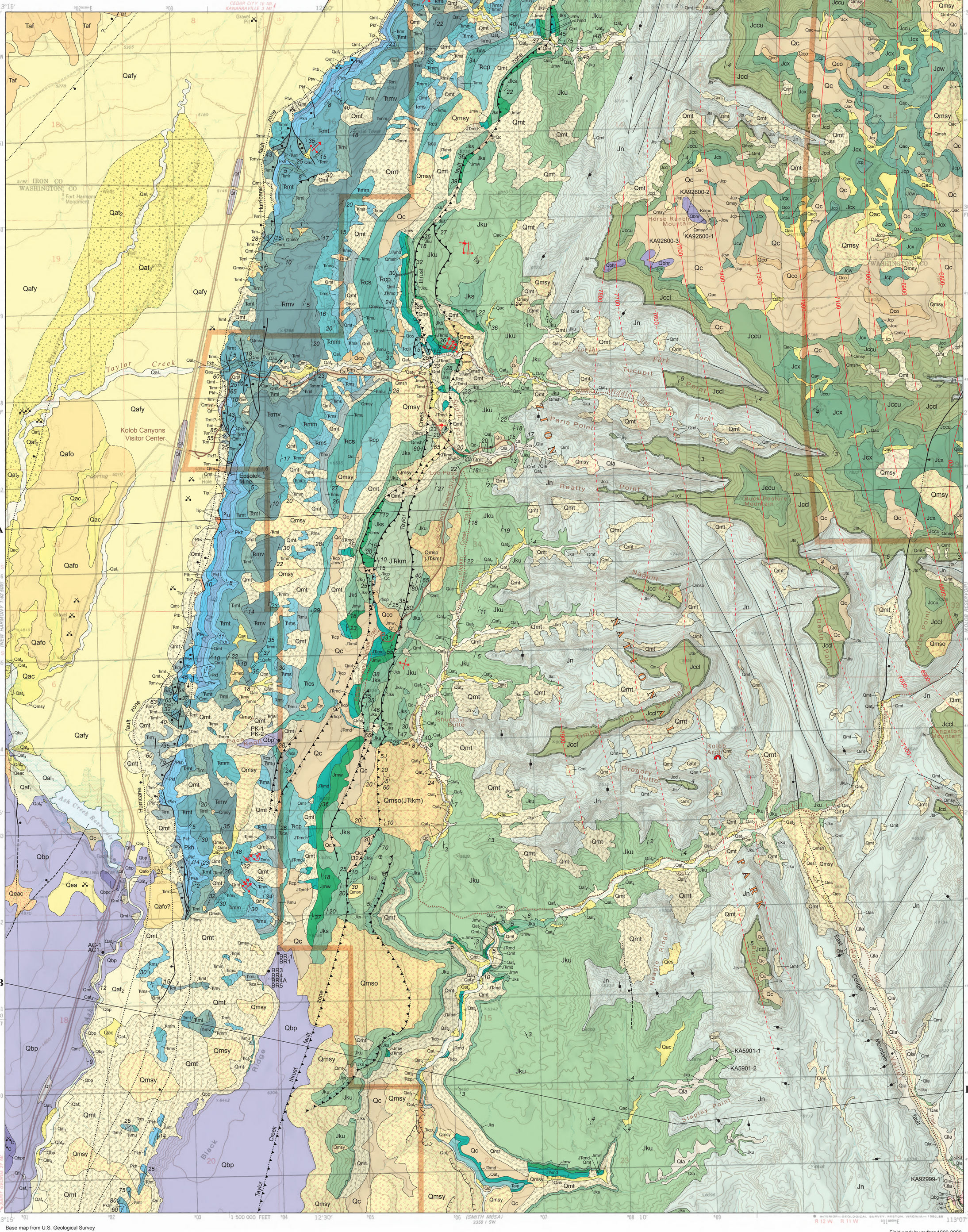
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
in cooperation with
National Park Service



Base map from U.S. Geological Survey
Kolob Arch, 7.5' quadrangle, 1980
Shaded topography generated from digital elevation data

This geologic map was funded by the Utah Geological Survey and the U.S. Department of the Interior, National Park Service. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

For use at 1:24,000 scale only. The UGS does not guarantee accuracy or completeness of data.

Utah Geological Survey, 1594 W. North Temple,
P.O. Box 146100, Salt Lake City, Utah 84114-6100.
Phone: 801-537-3300; fax 801-537-3400;
www.geology.utah.gov

12°29'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2007

SCALE 1:24,000
1 — 1/2 — 0 — 1 MILE
1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET
1 — .5 — 0 — 1 KILOMETER
CONTOUR INTERVAL 80 FEET

GEOLOGIC MAP OF THE KOLOB ARCH QUADRANGLE AND PART OF THE KANARRAVILLE QUADRANGLE, WASHINGTON AND IRON COUNTIES, UTAH

by

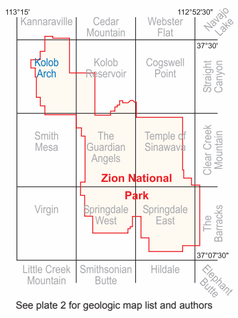
Robert F. Biek

2007

Key access roads, selected trails, and prominent features in and near Zion National Park shown in brown. Condition and status of roads and trails may change over time. Some not shown. From data provided by National Park Service.

Field work by author 1999-2000
Project Manager, Grant C. Willis
GIS Analysts, Kent D. Brown and J. Buck Ehler
Cartography, Kent D. Brown and Lori J. Douglas

QUADRANGLE LOCATION



See plate 2 for geologic map list and authors

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
in cooperation with
National Park Service

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal1 — **Stream deposits** (Holocene) - Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel in stream channels and flood plains; locally includes small alluvial-fan and colluvial deposits, and minor stream-terrace deposits as much as 10 feet (3 m) above current stream level; generally 0 to 20 feet (0-6 m) thick, although deposits west of Ash Creek Reservoir are likely thicker.

Qat2-3 — **Stream-terrace deposits** (Holocene and upper Pleistocene) - Stratified, moderately to well-sorted sand, silt, and pebble to boulder gravel that form level to gently sloping terraces above modern drainages; because incision rates differ across the Hurricane fault and also likely upstream along major drainages, age equivalency of Qat2 and Qat3 deposits across the quadrangle is not known; subscript thus denotes only height above active drainages: level 2 deposits are 10 to 30 feet (3-9 m) and level 3 deposits are 30 to 90 feet (9-27 m) above modern drainages; deposited in stream-channel and flood-plain environments; may include colluvial and alluvial-fan deposits too small to map separately; 0 to 30 feet (0-9 m) thick.

Qao — **Older stream deposits** (middle to upper Pleistocene) - Moderately sorted sand, silt, and pebble to boulder gravel that form isolated deposits high above Taylor and La Verkin Creeks; prominent clasts include gray limestone from the Carmel Formation, some of which contain *Isocrinus* sp. crinoid columnals and pelecypods, yellowish-brown, iron-stained Cretaceous sandstone, reddish-brown to reddish-orange sandstone from the Kayenta and Navajo Formations, and basalt; Taylor Creek deposits also contain clasts derived from the Chinle and Moenkopi Formations; Taylor Creek deposits lie as much as 170 feet (50 m), and La Verkin Creek deposits as much as 250 feet (75 m), above adjacent drainages; age based on regional incision rates of Willis and Biek (2001); deposited in stream-channel environment; 0 to 30 feet (0-9 m) thick.

Qas — **Alluvial sand deposits** (Holocene) - Well-sorted, fine- to medium-grained sand weathered from the Navajo Sandstone and re-deposited in narrow washes; forms planar surfaces, entrenched by intermittent streams, in the southeast corner of the quadrangle; also mapped on the floor of Hop Valley, where the Hop Valley stream has reworked the upper few feet of sandy basin-fill deposits; 0 to about 25 feet (0-8 m) thick, but only a few feet thick in Hop Valley.

Qaf1, Qaf2 — **Alluvial-fan deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, non-stratified, boulder- to clay-size sediment deposited as small alluvial fans along major drainages; level 1 deposits form active depositional surfaces, although locally the master stream is deeply entrenched; typically overlies coeval stream-channel deposits at the toes of the fans, and may include minor colluvium and talus along the upslope margins of the fans; level 2 deposits form deeply incised surfaces as much as 100 feet (30 m) above active drainages; generally 0 to 40 feet (0-12 m) thick.

Qafy — **Younger coalesced alluvial-fan deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, non-stratified, boulder- to clay-size sediment deposited as broad, coalescing alluvial fans in the New Harmony basin west of the Hurricane Cliffs; deposited principally as debris flows issuing from small drainages off the Hurricane Cliffs; forms active depositional surface adjacent to the Hurricane Cliffs, but major streams, including Taylor, Kanarra, and Ash Creeks, are deeply incised along the lower parts of the fans; gradational with talus (Qmt) deposits at the base of the Hurricane Cliffs; well-developed debris-flow levies are locally present on the upper parts of the fans; thickness uncertain, but probably less than about 200 feet (60 m) thick.

Qafo — **Older alluvial-fan deposits** (upper to middle[?] Pleistocene) - Poorly to moderately sorted, non-stratified, boulder- to clay-size sediment with moderately developed pedogenic carbonate; forms deeply incised surface above active drainages at the west-central edge of the quadrangle where it may be exposed due to relative uplift along normal faults near the west edge of the quadrangle; exposed thickness as much as about 100 feet (30 m). Also preserved on and adjacent to the Hurricane Cliffs both north and south of Pace Knoll where clasts consist principally of subangular upper Moenkopi and Shinarump strata and basalt; query indicates uncertain designation; 0 to at least 100 feet (0-30 m) thick. Both areas represent deposition principally as debris flows issuing from small drainages off the Hurricane Cliffs; the thickness of unconsolidated basin-fill deposits west of the Hurricane Cliffs in the Kolob Arch quadrangle, of which Qafy and Qafo represent the uppermost part, is not well constrained; Hurlow (1998) estimated that they may be up to 2000 feet (600 m) thick.

