UTAH GEOLOGICAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES
in cooperation with the
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Plate 1
Utah Geological Survey Open-File Report 393
Interim Geologic Map of the Springdale East Quadrangle

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by

Hellmut H. Doelling, Grant C. Willis, Barry J. Solomon, Edward G. Sable, Wayne L. Hamilton, and Laird P. Naylor II

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OPEN-FILE REPORT 393 **July 2002**
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Interim Geologic Map of the Springdale East Quadrangle, Washington County, Utah

by

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Springdale East Quadrangle
Description of Map Units

QUATERNARY

Fill Deposits

Qf **Fill (Historical)** -- Fill placed by humans in dams and dikes; most road fill not shown; 0 to 100 feet (0-30 m) thick.

Alluvial Deposits

Low-level alluvial deposits of the Virgin River (upper Holocene) -- Moderately to well-sorted gravel, sand, silt, and clay in lenses and thin layers deposited by fluvial processes in larger, well-graded river valleys; generally reddish brown to pale brown; clasts are subrounded to well-rounded, mostly exotic (derived from sources many miles upstream) with some locally derived (from within quadrangle area), and are mostly quartzite, basalt, limestone, chert, and sandstone; most clasts are pebble to small cobble sized, especially below Springdale; upstream, most clasts are up to 1 foot (0.3 m) in diameter; a few locally derived clasts are more than 3 feet (1 m) in diameter; differs from alluvial deposits in small side canyons in that clasts are significantly better sorted and a large percentage are exotic; forms river channels and terraces up to about 25 feet (0-8 m) above the modern river level; 0 to 30 feet (0-9 m) thick.

Working with low-level terrace deposits in the Springdale area, Hereford and others (1995) recognized four episodes of terrace construction that are distinguished by elevation above the active channel, development of soils and vegetation, dating of trees, and archeological artifacts. Terrace deposits shown on this map approximately correlate with Hereford and others' divisions, but are more generalized -- age and correlation of most terrace segments were determined from aerial photographs and were only locally verified, and mapped terrace segments locally include segments from other fluvial episodes too small to map separately.

Qala **Level 1 (active channel) alluvial deposits (Historical)** -- Deposits in active river channel up to average annual high-water line about 4 feet (1.2 m) above modern river channel; deposited or reworked by the Virgin River mostly after A.D. 1980. Note: the river position shown on the gray topographic base map was taken from 1973 aerial photographs; the position of the river channel shown on the geologic map (map unit Qala) was taken from 1994 aerial photographs; during that time interval, the river channel in the Springdale East quadrangle has remained within a few feet of the same position in most areas, unlike areas downstream where more lateral migration has occurred (Willis and others, 2002); the most notable change is the relocation of a meander on the East Fork near Shunesburg.

Qatm **Level 2 ("modern") alluvial terrace deposits (Historical)** -- Deposits between about 4 feet (1.2 m) and 8 feet (2.4 m) above the active channel; generally vegetated with weeds and shrubs such as tamarisk; commonly covered every few years to decades by floods during unusually high spring runoff and following intense thunderstorms; Hereford and others (1995) referred to these sediments as the "modern" level and noted that they were deposited mostly between A.D. 1940 and 1980.

Qath **Level 3 ("historic") alluvial terrace deposits (Historical)** -- Deposits forming terraces 8 to 15 feet (2.4-4.6 m) above active channel; commonly mantled by fine-grained overbank silt, sand, and clay deposits; vegetated by cottonwood trees and mature shrubs; Hereford and others (1995) called these deposits the "historic" level; historic photographs show that the sediments of this level were deposited

mostly between A.D. 1883 and 1926 (1926 to 1940 was a period of arroyo cutting) (Hereford and others, 1995).

Qats **Level 4 ("settlement and late prehistoric") alluvial terrace deposits (upper Holocene)** -- Deposits forming terraces 15 to 25 feet (4.6-8 m) above the active channel; generally forms a broad terrace along the Virgin River and in side canyons that was the main surface for cultivation by the early settlers; today, where not cultivated, surface is covered mostly by sagebrush and is above the zone of abundant cottonwood trees in the river flood plain; in many areas terraces of this level are mostly covered by Qafc deposits; Hereford and others (1995) named this surface the "settlement surface" because earlier pioneer settlers built on and farmed it; they noted that during that time the fields and settlements were occasionally flooded during unusually high spring runoff; the settlement surface contains no Ancestral Puebloan (Anasazi) Indian artifacts, indicating that the sediment was deposited after about A.D. 1200; Hereford and others (1995) noted that river deposition on this surface ended by about A.D. 1880 as renewed arroyo cutting lowered the river channel; as generalized for this map, this unit locally includes surfaces mostly between about 25 and 33 feet (8-10 m), but locally as low as 20 feet (6 m) above the active channel that Hereford and others referred to as "prehistoric" and that may date to A.D. 800-1200.

Qat3, Qat4

High-level alluvial terrace deposits (middle Holocene to upper Pleistocene) -- Moderately to well sorted, pale-gray to pale-brownish-gray cobble gravel with sand, silt, and clay in lenses and matrix; clasts are mostly exotic and consist of quartzite, basalt, sandstone, limestone, and chert; form terrace remnants that cap hills and bluffs along the Virgin River; show moderate soil development; locally partially mantled by windblown sand, colluvium, and talus; as mapped, locally includes a thin apron of colluvium that sloughed downslope from the terraces; terraces of several different levels are grouped into two map units: Qat3 between 30 and 90 feet (9-27m) and Qat4 from 90 to 140 feet (27-43 m) above the active channel; 0 to 80 feet (0-24 m) thick.

The age of river-terrace and other deposits that are graded to the Virgin River can be estimated using calculated long-term incision rates, combined with amount of soil development and lithification. Present height of remnants of well-dated basaltic lava that flowed into the ancestral river channel downstream near the town of Virgin indicates about 1,300 feet (400 m) of incision in the last one million years, or 1.3 feet (0.4 m) per thousand years. Using this rate, Qat3 deposits are calculated between about 20,000 and 70,000 years old, and Qat4 deposits between 70,000 and 110,000 years old. However, these calculations do not take into account fluctuations in incision rates during this time, which could shift these age estimates significantly; in addition, low-level deposits show incision of 25 feet (8 m) or more in just the last few hundred years, though this type of variation probably reflects short-term cyclicity more than long-term incision rates; thus, Qat3 deposits, which would be most affected by short-term cyclicity, may be as young as middle Holocene.

Qa1 **Level 1 alluvial stream deposits (upper Holocene)** -- Stratified, fine- to coarse-grained, pale-orange to yellowish-brown sand with varying amounts of poorly to moderately sorted, clay, silt, and subangular to subrounded pebble to small boulder gravel with sandstone, limestone, and basalt clasts; mapped along larger tributaries of the Virgin River; up to about 10 feet (3 m) above the active channel; less well sorted than Qala and Qatm deposits, and does not include exotic clasts; generally less than 10 feet (3 m) thick.

Qa2 **Level 2 alluvial stream deposits (Holocene)** -- Same as Qa1deposits except forms incised terraces 10 to 30 feet (3-9 m) above the active channel and locally covered by windblown silt and fine-grained sand; as much as 20 feet (6 m) thick.

Qas **Alluvial sand deposits (Holocene to upper Pleistocene)** -- Well-sorted, fine- to medium-grained sand weathered from the Navajo Sandstone and deposited in washes; locally includes minor silt, gravel, and colluvium; 0 to 20 feet (0-6 m) thick.

Mixed Alluvial, Colluvial, and Eolian Deposits

Qafc **Young alluvial-fan and colluvial deposits (Holocene to upper Pleistocene)** -- Reddish-brown, poorly stratified, poorly sorted, coarse- to fine-grained sand and pebble to cobble gravel with silt and scattered boulders; clasts are angular to subangular and locally derived; deposited by debris flows and sheet wash at decrease in slopes and at mouths of small ephemeral channels that flow into Virgin River valley and major tributaries; mostly graded to and partially mantle Qath and Qats alluvial deposits, and commonly includes small secondary fan (not mapped separately) inset into main deposit that is graded to the active or modern channel; commonly interfingers with and covers alluvial stream deposits; forms most surfaces cultivated and built on by communities of Rockville and Springdale; in many areas debris flows have been deposited on these surfaces in historical times, sometimes causing considerable damage to buildings and roads; 0 to 30 feet (0-9 m) thick.

