudstone above. I placed it at the base of the first thick gypsum bed of the Shnabkaib Member. Stewart and others (1972) noted that in many places this contact corresponds to a transition zone that is about 100 to 300 feet (30-100 m) thick. The middle red member is about 400 to 500 feet (120-150 m) thick along the southeastern flank of Harrisburg Dome. Reeside and Bassler (1921) assigned 435 feet (133 m) of beds near Harrisburg Dome to what is now known as the middle red member. To the south in the Washington Dome quadrangle, Higgins (1998) reported the member is 400 feet (120 m) thick. To the southwest in the St. George quadrangle, the middle red member is 372 feet (113 m) thick along the northeast side of Bloomington dome (Higgins and Willis, 1995). The middle red member was probably deposited in a tidal-flat environment (Stewart and others, 1972; Dubiel, 1994).

Shnabkaib Member (TRms): The Shnabkaib Member is well exposed in the core of the Virgin anticline where it forms a striking, red- and white-banded ("bacon-striped") sequence of interbedded pale-red to moderate-reddish-brown, slope-forming mudstone and siltstone and white to greenish-gray, ledge- or ridge-forming gypsum. Where protected by the resistant Shinarump cuesta, the Shnabkaib Member forms steep, ledgy slopes. Elsewhere, and more commonly, it weathers to low, rounded strike ridges that are upheld by resistant gypsum beds. The type section of the Shnabkaib Member is at Shinob Kibe butte immediately south of the Harrisburg Junction quadrangle, in section 24, T. 42 S., R. 15 W. It was originally named the *Shnabkaib* shale member by Reeside and Bassler (1921), who stated that the name Shnabkaib is probably a corruption of an old Indian name meaning *Coyote Mountain*. Gregory (1950), however, indicated that the name *Shnabkaib* may be a misspelling of the Piute *Shinob* (Great Spirit) and *Kaib* (mountain), loosely translated as *Mountain of the Lord*.

The mudstones and siltstones of the Shnabkaib Member are commonly gypsiferous in laminated to thin beds; strata with ripple cross-stratification are rarely exposed. Gypsum is present in: laterally continuous, very thick beds; finely laminated, commonly silty or muddy beds; nodular horizons; and secondary cavity fillings and cross-cutting veins. The gypsum beds vary from less than one inch (2.5 cm) to about 9 feet (3 m) thick. The Shnabkaib Member also contains thin, laminated, light-gray dolomite beds that, being more resistant than enclosing rocks, weather out, causing dolomite debris to accumulate at the surface. Shnabkaib strata weather to soft, punky, gypsiferous soils commonly covered by a delicate microbiotic crust.

The upper contact of the Shnabkaib Member is gradational. I placed it at the top of the highest, thick gypsum bed, above which are laminated to thin-bedded, moderate-reddish-brown mudstone and siltstone beds of the upper red member. The contact corresponds to a prominent color change from generally lighter colored Shnabkaib strata below, which are dominated by white, greenish-gray, and pale-red hues, to darker colored upper red beds above, which are uniformly colored moderate reddish brown.

Due to small-scale but widespread deformation in the core of the Virgin anticline, the thickness of the Shnabkaib Member is difficult to determine in the Harrisburg Junction quadrangle. I estimate it is 600 to 700 feet (180-210 m) thick. Lambert (1984) reported the Shnabkaib Member is only about 425 feet (130 m) thick east of Hurricane, at Hurricane Mesa and Little Creek Mountain. Higgins (1998) reported that Shnabkaib strata total about 750 feet (230 m) thick in the Washington quadrangle. Higgins and Willis (1995) measured 996 feet (302 m) of Shnabkaib strata in the St. George quadrangle to the southwest. Reeside and Bassler (1921) assigned 630 feet (192 m) to the member at Harrisburg Dome. Lambert (1984) suggested that Shnabkaib strata were deposited in a variety of supratidal, intertidal, and subtidal environments on a broad coastal shelf of very low relief. The intricate interbedding of evaporites and red beds suggests complex water-table fluctuations, probably associated with minor sea-level fluctuations (Dubiel, 1994).

Upper red member (TRmu): The upper red member is well exposed below cliffs of Shinarump Conglomerate in the core of the Virgin anticline. Some of the best and most accessible exposures are where Utah Highway 9 cuts through the flanks of the Virgin anticline. With the exception of a lower, cliff-forming yellowish sandstone described below, the lower part of the member generally forms ledgy slopes. The upper part of the member forms ledges and low cliffs.

The upper red member consists of a generally upward-coarsening sequence of interbedded, mostly thin- to medium-bedded, uniformly colored, moderate-reddish-orange to moderate-reddish-brown siltstone, mudstone, and very fine- to fine-grained sandstone. A very thick-bedded, yellowish sandstone is present near the base of the member. Planar, low-angle, and ripple cross-stratification are common, as are well-preserved ripple marks.

A prominent, normally cliff-forming, pale-yellowish-orange to grayish-orange, fine-grained sandstone with Liesegang banding is present about 50 feet (15 m) above the base of the member. This yellowish sandstone is informally known as the Purgatory sandstone (figure 4). It is medium to very thick bedded with both planar and low-angle cross-stratification and includes minor, similarly colored, thin- to medium-bedded siltstone and very fine-grained sandstone interbeds. This sandstone unit is 108 feet (33 m) thick southeast of Quail Creek Reservoir, in the NE1/4 section 35, T. 41 S., R. 14 W. It appears to thin to the south, probably due to faulting southwest of Utah Highway 9 along the west flank of the Virgin anticline, and appears to pinch out entirely in the NE1/4SE1/4 section 8, T. 41 S., R. 14 W. This sandstone reappears west of the county landfill, in the SE1/4 section 8, T. 41 S., R. 14 W., and thickens to about 100 feet (30 m) near the southern boundary of the quadrangle. It appears to maintain a relatively constant thickness along the east flank of the anticline.

The upper red member is 397 feet (120 m) thick southwest of Quail Creek Reservoir, in the SW1/4SE1/4NW1/4 section 35, T. 41 S., R. 14 W. To the south in the Washington Dome quadrangle, Higgins (1998) reported that upper red strata are 475 feet (144 m) thick. Higgins and Willis (1995) measured 363 feet (110 m) of upper red strata south of St. George, on the northwest flank of the Virgin anticline, in the SW1/4NW1/4NE1/4 section 7, T. 43 S., R. 15 W. Proctor (1953) measured 376 feet (115 m) of what are now called upper red strata north of Utah Highway 9. Proctor and Brimhall (1986) reported just 284 feet (87 m) of upper red strata on the east limb of the Virgin anticline, apparently near Harrisburg Gap. Reeside and Bassler (1921) assigned 475 feet (145 m) to this member near Harrisburg Dome. These widely varying thicknesses in the Harrisburg Junction quadrangle may be due in part to differences in placing the lower contact, and perhaps to structural complications. The upper red member was probably deposited in tidal-flat and coastal-plain environments (Stewart and others, 1972; Dubiel, 1994).

Chinle Formation

The Chinle Formation in southwestern Utah consists of the Shinarump Conglomerate and Petrified Forest Members. The Shinarump Conglomerate forms a prominent cuesta along the flanks of the Virgin anticline, whereas the overlying Petrified Forest Member is generally poorly exposed in adjacent strike valleys. The Chinle Formation is Late Triassic in age, based principally on vertebrate and plant remains, and was deposited in a variety of fluvial and lacustrine environments (Stewart and others, 1972; Dubiel, 1994). Shinarump strata were deposited principally in braided-stream channels by north- and northwest-flowing streams; Petrified Forest fluvial systems mimicked this paleoflow, but with a much greater abundance of high-sinuosity stream deposits and flood-plain mudstones (Dubiel, 1994). In southwestern Utah, the (Ꞧ-3) regional unconformity separates Lower Triassic (Moenkopi Formation) and Upper Triassic (Chinle Formation) rocks and corresponds to a change from mostly shallow-marine to continental sedimentation. In the Harrisburg Junction quadrangle, the (Ꞧ-3) unconformity is a disconformity with minor channeling at the base of the Shinarump Conglomerate Member. Dubiel (1994) assigned Chinle strata to the early Carnian to late Norian (Late Triassic) with an unconformity of several million years separating the two members. I found no evidence of such an unconformity in the quadrangle.

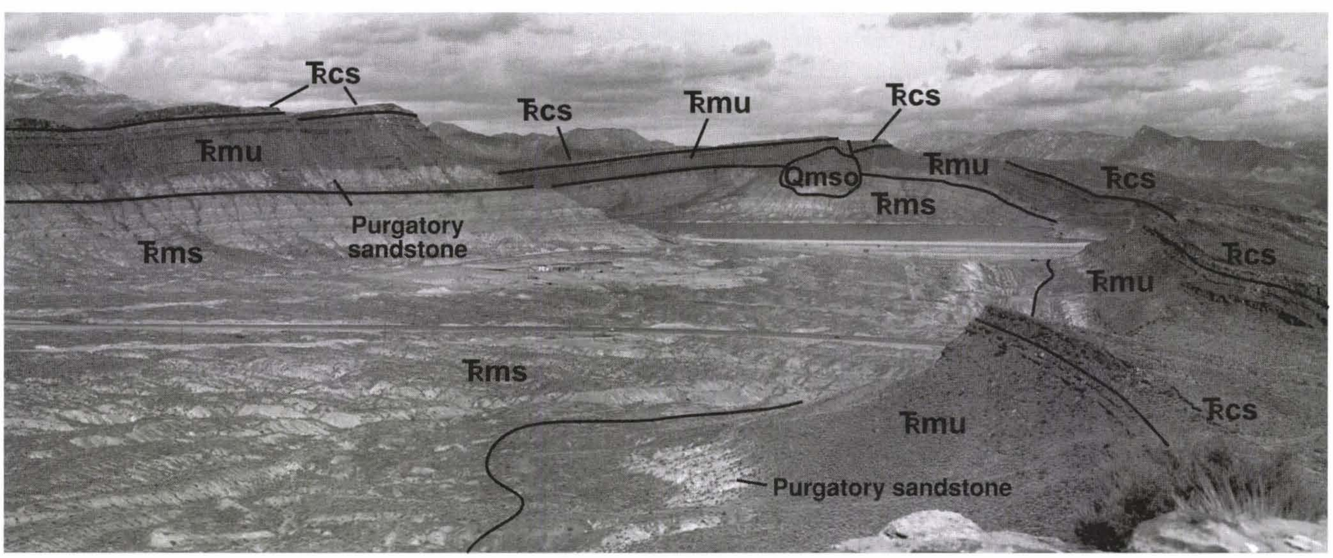

Figure 4. *View northeast to Quail Creek Reservoir, along the axis of the Virgin anticline; photo taken from the SE1/4 section 3, T. 42 S., R. 14 W. Resistant Shinarump Conglomerate (Ꞧcs) strata form the flanks and crest of the anticline, below which are ledgy slopes of the upper red member (Ꞧmu) of the Moenkopi Fomation. The light band near the base of the upper red member is informally known as the Purgatory sandstone. Red-and-white banded strata of the Shnabkaib Member (Ꞧms) form the eroded floor of the anticline. Note bright white beds below the dam, which were scoured clean following the catastrophic dike failure of January 1, 1989. Note also the deeply dissected landslide deposit (Qmso) north of Quail Creek Reservoir. Utah Highway 9 cuts across center of photograph.*

Shinarump Conglomerate Member (TRcs): Because of its resistance to erosion, the Shinarump Conglomerate Member forms a prominent cuesta along both flanks of the Virgin anticline. It is nearly everywhere well exposed in cliffs along the interior of the anticline. The best exposures of the lower contact are where Utah Highway 9 cuts through both the east and west flanks of the Virgin anticline. The upper contact is only well exposed at the south end of Washington Black Ridge, in the SE1/4SE1/4 section 13, T. 42 S., R. 15 W.

The Shinarump Conglomerate consists of a laterally and vertically variable sequence of cliff-forming, fine- to very coarse-grained sandstone, pebbly sandstone, and minor pebbly conglomerate. It is commonly thick to very thick bedded with both planar and low-angle cross-stratification, although thin, platy beds with ripple cross-stratification are locally present. The sandstones are predominantly pale- to dark-yellowish orange, but pale-red, grayish-red, very pale-orange, and pale-yellowish-brown hues are common. Small, subrounded pebbles are primarily quartz, quartzite, and chert. Regionally, the Shinarump Conglomerate forms a generally fining-upward sequence from conglomeratic and planar-stratified sandstone at the base to medium-grained, cross-stratified sandstone at the top believed to represent a change from braided streams to low-sinuosity fluvial systems dominated by sand waves and point-bar deposits (Dubiel, 1994). In the Harrisburg Junction quadrangle, however, pebbly conglomerates and pebbly sandstones are common in many exposures throughout the section and no such fining-upward sequence is evident.

Shinarump strata are strongly jointed and major joints trend subparallel to the strike and dip of bedding. Well-developed slickensides, with a wide variety of orientations, are common in the Shinarump Conglomerate Member and suggest minor movement along and between bedding planes, even where beds are not otherwise affected by faulting or minor folding. Shinarump strata are locally heavily stained by iron-manganese oxides, commonly in the form of Liesegang banding. This banding invariably follows joints, so that large blocks become concentrically zoned in a variety of interesting patterns. Where these color bands are in fine- to medium-grained sandstones, they are much sought after as "picture stone" or "landscape stone." Coarser sandstones and pebbly sandstones locally contain poorly preserved petrified wood, commonly replaced in part by iron-manganese oxides; small logs several feet in length are common though not abundant. Plant fragments replaced in part by iron-manganese oxides are also common.

The Shinarump Conglomerate varies widely in thickness. Southwest of Quail Creek Reservoir, in the SE1/4NW1/4 section 35, T. 41 S., R. 14 W., Shinarump strata are 104 feet (32 m) thick. At the southern end of Washington Black Ridge, in the SE1/4SE1/4 section 13, T. 42 S., R. 15 W., the member is 165 feet (50 m) thick. Proctor (1953) measured 115 feet (35 m) of Shinarump strata north of Utah Highway 9. Proctor and Brimhall (1986) reported Shinarump strata are 95 feet (29 m) thick in the Silver Reef mining district. Near East Reef, Stewart and others (1972) measured 162 feet (49 m) of Shinarump beds. In the adjacent Washington Dome and St. George quadrangles, Shinarump strata vary from 5 to 200 feet (1.5-60 m) thick (Higgins, 1995; Higgins and Willis, 1995). Such wide variations in thickness are likely due to paleotopography on the underlying TR-3 unconformity and deposition in braided-stream channels, and, perhaps, to difficulty in placing the locally gradational upper contact.

The upper contact with the Petrified Forest Member is only exposed at the southern end of Washington Black Ridge, in the SE1/4SE1/4 of section 13, T. 42 S., R. 15 W. There, the contact appears conformable and gradational and corresponds to a prominent bench. The uppermost Shinarump consists of pale-red to grayish-red, thin- to medium-bedded, platy weathering, fine-grained sandstone with well-developed ripple cross-stratification. Basal Petrified Forest strata are poorly exposed but consist of about 35 feet (10.5 m) of moderate- to dark-reddish-brown, very fine-grained silty sandstone overlain by at least 42 feet (13 m) of fine- to very coarse-grained sandstone typical of the Shinarump Conglomerate. When traced to the west, to and across Grapevine Pass Wash, these reddish-brown, fine-grained silty sandstones grade into ledgy, thin- to medium-bedded sandstones and pebbly sandstones that are otherwise identical to underlying, generally more thickly bedded Shinarump strata. The contact at the southern end of Washington Black Ridge is thus gradational and intertonguing and I placed it at the base of the thick, reddish-brown silty sandstone. The contact is traced with difficulty to the west where it roughly corresponds to the first appearance of ledgy, thin- to medium-bedded sandstones. This sequence of lower Petrified Forest beds is similar, though thicker, than that reported by Stewart and others (1972) near East Reef, on the northeast flank of the Virgin anticline. They suggested that the lower sandstone may be a tongue of the Shinarump Conglomerate.

Basal Petrified Forest strata are also exposed west of Harrisburg Dome, in the east-central part of section 18, T. 42 S., R. 14 W., where they consist of interbedded, moderate- to dark-yellowish-brown, grayish-red, and grayish-red-purple, thin- to thick-bedded, fine- to medium-grained sandstone with ripple cross-stratification. These beds and similar strata exposed in the lower Petrified Forest Member north of Quail Creek Reservoir suggest a gradational contact at these locations as well.

Petrified Forest Member (TRcp): Because of widespread deformation and extensive Quaternary cover, a complete section of the Petrified Forest Member is not exposed in the Harrisburg Junction quadrangle. Still, portions of the member are well exposed, including its base as described earlier. The best exposure was in an abandoned clay pit in the SE1/4SE1/4SE1/4 section 5, T. 42 S., R. 14 W. (now reclaimed as a golf-course pond). Good exposures are also between the north- and south-bound lanes of Interstate 15, just south of Cottonwood Creek, in section 27, T. 41 S., R. 14 W., and in scattered exposures in the Harrisburg Flat area.

The Petrified Forest Member consists of variably colored mudstone, claystone, siltstone, lesser sandstone and pebbly sandstone, and minor chert and nodular limestone. It contains a wider lithologic variation than might be expected given the prominent varicolored swelling mudstones that typify the member. Petrified Forest strata commonly form rotational landslides, especially where exposed along steep hillsides. In the Harrisburg Junction quadrangle, such landslides are especially common along the southern reaches of Washington Black Ridge.

Mudstones and claystones of the Petrified Forest Member are typically various shades of purple, although grayish-red, dark-reddish-brown, light-greenish-gray, brownish-gray, olive-gray, and similar hues are common. Bentonitic clays that swell conspicuously when wet are common and give weathered surfaces a "popcorn" appearance. These swelling clays are also responsible for numerous foundation problems in the area. The clays are usually poorly exposed, but their bright colors commonly show through to the surface.

Sandstones of the Petrified Forest Member exhibit a wide variation in grain size and bedding characteristics. At the southern end of Washington Black Ridge, basal Petrified Forest mudstones are overlain by at least 42 feet (13 m) of fine- to very coarse-grained sandstone typical of the Shinarump Conglomerate. A 40-foot-thick (12 m), ledge-forming, very pale-orange to pinkish-gray, medium- to coarse-grained, locally pebbly sandstone is exposed north of Harrisburg Flat just west of Interstate 15. This thick channel sandstone can be traced to the northeast where it forms the northeast-plunging, tightly folded Leeds anticline at Leeds Reef. Faulting renders the true stratigraphic position of this sandstone uncertain, but it probably corresponds to the basal Petrified Forest sandstones described at the southern end of Washington Black Ridge. Near the top of the member at Buckeye Reef, immediately east of the quadrangle in the NE1/4NE1/4NE1/4 section 1, T. 40 S., R. 14 W., there is a very pale-orange, very thick-bedded, coarse- to very coarse-grained pebbly sandstone about 10 feet (3 m) thick. This same sandstone is present to the southwest below White Reef, in the NE1/4 section 14, T. 41 S., R. 14 W.

As its name implies, petrified wood, locally well silicified and brightly colored, is common in the Petrified Forest Member. Petrified wood is more abundant in uppermost Petrified Forest strata.

Even though the color change between Petrified Forest and overlying Dinosaur Canyon strata is locally well developed below portions of White Reef and in the Harrisburg Flat area, their contact is nowhere well exposed. The contact corresponds to the horizon between a slope-forming interval of purplish swelling mudstones below that change upward to moderate-reddish-brown, non-bentonitic, very fine- to fine-grained sandstone, silty sandstone, and lesser siltstone and mudstone characteristic of overlying Dinosaur Canyon strata. The upper 30 feet (9 m) of the Petrified Forest Member commonly contains scattered selenite crystals, whereas the upper 15 feet (4.5 m) contains abundant light-gray to light-olive-gray limestone nodules. A silicified bed up to one foot (0.3 m) thick near the top of the Petrified Forest Member is exposed just east of the quadrangle at Buckeye Reef, in the NE1/4NE1/4NE1/4 section 12, T. 40 S., R. 14 W. This bed is moderate red to moderate reddish orange, with streaks of light greenish gray. It appears similar to a silicified peat or paleosol. Float from this same bed lies scattered about the White Reef and Harrisburg Flat areas. This is the same "agate bed" noted by Proctor (1953) and included in his informally named "Fire Clay Hill bentonitic shales" unit. The upper contact of the Petrified Forest Member is the J-0 unconformity and represents a gap of about 10 million years during the Late Triassic and Early Jurassic (Pipiringos and O'Sullivan, 1978).

In the Harrisburg Junction quadrangle the Petrified Forest Member is everywhere deformed by folding and faulting, making its local true thickness uncertain. It is probably about 400 to 450 feet (120-135 m) thick in the Harrisburg Junction quadrangle. The member is reasonably well exposed south of Buckeye Reef in the adjacent Hurricane quadrangle, where Proctor and Brimhall (1986) reported Petrified Forest strata are 446 feet (135 m) thick. In the East Reef area of the adjacent Hurricane quadrangle, Stewart and others (1972) measured 408 feet (124 m) of Petrified Forest beds. The member is estimated to be about 700 feet (210 m) thick in the St. George and Washington Dome quadrangles (Higgins and Willis, 1995; Higgins, 1998). The Petrified Forest Member was deposited in fluvial, flood-plain, and lacustrine environments (Stewart and others, 1972; Dubiel, 1994). Mottled, variegated mudstones probably represent paleosols. Abundant bentonitic mudstones in the Petrified Forest Member are probably derived from volcanic ash blown in from a magmatic arc along the continental margin to the west (Dubiel, 1994).

