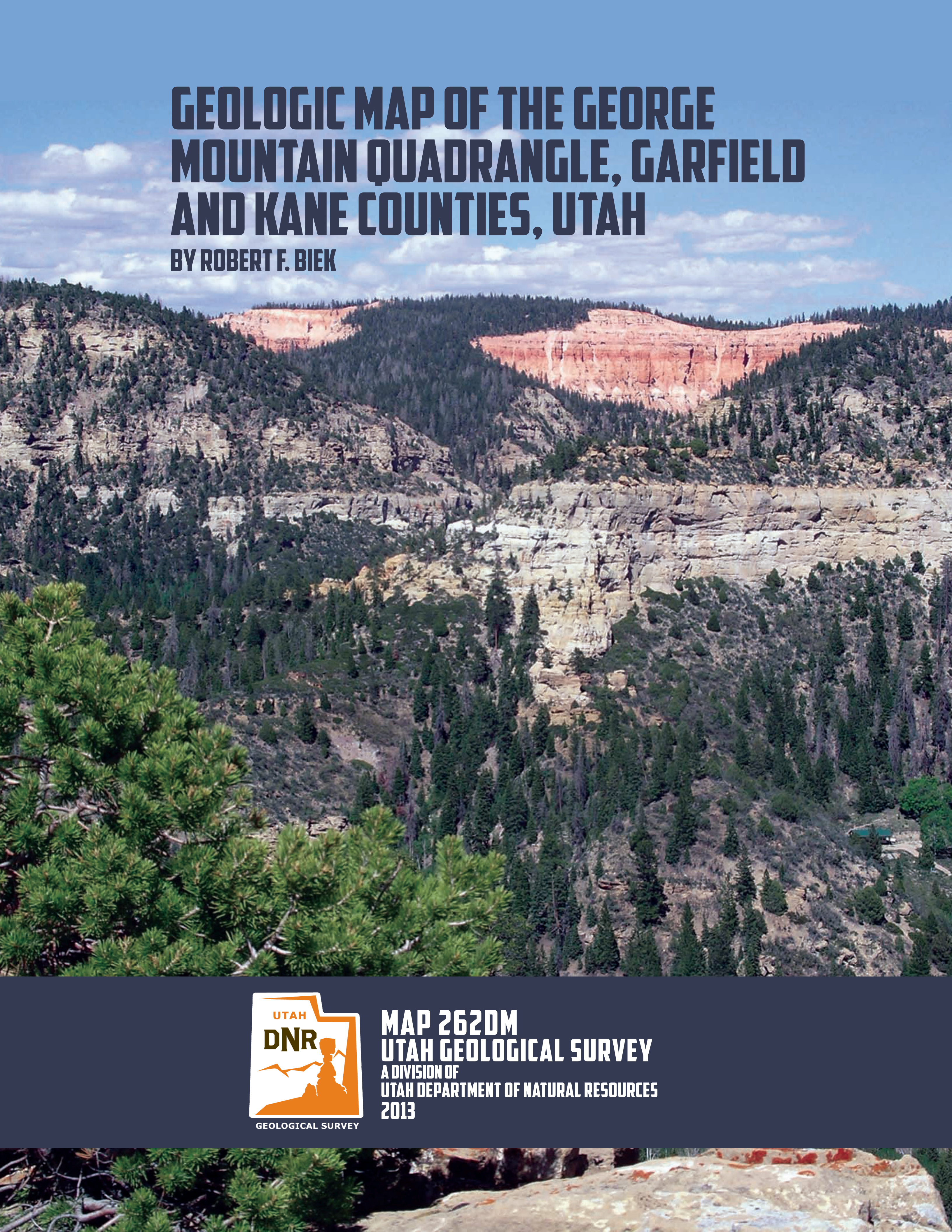

GEOLOGIC MAP OF THE GEORGE MOUNTAIN QUADRANGLE, GARFIELD AND KANE COUNTIES, UTAH

BY ROBERT F. BIEK

MAP 262DM
UTAH GEOLOGICAL SURVEY
A DIVISION OF
UTAH DEPARTMENT OF NATURAL RESOURCES
2013

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Cover photo: *View northeast across Johnson Canyon showing the pink member of the Claron Formation in the distant cliffs. The prominent ledge of white pebbly sandstone in the middle of the photograph is the Drip Tank Member of the Straight Cliffs Formation; the canyon bottom is eroded into the John Henry Member.*

UTAH DNR GEOLOGICAL SURVEY

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GEOLOGIC MAP OF THE GEORGE MOUNTAIN QUADRANGLE, GARFIELD AND KANE COUNTIES, UTAH

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MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal_1 **Stream alluvium** (Holocene) – Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active stream channels and floodplains of the Sevier River and Mammoth and Asay Creeks; locally includes minor stream-terrace alluvium as much as about 10 feet (3 m) above current stream level; probably less than 30 feet (<9 m) thick.

Qath, Qat_{2-5}

Stream-terrace alluvium (Holocene to middle? Pleistocene) – Moderately sorted sand, silt, and pebble to boulder gravel that forms incised gently sloping terraces above the Sevier River and Asay Creek; deposited in stream-channel environment, but locally includes colluvium and small alluvial fans near margins of terraces; terraces are at elevations of 10 to about 200 feet (3–60 m) above adjacent streams; subscript denotes relative age and height above adjacent drainage: Qath, which may be in part of historical age, ranges from about 5 to 10 feet (1.5–3 m), Qat_2 ranges from about 10 to 25 feet (3–8 m), Qat_3 ranges from about 25 to 50 feet (8–15 m), Qat_4 ranges from about 50 to 100 feet (15–30 m), and Qat_5 ranges from about 100 to 200 feet (30–60 m) above adjacent stream channels; typically less than 20 feet (<6 m) thick.

Qaly **Younger stream alluvium** (Holocene) – Similar to stream alluvium (Qal_1) and lower elevation stream-terrace alluvium (Qath, Qat_2), but undivided here due to limitations of map scale; includes small alluvial-fan and colluvial deposits from tributary drainages and adjacent slopes; commonly includes historical debris-flow and debris-flood deposits, especially along upper reaches of streams; typically less than 20 feet (<6 m) thick, but deposits of major stream valleys may locally exceed 30 feet (9 m) thick.

Qaf_1 **Level 1 fan alluvium** (Holocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages; equivalent to the upper part of younger fan alluvium (Qafy), but differentiated because Qaf_1 typically forms smaller, isolated fans; probably less than 30 feet (<9 m) thick.

Qaf_2 **Level 2 fan alluvium** (Holocene and upper Pleistocene) – Similar to level 1 fan alluvium (Qaf_1), but forms inactive, incised surfaces cut by younger stream and fan deposits; equivalent to the older, lower part of younger fan alluvium (Qafy); probably less than 40 feet (<12 m) thick.

Qafy **Younger fan alluvium** (Holocene and upper Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment deposited at the mouths of streams and washes; forms both active depositional surfaces (Qaf_1 equivalent) and low-level inactive surfaces incised by ephemeral streams (Qaf_2 equivalent) that are undivided here; deposited principally as debris flows and debris floods; small, isolated deposits are typically less than 20 feet (6 m) thick, but large, coalesced deposits west of the Sevier fault zone likely exceed several tens of feet thick and form the upper part of basin-fill deposits.