Artificial deposits

Qf — **Artificial fill** (Historical) - Engineered fill used to create roadbeds and dams; although only the larger, thicker deposits are mapped, fill should be anticipated in all developed areas; as much as 70 feet (20 m) thick.

Qfm — **Mine-dump deposits** (Historical) - Waste rock from uranium mining near the Kolob Canyons Visitor Center (Dasch, 1967); 0 to about 20 feet (0-6 m) thick.

Colluvial deposits

Qc, Qco — **Colluvial deposits** (Holocene to middle[?] Pleistocene) - Poorly sorted, angular, clay- to boulder-size, locally derived sediment deposited principally by slope wash and soil creep; locally includes talus, alluvial, and eolian deposits too small to map separately; gradational with talus deposits; younger colluvial deposits (Qc) form active depositional surfaces; older colluvial deposits (Qco) mapped along Taylor Creek and on the Kolob Plateau in the northeast corner of the quadrangle form deeply dissected surfaces; Qco deposits on the Kolob Plateau cap ridge crests and consist principally of reworked Dakota strata; Qc deposits are generally less than 20 feet (6 m) thick; Qco deposits are 0 to 100 feet (0-30 m) thick.

Eolian deposits

Qes — **Eolian sand deposits** (Holocene) - Well- to very well sorted, fine- to medium-grained, well-rounded, frosted quartz sand derived from the Navajo Sandstone; mapped only on top of the Hop Valley landslide and at Neagle Ridge where it partly fills irregular depressions; 0 to 20 feet (0-6 m) thick.

Lacustrine and basin-fill deposits

Qla — **Lacustrine and basin-fill deposits** (Holocene) - Well-stratified sand, silt, and lesser clay deposited in small lakes or basins created by landslides and rock falls; typically grades into colluvial, alluvial, and alluvial-fan deposits at basin margins and in upper part of deposits; forms planar surfaces that slope downstream, which are now incised by streams once blocked by mass movements (Beatty Lake deposits are not yet incised by the Middle Fork of Taylor Creek); because they are located in small catchment basins, most if not all of these "lakes" probably held water only during brief wet periods – most were probably more like bogs or broad alluvial plains. A radiocarbon age of 2640 ± 60 14C yr B.P. (sample KA92299-1; Beta Analytic and UGS [2006]) establishes a minimum age for the formation of Hop Valley Lake (Biek and others, 2003), and Eardley (1966) obtained a radiocarbon age of 670 ± 200 14C yr B.P. from the upper part of these deposits; deposits in Hop Valley are probably about 250 feet (75 m) thick, tapering to a few tens of feet in the south part of the basin. Paria Lake deposits are as much as about 30 feet (9 m) thick; the lake existed from about 3900 ± 60 14C yr B.P. to 2880 ± 200 14C yr B.P. (Eardley, 1966; Hamilton, 1995). Two new radiocarbon ages of 2900 ± 70 14C yr B.P. and 630 ± 40 14C yr B.P. (samples KA15901-2 and KA15901-1, respectively; Beta Analytic and UGS [2006]) establish the duration of Currant Creek Lake, nearby Cane Creek Lake deposits are likely of similar age. Beatty Lake deposits may be as much as 200 feet (60 m) thick; the time of lake or basin formation is not known, but is likely about 1000 to 2000 years ago.

Mass-movement deposits

Qmsh, Qmsy, Qmso (Qmso[JTRkm]) — **Landslide deposits** (Historical to middle Pleistocene) - Very poorly sorted, clay- to boulder-size, locally derived material deposited principally by rotational slides; includes large, collapsed wall of Navajo Sandstone that blocks Hop Valley; characterized by hummocky topography, numerous internal scarps, and chaotic bedding attitudes; basal slip surfaces most commonly form in Petrified Forest, Shnabkaib, middle red, upper red, Kayenta, and Crystal Creek strata, as well as talus deposits, and the slides themselves incorporate these and overlying map units; Qmsh denotes slides with historical movement; younger landslides (Qmsy) may have historical movement, but typically are characterized by slightly more subdued landslide features indicative of early Holocene to late Pleistocene age; older landslides (Qmso) are deeply incised and their main scarps and hummocky topography have been extensively modified by erosion, but they too may be locally active; they are likely late to middle Pleistocene in age; the older landslide about one mile (1.6 km) southwest of Beatty Point (Qmso[JTRkm]) is principally Springdale Sandstone Member displaced but not greatly disturbed by block-slide failure on a near dip slope; the older landslide (Qmso[JTRkm]) southwest of Shuntavi Butte shows the attitude of relatively intact blocks within the larger landslide mass; typically several tens of feet thick, but some deposits may exceed 200 feet (60 m) thick.

Qmt — **Talus deposits** (Holocene to upper Pleistocene) - Very poorly sorted, angular boulders and finer-grained interstitial sediment deposited principally by rock fall on and at the base of steep slopes; typically grades downslope into colluvial deposits and may include colluvial deposits where impractical to differentiate the two; generally less than 30 feet (9 m) thick, although deposits on the Hurricane Cliffs in the southwest corner of the quadrangle are likely at least 100 feet (30 m) thick.

Mixed-environment deposits

Qac — **Alluvial and colluvial deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediments deposited principally in swales, small drainages, and the upper reaches of large streams by fluvial, slope-wash, and creep processes; gradational with both alluvial and colluvial deposits; generally less than 20 feet (6 m) thick.

Qea — **Eolian and alluvial deposits** (Holocene to middle Pleistocene) - Well-sorted, fine- to medium-grained, reddish-brown eolian sand reworked by alluvial processes; mapped south of Ash Creek Reservoir where it locally conceals the Pintura flow; 0 to about 20 feet (0-6 m) thick.

Qeac — **Eolian, alluvial, and colluvial deposits** (Holocene to middle Pleistocene) - Similar to mixed eolian and alluvial deposits (Qea), but with a significant amount of basalt colluvium shed from adjacent slopes; mapped south of Ash Creek Reservoir where it locally conceals the Pintura flow; 0 to about 20 feet (0-6 m) thick.

Qaeo — **Older alluvial and eolian deposits** (Holocene to middle Pleistocene) - Moderately sorted cobble to small boulder gravel, sand, and silt incised by modern streams; partially mantled by eolian sand; mapped at the south end of Hop Valley; 0 to about 50 feet (0-15 m) thick.

Volcanic rocks

See NMGRL and UGS (2006) and UGS website http://geology.utah.gov/online/analytical_data.htm for whole-rock geochemical and $^{40}Ar/^{39}Ar$ analytical data; rock names are after LeBas and others (1986).

Qbg — **Grapevine Wash lava flows** (middle Pleistocene) - Medium-gray, weathering to dark-brownish-gray to dark-brownish-black, fine-grained olivine basaltic trachyandesite lava flow; five $^{40}Ar/^{39}Ar$ ages on these flows range from 0.22 ± 0.03 Ma to 0.31 ± 0.02 Ma (Willis and Hylland, 2002); erupted from a number of vents on the Lower Kolob Plateau, including the Firepit Knoll and Spendlove Knoll cinder cones; only distal end of one lava flow is preserved at the south end of Hop Valley, where it is about 20 feet (6 m) thick.

Qbp, Qbpc — **Pintura lava flow and cinder cone** (lower Pleistocene) - Medium- to dark-gray, fine- to medium-grained olivine basalt or trachybasalt lava flow; some cooling units contain small plagioclase phenocrysts; forms resistant cap of Pace Knoll and Black Ridge, and covers the downthrown hanging wall of the Hurricane fault in the southwest corner of the quadrangle; yielded five $^{40}Ar/^{39}Ar$ ages of 0.89 ± 0.02 Ma, 0.81 ± 0.10 Ma, 0.87 ± 0.04 Ma, 0.88 ± 0.05 Ma, and 0.84 ± 0.03 Ma, (Lund and others, 2001, 2002; Biek, 2003); these last two ages are from the Kolob Arch quadrangle, from Ash Creek (sample AC-1) and the north end of Black Ridge (sample BR-1), respectively; cooling units are generally 10 to 30 feet (3-9 m) thick, but thicken where they fill paleodrainages; a stacked series of about 12 cooling units is 780 feet (240 m) thick on Black Ridge immediately north of the southern boundary of the quadrangle; Qbpc indicates cinder cone at southwest corner of quadrangle, likely the principal source of the flows; cinders are also mapped near Ash Creek Reservoir.

Qbhr — **Horse Ranch Mountain lava flow** (lower Pleistocene) - Medium-gray, fine- to medium-grained olivine basalt lava flow; where the flow caps Horse Ranch Mountain, it is underlain by about 50 feet (15 m) of poorly exposed, unmapped, rubbly, vesicular basalt; sample KA92600-2 yielded an $^{40}Ar/^{39}Ar$ plateau age of 1.03 ± 0.06 Ma (Biek and others, 2003); a single cooling unit about 30 feet (10 m) thick caps the northeast end of Horse Ranch Mountain, whereas the westernmost basalt exposure in section 23 contains at least seven cooling units that total about 125 feet (38 m) thick; vesicle alignment and paleotopography show that the basalt flowed generally from east to west; the source of the flow is unknown, but it may be at Horse Ranch Mountain or in the Cedar Mountain quadrangle to the northeast.

unconformity

TERTIARY

Taf — **Basin-fill deposits** (Miocene to Pliocene[?]) - Deeply dissected, poorly to moderately consolidated, boulder- to clay-size sediment mapped on the southeast flank of the Harmony Mountains in the northwest corner of the quadrangle, where it dips about 15 to 25 degrees east (Averitt, 1967; Rowley and others, 2006); prominent clasts include Miocene volcanic and plutonic rocks and recycled Tertiary to late Paleozoic sedimentary rocks probably derived from the Claron Formation; deposited principally by debris flows probably derived from the west (see Hurlow, 1998 and references therein); Averitt (1967) described two informal units that may be exposed in the northwest corner of the quadrangle; Hurlow (1998) described three informal units that total about 1500 feet (450 m) thick, but only the upper few hundred feet of his upper unit is exposed in the quadrangle.