Qafco **Middle-level alluvial-fan and colluvial deposits (lower Holocene to upper Pleistocene)** -- Similar to Qafc deposits described above, except deposits are graded to older alluvial surfaces (Qat3 and Qat4), are incised by modern stream channels, and are no longer accumulating sediment; deposited by debris flows issuing from small side canyons; thickness probably less than 20 feet (6 m).

Qac **Mixed alluvium and colluvium (Holocene to upper Pleistocene)** -- Poorly to moderately sorted, poorly stratified sand, silt, and clay with scattered subangular to angular boulders, cobbles, and pebbles; brown to gray; deposited in minor drainages and topographic depressions primarily by ephemeral streams, slope wash, and creep processes; includes mix of alluvial materials carried down drainages and colluvial materials derived from adjacent slopes; may be dissected up to about 20 feet (6 m) by modern ephemeral stream channels; thickness less than 30 feet (9 m).

Qaco **Older mixed alluvium and colluvium (lower Holocene to upper Pleistocene)** -- Similar to mixed alluvium and colluvium (Qac) described above, but deeply dissected by ephemeral stream channels.

Qae **Mixed alluvial and eolian deposits (Holocene to upper Pleistocene) --** Locally derived, moderately to moderately well-sorted, mostly silt, clay, and fine sand with scattered lenses of subangular to angular gravel; deposited in shallow topographic depressions and on broad gentle slopes by slope wash and wind; includes small fans and colluvium from adjacent slopes; 0 to 20 feet (0-6 m) thick.

Qaes **Mixed alluvial and eolian sand deposits (Holocene to upper Pleistocene) --** Primarily pale-yellowish- to pale-reddish-gray, well-sorted sand deposited or reworked by ephemeral streams, with minor intermixed alluvial sand and pebble gravel deposits, rock-fall debris, and colluvium; deposited in stream channels and deep slot canyons cut into Navajo Sandstone; deposits in slot canyons commonly include windblown and talus sand; 0 to 20 feet (0-6 m) thick.

Qea **Mixed eolian and alluvial deposits (Holocene to upper Pleistocene)** -- Well-sorted, pale-reddish-brown to pale-yellowish-gray, windblown sand locally redeposited by alluvial processes; locally includes minor alluvial gravel; covers broad, gently sloping surfaces; deposits are relatively old and stable and are isolated from most erosion, allowing eolian sediments to gradually accumulate; scattered incisions through the deposits reveal stage II to IV pedogenic carbonate soil; generally less than 20 feet (6 m) thick.

Eolian and Residual Deposits

Qer **Mixed eolian and residual deposits (Holocene to upper Pleistocene)** -- Pale reddish-orange, windblown, well-sorted, mostly fine-grained sand with scattered to common angular to subrounded, residual sandstone blocks derived from the Navajo Sandstone; locally includes minor alluvial sand; occurs as sheets, mounds, and poorly formed dunes in shallow topographic depressions and on gently sloping surfaces mostly on Navajo Sandstone; 0 to 20 feet (0-6 m) thick.

Qre **Mixed fine-grained residual and eolian deposits (Holocene to upper Pleistocene) --** Reddish-brown to

pale-yellowish-gray, residual silt, clay, and fine sand with scattered subangular gravel deposited on flat surfaces eroded on lower part of Co-op Creek Limestone Member of the Carmel Formation; partly reworked by eolian processes; 0- to 10-foot-thick (0-3m).

Colluvial, Mass-Movement, and Related Deposits

Qc **Colluvium (Holocene to upper Pleistocene)** -- Poorly sorted, nonstratified sand and silt with subangular to angular mostly sandstone blocks; color and clast composition vary with parent material; deposited primarily by creep and slope wash on moderate slopes; locally includes talus and alluvial deposits; generally less than 20 feet (6 m) thick.

Qco **Older colluvium (lower Holocene to upper Pleistocene)** – Similar to colluvium (Qc) described above, but deeply dissected by ephemeral stream channels.

Qmt **Talus (Holocene to upper Pleistocene)** -- Primarily very poorly sorted, coarse, angular blocks on steep slopes; fine-grained interstitial component varies from abundant to absent; composed of blocks derived from immediately upslope ledges and cliffs; locally contains small landslide and slump masses and boulders with diameters exceeding 30 feet (9 m); mantles steep slopes beneath cliffs and ledges; locally includes undifferentiated colluvium and landslide deposits; commonly grades downslope into colluvial and alluvial deposits; generally 15 feet thick (4.5 m) or less, locally exceeds 30 feet (9 m) thick.

Qmts **Talus sand (Holocene to upper Pleistocene)** -- Cone-shaped deposits of sand commonly mantling talus, colluvium, and other slope-forming units; locally contains small landslide and slump masses and rock-fall blocks and boulders with diameters exceeding 30 feet (9 m); sand was mostly derived from eroding bare sandstone exposed upslope; locally concentrated by wind; up to 20 feet (6 m) thick.

Qmsh **Historical undifferentiated mass-movement slide and slump deposits (Historical)** -- Masses of rock and unconsolidated material that have undergone translational and/or rotational downslope movement; include zones of highly disturbed material, especially at landslide toes where movement is characterized by earth flow; typically associated with low-strength bentonitic mudstone and claystone in the Petrified Forest Member of the Chinle Formation and the Kayenta Formation; landslide features such as scarps and slide blocks are morphologically distinct; historical age documented by disturbed vegetation and open fractures; deposits may deflect stream flow; vary greatly in thickness, but most are estimated to be less than 50 feet (15 m) thick.

Qmsy **Younger undifferentiated mass-movement slide and slump deposits (Holocene to upper Pleistocene)** -- Masses of rock and unconsolidated material that have undergone translational and/or rotational downslope movement; bedrock strata within the blocks are commonly tilted and shattered; individual blocks may be as much as several hundred feet long; slip surfaces commonly develop in the clays of the Petrified Forest Member of the Chinle Formation and in silt and clay units in the Kayenta Formation; similar in character and occurrence to Qmsh, but landslide features such as scarps and slide blocks are morphologically less distinct as the result of weathering and erosion; locally includes deposits with historical movement; probably formed mostly during wet climatic regimes in the Pleistocene, but continue to move near springs and other wet areas, and where undercut or oversteepened by stream erosion or human activity; vary greatly in thickness, but most are probably less than 50 feet (15 m) thick.

Qmso **Older undifferentiated mass-movement slide and slump deposits (lower Holocene to middle Pleistocene)** -- Similar to Qmsy deposits but forms isolated mounds and erosional remnants of once larger landslide masses; includes large piles of debris from collapse of a rock wall near The Sentinel in Zion Canyon; locally may be more than 300 feet (90 m) thick.

Qmsc, Qms(n) Undifferentiated landslide complex (Holocene to middle Pleistocene) -- Large complex mass of slump, slide, and earthflow deposits; forms large hummocky mounds and hills in southwestern part of quadrangle; includes older, younger, and historical landslide deposits; locally reactivated with historical

movement along and upslope from incised channels; large mostly intact blocks of Navajo Sandstone mapped as Qms(n); 0 to 200 feet (0-60 m) thick.

Qmcp1, Qmcp2, Qmcp3

Older mass-movement, colluvial, and alluvial pediment-mantle deposits (lower Holocene to middle Pleistocene) -- Remnants of poorly sorted rock-fall, small slump block and landslide, colluvial, and generally minor alluvial-fan debris that mantle and armor gently sloping, pediment-like benches cut across bedrock; consist of angular and subangular, up to house-sized boulders to fine-grained sand, and lesser amounts of silt and clay derived from local cliffs and ledges; color is dependent on source formations; materials become coarser upslope; preserved as remnants that form inclined benches near steep bedrock slopes at high levels; these benches may be either remnants of much larger surfaces that were graded to the ancestral Virgin River, which at the time of deposition must have been up to several hundred feet above its present position, or are the remnants of sloping erosional surfaces mantled and protected from erosion by the coarse deposits and were not graded to the river; mapped deposits locally include aprons of colluvium derived from the pediment-mantle deposits; as much as 30 feet (9 m) thick; graded to several levels that project up to 700 feet (210 m) above the modern river channel; here divided into low-level (Qmcp1, in which the inclined surface projects less than about 100 feet [30 m] above the river), middle-level (Qmcp2, about 100 to 200 feet [30-60 m]), and high-level (Qmcp3, 200 to 700 feet [60-180 m]) deposits.