Jurassic

Moenave Formation

The Moenave Formation forms a distinctive, three-part clastic sequence on the northwest flank of the Virgin anticline, where it is repeated by thrusting. Moenave strata are also exposed on the anticline's southeast flank where not covered by basalt flows and younger alluvium. The Moenave Formation is divided into, in ascending order: the Dinosaur Canyon Member, which consists of uniformly colored, moderate-reddish-brown, slope-forming, very fine-grained sandstone and interbedded siltstone; the Whitmore Point Member, which consists of varicolored, thin-bedded, slope-forming claystone, mudstone, siltstone, very fine- to fine-grained sandstone, and lesser dolomite; and the ledge-forming, massive-weathering Springdale Sandstone Member, which consists of varicolored, fine- to medium-grained sandstone that hosts the ore minerals of the Silver Reef mining district.

The Moenave Formation is 391 feet (119 m) thick at Harrisburg Flat, in the E1/2 section 22, T. 41 S., R. 14 W. and the W1/2 section 23, T. 41 S., R. 14 W. Proctor and Brimhall (1986) reported the Moenave Formation is just 261 feet (79 m) thick in the Silver Reef mining district, but it is unclear whether their upper and lower contacts are the same as those used in this report; Wilson and Stewart (1967) reported Moenave strata there are about 355 feet (108 m) thick. On the northeast flank of the Virgin anticline about 2.5 miles (4 km) south-southeast of Leeds, Stewart and others (1972) measured 356 feet (108 m) of Moenave strata. The Moenave Formation is 310 feet (94 m) thick to the south in the Washington Dome quadrangle (Higgins, 1998). Higgins and Willis (1995) measured a complete section of Moenave strata that totaled 420 feet (127 m) thick near the center of section 28, T. 42 S., R. 15 W., just east of Middleton Black Ridge. The Moenave Formation is Early Jurassic in age (Olsen and Galton, 1977; Peterson and others, 1977; Imlay, 1980; Clark and Fastovsky, 1986), and was deposited in a variety of fluvial and lacustrine environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998).

Dinosaur Canyon Member (Jmd): The Dinosaur Canyon Member is exposed in a narrow belt from White Reef in the north to the quadrangle's southwest corner, and in a small exposure along the Virgin River on the southeast flank of the

Virgin anticline. The member consists of interbedded, mostly slope-forming, generally thin-bedded, very fine- to fine-grained sandstone, very fine-grained silty sandstone, and lesser siltstone and mudstone. Planar, low-angle, and ripple cross-stratification are common. Sandstone beds in the upper portion tend to be medium to thick bedded and commonly form ledges. Dinosaur Canyon strata are uniformly colored moderate reddish brown to moderate reddish orange, although beds are locally mottled very pale orange. In aggregate, Dinosaur Canyon strata are distinctly browner than Kayenta beds, although isolated exposures are difficult to identify.

The contact with the overlying Whitmore Point Member is conformable and gradational. I placed it at the base of a laterally persistent, thin-bedded, 6- to 18-inch-thick (15-46 cm), light-gray dolomitic limestone with algal structures. This bed appears bioturbated; weathers to mottled colors of yellowish gray, white, and grayish orange pink; and contains light-brown to dark-reddish-brown, irregularly shaped chert nodules, some of which may fill burrows or root casts. In exposures north of Harrisburg Flat, this carbonate bed overlies about 3 feet (1 m) of ledge-forming, thin- to medium-bedded, yellowish-gray to light-greenish-gray, very fine- to fine-grained sandstone with common green copper carbonate stains, here assigned to the Dinosaur Canyon Member. This carbonate and underlying sandstone are clearly visible on 1:24,000-scale color aerial photographs. About 25 feet (7.5 m) of brown sandstone, typical of underlying Dinosaur Canyon strata, overlie the dolomitic limestone and are here included in the Whitmore Point Member, pointing to the conformable, intertonguing nature of this member contact. Thus, the contact used here differs slightly from that used by Willis and Higgins (1995) in the Washington quadrangle to the west. There, they placed the contact between the highest, reddish-brown sandstone, included in the Dinosaur Canyon Member, and the purplish-gray-green claystone of the Whitmore Point Member; Willis and Higgins intend to adjust their contact to the same horizon mapped here before formal publication of their map.

The Dinosaur Canyon Member is 163 feet (50 m) thick in the E1/2 section 22, T. 41 S., R. 14 W. and the W1/2 section 23, T. 41 S., R. 14 W. Wilson and Stewart (1967) reported about 200 feet (60 m) of Dinosaur Canyon strata in the Leeds area, and Stewart and others (1972) measured an identical thickness at East Reef, on the northeast flank of the Virgin anticline. Higgins (1998) reported 155 feet (47 m) of Dinosaur Canyon strata in the Washington Dome quadrangle to the south. Dinosaur Canyon strata are 250 feet (75 m) thick east of Middleton Black Ridge, in the E1/2 SW1/4 section 28, T. 42 S., R. 15 W. (Higgins and Willis, 1995). The Dinosaur Canyon Member was deposited in river and flood-plain environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998).

Whitmore Point Member (Jmw): The Whitmore Point Member weathers to poorly exposed slopes except where protected by resistant cliffs and ledges of the overlying Springdale Sandstone Member. Even so, slopes on Whitmore Point strata are typically brightly colored and littered with a lag of resistant Whitmore Point lithologies, thus making the member an important marker horizon. Some of the best exposures are in the Utah Highway 9 road cut at the common border of sections 4 and 5, T. 42 S., R. 14 W.; along Cottonwood Creek near the center of section 27, T. 41 S., R. 14 W.; along Quail Creek in the NW1/4NW1/4 section 23, T. 41 S., R. 14 W.; and in numerous exposures along the southeastern flank of White Reef.

The Whitmore Point Member consists of interbedded, varicolored mudstone and claystone; lesser moderate-reddish-brown, very fine- to fine-grained sandstone and siltstone; and several thin dolomitic limestone beds. A 5-foot-thick (1.5 m), yellowish-gray to light-olive-gray, medium- to very coarse-grained sandstone is present in the upper part of the member at Cottonwood Creek. The mudstones and claystones vary from pale red purple, to greenish gray, to blackish red in color, in sharp contrast to enclosing Moenave members. Dark-yellowish-orange micaceous siltstone and very pale-orange, very fine- to fine-grained sandstone interbeds are present but not common. The dolomitic limestones range from 3 to 18 inches (7-48 cm) thick and vary in color from light greenish gray, to very light gray, to yellowish gray; they weather to mottled colors of pale yellowish orange, white, yellowish gray, and pinkish gray, commonly with green copper-carbonate stains. These limestones appear bioturbated and contain grayish-orange-pink to moderate-reddish-brown chert nodules, sparse fossil fish scales of *Semionotus kanabensis* (Hesse, 1935; Schaeffer and Dunkle, 1950), and poorly preserved and contorted algal structures. The lower 25 feet (7.5 m) of the member consists of brown sandstones similar to those of the Dinosaur Canyon Member. Along Cottonwood Creek near the center of section 27, T. 41 S., R. 14 W., these Dinosaur Canyon-like beds are overlain by about 35 feet (11 m) of poorly exposed, interbedded siltstone, mudstone, and very fine-grained sandstone that weathers to pastel colors similar to, but less striking than, overlying Whitmore Point strata.

The upper contact is generally conformable, although the base of the Springdale Sandstone Member contains local channel deposits and mudstone rip-up clasts. I placed the upper contact at the base of thick- to very thick-bedded sandstone with planar and low-angle cross-stratification. The contact generally corresponds to a pronounced break in slope, with the resistant Springdale Sandstone forming prominent ledges above gentle Whitmore Point slopes. The Whitmore Point Member is 64 feet (19 m) thick in the E1/2 section 22, T. 41 S., R. 14 W. and the W1/2 section 23, T. 41 S., R. 14 W. Just one mile (1.6 km) to the south, along Cottonwood Creek near the center of section 27, T. 41 S., R. 14 W., the member is 125 feet (38 m) thick, apparently due in part to the brown sandstone transitional beds described above. To the south, along the southeast flank of Washington Dome, Higgins (1998) reported about 30 feet (9 m) of Whitmore Point strata, although her member contact is different from that used in this report. Higgins and Willis (1995) reported that the member is 55 feet (17 m) thick east of Middleton Black Ridge, in the NE1/4NE1/4SE1/4 section 28, T. 42 S., R. 15 W., although their member contact is different from that used in this report. Biek, Higgins, and Willis have since decided that for mapping purposes the Whitmore Point Member should include a thin dolomitic limestone bed and overlying Dinosaur Canyon-like strata. Wilson and Stewart (1967) reported the member is about 60 feet (18 m) thick in the Leeds area. Stewart and others (1972) assigned 61 feet (18 m) of strata to the Whitmore Point Member at East Reef, on the northeast flank of the Virgin anticline. The

Whitmore Point Member was deposited in flood-plain and lacustrine environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998). Peterson and others (1977) and Imlay (1980) indicated that palynomorphs from the Whitmore Point Member date the unit as latest Sinemurian to earliest Pliensbachian (Lower Jurassic). Olsen and Padian (1986) noted the fossil fish *Semionotus kanabensis* is not age diagnostic, and discussed the resolution of the long-standing debate on the age of the Moenave, Kayenta, and Navajo Formations.

Springdale Sandstone Member (Jms): The Springdale Sandstone Member is well exposed in the west-dipping hogback of White Reef, and in numerous outcrops along strike to the south. The best exposure south of White Reef is along Cottonwood Creek, near the center of section 27, T. 41 S., R. 14 W. Although complicated by faulting, good exposures are also present southwest of Harrisburg Junction, in the SE1/4 section 5 and the NW1/4 section 8, T. 41 S., R. 14 W. The Springdale Sandstone Member hosts ore deposits of the Silver Reef mining district, near Leeds. There, the member was known as the Silver Reef sandstone, which was informally divided into the lower white to brown Leeds sandstone and the upper lavender Tecumseh sandstone (Proctor, 1953).

The Springdale Sandstone Member consists predominantly of medium- to very thick- bedded, fine-grained or rarely medium-grained sandstone, with planar and low-angle cross-stratification, that commonly weathers to rounded cliffs and ledges. Springdale sandstones are distinguished from overlying Kayenta sandstones by their more variable, pastel colors of pale red, pale pink, pinkish gray, yellowish gray, pale red purple, pale yellowish orange, and dark yellowish orange, as opposed to moderate-reddish-brown hues that dominate Kayenta beds. Springdale strata also have common Liesegang banding; generally very thick bedding rather than thin- to medium-bedding typical of Kayenta strata; and characteristic small, resistant, 0.13-inch- diameter (2 mm) concretions that give weathered surfaces a pimply appearance. Also common in Springdale sandstones are poorly cemented concretions up to 1 inch (25 mm) in diameter, which impart a pitted appearance to weathered surfaces. Poorly preserved, petrified and carbonized fossil plant remains are locally abundant. Springdale sandstones also commonly contain thin, discontinuous lenses of intraformational conglomerate, with mudstone and siltstone rip-up clasts. Thin interbeds of moderate-reddish-brown or greenish-gray mudstone and siltstone are present though not abundant.

The upper contact is conformable and locally gradational and corresponds to a pronounced color, topographic, and lithologic change. Variously colored, ledge- and cliff-forming, very thick-bedded, fine-grained sandstone of the Springdale Sandstone is overlain by reddish-brown, slope-forming, thin-bedded, very fine- to fine-grained silty sandstone of the Kayenta Formation. Wilson and Stewart (1967) noted that Springdale and Kayenta strata appear to intertongue in the Leeds area. The Springdale Sandstone Member attains a local maximum thickness of 164 feet (50 m) near Harrisburg Flat, in the E1/2 section 22 and W1/2 section 23, T. 41 S., R. 14 W. It thins to the north where Proctor and Brimhall (1986) reported the member is about 105 feet (32 m) thick in the Silver Reef mining district; Wilson and Stewart (1967) reported Springdale strata are about 95 feet (29 m) thick in this same area. Stewart and others (1972) measured 95 feet (29 m) of Springdale strata at East Reef, on the northeast flank of the Virgin anticline. One mile (1.6 km) south of Harrisburg Flat, along Cottonwood Creek near the center of section 27, T. 41 S., R. 14 W., Springdale strata are 120 feet (36 m) thick. The member is 125 feet (38 m) thick in the Washington Dome quadrangle to the south (Higgins, 1998). Higgins and Willis (1995) reported the member is 115 feet (35 m) thick east of Middleton Black Ridge, in the SE1/4SE1/4NW1/4 section 28, T. 42 S., R. 15 W. The Springdale Sandstone was probably deposited in braided-stream and minor flood-plain environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998).

Kayenta Formation (Jk)

The Kayenta Formation consists of a thick, monotonous sequence of interbedded, thin- to medium-bedded, moderate-reddish-brown siltstone, fine-grained sandstone, and mudstone. Kayenta sandstones are less commonly moderate reddish orange or yellowish gray. To the west in the Washington quadrangle, Willis and Higgins (1995) divided the Kayenta into three informal members, following the threefold division of Hintze and others (1994) in the Gunlock area. Willis and Higgins (1996) later mapped just two informal members and reassigned most of the upper member of Willis and Higgins (1995) to the transition zone of the Navajo Sandstone. Wilson and Stewart (1967) described the Kayenta in the Leeds-St. George area as consisting of two parts, but much of their upper part included beds I assign to the Navajo Sandstone. In the Harrisburg Junction quadrangle, I did not find suitable horizons for subdividing the unit. In the St. George area, the formation is generally divisible into two members in western exposures (Willis and Higgins, 1996; Higgins, 1998), but remains undivided in eastern exposures (Biek, 2002; Higgins, 2000; Hurlow and Biek, 2000).

Kayenta strata generally weather to poorly exposed slopes, except in the upper part of the formation where ledges and small cliffs are common. However, the lower part of the formation is well exposed in Cottonwood Creek, in the SE1/4SE1/4NW1/4 section 27, T. 41 S., R. 14 W.

Kayenta strata are commonly mottled with small circular and irregularly shaped reduction spots. Planar, low-angle, and ripple cross-stratification is common. East of Harrisburg Flat, approximately 100 feet (30 m) above the base of the formation, are several thin, light-olive-gray-weathering, light-gray dolomite beds each less than 1 inch (2.5 cm) thick. Thin dolomite beds from 1 to 5 inches (2.5-12.5 cm) thick are also at 427 and 682 feet (129 and 207 m) above the base of the formation at Harrisburg Flat. Although similar beds in the lower Kayenta are also present elsewhere in the quadrangle, for example west of Washington Black Ridge in the NW1/4SE1/4NW1/4 section 7, T. 42 S., R. 14 W., intervening exposures are poor and the lateral continuity of these dolomite beds is uncertain. The lower middle part of the formation commonly weathers to soft, punky, gypsiferous soils, although gypsum is rarely exposed.

Three-toed dinosaur footprints (*Eubrontes*) are present in the lower Kayenta, about 15 feet (5 m) above the base of the formation in Grapevine Pass Wash. There, about seven sets of parallel tracks are in a very pale-orange, medium-bedded, very fine- to fine-grained sandstone that is overlain by thin-bedded, reddish-brown mudstone and siltstone. The tracks are up to 16 inches (40 cm) long, 12 inches (30 cm) wide, and 2 inches (5 cm) deep. Similar tracks are in a wash just below the Kayenta/Navajo contact immediately west of the quadrangle boundary.

In southwestern Utah, generally west of the Hurricane fault, the Kayenta/Navajo contact corresponds to a transition zone up to several hundred feet thick (Tuesink, 1989; Sansom, 1992). Previous workers variously included these transition beds in the upper Kayenta or lower Navajo, as discussed below. In coordination with the mapping of Higgins and Willis (1995), Willis and Higgins (1995), and Higgins (1998), I placed the Kayenta/Navajo contact at the top of the highest mudstone interval, thereby including several ledge-forming sandstone beds in the upper Kayenta. The contact corresponds to a slight color change, visible from a distance, with darker reddish-brown Kayenta strata below and lighter moderate-red-orange Navajo beds above. Northeast of Washington Black Ridge, the contact locally coincides with a laterally continuous, 3- to 8-inch-thick (7-20 cm), white-weathering, limy dolomite marker bed (dm). Transitional strata are thus included principally in the Navajo Sandstone. My contact lies about 80 feet (24 m) above the contact chosen by Sansom (1992).

The Kayenta Formation is 925 feet (282 m) thick west of Harrisburg Flat, in the NE1/4 section 22, T. 41 S., R. 14 W. In the Hurricane quadrangle to the east, Kayenta strata are 935 feet (285 m) thick (Stewart and others, 1972). The Kayenta Formation is Early Jurassic in age (Imlay, 1980). The Kayenta Formation was deposited in fluvial, distal fluvial/playa, and minor lacustrine environments (Sansom, 1992; Blakey, 1994; Peterson, 1994).

Navajo Sandstone (Jn)

The Navajo Sandstone and correlative sandstones are renowned as one of the world's largest coastal and inland paleodune fields, which covered much of what is now Utah and portions of adjacent states in the Early Jurassic (Blakey and others, 1988). Navajo strata are renowned too for their great thickness, locally exceeding 2,000 feet (600 m), and for their uniformity. Except for the transitional zone described below, they consist almost entirely of massively cross-bedded, fine- to medium-grained quartz sandstone that weathers to bold, rounded cliffs. Sandstone grains are almost entirely poorly to moderately well cemented, well rounded and frosted quartz.

In the Harrisburg Junction quadrangle, the Navajo Sandstone is exposed north and west of Interstate 15 where it forms bold cliffs, and southeast of the Virgin River where it is largely concealed by a thin cover of eolian sand deposits. Lower and middle Navajo strata are generally moderate reddish orange to moderate orange pink, although irregularly shaped areas are locally very pale orange to yellowish gray. The upper part of the formation is commonly very pale orange to yellowish gray. Dark-brown to black iron and manganese oxides are locally common as thin coatings on fractures and as sandstone concretions. Navajo strata are also strongly jointed and locally brecciated. Navajo strata weather easily, liberating large amounts of sand that accumulate in channels and in broad, open swales.

Along the southern flank of the Pine Valley Mountains, the contact between upper Kayenta and lower Navajo is conformable and gradational and records the transition from distal fluvial, to sabkha, to erg-margin, and finally to erg-center depositional environments (Tuesink, 1989; Sansom, 1992) (figure 5). Cook (1957) was among the first to recognize this transitional interval in Washington County, and in particular near Leeds, where he included about 100 feet (30 m) of these transitional beds in his lower Navajo. Hintze and others (1994) included these transitional beds in their upper Kayenta. Tuesink (1989) included these strata in what she informally called the "Transitional Navajo." Sansom (1992) referred to the "Transitional Navajo" as the "Transition Zone" but did not specify to which formation it belonged.

As previously described, I placed the contact at the top of the highest mudstone interval, where it locally coincides with a dolomite marker bed. This contact lies about 80 feet (24 m) above the base of the transition interval as described by previous workers (Cook, 1957, 1960; Sansom, 1992). Sansom (1992) described lateral and vertical variations in the transition zone, and noted that it reached a maximum thickness of 305 feet (93 m) at the Red Cliffs Recreation Area in the NE1/4 section 15, T. 41 S., R. 14 W. The transition interval is about 164 feet (50 m) thick at Snow Canyon, and 236 feet (72 m) thick in the Gunlock area (Sansom, 1992). Tuesink (1989) assigned 312 feet (95 m) to this transitional interval near Leeds.

The transition-zone beds are characterized by very fine- to fine-grained sandstone and fine-grained silty sandstone with thin siltstone interbeds, and less common but resistant cross-stratified sandstone. Bedding is thin to thick and planar, with common ripple and uncommon trough cross-stratification. Wavy bedding, dark flaser-like laminae, and soft-sediment deformation features, including flame and load structures and bioturbation, are common. Although the sandstones are generally very fine- to fine-grained, some beds have sparse medium-grained, rounded, frosted quartz sand. Most of these transition beds belong to the S6 facies (crinkly and wavily laminated fine-grained or silty sandstone), with fewer S1 facies (wind ripple sets) of Sansom (1992). Unlike in exposures near Moab, Sansom (1992) identified no super surfaces or significant depositional hiatuses in the greater St. George area.

Sansom (1992) defined the top of the transition zone as the highest well-defined sabkha-eolian cycle. Such cycles are generally 6 to 66 feet (2-20 m) thick and are best developed in the St. George-Leeds area, on the southeastern flank of the Pine Valley Mountains. The idealized cycle has basal muddy and sandy sabkha deposits overlain by sandy eolian deposits, but Sansom noted wide facies variations and an overall upward coarsening through the transition zone.