Qafo **Older fan alluvium** (upper and middle Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with moderately developed calcic soils (caliche); forms broad, gently sloping, incised surfaces west of the Sevier fault zone; may be cut by previously unreported fault scarps in the north-central part of the map area; deposited principally as debris flows and debris floods; likely exceeds several tens of feet thick.

$Qafo_2$ **Oldest fan alluvium** (middle? and lower Pleistocene) – Similar to older fan alluvium, but forms deeply dissected surfaces; fan morphology remains in the south-central part of the quadrangle where it is preserved beneath unmapped, resistant, moderately cemented fan alluvium (mapped as pediment alluvium by Tilton [2001a]), but elsewhere little or no fan morphology is present; preserved in the hanging wall of the Sevier fault zone where it overlies a surface beveled across Limerock Canyon and Brian Head Formations and the upper parts of the white member of the Claron Formation; maximum exposed thickness is about 300 feet (90 m).

Artificial deposits

Qf **Artificial fill** (Historical) – Engineered fill and general borrow material used for stock ponds and one area of Highway 89; fill of variable thickness and composition should be anticipated in all developed or disturbed areas; typically less than 20 feet (6 m) thick.

Colluvial deposits

Qc **Colluvium** (Holocene and upper Pleistocene) – Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; commonly grades downslope into deposits of alluvial or mixed alluvial and colluvial origin; mapped only where it conceals contacts or fills broad depressions; typically less than 20 feet (6 m) thick.

Mass-movement deposits

Qms **Landslides** (Historical? and upper? Pleistocene) – Very poorly sorted, locally derived material deposited by rotational and translational movement; composed of clay- to boulder-size debris as well as large, partly intact bedrock blocks; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and common small ponds, marshy depressions, and meadows; largest landslide complexes involve mudstone, siltstone, and sandstone interval of the white member (Tcwm) of the Claron Formation; undivided as to inferred age because even landslides having subdued morphology (suggesting that they are older, weathered, and have not experienced recent large-scale movement) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); query indicates areas of unusual morphology that may be due to landsliding; thickness highly variable, but typically several tens of feet or more thick.

Vegetation and widespread unmapped colluvium may conceal unmapped landslides, and more detailed imaging techniques such as LiDAR may show that many slopes host surficial deposits that reveal evidence of creep or shallow landsliding. Understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations.

Qmt **Talus** (Holocene and upper Pleistocene) – Poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rock fall on or at the base of steep slopes; commonly grades downslope into colluvium; talus is common at the base of steep slopes across the map area, but is only mapped where it conceals contacts or forms broad aprons below cliffs of resistant bedrock units; typically less than 30 feet (9 m) thick.

Mixed-environment deposits

Qac **Alluvium and colluvium** (Holocene and upper Pleistocene) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.

Qacf **Colluvium and fan alluvium** (Holocene and upper Pleistocene) – Poorly to moderately sorted, poorly or non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and at the base of steep slopes, especially along the Claron outcrop belt; locally reworked by small, ephemeral streams; forms coalescing apron of fan alluvium and colluvium not practical to map separately at this scale; typically 10 to 40 feet (3–12 m) thick.

Qacfo **Older colluvium and fan alluvium** (Pleistocene) – Similar to Qacf, but forms incised surface in the southwest part of the map area; probably about 20 feet (6 m) thick.

Qmtc **Talus and colluvium** (Holocene and upper Pleistocene) – Poorly sorted, angular to subangular, cobble- to boulder-size and finer-grained interstitial sediment deposited principally by rock fall and slope wash on steep slopes; mapped along the Sevier fault zone; generally less than 40 feet (12 m) thick.

Spring deposits

Qst **Calcareous tufa** (Holocene) – Two small areas of calcareous spring tufa mapped on the south side of Big Hollow and along the Sevier fault zone between Pole and Don Canyon where it forms a thin carapace over Upper Cretaceous strata.

Lava Flow

Qbhk **Henrie Knolls lava flows** (upper Pleistocene) – Medium- to dark-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; lava flow erupted from a vent at one of the Henrie Knolls cinder cones west of the map area and flowed at least 12 miles (19 km) eastward down Wilson Creek and Mammoth Creek to its confluence with the Sevier River (Biek and others, 2011); major- and trace-element chemistry is available in (Biek, in preparation); age unknown, but likely late Pleistocene because the north end of the flow complex is incised by Tommy Creek and capped by level 4 stream-terrace deposits (Biek and others, 2012); sample HK092106-1 near Henrie Knolls yielded a low-precision $^{40}Ar/^{39}Ar$ age of 0.058 ± 0.035 Ma (UGS and NMGRL, 2009; Biek and others, 2012); lava flow is typically several tens of feet thick, but is about 80 feet (25 m) thick where it fills paleotopography of Mammoth Creek.

TERTIARY

Taf **Upper Tertiary fan alluvium** (Pliocene? to Miocene?) – Moderately to poorly consolidated, brown and grayish-brown sandstone, siltstone, pebbly sandstone, and conglomerate that forms incised, gently east-tilted surface of low, rounded hills on Mammoth Ridge; clasts are of various volcanic rocks (95%) and about 5% quartzite and sandstone (Kurlich and Anderson, 1997); clasts were derived from the west and north from the Mount Dutton Formation and regional ash-flow tuffs and deposited as aggrading alluvial fans, possibly in a structurally closed basin later incised by through-going drainage of the Sevier River (Moore and Straub, 1995; Kurlich and Anderson, 1997); includes uncommon, thin, ash-fall tuff beds; lower part on Mammoth Ridge was mapped by Moore and others (1994) as late Tertiary volcaniclastic deposits that weather to a distinctive, reddish-brown earthy slope that includes chert-pebble conglomerate and pebbly sandstone; unconformably overlies Limerock Canyon/Brian Head strata on Mammoth Ridge; north of the map area, Taf is interbedded with upper Tertiary basaltic lava flows (including the 5.0 Ma Rock Canyon lava flow and the 5.3 Ma Dickinson Hill lava flow) and uncommon, thin, lenticular beds of lacustrine limestone (Biek and others, 2012); only the distal edge of deposits are exposed in the map area, where they are about 150 feet (45 m) thick; the unit is as much as 760 feet (230 m) thick to the north in the Hatch quadrangle (Kurlich and Anderson, 1997) and at least 1000 feet (300 m) thick in the Panguitch quadrangle (Moore and Straub, 1995).

