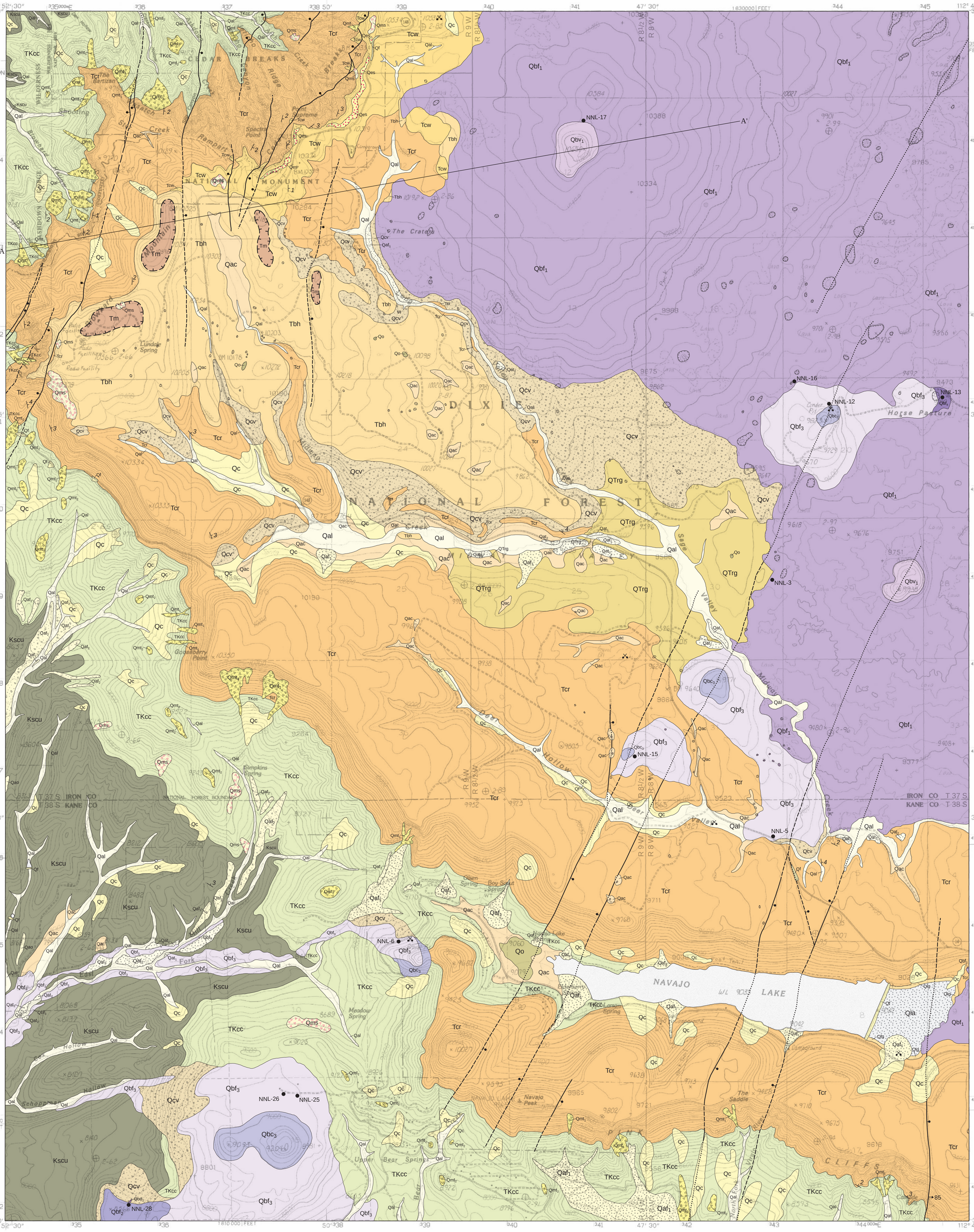
UTAH GEOLOGICAL SURVEY
a division of the
Utah Department of Natural Resources
in cooperation with
U. S. Geological Survey
and
National Park Service



Base map from U.S. Geological Survey
Navajo Lake 7.5' quadrangle, 1985

Fieldwork in 1990-1993, 2002
Cartographer, Lori J. Douglas

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 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

12.8°
228 mils

2004 MAGNETIC DECLINATION
AT CENTER OF SHEET

UTAH

QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Flanigan Arch
2 Brian Head
3 Panguitch Lake
4 Webster Flat
5 Henrie Knolls
6 Cogswell Point
7 Straight Canyon
8 Strawberry Point

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 1-55791-599-7

Funded through cooperative agreement between U.S. Geological Survey, Utah Geological Survey, and National Park Service.

GEOLOGIC MAP OF THE NAVAJO LAKE 7.5' QUADRANGLE, KANE AND IRON COUNTIES, UTAH

by

David W. Moore[1], L. David Nealey[2], Peter D. Rowley[3], Stanley C. Hatfield[4], David J. Maxwell[5], and Eric Mitchell[5]

2004

[1] U.S. Geological Survey, Federal Center, Denver, CO 80225
[2] 11226 West Arbor Dr., Littleton, CO 80127
[3] Geologic Mapping, Inc., New Harmony, UT 84757
[4] Mathematics and Science Dept., Southwestern Illinois College, Bellville, IL 62221
[5] Dept. of Physical Science, Southern Utah University, Cedar City, UT 84720

UTAH GEOLOGICAL SURVEY
a division of the
Utah Department of Natural Resources
in cooperation with
U. S. Geological Survey *and*
National Park Service

DESCRIPTION OF MAP UNITS

[This map is intended to update the preliminary geologic map of the same area, at the same scale (Moore and Nealey, 1993). Updating required new fieldwork by P.D. Rowley and S.C. Hatfield, especially in Cedar Breaks National Monument in the northwestern part of the quadrangle. This fieldwork was funded and supported by the National Park Service. The new fieldwork, as well as new data from nearby areas, resulted in new geologic interpretations, as presented by Hatfield and others (2000a, b; Hatfield, Rowley, and Anderson, 2000). These new interpretations are reflected in this map. Although most bedrock in the map area is concealed by colluvium (Qc, Qcv), only a fraction of this colluvium was mapped because the main emphasis of this map is to show the distribution and structure of the bedrock.]

SURFICIAL DEPOSITS

Qf Artificial-fill deposits (Historical)--*Deposits of artificial fill, mostly for dams and highways.*

Qal Alluvium (Holocene)--*Interbedded gravel, sand, silt, and clay deposits on flood plains and in stream channels. Unit grades laterally into colluvium (Qc) and fan alluvium (Qaf$_1$). Flood-plain deposits along Midway Creek (north of Navajo Lake) are brown, thick- to thin-bedded, gravelly sand. The clasts in the deposits along Midway Creek consist of basalt and limestone (1-20 inches [2-50 cm] in diameter), subordinate gray ash-flow tuff of the Isom Formation (1-10 percent), white chalcedony (1-2 percent), and well-rounded black chert pebbles (2-3 percent). In the southeastern part of the quadrangle, Deer Valley alluvium is yellowish-red, slightly sandy, laminated to massive, silty clay to clayey silt that contains 1-to-16-in- (2-40 cm) thick lenses of angular limestone pebbles and some cobbles. Flood-plain alluvium of Mill Creek (southwest quarter of quadrangle) is medium-gray, sandy and clayey silt to silty clay containing thin lenses of limestone, basalt, and sandstone pebbles and in places is terraced behind old beaver dams. Base of unit covered; estimated thickness 6 to 16 ft (2-5 m).*

Qat$_1$ Alluvial-terrace deposits (Holocene)--*Along Midway Creek, the unit consists of sandy, poorly sorted, resistant gravel of mostly ash-flow tuff of the Isom Formation, about 15 percent basalt, and the remainder chalcedony and sparse, round chert and quartzite pebbles. The top of the deposit is 3 to 6 ft (1-2 m) above stream channel. On Mill Creek, the unit consists of silty, fine quartz sand, and heterogeneous gravel composed of limestone, calcite-cemented sandstone, and minor basalt (10 percent); silty sand is dark yellowish brown and friable. Estimated thickness 3 to 6 ft (1-2 m).*

Qat$_2$ Older alluvial-terrace deposits (upper Pleistocene)--*Poorly sorted gravel, grus, and sand. Composition variable, in places made up predominantly of vesicular and dense basalt boulders (as large as 6 ft [2 m] across) and 1 to 3 percent clasts of ash-flow tuff (Isom Formation); elsewhere, clasts of ash-flow tuff are dominant. Both clast and matrix supported. Spheroidal weathering and limited stream transport has rounded the corners of many of the subangular clasts. Deposits mantle terraces adjacent to and 40 to 60 ft (12-18 m) higher than main ephemeral streams. Along Long Valley Creek (southeast of Cedar Breaks National Monument) and Midway Creek, however, the terraces are small and discontinuous. Active downslope creep apparently has imparted a slightly domal form to the Qat$_2$ deposits. Includes colluvium. Thickness of deposits 6 to 13 ft (2-4 m).*