unconformity

Tip — **Quartz monzonite porphyry** (Miocene) - Grayish-pink quartz monzonite porphyry deeply weathered to grus-like soils; probably the Pine Valley laccolith (intrusive phase) (Dave Hacker, verbal communication, July 22, 2004), but may be the Pine Valley latite (extrusive phase) (see, for example, Hacker, 1998; Hacker and others, 2002); exposed in fault blocks at the base of the Hurricane Cliffs, just south of the Kolob Canyons Visitor Center and at the mouth of Wayne Canyon; the Pine Valley laccolith yielded several $^{40}Ar/^{39}Ar$ plateau ages of 20.5 million years old (Hacker and others, 1996; Rowley and others, 2006); maximum exposed thickness is about 115 feet (35 m).

unconformity

Tc? — **Claron Formation(?)** (Paleocene to Eocene) - Thin- to medium-bedded, orangish-red, reddish-brown, and yellowish-brown, calcareous silty sandstone and siltstone; identification uncertain because it is poorly exposed in highly fractured fault blocks at the base of the Hurricane Cliffs, where it weathers to brightly colored slopes; Claron strata were deposited in fluvial and lacustrine environments modified by pedogenic processes (Mullett and others 1988a, 1988b; Mullett, 1989); exposed thickness uncertain, but possibly as much as 300 feet (90 m) thick.

unconformity

CRETACEOUS

Kd — **Dakota Formation** (Upper Cretaceous, Cenomanian) - Interbedded, slope- and ledge-forming sandstone, siltstone, mudstone, claystone, carbonaceous shale, coal, and marl; exposed in the southeast corner of the Kanarraville quadrangle and may be concealed by colluvium near the top of Horse Ranch Mountain; see Biek (2007) for full unit description.

unconformity

Cedar Mountain Formation

Kcmc — **Conglomerate member** (Cretaceous, Cenomanian to Albian) - Very poorly exposed at Horse Ranch Mountain; the following description is based largely on exposures in the adjacent Kolob Reservoir quadrangle (Biek, 2007); thick- to very thick bedded, yellowish-brown, channel-form conglomerate, pebbly sandstone, and pebbly gritstone; clasts are subrounded to rounded, pebble- to small-cobble-size quartzite, chert, and limestone; locally stained reddish brown to dark yellowish brown; discernable at Horse Ranch Mountain due to quartzite and chert pebbles weathering out and accumulating on the surface; colluvium below Horse Ranch Mountain contains angular, cobble- to boulder-size Dakota-like sandstone blocks, suggesting that several feet of Dakota strata may be concealed above the conglomerate; deposited in river-channel environment on a broad lowland (see, for example, Kauffman, 1977; Tschudy and others, 1984; am Ende, 1991); Biek and Hylland (2007) reported a single-crystal $^{40}Ar/^{39}Ar$ age of 97.9 ± 0.5 Ma on sanidine from a volcanic ash in mudstone immediately above this conglomerate bed in the Straight Canyon quadrangle to the east; pollen analyses indicate an Albian or older age for these beds (Doelling and Davis, 1989; Hylland, 2001); upper contact not exposed, but regionally, east of the Hurricane fault, is unconformably overlain by the Dakota Formation (see, for example, Kirkland and others, 1997); previously mapped as the lower part of the Dakota Formation, but the lithology, age, and stratigraphic position of these beds suggest correlation to the Cedar Mountain Formation; probably 20 to 25 feet (6-8 m) thick at Horse Ranch Mountain.

unconformity (K)

JURASSIC

Carmel Formation

Jcw — **Winsor Member** (Middle Jurassic) - Light-reddish-brown, very fine to medium-grained sandstone and siltstone; poorly cemented and so weathers to densely vegetated slopes, but locally forms badland topography; upper contact is the basal Cretaceous unconformity; at Horse Ranch Mountain, Winsor strata are unconformably overlain by the very poorly exposed conglomerate member of the Cedar Mountain Formation; deposited on a broad, sandy mudflat (Imlay, 1980; Blakey and others, 1983); about 320 feet (100 m) thick.

Jcp — **Paria River Member** (Middle Jurassic) - Laminated to very thin bedded, light-gray to light-yellowish-gray argillaceous limestone and micritic limestone that overlies a thick, white, alabaster gypsum bed; limestone weathers to small chips and plates, forms steep, ledgy slopes, and locally contains small pelecypod fossils; upper contact is sharp and planar; deposited in shallow-marine and coastal-sabkha environments (Imlay, 1980; Blakey and others, 1983); about 125 feet (40 m) thick.

Jcx — **Crystal Creek Member** (Middle Jurassic) - Thin- to medium-bedded, medium-reddish-brown gypsiferous siltstone, mudstone, and very fine to medium-grained sandstone; typically friable and weakly cemented with gypsum; forms vegetated, poorly exposed slopes; upper contact is sharp and broadly wavy and corresponds to the base of a thick Paria River gypsum bed; deposited in coastal-sabkha and tidal-flat environments (Imlay, 1980; Blakey and others, 1983); about 250 feet (75 m) thick.

Co-op Creek Limestone Member (Middle Jurassic) - Thin- to medium-bedded, light-gray to light-yellowish-gray micritic limestone and calcareous shale; locally contains *Isocrinus* sp. (formerly *Pentacrinus*) columnals, pelecypods, and gastropods; deposited in a shallow-marine environment (Imlay, 1980; Blakey and others, 1983).

Jccu — **Upper unit** - Thin- to medium-bedded, light-gray to light-yellowish-gray micritic limestone; locally oolitic and sandy; forms sparsely vegetated, ledgy slopes and cliffs; upper contact is sharp and planar; about 140 to 200 feet (43-60 m) thick.

Jccl — **Lower unit** - Mostly thinly laminated to thin-bedded, light-gray to light-yellowish-gray calcareous shale and platy limestone; forms steep, vegetated slopes; contact with upper unit is gradational and corresponds to a subtle break in slope and vegetation patterns; about 380 feet (115 m) thick.

unconformity (J-2)

Temple Cap Formation

Jts — **Sinawava Member** (Middle Jurassic) - Interbedded, slope-forming, moderate-reddish-brown mudstone, siltstone, and very fine grained silty sandstone; forms narrow but prominent deep-reddish-brown, vegetated slope at the top of the Navajo Sandstone; upper unconformable contact is poorly exposed, but corresponds to the base of light-gray calcareous shale and micritic limestone; deposited in coastal-sabkha and tidal-flat environments (Blakey, 1994, Peterson, 1994); about 10 feet (3 m) thick. The overlying White Throne Member, well developed at Zion Canyon, is erosionally truncated under the J-2 unconformity just east of the quadrangle (Willis and Hylland, 2002; Biek, 2007).

unconformity (J-1)

Jn — **Navajo Sandstone** (Lower Jurassic) - Moderate-reddish-orange to moderate-orange-pink, massively cross-bedded, poorly to moderately well-cemented, well-rounded, fine- to medium-grained, frosted quartz sandstone; contains a few planar interdune deposits; forms spectacular, sheer cliffs and is locally prominently jointed; upper, unconformable contact is sharp and planar and corresponds to a prominent break in slope, with cliff-forming, cross-bedded sandstone below and reddish-brown mudstone of the Temple Cap Formation above; divided into three informal units – the lower brown, middle pink, and upper white units – in the main part of Zion National Park (Doelling, 2002; Doelling and others, 2002; Willis and Hylland, 2002; Willis and others, 2002), but the white unit is missing and the color difference between the brown and pink units is less prominent in the northern part of the park and so the Navajo is undivided here; deposited in a vast coastal and inland dune field with prevailing winds principally from the north (Blakey, 1994, Peterson, 1994); the lower few hundred feet is characterized by planar sandstone beds and represents deposition in a sand-dominated sabkha environment (Tuesink, 1989; Sansom, 1992); much of the sand may originally have come via a transcontinental river system that tapped Grenvillian-age (about 1.0 to 1.3 billion-year-old) crust involved in Appalachian orogenesis of eastern North America (Dickinson and Gehrels, 2003; Rahl and others, 2003); about 2100 to 2200 feet (640-670 m) thick.

JTRkm — **Kayenta and Moenave Formations, undivided** (Lower Jurassic to Upper Triassic) - Springdale Sandstone, Whitmore Point, and Dinosaur Canyon strata caught between splays of the Taylor Creek thrust along the Kolob Canyons Scenic Drive; may locally include basal strata of the upper member of the Kayenta Formation; undivided due to extensive fracturing and deformation and generally poor exposures.

Kayenta Formation

Marzolf (1994) and Blakey (1994) presented evidence to restrict the Moenave Formation to the Dinosaur Canyon and Whitmore Point Members, with a major regional unconformity at the base of the Springdale Sandstone. Further work supports this evidence, indicating that the Springdale Sandstone is more closely related to the Kayenta Formation and should be made its basal member (see, for example, Lucas and Heckert, 2001; Molina-Garza and others, 2003; Steiner, 2005). We anticipate that this change will be formalized, and so here informally reassign the Springdale Sandstone as the basal member of the Kayenta Formation.

Jku — **Upper member** (Lower Jurassic) - Interbedded, thin- to very thick bedded, moderate-reddish-brown siltstone, fine-grained sandstone, and mudstone with planar, low-angle, and ripple cross-stratification; lower part contains several thin, light-olive-gray weathering, light-gray dolomite beds; lower part generally weathers to poorly exposed slopes, upper part to ledges and small cliffs; upper contact is conformable and gradational and corresponds to the top of the highest thin siltstone and mudstone beds, above which lie the towering cliffs of Navajo Sandstone; throughout much of the Kolob Canyons area, the contact is at the base of a white-weathering sandstone bed; deposited in fluvial, distal fluvial/playa, and minor lacustrine environments (Tuesink, 1989; Sansom, 1992; Blakey, 1994, Peterson, 1994); about 1000 feet (300 m) thick.