These deposits were previously referred to as the Sevier River Formation, which was named by Callaghan (1938) for partly consolidated basin-fill deposits near Sevier, Utah, on the north side of the Marysvale volcanic complex (see, for example, Anderson and Rowley, 1975; Anderson and others, 1990; Moore and others, 1994; Rowley and others, 1994). The name Sevier River Formation formerly had value in reconnaissance-scale studies in the High Plateaus; in and near its type area, it contains ash-fall tuffs that have fission-track and K-Ar ages of 14 and 7 Ma and basaltic lava flows that have K-Ar ages of 9 and 7 Ma (Steven and others, 1979; Best and others, 1980; Rowley and others, 2002), which are older than this map unit. In later, more detailed mapping in the High Plateaus, the name Sevier River Formation was restricted to its type area for older basin-fill sediments deposited in post-20 Ma basins, but that preceded development of the present topography (Rowley and others, 2002) (later basin-fill deposits of the main phase of basin-range deformation in the northern Marysvale area were referred to as "sedimentary basin-fill deposits [QTs]"; Rowley and others, 2002). J.J. Anderson (verbal communication, November 16, 2004) referred to these deposits as the Panguitch gravels.

The Sevier River Formation and other late Tertiary basin-fill deposits provide control on the structural development of the High Plateaus area. Rowley and others (1981) used K-Ar ages of mapped volcanic rocks in the Sevier Plateau to the north to constrain the main phase of basin-range faulting to between 8 and 5 Ma, during which time the Sevier Plateau was uplifted along the Sevier fault zone at least 6000 feet (2000 m). Pediment deposits preserved atop the Spry intrusion, about 400 feet (120 m) above Circleville Canyon about 20 miles (32 km) north of the map area (Anderson and others, 1990), led Anderson (1987) to suggest that basin-fill deposits once filled the ancestral valley of the Sevier River to a similar depth above the modern river. However, I see no evidence for such vast exhumation of late Tertiary fan alluvium in this area. Rather, the structural high of the Spry intrusion and its capping pediment deposits may be due to an inferred fault segment boundary of the Sevier fault zone; that is, the long-term displacement rate there may be lower than that in the basins to the south and to the north. Thus, I interpret the capping pediment deposits simply to be remnants stranded by continued downcutting of the Sevier River as a result of differential slip on the Sevier fault, not due to exhumation of basin-fill deposits of Circleville Valley and Panguitch valley.

Tlbh **Limerock Canyon and Brian Head Formations, undivided** (lower Miocene and lower Oligocene to middle Eocene) – Sable and Maldonado (1997b) described the difficulty of differentiating similar volcaniclastic strata of the Limerock Canyon, Bear Valley, and Brian Head Formations. We remain uncertain how to distinguish apparently similar strata of the Brian Head and Limerock Canyon Formations at Hatch Mountain and areas to the south. The type section of the Limerock Canyon Formation (west of Hatch, just north of the map area) contains a few tens of feet of strata that we reassign to the Brian Head Formation, and we suggest that the limestone that Kurlich and Anderson (1997) assigned to the Brian Head Formation at the base of this type section is in fact the upper white member of the Claron Formation as originally described by Kurlich (1990).

White, light-gray, and pale- to olive-green, commonly tuffaceous, volcaniclastic sandstone, pebbly sandstone, gritstone, pebbly conglomerate, mudstone, porcellanite, and minor chalcedony and tuffaceous limestone; includes at least 10 thin beds of ash-fall tuff; contains root casts and is commonly bioturbated; clasts are about 90% volcanic, but include as much as 10% quartzite and sandstone; Kurlich and Anderson (1997) stated that the formation lacks Needles Range, Isom, Bear Valley, and Mount Dutton clasts, but 27- to 26-Ma Isom clasts are indeed abundant and many of the mafic volcanic clasts that they reported could be derived from Mount Dutton Formation; mapped at the east edge of the Markagunt Plateau where it is unconformably overlain by upper Tertiary fan alluvium (Taf) and where it may be preserved in a subtle basin in front of an inferred blind west-trending thrust fault (the inferred westward continuation of the Ruby's Inn thrust fault); deposited in fluvial, floodplain, and minor lacustrine environments (Kurlich and Anderson, 1997); two ash-fall tuff beds, about 100 feet (30 m) and 200 feet (60 m) above the base of the formation at the type section west of Hatch, respectively, yielded K-Ar ages of 21.5 ± 0.6 Ma (biotite) and 21.0 ± 1.0 Ma (sanidine), and 20.2 ± 1.4 Ma (biotite) and 19.8 ± 0.8 Ma (sanidine) (Sable and Maldonado, 1997); Sable and Maldonado (1997) also reported $^{40}Ar/^{39}Ar$ ages of 20.48 ± 0.8 Ma (biotite) and 21.0 ± 1.0 Ma (sanidine); Biek and others (2012) reported a U-Pb age on zircon from an ash-fall tuff near the middle of the formation of 20.52 ± 0.49 Ma (UGS and A2Z, Inc., 2013); as much as 290 feet (88 m) thick in a composite type section west of Hatch (Kurlich, 1990; Kurlich and Anderson, 1997).

unconformity

Tbm **Conglomerate at Boat Mesa** (middle Eocene) – Light-gray conglomerate, lesser light-gray to light-brown calcareous sandstone and conglomeratic sandstone, and minor white to light-gray limestone and conglomeratic limestone; clasts are rounded pebbles of black chert, and minor brown, gray, and distinctive greenish quartzite; no volcanic or intrusive clasts are present; in the limestone intervals, clasts commonly appear to float in a carbonate mud matrix, but otherwise the conglomerates are clast supported; commonly weathers to a chert-pebble-covered bench or to a white ledge, making it difficult to distinguish from the upper white limestone unit of the Claron Formation on aerial photographs or from a distance; unconformably overlain by white to light-gray volcaniclastic mudstone and sandstone of the Limerock Canyon and Brian Head Formations (Tlbh); about 3 to 15 feet (1–5 m) thick in the map area and so locally mapped as a marker bed, but as much as 100 feet (30 m) thick at its type area of Boat Mesa in Bryce Canyon National Park (Bowers, 1990) and on the southern Sevier Plateau (Biek and others, 2012).

The conglomerate at Boat Mesa represents deposits of braided stream channels and minor floodplains incised into deposits of the Claron Formation. Bowers (1990) suggested the conglomerate at Boat Mesa was Oligocene and Davis and Pollock (2010) suggested it was Oligocene or Miocene, but a complete lack of volcanic clasts suggests a latest middle Eocene age, confirmed by a U-Pb age of 36.51 ± 1.69 Ma for an overlying basal volcanic ash in the Brian Head Formation on the southwestern Sevier Plateau, and by a U-Pb detrital age on zircon of 37.97 +1.78 -2.70 Ma (Gary Hunt, UGS, written communication, March 7, 2012) for this map unit (Tbm) on the southwest flank of the Sevier Plateau (Biek and others, 2012; UGS and A2Z Inc., 2013).

unconformity

Claron Formation (Eocene to Paleocene) – Mapped as four informal lithostratigraphic units following the subdivision of Biek and others (2012) at the west edge of the Markagunt Plateau: an upper white member (which is itself divided into an uppermost mudstone interval not present in this map area, an upper limestone interval, a middle mudstone and sandstone interval, and a lower limestone interval) and the lower pink member. The Claron Formation consists of mudstone, siltstone, sandstone, limestone, and minor conglomerate deposited in fluvial, floodplain, and lacustrine environments of an intermontaine basin bounded by Laramide uplifts (Schneider, 1967; Goldstrand, 1990, 1991, 1992; Taylor, 1993; Ott, 1999). Much of the pink member, and clastic parts of the white member, were greatly modified by bioturbation and pedogenic processes, creating a stacked series of paleosols (Mullett and others, 1988a, b; Mullett, 1989; Mullett and Wells, 1990; see also Bown and others, 1997). Ott (1999) reported cyclicity within the Claron Formation at Bryce Canyon

National Park, with multiple regressive cycles, each exhibiting increasing pedogenesis toward their tops, stacked one upon the other. Bown and others (1997) reported on trace fossils of ants, wasps, and bees in the upper part of the pink member and lower part of the white member, recording nest activity during paleosol formation. Hasiotis and Bown (1997) reported on crayfish burrows in Claron strata of the Markagunt Plateau that record relatively deep and highly fluctuating water tables in the pink member, and relatively shallow water tables in alluvial parts of the white member. Detrital zircon studies of the Claron Formation from the Escalante Mountains east of the map area show that the formation there was largely derived from erosion of lower Paleozoic sandstones exposed in surrounding Laramide uplifts (Link and others, 2007; Larsen and others, 2010).