Qao Older alluvium (middle Pleistocene)--*Poorly sorted material ranging from silt to boulders composed of micritic limestone (70 percent), metaquartzite (20 percent), sandstone and some limonite (after pyrite) concretions (10 percent), and olivine basalt (less than 1 percent); clasts round to subround. Two isolated deposits form a sloping, rounded, resistant armor on narrow interfluves of relatively soft rocks of the Straight Cliffs Formation (Kscu) west of Mill Creek at the southwest edge of quadrangle. Original landform eradicated by gravity and erosion; probably old stream-terrace or fan alluvium. Estimated thickness 6 to 16 ft (2-5 m).*

Qaf$_1$ Alluvial-fan deposits (Holocene)--*Interbedded gravel, silt, and clay deposits of alluvial fans. Many of the best exposed fans are around Navajo Lake. Here upper parts of fans consist chiefly of clast-supported coarse gravel of limestone and minor sandstone and conglomerate containing some sandy matrix. The middle to lower parts of fans consist of pebbly sand to sandy pebble gravel of angular small limestone pebbles and sparse small cobbles (3 inches in diameter); and reddish-yellow, poorly sorted, loamy fine quartz sand. The distal parts of fans are of crudely stratified, silty, slightly pebbly and clayey, fine to coarse quartz and limestone sand. Some hard layers 4 to 8 in (10-20 cm) thick are cemented by calcium carbonate. East of the Navajo Lake dam, the map unit interfingers with and grades into lake sediment (Qla) along the axis of the valley, whereas along the shore of the former lake, it interfingers with and grades into lake gravel (Qlg). At the west end of the valley of Midway Creek, cobble to boulder gravel 8 to 30 in (20-80 cm) in diameter is composed of ash-flow tuff (Isom Formation) in a moderate-brown, silty fine sand matrix. On and south of the south-facing plateau escarpment (Pink Cliffs), fan alluvium consists of dark-yellowish-brown interbedded sand, silt, and poorly to moderately well-sorted sand, pebbly sand, and silt. Thickness is estimated to be 16 to 23 ft (5-7 m) at mid-fan locations.*

Qaf$_2$ Older alluvial-fan deposits (upper Pleistocene)--*Poorly sorted, crudely stratified gravel and matrix; particle size ranges from clay to boulders. Chiefly limestone and sandstone gravel in a firmly cemented, light-brown, slightly clayey, sand and silt matrix; includes lenses of stratified, moderately sorted, fine quartz sand 3 to 6 ft (1-2 m) thick. Visually estimated composition of clasts is as follows: subrounded to rounded clasts of gray, white, and pink limestone of the Claron Formation (65 to 70 percent); white pebbles and cobbles of well-rounded, tan and white metaquartzite (20 percent); light-brown, arkosic, subarkosic, and slightly feldspathic quartzose sandstone and dark-brown, limonitic (oxidized pyritic) concretions (10 percent); and olivine basalt (1 percent). A few clasts of mudstone and ash-flow tuff are present in places. Deposited downslope from the Pink Cliffs between 8,400 and 9,200 ft (2,560 and 2,800 m) elevation. Forms elongate erosional remnants that cap interfluves on relatively soft strata and that occur at a topographic level 13 to 32 ft (4-10 m) higher than younger fans (Qaf$_1$); forms sloping surfaces at head of drainages and base of cliffs. Thickness 6 to 23 ft (2-7 m).*

Qac Sheetwash alluvium (Holocene)--*Grayish-orange-pink, interbedded clay, silt, fine sand, and fine gravel. Contains subangular to subround limestone pieces 0.1 to 6 in (2 mm-15 cm) long in a brown, sandy, silty clay to clayey silt matrix. Upper 6 ft (2 m) is chiefly silt that contains minor gravel. Contains laminations that are 0.04 to 0.1 in (1-3 mm) thick and beds that are 4 to 8 in (10-20 cm) thick. On Markagunt Plateau, deposits accumulate in topographic lows developed on the Claron Formation. Base covered; estimated thickness 6 to 16 ft (2-5 m).*

Qc Limestone and sandstone gravel colluvium (Holocene to upper Pleistocene)--*Widespread interbedded gravel, grus, silty fine sand, clayey silt, and clay derived from weathered rock. Light brown to moderate reddish orange where dry, brown to reddish brown where moist. Made up chiefly of limestone and sandstone clasts that range from granules to small boulders; some clasts are as large as 16 to 23 ft (5-7 m) across. Locally contains subordinate volcanic tuff and (or) basalt. Mapped only where deposits are thickest. Matrix is unsorted, rarely stratified. Thickness of mapped colluvium estimated to be 13 to 55 ft (4-17 m).*

Qcv Volcanic gravel colluvium (Holocene to upper Pleistocene)--*Blocks, boulders, gravel, grus, lithic sand, silt, and clay. In the northern half of the quadrangle, it mantles most hillslopes formed on the Markagunt Megabreccia (Tm), Brian Head Formation (Tbh) and basaltic lava flows (Qbf$_1$) but is shown only where it conceals contacts. It is derived from blocks transported downhill during weathering and creep of the Markagunt Megabreccia and basaltic lava flows. Some of this debris forms large masses mapped as the gravelly decomposition residuum and colluvium unit (QTrg). Over much of the northern half of the quadrangle, isolated blocks as long as 16 ft (5 m) of mostly the Isom Formation (Hatfield and others, 2000a, figure 6) represent the Qcv deposit but cannot be mapped individually at 1:24,000 scale. These blocks mark the original (depositional) extent of the Markagunt Megabreccia. The matrix of the volcanic gravel colluvium is grus, lithic sand, and silt. Composition reflects that of the nearest bedrock or blocks exposed upslope, notably calc-alkaline ash-flow tuff of the Isom Formation and basaltic rocks of the lava flows. In places, tuff and basalt clasts are mixed. Some basalt clasts are blocky with angular to subrounded edges where they are recently derived from young basalt flows. Spheroidal weathering has occurred on clasts derived from older basalt flows and the Isom Formation. Base covered, estimated thickness 6 to 10 ft (2-3 m), but as much as 13 ft (4 m) thick at the foot of relatively steep hillslopes.*

Qmt$_1$ Talus (Holocene)--*Loose, angular rock fragments deposited on steeply sloping surfaces by rock falls. Most fragments range from silt size to blocks 3 to 16 ft (1-5 m) across; finer material is light brown. Clasts are of limestone, sandstone, and subordinate quartz-pebble conglomerate; a few blocks as large as 25 to 30 ft (8-10 m) across rest at the foot of some steep hillslopes. Downslope, unit grades into colluvium. Thickness about 6 to 50 ft (2-15 m).*

Qmt$_2$ Older talus and colluvium (upper Pleistocene)--*Composition like younger talus (Qmt$_1$) except deposits form degraded erosional remnants that armor small hilltops downslope from the Pink Cliffs. Estimated thickness 6 to 23 ft (2-7 m).*

Qla Lacustrine and alluvial deposits (Holocene to upper Pleistocene)--*Sediment washed from adjacent hillslopes into a natural, intermittent, lake basin. The lake formed upstream of a lava flow (Qbf$_1$) and predates the man-made Navajo Lake shown on the map. Deposit is stratified light-brown and moderate-yellowish-brown, silty, very fine quartz sand; includes interbeds of brown, slightly sandy and silty clay and light-gray clayey silt. The beds are 8 to 20 inches (20-50 cm) thick. Scattered subangular limestone pebbles are in the center of the lake basin, grading to lacustrine gravel (Qlg) near the former shore. Contains high-spired, fragile, white snail shells 0.2 in (0.5 cm) in diameter. Deposits are sporadically flooded. Base of deposits generally not exposed, but basalt boulders were observed partially exposed in sinkholes that are too small to be mapped (called Navajo Sinks by Wilson and Thomas, 1964) under 5 ft (1.5 m) of lake sediment about 1,300 ft (400 m) east of the man-made dam. This sediment-basalt boulder contact may mark the base of the unit. Estimated thickness 5 to 16 ft (1.5-5 m).*

Qlg Lacustrine gravel (Holocene and upper Pleistocene)--*Pale-orange, sandy, limestone-pebble gravel. Grades into lacustrine and alluvial deposits (Qla). Estimated thickness 2 to 6 ft (0.5-2 m).*