Sansom (1992) divided the Navajo Sandstone (exclusive of the basal transition beds) into a comparatively thin lower unit of interbedded dune and thin interdune deposits and an upper unit composed entirely of dune deposits. At the Red Cliffs Recreation Area, she noted that the lower Navajo is 125 feet (38 m) thick, whereas the upper Navajo is in excess of 1,900 feet (600 m) thick. The upper Navajo is represented by a monotonous sequence of massively cross-bedded sandstone deposited by simple dunes and draas; planar interdune deposits are rare. The boundary between the lower and upper units is gradational and somewhat subjective.

Sansom (1992) also noted that the Navajo Sandstone

Figure 5. *View north of the transition zone between the Kayenta Formation (Jk) and Navajo Sandstone (Jn); photo taken from the Red Cliffs Recreation Area overlook, NE1/4NE1/4 section 15, T. 41 S., R. 14 W. Note planar-bedded strata and thin, slope-forming siltstone intervals in lower part of transition zone. I placed the contact with the underlying Kayenta Formation about 80 feet (24 m) above the base of the lowest cliff-forming sandstone.*

was deposited by paleowinds that blew mostly from the north, except in the Red Cliffs Recreation Area where northeast winds appear to have been dominant. A northeast wind direction was also reported by Tuesink (1989) for transition-zone strata near Leeds.

Because overlying Temple Cap strata form a slope on the broad bench of Navajo Sandstone, their contact, termed the J-1 unconformity by Pipiringos and O'Sullivan (1978), is nowhere well exposed in the Harrisburg Junction quadrangle. The contact, however, corresponds to a prominent change in lithology, with moderate-reddish-brown, thin-bedded siltstone and grayish-orange-pink, very fine-grained silty sandstone of the Sinawava Member of the Temple Cap Formation overlying the massively cross-bedded Navajo Sandstone. I estimate the Navajo Sandstone is 2,300 feet (700 m) thick in the Harrisburg Junction quadrangle.

Temple Cap Formation

At its type locality in Zion National Park, the Temple Cap Formation, named for beds that cap the West Temple, consists of two members: the lower, thin Sinawava Member and the overlying, thicker, White Throne Member (Peterson and Pipiringos, 1979). The White Throne Member thins westward and pinches out east of the Hurricane fault. Only the Sinawava Member, which thickens westward, is in the Harrisburg Junction quadrangle.

Sinawava Member (Jts): The Sinawava Member is exposed in the northwest part of the quadrangle, where it forms conspicuous bright-red slopes, separated by a middle gray portion, atop a broad bench of Navajo Sandstone and below ledge-forming Carmel strata. The Sinawava Member typically weathers to soft, gypsiferous soils and so exposures are poor except along the bottom of drainages. The best exposure, and only of the upper part of the member, is along the west side of Big Hollow, about 500 feet (155 m) north of the road crossing (at the north section line, NW1/4, section 8, T. 41 S., R. 14 W.).

The Sinawava Member typically consists of interbedded, slope-forming, moderate-reddish-brown mudstone, siltstone, very fine-grained silty sandstone, and lesser gypsum. Beds in the middle of the formation are commonly moderate reddish orange, white, and pinkish gray, tend to be gypsiferous, and consist of mostly fine- to medium-grained sandstone; they appear white on full-color aerial photographs. Sinawava strata commonly have small reduction spots or irregular mottles. Soils developed on the member tend to be soft and gypsiferous, especially in the middle part, although gypsum beds themselves are rarely exposed. The gypsum varies from white to gray to pink and is both bedded and nodular in beds up to about 10 feet (3 m) thick. Several small prospect pits for gypsum, and one gypsum claim (in the SE1/4 section 12, T. 41 S., R. 14 W.), are in the quadrangle. Thin, pale-greenish-gray mudstone beds with abundant biotite, which are altered volcanic-ash layers, are common.

A coarser facies is present in two beds about one-third the way up from the base of the member near the center of section 7, T. 41 S., R. 14 W. This facies is from 55 to 57 feet (17-17.5 m), and from 75 to 76.5 feet (23-23.5 m) above the base of the formation; intervening strata are covered. The lower bed consists of ledge-forming, pinkish-gray, locally mottled moderate-reddish-brown, calcareous, fine-grained sandstone with rounded medium- to coarse-grained quartz sand; locally the bed is entirely medium- to coarse-grained sandstone. The upper bed is coarser yet. It consists of ledge-forming, light-greenish-gray, non-calcareous, medium- to coarse-grained sandstone with lenses of quartzitic, rounded, very coarse-grained sandstone to pebbly sandstone. Moderate-reddish-brown mudstone is exposed at the base of this bed, so it is unlikely that the intervening covered slopes contain much, if any, similar coarse-clastic sediments. The base of the upper coarse bed may correspond to the J-2 unconformity of Pipiringos and O'Sullivan (1978) and Peterson and Pipiringos (1979).

The lower Sinawava Member also contains several zones of white to pinkish-gray chert nodules that weather out and accumulate at the surface. The nodules are disc shaped, 0.25 inch to 1 inch (6-25 mm) thick and 1 to 3 inches (25-75 mm) in diameter, and appear to be composed of an aggregate of much smaller blebs and flakes. These nodules may be silicified bentonite.

I placed the upper contact with the Co-op Creek Limestone Member of the Carmel Formation at a color change from moderate reddish brown to yellowish gray, which is near the top of a clastic sequence. Moderate-reddish-brown mudstone and siltstone, locally mottled yellowish gray, of the Sinawava Member is overlain by about 6 feet (2 m) of yellowish-gray to pale-olive calcareous siltstone of the Carmel Formation, above which lies yellowish-gray, thin-bedded limestone of the Carmel Formation.

The Sinawava Member is 187 feet (57 m) thick near the center of section 7, T. 41 S., R. 14 W. Willis and Higgins (1995) measured 199 feet (60 m) of Sinawava strata near the western margin of the Harrisburg Junction quadrangle. In a measured section about 1.5 miles (2.5 km) north of the quadrangle, Wright and others (1979) reported the Temple Cap Formation is 236 feet (72 m) thick. In the Hurricane quadrangle to the east, Sinawava beds are about 220 feet (70 m) thick (Biek, 2002). Based on correlation with strata of known age, the unfossiliferous Temple Cap Formation is assigned an early to middle Bajocian age (early Middle Jurassic) (Peterson and Pipiringos, 1979). Kowallis and others (reported in Christiansen and others, 1994) reported an $^{40}Ar/^{39}Ar$ age of 169.4 Ma (Bajocian) obtained from a bentonitic ash bed in Temple Cap strata.

Carmel Formation

In southwestern Utah, the Carmel Formation forms an eastward-thickening wedge, preserved beneath a regional unconformity, across the southern flank of the Pine Valley Mountains. In the Harrisburg Junction quadrangle, it consists of two gray carbonate members – the lower Co-op Creek Limestone Member and the upper Paria River Member – separated by a sequence of mostly red mudstones, the Crystal Creek Member. The regional unconformity, termed the K unconformity by Pipiringos and O'Sullivan (1978), truncates the Paria River Member at Big Hollow, so that only the lower two members are exposed at the quadrangle's western boundary. The Paria River Member has not previously been reported west of the Hurricane fault, presumably due to assumed truncation beneath the K unconformity. The Carmel Formation is Bajocian to Bathonian (Middle Jurassic) in age (Imlay, 1980). It was deposited in a variety of shallow-marine, shoreline, and sabkha environments (Blakey and others, 1983).

Co-op Creek Limestone Member (Jcco): When viewed from a distance, Co-op Creek strata are readily divisible into two units of approximately equal thickness, although I did not map them separately. The lower unit weathers to pale yellowish gray, whereas the upper unit weathers to distinctly darker yellowish-brown hues, and both form steep ledgy slopes. West of the Harrisburg Junction quadrangle, Willis and Higgins (1995) reported that the lower part of the member was predominantly limestone and the upper part limestone with interbedded light-olive-brown sandstone and pale-greenish-brown mudstone, but I did not observe these lithologic generalities in the Harrisburg Junction quadrangle. Collectively, these two units consist of a laterally variable sequence of interbedded, generally thin-bedded mudstone, siltstone, limestone, and, especially in the lower portion, minor gypsum and very fine- to fine-grained sandstone. No sandstones were reported in the Danish Ranch measured section of Wright and others (1979), located in the NE1/4 section 34, T. 40 S., R. 14 W.

Thin-bedded, yellowish-gray to very pale-orange limy mudstone, and interbedded, similarly colored siltstone and limestone characterize the lower unit of the Co-op Creek Limestone Member. Limestones in this part of the member are generally micritic and unfossiliferous, although thin, coarsely crystalline, fossiliferous beds are present. This lower unit also includes several beds of ledge-forming, light-olive-gray to white or locally pink, nodular and parallel to wavy laminated gypsum beds up to 6 feet (2 m) thick.

Thin-bedded, pale-yellowish-brown fossiliferous limestone, with abundant *Pentacrinus* sp. columnals, bivalves, and mollusks characterize the upper portion of the Co-op Creek Limestone Member. Many of the upper limestones are oolitic and sedimentary structures, including ripple marks, ripple cross-stratification, and trace fossils on bedding planes, are common. Some limestones weather to a saccharoidal surface. In the north-central portion of the quadrangle, a 3- to 12-foot-thick (1-4 m), parallel to wavy laminated gypsum bed is present near the top of the member.

In the Harrisburg Junction quadrangle, a distinctive, yellowish-gray to greenish-gray, silicified mudstone with abundant moderate-reddish-brown blebby jasper and medium-sand-size biotite flakes everywhere marks the uppermost Co-op Creek Limestone Member. This resistant bed is about 6 inches (15 cm) thick and, in the western portion of the quadrangle, overlies nearly 30 feet (9 m) of yellowish-gray mudstone with a few thin interbeds of brown-weathering platy limestone. When traced eastward to the north-central part of the quadrangle, a 3- to 12-foot-thick (1-4 m), ledge-forming, planar to wavy laminated, greenish-gray-weathering gypsum replaces the upper part of the interbedded mudstone and limestone. The lower part of this interbedded mudstone and limestone locally contains a distinctive oyster-shell coquina that weathers out as rounded, resistant cobbles and small boulders.

The upper contact of the Co-op Creek Limestone Member corresponds to a prominent color change from various shades of pale yellowish gray and brownish gray below to moderate reddish brown above. It is marked by the yellowish- to greenish-gray, jasper-bearing silicified mudstone described earlier, above which lies slope-forming, pale- and moderate-reddish-brown mudstone and siltstone.

The Co-op Creek Limestone Member generally thickens eastward across the southern flank of the Pine Valley Mountains. Just west of the quadrangle boundary, in the SW1/4 section 2, T. 41 S., R. 15 W., Willis and Higgins (1995) measured 285 feet (87 m) of Co-op Creek Limestone strata; Wright and others (1979) measured 258 feet (79 m) near the same location. In the SE1/4 section 1, T. 41 S., R. 15 W., the Co-op Creek Limestone Member is 342 feet (104 m) thick. About 4 miles (6.5 km) to the northeast, in the NE1/4 section 34, T. 40 S., R. 14 W., Wright and others (1979) reported a nearly complete section of Co-op Creek Limestone strata is 446 feet thick (136 m). In the Hurricane quadrangle to the east, the Co-op Creek Limestone Member is 130 feet (39 m) thick and is unconformably overlain by the Iron Springs Formation (Biek, 2002).

Crystal Creek Member (Jcx): In the Harrisburg Junction quadrangle, Crystal Creek strata form a thin, pale- to moderate-reddish-brown and grayish-orange slope between the more resistant gray carbonates of the enclosing Co-op Creek Limestone and Paria River Members. Although poorly exposed, the Crystal Creek Member is readily distinguished from enclosing strata.

The lower part of the Crystal Creek Member consists of interbedded, generally thin- bedded, pale- to moderate-reddish-brown mudstone, siltstone, very fine-grained sandstone, and gypsum. Like the underlying Co-op Creek Limestone Member, Crystal Creek strata form a laterally variable sequence. The reddish-brown units contain thin interbeds of yellowish-gray to light-olive-gray mudstone with abundant fine- to coarse-sand-size biotite flakes. Moderate-reddish-brown blebby jasper, like that seen in the uppermost Co-op Creek bed, is common in the lower part of the Crystal Creek Member. The lower 10 to 20 feet (3-6 m) of the member is gypsiferous and, in section 5, T. 41 S., R. 14 W., contains a single bed of nodular gypsum up to 11 feet (3.4 m) thick.

In western exposures within the Harrisburg Junction quadrangle, uppermost Crystal Creek strata contain about 10 feet (3 m) of yellowish-gray to white, slope-forming, generally noncalcareous, very fine- to fine-grained quartz sandstone that is unconformably overlain by Cretaceous bentonitic beds. To the east, in the vicinity of Big Hollow, upper Crystal Creek strata consist of 73 feet (22 m) of upward-coarsening, grayish-orange-pink to light-brown to dark-yellowish-orange, slope-forming, calcareous, very fine- to medium-grained sandstone (with minor interbedded mudstone and siltstone), which is conformably overlain by platy weathering Paria River limestone. This light-colored sandstone overlies interbedded, pale- to moderate-reddish-brown mudstone, siltstone, and lesser very fine-grained sandstone typical of underlying Crystal Creek beds.

In the Harrisburg Junction quadrangle, an eastward-thickening wedge of Crystal Creek strata is preserved below the regional K unconformity of Pipiringos and O'Sullivan (1978). Just west of the quadrangle, in the SW1/4 section 2, T. 41 S., R. 15 W., Willis and Higgins (1995) measured 48 feet (14.6 m) of Crystal Creek beds; Wright and others (1979) measured 50 feet (15 m) in about the same location. In the SE1/4 section 1, T. 41 S., R. 15 W., the Crystal Creek Member is 69 feet (21 m) thick, and in the SW1/4 section 5, T. 41 S., R. 14 W., the member is 144 feet (44 m) thick.

Paria River Member (Jcp): In section 5, T. 41 S., R. 14 W., in the north-central portion of the quadrangle, the uppermost Carmel Formation is capped by 28 feet (9 m) of yellowish-gray to light-olive-gray, thin- to medium-bedded, platy weathering, ledge-forming limestone and lithographic limestone that contains sparse bivalve fossils. West of Big Hollow, this limestone is truncated under the K unconformity, although underlying, similarly colored sandstone assigned to the Crystal Creek Member is present. I assign this limestone to the Paria River Member.

The Paria River Member has not previously been reported west of the Hurricane fault, presumably due to assumed truncation beneath the K unconformity. However, in a measured section at Danish Ranch, just north of the Harrisburg Junction quadrangle in the NE1/4 section 34, T. 40 S., R. 14 W., Wright and others (1979) reported similar limestones at the top of the Carmel Formation. Biek and Hylland (2002) mapped Paria River strata in the Cogswell Point quadrangle on the Kolob Terrace, including a prominent alabaster gypsum bed locally present at the base of the member. Gypsum, however, is lacking in exposures of the Paria River Member in the Harrisburg Junction quadrangle.

Cretaceous bentonitic beds that weather to readily recognizable, soft, "popcorn" soils unconformably overlie the Paria River Member. The contact, however, is everywhere concealed by slumping and colluvium. Farther northeast, in the Signal Peak quadrangle in the NE1/4 section 34, T. 40 S., R. 14 W., Paria River limestones are unconformably overlain by pebbly and cobbly conglomerate that may be correlative with late Early Cretaceous strata, recently recognized in the Zion National Park region (Hylland, 2000; Biek and others, 2000; Biek and Hylland, 2002).

Cretaceous

A thin bentonitic interval overlies the K unconformity along the southern flank of the Pine Valley Mountains. West of the Harrisburg Junction quadrangle, in the Washington quadrangle, Willis and Higgins (1995) tentatively correlated this interval with a bentonitic bed mapped by Hintze and others (1994) in the Gunlock area. The bed occupies the same stratigraphic interval and is of similar thickness as the Gunlock bentonitic bed, although it weathers to light brownish gray rather than moderate red, and lacks the barite nodules that are common in the Gunlock area, facts also noted by Willis and Higgins (1995).

The bentonitic bed weathers to soft, "popcorn" soils and so is poorly exposed. Fresh samples are brownish gray and have common limonite stains. Willis and Higgins (1995) reported quartz crystals in the bentonitic soils that give slopes a sparkly sheen, but these were not observed in the Harrisburg Junction quadrangle. In the western part of the Harrisburg Junction quadrangle, however, the bentonitic bed is enclosed by white to very pale-orange, very fine- to fine-grained quartz sandstone that belongs to enclosing Crystal Creek and Iron Springs strata. To the east near Big Hollow, in section 5, T. 41 S., R. 14 W., the bentonitic bed overlies yellowish-gray limestone of the Paria River Member.

The bentonitic bed is about 20 to 25 feet (6-8 m) thick throughout the Harrisburg Junction quadrangle, although the upper contact is everywhere obscured by colluvium making thicknesses difficult to determine. Willis and Higgins (1995) measured a maximum thickness of about 90 feet (27 m) near Diamond Valley, in the northwestern part of the Washington quadrangle. Hintze and others (1994) reported a fission-track age of 80.0 ± 5 Ma (Campanian) from zircon obtained from the bentonitic beds in the Gunlock area. Dyman and others (2002) obtained an $^{40}Ar/^{39}Ar$ age of 101.7 ± 0.42 Ma on sanadine from this bed. I have since revisited these exposures and now believe that the Gunlock-area section represents strata correlative with the Cedar Mountain Formation, which is newly recognized on the Kolob Terrace (Hylland, 2000; Biek and Hylland, 2002). The bentonitic bed mapped by Willis and Higgins (1995) is probably the lowermost Iron Springs Formation and thus of early Late Cretaceous age.

Iron Springs Formation (Kis)

The Iron Springs Formation forms steep, ledgy slopes in the northwestern part of the quadrangle. Only about the lower 250 feet (75 m) of the formation is present in the quadrangle, but the formation is about 3,500 to 4,000 feet (1,070-1,220 m) thick in the area (Cook, 1960; Hintze and others, 1994). It consists of interbedded, ledge-forming, mildly calcareous, cross-bedded, fine- to medium-grained sandstone and less resistant, poorly exposed sandstone, siltstone, and mudstone. The formation is variously colored grayish orange, pale yellowish orange, dark yellowish orange, white, and pale reddish brown, and is locally heavily stained by iron-manganese oxides; Liesegang banding is common. Hintze and others (1994) reported a palynomorph assemblage from the formation in the Gunlock area that suggested a Turonian to Cenomanian (about 90-100 Ma) age. The basal Iron Springs Formation is thus early Late Cretaceous in age. In a study of the formation in the Gunlock area to the west, Johnson (1984) suggested that Iron Springs strata were deposited in braided-stream and flood-plain environments.

Quaternary

Basaltic Flows and Related Deposits

Basaltic rocks from two distinct vents, one of which is present in the Harrisburg Junction quadrangle, are present on either side of the Virgin anticline. These rocks are part of the western Grand Canyon basaltic field, a large area of late Tertiary to Holocene basaltic volcanism in northwestern Arizona and adjacent Utah (Hamblin, 1970; Best and Brimhall, 1974; Smith and others, 1999). Although relatively small in volume compared to other volcanic regions in the western United States, these flows provide important constraints on local tectonic and geomorphic development. The region is known for its inverted valleys and isolated, basalt-capped buttes and mesas. Based on the degree of erosion and weathering of individual flows, Hamblin (1963, 1970, 1987) identified four major periods, or stages, of mafic volcanism in the western Grand Canyon region. Stage I flows are high, isolated remnants that bear little or no relation to modern drainages, whereas stage IV flows were deposited in modern drainages and show little evidence of erosion or alteration. Hamblin also identified substages based on local geomorphic relations. Whereas stage designations are useful for comparison of flows within individual, large, fault-bounded blocks, the complex downcutting history across major faults in southwestern Utah can render stage designations misleading (Willis and Biek, in press). Because we also have many new $^{40}Ar/^{39}Ar$ and K-Ar ages on these flows, I do not use Hamblin's stage designations.

I differentiated basaltic flows in the Harrisburg Junction quadrangle using a combination of field relationships, hand sample identification, isotopic age determinations, and geochemistry; preliminary paleomagnetic data made available by Michael J. Hozik (The Richard Stockton College of New Jersey) have also been useful in correlating flows. Geochemical data for these flows are summarized in the appendix I, $^{40}Ar/^{39}Ar$ data are in appendix II.

Best and Brimhall (1974) noted that the dominant lavas in the western Grand Canyon region – basinite, alkali olivine basalt, hawaiite, and quartz-bearing basaltic andesite – display a chemical continuum that cannot be accounted for by simple crystal fractionation of a single melt. They suggested that the lavas originated as distinct partial melts of mantle peridodite over a range of depths, followed by independent fractionation within each magma. They also noted that the inception of hawaiite (sodium-rich trachybasalt) volcanism migrated eastward at a rate of about 0.4 inch (1 cm) per year.