The age of the white member is well constrained as late middle Eocene (Duchesnean Land Mammal Age) based on sparse vertebrate fossils from this unit on the eastern Markagunt Plateau (Eaton and others, 2011); by limiting ages of 35.77 ± 0.28 Ma and 36.51 ± 1.69 Ma for overlying basal Brian Head Formation on the Markagunt and Sevier Plateaus, respectively (Biek and others, 2012); and by a U-Pb detrital zircon age of 37.97 +1.78 -2.70 Ma from the conglomerate at Boat Mesa on the southwestern Sevier Plateau (Biek and others, 2012). Middle Eocene vertebrate fossils and charophytes are also known in basal Brian Head strata on the southwestern Sevier Plateau (Eaton and others, 1999; Feist and others, 1997).

The maximum age of the mostly nonfossiliferous pink member, however, is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994). Goldstrand (1990) reported unspecified late Paleocene palynomorphs from lower Claron strata on the east side of the Pine Valley Mountains, and noted the Paleocene to Eocene gastropods *Viviparus trochiformis, Physa* sp., and *Goniobasis* sp. from the pink member. Goldstrand (1992, 1994) suggested that the pink member may be time transgressive, being older in western exposures and possibly no older than middle Eocene on the Table Cliff Plateau. This idea, however, was based on fission-track analysis of a single sample from the underlying Pine Hollow Formation, which may be suspect. For one, such a young age seems at odds with the time required to accummulate such a thick stack of mature paleosols. Larsen and others (2010) suggested a late Paleocene to early Eocene age for the underlying Pine Hollow Formation on the Table Cliff Plateau, although they noted a complete lack of fossils, datable ash layers, or age-constraining detrital zircons on which to constrain that assumption. Bowers (1972) also noted a complete lack of datable materials in the Pine Hollow, and although he preferred a Paleocene(?) age for the formation, he correctly noted that a latest Cretaceous age cannot be ruled out, as did Anderson and Rowley (1975) and Rowley and others (1979). The lower part of the pink member is likely Paleocene in age, but given its paucity of datable materials, we cannot yet rule out the possibility they are latest Cretaceous.

Tcw **White member, undivided** (Eocene) – Shown on cross section only; about 350 feet (107 m) thick.

Tcwu **Upper limestone unit of white member** (Eocene) – White, pale-yellowish-gray, pinkish-gray, and very pale orange micritic limestone and pelmicritic limestone; locally contains intraformational rip-up clasts, sparse charophytes, and rare planispiraled snails; typically poorly bedded and knobby weathering; locally vuggy with calcite spar and commonly cut by calcite veinlets; resistant and so forms prominent ledge; upper unconformable contact with the conglomerate at Boat Mesa (Tbm) corresponds to the first appearance of chert pebble conglomerate; about 50 to 80 feet (15–25 m) thick; Moore and others (1994) reported that the unit is 80 to 160 feet (24–50 m) thick in the adjacent Asay Bench quadrangle.

Tcwm **Middle mudstone, siltstone, and sandstone unit of white member** (upper middle Eocene) – Varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, yellowish-gray, dark-yellowish-orange, and grayish-pink calcareous mudstone and siltstone, and minor fine-grained calcareous sandstone and chert-pebble conglomerate that weathers to a poorly exposed slope; upper conformable contact corresponds to a pronounced color change from brightly colored reddish-orange mudstone and siltstone below to white to very pale orange micritic limestone above; Eaton and others (2011) reported the first sparse late middle Eocene (Duchesnean Land Mammal Age) vertebrate fossils and ostracods of *Cypris* sp. from this unit on the eastern Markagunt Plateau; about 160 to 220 feet (50–67 m) thick; Moore and others (1994) reported that their middle sandy unit is 175 to at least 220 feet (54–67 m) thick in the Asay Bench quadrangle.

Tcwl **Lower limestone unit of white member** (Eocene) – Micritic limestone similar to the upper white limestone unit (Tcwu); appears to be less well developed in southern exposures such that it is difficult to differentiate the middle interval (Tcwm) from the pink member (Tcp); typically forms cliff or steep, ledgy, white slope above more colorful but typically subdued slopes of the pink member (Tcp); contains sparse charophytes; upper conformable contact corresponds to a pronounced color change from white to very pale orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above; about 40 to 60 feet (12–18 m) thick; Moore and others (1994) reported that their lower white limestone is generally 85 to 120 feet (26–36 m) thick, but as much as 180 feet (55 m) thick, in the Asay Bench quadrangle.

Tcp **Pink member** (Eocene and Paleocene) – Alternating beds of varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, and grayish-pink sandy and micritic limestone, calcite-cemented sandstone, calcareous mudstone and siltstone, and minor pebbly conglomerate that weathers to colluvium-covered ledgy slopes; several sinkholes are present in the northeast part of the map area. Limestone is poorly bedded, microcrystalline, generally sandy with 2 to 20% fine-grained quartz sand, and is locally argillaceous; contains common calcite veinlets, calcite spar-filled vugs, calcite spar- and micrite-filled burrows, and stylolites; also contains sparse small bivalves and planispiral gastropods; many of these limestone beds are calcic paleosols (Mullett and others, 1988a, b; Mullett, 1989; Mullett and Wells, 1990). Sandstone is thick-bedded, fine- to coarse-grained, calcareous, locally cross-bedded quartz arenite that typically weathers to sculpted or fluted ledges that pinch out laterally; sandstone locally contains pebble stringers. Mudstone is generally moderate reddish orange, silty, calcareous, contains calcareous nodules, and weathers to earthy, steep slopes between ledges of sandstone and limestone. Pebbly conglomerate is uncommon but forms lenticular beds 5 to 15 feet (2–5 m) thick with rounded limestone, quartzite, and chert pebbles, cobbles, and, locally, small boulders; dark-gray and bluish-gray limestone clasts are common and more abundant than in Upper Cretaceous strata. Upper, conformable contact corresponds to a pronounced color and lithologic change from brightly colored reddish-orange mudstone and siltstone below to a white to very pale orange micritic limestone above.