Qo Peat (Holocene and upper Pleistocene)--*Brownish-black, water-saturated, partly decomposed plant material and minor clay and silt. Consists of a dense organic mat of grass roots, moss, and herbaceous annuals. Has a spongy, soft surface. Contains scarce, light-gray chitinous bivalve shells 0.1 to 0.2 in (3-5 mm) across. In the quadrangle, the peat forms on slopes of from 0 to 0.5 degrees on the valley floor west of Navajo Lake and in some sinkholes in the Brian Head Formation (Tbh) and the gravelly decomposition residuum and colluvium (QTrg) on the Markagunt Plateau. In adjacent quadrangles near Cedar Breaks National Monument, pollen fossils and tephra that erupted from the Mono Craters of California demonstrate that the peat bogs of the high Markagunt Plateau are at least 17,000 years old (Canaday and others, 2001). Estimated thickness 2 to 10 ft (0.5-3 m).*

Qes Eolian deposits (Holocene)--*Grayish-orange to pale-yellowish-brown, clayey calcareous sand. Most deposits are accumulations of loose grains of sedimentary rock on the rim of Cedar Breaks National Monument (northwest part of quadrangle) that were carried by winds that ascended the west-facing cliffs. Subspherical medium sand-sized aggregates of weathered limestone and calcareous mudstone, clay-, silt-, and a few very fine sand-size quartz grains. Soft when dry; slightly plastic when wet (consistency terms from Soil Survey Staff, 1951, p. 232). Contains 5 to 10 percent angular wind-deposited limestone pieces 0.1 to 0.6 in (2-15 mm) long. Minor active slumping of the deposit (not mapped separately) indicated by tilted trees on hummocky hillslopes. Unit buries a 3-ft (1-m)-thick layer of the Brian Head Formation (Tbh) that mantles the white member of the Claron Formation (Tcw). About 6 to 26 ft (2-8 m) thick*

Qms Mass-movement deposits (Holocene to upper Pleistocene)--*Broken and disaggregated masses of gravitationally displaced colluvium, soil, and rock. Mostly represented by landslide and small slumps, although some deposits are represented by rotational slides that contain large, relatively coherent blocks of strata. Estimated thickness 6 to 20 ft (2-6 m); largest slides may be as thick as 50 ft (15 m).*

QTrg Gravelly decomposition residuum and colluvium (Holocene to upper Tertiary)--*Sandy and silty heterogeneous unsorted, mostly angular gravel and breccia ranging in size from small pebbles to boulders as large as 6 ft (2 m) across but locally larger. Forms a surface lag of gravel, grus, sand, and silt of ash-flow tuff (Isom Formation), basalt, and 3 to 5 percent smooth, well-rounded, fine- to medium-sized pebbles of grayish-black chert and pale-brown and dark-reddish-brown quartzite. The rounded pebbles are derived from pebble conglomerate in the white member of the Claron Formation (Tcw) and from the Brian Head Formation (Tbh). Most of the map unit probably was let down vertically from a higher surface by sapping and dissolution (chemical weathering) of underlying limestone of the Claron Formation, as manifested by the many sinkholes developed in the Claron and overlying units. The texture and composition of most of the map unit suggests that a continuous breccia mantle of Markagunt Megabreccia (Tm) made up of mostly ash-flow tuff (Isom Formation) was partly covered by a basalt flow, followed by a long period of weathering. Unit was produced by chemical decay and physical disintegration of boulders with little subsequent lateral transport except for downslope creep; forms unusually smooth, symmetrical, slightly domal hills that have 1- to 2-degree summit slopes and 2- to 4-degree shoulder slopes. Characteristics of the Bt horizon (layer of translocated clay accumulation in soil) suggest weathering during an extended period of time. The Bt horizon is 3 to 5 ft (1-1.5 m) thick, dark brown (when wet), gravelly clay to clay loam, having strong, large blocky soil structure and thick clay films. Covering the Bt horizon is a surficial thin layer (A horizon) that is moderate-yellowish-brown, pebbly, slightly clayey silt to silty fine sand. In sinkholes, basalt boulders that were emplaced when the sinks collapsed have become spheroidally weathered. Estimated maximum thickness of deposit 20 ft (6 m).*

BEDROCK

Qbf$_1$ / Qbv$_1$ Olivine-plagioclase mafic volcanic rocks (Holocene to upper Pleistocene?)--*Blocky lava flows and central volcano vents of fine- to medium-grained porphyritic basalt, basaltic andesite, and some trachyandesite (figure 1) containing phenocrysts of olivine and plagioclase. Most of the rocks consist of lava flows, mapped as Qbf$_1$, but some rocks were erupted from small central vent areas, mapped as Qbv$_1$. Flows locally contain vesicle pipes. Mostly unvegetated and little eroded, thus probably Holocene. Flowed into the valley now occupied by Navajo Lake, creating a natural dam and forming a prehistoric lake subsequently amplified by a human-made dam. Rocks have conspicuous olivine+plagioclase+clinopyroxene glomerocrysts (aggregates of crystals). Phenocrysts and glomerocrysts are set in a matrix of olivine, plagioclase, clinopyroxene, Fe-Ti oxides, and glass. Sparse to common olivine phenocrysts attain maximum dimensions of 0.1 in (2 mm). Olivine frequently encloses brown Cr-Al spinel inclusions. Sparse to common plagioclase phenocrysts attain maximum lengths of 0.1 in (2 mm) and average lengths of 0.04 in (1 mm). Compositions represented by samples NNL-3, NNL-17, and NNL-16 in figure 1 and table 1. Thickness of individual flows commonly less than 16 ft (5 m) but aggregate thickness, especially in paleovalleys, is much greater and in vent areas the flows accumulated to at least 800 ft (240 m).*

Qbf$_2$ / Qbd$_2$ Clinopyroxene-olivine basalt (upper Pleistocene)--*Mesa-capping lava flow and a source dike of medium-grained, porphyritic basalt containing phenocrysts of clinopyroxene, olivine, and plagioclase. The lava flow is mapped as Qbf$_2$, whereas the dike is mapped as Qbd$_2$. The flow and dike are exposed only in the southwest corner of the quadrangle, and the flow extends south into the Straight Canyon quadrangle. Contains conspicuous clinopyroxene+olivine glomerocrysts as large as 0.3 in (7 mm) in diameter. Phenocrysts and glomerocrysts are in a matrix of clinopyroxene, olivine, plagioclase, Fe-Ti oxides, and glass. Common clinopyroxene phenocrysts attain maximum dimensions of 0.1 in (3 mm) and average dimensions of 0.04 in (1 mm). Common olivine phenocrysts attain a maximum size of 0.1 in (3 mm) and an average size of 0.08 in (2 mm). Clinopyroxene shows varieties of hourglass, concentric, and other complex zoning patterns. Composition represented by sample NNL-28 in figure 1 and table 1. Thickness about 35 ft (10 m).*

Qbf$_3$ / Qbc$_3$ Olivine-clinopyroxene-plagioclase basalt (upper to lower? Pleistocene)--*Blocky and cinder-covered lava flows and cinder cones of medium-grained porphyritic basalt containing phenocrysts of olivine, clinopyroxene, and sparse plagioclase. The lava flows are mapped as Qbf$_3$, whereas the cinder cones are mapped as Qbc$_3$. Only moderately eroded. Common glomerocrysts of olivine+plagioclase+ clinopyroxene, with maximum dimensions of more than an inch (several centimeters) and an average size of less than 0.5 in (1 cm) in diameter, are in a matrix of olivine, clinopyroxene, plagioclase, Fe-Ti oxides, and glass. Common olivine phenocrysts attain maximum dimensions of 0.16 in (4 mm) and average dimensions of 0.04 in (1 mm). Olivine commonly encloses brown Cr-Al spinel inclusions. Common plagioclase phenocrysts attain maximum dimensions of 0.5 in (1 cm) and average dimensions of 0.02 to 0.04 in (0.5-1 mm). Sparse clinopyroxene phenocrysts are as large as 0.08 in (2 mm) in diameter. Compositions represented by samples NNL-5, NNL-6, NNL-12, NNL-15, NNL-25, and NNL-26 in figure 1 and table 1. Unit may correlate with either the middle Pleistocene Three Creeks flow or the early Pleistocene Horse Knoll flow, exposed in the Cogswell Point quadrangle within about 1.2 mi (2 km) southwest of the quadrangle (Biek and Hylland, 2002). The Horse Knoll flow has a K-Ar date of 0.8 Ma (Best and others, 1980). Thickness less than 16 ft (5 m) but in vent areas accumulated to as much as 300 ft (90 m).*

Qbf$_4$ Olivine-plagioclase trachybasalt (upper to lower Pleistocene)--*Lava flow of fine-grained porphyritic trachybasalt, containing phenocrysts of olivine, plagioclase, and clinopyroxene. Common olivine and plagioclase phenocrysts average about 0.04 in (1 mm) in maximum dimension. Flow underlies younger, olivine-plagioclase, mafic volcanic rocks (Qbf$_1$) near the east edge of the quadrangle, and is distinguished from these younger mafic volcanic rocks by a lighter color caused by more abundant plagioclase crystals. Flow erupted from an unknown source. Composition represented by sample NNL-13 in figure 1 and table 1. Thickness less than 16 ft (5 m).*