Washington flow, cinder cone, and associated deposits (Qbw, Qbwc, Qagw): The Washington flow (Qbw), which forms a prominent inverted valley called Washington Black Ridge, has its source at a deeply dissected cinder cone (Qbwc) at the common border of sections 25 and 36, T. 41 S., R. 15 W. (figure 6). The flow is about 5.5 miles (8.8 km) long and maintains a relatively constant thickness of about 25 to 35 feet (7.5-10.5 m) along its length, except near its source. There, where Grapevine Wash plunges over the flow in the NE1/4NE1/4 section 36, T. 41 S., R. 15 W., the flow is about 100 feet (30 m) thick. At its southern end, the Washington flow is about to 360 feet (110 m) above the Virgin River. Incision decreases upstream to about 60 feet (18 m) at a nick point in the extreme NW1/4 section 6, T. 41 S., R. 14 W. Farther upstream, incision varies from zero to a few tens of feet. The flow has an average gradient of about 150 feet per mile (27 m/km). The flow trends south-southeast from the vent, along the course of the ancestral Grapevine Wash. The flow is deflected to the southwest and west by the resistant Shinarump hogback on the west flank of the Virgin anticline. The west-trending portion of Washington Black Ridge locally overlies well-cemented ancestral Virgin River gravels (Qagw). Extensive mass-movement deposits characterize the lower portions of the flow that overlie swelling mudstones of the Petrified Forest Member. The extreme western end of the flow crosses the Washington fault and is cut by a series of small normal faults having both down-to-the-east and down-to-the-west displacement.

The Washington flow itself is made up of at least four flow units. A flow unit is defined as lava pulses from the same eruption separated by short time intervals, whereas flows are from different eruptions and are typically separated by enough time to be weathered. At the southern end of Washington Black Ridge, in the SW1/4SW1/4 section 18, T. 42 S., R. 14 W. and the SE1/4 section 13, T. 42 S., R. 15 W., three flow units total about 40 feet (12 m) thick. Only two flow units are exposed in the unusually thick section in the NE1/4NE1/4 section 36, T. 41 S., R. 15 W.

The margins of the Washington flow are eroded and the top of the flow is largely concealed by mixed eolian and alluvial deposits. The flow displays well-developed columnar jointing. The upper portion of the flow is highly vesicular and has local Stage V (Birkeland and others, 1991) secondary calcium-carbonate deposits. The best exposure of these

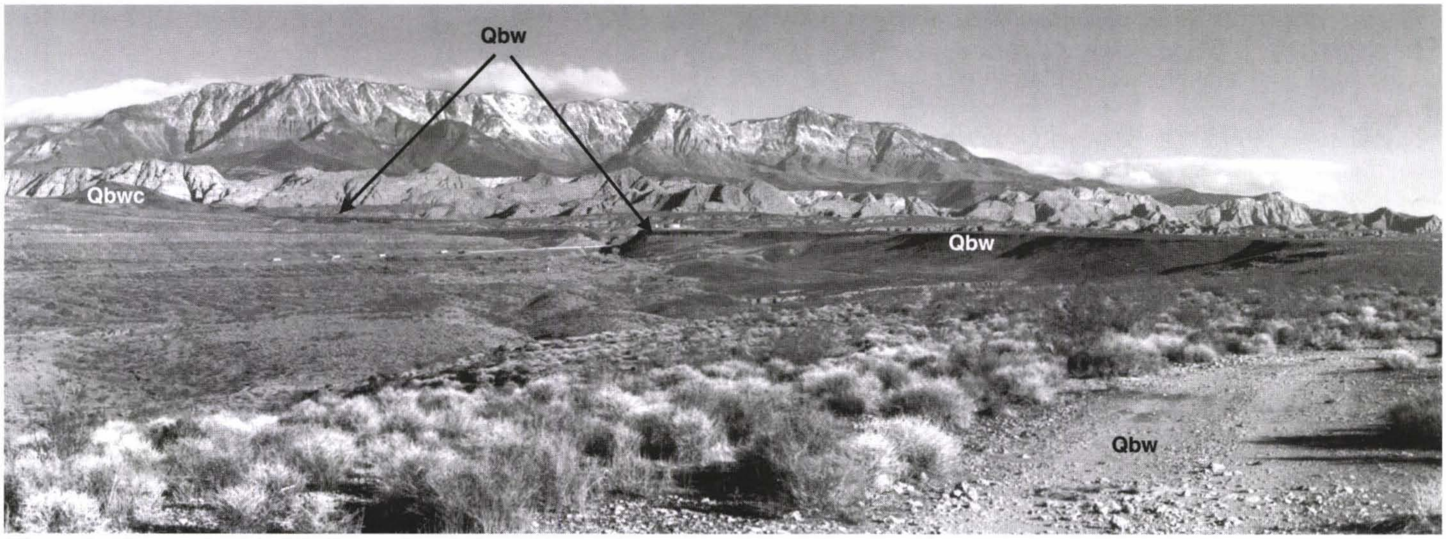

Figure 6. *View north of the Washington basalt flow (Qbw) and, at extreme left, cinder cone (Qbwc); photo taken from the southern end of Washington Black Ridge, in the SE1/4 section 13, T. 42 S., R. 15 W. The Washington flow forms a prominent inverted valley along its middle and lower portions, where it maintains a uniform thickness of 25 to 35 feet (8-13 m). Interstate 15 passes through Grapevine Wash near the center of the photograph. The Navajo Sandstone forms the light-colored hills in the middle distance, above which rise the Pine Valley Mountains, a Miocene-age laccolith.*

secondary calcium-carbonate deposits is in a road cut on the west side of the ridge, in the SW1/4NE1/4NW1/4 section 7, T. 42 S., R. 14 W.

The Washington flow erupted from a highly dissected cinder cone (Qbwc) located at the common border of sections 25 and 36, T. 41 S., R. 15 W. The cone itself is upheld by a core of volcanic breccia, welded spatter or agglutinate, and small, highly vesicular flows, which are also exposed on the cone's southeastern flank. Volcanic cinders and bombs form the remainder of the cone.

Geochemically, the Washington flow is a basinite to borderline picrobasalt according to the total alkali versus silica (TAS) diagram of LeBas and others (1986) (figure 7; appendix I); Best and others (1980) also reported the Washington flow to be borderline picrobasalt, as did Alexander Sanchez (University of Nevada, Las Vegas, written communication, April 17, 1998). Petrographically, it is an ankaramite, indicating that it contains abundant clinopyroxene and olivine phenocrysts. Best and Brimhall (1974) suggested that the Washington flow originated by accumulation of olivine and clinopyroxene in a fractionating, high-pressure basinite magma chamber. Best and Brimhall (1970) described five main basalt types in the western Grand Canyon basaltic field, the volumetrically least significant of which is the Washington basalt type, which takes its name from the Washington flow. They noted that it is the most mafic of the five types and that, interestingly, it lies just 5 miles (8 km) east of the Middleton flow, which is the most siliceous and feldspathic. Abundant phenocrysts of olivine and pyroxene up to about 0.1 inch (3 mm) across are the only recognizable minerals in hand samples. The phenocrysts are set in a medium- to dark-gray, very fine-grained groundmass of plagioclase and titaniferous magnetite (Best and Brimhall, 1974). Near the vent, in the SE1/4NE1/4NE1/4 section 36, T. 41 S., R. 15 W., the upper flow unit contains conspicuously more olivine, much of which is brownish in color, probably due to an alteration rind of "iddingsite." This flow unit is not present at the southern end of Washington Black Ridge, where each of the three flow units are similar to the lower flow unit exposed near the vent.

Hamblin (1987) assigned the Washington flow to stage IIb, indicating that it was deposited on a surface that has a similar slope and gradient to the present drainage but that now lies 200 to 500 feet (60-150 m) above the modern stream. Best and others (1980) reported a K-Ar age of 1.7 ± 0.1 Ma for this flow from a sample near the center of section 7, T. 42 S., R. 14 W. However, we obtained two $^{40}Ar/^{39}Ar$ plateau ages of 0.98 ± 0.02 Ma (sample VR4007) and 0.87 ± 0.04 Ma (sample HJ11299-2) for the Washington flow (appendix II).

Moderately sorted, moderately to well-cemented pebble to cobble gravel, with rounded clasts of quartzite, limestone, and basalt, is exposed both above and below the Washington flow in the SW1/4 section 13, T. 42 S., R. 15 W. Gravel under the flow is probably less than 15 feet (5 m) thick, although the lower contact of the gravel is concealed by colluvium and thicknesses are difficult to determine. Overlying gravel is about 5 feet (1.5 m) thick. These gravels (Qagw) are channel deposits of the ancestral Virgin River.

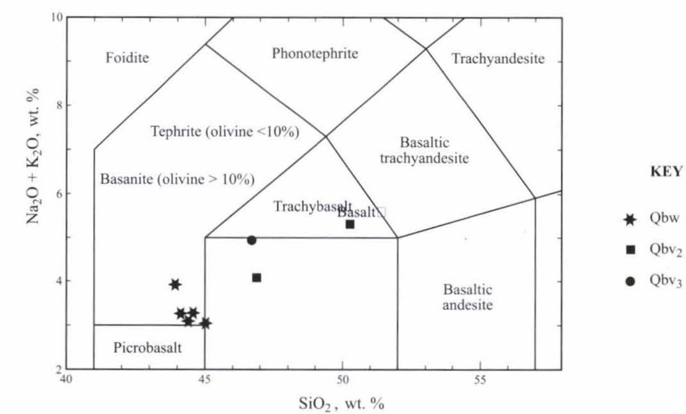

Figure 7. *Geochemical classification of basaltic rocks in the Harrisburg Junction quadrangle using scheme of LeBas and others (1986). Major oxides are normalized to 100 percent. See appendix for analytical results and plate 1 for sample locations.*

Volcano Mountain flows and associated deposits (Qbv_2, Qbv_3, Qec/Qbv_2, Qagv): Two basalt flows in the southeast corner of the quadrangle are well exposed only in vertical cliffs along the Virgin River and in the vicinity of Berry Springs, especially in the Utah Highway 9 road cut at the common border of section 1 and 2, T. 42 S., R. 14 W. Elsewhere, the flows are largely concealed by eolian and other sediments. Eolian sand and pedogenic carbonate (Qec/ Qbv_2) up to about 3 feet (1 m) thick partly cover the level 2 flow. The contact between these flows is also concealed.

Biek (2002) showed that Volcano Mountain (section 5, T. 42 S., R. 13 W.) is the likely source of these flows. Field relationships further suggest that the flow at the lowest elevation, Qbv_3, is slightly older than the mid-level flow, Qbv_2. Sanchez (1995) reported an $^{40}Ar/^{39}Ar$ isochron age of 258 ± 24 ka for the youngest of the Volcano Mountain flows (mapped as Qbv_1 in the adjacent Hurricane quadrangle (Biek, 2002), and an $^{40}Ar/^{39}Ar$ isochron age of 353 ± 45 ka for what I interpret to be the Qbv_2 flow (Biek, 2002). Both flows are are classified as alkali basalt or borderline trachybasalt (figure 7; appendix I), similar to findings reported in Sanchez (1995), (Biek, 2002), and Smith and others (1999). However, the Qbv_2 and Qbv_3 flows are chemically distinct as described by Biek (2002). Still, both flows look similar in hand sample and both contain sparse, unaltered, millimeter-size olivine phenocrysts in a grayish-black, very fine-grained groundmass. The Qbv_3 flow may contain slightly more abundant olivine phenocrysts.

I interpret these flows differently than did previous workers. Hamblin (1970) classified the southwest portion of these flows, roughly that part exposed in the Harrisburg Junction quadrangle, as stage III. Sanchez (1995) suggested that flows in the Harrisburg Junction quadrangle be classified as stage IIb and stage III, both of which, based principally on geochemistry, he interpreted as having originated at Ivans Knoll (near the common border of sections 5 and 8, T. 42 S., R. 13 W.), just south of Volcano Mountain. Based on my mapping in the Hurricane quadrangle and subsequent additional $^{40}Ar/^{30}Ar$ ages, geochemistry, and paleomagnetic data (Biek, 2002; Mike Hozik, The Richard Stockton College of New Jersey, verbal communication, 1999), I believe the Qbv_2 and Qbv_3 flows are significantly younger than the Ivans Knoll flow and had their source at Volcano Mountain. Regardless, the lower flow (Qbv_3) reaches to current base level along the Virgin River and so may be better classified as a stage IV flow. That apparently older flows can be assigned a more youthful stage designation points to the complex down-cutting history across the St. George basin (Willis and Biek, in press). Still, the two flows are differentiated on the basis of elevation. The subscript denotes relative elevation, with Qbv_3 lower and older, and Qbv_2 higher and younger. The Qbv_3 flow is about 40 to 45 feet (12-14 m) thick, except where it thins at its southern margin. Flow Qbv_2 is 30 to 45 feet (9-14 m) thick.

Best and Brimhall (1974) suggested that the Volcano Mountain flows originated at shallow lower-mantle depths and experienced extensive fractionation of olivine and perhaps limited accumulation of plagioclase. They classified them as hawaiite (Grand Wash basalt of earlier reports), the most voluminous of the five main types of basalt in the western Grand Canyon region. Smith and others (1999) also investigated the geochemistry of these basalts and their implications for small- and large-scale chemical variability of the lithospheric mantle.

Ancestral Virgin River gravels (Qagv) are well exposed in several areas both under and over the Qbv_3 flow. These gravels are similar to those associated with the Washington flow. They consist of moderately sorted, moderately to well-cemented pebble to cobble gravel, with rounded clasts of quartzite, limestone, and basalt. In two areas – in the NE1/4SW1/4 section 2, T. 42 S., R. 14 W. and in the NE1/4SE1/4 section 16, T. 42 S., R. 14 W. – these gravels enclose thin tongues of basalt, suggesting that the river re-occupied its channel soon after the Qbv_3 flow was deposited. The gravels reach up to 20 feet (6 m) thick.

Alluvial Deposits

Alluvial-boulder deposits (Qab, Qabo): Two levels of coarse boulder gravel deposits form narrow, elongate ridges that trend radially away from the Pine Valley Mountains in the northwestern portion of the quadrangle. They consist of very poorly sorted sand to boulder deposits with clasts in excess of 10 feet (3 m) in diameter. Most clasts, and all of the larger clasts, are from the Pine Valley intrusive complex. The Pine Valley clasts are highly weathered such that the outer rind easily disaggregates into its constituent grains, forming a granular soil. The basal portion of many of the deposits contains a more varied suite of clasts, including sandstone, limestone, and reworked quartzite and pebbly conglomerate cobbles derived from Jurassic and Cretaceous strata exposed on the flanks of the mountain.

These deposits formed by alluvial and debris-flow processes. Qab deposits are up to about 200 feet (60 m) above nearby drainages, whereas Qabo deposits lie up to about 400 feet (120 m) above nearby drainages. The deposits vary from 0 to about 160 feet (0-50 m) thick. The age of these deposits is uncertain, but they are probably early to middle Pleistocene in age.

Older alluvial-fan deposits (Qaf_5, Qaf_6): Older alluvial-fan deposits along the west flank of the Virgin anticline form an extensive, locally deeply dissected surface. I mapped small, isolated, correlative deposits along Cottonwood Creek and Heath Wash as older alluvial-terrace deposits (Qato). Although these older alluvial-fan and alluvial-terrace deposits appear to be virtually identical in composition, clast size, and other characteristics to the alluvial-boulder deposits (Qab, Qabo) described earlier, they are not well graded to major drainages and I do not know whether they are in part correlative. The deposits have their principal sources in the Leeds Creek drainage just north of the quadrangle, and in the Cottonwood Canyon and Heath Wash areas. The younger, Qaf_5 deposits are generally 40 to 100 feet (12-30 m) above nearby drainages, whereas Qaf_6 deposits are 120 to 200 feet (36-60 m) above nearby drainages. Both deposits range from 0 to about 30 feet (0-9 m) thick.

Older alluvial-terrace deposits (Qato): Older alluvial-terrace deposits in Cottonwood Canyon and Heath Wash form isolated, planar, gently sloping surfaces about 120 to 200 feet (37-60 m) above these drainages. Older alluvial-terrace deposits are characterized by abundant clasts from the Pine Valley intrusive complex and are correlative with older alluvial-fan deposits (Qaf_5). Older alluvial deposits are generally 0 to 30 feet (0-10 m) thick.

Stream-terrace deposits (Qat_2, Qat_3, Qat_4): Stream-terrace deposits are restricted to modern drainages and truncate the older alluvial and alluvial-fan deposits described above. They consist of moderately to well-sorted, poorly cemented sand, silt, clay, and pebble to boulder gravel that form isolated, level to gently sloping surfaces above adjacent drainages (figure 8). Level 2 deposits are generally 10 to 30 feet (3-9 m), level 3 deposits range from 30 to 90 feet (9-27 m), and level 4 deposits are generally 90 to 140 feet (27-43 m) above adjacent drainages. Stream-terrace deposits vary from 0 to 20 feet (0-6 m) thick and were deposited principally in river-channel and flood-plain environments. The ages of these deposits can be estimated based on long-term downcutting rates determined from dated basalt flows that entered the channel of the ancestral Virgin River (Willis and Biek, in press). Level 4 deposits are likely middle Pleistocene, level 3 deposits late Pleistocene, and level 2 deposits late Pleistocene to Holocene in age.

Stream deposits (Qal_1): Stream deposits along the Virgin River and other principal drainages in the quadrangle include river-channel and flood-plain sediments and minor terraces up to about 10 feet (3 m) above current stream levels. The deposits consist of moderately to well-sorted sand, silt, clay, and local pebble to boulder gravel normally less than about 10 feet (3 m) thick; deposits along the Virgin River are likely about 20 to 40 feet (6-12 m) thick. Stream deposits are gradational with mixed alluvial and colluvial deposits (Qac), and locally include small alluvial-fan (Qaf_1) and colluvial (Qc) deposits. Where not constrained by topography, deposits along the Virgin River are marked by numerous meander scars.

Artificial Deposits (Qf, Qfl, Qfm)

Artificial fill (Qf) – used for road construction, dams and retaining ponds, and building foundations – is present throughout the quadrangle. Artificial fill consists of engineered fill and general borrow material and varies greatly in composition and thickness. I mapped fill along Interstate 15 only where it forms thick deposits in cross-cutting drainages. Although I mapped only a few areas of artificial fill, fill should be anticipated in all developed areas, many of which appear on the topographic base map.

I mapped three landfill deposits (Qfl) along the western flank of Harrisburg Dome. The landfills contain municipal trash and general borrow material and are currently operated by Washington County.

Waste rock from mining (Qfm) is present along White Reef in the northeastern corner of the quadrangle. I mapped only the larger deposits, which consist principally of angular blocks of Springdale strata, and a reclaimed tailings pile.

Colluvial Deposits (Qc, Qco)

Colluvial deposits consist of poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited principally by slopewash and soil creep on moderate slopes. Although it is common on most slopes in the quadrangle, I mapped colluvium only where it conceals large areas of bedrock. Colluvium grades into talus deposits, and locally include talus, mixed alluvial and colluvial, and eolian deposits that are too small to be mapped separately. I differentiated two units of colluvium, which are in part gradational with one another. Older colluvial deposits (Qco) form

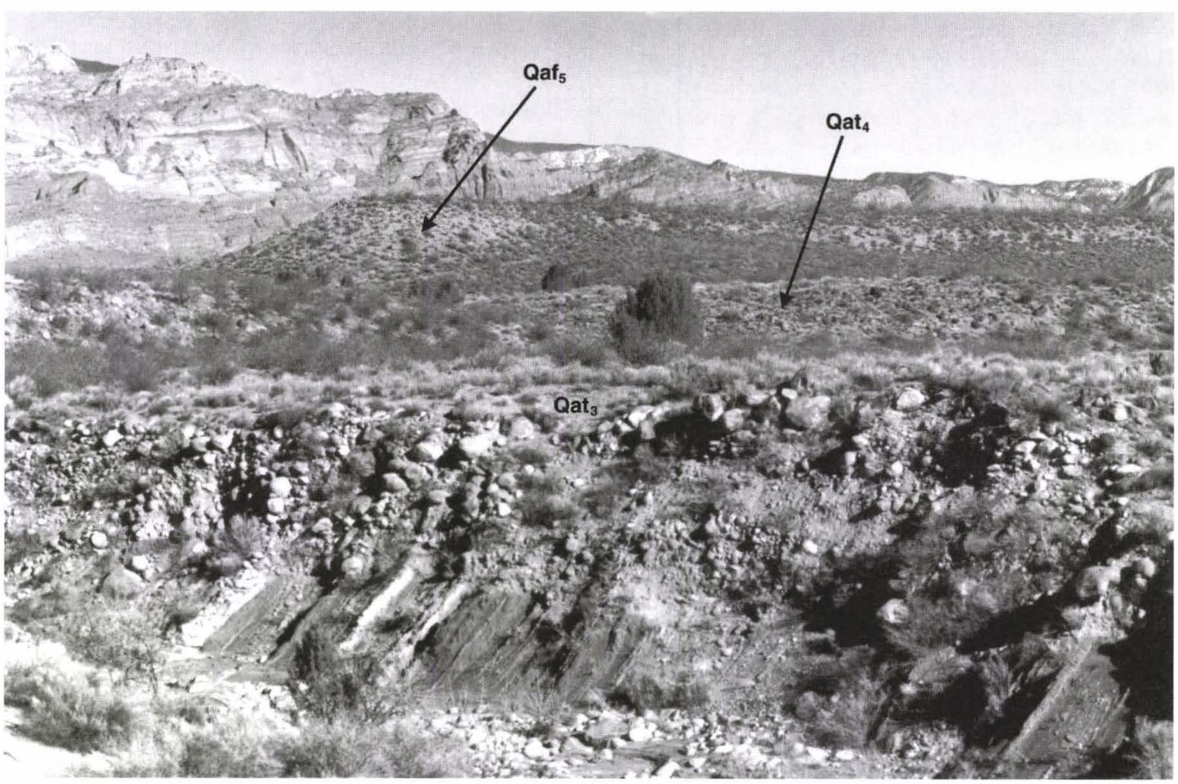

Figure 8. *View north across Cottonwood Creek to terrace gravels overlying steeply dipping Kayenta strata; photo taken from the SE¼NW¼ section 27, T. 41 S., R. 14 W. Terrace deposits in the foreground are Qat_3, whereas those in the middle distance, beyond the small tree are Qat_4. Level 5 alluvial-fan deposits form the highest surface in the distance. The Navajo Sandstone forms cliffs in the background.*

incised, largely inactive surfaces and are probably Pleistocene in age. Younger colluvial deposits (Qc) are only locally incised along their lower margins and are probably late Pleistocene to Holocene in age. Both deposits vary from 0 to 30 feet (0-9 m) thick.