Lacustrine and Basin-Fill Deposits

Qls **Lacustrine and basin-fill deposits of Sentinel Landslide (Holocene)** -- Well-sorted, pale-gray, pale-yellowish-brown, to pale-reddish-brown, thin-bedded to laminated, planar-bedded clay, silt, sand, and marl; locally with soft-sediment slump features; form remnants draped across older alluvial, mass-movement, and bedrock deposits; locally as much as 150 feet (45 m) thick; deposits are mapped near canyon floor in Court of the Patriarchs to The Grotto area; organic debris from clayey lake deposits from drill hole near Court of the Patriarchs (NE1/4NE1/4SE1/4 section 10, T. 41 S., R. 10 W. yielded ^{14}C ages of 7,150"810 and 6,800"580 yrs B.P. (unpublished UGS data); sample from near top of deposits near Birch Creek yielded age of 3,600"400 yrs B.P. (Hamilton, 1995); lake was created by massive wall of Navajo Sandstone that collapsed, plugging Zion Canyon (mapped as Qmso deposits in The Sentinel area), and forming a dam that apparently lasted up to a few thousand years; even today the Virgin River has not fully incised the dam and lake deposits as the drill hole penetrated about 30 feet (9 m) of lake deposits below the level of the river.

Qlg **Lacustrine and basin-fill deposits of ancestral Lake Grafton (upper or middle Pleistocene)** -- Well-sorted, pale-gray, pale-yellowish-brown, and pale-reddish-brown, planar, thin-bedded to laminated clay, silt, sand, and marl, interbedded with lenses of pebble gravel to coarse sand; deposited by lacustrine and deltaic processes; caps Moquitch Hill; this outcrop is the only known preserved deposit in this quadrangle from a large lake that formed behind the Crater Hill basalt flow about 5 miles (8 km) down-river of Springdale; the lake extended upriver into the southern part of Zion Canyon; about 60 feet (20 m) thick, though base is poorly exposed; estimated at about 100,000 years old.

JURASSIC

Carmel Formation

Co-op Creek Limestone Member -- Interbedded light-bluish-gray to yellowish-gray, resistant, very thin- to medium-bedded, blocky weathering limestone and slope-forming calcareous shale; overall, forms steep ledgy slopes or a bench on top of the Temple Cap Formation; limestone is mostly micritic, but some beds are oolitic and sandy; has minor thin-bedded dolomite and sandstone; has locally abundant fossils, including pelecypods, gastropods, and crinoid columnals; *Pentacrinus asteriscus,* a Middle Jurassic crinoid, is common in some of the limestone beds; deposited in a marine (shallow sea) environment; uppermost part not preserved in quadrangle; complete member is 250 to 280 feet (76-85 m) thick.

Jccu **Upper ledgy unit** -- Thin- to medium-bedded, pale-yellowish-gray-weathering, micritic limestone; forms sparsely vegetated slopes and cliffs; about 100 to 110 feet (30-33 m) preserved in the quadrangle.

Jccl **Lower unit** -- Mostly thinly laminated to thin-bedded, pale-yellowish-gray weathering, calcareous shale and platy limestone; local ripup clast conglomerate at the base; forms steep, vegetated to partially barren slopes; contact with upper unit gradational and corresponds to a subtle break in slope and vegetation patterns; 150 to 170 feet (46-52 m) thick.

J-2 unconformity

Temple Cap Formation

Jtw **White Throne Member** -- Very light-gray to pale-orange, cliff-forming sandstone resembling the white Navajo Sandstone; consists of fine-grained, well-sorted, cross-bedded sandstone; has high-angle tabular-planar or wedge-planar cross-beds in sets as much as 20 feet (6 m) thick; deposited in an eolian environment; thickness varies due to unconformity at top; upper contact is sharp and marked by a reddish zone at the base of the Co-op Creek Limestone Member of the Carmel Formation; 60 to 165 feet (18-50 m) thick; thins westward.

Jts **Sinawava Member** -- Interbedded, fine-grained sandstone, silty sandstone, and mudstone; generally forms prominent reddish-brown to dark-red vegetated bench or ledgy slope; locally forms recessed cliff between the White Throne Member and the white Navajo Sandstone; red color locally streaks the white Navajo cliffs below; interfingers with the White Throne Member at the top; deposited in coastal sabkha and tidal-flat environments; 80 to 140 feet (24-42 m) thick; thins eastward.

J-1 unconformity

Jn **Navajo Sandstone** -- (undivided on cross section only) Massive, cliff-forming, cross-bedded, locally highly jointed sandstone; forms spectacular sheer cliffs, deep canyons, and impressive spires, promontories, and monoliths; consists mostly of well-sorted, fine- to medium-grained, quartzose sandstone; bedding consists of high-angle, large-scale cross-bedding in tabular-planar, wedge-planar, or trough-shaped sets 10 to 45 feet or more (3-14+ m) thick; ironstone bands and concretions locally common (white friable sandstone contains about 0.1% Fe_2O_3; densest ironstone samples contain up to 21% Fe_2O_3; table 1); deposited in a vast eolian coastal to inland erg (dune field) environment with prevailing winds principally from the north; lower 200 to 400 feet (60-120 m) consists of a transitional interval with planar bedding, evaporite mineral casts, crinkly or wavy bedding, load structures (typically a few inches in amplitude), and bioturbation indicative of a coastal sabkha environment; upper contact is an unconformity that makes a sharp break below the slope of the red Sinawava Member; surface of unconformity is imperceptibly broadly rolling, but across the quadrangle resulting in a nearly imperceptible thickness difference of the Navajo of a few hundred feet; divided into three generalized non-stratigraphic units based on color and weathering habit; 1,800 to 2,200 feet (550-670 m) thick.

Jnw **White Navajo** -- Upper part of Navajo Sandstone; very light gray or white because of alteration, remobilization, and bleaching of limonitic and hematitic (iron-bearing) cement; generally forms a massive cliff; includes upper 400 to 800 feet (120-240 m) of the formation in Zion National Park.

Jnp **Pink Navajo** -- Middle part of Navajo Sandstone; generally less resistant than the white Navajo above and brown Navajo below; forms benches, steep slopes, and cliffs; pale-reddish-brown color is more uniform than in units above and below due to more uniformly dispersed hematitic (iron-bearing) cement; locally contains dark green cement (possibly celadonite - an iron-bearing micaceous mineral), and ironstone bands, concretions, and cement; 400 to 1,000 feet (120-300 m) thick.

Jnb **Brown Navajo** -- Lower part of the Navajo Sandstone; upper contact is at the top of a dark-brown, irregular and undulating band overlain by a broad light-colored band; generally forms a massive cliff;

roughly correlative with the lower transitional beds of the Navajo; 400 to 600 feet (120-180 m) thick.

Jk **Kayenta Formation (entire formation in areas where Lamb Point Tongue of Navajo Sandstone not mapped, and in cross section; lower part (main body) in areas where Lamb Point and Tenney Canyon Tongues are mapped separately)** -- Moderate to dark reddish-brown siltstone and sandstone similar to that described for the Tenney Canyon Tongue; contains 20 to 30 percent sandstone ledges in the Zion National Park area; forms steep ledgy slope; upper contact gradational over a few feet but placed at top of steep slope- or ledgy cliff-forming, thin- to medium-bedded sandstone with siltstone partings, and at base of laterally continuous, thick- to massive-bedded, cliff-forming sandstone; deposited in an area of little relief near a terrestrial-marine transition zone alternating between mudflats and fluvial environments; locally has thin to medium ledgy sandstone beds similar to Springdale Sandstone in lower part; entire formation is between 550 and 700 feet (170-210 m) thick; lower part below the Lamb Point Tongue is about 290 to 400 feet (88-120 m) thick.

Jkt **Tenney Canyon Tongue of Kayenta Formation** -- Upper part of Kayenta Formation in areas where Lamp Point Tongue is present; lenticular beds of pale-reddish-brown to moderate reddish-orange siltstone and very fine-grained sandstone; minor claystone and limestone; forms a steep slope; 140 to 315 feet (43-96 m) thick where separated from the main body.

Jnl **Lamb Point Tongue of Navajo Sandstone** -- Mostly reddish-brown, fine to very fine-grained, well-sorted, quartzose sandstone; prominently jointed; forms a vertical ledge in the upper one-third of the Kayenta Formation; strongly cross-bedded; contains scattered thin lenses of flat-bedded, pale-reddish-brown siltstone and claystone similar to Kayenta Formation beds; upper contact placed at top of thick, laterally consistent ledge interval; locally contains a 1-foot-thick (30 cm) bed of limestone near the top; deposited in an eolian erg and sabkha environment; thins and pinches out to west in the quadrangle; 0 to 120 feet (0-37 m) thick.