Tm Markagunt Megabreccia (Miocene)--*Poorly exposed, structurally chaotic assemblage of angular clasts and broken masses of older rock units spread over the crest of the northern and central Markagunt Plateau (Sable and Anderson, 1985; Anderson, 1993; Sable and Maldonado, 1997b). Notable among these older rock units is the Isom Formation, a regional ash-flow tuff of about 26 Ma (Mackin, 1960; Fleck and others, 1975; Best and others, 1989). Most information on the Markagunt Megabreccia comes from exposures northeast of the quadrangle, where Anderson (1993) defined the unit and described a type section. Along with Anderson (1993), Hatfield, Rowley, and Anderson (2000), and Hatfield and others (2000a, b), we interpret the unit as a gravity slide that moved on subhorizontal surfaces (shown on the map as "gravity slide faults") in incompetent sedimentary units, notably the Brian Head Formation, but the age and origin of the gravity slide have several interpretations (e.g., Sable and Maldonado, 1997b). The youngest rocks on which this gravity-slide mass rests belong to the Leach Canyon Formation, a regional ash-flow tuff whose ^{40}Ar/^{39}Ar age is 23.8 Ma (Best and others, 1989; Hatfield and others, 2000a). The megabreccia is locally overlain by an ash-flow tuff, the Haycock Mountain Tuff, with an ^{40}Ar/^{39}Ar age of 22.75 Ma (Anderson, 1993; Hatfield and others, 2000a). In the quadrangle, all that remains of the Markagunt Megabreccia is a rubbly surficial deposit that Moore (1992) and Moore and Nealey (1993) mapped as the gravelly decomposition residuum and alluvium (QTrg) and interpreted to be the result of repeated landsliding of higher sheets of volcanic tuff that once covered the quadrangle. Brian Head, about 4 mi (6 km) north of the quadrangle, is a remnant of such higher sheets. Angular rock fragments of the Isom Formation as much as 16 ft (5 m) long dominate in the Markagunt Megabreccia, with subordinate smaller clasts of white to pale-brown tuffaceous sandstone, mudstone, limestone, pebbles of chert and quartzite, and variegated chalcedony. Many clasts of the Isom Formation are brecciated (Hatfield and others, 2000a, figures 6 and 7). The best exposures in the map area are on Blowhard Mountain, in the northwestern part of the quadrangle, where the unit is about 130 ft (40 m) thick and is unconsolidated; it rests on red sandstone and gray conglomerate of the Brian Head Formation. The unconsolidated nature of the Markagunt Megabreccia in the quadrangle was attributed by Hatfield and others (2000a, b) to being let down from a higher level surface by sapping and dissolution of the underlying Claron limestone, which is marked by abundant sinkholes in the area.*

Tbh Brian Head Formation (Oligocene to Eocene)--*Light-gray, soft, tuffaceous fluvial and lacustrine sedimentary rocks. First defined by Gregory (1944) to include a thick package of sedimentary and volcanic rocks that included at its base the white member of the Claron Formation. Abandoned by Anderson and Rowley (1975) because of confusion over its use, especially the improper inclusion of basal volcanic rocks of the Marysvale volcanic field in areas to the north. Based on mapping in the Red Hills west of the Markagunt Plateau, Maldonado and others (1990) proposed an informal name "sedimentary and volcanic rocks of the Red Hills" for a much restricted part of the sequence, and Anderson (1993) reintroduced Brian Head Formation for the same restricted unit in the Markagunt Plateau. The formation rests unconformably upon the Claron Formation. Sable and Maldonado (1997a) provided a detailed discussion and type section of the redefined Brian Head Formation, which they divided into three units. Two of these are poorly exposed in the quadrangle. The lower is soft, thin-bedded, reddish-brown and pink non-tuffaceous sandstone and conglomerate, with subordinate siltstone, claystone, and micritic limestone. The upper unit (middle member of Sable and Maldonado, 1997a) is a thick, soft, thin-bedded, gray, greenish-gray, and yellowish-gray, bioturbated, volcaniclastic clayey sandstone, conglomeratic sandstone, claystone, micritic limestone (commonly replaced by chalcedony), and air-fall tuff. Largely because of air-fall tuff contained within, and weathered to bentonitic clay, this middle member is incompetent and prone to landsliding. The Markagunt Megabreccia is interpreted to have slid primarily on this unit in the quadrangle. The lower unit is considered to be middle to late Eocene based on paleontological evidence (Sable and Maldonado, 1997a), whereas the upper part of the middle unit beneath Brian Head contains ash-flow tuff dated between about 35 and 29.5 Ma, early to middle Oligocene (Sable and Maldonado, 1997a; Hatfield and others, 2000a). As mapped, the Brian Head Formation is rarely exposed because it is largely buried beneath a colluvial mantle of debris (formerly mapped by Moore and Nealey [1993] as the gravelly decomposition residuum and colluvium unit) let down from the overlying Markagunt Megabreccia. The contact between the map unit and the Markagunt Megabreccia is not exposed. In the northern part of the quadrangle, the formation is about 300 ft (90 m) thick.*

Claron Formation (Eocene to Paleocene)--*Varicolored lacustrine and fluvial sedimentary rocks. Alternating beds of sandy limestone and calcareous sandstone with fewer beds of calcareous mudstone and conglomerate; mostly nonfossiliferous. Previously called the Wasatch Formation (Richardson, 1909; Gregory and Moore, 1931) and Cedar Breaks Formation (Schneider, 1967). Called Claron Formation by Mackin (1960) and Anderson and Rowley (1975), who divided it into the upper white member and the lower red member. Forms escarpment 900 to 1,100 ft (270-340 m) high at the edge of the Markagunt Plateau, mostly covered by colluvium and forest, but spectacularly exposed as the colorful beds of the "Pink Cliffs" at Cedar Breaks National Monument in the northwest part of the quadrangle and at Cascade Falls in the southeast part of the quadrangle. The unit also makes up most of the famous landforms of Bryce Canyon National Park, located 50 mi (80 km) east-northeast of the quadrangle. Dissolution of faulted and fractured limestone, especially in the red member, has resulted in many sinkholes that are well expressed at the surface and thus mapped. Many of these sinkholes have dropped down overlying rock units, especially basaltic flows. Hatfield and others (2000a, b) and Hatfield, Rowley, and Anderson (2000) suggested that, over time, multiple sinkholes let down much of the Markagunt Megabreccia (Tm). If so, this would explain why little of that formerly extensive gravity-slide mass remains intact.*

Tcw White member--*Limestone, mudstone, and minor sandstone. Base of member is at the base of a conspicuous 40-ft-(12-m)- high cliff of white and pale-orange, uniformly micritic to locally pelmicritic limestone (informally called the "lower white limestone" in the Cedar Breaks National Monument area). Very sparsely charophyte-bearing in places. Above the basal limestone is a 310-ft (94 m)-thick slope-forming interval of interbedded mudstone and sandstone that are yellowish gray and moderate yellowish brown. Sandstone is dark-yellowish-orange to light-brown, cross-bedded, fine- to medium-grained sandstone made up mostly of quartz but with about 20 percent black chert and minor feldspar (a "salt-and-pepper" sandstone). Near the middle of the 310-ft (94-m)-thick interval is a laterally persistent 6 to 10-ft (2-3 m)-thick interval containing lenses of chert pebble conglomerate; the chert pebbles are distinctive in that they are remarkably smooth, well-rounded, uniformly black, and abundant. The uppermost bed in the white member is a 43-ft (13-m)-thick, cliff-forming, micritic limestone (the "upper white limestone"). The upper white limestone is pale yellowish gray to pale orange and weathers white to pale yellowish gray; it contains intraclasts (torn up and redeposited pieces of micrite), pellets, calcite spar-filled vugs, and networks of calcite veinlets. The basal 3 to 5 ft (1-1.5 m) of the upper white limestone contains a few discontinuous irregular zones of chalcedony replacing limestone. The "lower" and "upper" white limestones, unlike limestones in the red unit, are nearly devoid of quartz sand. The white member of the Claron Formation is about 350 ft (110 m) thick at the northern part of the quadrangle but it pinches out near the southern boundary of Cedar Breaks National Monument. The pinching out is at least partly due to erosion prior to deposition of the Brian Head Formation.*