Jks — **Springdale Sandstone Member** (Lower Jurassic) - Medium- to very thick bedded, pale-red, light-brown, and pale-reddish-brown, fine-to medium-grained sandstone with 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; forms prominent cliff; contains locally abundant petrified and carbonized fossil plant remains; upper contact is conformable and corresponds to a prominent break in slope, with slope-forming, thin-bedded, reddish-brown, fine-grained silty sandstone above and cliff-forming, very thick bedded sandstone below; although the lower part of the upper member contains several thin beds of Springdale-like sandstone; deposited in braided-stream and minor flood-plain environments (Clemmensen and others, 1989; Blakey, 1994, Peterson, 1994; DeCourten, 1998); about 100 to 140 feet (30-43 m) thick; measured section west of Horse Ranch Mountain is 125 feet (38 m) thick.

unconformity (J-sub K)

JURASSIC AND TRIASSIC

Moenave Formation

JTRm — **Moenave Formation, undivided** (Lower Jurassic to Upper Triassic) - Shown on cross section only.

Jmw — **Whitmore Point Member** (Lower Jurassic) - Contains several thin pale-red-purple, greenish-gray, and blackish-red mudstone and claystone horizons interbedded with light-brown, pale- to moderate-reddish-brown, and moderate-reddish-orange, very fine to fine-grained sandstone beds; a single dolomitic limestone bed about 2 to 12 inches (5-30 cm) thick marks the base of the member; this bed is very light gray to yellowish gray, bioturbated, and locally contains small reddish-brown chert blebs, algal structures, and rare fossil fish scales likely of *Semionotus kanabensis* (Hesse, 1935; Schaeffer and Dunkle, 1950); a thin gritstone bed is locally present near the middle of the member; weathers to poorly exposed, locally brightly colored slopes; upper contact corresponds to a major regional unconformity (Blakey, 1994; Marzolf, 1994); deposited in flood-plain and lacustrine environments (Clemmensen and others, 1989; Blakey, 1994, Peterson, 1994; DeCourten, 1998); generally about 70 to 110 feet (21-34 m) thick, but measured section west of Horse Ranch Mountain is 142 feet (43 m) thick.

JTRmd — **Dinosaur Canyon Member** (Lower Jurassic to Upper Triassic) - 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; basal part includes a single bed of reddish-brown, very fine to fine-grained silty sandstone several tens of feet thick; a thin chert-pebble conglomerate marks the base of the member; forms ledgy slopes; upper contact is conformable and gradational and corresponds to the base of a thin dolomite bed and the top of a white to greenish-gray sandstone bed that is 1 to 10 feet (0.3-3 m) thick; deposited in river-channel and flood-plain environments (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994; DeCourten, 1998); age from Lucas and others (2005); about 250 feet (75 m) thick; measured section west of Horse Ranch Mountain is 235 feet (72 m) thick.

unconformity (J-0)

TRIASSIC

Chinle Formation

TRc — **Chinle Formation, undivided** - shown on cross section only.

TRcp — **Petrified Forest Member** (Upper Triassic) - Varicolored, typically gray to purple, bentonitic mudstone, claystone, siltstone, lesser sandstone and pebbly sandstone, and minor chert and nodular limestone; regionally and in southwest Utah is divisible into three parts, ascending – the bentonitic Blue Mesa unit, the pebbly sandstone of the Mossback or Sonsela unit, and the bentonitic Painted Desert unit (Lucas, 1993) – that are undivided here; lowermost part locally contains light-gray, fine- to medium-grained sandstone with abundant petrified wood and cobble- to small boulder-size, "cannonball-like" sandstone concretions that may represent a distal, unmapped facies of the Monitor Butte Formation; middle part of formation marked by a distinctive, thick-bedded, white sandstone and pebbly sandstone with well rounded chert and quartzite clasts likely correlative with the Sonsela unit; mudstones weather to a "popcorn" surface and cause foundation problems; typically poorly exposed and commonly forms slumps; contains petrified wood, especially in sandstone beds; upper unconformable contact is poorly exposed but corresponds to a thin chert-pebble conglomerate overlain by reddish-brown, non-bentonitic siltstone and fine-grained sandstone, below which lies brightly colored swelling mudstone with abundant nodular limestone; deposited in a variety of fluvial, flood-plain, and lacustrine environments (Stewart and others, 1972a; Lucas, 1993; Dubiel, 1994; DeCourten, 1998); about 400 to 500 feet (120-150 m) thick.

TRcs — **Shinarump Conglomerate Member** (Upper Triassic) - Laterally and vertically variable, cliff-forming, pale- to dark-yellowish-orange, fine- to very coarse grained sandstone, pebbly sandstone, and minor 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 occur locally; locally stained by iron-manganese oxides forming "picture stone;" contains poorly preserved petrified wood and plant fragments, commonly replaced in part by iron-manganese oxides; forms a prominent east-dipping cuesta on east limb of the Kanarra anticline; upper contact corresponds to a prominent break in slope, with resistant sandstone and pebbly sandstone below and, generally, brightly colored mudstone above; variable thickness from about 110 to 180 feet (35-55 m), probably due to paleotopography and deposition in braided-stream channels (Stewart and others, 1972a; Lucas, 1993; Dubiel, 1994; DeCourten, 1998).

unconformity (TR-3)

Moenkopi Formation

TRm — **Moenkopi Formation, undivided** (Middle to Lower Triassic) - West-dipping, fault-bounded blocks of lower, middle, or upper red strata along the Hurricane fault; also used on cross section to denote entire formation.

TRmu — **Upper red member** (Middle to Lower Triassic) - 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; upper part includes two prominent sandstone ledges; upper unconformable contact is sharp and shows minor channeling at the base of the Shinarump Conglomerate Member; deposited in tidal-flat and coastal-plain environments (Stewart and others, 1972b; Dubiel, 1994); about 250 feet (75 m) thick.

TRms — **Shnabkaib Member** (Lower Triassic) - 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 present as laterally continuous very thick 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; upper conformable and gradational contact corresponds to the top of the highest thick gypsum bed; deposited in a restricted marine and coastal-sabkha environment on a broad, coastal shelf of low relief (Stewart and others, 1972b); about 450 feet (135 m) thick.

TRmm — **Middle red member** (Lower Triassic) - 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, especially in the lower part of the member; upper conformable and gradational contact corresponds to the base of the first thick gypsum bed; deposited in a tidal-flat environment (Stewart and others, 1972b; Dubiel, 1994); about 550 feet (170 m) thick.

TRmv — **Virgin Limestone Member** (Lower Triassic) - 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; contains three prominent limestone ledges separated by poorly exposed mudstone slopes; forms prominent east-dipping cuesta on the east limb of the Kanarra anticline; upper conformable contact corresponds to the top of the uppermost Virgin limestone bed; deposited in a shallow-marine environment (Stewart and others, 1972b; Dubiel, 1994); about 200 feet (60 m) thick.

TRml — **Lower red member** (Lower Triassic) - Interbedded, laminated to thin-bedded, moderate-reddish-brown mudstone and siltstone containing local, thin, laminated, light-olive-gray gypsum beds and veinlets; upper unconformable contact corresponds to the base of the lowest Virgin limestone bed; deposited in a tidal-flat environment (Stewart and others, 1972b; Dubiel, 1994); about 280 feet (85 m) thick.

TRmt — **Timpoweap Member** (Lower Triassic) - Lower part consists of light-brown weathering, light-gray to grayish-orange, thin- to thick-bedded, planar-bedded limestone and cherty limestone; upper part consists of grayish-orange, thin- to thick-bedded, planar-bedded, very fine grained sandstone, siltstone, and mudstone; both parts contain locally abundant, but poorly preserved, bivalve fossils; chert is present as disseminated blebs and grains in the limestone, thus yielding a very rough weathering surface; caps the Hurricane Cliffs where it forms low cliffs and ledges and a gently undulating surface on top of the Permian-Triassic unconformity; upper contact is conformable and gradational and corresponds to a change from yellowish-brown, fine-grained sandstone, siltstone, and minor limestone below to reddish-brown siltstone and mudstone above; query indicates uncertain designation due to structural complications; deposited in a shallow-marine environment (Nielson and Johnson,1979; Dubiel, 1994); ranges from about 60 to 120 feet (18-37 m) thick (Nielson, 1981).

TRmr — **Rock Canyon Conglomerate Member** (Lower Triassic) - Consists of two main rock types: (1) a pebble to cobble, clast-supported, channel-form conglomerate with subrounded to rounded chert and minor limestone clasts derived from Harrisburg strata, which was deposited in paleovalleys and is 0 to about 90 feet (0-27 m) thick; and (2) a widespread, but thin, breccia 0 to about 5 feet (0-1.5 m) thick, which probably formed as a regolith deposit on Harrisburg strata (see, for example, Nielson, 1981, 1991); conformably and gradationally overlain by limestone of the Timpoweap Member; only the conglomeratic facies is mapped separately; the breccia facies is present along strike beyond mapped conglomeratic facies at the Harrisburg-Timpoweap contact.

unconformity (TR-1)

PERMIAN

Kaibab Formation

Pk — **Kaibab Formation, undivided** - shown on cross section only.

Pkh — **Harrisburg Member** (Lower Permian) - Laterally variable, slope- and ledge-forming, thin- to thick-bedded limestone and dolomite containing common white nodular and ribbon chert; contains minor gypsiferous mudstone and intraformational pebbly conglomerate; unconformably overlain by Rock Canyon Conglomerate river-channel and breccia deposits; deposited in shallow-marine and sabkha environments (McKee, 1938; Nielson, 1986; Sorauf and Billingsley, 1991); about 100 feet (30 m) thick (Nielson, 1981).

Pkf — **Fossil Mountain Member** (Lower Permian) - Light-gray, thick- to very thick bedded, planar-bedded, fossiliferous limestone and cherty limestone; fossils are well-preserved brachiopods, bryozoans, and disarticulated crinoids; forms prominent "black-banded" cliff due to abundant reddish-brown, brown, and black nodular and ribbon chert; upper contact is conformable and corresponds to a sharp break in slope; query indicates uncertain identification due to structural complications; deposited in a shallow-marine environment (McKee, 1938; Nielson, 1986; Sorauf and Billingsley, 1991); about 200 to 250 feet (60-75 m) thick (Nielson, 1981).