Moenave Formation

Jms **Springdale Sandstone Member of Moenave Formation** -- Mostly pale-reddish-purple to pale-reddish-brown, moderately sorted, very fine- to medium-grained, medium- to thick-bedded, cross-bedded sandstone; locally contains intraformational conglomerate consisting of rounded chips of mudstone and siltstone in a sandstone matrix; has large lenticular and wedge-shaped, low-angle, medium- to large-scale cross-bedding; secondary color banding that varies from concordant to discordant with cross-bedding is common in the sandstone; generally forms a vertical to irregular ledgy cliff; upper contact with Kayenta Formation is generally sharp and even; deposited in a fluvial environment of constantly shifting stream channels; 90 to 150 feet (27-46 m) thick.

Jmw **Whitmore Point Member of Moenave Formation** -- Grayish-red, pale-reddish-brown, and pale-greeenish-gray siltstone, fine-grained sandstone and claystone; sandstone beds are similar to sandstone in Springdale Sandstone; siltstone is commonly thin bedded to laminated in lenticular or wedge-shaped beds; claystone is generally flat-bedded; slope forming; the upper contact of the member is generally sharp but irregular where scoured by the overlying Springdale; locally contains fish scales and bone fragments; deposited in low-energy lacustrine and fluvial environments; about 60 to 85 feet (18-26 m) thick.

Jmd **Dinosaur Canyon Member of Moenave Formation** -- Uniformly colored, moderate to dark reddish-orange to pale-reddish-brown, thin-bedded siltstone, very fine-grained sandstone, and claystone; near the base, contains a minor amount of conglomerate similar to beds in underlying Petrified Forest Member of the Chinle Formation; forms an irregular slope slightly steeper than that of the Whitmore Point; the upper part is marked by a series of more resistant sandstone beds that help define the contact with the Whitmore Point Member above; commonly ripple-marked or mud-cracked; deposited on a broad, low, stream-meander floodplain that was locally shallowly flooded by water (fluvial mudflat); about 150 to 270 feet (46-82 m) thick.

J-0 unconformity

TRIASSIC

Chinle Formation

TRcp **Petrified Forest Member of Chinle Formation** -- Brightly variegated, light-brownish-gray, pale-greenish-gray, to grayish-purple, smectitic shale, siltstone, claystone, sandstone, and pebble to small cobble conglomerate; contains common, locally mineralized fossil wood (table 1); weathers as badlands; mostly slope-forming; very prone to landsliding; upper contact is an erosional surface with only slight relief; contains locally prominent, thick, resistant sandstone and conglomerate ledges in lower and middle parts of unit; deposited in lacustrine, floodplain, and braided-stream environment; about 400 to 500 feet (120-150 m) thick.

TRcs **Shinarump Conglomerate Member of Chinle Formation** -- Shown on cross section only; about 60 to 135 feet (18-41 m) thick.

TRm **Moenkopi Formation, undivided** -- Shown on cross section only; about 1,700 feet (520 m) thick.

REFERENCES

Hamilton, W.L., 1995, The Sculpturing of Zion: Springdale, Utah, Zion Natural History Association, 132 p.

Hereford, R., Jacoby, G.C., and McCord, V.A.S., 1995, Geomorphic history of the Virgin River in the Zion National Park area, southwest Utah: U.S. Geological Survey Open-File Report 95-515, 75 p.

Willis, G.C., Doelling, H.H., Solomon, B.J., and Sable, E.G., 2002, Interim geologic map of the Springdale West quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 394, xx p., 1:24,000.

Willis, G.C., and Hylland, M.D., 2002, Interim geologic map of The Guardian Angels quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 395, xx p., 1:24,000.

Caption for plate 2 index map:

Zion National Park area. Available 1:24,000 scale, 7.5' quadrangle geologic maps are: Open-file report (black and white) geologic maps: Kolob Arch quadrangle - Biek, 2002, Utah Geological Survey Open-File Report 386; Kolob Reservoir quadrangle - Biek, 2002, Utah Geological Survey Open-File Report 387; Cogswell Point quadrangle, Biek and Hylland, 2002, Utah Geological Survey Open-File Report 388; The Guardian Angels quadrangle - Willis and Hylland, 2002, Utah Geological Survey Open-File Report 395; Temple of Sinawava quadrangle - Doelling, 2002, Utah Geological Survey Open-File Report 396; Clear Creek Mountain quadrangle, Hylland, 2001, Utah Geological Survey Open-File Report 371; Springdale West quadrangle - Willis and others, 2002, Utah Geological Survey Open-File Report 394; Springdale East quadrangle - Doelling and others, 2002, Utah Geological Survey Open-File Report 393. Published (color) geologic maps: The Barracks quadrangle - Sable and Doelling, 1993, Utah Geological Survey Map 147; Smithsonian Butte quadrangle - Moore and Sable, 2001, Utah Geological Survey Miscellaneous Publication 01-1; Hildale quadrangle - Sable, 1995, Utah Geological Survey Map 167.

Grand Staircase figure caption:

Zion National Park is near the western edge of the Grand Staircase, which starts at the Grand Canyon in Arizona and "stair-steps" northward to the high plateaus of southern Utah. Risers are resistant cliff-forming layers of rock; treads are eroded non-resistant layers that form benches and mesas several miles across.