Tcr Red member--*Alternating beds of pale-red to pink, sandy limestone, calcite-cemented sandstone, calcareous mudstone, and minor pebble conglomerate. Limestone is varicolored, commonly moderate red, moderate reddish orange and pale orange, with mottled colors of grayish orange, dark yellowish orange, and moderate pink; the limestone is microcrystalline, locally argillaceous, and generally sandy (2-20 percent uniformly dispersed fine quartz sand). It commonly contains calcite spar-filled vugs and thin branching veinlets of calcite spar, with crystals 0.02 to 0.08 in (0.5-2 mm) long. Contains stylolites. The member is locally cavernous, with abundant dissolution cavities and surficial sinkholes. Calcite spar- and micrite-filled vertical burrows 0.2 to 2 in (0.5-4 cm) in diameter and 4 to 20 in (10-50 cm) long are abundant in some limestone beds. Limestone contains scattered, sparse, aquatic, small bivalves (pelecypods?, branchiopods?, ostracodes?) and planispiral-coiled shells of gastropods; most limestone beds are massive (3 to 6 ft [1-2 m] thick); in detail, limestone is relatively pure, structureless micrite that grades to micrite containing dispersed quartz sand, and (or) micrite balls 0.08 to 1 in (0.2-2 cm) in diameter that have concentric laminations, or "onion-like" structures (oncolites? or oolites?), and (or) pebble-sized intraclasts (Folk, 1959) and pellets that are in places angular and chaotically juxtaposed and so impart a breccia-like appearance to the rock. The limestone textures thus suggest penecontemporaneous erosion, mixing, and deposition - with little or no transport - of soft marly sediment in a moderately energetic aqueous environment or post-deposition alteration that mimics such deposition. Crystalline calcite that fills vugs and replaces shells is diagenetic, as is some matrix. How the micrite bodies and breccia-like sedimentary structures formed is uncertain; formation in fossil soil horizons has been suggested (Mullett and others, 1988). Interbedded throughout the unit is sandstone and mudstone. Sandstone forms ledges and is a varicolored, thick-bedded, calcite-cemented quartz arenite that is cross-bedded in places. Mudstone is silty and calcareous, contains calcareous nodules, and weathers to earthy, steep slopes between ledges of sandstone and limestone. Conglomerate crops out as lenticular beds, 6 to 16 ft (2-5 m) thick, and it interfingers with grayish-pink to medium-gray, firmly cemented, quartzose sandstone. Sandy quartzite-pebble conglomerate was seen at 30 ft (9 m), 39 ft (12 m), 138 ft (42 m), and 207 ft (63 m) above the base of the red member of the Claron Formation. Conglomerate beds persist 300 to 1,000 ft (100-300 m) laterally before pinching out; they apparently are fluvial point-bar and channel deposits. The base of the red member is placed at the bottom of the first limestone beds above mudstone and sandstone assigned to the formation of Cedar Canyon (TKcc). The basal limestone beds form a conspicuous pale-reddish-brown cliff 62 to 75 ft (19-23 m) high that is unbroken around the south edge of the Markagunt Plateau. At the base of the cliff are shallow caves and rough, irregularly eroded rock columns, and a recessive bed from which springs (such as Cascade Falls) issue in places. The lower contact is gradational to sharp. Maximum exposed thickness is 750 ft (228 m) in the southeast corner of the quadrangle at Cascade Falls. Schneider (1967, p. 189) measured 978 ft (298 m) in thickness for the red member (his section 2B of Cedar Breaks Formation) at Adams Barrier in Cedar Breaks National Monument (1 mi [1.6 km] north of the Navajo Lake quadrangle).*

TKcc Formation of Cedar Canyon (Paleocene to Upper Cretaceous)--*Along the western scarp of the Markagunt Plateau, in the area of the Navajo Lake and Brian Head quadrangles, a thick sequence of rocks between the Straight Cliffs Formation and the Claron Formation has been correlated with various local units and has been interpreted at various ages. Moore and Nealey (1993) interpreted the sequence to consist of two units, which they called Kaiparowits(?) Formation and the underlying Wahweap Sandstone (both Upper Cretaceous). Of these, the unit they mapped in the Navajo Lake quadrangle as the Kaiparowits(?) Formation consists of sandstone and subordinate mudstone and conglomeratic sandstone that is 200 ft (60 m) thick. They described the upper 33 to 59 ft (10-18 m) of the formation as chiefly cherty, argillaceous, yellowish and orange-colored "dirty salt-and-pepper" sandstone, whereas the remainder of the unit is predominately "clean" gray-colored quartz arenite containing subordinate interbeds of mudstone. The "dirty" sandstone crops out as a cliff or series of ledges 3 to 5 ft (1-1.5 m) thick immediately beneath the basal limestone of the Claron Formation. The "dirty" sandstone is pale yellowish orange, pale yellowish brown, and dark grayish orange, and it weathers grayish orange and moderate yellowish-brown. It is poorly to moderately sorted, subangular fine- to coarse-grained subfeldspathic lithic wacke to subfeldspathic lithic arenite (Williams and others, 1958, p. 292). The "dirty" sandstone contains 8 to 15 percent black chert grains; 20 to 25 percent light-gray, white, and tan angular chert grains; and 10 to 30 percent varicolored, silty and clayey microcrystalline calcite (micrite) and siltstone sand grains, pellets, granules, small pebbles, and irregular bodies 0.2 to 3 in (0.5-8 cm) across. Accessory components in the sandstone include weathered feldspar grains (volumetrically as much as 20 percent locally) and traces of greenish-gray mica. The "dirty" sandstone is medium- to thick-bedded, with uneven planar bedding and sets of small- to medium-scale, 1 to 3 ft (0.3-1 m) thick cross-beds and 0.5-in (1 cm)-thick sets of tabular ripple cross laminae that pinch out laterally. The "dirty" sandstone also contains calcite spar-filled vugs, pelecypod shells (heart-shaped and as large as 3.5 in [9 cm]), fossil wood, vertebrate bone (one specimen was found, which was 6 in [15 cm], long), and common limonitic replacement of organic fibrous material (bone or plant material?). The base of this "dirty" sandstone is sharp and undulatory in places. In other places it interfingers with underlying well-sorted, cross-bedded, slightly feldspathic quartz arenite and silty mudstone. The sandstone below the "dirty" sandstone is predominately light-gray to pale-yellowish-gray, very friable, well-sorted, fine- to medium-grained quartz arenite. Its lower part is mostly covered and contains interfingering beds of Wahweap-like sandstone and thus appears to grade into the unit that Moore and Nealey (1993) correlated with the Wahweap Sandstone. Continuing downward, the lower part of their "Kaiparowits(?)" unit becomes a thick continuous sequence of quartz arenite from the southeast corner of the quadrangle (at Cascade Falls) toward the northwest. In the northwest corner, the lower sandy part is a light-gray (where dry) and dark-gray (where wet), friable, water-bearing, cross-bedded quartz arenite.*

The unit that Moore and Nealey (1993) mapped as Wahweap consists of 870 to 1,050 ft (265-320 m) of interbedded varicolored mudstone, sandstone, and lesser siltstone. The unit is chiefly mudstone that is brownish gray, light olive brown, and moderate reddish brown; it weathers pale red and other mottled colors. It contains 30 to 40 percent silty to fine-grained quartz sand and sparse pure clay. It includes interbedded grayish-orange to dark-yellowish-orange, soft to friable, lenticular beds of cross-bedded clayey sandstone that are 3 to 8 ft (1-2.5 m) thick. Ratio of mudstone to sandstone ranges from 2:1 to 4:1 in exposures along Utah Highway 14, 0.6 to 1.2 mi (1-2 km) west of the quadrangle boundary. Leaf impressions are common in the sandstone. In the southeast corner of the quadrangle, 40 ft (12 m) of friable, water-bearing, dark-gray to olive-black (where wet), silty, slightly clayey, fine-grained quartz arenite is exposed in a streamcut where all surrounding bedrock is covered. The upper one-third of the "Wahweap" contains more sandstone than the lower two-thirds, which is predominantly mudstone. The sandstone is clean and well-sorted and contains thin planar laminated sets (6-8 in [15-20 cm] thick) of trough cross-beds and common convoluted laminae that record penecontemporaneous deformation. The sandstone forms an aquifer. It contains thin layers of carbonized fossil wood and spherical, pyrite-cemented, quartz-sand concretions, which are calcareous and locally oxidized to limonite. The "Wahweap" is a slope-forming unit that is eroded into ravines and rounded, narrow interfluves, all heavily forested.