Toroweap Formation

Pt — **Toroweap Formation, undivided** - shown in cross section only.

Ptw — **Woods Ranch Member** (Lower Permian) - Interbedded, slope- and ledge-forming, yellowish-gray to light-gray, laminated to thin-bedded cherty limestone, cherty dolomite, and calcareous siltstone; contains minor gypsiferous mudstone and collapse breccia; contact with Fossil Mountain Member is conformable and corresponds to a break in slope at the first appearance of black-banded, cliff-forming limestone; deposited in shallow-marine, supratidal, and sabkha environments (McKee, 1938; Rawson and Turner-Peterson, 1979; Nielson, 1986); query indicates uncertain identification due to structural complications; ranges from 115 to 145 feet (35-44 m) thick (Nielson, 1981).

Ptb — **Brady Canyon Member** (Lower Permian) - Light- to medium-gray, medium- to coarse-grained, thick- to very thick, planar-bedded, fossiliferous limestone and cherty limestone; fossils are broken brachiopods, bryozoans, and crinoids; black to reddish-brown ribbon chert and irregular chert nodules locally make up to 30 to 40 percent of the rock; upper, unconformable contact corresponds to a break in slope; deposited in a shallow-marine environment (McKee, 1938; Rawson and Turner-Peterson, 1979; Nielson, 1986); typically forms prominent cliff, but only upper 150 feet (45 m) is exposed near the base of the Hurricane Cliffs; the member is 220 to 255 feet (67-78 m) thick to the southwest in the Pintura quadrangle (Nielson, 1981; Hurlow and Biek, 2003).

Pts — **Seligman Member** (Lower Permian) - Not exposed.

Subsurface Units

Pq — **Queantoweap Sandstone** - shown on cross section only.

Pzu — **Paleozoic** (pre-Queantoweap), undivided - shown on

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
in cooperation with
National Park Service

NOTES ON THE GEOLOGY OF THE KOLOB ARCH QUADRANGLE

by Robert F. Biek

INTRODUCTION

These notes are presented as a series of short summaries on selected geologic features of the Kolob Arch quadrangle. Topics relate to geologic structures of the quadrangle, including the Kanarra anticline, Taylor Creek thrust fault, and Hurricane fault; the age and field relations of Quaternary basaltic flows; Holocene lacustrine and basin-fill sediments deposited behind landslide dams; and scenic but little known features of the Kolob Canyons part of Zion National Park.

The Kolob Arch quadrangle is at the western margin of the Colorado Plateau, in the transition zone between the Colorado Plateau and Basin and Range physiographic provinces (figure 1). The Colorado Plateau province 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 basaltic lava flows. The Basin and Range Province is characterized by thinned crust and roughly east-west extensional tectonics, with block faulting and widespread igneous activity. The Hurricane fault, which bisects the quadrangle, is the easternmost major fault of the Basin and Range Province in southern Utah. The transition zone is characterized by sedimentary strata and structures common to both physiographic provinces. In southwest Utah, the transition zone also roughly corresponds to the leading edge of the Late Cretaceous to early Tertiary Sevier orogenic belt, which is expressed as the fault-propagation folds of the Kanarra and Virgin anticlines.

The Kolob Arch quadrangle includes over 7000 feet (2150 m) of Lower Permian through middle Cretaceous sedimentary rocks exposed in the east limb of the Kanarra anticline and west edge of the Kolob Plateau (figure 2), fault blocks of the Paleocene-Eocene Claron Formation and Miocene-age quartz monzonite porphyry exposed at the base of the Hurricane Cliffs, and a variety of basaltic lava flows and surficial deposits that record the recent geologic history of the area. The Sculpturing of Zion (Hamilton, 1995), "The Geology of Zion National Park, Utah" (Biek and others, 2003), "Geologic Road and Trail Guides to Zion National Park, Utah" (Biek and others, 2005), and "Water, Rock, and Time" (Eves, 2005) provide non-technical introductions to the geologic history that these units and structures record.

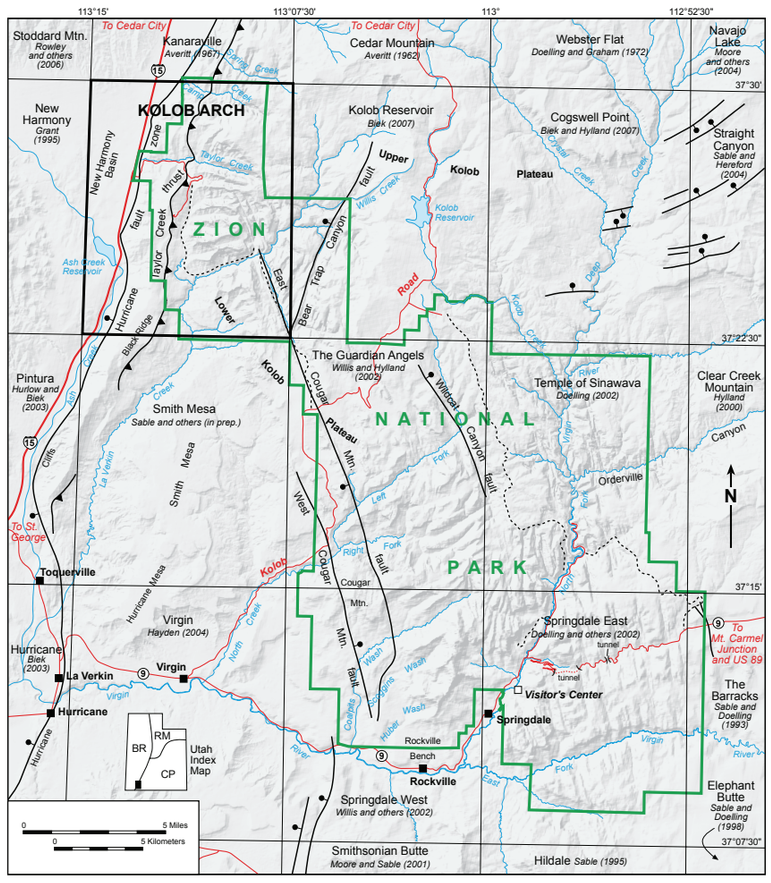


Figure 1. Location of the Kolob Arch quadrangle and other quadrangles in the Zion National Park area. Also shown are geologic maps available for surrounding 7.5´ quadrangles. Inset shows major physiographic provinces of Utah (BR = Basin and Range, CP = Colorado Plateau, RM = Rocky Mountain). Modified from Biek and others (2003).

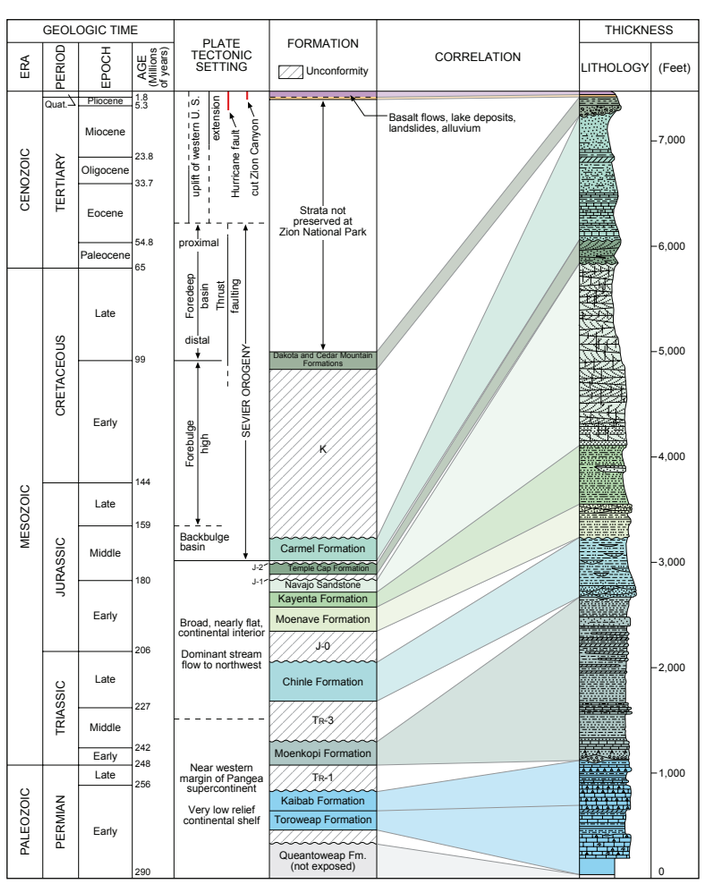


Figure 2. Summary of the geologic history of sedimentary bedrock formations of the Kolob Arch quadrangle and Zion National Park. Formations of Cretaceous to late Tertiary age total several thousand feet thick immediately outside the park, but were removed by erosion from the park itself. Unconformity designations from Pipiringos and O'Sullivan (1978). Modified from Biek and others (2003).

Gregory (1950) reviewed the early exploration of the area and is generally credited with producing the first detailed account and geologic map (at a scale of 1:125,000) of the Zion National Park region. Other geologic maps that cover parts of the Kolob Arch quadrangle and that have proven useful in this mapping project are by Kurie (1966), who mapped the Hurricane Cliffs area from Anderson Junction to Murie Creek; Hamilton (1978, revised 1987), who mapped Zion National Park at a scale of 1:31,680; Van Loenen and others (1989), who mapped small parts of the Kolob Arch, Kolob Reservoir, and Cogswell Point quadrangles for their study of eight wilderness study areas bordering Zion National Park; and Grant (1987), who mapped part of the Taylor Creek area at a scale of 1:24,000. Cook (1960) mapped the geology of Washington County at a scale of 1:125,000, Biek and others (2007) compiled a geologic map of the St. George 30´ x 60´ quadrangle, and Rowley and others (2006) mapped the geology of the adjacent Cedar City 30´ x 60´ quadrangle. Geologic maps available for surrounding 7.5´ quadrangles are shown on figure 1. My mapping of the Kolob Arch quadrangle, from 1999 to 2000, was part of a Utah Geological Survey/National Park Service cooperative project to map the park and surrounding area at a scale of 1:24,000.