Eolian Deposits

Older eolian sand and caliche deposits (Qeo): These deposits generally form exhumed planar surfaces covered with abundant secondary calcium carbonate (caliche) (Stage IV of Birkeland and others, 1991) and sparse eolian sand. They are equivalent to the lower part of the eolian sand deposits described below, but most of the overlying unconsolidated sand has been removed by erosion. Eolian sand and caliche deposits cap planated bedrock surfaces in the southeast corner of the quadrangle where they generally range from 0 to 10 feet (0-3 m) thick.

Three small deposits of pale-red, secondary calcium carbonate (Stage IV-V of Birkeland and others, 1991) are on Shinarump strata on the east limb of the Virgin anticline, immediately south of Utah Highway 9. The deposits are very rough weathering and vary from 2 to 5 feet (0.6-1.5 m) thick. The origin of these caliche deposits is uncertain. They are probably early to middle Pleistocene in age.

Eolian sand and eolian dune sand deposits (Qes, Qed): Eolian sand (Qes) covers broad, irregular areas on the Navajo Sandstone and adjacent bedrock formations. The sand is well rounded, well- to very well-sorted, fine- to very fine-grained quartz derived from Navajo and upper Kayenta strata. It forms an irregular blanket, stabilized in part by sparse vegetation, that varies from 0 to about 30 feet (0-9 m) thick. Local, small, active dune deposits (Qed), which range from about 0 to 15 feet (0-5 m) thick, are mapped separately. In most areas, eolian sand and dune sand deposits likely overlie a thick secondary calcium carbonate (Stage IV of Birkeland and others, 1991), which is rarely exposed in washes and as isolated nodules at the surface. Large exposures of older eolian sand and caliche (Qeo) are mapped separately.

Mass-Movement Deposits

Landslide deposits (Qmsy, Qmso): Most landslide deposits in the quadrangle are characterized by moderately subdued hummocky surfaces and internal scarps, suggesting the most recent movement is middle to late Holocene in age; evidence for historical movement is unknown. I mapped these deposits as younger landslide deposits (Qmsy). Basal slip surfaces are most common in the Petrified Forest Member of the Chinle Formation, the upper red member of the Moenkopi Formation, and the Carmel Formation. The slides themselves incorporate these units and overlying formations. The largest landslides are in the Petrified Forest Member of the Chinle Formation where these strata form steep slopes along the flanks of Washington Black Ridge. These landslides are characterized by hummocky topography, numerous internal scarps, and chaotic bedding attitudes, and are covered in part by blocks of basalt derived from the Washington flow. I mapped a block-glide detachment, with failure at or near the top of the upper red member of the Moenkopi Formation, in the NE1/4 section 10, T. 42 S., R. 14 W. There, large blocks of Shinarump strata are undercut by the Virgin River and have slid part way down a dip slope.

I mapped a single older landslide deposit (Qmso) immediately north of Quail Creek Reservoir. This deeply dissected rotational landslide involves strata of the Shnabkaib and upper red members of the Moenkopi Formation and is probably middle to late Pleistocene in age.

Talus deposits (Qmt): I mapped talus deposits on and at the base of steep slopes, principally below the Shinarump Conglomerate and Navajo Sandstone. Talus consists of locally derived, very poorly sorted, angular boulders and minor fine-grained interstitial sediments deposited principally by rockfall. These deposits grade into colluvial deposits and vary from 0 to about 20 feet (0-6 m) thick.

Mixed-Environment Deposits

Older alluvial and colluvial deposits (Qaco): Older mixed alluvial and colluvial deposits are present only near the southern end of Harrisburg Dome. They are similar to younger alluvial and colluvial deposits, except that they form incised, inactive surfaces up to about 20 feet (6 m) above adjacent drainages. They consist principally of poorly to moderately sorted, locally derived or reworked sediments. Most deposits are less than about 20 feet (6 m) thick.

Younger alluvial and colluvial deposits (Qac): Younger mixed alluvial and colluvial deposits are present throughout the quadrangle and consist principally of poorly to moderately sorted, locally derived or reworked sediments. These deposits generally are in small, nearly enclosed depressions that receive diffuse, locally derived clastic input from surrounding slopes, unlike alluvial deposits, which have a definite unidirectional source and transport. Some deposits are in narrow washes that receive significant slopewash sediment. Younger mixed alluvial and colluvial deposits are gradational and correlative with both younger alluvial and younger colluvial deposits. Most younger mixed alluvial and colluvial deposits are less than about 20 feet (6 m) thick.

Older alluvial and eolian deposits (Qaeo): Older mixed alluvial and eolian deposits are similar to younger alluvial and eolian deposits, except that the older deposits generally form incised, inactive, gently sloping surfaces about 20 feet (6 m) above adjacent drainages. Older mixed alluvial and eolian deposits consist of poorly to moderately sorted, clay- to boulder-size sediments with well-sorted eolian sand and reworked eolian sand, commonly with well-developed secondary calcium carbonate. The deposits west of Harrisburg Flat are gypsiferous. I mapped older mixed alluvial and eolian deposits principally along the Kayenta outcrop on the west side of the Virgin anticline. Older mixed alluvial and eolian deposits are less than about 30 feet (9 m) thick and are correlative with level 2 and level 3 stream-terrace deposits.

Younger alluvial and eolian deposits (Qae): Younger mixed alluvial and eolian deposits consist of poorly to moderately sorted, clay- to boulder-size sediments with well-sorted eolian sand and reworked eolian sand. These deposits are in modern channels and cover broad, gently sloping depressions. Younger mixed alluvial and eolian deposits are gradational and correlative with younger alluvial and eolian deposits, and with mixed eolian and alluvial deposits. They are differentiated from the latter by their preponderance of alluvial sediments and sedimentary structures over eolian sediments and features. Most younger mixed alluvial and eolian deposits are less than about 20 feet (6 m) thick.

Eolian and alluvial deposits (Qea): Mixed eolian and alluvial deposits north of Washington City consist of well-sorted eolian sand and reworked eolian sand and lesser clay- to pebble-size alluvial sediments, normally with thick secondary calcium carbonate. Eolian and alluvial deposits are correlative and gradational with mixed alluvial and eolian deposits. Mixed eolian and alluvial deposits are generally less than about 20 feet (6 m) thick.

Alluvial, eolian, and colluvial deposits (Qaec): I mapped mixed alluvial, eolian, and colluvial deposits in several areas between Washington and Harrisburg Junction, and in the middle reaches of Cottonwood Wash. These deposits consist chiefly of poorly to moderately sorted, clay- to small boulder-size sediments with well-sorted eolian sand and reworked eolian sand, but with a significant component of colluvial or slopewash sediment. The deposits on the southern flank of the cinder cone in section 36, T. 41 S., R. 15 W., however, contain a greater proportion of colluvial debris shed off the cone itself. Mixed alluvial, eolian, and colluvial deposits are generally less than about 20 feet (6 m) thick.

Eolian and alluvial deposits with thick carbonate soil on basalt flow (Qeca): These deposits consist of eolian clay, silt, and sand that overlie alluvial gravel which was deposited on top of the Washington flow. Soils developed on the deposits have well-developed secondary calcium carbonate (Stage V of Birkeland and others, 1991) up to several feet thick. Collectively, these eolian and alluvial deposits vary from 0 to 10 feet (0-3 m) thick.

Spring Deposits (Qst)

Calcareous spring tufa of uncertain thickness is exposed in a trench northeast of Washington in the NW1/4NW1/4 NW1/4 section 13, T. 42 S., R. 15 W. The tufa is light gray to brownish gray, porous, and contains a sponge-like network of vesicles.

Stacked-Unit Deposits (Qr/Jk, Qr/Jms, Qes/Qmsy)

I mapped angular cobble- to boulder-size basalt clasts that form a blocky surface that drapes over and mostly conceals Springdale Sandstone (Qr/Jms) and Kayenta (Qr/Jk) strata west of Washington Black Ridge as residual deposits over bedrock. The basalt clasts represent a lag deposit derived from the Washington flow. I mapped a thin cover of eolian sand that largely conceals landslide deposits (Qes/Qmsy) along the east side of Washington Black Ridge.

STRUCTURE

Regional Setting

The Harrisburg Junction quadrangle lies within the north-trending transition zone between the Basin and Range and Colorado Plateau physiographic provinces. The Basin and Range Province is characterized by roughly east-west extensional tectonics, including block faulting and widespread igneous activity. The Colorado Plateau is a relatively coherent and tectonically stable region underlain by generally horizontal sedimentary strata that are locally disrupted by early Tertiary Laramide basement-block uplifts, Oligocene/Miocene igneous intrusions, and late Tertiary to Quaternary basalt flows. The transition zone is characterized by sedimentary strata and structures characteristic of both physiographic provinces. In southwestern Utah, it includes two major down-to-the-west normal fault zones that step down from the Colorado Plateau to the Basin and Range. The greater St. George area, including the Harrisburg Junction quadrangle, lies on the intermediate structural block thus created, bounded on the east by the Hurricane fault and on the west by the Gunlock and Grand Wash faults (figure 1).

The transition zone also roughly coincides with the leading edge of the Sevier orogenic belt. This middle Cretaceous to early Tertiary compressional event gives the quadrangle its most prominent structural feature – the Virgin anticline, which trends northeast through the quadrangle. Several west-dipping thrust faults repeat Triassic and Jurassic strata on the northwest flank of the anticline.

Folds

Virgin Anticline

The Virgin anticline – the dominant structural feature of the Harrisburg Junction quadrangle – is a 30-mile-long (48 km), northeast-trending, generally symmetrical fold that is co-linear with the Kanarra anticline to the north. The resistant Shinarump Conglomerate Member of the Chinle Formation, which forms a hogback around a central core of Moenkopi and Kaibab strata that outcrop along the axial surface of the fold, neatly outlines the central portion of the Virgin anticline (figure 4). The anticline has three similar structural domes along its length. From south to north these are Bloomington dome, Washington Dome, and, in the Harrisburg Junction quadrangle, Harrisburg Dome; the latter two are formally named geographic features. The Early Permian Kaibab Formation forms the exposed core of each dome. In the Harrisburg Junction quadrangle, dips of 20 to 35 degrees are common on the flanks of the Virgin anticline, whereas the flanks of Harriburg Dome have steeper dips of 30 to 50 degrees.

Harrisburg Dome lends its name to the Harrisburg Member of the Kaibab Formation, which forms the core of this elongate dome. Only the upper portion of the Harrisburg Member, above and including the medial limestone, is exposed at the dome. All but the southern end of the dome is neatly outlined by a thin, low, resistant hogback of Virgin Limestone. Based on dips of the Virgin Limestone, the northern end of the dome plunges northeast at about 8 degrees. The south part appears to plunge gently southwest as well, based on exposures of Harrisburg strata at Harrisburg and Washington Domes. An axial backthrust cuts the core of the dome as described below.

I mapped several minor subsidiary folds, with axes generally parallel to the axial surface of the Virgin anticline. Most are related to folding associated with west-dipping thrust faults west and south of Harrisburg Junction and north of old Harrisburg. The Shnabkaib Member of the Moenkopi Formation is tightly folded along the northwest flank of Harrisburg Dome, and, covered by the reservoir, immediately north of the Quail Creek south dam. These folds, too, appear to be associated with west-dipping thrust faults.

The age of formation of the Virgin anticline and subsidiary folds is difficult to determine because of inadequate cross-cutting relationships. The early Late Cretaceous Iron Springs Formation is the youngest bedrock unit involved in folding of the Virgin anticline. The formation of the Virgin anticline appears to be related to the Pintura anticline, a co-linear fold just to the north in the Pintura quadrangle. The Pintura anticline is unconformably overlain by the Canaan Peak Formation, the oldest beds of which are late Campanian (Late Cretaceous) in age (see, for example, Hurlow and Biek, 2000). The Virgin anticline thus likely formed between early and late Campanian time (about 84 to 72 million years ago), the youngest known age of the Iron Springs Formation and the oldest known age of the Canaan Peak Formation, respectively (Goldstrand, 1992, 1994), but both ages are poorly constrained. Davis (1999) suggested that the Virgin anticline formed above a blind detachment in underlying Cambrian and Precambrian strata.

Leeds Anticline and Leeds Syncline

The Leeds anticline and Leeds syncline are 2- to 3-mile-long (3-5 km) subsidiary folds on the northwest flank of the Virgin anticline (Proctor, 1953). The Leeds anticline forms Tecumseh Hill, northwest of Leeds, immediately east of the quadrangle boundary. There, the Springdale Sandstone forms the crest of this fold, which plunges about 10 degrees north. South of Buckeye Reef, which forms the west flank of this fold, the axial surface bends abruptly to the southwest along Leeds Reef. A west-dipping thrust fault east of the axial surface truncates the southern portion of the anticline. Only this southern part of the Leeds anticline is in the Harrisburg Junction quadrangle.

Folded beds previously mapped as the Shinarump Conglomerate Member of the Chinle Formation (Proctor, 1953; Proctor and Brimhall, 1986) form Leeds Reef, along the core of the Leeds anticline. Exposures in the SE1/4 section 14, T. 41 S., R. 14 W., however, show that these beds are underlain by brightly colored swelling mudstones characteristic of the Petrified Forest Member. Immediately to the southeast, on the west-dipping Shinarump cuesta, the contact between Petrified Forest and Shinarump strata is gradational. I reinterpret these Shinarump-like strata as thick channel sandstones within the basal part of the Petrified Forest Member, similar to those exposed at the southern end of Washington Black Ridge.

The Leeds syncline, which lies between and roughly parallel to the Leeds and Virgin anticlines, plunges gently northeast beneath the town of Leeds, immediately east of the Harrisburg Junction quadrangle. The Petrified Forest Member of the Chinle Formation forms the core of the syncline, whereas its flanks are upheld by the Shinarump Conglomerate and basal sandstones of the Petrified Forest Member. The syncline is mostly concealed by Quaternary deposits under the town of Leeds and along the Interstate 15 corridor. It is poorly defined in the Harrisburg Junction quadrangle due to thrust faulting and minor folds along the east side of Leeds Reef. Thus, I was not able to map the axial trace of the syncline.

St. George Syncline

Along the southern flank of the Pine Valley Mountains, strata between the Virgin anticline and Gunlock fault form a broad, shallow fold that Cordova (1978) called the St. George syncline. Strata in the northwest portion of the Harrisburg Junction quadrangle and adjacent areas to the west and north are interpreted to form the ill-defined east limb of this fold. Willis and Higgins (1995) noted that this fold may die out near the middle of the Washington quadrangle, immediately west of the Harrisburg Junction quadrangle.

Faults

Thrust and Tear Faults

Several west-dipping thrust faults are present along the west flank of the Virgin anticline. Proctor (1948, 1953) was the first to recognize the largest and westernmost such fault amid considerable controversy over structural interpretations of the Silver Reef mining district. This fault separates Buckeye Reef and White Reef and extends at least 7 miles (11 km) to the southwest. The fault repeats the Moenave Formation in the reefs, farther south at Cottonwood Creek, and west of Harrisburg Junction. The Moenave Formation is not duplicated at Harrisburg Flat, suggesting that the fault is not everywhere parallel to bedding but undulates between upper Petrified Forest and lower Kayenta strata. The fault plane is visible in the SW1/4 section 12, T. 41 S., R. 14 W., about 300 feet (90 m) from the west section line and 700 feet (210 m) from the south section line. It is also visible in the NW1/4 section 12, T. 41 S., R. 14 W., about 1,900 feet (580 m) from the west section line and 2,400 feet (730 m) from the north section line. In the Utah Highway 9 road cut at the common border of sections 4 and 5, T. 42 S., R. 14 W., a prominent drag fold is exposed below the fault zone (figure 9). Based on surface and subsurface data, the fault dips about 30 degrees west-northwest (Proctor and Brimhall, 1986). Proctor and Brimhall (1986) estimated that in the Silver Reef mining district the Springdale Sandstone Member was displaced eastward at least 2,000 feet (600 m) on this fault.

Proctor and Brimhall (1986) also described a smaller thrust fault between Buckeye and Butte Reefs, in the adjacent Hurricane quadrangle. This fault extends southwest into the Harrisburg Junction quadrangle and appears to be a splay of the thrust fault that truncates the east limb of the Leeds anticline at Leeds Reef.

Two minor thrust faults cut the resistant hogback of Shinarump strata on the west flank of the Virgin anticline. Near the Washington County landfill, Shinarump strata reveal a stratigraphic separation of about 200 feet (60 m). Except for minor folding of the Shnabkaib Member, Moenkopi strata below the upper part of the upper red member are unaffected by this faulting. Outcrop patterns suggest that the fault dips northwest parallel to bedding in the upper red member, but abruptly bends at its southern terminous to merge with a northwest-trending, steeply northeast-dipping fault that may represent a tear fault. Shinarump strata in the hanging wall of this fault block are tightly folded into a series of poorly expressed, northeast-trending folds.

Farther north, at Quail Creek Reservoir, a similar west-dipping thrust fault displaces Shinarump beds. The stratigraphic separation is only a few tens of feet but is readily visible where the fault displaces the lower, yellow, cliff-forming sandstone (the Purgatory sandstone) of the upper red mem-

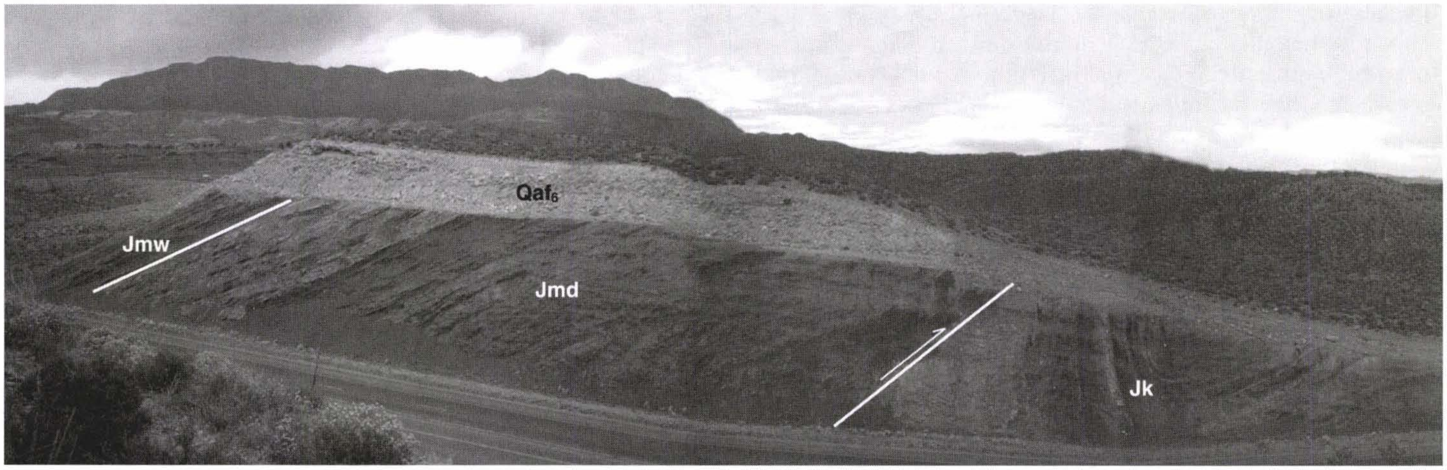

Figure 9. *View north of Utah Highway 9 road cut at the common border of sections 4 and 5, T. 42 S., R. 14 W. Here, west-dipping Moenave strata are thrust eastward over tightly folded Kayenta strata, causing repetition of Moenave beds that are exposed in normal stratigraphic sequence about 1,000 feet (300 m) to the east. The west-dipping thrust fault is marked by a block of highly deformed sandstone immediately west of the steeply dipping Kayenta (Jk) beds. Dinosaur Canyon strata (Jmd) form the bulk of the exposure. An algal limestone marks the contact with the overlying Whitmore Point Member (Jmw) near the west end of the road cut, whereas Springdale beds are along the west side of the ridge just out of view. The ridge itself is capped by* Qaf_6 *deposits.*

ber. Upper red member strata in the footwall of this block are deformed by at least one secondary thrust fault near the center of section 26, T. 41 S., R. 14 W. The fault dies out in Shnabkaib strata. Kink folds and a small back thrust associated with this thrust fault are exposed in a wash in the SW1/4 section 26, T. 41 S., R. 14 W., about 400 feet (120 m) north of the south section line and 2,200 feet (670 m) east of the west section line. An east-northeast-trending anticline-syncline pair, now inundated by Quail Creek Reservoir, is present immediately north of Quail Creek south dam.