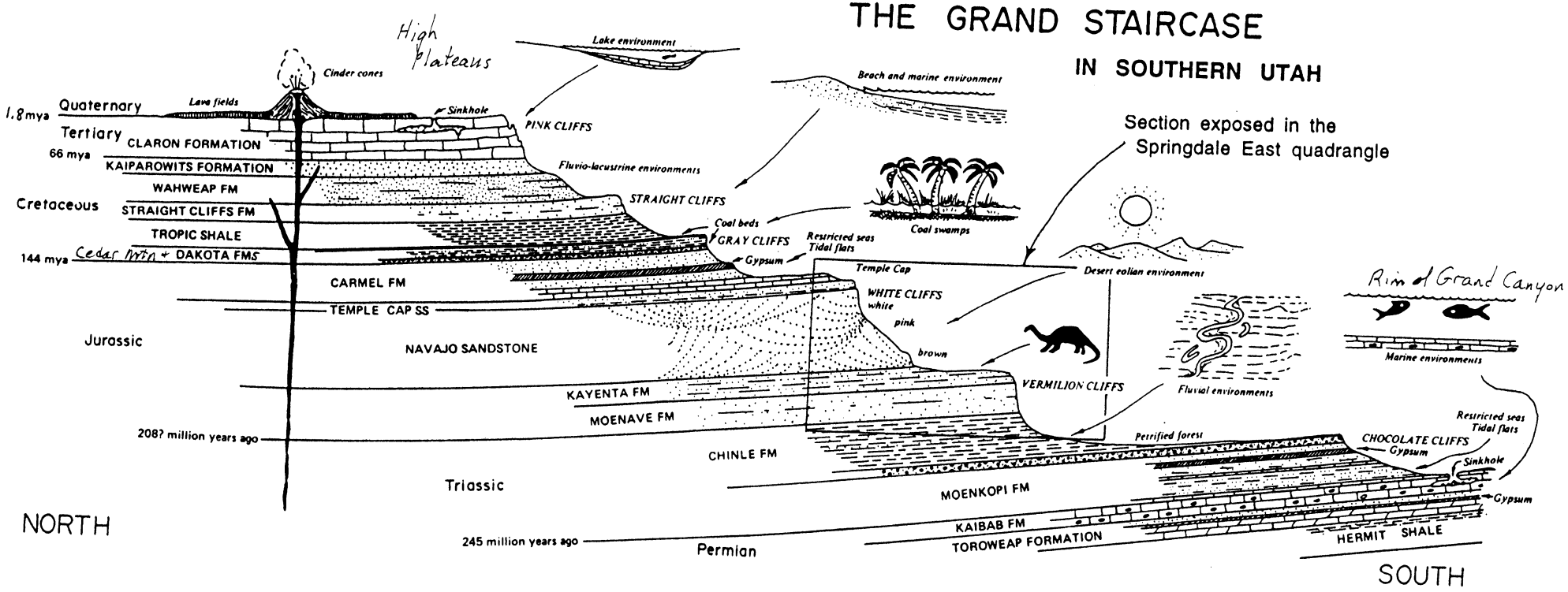

THE GRAND STAIRCASE
IN SOUTHERN UTAH
Section exposed in the Springdale East quadrangle
High plateaus
Cinder cones
Lava fields
Sinkhole
Lake environment
Beach and marine environment
Fluvio-lacustrine environments
Coal swamps
Coal beds
Restricted seas Tidal flats
Gypsum
Desert eolian environment
Temple Cap
Rim of Grand Canyon
Marine environments
Flusial environments
Petrified forest
Restricted seas Tidal flats
Gypsum
Sinkhole
1.8mya
Quaternary
Tertiary
66 mya
Cretaceous
144 mya
Jurassic
208? million years ago
Triassic
245 million years ago
Permian
PINK CLIFFS
CLARON FORMATION
KAIPAROWITS FORMATION
WAHWEAP FM
STRAIGHT CLIFFS
STRAIGHT CLIFFS FM
GRAY CLIFFS
TROPIC SHALE
Cedar Mtn + DAKOTA FMS
CARMEL FM
TEMPLE CAP SS
WHITE CLIFFS
white
pink
brown
NAVAJO SANDSTONE
VERMILION CLIFFS
KAYENTA FM
MOENAVE FM
CHINLE FM
CHOCOLATE CLIFFS
MOENKOPI FM
KAIBAB FM
TOROWEAP FORMATION
HERMIT SHALE
NORTH
SOUTH

Table 1. Analyses of selected samples from the Springdale East quadrangle (see map for location).

Samples indicating variability of cementation and alteration in Navajo Sandstone:
ZP1002 Fine-grained sandstone fallen from overlying cliffs; dark-green (possibly celadonite) cement
ZP3201 White friable fine-grained sandstone
ZP3202 Dark brownish red to yellowish red, oxidized sandstone in alternating color bands
ZP3203 Ironstone composed of fine-grained sandstone with dull greenish-brown mottling
ZP3204 Densely cemented ironstone composed of fine-grained sandstone with shiny dark-brown to brownish-black ribbed veins
ZP3205 Reddish-brown fine-grained sandstone ("typical Navajo Sandstone"); collected in The Guardian Angels quadrangle (Willis and Hylland, 2002)

Sample indicating unusually high mineralization of petrified wood from Petrified Forest Member of Chinle Formation
ZP1021 Petrified wood in alluvium; strong copper mineralization

Part 1. Note variability of oxidized iron (Fe_2O_3). Very low FeO (reduced iron) reflects strong oxidation of Navajo Sandstone. Analyzed by X-Ray Refractometry (in percent).

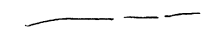
Sample	Al2O3	CaO	Cr2O3	Fe2O3	K2O	MgO	MnO	Na2O	P2O5	SiO2	TiO2	LOI	Total	(FeO)
ZP3201	2.1	0.03	<0.01	0.11	1.21	<0.01	<0.01	<0.01	0.03	95.31	0.04	0.24	99.07	0.09
ZP3202	1.4	0.08	<0.01	11.12	0.63	<0.01	0.94	<0.01	0.09	82.41	0.13	2.22	99.02	0.25
ZP3203	2.09	7.62	<0.01	1.14	1.44	0.20	0.11	0.19	0.02	79.71	0.05	6.52	99.09	<0.01
ZP3204	1.65	0.04	<0.01	21.25	0.77	<0.01	0.08	<0.01	0.05	71.81	0.14	3.24	99.03	0.15
ZP3205	4.18	4.21	0.02	0.93	2.65	1.48	0.06	<0.01	0.06	79.97	0.26	5.26	99.08	0.11

Part 2. Note gold, silver, and copper in ZP1021. Analyzed by ICP method. ppb-parts per billion; ppm-parts per million

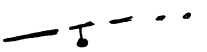
Sample	Au ppb	Ag ppm	Cu	Mo ppm	Ni ppm	Co ppm	Cd ppm	Pb ppm	Bi ppm	Zn ppm	As ppm	Sb ppm	Fe %	Mn ppm	Te ppm	Ba ppm	Cr ppm	V ppm	Sn ppm	W ppm	La ppm	Al %	Mg %	Ca %	Na %	K %	Sr ppm	Y ppm	Ga ppm	Li ppm	Nb ppm	Sc ppm	Ta ppm	Ti %	Zr ppm
ZP1002	<5	<0.2	12ppm	1	10	4	<0.2	4	<5	36	<5	<5	0.86	1359	<10	209	117	8	<20	<20	<1	0.07	2.78	5.36	0.01	0.11	26	4	<2	5	2	<5	<10	<.01	2
ZP1021	583	31.1	6%	2	5	2	<0.2	37	24	10	7	<5	0.41	293	<10	181	150	83	<20	<20	<1	0.06	0.03	0.30	0.02	0.01	55	17	<2	<1	25	<5	<10	<.01	<1

Explanation of Map Symbols

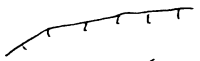
Springdale East Quadrangle



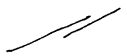
Contact -- dashed where approximately located



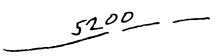
Normal fault -- dashed where approximately located, dotted where concealed, bar and ball on down-thrown side



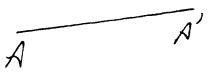
Landslide or slump scarp



Major joint -- near vertical, only small percentage mapped individually



Structural contour -- drawn on base of Navajo Sandstone; dashed where projected above ground surface; contour interval 100 feet (30 m); datum sea level

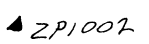


Cross section line

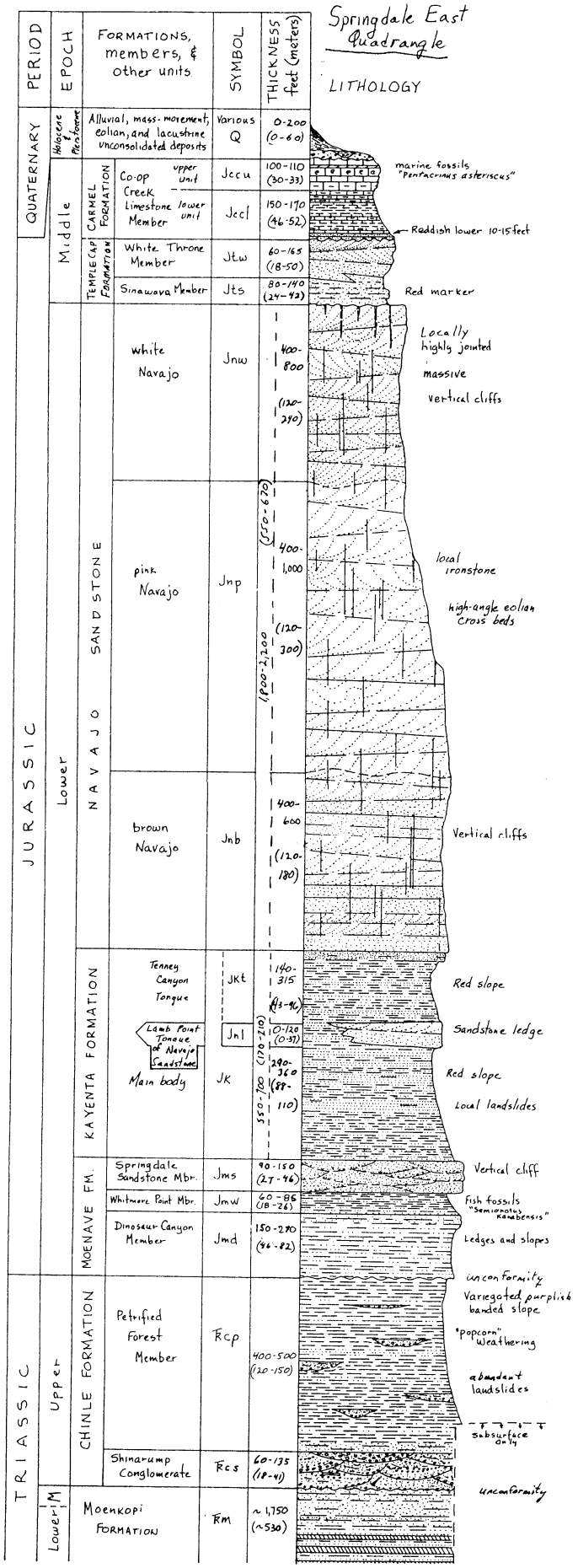
Primary and secondary joints -- near vertical