Herbert Gregory, a U.S. Geological Survey geologist whose Professional Paper remains a benchmark on the geology and natural and human history of the region, understood the geologic diversity of the Kolob Canyons area and its strategic location at the boundary between two great physiographic regions. In an August 8, 1936 letter to the Acting Assistant Director of the National Park Service, he wrote:

> If only one spot in Utah and Arizona were available as a platform for a lecture on the geology of the Colorado Plateau country, I think I would choose Kanarra Mountain [not directly identified, but probably Horse Ranch Mountain] where the sedimentary series (Kaibab to Wasatch) is in sight, the Great Basin topography abuts against the Plateau topography, and where the erosion, the faulting, and the volcanism characteristics of the Plateau Province could be discussed and illustrated with nearby examples.

Gregory's letter was doubtless important in getting the Kolob Canyons area established as a National Monument the following year in 1937; it became part of Zion National Park in 1956.

Despite its fascinating geology and breathtaking scenery, the Kolob Canyons part of Zion National Park receives only a small fraction of the park's 2.5 million annual visitors. "The name Kolob is derived from Mormon Church doctrine as the star in the center of the universe – the star nearest to the throne of God" (Van Cott, 1990). This part of Zion National Park is indeed a special place, as illustrated by the colorful booklet "Next to the Throne of God" (Leach, 1994). The Kolob Canyons straddle the spectacular western escarpment of the Markagunt Plateau, and are also known as the Finger Canyons of the Kolob. Here, the plateau margin is eroded into a number of west-trending canyons with intervening promontories held up by great cliffs of Navajo Sandstone (figure 3). Depending on how they are counted, however, there are seven or more sheer promontories of Navajo Sandstone – the "fingers" – that project westward from the plateau, showing that the analogy with a normal human hand, while expressive, is somewhat exaggerated. Still, in many respects, each canyon is like a miniature, but uncrowded, Zion Canyon, broad at the mouth where erodable, pre-Navajo strata are exposed, and narrowing to a slot canyon in its upper reaches.

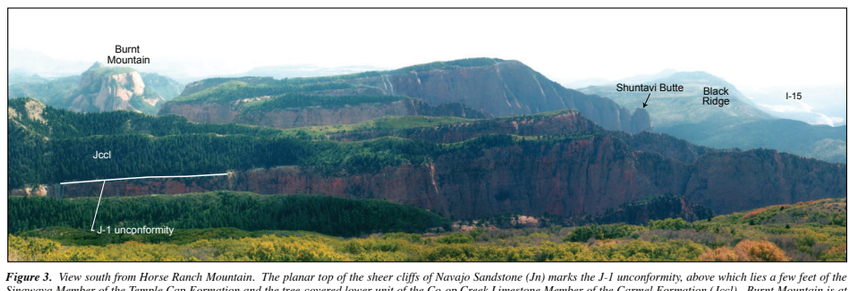


Figure 3. View south from Horse Ranch Mountain. The planar top of the sheer cliffs of Navajo Sandstone (Jn) marks the J-1 unconformity, above which lies a few feet of the Sinawava Member of the Temple Cap Formation and the tree-covered lower unit of the Co-op Creek Limestone Member of the Carmel Formation (Jccl). Burnt Mountain is at left, Black Ridge and Interstate 15 are on the right. The Kolob Canyons Scenic Overlook is just hidden from view to the right of Shuntavi Butte.

SELECTED GEOLOGIC FEATURES

Kanarra Anticline

The Kanarra anticline extends nearly 40 miles (65 km) from near Toquerville on the south to near Cedar City on the north (Gregory and Williams, 1947; Threet, 1963, Kurie, 1966; Averitt, 1967; Averitt and Threet, 1973; Hurlow and Biek, 2003). The east limb of the fold is overturned near Toquerville (Hurlow and Biek, 2003) and near Kanarraville (Averitt, 1967), but is an open, upright fold in the Kolob Arch area where beds on the east limb generally dip between 20º to 35º east and shallow abruptly as they pass under the great cliffs of Navajo Sandstone. The west limb of the fold, and in places the crest and part of the fold's east limb, were sheared off by the Hurricane fault along a line roughly parallel with its axial plane. In the Kolob Arch quadrangle, only the east limb of the fold is conspicuous, although parts of the crest of the fold are preserved at the mouths of Taylor Creek and Camp Creek.

The Kanarra anticline is colinear with the 30-mile-long (48 km) Virgin anticline to the southwest, and both represent frontal folds of the Sevier orogenic belt. The Kanarra anticline exposes Lower Permian to Upper Cretaceous strata, and the age of this fold is probably linked to the development of the nearby Pintura structural culmination during the early to late Campanian, about 83 to 71 million years ago (Hurlow and Biek, 2003). Grant and others (1994) depicted the Kanarra anticline as a fault-propagation fold related to an east-directed thrust fault in the sub-surface.

The east limb of the Kanarra anticline is well exposed north of Ash Creek Reservoir, and the Kolob Canyons Scenic Drive traverses Permian, Triassic, and Jurassic units that make up the exposed core of the fold. Resistant units such as the Virgin Limestone, Shinarump Conglomerate, and Springdale Sandstone form east-dipping hogbacks that help to define the fold's geometry. Excellent traverses of the fold can be made by following the bed of Taylor Creek, where the east limb of the fold dips moderately east, and in Spring Creek Canyon, just southwest of Kanarraville, where the fold is locally overturned.

Taylor Creek Thrust Fault Zone

The east limb of the Kanarra anticline is complicated by the Taylor Creek thrust fault zone, and this map refines structural relationships along the fault zone in greater detail than earlier smaller scale maps. Along much of its length, the Taylor Creek thrust fault consists of two or three main thrust splays, best illustrated by repetition of the resistant, cliff-forming Springdale Sandstone Member of the Kayenta Formation. Smaller thrust faults locally displace Kayenta, Chinle, Moenkopi, and Kaibab strata in the Kolob Arch quadrangle. North of the latitude of Shuntavi Butte, the thrust fault is well exposed and reveals classic, westward-directed compressional deformation on the east limb of the Kanarra anticline, first understood and mapped in some detail as a backthrust by Kurie (1966). In this area, the fault zone consists of as many as three main, east-dipping thrust faults that repeat the Moenave Formation (figure 4). Kurie (1966) estimated at least 2000 feet (600 m) of vertical and about 2500 feet (760 m) of horizontal displacement on the Taylor Creek thrust fault (likely determined at Taylor Creek). Depending on the inferred geometry of the thrust faults, horizontal shortening along these faults may be two to three times what Kurie (1966) depicted.

Figure 4. View north across Taylor Creek canyon of the Taylor Creek thrust fault. Two main splays of the back thrust result in three east-dipping sections of the Moenave and basal Kayenta Formations. Hogbacks of Springdale Sandstone (Jks) and Shinarump Conglomerate (TRcs) are labeled.

Though well exposed north of Shuntavi Butte, south of the butte the Pintura lava flow and large landslide complexes conceal much of the outcrop belt of the Taylor Creek thrust fault zone, complicating interpretations of this area. Lovejoy (1964) and Kurie (1966) interpreted part of this area, the poorly exposed slope west of the junction of Timber and La Verkin Creeks, as the "Current Creek gliding klippe," which they believed was derived from the west. Hamilton (1978, revised 1987) also mapped most of this immediate area as a klippe, and part as Quaternary landslide. One mile (1.6 km) to the north, he mapped a number of detachment, thrust, and tear faults that displace Moenave and Kayenta strata. In my interim geologic map of the quadrangle (Biek, 2002), I also mapped this latter area as part of a detached block of Kayenta and Moenave Formations that was displaced eastward by gravity sliding. Here I present a new interpretation, based on additional field mapping in 2005, because all earlier interpretations have two significant problems: (1) older strata are displaced over younger strata, which is highly unusual for a detachment fault, and (2) more detailed mapping shows that large areas previously mapped as fault-bounded bedrock are in fact post-Pintura lava flow, Quaternary-age landslide deposits.

At the latitude of Shuntavi Butte, the westernmost splay of the Taylor Creek thrust fault zone cuts down section to the west where displacement likely dies out in a series of folds in the middle red and Shnabkaib Members of the Moenkopi Formation. The two other main splays also continue south where they place Springdale Sandstone on top of itself; the faults themselves are mostly concealed by colluvium and, in the SE1/4 section 4, T. 39 S., R. 12 W., by a large landslide complex developed principally in the Kayenta Formation. Farther south, the west-directed Taylor Creek thrust fault zone underlies the Pintura lava flow; it re-emerges in the northwest corner of the Smith Mesa quadrangle, in sections 29 and 32, T. 39 S., R. 12 W., where it appears to die out in the steeply dipping and overturned east limb of the Kanarra anticline (Biek and others, 2007).

However, part of the Taylor Creek thrust fault zone in the Kolob Arch quadrangle contains an east-directed thrust fault, and it is this relationship that has so puzzled previous mappers. This relationship is best expressed in the SW1/4SE1/4 section 16, T. 39 S., R. 12 W., where the Springdale Sandstone Member of the Kayenta Formation and probably part of the Whitmore Point Member of the Moenave Formation lie above the basal part of the upper unit of the Kayenta Formation. I interpret this feature as a small, east-directed thrust fault that likely accommodates space problems developed due to progressively steeper dips on the east flank of the Kanarra anticline as it is traced southward (see cross section B-B´).