Several small tear faults displace Shnabkaib beds south of Utah Highway 9. Each fault shows a small amount of left-lateral displacement, as expected given their proximity to Harrisburg Dome.

Axial Reverse Fault

A steeply east-dipping reverse fault repeats Harrisburg Member strata along the southeast flank of Harrisburg Dome. The cuesta immediately east of the dome's axial surface consists of east-dipping strata of the lower red member of the Moenkopi Formation that is overlain in fault contact with east-dipping strata of the Harrisburg Member of the Kaibab Formation (figures 2 and 3). The reverse fault cuts gradually up through Harrisburg beds when traced from north to south, but is otherwise substantially parallel to bedding. Near the center of the dome the fault shows an apparent maximum displacement of about 1,000 feet (300 m), with displacement decreasing both to the north and south; the maximum stratigraphic separation is about 400 feet (120 m). Noweir (1990) interpreted this as an axial thrust fault that developed in response to tight folding in the core of the Virgin anticline. Noweir (1990) postulated that the shape of the fold is due to a basal detachment at the Cambrian/Precambrian boundary.

High-Angle Normal Faults

The Washington fault is a 42-mile-long (68 km), down-to-the-west normal fault that extends from northern Arizona into southern Utah. Displacement decreases northward from an estimated maximum of 2,460 feet (750 m) in Arizona (Anderson and Christenson, 1989). Higgins (1998) reported about 1,500 feet (460 m) of displacement on the Washington fault in the Washington Dome quadrangle to the southwest. The fault splays and dies out in the adjacent Washington quadrangle to the west (Willis and Higgins, 1995). Higgins and Willis (1995) suggested that the Washington fault may have about 700 feet (210 m) of displacement in the Washington area, in the northeast corner of the St. George quadrangle.

Several down-to-the-west and down-to-the-east splays of the Washington fault displace the 950,000-year-old Washington basalt flow in the extreme southwest corner of the Harrisburg Junction quadrangle and adjacent quadrangles. In the adjacent Washington Dome quadrangle to the south, Shinarump and upper red member strata are displaced as well (Higgins, 1998). The shallow horsts and grabens thus formed show up to about 15 feet (4.5 m) of displacement on the basalt flow. The fault also displaces late Pleistocene sediments south of the quadrangle (Anderson and Christenson, 1989; Hecker, 1993; Higgins, 1998). Additional splays of the Washington fault are present immediately to the north where they displace Jurassic strata.

Joints

Joints are common in all bedrock units in the Harrisburg Junction quadrangle, but are best developed in the Navajo Sandstone and the Shinarump Conglomerate Member of the Chinle Formation. Joints in the latter unit are generally widely spaced (from a few to several tens of feet) and form a conjugate set subparallel to the strike and dip of bedding. The joint surfaces and adjacent rock are heavily stained by iron-manganese oxides, commonly forming "picture stone."

Joint density in the Navajo Sandstone varies considerably across the Harrisburg Junction quadrangle. Some areas are intensely jointed, forming joint zones (Hurlow, 1998), whereas others are broken only by widely spaced joints.

Because the Navajo Sandstone is commonly pervasively jointed in the quadrangle, it is more easily eroded and forms fewer high cliffs than is typical of less jointed Navajo exposures a few tens of miles to the east. The most prominent joints are high-angle, open joints that trend roughly parallel to the Navajo outcrop belt, swinging from northeasterly to more northerly trends when traced northward through the quadrangle. They form a conjugate set with similar but less well-developed, generally northwest-trending joints. Hurlow (1998) reported similar joint-orientation maxima in his study of the region's ground-water conditions. The prominent joints tend to form long, straight, deep, narrow cracks in the rock; evidence of brecciation or recementation is uncommon. Only some of the larger, more prominent joints are shown on the map.

Similar, though shorter and more closely spaced joints are also common throughout the Navajo Sandstone. These joints exhibit wide variation in orientation, and commonly appear curvilinear in many exposures, suggesting that they may be related in part to unloading and exfoliation. Where well developed, they are shown on the map by a joint symbol.

ECONOMIC GEOLOGY

Sand and Gravel

Sand and gravel are currently being mined at the southeast end of Harrisburg Dome, in deposits mapped as Qat_3. The Utah Department of Highways Materials Inventory of Washington County contains analytical information on these and other aggregate deposits in the quadrangle (Utah Department of Highways, 1964), and Blackett and Tripp (1998) discussed issues affecting development of sand and gravel and aggregate resources in Washington County. Abandoned sand and gravel pits, shown on the map with a symbol, are common throughout the lower elevations of the quadrangle. Most are in deposits mapped as Qaf_5, Qaf_6, Qal_1, and Qat_3. Trenches in many deposits – for example in Qat_3 deposits at the common corner of sections 15, 16, 21, and 22, T. 42 S., R. 14 W., and in Qaf_6 deposits northwest of Harrisburg Junction – indicate that some sand and gravel deposits in the quadrangle were evaluated but not developed. Level 5 alluvial-fan deposits along the west flank of the Virgin anticline, although not as well sorted as Virgin River gravels, may provide a significant source of coarse sand and gravel.

Moderately sorted sand and silt is mined for use as a road base and general borrow material from Qal_1 deposits in the NE1/4 section 18, T. 42 S., R. 14 W. Similar deposits, mapped as Qae and Qaeo, are in section 13, T. 42 S., R. 15 W.

Well-sorted eolian sand (Qes) is present throughout the quadrangle in generally thin, widely scattered exposures. The most extensive deposits are southeast of the Virgin River where they largely conceal the Navajo Sandstone from which they are mostly derived.

Gypsum

Temple Cap strata host two small gypsum quarries in the northwest portion of the quadrangle. One, still active in 1998, is in the SE1/4 section 12, T. 41 S., R. 14 W. It provides small blocks of white, gray, or pink gypsum (alabaster) sold for use in sculpting. A similar quarry, now abandoned, is in the SW1/4 section 4, T. 41 S., R. 14 W. Gypsum, suitable for sculpting, is present elsewhere in Temple Cap strata within the quadrangle, and it is also common in the overlying Co-op Creek Limestone and Crystal Creek Members of the Carmel Formation. These bedded and nodular gypsum deposits are up to 12 feet (4 m) thick.

A gypsum prospect in the Harrisburg Member of the Kaibab Formation is on the southeast flank of Harrisburg Dome, in the SE1/4 section 17, T. 42 S., R. 14 W. The upper part of the Harrisburg Member at Harrisburg Dome is very gypsiferous, but the gypsum is in impure beds and as gypsiferous mudstone. The Shnabkaib Member of the Moenkopi Formation is similarly gypsiferous, but no prospects in this unit are known in the quadrangle.

Building and Ornamental Stone

The Shinarump Conglomerate, Springdale Sandstone, Navajo Sandstone, Sinawava Member of the Temple Cap Formation, and Washington basalt flow have all been quarried for building or ornamental stone in the Harrisburg Junction quadrangle. The quarries are small, having produced rough blocks for building and landscaping. A recently worked quarry in the Navajo Sandstone is in the east-central portion of section 11, T. 41 S., R. 15 W. A smaller, apparently abandoned quarry is in the south-central portion of section 7, T. 41 S., R. 14 W. Lower Temple Cap sandstone was quarried in the SW1/4 section 4, T. 41 S., R. 14 W. and the NW1/4 section 9, T. 41 S., R. 14 W. The Springdale Sandstone was used to build several historic buildings at and near the old Harrisburg site and in the Silver Reef mining district.

Basalt columns and blocks from the southern end of Washington Black Ridge were quarried in the past, probably principally for small retaining walls, landscaping, and building foundations. Similar columns are present and accessible elsewhere along the flow.

The Shinarump Conglomerate is widely quarried for decorative stone and, when thinly cut, for "picture stone" that is made into tiles and coasters. The Shinarump Conglomerate contains prominent but widely spaced joints. Joints control staining by iron-manganese oxides such that large blocks become concentrically zoned in a variety of interesting patterns. The largest quarries, active in 1998, are along the lower reaches of Cottonwood Wash, in the SW1/4 section 18, T. 42 S., R. 14 W. Other inactive quarries, identified on the map by symbols, are present to the north along the northwest flank of the Virgin anticline. I did not map the numerous small workings, made largely by hand. "Picture stone" is also common in the Iron Springs Formation, although no workings in Iron Springs strata are known in the quadrangle.

Most bedrock units in the Harrisburg Junction quadrangle could be suitable as sources of decorative stone for landscaping. Petrified wood from the Petrified Forest Member of the Chinle Formation is used locally as an ornamental stone. The collection of petrified wood from public lands is now controlled by law.

Clay

A single clay pit in upper Petrified Forest Member strata, incorrectly labeled a gravel pit on the topographic base map in the SE1/4 section 5, T. 42 S., R. 14 W., was recently reclaimed as a golf course pond. The pit was about 500 feet (150 m) long by about 35 feet (11 m) deep. The clay is brightly colored swelling clay typical of the Petrified Forest Member. The clay may have been used to line retaining ponds or the area behind the Quail Creek south dike.

Metals

Silver Reef Mining District

The Silver Reef mining district is noted for its uncommon occurrence of ore-grade silver chloride (chlorargyrite or horn silver) in sandstone, unaccompanied by obvious alteration or substantial base-metal ores. High-grade silver chloride float was first discovered near Harrisburg in 1866, but it wasn't until 1876 that the silver rush was underway in earnest (Proctor, 1953; Proctor and Brimhall, 1986). Proctor and Shirts (1991) provide a fascinating account of the discovery, disbelief, re-discovery, and development of this unusual mineral occurrence.

The Silver Reef mining district consists of four "reefs" along the northeast-plunging nose of the Virgin anticline: White, Buckeye, and Butte Reefs are on the anticline's northwest flank, and East Reef is on the anticline's east flank (figure 10). The ore horizons are contained within the Springdale Sandstone Member of the Moenave Formation, known locally as the Leeds and Tecumseh Sandstones, which is repeated by thrust faults on the anticline's northwest flank to form the three reefs. Only the southern part of White Reef and the extreme southern portion of Buckeye Reef are in the Harrisburg Junction quadrangle.

The principal mining activity in the district lasted only through 1888, with lessee operations through 1909, after which operations essentially ceased. The Silver Reef mining district produced about 8 million ounces (226,800,000 g) of silver prior to 1910, nearly 70 percent of which came from the prolific Buckeye Reef immediately east of the quadrangle. Sporadic production between 1949 and 1968 amounted to about 30 ounces (850 g) of gold, 166,000 ounces (4,706,100 g) of silver, 60 short tons (54,000 kg) of copper, and at least 2,500 pounds (1,125 kg) of uranium oxide (Houser and others, 1988). The mines were shallow, less than 350 feet (110 m) deep, and most ore bodies were lens shaped, averaging 200 to 300 feet (60-90 m) long by about half as wide. The ore averaged 20 to 50 ounces (567-1,417 g) silver per ton, but varied from only a few ounces to about 500 ounces (14,175 g) per ton (Proctor and Brimhall, 1986; Eppinger and others, 1990).

A leach-pad operation established between White and Buckeye Reefs to process tailings opened in 1979, but this venture closed with the collapse of silver prices (Chris Rohrer, Utah Abandoned Mine Land Reclamation Program, verbal communication, April 7, 1997). In 1998, a Canadian mining company re-evaluated a portion of the Silver Reef mining district (Van Splawn, 1998).

In the early 1950s, the U.S. Atomic Energy Commission initiated a drilling program to evaluate uranium resources in the Silver Reef mining district (Stugard, 1951; Poehlmann and King, 1953). Over 350 holes were drilled at Buckeye Reef, immediately east of the quadrangle boundary. Poehlmann and King (1953) noted that uranium mineralization was controlled by lithology and structure, with faults and joints serving as conduits for transporting mineralized solutions to favorable beds. The Silver Reef mining district produced several hundred tons of uranium ore beginning with an initial shipment in 1950. Carnotite, the predominant uranium and vanadium mineral, is present as a cementing agent, and, more commonly, as a fracture filling and in association with carbonized wood fragments.

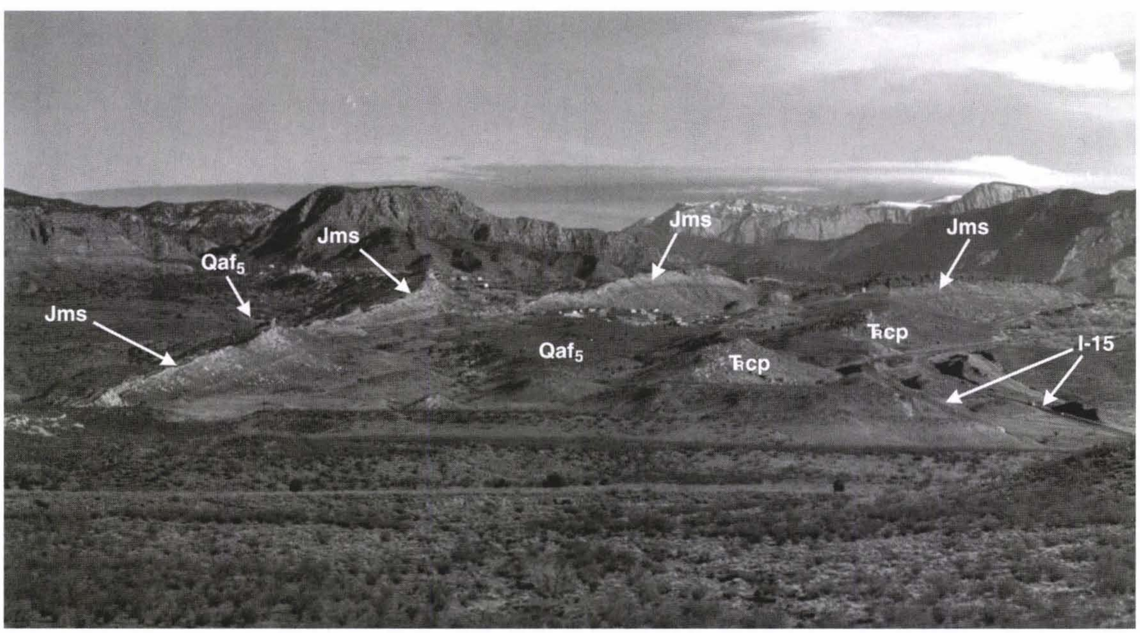

Figure 10. *View northeast to the Silver Reef mining district; photo taken from the SW1/4 section 27, T. 41 S., R. 14 W. The west-dipping Springdale Sandstone (Jms) forms the crest of White Reef, in the west (left) half of the photograph, and the nose of the Leeds anticline (Buckeye Reef) in the east (right) half of the photograph. West-dipping Shinarump-like beds in the Petrified Forest Member of the Chinle Formation (Ꞧcp) form Leeds Reef in the right-center of the photograph, immediately west of Interstate 15. Note planar surfaces of alluvial-fan deposits (Qaf_5) on either side of White Reef. Cottonwood Creek is in the foreground.*

The genesis of these deposits has been the subject of considerable debate ever since their discovery, and it remains equivocal. Proctor (1953), Wyman (1960), Cornwall and others (1967), Heyl (1978), James and Newman (1986), Proctor and Brimhall (1986), and Eppinger and others (1990) discuss mineral occurrences and proposed models for the Silver Reef mining district. Several of these models are summarized by Houser and others (1988).

Other Prospects

Numerous prospect pits and a few short adits and shafts are present outside the Silver Reef mining district. Most are located in Moenave strata to the south, along the west flank of the Virgin anticline. Numerous prospect pits and minor shafts are in Dinosaur Canyon strata in the NW1/4 section 8, T. 42 S., R. 14 W., and two vertical shafts in excess of 20 feet (6 m) deep are in Dinosaur Canyon strata in the SE1/4 section 12, T. 42 S., R. 15 W. Prospects and minor inclined shafts are also in Springdale Sandstone in the NW1/4 section 8, T. 42 S., R. 14 W.; in the SW1/4 section 27, T. 41 S., R. 14 W.; and in the SE1/4 section 22, T. 41 S., R. 14 W. A prospect in Whitmore Point strata is in the SE1/4 section 5, T. 41 S., R. 14 W. Each of these prospects reveals malachite and minor azurite mineralization.

Three prospect pits in white, highly fractured chert of the Harrisburg Member of the Kaibab Formation are present at the north end of Harrisburg Dome. The chert is thin bedded with poorly preserved low-angle cross-stratification and has minor fracture-controlled malachite staining.

Oil and Natural Gas

Two unsuccessful wildcat wells, now abandoned, were drilled in the Harrisburg Junction quadrangle. According to records at the Utah Division of Oil, Gas and Mining (DOGM), the Harry T. Cypher Co. #1 well (formerly the Virgin Dome Oil Co.) (API #43-053-20516) was drilled to a depth of 3,400 feet (1,037 m) before 1923. The hole was later re-entered and abandoned in 1941 at a total depth of 3,508 feet (1,070 m). This was the first wildcat well drilled on the Virgin anticline following the discovery of oil at the Virgin oil field, about 10 miles (16 km) to the east. These records conflict slightly with those reported by Boshard (1952) who stated that the well was begun in 1919 and after intermittent drilling reached a total depth of 3,400 feet (1,037 m) in 1934. Cook (1960) reported that the well was spudded in 1918 and implied that a second well was drilled between 1929 and 1936 to a depth of 2,540 feet (774 m); however, I found no other reports of such a well. No oil shows were reported in DOGM records or in Boshard (1952), but Bassler and Reeside (1921) stated that a light showing of oil was reported at a depth of about 1,000 feet (300 m), near the top of what was then called the Coconino-Supai sandstone. The well is in the NE1/4NW1/4NW1/4 section 16, T. 42 S., R. 14 W. Reeside and Bassler (1921) summarized a stratigraphic section from this well, although no log is available. A second wildcat well (API #43-053-20500), abandoned in 1938 at a total depth of just 47 feet (14 m), is in the SW1/4SW1/4 section 24, T. 41 S., R. 14 W.

The Virgin oil field, the oldest oil field in Utah, was first developed in 1907 following the discovery of oil and asphalt seeps about 10 miles (16 km) east of the Harrisburg Junction quadrangle near the town of Virgin. The primary productive interval at the Virgin oil field is the uppermost part of the Timpoweap Member of the Moenkopi Formation. This interval is not present at Harrisburg Dome, probably due to depositional patterns that were influenced by paleotopography. Timpoweap strata are exposed at Bloomington dome, although no shows of oil or asphaltic material were discovered there (Higgins and Willis, 1995). Timpoweap strata may be present in the Harrisburg Junction quadrangle in the subsurface. Significant shows of oil at the Virgin oil field are also reported from the Kaibab, Pakoon, and Callville Formations, the latter two of which have apparently not been drilled at Harrisburg Dome (although they were penetrated in the California Oil Company No. 1 St. George Unit well on Bloomington dome) (Heylmun, 1993). Possible structural traps are present along the western flank of the Virgin anticline, as well as along the anticline's crest.

Along the central portion of the Virgin anticline, the lower part of the upper red member of the Moenkopi Formation (the 100-foot-thick (30 m), light-yellowish-brown, cliff-forming Purgatory sandstone) stands in marked contrast to enclosing red beds. I found no evidence of oil at this horizon, but the yellowish color of the bed may have been caused by reducing hydrocarbon brines once trapped in the core of the Virgin anticline.

Geothermal Resources

Budding and Sommer (1986) conducted an assessment of low-temperature geothermal resources in the St. George basin. They recorded the highest spring-water temperature, 108°F (42°C), at the Pah Tempe Hot Springs, which is 6 miles (10 km) east of the Harrisburg Junction quadrangle between LaVerkin and Hurricane. They also identified an area of possible low-temperature geothermal potential, with warm well water (>76°F [24.5°C]), in the area north of Washington and St. George. Low-temperature geothermal resources in this region appear to be related to structure, rather than to recent volcanic activity. Basalts in the region are believed to have originated at considerable depth, rising to the surface through narrow conduits, thus precluding the basaltic magmas from being a significant heat source (Budding and Sommer, 1986). The Washington fault may provide a conduit for warm ground water north of Washington.

WATER RESOURCES

With an average annual precipitation of 10 to 12 inches (25.4-30.5 cm) (Cordova and others, 1972), and the recent surge in popularity of the greater St. George area as a retirement and vacation center, water is a major issue in the development of the area. The 1993 State Water Plan for the Kanab Creek/Virgin River Basin (Utah Division of Water Resources, 1993) summarizes water availability and use for the basin, as well as development, regulatory, and other issues that relate to water management. Several other studies of water use and availability, cited below, involve the St. George basin.

Surface Water

The Virgin River, the trunk river of the Virgin River basin, bisects the southeastern portion of the Harrisburg Junction quadrangle. Just upstream at Virgin, it has an average annual flow of about 145,000 acre-feet (189,486,000 m^3) (Cordova and others, 1972). Leeds Creek, the only perennial tributary stream in the quadrangle, has an average annual flow of about 5,000 acre-feet (6,534,000 m^3) (Cordova and others, 1972). Water Canyon, Big Hollow, Heath Wash, Bitter Creek, and Cottonwood Canyon commonly carry streams in their upper reaches but are normally dry in their middle and lower reaches. Heath Wash, in the SE1/4 section 5, T. 41 S., R. 14 W., had a fairly consistent flow of 20 to 30 gallons per minute (75-115 L/min) during the course of this mapping project.