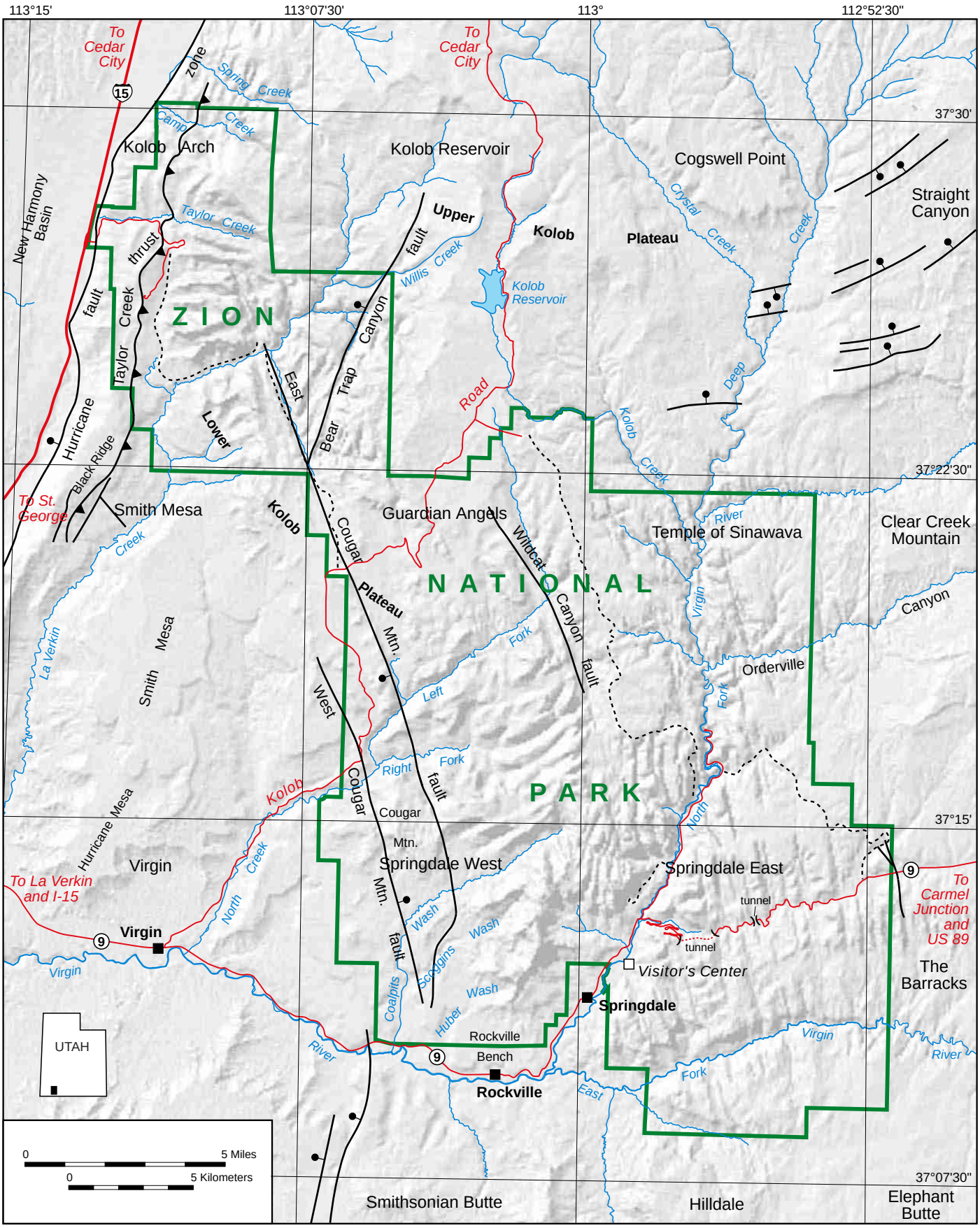
Strike and dip of bedding -- measured photogrammetrically