Hurricane and East Cougar Mountain Faults

The Hurricane fault trends north through the Kolob Arch quadrangle and lies at or near the base of the Hurricane Cliffs. The Hurricane fault is a major, active, steeply west-dipping normal fault that stretches at least 155 miles (250 km) from south of the Grand Canyon northward to Cedar City (see Lund and others, 2001, 2002, 2007 and references therein). In this quadrangle and elsewhere in southwest Utah the Hurricane fault is characterized by: (1) a scarcity of fault scarps in Quaternary sediments, and (2) a narrow zone of west-dipping fault slivers of Triassic and Jurassic strata in fault contact with Permian strata. The part of the fault in the Kolob Arch quadrangle is known as the Ash Creek segment (Stewart and Taylor (1996). Tectonic displacements along the fault are about 3600 feet (1100 m) and 4900 feet (1500 m) at the latitudes of St. George and Toquerville, respectively (Anderson and Christenson, 1989; Biek, 2003; Hurlow and Biek, 2003). Because hanging wall rocks are buried under the New Harmony and Kanarraville basins, tectonic displacement in the Kolob Arch quadrangle is not known; it is likely comparable to and perhaps greater than the displacement near Toquerville. As discussed under the "Basaltic Lava Flows" part of this report, Lund and others (2001; see also Lund and others, 2007) determined an average slip rate for the Ash Creek segment near Ash Creek Reservoir of about 0.023 inches/yr (0.57 mm/yr) since about 850,000 years ago.

The Hurricane fault trends about N. 80º E. through the Kolob Arch quadrangle, but has two subtle bends to the northeast, one near Ash Creek Reservoir and one near the Washington County line. In these two areas, the footwall of the fault is complicated by subsidiary faults that drop Triassic strata down to the west; similar footwall complications are common at bends in the fault to the south (Biek, 2003; Hurlow and Biek, 2003). The footwall of the Hurricane fault is also complicated by subsidiary faults at Taylor Creek; there, the Kolob Canyons Scenic Drive takes advantage of a small relay ramp between strands of the Hurricane fault. The footwall of the Hurricane fault is well exposed where crossed by Taylor Creek and Camp Creek. At both localities, Lower Permian Harrisburg Member and Lower Triassic Moenkopi strata in the footwall display prominent fault drag and are in fault contact with basin-fill deposits of the hanging wall.

In addition in the Kolob Arch quadrangle, highly fractured, deeply weathered, fault-bounded blocks of the Claron Formation(?) and quartz monzonite porphyry are exposed at the base of the Hurricane Cliffs just south of the Kolob Canyon Visitor Center and at Wayne Canyon. These exposures suggest that rocks of the Pine Valley quartz monzonite (likely the intrusive phase), and the Claron Formation, at least locally underlie the New Harmony basin west of the Hurricane fault, and once extended east of the fault. That the Pine Valley laccolith apparently once extended east of what is now the Hurricane fault helps to explain the presence of Pine Valley quartz monzonite megaboulders scattered on the Kolob Plateau (Averitt, 1962, 1967; Anderson and Mehnert, 1979; Biek and others, 2003; Biek, in prep.; Biek and Hylland, in prep.).

The East Cougar Mountain fault is about 13 miles (21 km) long and extends from near State Highway 9 in the south, northwest to La Verkin Creek. The fault is responsible for the northwest trend of Hop Valley. The timing of movement on the fault is poorly constrained. The fault trends beneath, but does not offset, the 220,000- to 310,000-year-old Grapevine Wash lava flows. The youngest sedimentary rock unit displaced by the fault is Lower Jurassic. However, displacement on the fault is down-to-the-west and is extensional in nature, suggesting that the fault is related to Basin and Range extension; it is probably Pliocene to middle Quaternary in age. In the southeast corner of the Kolob Arch quadrangle, the fault places cross-bedded Navajo Sandstone down against uppermost Kayenta strata; the planar bedded, lower Navajo appears to be faulted out, and if true, displacement on the fault there is likely about 500 feet (150 m).

Basaltic Lava Flows

Parts of three basaltic lava flows – the Grapevine Wash, Pintura, and Horse Ranch Mountain lava flows – are in the Kolob Arch quadrangle. In addition to providing a striking contrast to redrock scenery, the flows provide important information on fault slip rates and long-term incision rates in the area.

The youngest lava flow in the Kolob Arch quadrangle, one of the Grapevine Wash lava flows, barely reaches into the southeast corner of the quadrangle in Hop Valley. The Grapevine Wash lava flows erupted from a number of vents, including Firepit and Spendlove Knolls, on the Lower Kolob Plateau in The Guardian Angels quadrangle between about 220,000 and 310,000 years ago (Willis and Hylland, 2002). Most of the flows moved south down ancestral Grapevine Wash into the Left Fork of North Creek where a stack of at least 17 distinct cooling units total more than 400 feet (120 m) thick. At Hop Valley, however, a single flow is only about 20 feet (6 m) thick; interestingly, it straddles but is not offset by the East Cougar Mountain fault, showing that the fault has not ruptured the surface in about the past 300,000 years.

The Pintura lava flow is about 850,000 years old and covers the southwest part of the quadrangle where it is displaced by the Hurricane fault. The principal source of the flow is at the Pintura volcanic center, a cinder cone that straddles the southwest corner of the Kolob Arch quadrangle (Grant, 1995); apparently smaller vents are on top of Black Ridge in the adjacent Smith Mesa quadrangle (Lund and others, 2001; Sable and others, in preparation). From the Pintura volcanic center, the Pintura lava flow spread out more than 3 miles (5 km) to the north and also south nearly 12 miles (19 km) to the Virgin River (Biek, 2003). At the time of its eruption, the Hurricane Cliffs were not present and there was no significant topographic barrier as the lava flowed from the west side of the Hurricane fault to the east side (from hanging wall to footwall). Now, however, the flow caps the Hurricane Cliffs at Black Ridge and is also exposed at the base of the cliffs – it is torn in half by movement along the Hurricane fault. Flows in the hanging wall near Ash Creek are tilted about 10 degrees toward the fault and show that reverse drag, associated with curvature of the Hurricane fault at depth, is an important aspect of deformation in the hanging wall and complicates estimates of tectonic throw on the fault (see, for example, Hamblin, 1965). The flow thus serves as a marker that Lund and others (2001) used to determine long-term slip rates on the Hurricane fault. Based on geochemically correlated, dated basalt flows, and accounting for the effects of hanging-wall deformation, Lund and others (2001) calculated a long-term slip rate of 0.023 inches/year (0.57 mm/yr) for the Hurricane fault in the southwest part of the Kolob Arch quadrangle.

The Horse Ranch Mountain lava flow is about one million years old and is known only from exposures at Horse Ranch Mountain; the source of the flow is likely to the northeast in the Cedar Mountain quadrangle. Because the basalt is resistant to erosion, the flow "holds up" Horse Ranch Mountain, the highest point in Zion National Park (figure 5).

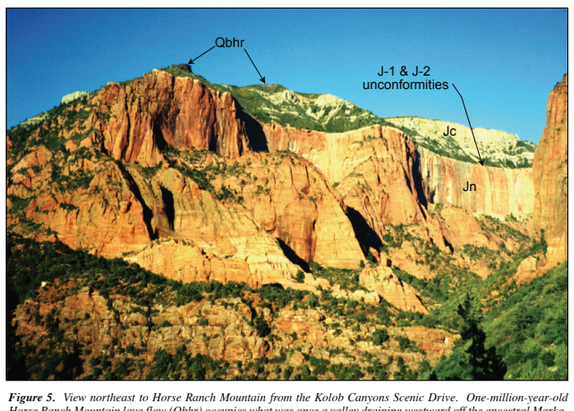


Figure 5. View northeast to Horse Ranch Mountain from the Kolob Canyons Scenic Drive. One-million-year-old Horse Ranch Mountain lava flow (Qbhr) occupies what was once a valley draining westward off the ancestral Markagunt Plateau, but that now, due to subsequent erosion of adjacent, less resistant sedimentary strata, forms resistant cap of Horse Ranch Mountain. Carmel Formation (Jc) and Navajo Sandstone (Jn) are separated by the remarkably planar J-1 and J-2 unconformities, between which is a few feet of the Sinawava Member of the Temple Cap Formation.

"Lakes" of Kolob Canyons

It may seem odd, situated as it is at the rugged, highly erosive, western margin of the Markagunt Plateau, but the Kolob Canyons area recently held several small Holocene lakes and ephemeral ponds, and one such ephemeral pond still exists in the spectacular canyon north of Beatty Point (figure 6). Because they are small and located in small catchment basins, most if not all of these "lakes" probably held water only during brief wet periods; most were probably more like bogs or broad alluvial plains. These small lakes and ephemeral ponds are known by the sediments they left behind, which, in the Kolob Canyons area, accumulated behind landslide dams that blocked small streams. Except for the Hop Valley and Beatty Lake dams, these dams are now entirely removed by erosion. The lake and basin-fill sediments locally contain fossil invertebrates, pollen, and even buried stumps and other plant debris indicative of environmental conditions at the time of deposition. Hamilton (1979, undated, 1995) described these lacustrine and basin-fill deposits.

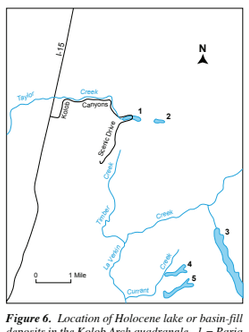


Figure 6. Location of Holocene lake or basin-fill deposits in the Kolob Arch quadrangle. 1 = Paria Lake, 2 = Beatty Lake, 3 = Hop Valley Lake, 4 = Currant Creek Lake, and 5 = Cane Creek Lake.

Hop Valley Lake - Hop Valley Lake is the youngest of the large landslide-dammed paleolakes of Zion National Park. The lake basin formed when a large landslide dammed the outlet from Hop Valley to La Verkin Creek in the southeast corner of the quadrangle. The landslide – or more properly, the collapse of an immense rock wall in the Navajo and Kayenta Formations – broke away along a series of joints that trend northwest, parallel to Hop Valley and the East Cougar Mountain fault. The thickness of lake and basin-fill sediments in Hop Valley is unknown, but they are probably about 250 feet (75 m) thick at the north end of the basin, and taper to a few tens of feet thick at the basin's south end. Depending on the gradient of the ancestral Hop Valley stream, the lake sediments could be as much as 320 feet (100 m) thick, as first estimated by Eardley (1966). The sediments are now partly dissected by the Hop Valley stream, creating terraces about 40 feet (12 m) high at the south end of the basin and about 15 feet (5 m) high at the north end. The terraces appear to be depositional surfaces, not erosional ones, for they lack meander scars or remnants of inset terraces, both common features of beveled surfaces. Normally, one might think that the terraces should be higher above the current stream near the outlet, where incision is greatest. However, the gentle northward slope of the terraces probably reflects the original northward slope of sandy basin-fill deposits, with the principal sediment supply to Hop Valley from the south end of the basin (Foos and Sharrow, 2002). The effect is an altogether enchanting valley seldom seen by visitors to the park (figure 7).