Hatfield and others (2000a) summarized the literature on the various stratigraphic designations of this map unit in the Cedar Breaks area. They concluded that the "dirty sandstone" of Moore and Nealey (1993) more likely is the Grand Castle Formation (Paleocene? and Upper Cretaceous) of Goldstrand (1992, 1994) and Goldstrand and Mullett (1997) but according to Goldstrand and Mullett, the Grand Castle is more than 650 ft (200 m) thick, not 200 ft (60 m). So Hatfield and others (2000a) named the overall sequence the Wahweap Sandstone/Grand Castle Formation of Paleocene? and Late Cretaceous age. Moore and Straub (2001) published a measured section and their interpretation of the overall sequence in Cedar Canyon. They concluded that the rocks they formerly called Wahweap seem likely to be Wahweap, whereas the overlying 142 ft (43 m) might be considered Grand Castle except that palynologic data indicate a Late Cretaceous age. Thus, they summarized that "further study is needed." Eaton and others (2001) made little effort to resolve the problem, referring to the lower unit as "Wahweap(?) Formation" and the upper unit as "white sandstone" that is most likely the middle sandstone member of the Grand Castle Formation of Goldstrand (1992). During the field trip of Eaton and others (2001), however, J.G. Eaton (verbal communication, 2001) noted that fossils that he has recovered from the overall sequence should be able to resolve the possible correlation and that, until he studies the fossils in detail, perhaps it is best to call the whole sequence by an informal name such as "formation of Cedar Canyon," which we use on this map. The total thickness of the unit is 1,070 to 1,250 ft (325-380 m).

Kscu Straight Cliffs Formation, undivided (Upper Cretaceous)--*In most areas the Straight Cliffs Formation is divided into an upper half (a slope-forming unit) and a lower half (a cliff-forming unit), after Sable and Hereford (1990). The lower unit, which is not exposed in the Navajo Lake quadrangle, forms gray cliffs south and west of the quadrangle and is chiefly sandstone formed in a marine littoral and nearshore environment. The upper unit, which underlies the slope below the Pink Cliffs, consists of a regressive sequence of flood-plain and channel deposits of streams that flowed across the coastal plain of the Late Cretaceous seaway. In the Navajo Lake quadrangle, the rocks consist predominantly of mudstone containing numerous thin (1-6 ft [0.3-2 m]) lenticular sandstone beds; a few lenticular sandstone beds as thick as 20 ft (6 m), and one or two 50-ft (15-m)-thick cliff-forming sandstone beds that are exposed in the upper quarter of the unit. Except for the lowest 165 ft (50 m), which is marine, the unit is chiefly clay and sand probably deposited by streams on a coastal or fluvial plain. Ratio of mudstone to sandstone ranges from 3:1 to 10:1. Mudstone is generally silty and sandy, slightly calcareous to noncalcareous, and varicolored (light gray, yellowish gray, pale yellowish brown, and moderate reddish brown to brownish gray); it weathers to a reddish-brown (where moist) and varicolored earthy slope. Sandstone interbeds are pale orange, grayish orange, and moderate yellowish brown, weathering to light brown. Sandstone is slightly feldspathic quartz arenite composed mostly of fine to medium, subangular quartz grains, with 4 to 8 percent black chert and 10 to 20 percent white feldspar grains. The sandstone is firm to slightly hard and exhibits flaggy parting and planar and trough cross-bedding in sets 4 to 8 in (10-20 cm) thick. It contains iron oxide-cemented laminations, nodules and fossil leaf impressions, silicified fossil wood pieces, carbonaceous plant fragments and films, and local mud pellet conglomeratic lenses. The lowest 165 ft (50 m) of strata, exposed in Schoppman Hollow (southwest corner of the quadrangle), is chiefly olive-black (where moist) to dark-yellowish-brown mudstone; some beds contain abundant oyster and clam shells and a few high-spired snail shells (cf. Craginia sp.; Eaton and others, 2001, p. 342). These clayey beds probably accumulated in a sheltered marine embayment fringed by brackish marshland; mudstone contains common lenses of shell hash and sparse beds of yellowish-orange, silty, cross-laminated, fine-grained, quarztose sandstone that weather to thin slabs. The top of the formation is placed at the top of a quartzite-pebble conglomerate and gray quartzose sandstone that together are about 65 ft (20 m) thick and can be traced into adjoining quadrangles. The conglomerate may be equivalent to the Drip Tank Member of Peterson (1969) (E.G. Sable, verbal communication, 1991), although this claimed equivalence can be questioned owing to the presence of one or two similar beds lower in the Kscu unit. The conglomerate is pale-yellowish-brown, soft, medium- to coarse-grained sandstone and conglomerate that weather to pale-yellowish-brown, light-gray, and light-olive-gray, loose sand and pebbles; the unit forms light-gray, sand-covered knobs, spurs, and sparse low cliffs. Its upper 6 to 23 ft (2-7 m) is siliceous pebble conglomerate that weathers to loose, well-rounded pebbles; 85 percent of the pebbles are 1 in (2 cm) diameter or less and the largest are about 2 in (6 cm). The siliceous conglomerate forms three to four rounded ledges totaling 23 ft (7 m) thick that expose high-angle foreset cross-beds in the NW¼ section 34, T. 37 S., R. 8 W. The map unit is well exposed 1 mi (1.6 km) south of the quadrangle near Lower Bear Spring in the SE¼ SE¼ section 22, T. 38 S., R. 9 W. Thickness of the Straight Cliffs in the quadrangle is about 1,200 ft (370 m).*

MAP SYMBOLS

Contact

85 Normal fault--*Bar and ball on downthrown side. Dashed where approximately located, dotted where concealed. Arrow and number show direction of dip of fault plane and its dip in degrees (only in southeast corner of map)*

Gravity-slide fault--*Subhorizontal basal shear plane of gravity-slide block masses of the Markagunt Megabreccia. Hachures on the hanging wall (downthrown side). Approximately located; dotted where concealed*

4 Strike and dip of beds

Borrow pit for sand and gravel, cinders, and crushed limestone--*Sand and gravel are from Quaternary alluvial map units. Loose basaltic cinders are at or near volcanic vents. Limestone is from the red member of the Claron Formation in section 25, T. 37 S., R. 8½ W.*

NNL-7 Sample location for geochemical analysis--*Giving sample number shown in figure 1 and table 1*

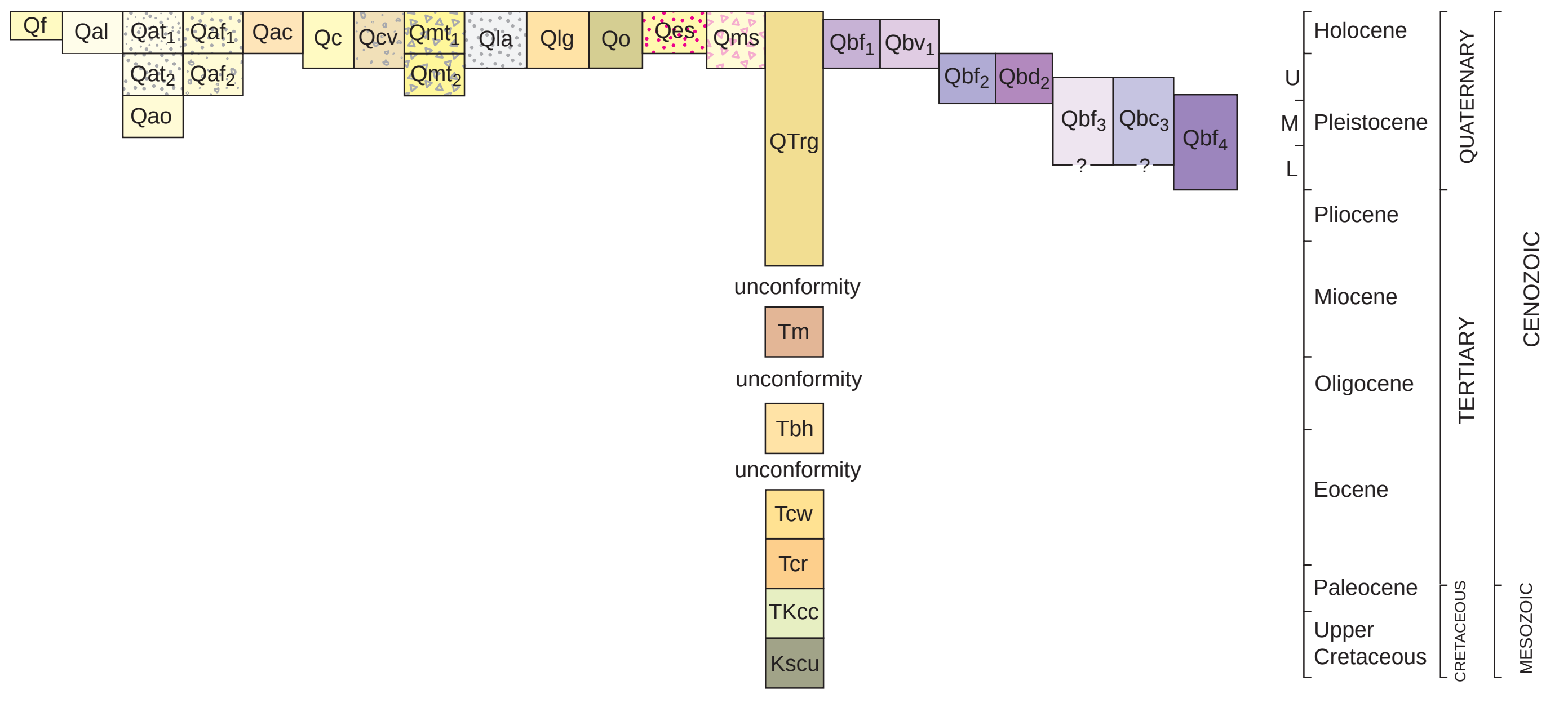
Sinkholes--*Closed depressions containing collapsed material of the same rock as outside the sinkhole. Some sinkholes are as large as 0.3 mi (0.5 km) across. Generally shown by closed topographic contours. Caused by solution collapse of underlying limestone beds of the Claron Formation*

Table 1. Major-and trace-element analyses and normative composition of volcanic rocks of the Navajo Lake quadrangle, Utah.