Quail Creek Reservoir, operated as an off-line reservoir by the Washington County Water Conservancy District, is located in the eroded core of the Virgin anticline, north of Utah Highway 9. Two zoned-earth embankments, completed in 1984 and 1985, originally impounded the reservoir. The south dike failed catastrophically in 1989 and was rebuilt in 1990 as a concrete gravity dam (O'Neill and Gourley, 1991; Gourley, 1992, Payton, 1992; Biek, 2000). At its maximum pool elevation of 2,985 feet (910 m), the reservoir covers 640 acres (256 hectares) and stores 40,325 acre-feet (49,745,700 m^3) of water. Most of the water is diverted from the Virgin River northeast of Hurricane to avoid the salty water discharge of Pah Tempe hot springs, and piped to the reservoir; a small amount comes from Quail and Leeds Creeks. The City of St. George recently purchased 10,000 acre-feet (13,068,000 m^3) per year from the Washington County Water Conservancy District, almost half of the reservoir's annual yield. (Horrocks-Carollo Engineers, 1993).

Herbert (1995) conducted a seepage study of selected reaches of the Virgin River between Ash Creek and Harrisburg Dome. He noted that the downstream reaches of his study area, including that segment of the river in the Harrisburg Junction quadrangle, had no substantial gain or loss from seepage.

The west abutment of the Sand Hollow Dam is in the extreme southeast corner of the Harrisburg Junction quadrangle (Graystone Environmental, 1997). The dam will impound an off-line reservoir for storage of Virgin River water. Anticipated seepage into the underlying Navajo Sandstone will replenish local ground water and effectively serve to increase the reservoir's capacity. A well field is planned to recapture this ground water.

Ground Water

The principal aquifers in the St. George basin are in Moenkopi, Chinle, Moenave, Kayenta, Navajo, and overlying unconsolidated strata. In the Harrisburg Junction quadrangle, most wells tap Navajo and Kayenta strata, or Quaternary alluvial deposits.

Several large wells in the Navajo Sandstone provide much of the drinking water for Washington and St. George (Horrocks-Carollo Engineers, 1993). The City of Washington recently completed a 950-foot-deep (290 m) well in the upper reaches of Grapevine Wash. This well penetrates Navajo/Kayenta transition strata but is a relatively poor producer. A 24-hour aquifer test of this well yielded an average production of just 180 gallons per minute (684 L/min) (Heilweil, 1997).

The principal recharge to the Navajo aquifer, which is unconfined, comes from precipitation over the Navajo outcrop belt and from streams that cross and seep into the formation; joints in the Navajo act as major conduits for infiltrating ground water (Cordova, 1978; Freethey, 1993; Hurlow, 1998). Ground water in the Navajo aquifer generally moves southward, against the gentle northward dip of bedrock strata and radially away from the Pine Valley Mountains, towards the Virgin River Valley. The Virgin River forms the major base level in the area.

Hurlow (1998) reported on the geology and groundwater conditions of the central Virgin River basin, which includes the Harrisburg Junction quadrangle. He noted that fracture permeability strongly influences ground-water conditions in the Navajo Sandstone and that north of the Virgin River, the Navajo is characterized by a dense fracture network of variable orientation. He further noted that joint zones – discrete, linear zones of high joint density – should be the primary targets for future water wells because the permeability of these zones is up to 35 times that of adjacent, less densely jointed rock.

A number of springs issue from lower Navajo and upper Kayenta strata between St. George and Washington. Several are shown on the topographic base map, and others are listed in Cordova and others (1972), Cordova (1978), Clyde (1987), and Freethey (1993). These springs issue from the base of the Navajo aquifer, above impermeable Kayenta beds, and represent water that is spilling over the lip of the gently north-dipping aquifer.

Ground-water quality in the St. George basin was reported in Cordova and others (1972), Cordova (1978), Clyde (1987), and Yelken (1996), and summarized in Freethey (1993). Water in the Navajo aquifer generally contains less than 1,500 mg/L, and commonly less than 500 mg/L, total dissolved solids and is therefore of generally high quality. Total dissolved solids are generally greater in deeper aquifers, and down-gradient within an individual aquifer.

GEOLOGIC HAZARDS

Geologic hazards are of increasing concern as the population of the greater St. George area, including the Harrisburg Junction quadrangle, expands into geologically hazardous areas. Geologic hazards associated with earthquakes; mass movements, including landslides and rock falls; expansive, gypsiferous, and collapsible soil and rock; flooding; abandoned mines; radon; and other hazards are known in the quadrangle and surrounding area. Christenson and Deen (1983), Christenson (1992), and Lund (1997) provided nontechnical summaries of such hazards in the greater St. George area. The Utah Geological Survey is now creating a digital folio of GIS-based, 1:24,000-scale geologic hazard maps of the greater St. George area, including the Harrisburg Junction quadrangle.

Earthquakes

The Harrisburg Junction quadrangle lies within the Intermountain seismic belt, a north-trending zone of pronounced seismicity that extends from northern Arizona to western Montana; in Utah, it includes the transition zone between the Basin and Range and Colorado Plateau physiographic provinces (Smith and Arabasz, 1991). Three major faults – the Gunlock, Washington, and Hurricane – are known to have Quaternary offset in southwestern Utah (Earth Sciences Associates, 1982; Anderson and Christenson, 1989; Christenson, 1992; Hecker, 1993; Lund and Everitt, 1998; Black and others, 2000; Lund and others, 2001). In particular, the Hurricane fault apparently has a relatively high long-term slip rate, yet sparse evidence of recurrent Holocene movement makes it difficult to determine average recurrence intervals of surface-faulting events (Stewart and others, 1997; Lund and Everitt, 1998; Lund and others, 2001). The region is generally considered capable of producing earthquakes of magnitude 7-7.5 (Arabasz and others, 1992), comparable to those that occurred prehistorically on the Wasatch fault in northern Utah.

Christenson and Deen (1983) compiled a record of 23 historical earthquakes of Richter magnitude 2.0 and greater within a 22-mile (35 km) radius of St. George that occurred during the period 1850 to 1981; Anderson and Christenson (1989) updated that record though 1988. The largest earthquake, with an estimated magnitude of 6.3, occurred in 1902 and had an epicenter in Pine Valley, about 20 miles (32 km) north of St. George. On July 16, 1998, a magnitude 3.7 earthquake with an epicenter about 3 miles (4.5 km) northeast of St. George was felt locally.

The most recent large earthquake in the greater St. George area occurred on September 2, 1992 (Black and Christenson, 1993; Pechmann and others, 1995). It had a magnitude of M_L 5.8 and an epicenter about 6 miles (9 km) east of St. George. The estimated focal depth of the earthquake was about 9 miles (15 km). Arabasz and others (1992) suggested that the earthquake may have been generated by normal dip-slip movement on the west-dipping subsurface projection of the Hurricane fault. Olig (1995) prepared a preliminary isoseismal map that shows the relative intensity of ground shaking in southwestern Utah and adjacent areas from this event. The maximum modified Mercalli intensity was VII in the Hurricane-Toquerville area. Although there was no evidence of surface fault rupture (Black and others, 1995), the earthquake caused damage up to 95 miles (153 km) from the epicenter (Carey, 1995; Olig, 1995). Borgione (1995) reported significant water-level fluctuations in the main Quail Creek dam, although design parameters were not exceeded and the dam was considered safe. Black and others (1995) discussed other geologic effects of the St. George earthquake.

In the extreme southwest corner of the Harrisburg Junction quadrangle and adjacent quadrangles, several down-to-the-west and down-to-the-east splays of the Washington fault displace the Washington basalt flow. The flow, dated at about 950,000 years old, is displaced up to 15 feet (4.5 m). The fault also displaces late Pleistocene sediments south of the quadrangle (Earth Sciences Associates, 1982; Anderson and Christenson, 1989; Hecker, 1993; Higgins, 1998). Anderson and Christenson (1989) interpreted the age of the last scarp-forming movement on the northern part of the Washington fault as middle to late Pleistocene (10-750 ka), older than the possible early Holocene age reported by Earth Sciences Associates (1982).

As the 1992 St. George earthquake demonstrated, hazards associated with earthquake activity include ground shaking, liquefaction, flooding, rock falls, and other seismically induced slope failures (Christenson, 1992; Black and Christenson, 1993; Black and others, 1995). Although not triggered by the St. George earthquake, surface fault rupture is also a potential hazard for large-magnitude events. Old, unreinforced masonry structures present a serious potential for personal injury and property damage in the event of an earthquake. Ground shaking can be amplified by certain foundation materials, further damaging structures, and may lead to liquefaction. Rock falls and landslides are of increasing concern as development encroaches on steep slopes. Buildings should be constructed in accordance with the International Building Code (2000).

Mass Movements

Landslides

In the Harrisburg Junction quadrangle, stratigraphic units especially susceptible to landslides include the Petrified Forest Member of the Chinle Formation, the Shnabkaib and upper red members of the Moenkopi Formation, and the Carmel Formation. I mapped several large landslide complexes that involve these and adjacent overlying strata. Although most of the movement in these slides apparently took place in the late Pleistocene when conditions were wetter than at present (Christenson and Deen, 1983; Christenson, 1992), they should be considered capable of renewed movement, especially if disturbed by construction activities.

The most prominent landslides are in the Petrified Forest Member of the Chinle Formation along the southern part of Washington Black Ridge. These strata normally weather to gentle slopes, but where protected by a resistant unit such as the Washington basalt flow, they form steep, unstable slopes. At Washington Black Ridge, these slopes are characterized by rotational slumps with partly subdued hummocky surfaces and numerous internal scarps, and are littered with blocks of basalt. Petrified Forest strata, especially those that contain brightly colored swelling clays, are notoriously unstable even where exposed in areas of low relief.

Landslides formed by translational rather than rotational movement are present on the southeast flank of the Virgin anticline. There, in the NE1/4 section 10, T. 42 S., R. 14 W., the Virgin River undercut moderately dipping Shinarump strata, exposing an unsupported dip slope. Shinarump strata, already jointed from folding associated with the formation of the Virgin anticline, slid downslope as coherent blocks above a slip surface in the upper red member of the Moenkopi Formation.

Rock Falls

Rock-fall deposits are present throughout the quadrangle as accumulations of large boulders at the base of steep slopes. Rock falls are a natural part of the erosion process and happen where resistant, fractured or jointed strata break apart and tumble downslope. They are commonly associated with heavy rainfall events or earthquakes, but many probably happen as isolated random events after prolonged weathering. Slopes that are oversteepened by construction activities may present additional rock-fall hazards.

Many map units within the quadrangle are capable of producing rock falls, but the most prolific are the upper red member of the Moenkopi Formation, Shinarump Conglomerate Member of the Chinle Formation, upper Kayenta Formation, and the Washington basalt flow. Particularly large blocks of Shinarump strata are present along the interior of the Virgin anticline, attesting to that unit's proclivity for producing rock falls.

Rock-fall hazards become of increasing concern as an expanding population encroaches upon steeper slopes. The extent of the hazard can be assessed by the relative abundance of rock-fall debris at the base of a slope. The relative hazard varies locally and depends upon the distance from the base of the slope, nature and stability of slope debris, and local topography (Christenson, 1992).

Problem Soil and Rock

Expansive Soil and Rock

Expansive soil and rock contain clay minerals that swell significantly when wet and shrink as they dry. This swelling and shrinking can cause foundation problems and can damage roads and underground utilities. The Petrified Forest Member of the Chinle Formation contains swelling bentonitic clays that are responsible for numerous foundation problems in the greater St. George area (Christenson and Deen, 1983; Christenson, 1992). Locally known as "blue clay," these clays are commonly brightly colored and typically weather to a cracked, popcorn-like surface. Mulvey (1992) noted that common problems associated with swelling soils include cracked foundations, heaving and cracking of floor slabs and walls, and failure of septic systems. Special foundation design and drainage control are necessary for construction in such areas (Christenson, 1992).

Although no mention of expansive clays was made in engineering reports of the Quail Creek dam and underlying Shnabkaib strata (Gourley, 1992; Payton, 1992), such clays are known in the Shnabkaib Member, and, to a lesser extent, in the lower, middle, and upper red members of the Moenkopi Formation (Christenson, 1992). Expansive clays may also be present in the Whitmore Point Member of the Moenave Formation, the Temple Cap and Carmel Formations, and Cretaceous strata. Fine-grained alluvial sediments derived from these strata may also have a moderate swell potential (Christenson and Deen, 1983).

Gypsiferous Soil and Rock

Dissolution of gypsum can lead to a loss of internal strength within a deposit, resulting in collapse of overlying strata. The resulting subsidence and sinkholes may be similar to those in limestone terrain. Gypsum dissolution is accelerated by increased amounts of water, as in proximity to a reservoir, leach fields, or irrigated areas. Gypsum is an important component of the Shanabkaib Member of the Moenkopi Formation and the Harrisburg Member of the Kaibab Formation. Gypsum is also common in the lower, middle, and upper red members of the Moenkopi Formation; in the Kayenta, Temple Cap, and Carmel Formations; and in fine-grained alluvial and eolian deposits derived from these units.

Dissolution of gypsum may lead to foundation problems and may affect roads, dikes, and underground utilities. Gypsum dissolution was an important factor in the January 1, 1989, failure of the Quail Creek dike (Gourley, 1992). Mulvey (1992) also noted that gypsum is a structurally weak material that has a low bearing strength, unsuitable for typical foundations. Sulphate derived from gypsum dissolution can react with certain types of cement, weakening foundations.

Collapsible and Compressible Soil

Collapse-prone soils are known in the Hurricane and Cedar City areas, and they may be present in the greater St. George area (Christenson and Deen, 1983; Mulvey, 1992). Collapsible soils have considerable strength and stiffness when dry, but can settle dramatically when wet, causing significant damage to structures and roads (Rollins and others, 1992). Such soils may be present in geologically young, loose, dry, low-density deposits such as are common in Holocene-age alluvial-fan and colluvial depositional environments. Some wind-blown deposits are also susceptible to hydrocompaction. Hydrocompaction, or collapse, can happen when susceptible soils are wetted below the level normally reached by rainfall, destroying the clay bonds between grains (Mulvey, 1992). Irrigation water, lawn watering, or water from leach fields can initiate hydrocompaction.

Flooding

In the Harrisburg Junction quadrangle, the Virgin River and its flood plain lie within a relatively narrow, mostly undeveloped corridor bounded by resistant Shinarump strata and basalt flows. Damage associated with a major Virgin River flood would likely be restricted to this narrow corridor within the quadrangle. The potential hazard associated with flash floods and debris flows in tributary drainages, however, is much more serious.

Although most streams in the quadrangle carry water only intermittently, they have large catchment basins on the flanks of the Pine Valley Mountains. Flash floods from rapid snowmelt or thunderstorm cloudbursts can turn these normally dry washes into raging torrents. In contrast to major riverine floods, flash floods are highly localized and unpredictable. They quickly reach a maximum flow and then quickly diminish. Flash floods commonly contain high sediment or debris loads and commonly begin or end as debris floods or flows (Lund, 1992), further adding to the destructiveness of such events.

The most recent major flood to scour the Virgin River channel occurred on January 1, 1989, following the catastrophic failure of the Quail Creek dike. O'Neill and Gourley (1991), Gourley (1992), and Payton (1992) summarized the events and conditions that led to the dike's failure as well as geotechnical aspects of its reconstruction. Evidence of the flood is still visible downstream of the dike where Shnabkaib strata were scoured clean of loose overlying sediment, and atop the basalt flow immediately south of the Utah Highway 9 bridge over the Virgin River, where well-cemented gravels overlying the basalt were scoured clean.

Abandoned Mines

The Abandoned Mine Land Reclamation Program (AMLRP), a part of the Utah Division of Oil, Gas and Mining, recently completed reclamation of the western portion of the Silver Reef mining district (Rohrer, 1997). Wright (1992) discussed early reclamation efforts of the AMLRP at Silver Reef, which began in 1988. A variety of methods were used to seal over 500 adits and shafts in the district. Detailed maps and information on mine openings are available from the AMLRP. The Harrisburg Junction topographic map shows some adits and shafts.

Additional potentially hazardous adits and shafts were present in Moenave strata southwest of the mining district. Their locations are shown on the map by a symbol and are also given in the economic-geology section of this report. These shafts were filled in 2000 during construction of a golf course and residential development.

Radon

Radon is an odorless, tasteless, colorless, radioactive gas present in small concentrations in nearly all rocks and soil. Radon can become a health hazard when it accumulates in sufficient concentrations in enclosed spaces such as buildings. A variety of geologic and non-geologic factors combine to influence indoor-radon concentrations, including soils or rocks with naturally elevated levels of uranium, soil permeability, ground-water levels, atmospheric pressure, building materials and design, and other factors. Indoor-radon concentrations can vary dramatically within short distances due to both geologic and non-geologic factors. Still, geologic factors can be assessed to create generalized maps that show areas where elevated indoor-radon levels are more likely to be present.

Solomon (1922a, 1992b, 1995) evaluated the radon-hazard potential of the greater St. George area, including the southwestern corner of the Harrisburg Junction quadrangle; the rest of the quadrangle was not evaluated. The part of the area evaluated was assigned a low to moderate indoor-radon-hazard potential, suggesting that indoor-radon concentrations are likely to be below 4 picocuries per liter, the current EPA action level. In his radon-hazard-potential map of Utah, Black (1993) showed the Harrisburg Junction quadrangle to have a moderate to high radon-hazard potential. It is important to note, however, that a quantative relationship between geologic factors and indoor-radon levels does not exist, and that localized areas of higher or lower radon potential are likely to be present in any given area. Actual indoor-radon levels can vary widely over short distances, even between buildings on a single lot.

Solomon's work also suggests that the Petrified Forest Member of the Chinle Formation, and clasts from the Pine Valley intrusive complex, are a local primary source of uranium. Uranium was mined from the Springdale Sandstone Member of the Moenave Formation in the Silver Reef mining district. The indoor-radon hazard may be greater in structures built on these formations or on sediments or tailings derived from them.

Volcanism

Basaltic flows and cinder cones show that the St. George basin was the site of numerous volcanic eruptions during the past 2 million years. The most recent flow in the area is the Santa Clara flow, which, based on geomorphic considerations, Willis and Higgins (1995) estimate is about 10,000 to 20,000 years old. Such relatively young flows suggest that additional eruptions will occur. Future eruptions can be expected to follow a similar pattern, producing relatively small cinder cones and lava flows that follow topographic lows. Such eruptions are likely to be preceeded by anomalous earthquake activity that may provide considerable warning of an impending eruption. Bugden (1992) discussed possible effects of volcanic hazards in southwestern Utah, including those associated with distant volcanoes.

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APPENDIX I

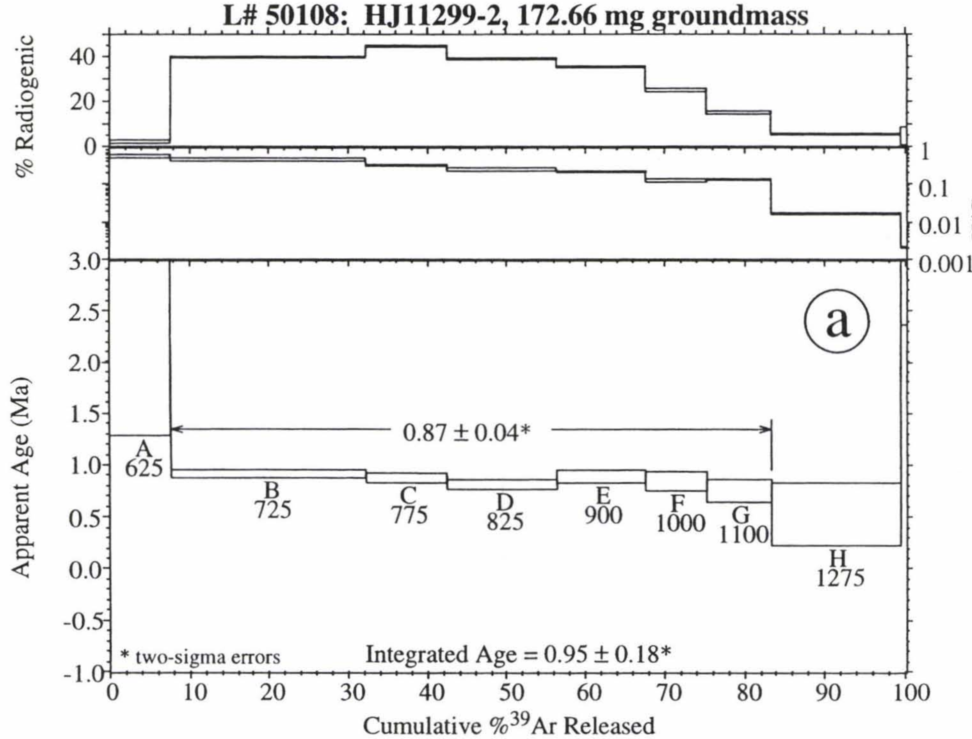
Whole-rock chemical analyses of basalt samples from the Harrisburg Junction quadrangle.