Eardley (1966) obtained a radiocarbon age of 670 ± 200 ^{14}C yr B.P. on wood collected at the north end of the Hop Valley deposits, about 15 feet (5 m) below the elevation of maximum fill. A peat deposit exposed in a stream bank at the southwest end of the basin (figure 8), first reported by Hamilton (1995), yielded a radiocarbon age of 2640 ± 60 ^{14}C yr B.P. (Beta Analytic Inc. and Utah Geological Survey, 2006), and may reflect the accumulation of organic debris blown by prevailing winds to the south end of the lake shortly after the lake's formation. Alternatively and more likely, Hop Valley Lake may never have filled completely during its initial stages, such that these peat deposits may reflect deposition sometime during the middle of the lake cycle, once part of the valley had filled with sediment. Regardless, the age of 2640 ± 60 ^{14}C yr B.P. establishes a minimum age for the lake's formation.

Figure 7. View north down Hop Valley from the Hop Valley trail. Hop Valley, in the southeast corner of the quadrangle, is filled with Holocene lacustrine and basin-fill sediments deposited when the valley outlet was blocked by a large landslide at least 2600 years ago. On skyline, note planar upper surface of the Navajo Sandstone, the J-1 unconformity.

Figure 8. Peat deposited at the south end of the Hop Valley basin yielded a radiocarbon age of 2640 ± 60 ^{14}C yr B.P. Photo by Grant Willis, Utah Geological Survey.

Paria Lake – Paria Lake formed behind a small landslide dam on the South Fork of Taylor Creek. The dam has been completely removed by erosion; it was probably located about 700 feet (200 m) west of the water gap formed by the Springdale Sandstone. The South Fork of Taylor Creek has since eroded through about 30 feet (9 m) of lake sediments. Thin-bedded, light-gray silty and sandy beds along the South Fork of Taylor Creek are visible from the Kolob Canyons Scenic Drive. Five radiocarbon ages from tree stumps preserved at the base of the deposits and organic debris near the top of the deposits show that the lake existed from about 3900 ± 60 ^{14}C yr B.P. to 2880 ± 200 ^{14}C yr B.P. (Eardley, 1966; Agenbroad and others, 1993; Hamilton, 1995). Pollen and snail shells collected from these beds suggest that the environment was more like a seasonal pond than a year-round lake (Hevly, 1979; Hamilton, 1995). Three stumps in growth position near the base of the deposits are progressively older downstream, also suggestive of a long period of aggradation of a shallow pond (Hamilton, undated).

Beatty Lake – About one-half mile (0.8 km) east of where the Kolob Canyons Scenic Road crosses the South Fork of Taylor Creek, a rockslide mass lies between Paria Point and Beatty Point. Eardley (1966) was the first to attribute a landslide origin to this dam, as later did Hamilton (1979), although Hamilton also noted that it looked almost like a terminal moraine. Agenbroad and others (1993) also suggested that the dam was of glacial origin. However, the southernmost glacial deposits identified in Utah are 15 miles (24 km) to the north at Brian Head at an elevation of over 10,000 feet (3000 m) (Mulvey and others, 1984), and the very small catchment basin between Paria and Beatty Points shows no evidence of ever holding glacial ice. The similarity to an end moraine is limited, and I, like Eardley, interpret the dam to have resulted from a massive rock fall of the Navajo Sandstone on the north side of Beatty Point. This rock fall formed a small, seasonal pond named Beatty Lake (figure 9). For most of the year, this "lake" is a small grassy meadow, but tree limbs and logs along the shoreline attest to at least seasonal flooding. The meadow lies in a closed basin about 10 feet (3 m) below the crest of the rock-fall dam. This seasonal pond has no drainage outlet, but springs are located near the toe of the rock fall. Upstream from the pond, the South Fork canyon is plugged with sediment deposited behind the dam, forming a flat, tree-covered valley floor that slopes gently up the drainage. Sediments continue to be deposited as the braided ephemeral wash of South Fork migrates across the valley floor, partly burying the trunks of mature trees (figure 10). Hamilton (undated) estimated the lake sediments to be about 200 feet (60 m) thick. The age of the rock fall is unknown, but based on comparison with nearby lake and basin-fill deposits, it is probably among the youngest large slides or rock falls in Zion National Park. Certainly it post-dates the 3000- to 4000-year-old Paria Lake deposits, present just downstream, which contain clays derived from Carmel strata; the Beatty Lake dam now blocks such sediment from reaching the lower reaches of the Middle Fork drainage. Agenbroad and others (1993) obtained a radiocarbon age of 310 ± 80 ^{14}C yr B.P. on bulk organics from a depth of 5.8 to 6.2 feet (1.79 to 1.90 m) in the meadow, from the younger part of the basin-fill deposits.

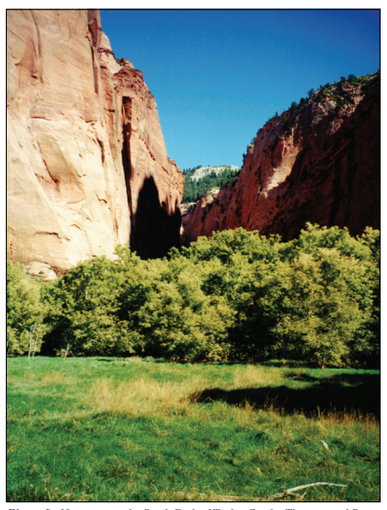


Figure 9. View east up the South Fork of Taylor Creek. The seasonal Beatty Lake periodically occupies the grassy meadow in the foreground.

Figure 10. Braided, ephemeral wash of the South Fork of Taylor Creek upsteam from Beatty Lake. Note how trees are slowly being buried as the South Fork migrates across the valley floor.

Currant Creek and Cane Creek Lakes – Currant Creek and Cane Creek basin-fill deposits are in the remote southeast part of the Kolob Arch quadrangle. The deposits are in a similar state of exhumation as the Paria Lake deposits, and the inferred dams for each have been entirely removed by erosion. The deposits are derived entirely from Navajo and Kayenta strata and so are sandier than Paria Lake deposits. The generally thin planar beds and thin peat lenses suggest deposition in a locally boggy alluvial basin. Two new radiocarbon ages of 2900 ± 70 ^{14}C yr B.P. and 630 ± 40 ^{14}C yr B.P. (Beta Analytic Inc. and Utah Geological Survey, 2006) establish the duration of Currant Creek Lake; based on their similar geomorphology, Cane Creek Lake deposits are likely of a similar age. Hamilton (undated) recovered a radius-ulna of *Ovis* sp. (bighorn sheep) associated with wood and gravel about 26 feet (8 m) above the base of the Currant Creek deposits. He also reported a radiocarbon age of 1650 ± 70 ^{14}C yr B.P. on a *Pinus*(?) stump in growth position near the upstream end of these deposits. While the similarities of the Currant and Cane Creek Lake deposits suggests that they may have formed at the same time, their location on separate drainages suggests a common method of landslide-dam formation, perhaps triggered by an earthquake on the Hurricane fault.

Kolob Arch

Kolob Arch, located just north of La Verkin Creek in the Kolob Canyons portion of Zion National Park, has a span of 310 feet (94.5 m), a window height of 330 feet (101 m), and a thickness of 80 feet (24 m) and is billed as the world's longest natural arch (Blake, 1984; Hamilton, 1995). The arch formed in the middle part of the massively cross-bedded Navajo Sandstone, and it appears to be related to north-northwest-trending joints, and possibly exfoliation joints, that are parallel to the East Cougar Mountain fault. Because the arch is located on an east-facing vertical wall, the best time to view the arch is in the morning. One cannot see the sky through the arch from the viewpoint, however, and a sign requests that hikers proceed no farther to protect the vegetation.

Uranium Prospect

Dasch (1967) reported uranium-bearing veins and pods with autunite and uranophane mineralization in brecciated Permian limestone of the Hurricane Cliffs just south of the Kolob Canyon Visitor Center. According to his report, the Kolob mine (named the Epsolon mine on the topographic base map) produced between 100 and 1000 tons of ore that was shipped sometime during the period 1949 to 1962. Several unprotected adits and small tailings piles are still visible in the cliffs.

ACKNOWLEDGMENTS

I appreciate the assistance of the following people and organizations: Dave Sharrow, National Park Service, who helped coordinate this mapping project; Laird Naylor, formerly with the National Park Service and now with the Bureau of Land Management, who also helped coordinate the early phases of mapping in Zion National Park; Pete Rowley, Geologic Mapping Inc., and Grant Willis, Mike Hylland, and Robert Ressetar, each with the Utah Geological Survey (UGS), for constructive reviews of this map and report; Gary Christenson, Sandy Eldredge, Hugh Hurlow, and Dave Tabet, each with the UGS, for also reviewing parts of this map and report; Bill Lund (UGS) and Stan Hatfield (Southwestern Illinois College) shared data on the Pintura basalt flow; Bill McIntosh and his colleagues at the New Mexico Geochronology Research Laboratory provided ^{40}Ar/^{39}Ar analyses; Dave Hacker, Kent State University, and Pete Rowley shared their knowledge of the Pine Valley laccolith and confirmed exposures of this rock along the Hurricane fault; Steve Heath (Southern Utah University) shared his knowledge of Herbert Gregory; Kent Brown (UGS) provided photogrammetric and GIS digital cartography support; Buck Ehler (UGS) assisted with final GIS preparation; and Jim Parker (UGS) drafted the illustrations. Lori Douglas and Sharon Hamre, both with the UGS, prepared plates 1, 2, and 3.