The pink member is mostly unfossiliferous and its age is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994) as described above. Only the upper few tens of feet is exposed west of Highway 89; the lower 800 feet (245 m) are exposed in the Sunset Cliffs in the southeast part of the map area; the complete pink member is about 1000 feet (300 m) thick at Cedar Breaks National Monument and about 600 feet (180 m) thick at Bryce Canyon National Park (Biek and others, 2012).

unconformity

CRETACEOUS

Kkl **Kaiparowits Formation, lower unit** (Upper Cretaceous, upper Campanian) – Consists of yellowish-brown, fine-grained sandstone and varicolored and mottled, reddish-brown, purplish-gray, and gray mudstone; map unit is best exposed about 5 miles (8 km) to the northeast in Hillsdale Canyon, where sandstone forms two prominent ledges at the base and near the middle of the unit and where it is conformably overlain by classic blush-gray feldspathic sandstone and mudstone of the Kaiparowits Formation (Biek and others, 2012); in this map area, upper, unconformable contact placed at the base of the first sandy limestone bed (calcic paleosol) or pebble to cobble conglomerate of the pink member of the Claron Formation; incomplete section is about 200 feet (60 m) thick in this map area, but the unit is about 250 feet (75 m) thick in the Hillsdale Canyon area and thins eastward under the Claron unconformity and is absent in exposures north-northeast of Tropic (Biek and others, 2012).

Although undated and lacking bluish-gray feldspathic sandstone and mudstone that characterize the bulk of the Kaiparowits Formation in the Kaiparowits Basin, I assign this interval to an informal lower unit of the Kaiparowits Formation because it appears lithologically similar to basal Kaiparowits strata along Henrieville Creek on the west flank of the Kaiparowits Plateau (Eaton, 1991) and because it is lithologically unlike the underlying capping sandstone member of the Wahweap Formation. Welle (2008) and Lawton and Bradford (2011) showed that the lower unit of the Kaiparowits Formation in the Kaiparowits Basin has a different detrital zircon signature than that of its middle and upper units, with more thrust-belt-derived grains, recording a transition in sediment source areas from the thrust-belt-sourced capping sandstone to arc-derived Kaiparowits.

The Kaiparowits Formation was deposited as an eastward-prograding clastic wedge in a relatively wet, subhumid alluvial plain with periodic to seasonal aridity near the western margin of the Late Cretaceous Western Interior Seaway (Roberts, 2007). It is abundantly fossiliferous, with one of the richest and most diverse terrestrial vertebrate faunas of the Cretaceous Western Interior Basin (Roberts, 2007). Roberts and others (2005) reported four $^{40}Ar/^{39}Ar$ ages on sanidine from altered volcanic ashes that bracket the age of the formation in the Kaparowits Basin between 76.1 and 74.0 Ma, and that demonstrate extremely rapid sediment accumulation rates of 16 inches/kyr (41 cm/kyr). Biek and others (2012) reported a new U-Pb age on zircon of 75.62 +3.08 -1.66 Ma for the bluish-gray smectitic mudstone at the base of the formation in Johnson Canyon on the west flank of the Paunsaugunt Plateau, about 3 miles (5 km) northeast of the map area (UGS and A2Z, Inc., 2012; Gary Hunt, written communication, September 26, 2011); they also recovered late Campanian to Maastrichtian palynomorphs from this location.

Wahweap Formation (Upper Cretaceous, middle Campanian) – Eaton (1991) divided the formation into four informal members in the Kaiparowits Basin, originally defined based principally on sandstone to mudstone ratios and fluvial architecture. In ascending order, these include his lower, middle, upper, and capping sandstone members. Due to poor exposure in this map area, we map his lower three members simply as lower Wahweap Formation, undivided (Kwl). The distinctive capping sandstone (Kwcs) is mapped separately.

The Wahweap Formation is mostly fine-grained sandstone, siltstone, and mudstone deposited in braided and meandering river and floodplain environments of a coastal plain (Tilton, 1991; Pollock, 1999; Lawton and others, 2003; Jinnah and others, 2011). Detrital zircon and provenance studies of Eaton's lower three members show that these rivers flowed longitudinally to the foreland basin and tapped sources in the Cordilleran magmatic arc in southern California or western Nevada and the Mogollon Highlands of southern Arizona, but that the capping sandstone member was deposited by transverse streams that tapped Mesozoic quartzose sandstones in the Sevier orogenic belt (Pollock, 1999; Lawton and others, 2003; Eaton, 2006; Jinnah and others, 2009). Thus the basal contact of the capping sandstone member represents an abrupt change in color, petrology, grain size, and fluvial style, documenting a major shift in depositional environments from meandering to braided rivers, and in source areas from arc to orogenic belt.

Jinnah and others (2009) reported an $^{40}Ar/^{39}Ar$ age of 80.6 ± 0.3 Ma (Campanian) on a devitrified volcanic ash located about 130 feet (40 m) above the base of the Wahweap Formation on the Kaiparowits Plateau, and further noted that the formation was deposited between about 81 and 76 Ma.

Kwcs **Capping sandstone member** (Upper Cretaceous, middle Campanian) – White to very pale orange, locally iron stained, very fine to coarse-grained, mostly medium-grained, trough cross-bedded quartz arenite that "caps" the Wahweap Formation in its type area; upper part contains abundant pebble stringers and conglomeratic beds with rounded quartzite, dolomite, chert, and limestone clasts; clasts are typically about 1 inch (2.5 cm) in diameter but as large as 2 to 3 inches (5–7.5 cm), and include common reddish-brown and purple quartzite clasts, unlike underlying Drip Tank strata; quartz grains are typically well rounded and commonly frosted, recycled from Mesozoic eolianites (Pollock, 1999; Lawton and others, 2003); locally contains carbonized or petrified plant debris, small mudstone rip-up clasts, iron concretions, and soft-sediment deformation features; typically poorly cemented, forming distinctive white, manzanita-covered slope-and-bench topography; Late Cretaceous age from Jinnah and others (2009), Hunt and others (2011), and Biek and others (2012); the member is about 200 feet (60 m) thick in this map area, but attains its maximum thickness on the Markagunt Plateau of 277 feet (85 m) in First Left Hand Canyon southeast of Parowan (this site was the type section of the equivalent and now abandoned middle member of the redefined Grand Castle Formation) (Biek and others, 2012).

Kw **Wahweap Formation, upper, middle, and lower members, undivided** (Upper Cretaceous, middle Campanian) – Yellowish-brown, fine-grained sandstone and silty sandstone and interbedded, variegated and mottled, brownish-gray, light-olive-brown, pale-reddish-purple, and moderate-reddish-brown mudstone and siltstone; becomes increasingly sandy northward so that stacked or amalgamated sandstone beds make up most of the lower part of the unit north of Big Hollow; query indicates uncertain designation along the Sevier fault zone north of Pole Canyon; thickness estimates of the Wahweap Formation on the west flank of the Paunsaugunt Plateau are complicated by the Sand Pass fault, which cuts out the middle part of the formation, but in this map area, an incomplete section of the Wahweap Formation is as much as about 600 feet (180 m) thick; the entire Wahweap Formation is about 1000 to 1100 feet (300–335 m) thick on the west flank of the Paunsaugunt Plateau (Biek and others, 2012, after reassigning their map unit Kwu to Kkl).