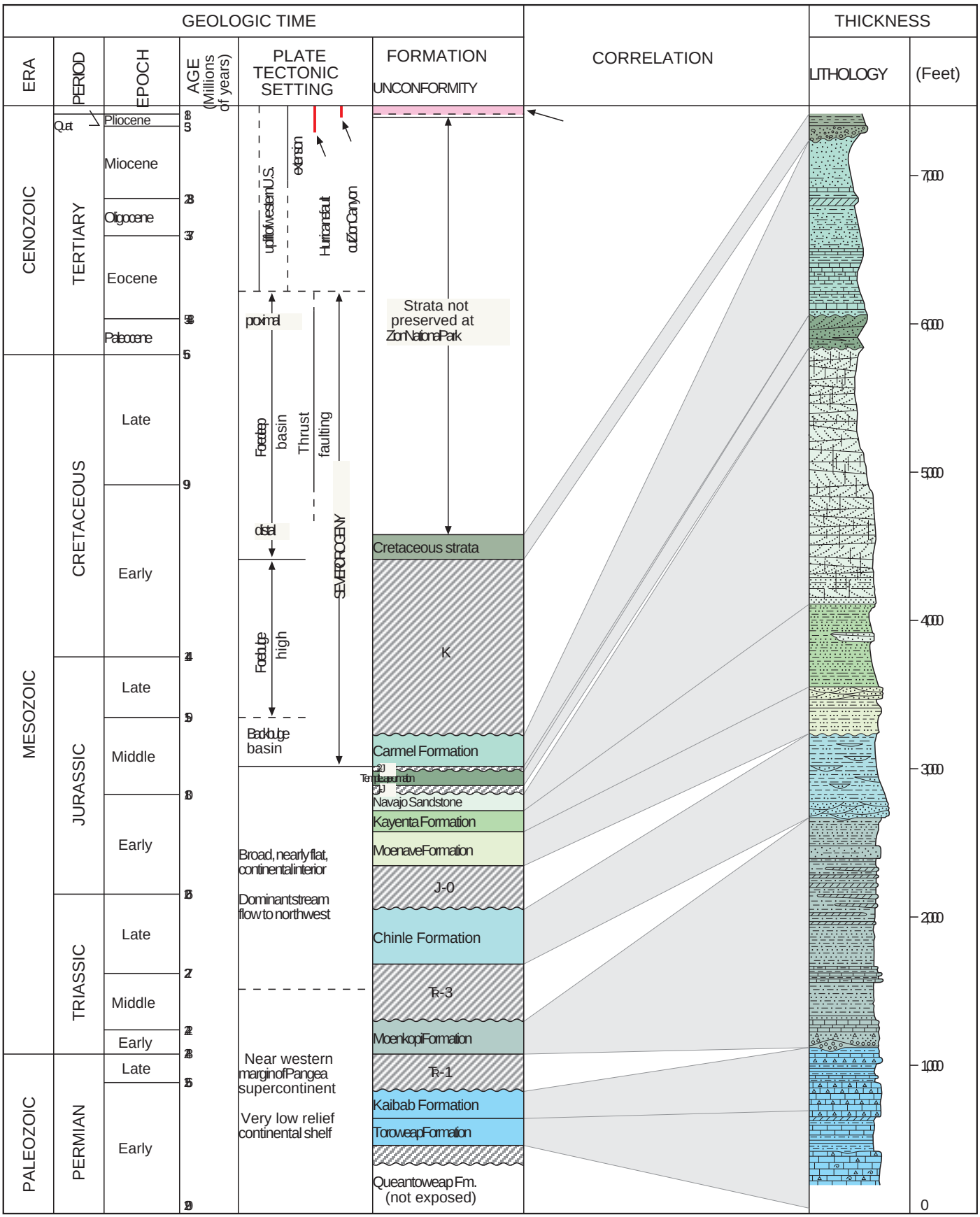
Shallow drill hole



Sample location with sample number

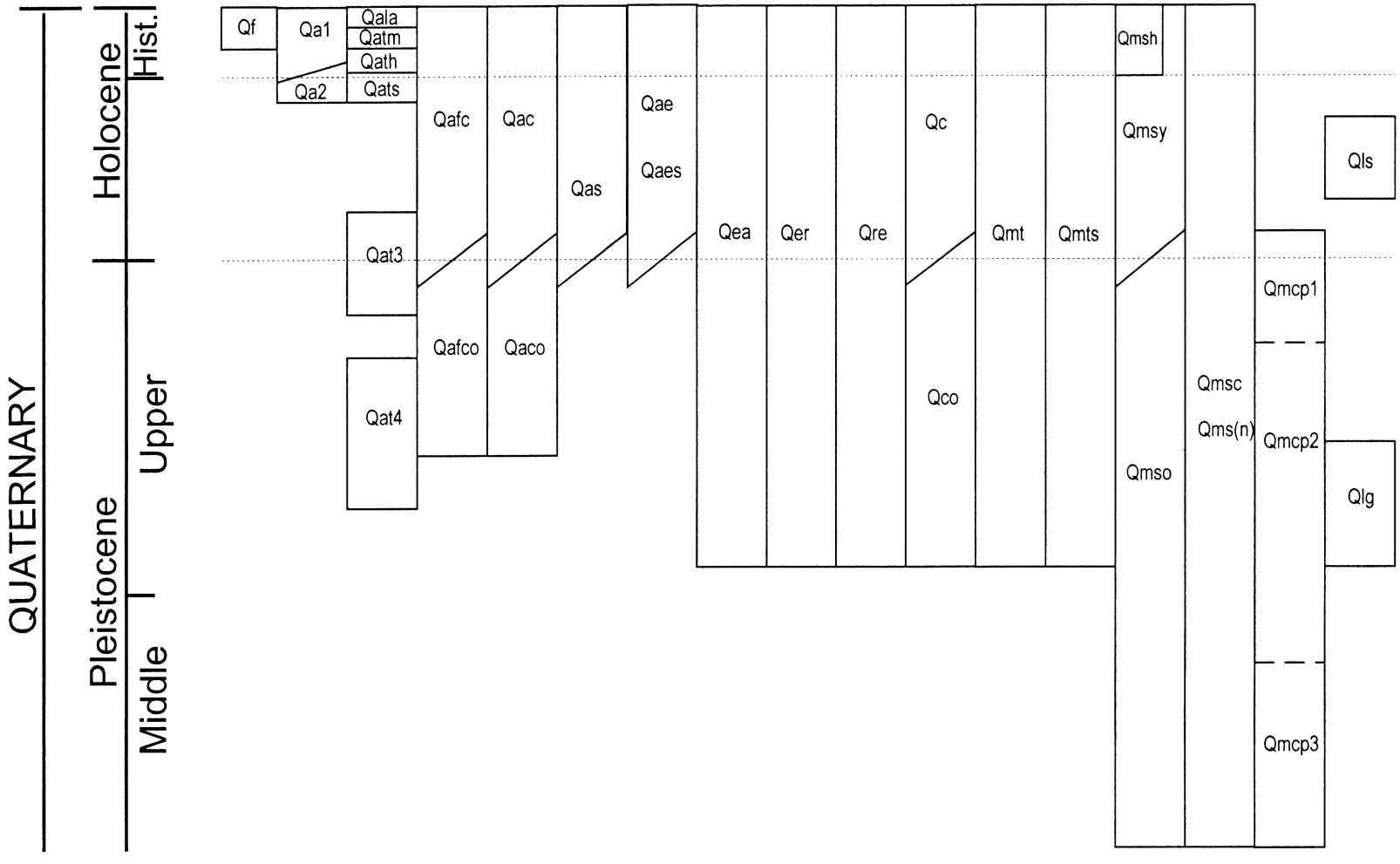

Springdale East Quadrangle
LITHOLOGY
PERIOD
EPOCH
FORMATIONS, members, & other units
SYMBOL
THICKNESS feet (meters)
QUATERNARY
TRIASSIC
JURASSIC
Holocene and Pleistocene
Alluvial, mass-movement, eolian, and lacustrine unconsolidated deposits
Various Q
0-200 (0-60)
Middle
Lower
Upper
Lower(?) M
CARMEL FORMATION
Co-op Creek Limestone Member
upper unit
lower unit
Jccu
Jccl
100-110 (30-33)
150-170 (46-52)
marine fossils "Pentacrinus asteriscus"
Raddish lower 10-15 feet
TEMPLE CAP FORMATION
White Throne Member
Jtw
60-165 (18-50)
Sinawava Member
Jts
80-140 (24-43)
Red marker
NAVAJO SANDSTONE
white Navajo
Jnw
400-800 (120-240)
Locally highly jointed massive vertical cliffs
pink Navajo
Jnp
400-1,000 (120-300)
local ironstone
high-angle eolian cross beds
brown Navajo
Jnb
400-600 (120-180)
Vertical cliffs
1,200-2,200 (350-670)
KAYENTA FORMATION
Tenney Canyon Tongue
JKt
140-315 (43-96)
Red slope
Lamb Point Tongue of Navajo Sandstone
Jnl
10-120 (0-37)
Sandstone ledge
Main body
JK
290-360 (88-110)
Red slope
Local landslides
550-700 (170-210)
MOENAVE FM.
Springdale Sandstone Mbr.
Jms
90-150 (27-46)
Vertical cliff
Whitmore Point Mbr.
Jmw
60-86 (18-26)
Fish fossils "Semionotus Kanabensis"
Dinosaur Canyon Member
Jmd
150-270 (46-82)
Ledges and slopes
unconformity
CHINLE FORMATION
Petrified Forest Member
Rcp
400-500 (120-150)
Variegated purplish banded slope
"popcorn" weathering
abundant landslides
subsurface only
Shinarump Conglomerate
Rcs
60-135 (18-41)
unconformity
MOENKOPI FORMATION
Rm
~1,750 (~530)


113°15'
113°07'30"
113°
112°52'30"
37°30'
37°22'30"
37°15'
37°07'30"
To Cedar City
To Cedar City
15
Zone
Spring Creek
Camp Creek
Kolob Arch
Kolob Reservoir
Cogswell Point
Straight Canyon
New Harmony Basin
Taylor Creek
thrust
fault
Creek
taylor
fault
Hurricane
Black Ridge
Lower
East
Trap
Bear
Canyon
Upper
Kolob
Plateau
Crystal
Creek
Creek
Willis Creek
Kolob Reservoir
Deep
Road
Kolob
Creek
ZION
NATIONAL
PARK
To St. George
Smith Mesa
Kolob
Cougar
Plateau
Guardian Angels
Wildcat
Canyon
fault
River
Temple of Sinawava
Clear Creek Mountain
Creek
La Verkin
Smith
Mesa
Mtn.
West
Fork
Left
Virgin
Canyon
Orderville
Fork
Right
Fork
Kolob
Cougar
fault
North
Hurricane Mesa
Virgin
Springdale West
Springdale East
To La Verkin and I-15
Creek
North
Mtn.
Wash
Wash
tunnel
tunnel
To Carmel Junction and US 89
Virgin
fault
Scoggins
Visitor's Center
The Barracks
Springdale
Coalpits
Huber
Wash
Rockville
Bench
Rockville
River
Virgin
River
Fork
East
UTAH
0
5 Miles
0
5 Kilometers
Smithsonian Butte
Hilldale
Elephant Butte