	[1]Major-oxides [Values in weight percent]										
Field number	NNL-17	NNL-16	NNL-12	NNL-13	NNL-3	NNL-5	NNL-15	NNL-6	NNL-25	NNL-26	NNL-28
[2]Rock type	Basalt	Basaltic andesite	Basalt	Trachy-basalt	Basaltic trachy-andesite	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
Map Unit	Qbf$_1$	Qbf$_1$	Qbf$_3$	Qbf$_4$	Qbf$_1$	Qbf$_3$	Qbf$_3$	Qbf$_3$	Qbf$_3$	Qbf$_3$	Qbf$_2$
SiO_2	51.7	52.8	49.7	51.0	52.3	49.3	50.2	48.0	48.5	48.7	45.6
Al_2O_3	16.8	15.5	16.6	16.9	16.7	16.5	16.6	15.2	16.5	15.8	15.6
[3]$FeTO_3$	10.0	9.31	11.0	9.61	8.28	11.1	10.1	11.0	11.4	11.4	10.5
MgO	6.41	7.72	7.88	6.99	6.63	6.47	7.23	8.58	7.19	8.32	8.29
CaO	9.28	8.07	9.9	8.02	6.77	10.0	10.5	10.7	9.12	9.45	13.0
Na_2O	3.49	3.35	3.15	3.9	4.28	3.27	3.35	3.34	3.16	3.25	3.15
K_2O	1.06	1.33	0.53	1.39	2.01	0.98	0.75	1.18	1.15	1.03	1.11
TiO_2	1.48	1.20	1.40	1.80	1.68	1.74	1.46	1.61	1.59	1.51	1.51
P_2O_5	0.37	0.38	0.28	0.47	0.55	0.42	0.37	0.69	0.50	0.47	1.08
MnO	0.16	0.14	0.17	0.15	0.12	0.17	0.16	0.17	0.17	0.17	0.19
[4]LOI	nd	0.13	nd	nd	nd	nd	nd	nd	1.14	0.04	nd
Total	100.75	99.93	100.61	100.23	99.32	99.95	100.72	100.47	100.42	100.14	100.03
	[5]Normative composition [Based on analyses recalculated to 100 percent volatile-free oxides]										
q[7]	0	0	0	0	0	0	0	0	0	0	0
or	6.22	7.88	3.11	8.2	11.96	5.79	4.4	6.94	6.84	6.08	6.56
ab	29.31	28.4	26.49	32.92	36.46	27.68	28.14	22.18	26.92	27.47	12.36
an	26.84	23.37	29.41	24.44	20.56	27.46	27.84	22.89	27.62	25.45	25.14
ne	0	0	0	0	0	0	0	3.22	0	0	7.74
di-wo	6.87	5.95	7.34	5.09	4.03	8.11	8.97	10.63	6.11	7.65	13.48
di-en	4.26	3.89	4.51	3.46	2.92	4.89	5.69	6.85	3.65	4.74	8.72
di-fs	2.21	1.65	2.41	1.23	0.74	2.79	2.7	3.07	2.14	2.46	3.85
hy-en	8.63	14.98	6.08	4.83	5.35	3.41	3.38	0	3.28	0.63	0
hy-fs	4.48	6.38	3.25	1.71	1.36	1.95	1.61	0	1.92	0.32	0
ol-fo	2.08	0.28	6.25	6.36	5.86	5.48	6.17	10.1	7.78	10.75	8.36
ol-fa	1.19	0.13	3.68	2.48	1.64	3.45	3.23	4.99	5.02	6.14	4.07
mt	4.29	3.92	4.18	4.77	4.64	4.7	4.26	4.49	4.51	4.36	4.36
il	2.79	2.28	2.64	3.41	3.21	3.31	2.75	3.04	3.04	2.86	2.87
ap	0.85	0.88	0.64	1.09	1.28	0.97	0.85	1.59	1.17	1.09	2.5
	[6]Trace elements [Values in parts per million]										
Nb	13	17	8.6	18	30	27	16	31	20	22	56
Rb	17	19	10	21	21	18	15	20	12	16	17
Sr	750	820	425	580	810	550	580	1100	710	680	1400
Zr	200	200	156	255	245	188	182	200	184	178	220
Y	27	24	25	29	21	28	30	24	24	24	27
Ba	790	1000	445	425	880	640	630	1100	940	740	2000
Ce	84	73	46	77	79	54	48	146	80	74	196
La	39	34	22	31	23	24	22	56	27	31	88
Cu	35	40	73	27	37	84	63	87	68	64	95
Ni	59	134	116	124	122	67	65	144	110	116	73
Zn	77	80	85	64	61	76	77	80	82	55	53
Cr	158	275	270	210	158	158	188	305	192	235	160

[1] Major elements determined by wavelength dispersive X-ray spectroscopy; J.E. Taggart, U.S. Geological Survey, analyst.
[2] Nomenclature based on total alkali and silica contents, following LeBas and others (1986).
[3] $FeTO_3$ = total iron as Fe_2O_3.
[4] LOI = loss on ignition.
[5] Total iron as Fe_2O_3; Fe_2O_3 in normative analyses calculated as TiO_2 + 1.5, following Irvine and Baragar (1971).
[6] Trace elements determined by energy dispersive X-ray spectroscopy; J. Kent, U.S. Geological Survey, analyst.
[7] q -- quartz, or -- orthoclase, ab -- albite, an -- anorthite, ne -- nepheline, di-wo -- diopside (wollastonite), di-en -- diopside (enstatite), di-fs -- diopside (clinoferrosilite), hy-en -- hypersthene (enstatite), hy-fs -- hypersthene (orthoferrosilite), ol-fo -- olivine (forsterite), ol-fa -- olivine (fayalite), mt -- magnetite, il -- ilmenite, ap -- apatite.

CORRELATION OF MAP UNITS



ACKNOWLEDGMENTS

We thank Steve Robinson of Cedar Breaks National Monument for many forms of assistance. We are grateful to Grant Willis and Robert Biek of the Utah Geological Survey for excellent technical reviews.

REFERENCES

Anderson, J.J., 1993, The Markagunt megabreccia--Large Miocene gravity slides mantling the northern Markagunt Plateau, southwestern Utah: Utah Geological Survey Miscellaneous Publication 93-2, 37 p.

Anderson, J.J., and Rowley, P.D., 1975, Cenozoic stratigraphy of the southwestern High Plateaus of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 1-52.

Best, M.G., Christiansen, E.H., Deino, A.L., Gromme, C.S., McKee, E.H., and Noble, D.C., 1989, Excursion 3A - Eocene through Miocene volcanism in the Great Basin of the western United States: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 91-133.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1,035-1,050.

Biek, R.F., and Hylland, M.D., 2002, Interim geologic map of the Cogswell Point quadrangle, Washington, Kane, and Iron Counties, Utah: Utah Geological Survey Open-File Report 388, scale 1:24,000.

Canaday, T.W., Bakewell, E.F., Chengyu, Weng, Corson, P.L., Ferris, D.E., Elias, S.A., Funkhouser, G.S., Hughes, R.E., Jackson, S.T., Madsen, D.B., Perry, Laureen, Sarna-Wojciki, Andrei, and Thompson, R.S., 2001, High-altitude archeological investigations at Cedar Breaks National Monument, Utah: National Park Service Cultural Resources Selections Series no. 17, 203 p.

Eaton, J.G., Laurin, Jiri, Kirkland, J.I., Tibert, N.E., Leckie, R.M., Sageman, B.B., Goldstrand, P.M., Moore, D.W., Straub, A.W., Cobban, W.A., and Dalebout, J.D., 2001, Cretaceous and early Tertiary geology of Cedar and Parowan Canyons, western Markagunt Plateau, Utah: Utah Geological Association field trip road log, September, 2001, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin-A symposium and field guide (The Mackin Volume): Utah Geological Association Publication 30 and Pacific Section AAPG Guidebook GB 78, p. 337-363.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in High Plateaus region of Utah: Geological Society of America Special Paper 160, p. 53-61.