Straight Cliffs Formation (Upper Cretaceous, lower Campanian to Turonian) – Peterson (1969) divided the Straight Cliffs Formation into four members in the Kaiparowits Basin: in ascending order, the Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank Members. The Straight Cliffs Formation forms an overall regressive sequence following the last marine incursion of the Western Interior Seaway (see, for example, Eaton and others, 2001; Moore and Straub, 2001; Tibert and others, 2003). The Tibbet Canyon Member represents initial progradational (overall regressive) strata of the Greenhorn Cycle deposited in shoreface, beach, lagoonal, and estuarine environments adjacent to a coastal plain (Laurin and Sageman, 2001; Tibert and others, 2003). The overlying Smoky Hollow, John Henry, and Drip Tank Members were deposited in fluvial and floodplain environments of a coastal plain (Peterson, 1969; Eaton and others, 2001).

Ksd **Drip Tank Member** (Upper Cretaceous, lower Campanian) – White to light-gray, fine- to coarse-grained quartzose sandstone, and, in the upper part of the unit, pebbly sandstone, and pebbly conglomerate; very thick bedded with prominent cross-stratification; clasts are subrounded to rounded, white and gray quartzite, gray Paleozoic limestone, and black chert, and lack the abundant reddish-brown and purple quartzite clasts found in capping sandstone strata; locally iron stained and locally contains casts of tree limbs; lower sandstone forms distinctive, manzanita-covered slopes and saddles, but upper part of unit tends to forms cliffs and ledges; upper contact with the Wahweap Formation appears to be conformable and corresponds to the top of white sandstone and pebbly sandstone, above which is yellowish-brown, fine-grained sandstone and lesser interbedded grayish-brown mudstone; Tilton (1991) described the Drip Tank Member as the most prominent and important marker horizon in the Upper Cretaceous section on the southern Paunsaugunt Plateau, but it is remarkably similar in lithology and outcrop habit to the capping sandstone member of the Wahweap Formation (Biek and others, 2012); deposited by east-and northeast-flowing braided streams (Tilton, 1991, 2001a, b); age from Jinnah and others (2009, 2011); ranges from about 100 to 200 feet (30–60 m) thick in the map area; Tilton (2001a) reported that the member is 185 to 215 feet (56–66 m) thick in the adjacent Alton quadrangle, probably due to differences in picking the upper contact.

unconformity

Ksj **John Henry Member** (Upper Cretaceous, Santonian to upper Coniacian) – Grayish-orange to yellowish-brown, fine-grained subarkosic sandstone and siltstone and interbedded, locally mottled, gray, brown, and reddish-brown mudstone; thin- to thick-bedded, forming ledgy slopes; sandstone is commonly bioturbated and locally stained by iron-manganese oxides; upper unconformable contact corresponds to a break in slope at the base of the white sandstone of the Drip Tank Member; deposited in fluvial and floodplain environments of a coastal plain (Eaton and others, 2001); incomplete section is as much as about 600 feet (180 m) thick in the map area; Tilton (2001a) reported that the member is about 670 feet (205 m) thick in the adjacent Alton quadrangle.

Ksh **Smoky Hollow Member** (Upper Cretaceous, middle Turonian) – Not exposed, shown on cross section only; Tilton (2001a, b) reported that the member is 125 to 140 feet (40–45 m) thick at the south end of the Paunsaugunt Plateau.

Kst **Tibbet Canyon Member** (Upper Cretaceous, Turonian) – Not exposed, shown on cross section only; Tilton (2001a, b) reported that the member is about 120 to 160 feet (37–50 m) thick at the south end of the Paunsaugunt Plateau.

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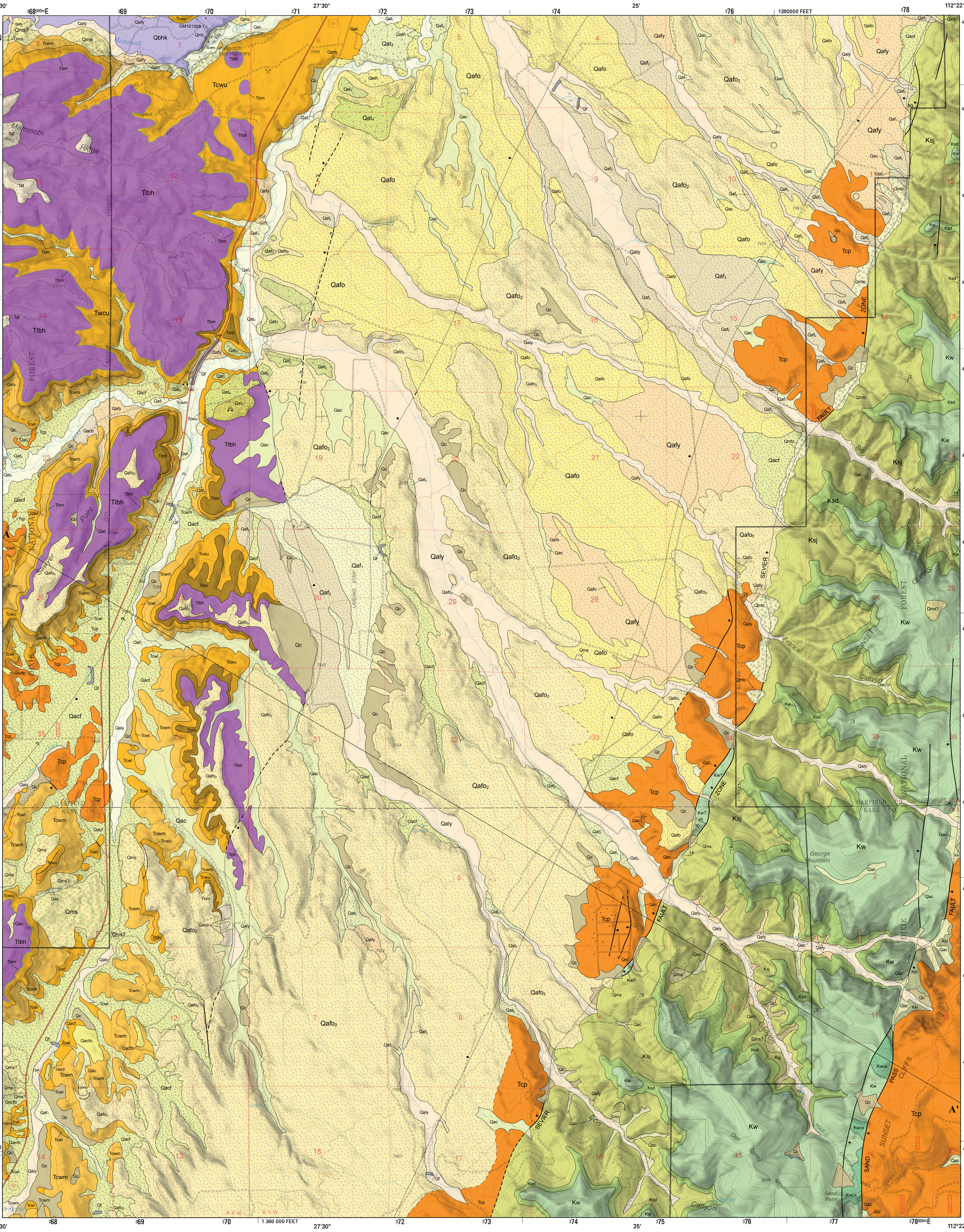

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UTAH
QUADRANGLE LOCATION

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

GEOLOGIC MAP OF THE GEORGE MOUNTAIN QUADRANGLE, GARFIELD AND KANE COUNTIES, UTAH

by
Robert F. Biek

2013

11°46'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2013

Base from USDA Forest Service George Mountain 7.5' Quadrangle (2012)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

Project Manager: Douglas A. Sprinkel
GIS and Cartography: Jay Hill and Basia Matyjasik

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This map was created from Geographic Information System (GIS) data.