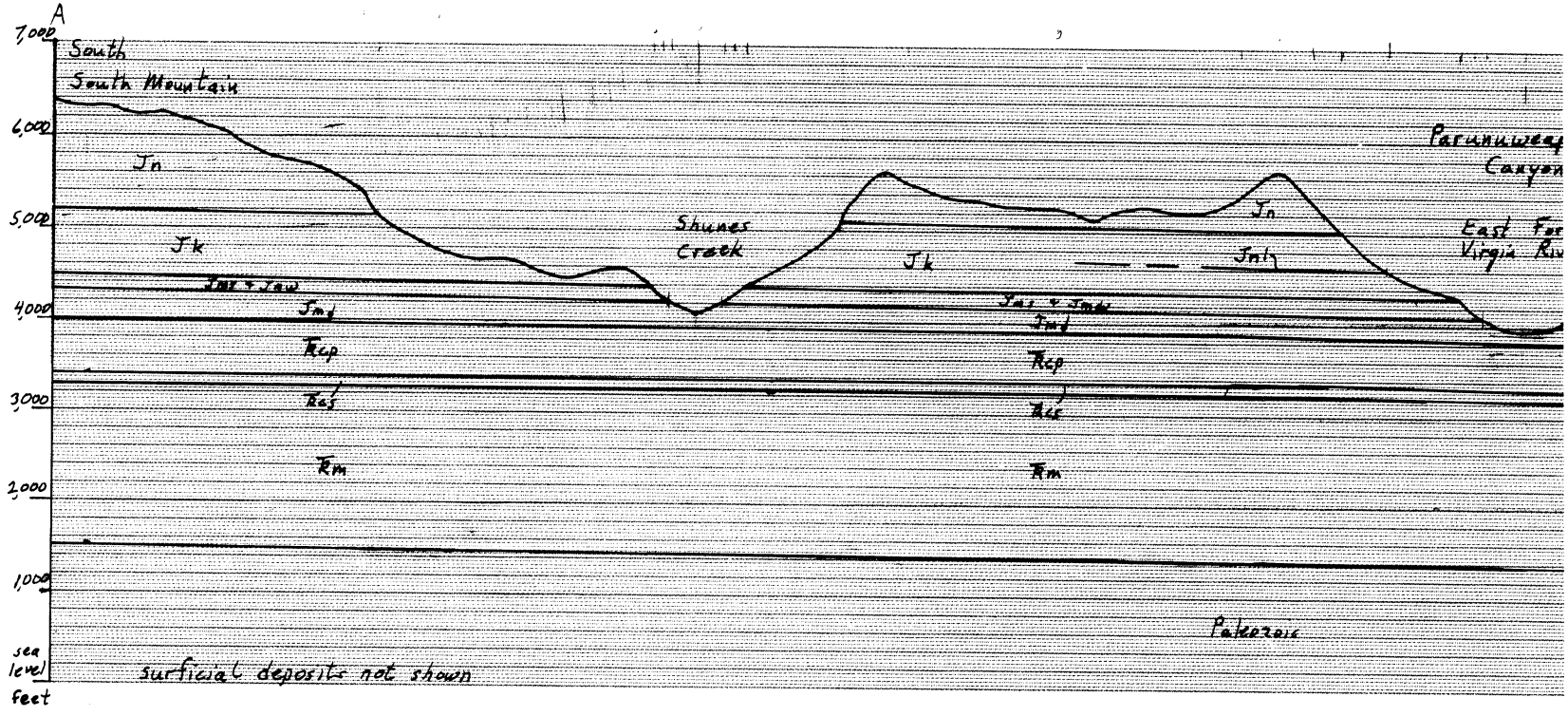


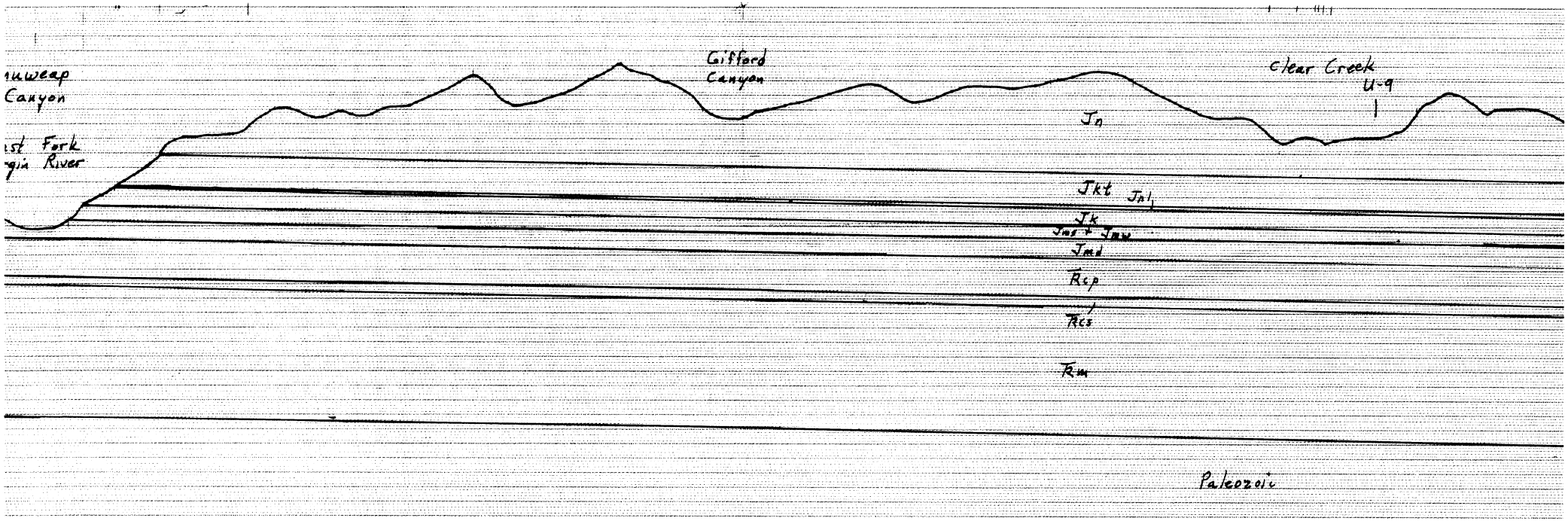
Relationship between age and thickness of rocks exposed in Zion National Park.

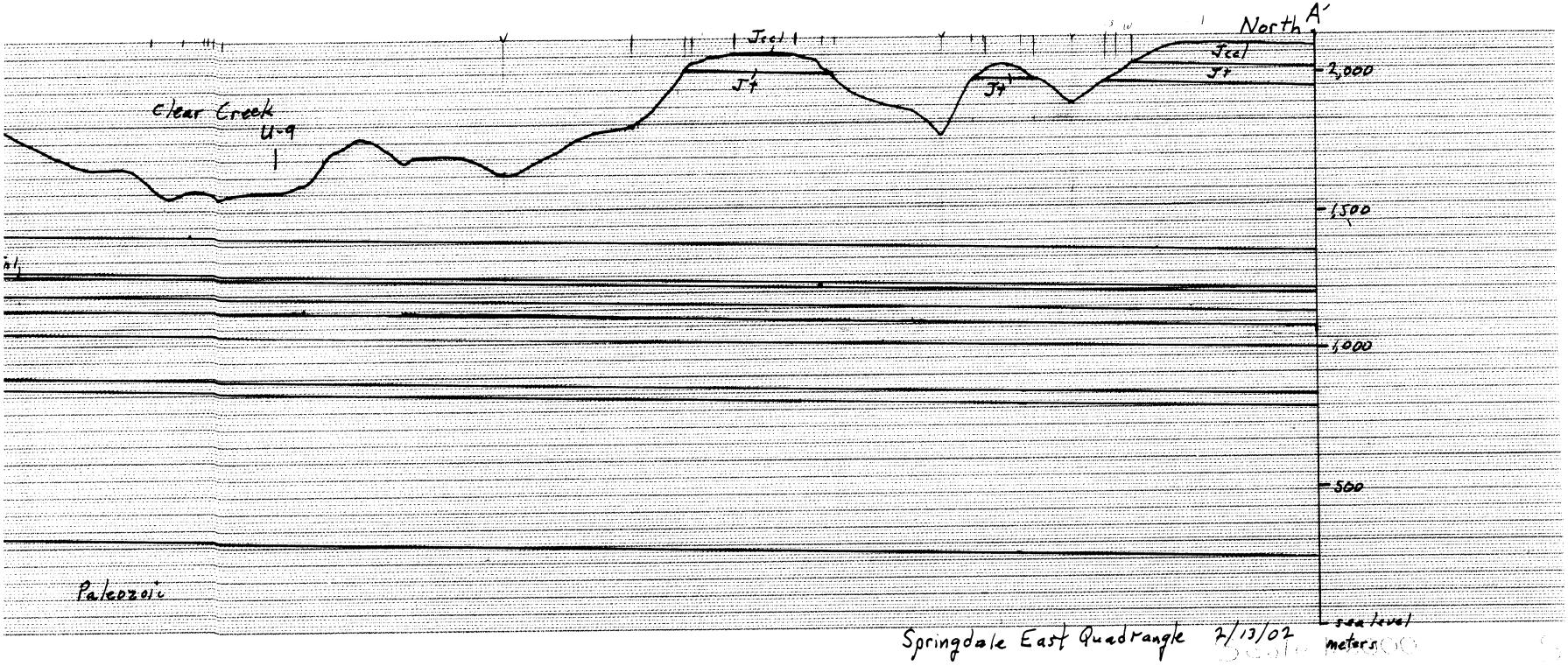
Correlation of Surficial Map Units



Springdale East Quadrangle


A
7,000
6,000
5,000
4,000
3,000
2,000
1,000
sea level
feet
South
South Mountain
Jn
Jk
Jmj
Rcp
Rcs
Rm
Shunes
Creek
Jn
Jmh
Paleozoic
surficial deposits not shown


nuweap
Canyon
1st Fork
gin River
Gifford
Canyon
clear Creek
U-9
Jn
Jkt
Jhl
Jk
Jms + Jmw
Jmd
Rcp
Rcs
Rm
Paleozoic



Springdale East Quadrangle 7/13/02

Scale 1:24000
10' Interval
50' Index