Folk, R.L., 1959, Practical petrographic classification of limestones: American Association of Petroleum Geologists Bulletin, v. 43, p. 1-38.

Goldstrand, P.M., 1992, Evolution of Late Cretaceous and early Tertiary basins of southwest Utah based on clastic petrology: Journal of Sedimentary Petrology, v. 63, p. 495-507.

----1994, Tectonic development of Upper Cretaceous to Eocene strata of southwestern Utah: Geological Society of America Bulletin, v. 106, p. 145-154.

Goldstrand, P.M., and Mullett, D.J., 1997, The Paleocene Grand Castle Formation - A new formation on the Markagunt Plateau of southwestern Utah, *in* Maldonado, Florian, and Nealey, L.D., editors, Geologic studies in the Basin and Range-Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1995: U.S. Geological Survey Bulletin 2153, p. 59-78.

Gregory, H.E., 1944, Geologic observation in the upper Sevier River Valley, Utah: American Journal of Science, v. 242, no. 11, p. 577-606.

Gregory, H.E., and Moore, R.C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U.S. Geological Survey Professional Paper 164, 161 p.

Hatfield, S.C., Rowley, P.D., and Anderson, J.J., 2000, Cedar Breaks National Monument, Utah - Giant gravity slides complicate an otherwise simple story [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A-263.

Hatfield, S.C., Rowley, P.D., Sable, E.G., Maxwell, D.J., Cox, B.V., McKell, M.D., and Kiel, D.E., 2000a, Geology of Cedar Breaks National Monument, Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, p. 139-154.

----2000b, Geologic road log of Cedar Breaks National Monument, Utah, *in* Anderson, P.B., and Sprinkel, D.A., editors, Geologic road, trail, and lake guides to Utah's parks and monuments: Utah Geological Association Publication 29, CD-ROM.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523-548.

LeBas, M.J., LeMaitre, R.W., Streckeisen, Albert, and Zanettin, Bruno, 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745-750.

Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, p. 81-131.

Maldonado, Florian, Sable, E.G., and Anderson, J.J., 1990, Shallow detachment of mid-Tertiary rocks, Red Hills (Basin and Range), with implications for a regional detachment zone in the adjacent Markagunt Plateau (Colorado Plateau), southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 94.

Moore, D.W., 1992, Origin of breccia of the Isom Formation near Cedar Breaks National Monument, Markagunt Plateau, southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 6, p. 54.

Moore, D.W., and Nealey, L.D., 1993, Preliminary geologic map of Navajo Lake quadrangle, Kane and Iron Counties, Utah: U.S. Geological Survey Open-File Report 93-190, 20 p., scale 1:24,000.

Moore, D.W., and Straub, A.W., 2001, Correlation of Upper Cretaceous and Paleogene(?) rocks beneath the Claron Formation, Crow Creek, western Markagunt Plateau, southwest Utah, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin-A symposium and field guide (The Mackin Volume): Utah Geological Association Publication 30 and Pacific Section AAPG Guidebook GB 78, p. 75-96.

Mullett, D.J., Wells, N.A., and Anderson, J.J., 1988, Early Cenozoic deposition in the Cedar-Bryce depocenter--Certainties, uncertainties, and comparisons with other Flagstaff-Green River basins [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 3, p. 217.

Peterson, Fred, 1969, Four new members of the Upper Cretaceous Straight Cliffs Formation in the southeastern Kaiparowits region, Kane County, Utah: U.S. Geological Survey Bulletin 1274-J, 28 p.

Richardson, G.B., 1909, The Harmony, Colob, and Kanab coal fields, southern Utah, in, Coal fields of Colorado, Utah, Oregon, and Virginia: U.S. Geological Survey Bulletin 341C, p. 379-400.

Sable, E.G., and Anderson, J.J., 1985, Tertiary tectonic slide megabreccias, Markagunt Plateau, southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 3, p. 263.

Sable, E.G., and Hereford, Richard, 1990, Preliminary geologic map of the Kanab 30- by 60-minute quadrangle, Utah and Arizona: U.S. Geological Survey Open-File Report 90-542, scale 1:100,000.

Sable, E.G., and Maldonado, Florian, 1997a, The Brian Head Formation (revised) and selected Tertiary sedimentary rock units, Markagunt Plateau and adjacent areas, southwestern Utah, *in* Maldonado, Florian, and Nealey, L.D., editors, Geologic studies in the Basin and Range-Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1995: U.S. Geological Survey Bulletin 2153, p. 5-26.

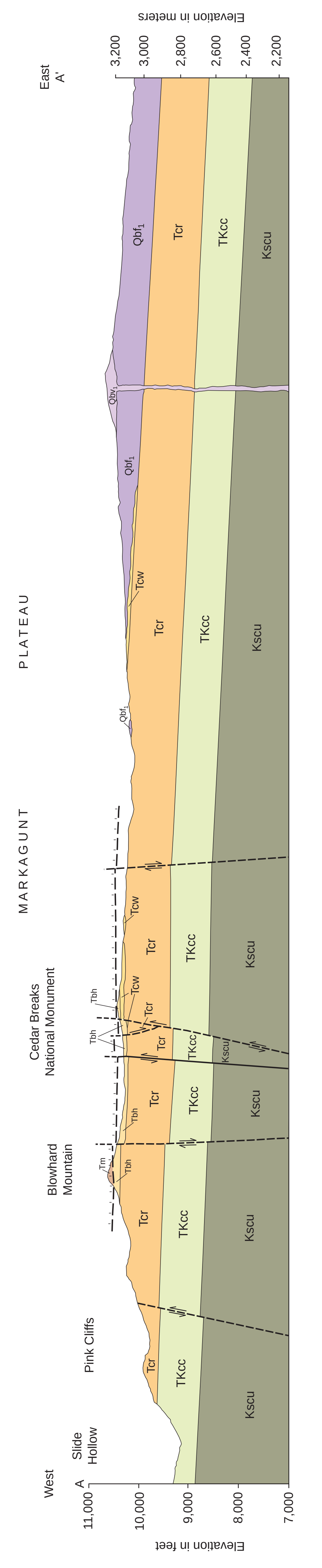
----1997b, Breccias and megabreccias, Markagunt Plateau, southwestern Utah-Origin, age, and transport directions, *in* Maldonado, Florian, and Nealey, L.D., editors, Geologic studies in the Basin and Range-Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1995: U.S. Geological Survey Bulletin 2153, p. 151-176.

Schneider, M.C., 1967, Early Tertiary continental sediments of central and south-central Utah: Brigham Young University Geology Studies, v. 14, p. 143-194.

Soil Survey Staff, 1951, Soil Survey Manual: U.S. Department of Agriculture Handbook no. 18, 503 p.

Williams, Howel, Turner, F.J., and Gilbert, C.M., 1958, Petrography: San Francisco, W. H. Freeman and Co., 406 p.

Wilson, M.T., and Thomas, H.E., 1964, Hydrology and hydrogeology of Navajo Lake, Kane County, Utah: U.S. Geological Survey Professional Paper 417-C, 26 p.



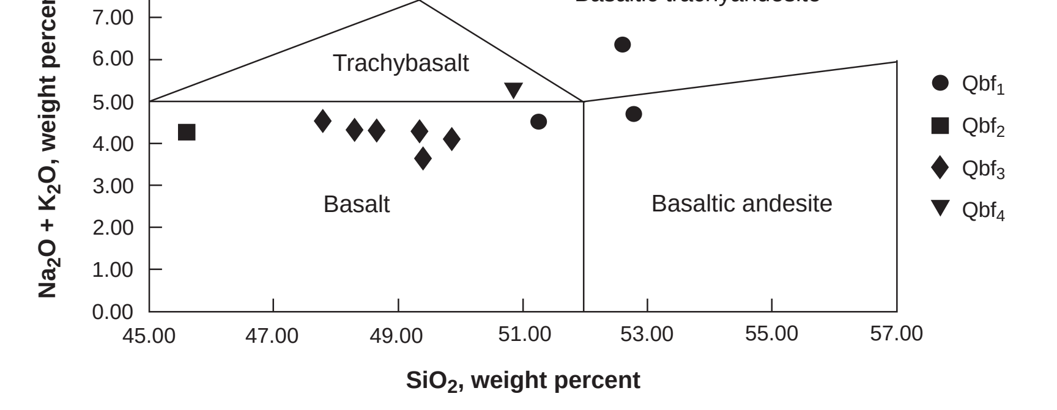


Figure 1. Total alkali versus silica variation diagram for basaltic rock of the Navajo Lake quadrangle. Analyses plotted on a volatile-free basis. Nomenclature after LeBas and others (1986).

COLUMNAR SECTION OF MAP UNITS