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1	2	3
4		5
6	7	8

1. Haycock Mountain
2. Hatch
3. Wilson Peak
4. Asay Bench
5. Tropic Reservoir
6. Long Valley Junction
7. Alton
8. Podunk Creek

ADJOINING 7.5' QUADRANGLE NAMES

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

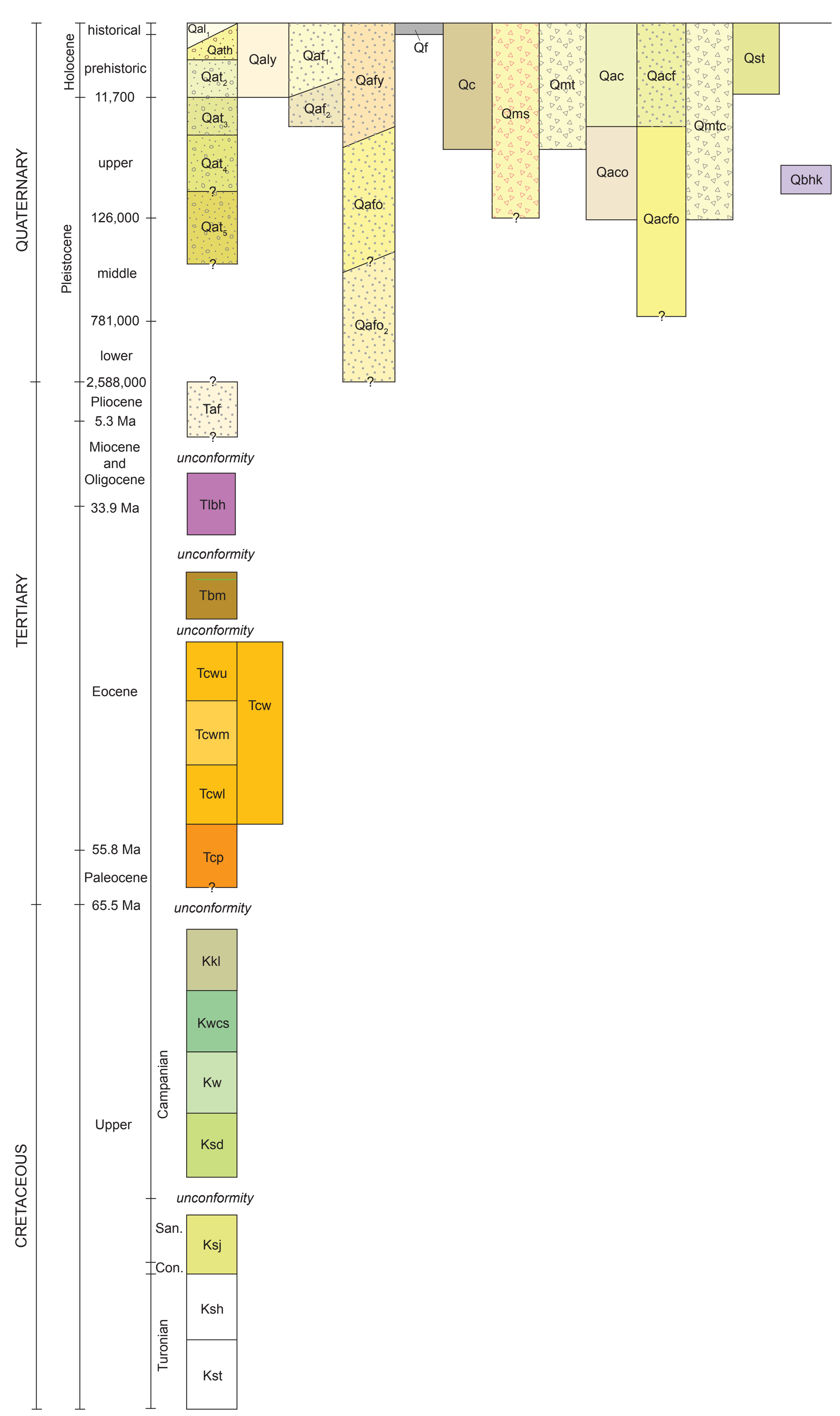
STRATIGRAPHIC COLUMN

Ma	System	Series and Stage	Map Unit	Map Symbol	Thickness feet (meters)	Depositional Environment	Dominant Rock Type	Weathering Profile
	QUAT.	Holocene / Pleistocene	various surficial deposits	Q	variable		sand, silt, clay, gravel	Henrie Knolls lava flow
2.59	TERTIARY	Pliocene	upper Tertiary fan alluvium	Taf	150⁺ (45⁺)	alluvial fan and river channel	conglomerate	
5.3	TERTIARY	Miocene	Limerock Canyon and Brian Head Formations, undivided	Tlbh	290 (88)	river channel and floodplain	local volcaniclastic sandstone, mudstone, and conglomerate and rhyolitic ash	*unconformity*
23.0	TERTIARY	Eocene	conglomerate at Boat Mesa	Tbm	3-15 (1-5)	river channel	pebble conglomerate	*unconformity* lacks volcanic clasts *unconformity*
	TERTIARY	Eocene	Claron Formation, white member: upper limestone	Tcw: Tcwu	about 350 (107): 50-80 (15-25)		micritic limestone	white limestone ledge
	TERTIARY	Eocene	Claron Formation, white member: middle interval	Tcw: Tcwm	about 350 (107): 160-220 (50-67)		mudstone	
	TERTIARY	Eocene	Claron Formation, white member: lower limestone	Tcw: Tcwl	about 350 (107): 40-60 (12-18)		micritic limestone	white limestone ledge
55.8	TERTIARY	Eocene –?– Paleocene	Claron Formation, pink member	Tcp	800⁺ (245⁺)	non-volcanic river and lake sediments modified by soil formation	mudstone, siltstone, sandstone	
65.5	CRETACEOUS	Upper, Campanian	Kaiparowits Formation lower unit	Kkl	200⁺ (60⁺)	floodplain and river channel	sandstone and mudstone	*unconformity*
	CRETACEOUS	Upper, Campanian	Wahweap Formation, capping sandstone member	Kwcs	200 (60)	braided river	sandstone and pebbly conglomerate	white pebbly sandstone *unconformity*
	CRETACEOUS	Upper, Campanian	Wahweap Formation, upper, middle, and lower members, undivided	Kw	600⁺ (180⁺)	floodplain and river channel	sandstone, mudstone siltstone	
83.5 Ma	CRETACEOUS	Upper, Campanian	Straight Cliffs Formation, Drip Tank Member	Ksd	100-200 (30-60)	river channel	sandstone and pebble conglomerate	white sandstone ledge and conglomerate *unconformity*
85.8 Ma	CRETACEOUS	Upper, Santonian, Con.	Straight Cliffs Formation, John Henry Member	Ksj	600⁺ (180⁺)	floodplain and river	sandstone, mudstone, siltstone	
88.6 Ma	CRETACEOUS	Upper, Turonian	Straight Cliffs Formation, Smoky Hollow Member	Ksh	125-140 (40-45)	lagoonal estuarine floodplain	mudstone, siltstone sandstone and minor coal and coquina limestone	not exposed
	CRETACEOUS	Upper, Turonian	Straight Cliffs Formation, Tibbet Canyon Member	Kst	120-160 (35-50)	beach and shoreface	sandstone	not exposed