Sample	**VR4007**	**HJ19-1**	**HJ19-2**	**HJ18-1**	**HJ11299-2**	**VR4009**	**HJ220-1**	**VR4008**
Map unit	Qbw	Qbw	Qbw	Qbw	Qbw	Qbv_2	Qbv_2	Qbv_3
Latitude	113.472	113.480	113.480	113.476	113.472	113.384	113.378	113.396
Longitude	37.138	37.182	37.182	37.129	37.159	37.164	37.174	37.162
X-Ray Fluorescence Analyses, wt.%								
SiO_2	42.64	44.10	43.14	43.23	43.50	48.78	45.69	45.30
TiO_2	1.56	1.47	1.54	1.51	1.58	1.67	2.16	2.09
$Al2O_3$	12.13	12.19	12.27	12.11	12.37	14.61	12.95	12.76
Fe_2O_3	12.37	12.31	12.14	12.22	12.26	11.11	12.26	12.11
MnO	0.20	0.20	0.19	0.20	0.20	0.16	0.17	0.17
MgO	12.70	13.31	12.99	13.00	12.46	7.74	9.92	9.90
CaO	12.09	11.90	12.69	12.36	12.37	8.35	10.78	10.38
Na_2O	2.45	2.24	2.38	2.19	2.35	3.07	2.70	2.91
K_2O	1.33	0.73	0.80	0.82	0.83	2.05	1.26	1.87
P_2O5	0.78	0.74	0.80	0.77	0.78	0.51	0.68	0.66
Cr_2O_3				0.08	0.08		0.04	
LOI	0.01	- 0.16	0.09	0.29	-0.18	0.01	0.28	0.01
Total	98.34	99.09	99.09	98.78	98.78	98.08	98.89	98.19
ICP Mass Spectrometer, ppm								
Ag				1	1		<1	
Ba	1060	972	1070	1100	1095	810	1080	1070
Ce				127.0	129.5		105.0	
Co				51.5	50.5		50.5	
Cs	1	<1	<1	0.3	0.4	1	0.4	1
Cu				65	70		70	
Dy				4.9	5.3		5.0	
Er				2.8	2.8		2.5	
Eu				2.6	2.5		2.6	
Gd				7.7	7.4		8.0	
Ga				17	18		21	
Hf	3	5	5	4	5	5	5	4
Ho				1.0	1.0		0.9	
La	69	63	66	71.5	70.5	40	54.0	52
Lu				0.3	0.4		0.3	
Nb	60	45	47	54	55	32	42	47
Nd				51.5	52.5		49.0	
Ni				330	200		185	
Pb				15	20		35	
Pr				13.9	14.0		12.2	
Rb	12	12	12	10.0	10.6	17	12.6	15
Sm				8.5	8.7		8.9	
Sn				1	1		1	
Sr	937	884	927	854	855	666	890	928
Ta	4	4	5	3.0	3.0	3	2.5	4
Tb				1.1	1.1		1.0	
Tl				<0.5	<0.5		<0.5	
Th				11	11		6	
Tm				0.4	0.4		0.3	
U				3.0	3.0		1.5	
V				290	300		270	
W				<1	<1		<1	
Y	27	25	25	24.5	24.5	23	22.5	23
Yb				2.1	2.5		1.9	
Zn				95	100		115	
Zr	167	154	159	169.5	180.0	164	185.5	164

Notes: LOI = loss on ignition.
Sample locations based on the North American datum of 1927.
All analyses performed by ALS Chemex Inc., Sparks, NV.

APPENDIX II

Analytical data for $^{40}Ar/^{39}Ar$ analyses.



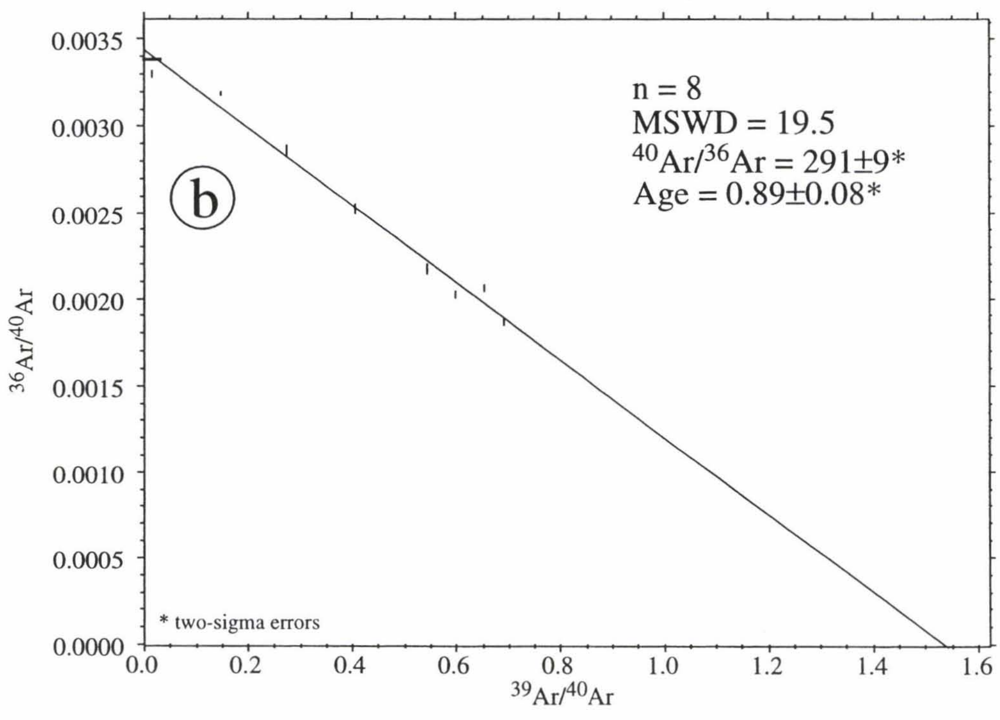


Table 1. *Analytical methods used for furnace analyses.*

Sample preparation and irradiation:

Samples provided by Robert Biek.
Groundmass concentrated by crushing, sieving and hand-picking of any contaminant phases.
Groundmass concentrates were loaded into a machined Al disc and irradiated for:
NM-103 7 hours in D-3 position, Nuclear Science Center, College Station, TX.
NM-109 1 hour in the L67 position, Ford Research Reactor, Univ. of Michigan.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990) relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
Samples step-heated in Mo double-vacuum resistance furnace. Heating duration 7 minutes.
Reactive gases removed by reaction with 3 SAES GP-50 getters, 2 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filiment operated at ~2000°C.

Analytical parameters:

Electron multiplier sensitivity averaged $1x10^{-16}$ moles/pA.
Total system blank and background averaged 200, 1, 0.1, 0.1, 1 x 10^{-17} moles
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 6 or 3 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
NM-103 $(^{40}Ar/^{39}Ar)_K = 0.0002\pm0.0003$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00028\pm0.000005$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.00089\pm0.00003$.
NM-109 $(^{40}Ar/^{39}Ar)_K = 0.025\pm0.005$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00026\pm0.00002$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.0007\pm0.00005$.

Age calculations:

Total gas ages and errors calculated by weighting individual steps by the fraction of ^{39}Ar released.
Plateau definition: 3 or more analytically indistinguishable contiguous steps comprising at least 50% of the total ^{39}Ar (Fleck et al., 1977).
Preferred age calculated for indicated steps when the sample does not meet plateau criteria.
Plateau or preferred ages calculated by weighting each step by the inverse of the variance.
Plateau and preferred age errors calculated using the method of (Taylor, 1982).
MSWD values are calculated for n-1 degrees of freedom for plateau and preferred ages.
Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
Decay constants and isotopic abundances after Steiger and Jäger (1977).
All final errors reported at ±2σ, unless otherwise noted.

Table 2. *$^{40}Ar/^{39}Ar$ analytical results for HJ11299-2.*

ID	Temp (°C)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$ (x 10^{-3})	$^{39}Ar_K$ (x 10^{-16} mol)	K/Ca	$^{40}Ar^*$ (%)	^{39}Ar (%)	Age (Ma)	±1σ (Ma)
HJ11299-2, 172.66 mg Groundmass, J=0.000758569±0.10%, NM-103, Lab#=50108-01										
A	*625*	*62.07*	*0.8749*	*204.9*	*63.9*	*0.58*	*2.5*	*7.7*	*2.17*	*0.44*
B	725	1.670	1.075	3.674	205.7	0.47	40.3	32.3	0.92	0.02
C	775	1.447	1.563	3.137	84.3	0.33	44.9	42.4	0.89	0.02
D	825	1.527	1.951	3.696	116.7	0.26	39.1	56.3	0.82	0.02
E	900	1.835	2.262	4.623	93.7	0.23	35.8	67.5	0.90	0.02
F	1000	2.450	3.816	7.253	64.6	0.13	25.4	75.3	0.85	0.04
G	1100	3.628	3.554	11.39	66.6	0.14	15.3	83.3	0.76	0.05
H	*1275*	*6.640*	*28.15*	*29.06*	*135.2*	*0.018*	*5.7*	*99.4*	*0.53*	*0.07*
I	*1700*	*79.98*	*233.9*	*322.6*	*4.67*	*0.002*	*5.0*	*100.0*	*6.9*	*1.6*
total gas age			n=9		835.3	0.28			0.95	0.18*
plateau	MSWD=5.5**		n=6	steps B-G	631.5	0.31		75.6	0.87	0.04*
isochron	MSWD=19.5**		n=8	$^{40}Ar/^{36}Ar$=291±9*					0.89	0.08*

Notes:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interferring reactions.
Individual analyses show analytical error only; plateau and total gas age errors include error in J and irradiation parameters.
Analyses in italics are excluded from final age calculations.

n= number of heating steps
K/Ca = molar ratio calculated from reactor produced $^{39}Ar_K$ and $^{37}Ar_{Ca}$.
Discrimination (D) = 1.00676±0.00134 a.m.u.
* 2σ error
** MSWD outside of 95% confidence interval

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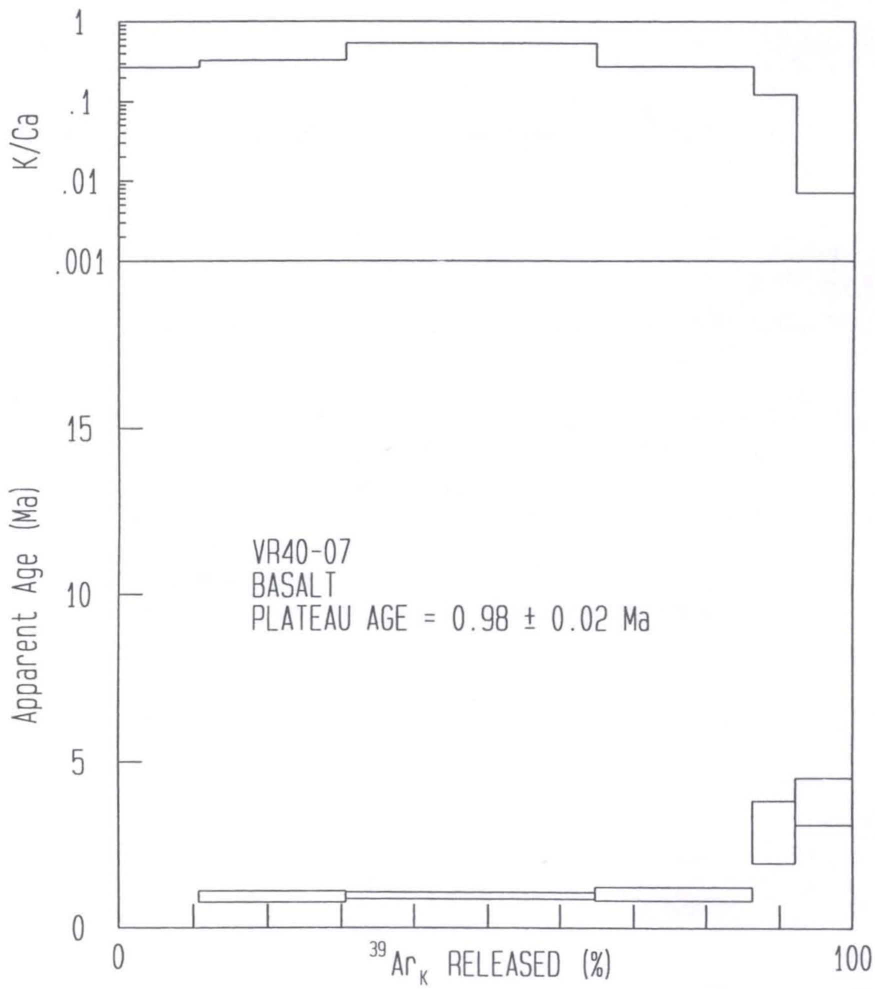
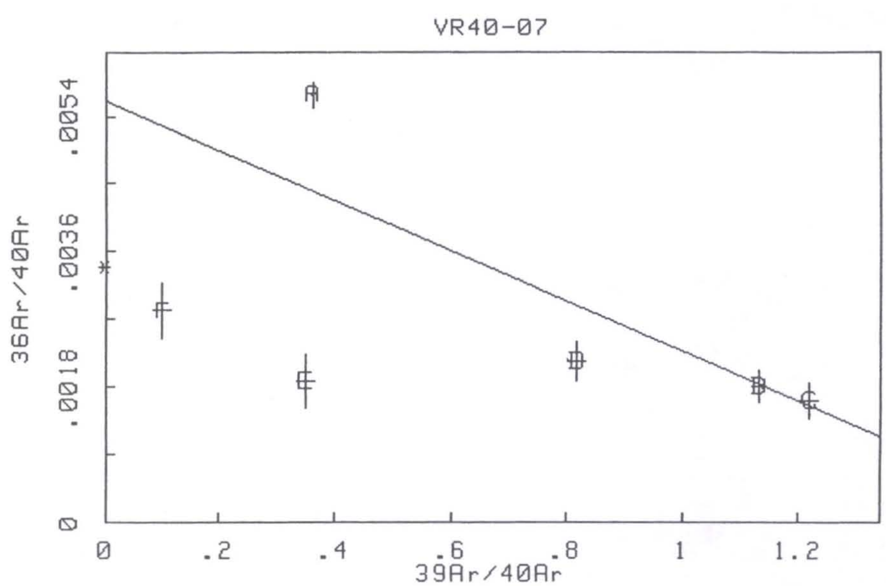


v 1/10/95 (40/36in = 295.5)



6 points regressed out of 6
Mean X = .700E+00 Mean Y = .327E-02 Slope = -.332E-02 ã+Ç .246E-03
36/40 = .559E-02 ã+Ç .198E-03 39/40 = .169E+01 ã+Ç .837E-01
Fit parameters: SUMS = 163.129 MSWD = 40.782
40Ar/36Ar = 178.83 ã+Ç 6.35 F = .593 ã+Ç .029 AGE = 1.35 ã+Ç .07 Ma

#58 KD4 VR40-07

J = 0.001265 ■ 0.50% SAMPLE WT = 0.2510 g

TEMP C	Initial & radiogenic 40Ar	Potassium derived 39Ar	Chlorine derived 38Ar	Calcium derived 37Ar	Initial 36Ar	AGE* in Ma	**
650	2.186E-12	7.927E-13	3.238E-14	1.523E-12	1.242E-14	-4.278 ■	.300
750	1.292E-12	1.463E-12	2.155E-14	2.310E-12	2.329E-15	.941 ■	.085
850	2.066E-12	2.519E-12	1.138E-14	2.462E-12	3.348E-15	.975 ■	.051
950	1.937E-12	1.587E-12	1.641E-14	3.000E-12	4.134E-15	1.029 ■	.103
1050	1.238E-12	4.355E-13	2.525E-14	1.856E-12	2.320E-15	2.895 ■	.467
1450	5.775E-12	5.773E-13	1.764E-13	4.276E-11	1.627E-14	3.819 ■	.349
TOTAL GAS	1.449E-11	7.374E-12	2.834E-13	5.392E-11	4.082E-14	.75	

75.5% of gas on plateau, steps 750 through 950 PLATEAU AGE = .976 + .021

Note: all gas quantities are in moles. No blank correction.
* Ages calculated assuming initial 40Ar/36Ar = 295.5 ■ 0
** 1-sigma precision estimates are for intra-sample reproducibility.
** 1-sigma precision estimates for plateaux are for intra-irradiation package reproducibility.
*** below detection limit

v 1/10/95

R A W D A T A

FILE	TEMP	40Ar	39Ar	38Ar	37Ar	36Ar ä regression	TRAP CURRENT	MANIFOLD OPTION
44777	650	167736	61148	3159	48496	1008	200	EALL
	■	1016	9	34	107	27		
44778	750	99558	112856	3164	73540	231	200	EALL
	■	1011	15	31	138	14		
44779	850	159284	194192	3459	78325	314	200	EALL
	■	1040	117	25	96	15		
44780	950	149003	122381	2869	95402	387	200	EALL
	■	1003	109	33	57	19		
44781	1050	95004	33643	2382	58996	221	200	EALL
	■	1004	113	24	302	23		
44782	1450	442434	46689	14153	1358273	2167	200	EALL
	■	1248	407	14	1211	23		

Raw counts and errors include blank corrections of:
40Ar = 7745 ■ 1003
36Ar = 79 ■ 12.5

C O R R E C T I O N S

TEMP |C	39Ar Decay	37Ar Decay	-----K-derived---- 40Ar	38Ar	37Ar	----Ca-derived---- 39Ar	38Ar	36Ar	Cl-der 36Ar	Initial 38Ar
650	20	70392	345	813	0	78	4	31	0	178
750	37	106841	636	1501	0	119	6	47	0	33
850	65	113895	1096	2585	0	127	6	50	0	48
950	41	138855	690	1628	0	155	7	61	0	59
1050	11	85945	189	447	0	96	5	38	0	33
1450	16	1980509	251	592	0	2204	104	864	1	233

All values in counts, corrected for mass discrimination

	TEMP C	% TOT 39Ar	RAD YIELD	APP K/Ca	APP K/Cl	F	AGE (Ma)	intra-sample	precision intra-package
A	650	10.7	-67.9	.27	59	-1.873	-4.278 ■	.300	.302
B	750	19.8	46.7	.33	164	.412	.941 ■	.085	.085
C	850	34.2	52.1	.53	535	.427	.975 ■	.051	.051
D	950	21.5	36.9	.27	234	.451	1.029 ■	.103	.103
E	1050	5.9	44.6	.12	42	1.270	2.895 ■	.467	.467
F	1450	7.8	16.7	.01	8	1.675	3.819 ■	.349	.354
Total gas				.3					

Precisions are 1 sigma, measured in Ma. Measured 40/36 atm = 287.9 ■.7
J = 0.001265 ■ 0.50% (intra-package) ■ 0.50% (inter-package)
Trap current factors- 40: 5.66 100: 0 200: 1
Manifold factors- ALL: 1 SPLIT 1: 3.3 SPLIT 2: 10.89 SPLIT 3: 35.937
EALL: 2 ESPLIT 1: 6.6 ESPLIT 2: 21.78
Sensitivity = 6.530E-18 % Reproducibility = .25 Detection limit = 40 counts
Data reduced assuming initial 40/36 = 295.50 ■ 0.00
Ca-factors: 3637=2.6E-04■1.7E-06 3837=3.2E-05■2.4E-07 3937=6.7E-04■3.7E-06
K-factors: 3739=0.0E+00■2.2E-03 3839=1.3E-02■2.4E-04 4039=5.7E-03■4.0E-03

Points AEF deleted;
3 points regressed out of 6 includes 75.5 % of 39Ar
Mean X = .108E+01 Mean Y = .183E-02 Slope = -.123E-02 ã+Ç .850E-03
36/40 = .315E-02 ã+Ç .928E-03 39/40 = .257E+01 ã+Ç .104E+01
Fit parameters: SUMS = .061 MSWD = .061
40Ar/36Ar = 317.36 ã+Ç 93.43 F = .389 ã+Ç .158 AGE = .89 ã+Ç .36 Ma

Points ADEF deleted;
2 points regressed out of 6 includes 54 % of 39Ar
Mean X = .117E+01 Mean Y = .172E-02 Slope = -.211E-02 ã+Ç .371E-02
36/40 = .419E-02 ã+Ç .436E-02 39/40 = .199E+01 ã+Ç .144E+01
40Ar/36Ar = 238.59 ã+Ç 248 F = .503 ã+Ç .364 AGE = 1.15 ã+Ç .83 Ma

A	650C	WT X = .21E+06	WT Y = .37E+08	R = .21E+00	Residual = .14E+02
B	750C	WT X = .72E+04	WT Y = .22E+08	R = .83E-01	Residual = -.40E-14
C	850C	WT X = .49E+04	WT Y = .18E+08	R = .25E-01	Residual = .00E+00
D	950C	WT X = .43E+04	WT Y = .14E+08	R = .20E-01	Residual = -.12E+01
E	1050C	WT X = .40E+04	WT Y = .78E+07	R = .13E-01	Residual = -.44E+01
F	1450C	WT X = .40E+04	WT Y = .76E+07	R = .39E-03	Residual = -.32E+01