Plate tectonic setting: Development of intermontaine basins (Paleocene-Eocene) and uplift of Western US (Eocene-Oligocene); uplift continues to present day (Q through Tcp); Laramide orogeny (Tbm through Tcp); foredeep basin of Sevier orogeny (Kkl through Kst).

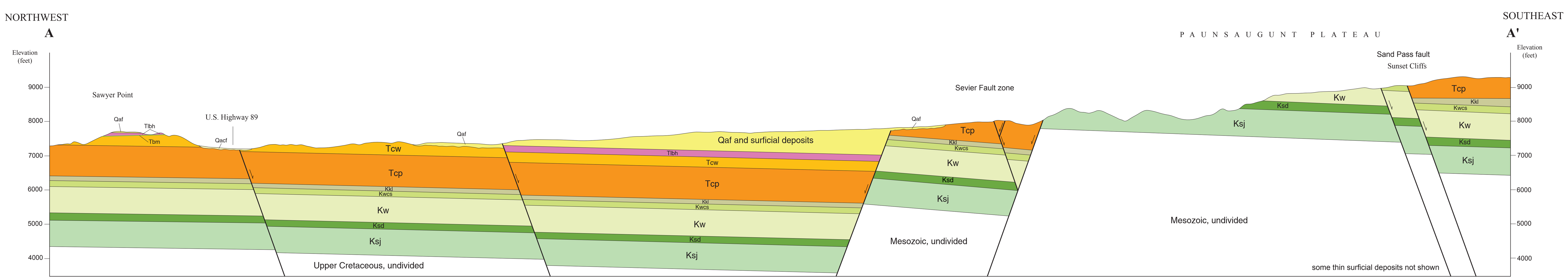
Depositional environment groups: basin-fill deposits (Q through Tlbh); intermontaine basins (Tbm through Tcp); coastal-plain environments (Kkl through Ksj).

GEORGE MOUNTAIN CORRELATION OF MAP UNITS

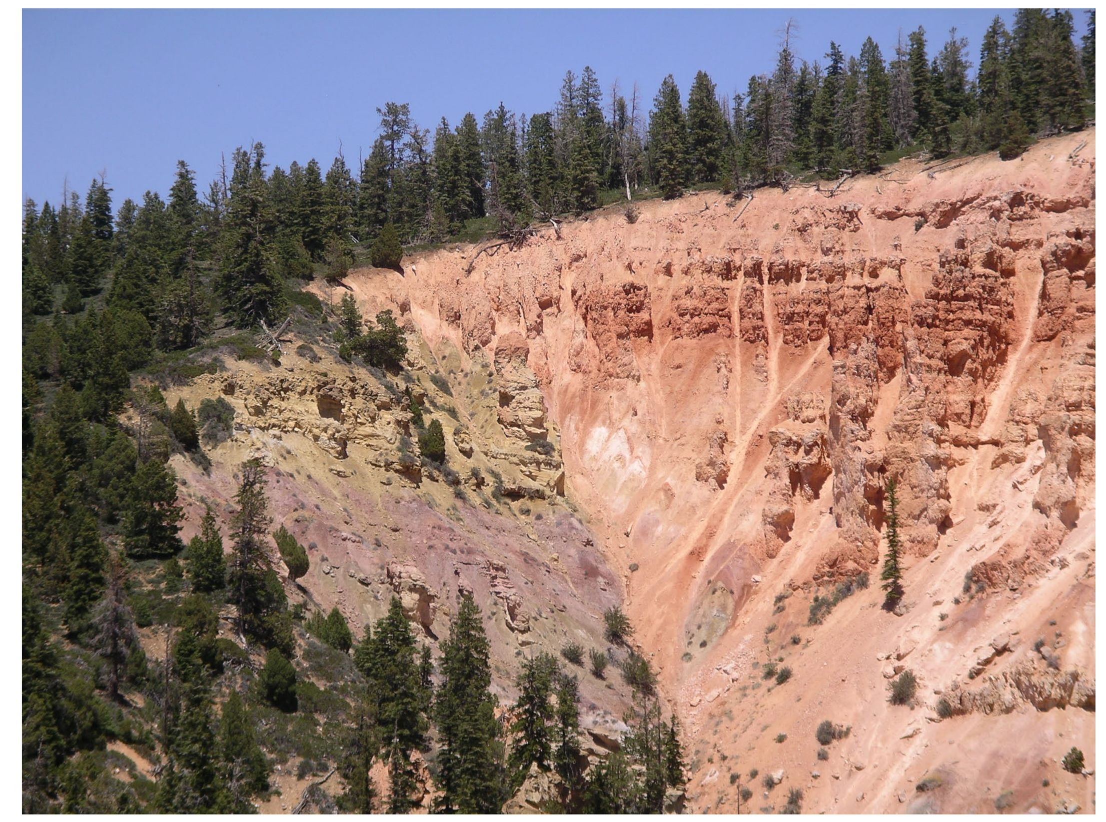


MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault, dashed where approximately located, dotted where concealed; queried where uncertain; bar and ball on down-dropped side where known
- Marker bed (Tbm), dashed where approximately located
- Landslide main scarp
- 2 — Strike and dip of inclined bedding
- 3 — Approximate strike and dip of inclined bedding
- Sand and gravel pit
- Quarry (crushed rock)
- Sinkhole
- Spring
- GM101508-1 — Sample location and number



View northeast across Johnson Canyon showing the pink member (Tcp) *of the Claron Formation in the distant cliffs. The prominent ledge of white pebbly sandstone in the middle of the photograph is the Drip Tank Member* (Ksd) *of the Straight Cliffs Formation; the canyon bottom is eroded into the John Henry Member* (Ksj). Kw = *Wahweap Formation.*



View north to the Sand Pass fault just southeast of George Mountain in the upper reaches of Johnson Canyon. Here, the fault (in the wash) places the pink member of the Claron Formation down on the east against variegated sandstone and mudstone of the Wahweap Formation.

Pebbly sandstone and conglomerate of the Drip Tank Member of the Straight Cliffs Formation.