U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Cedar Breaks National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Cedar Breaks National Monument

cebr_geology.pdf

Version: 6/7/2022

Geologic Resources Inventory Map Document for Cedar Breaks National Monument

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Geologic Resources Inventory Map Document

Cedar Breaks National Monument, Utah

Document to Accompany Digital Geologic-GIS Data

cebr_geology.pdf

Version: 6/7/2022

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Cedar Breaks National Monument, Utah (CEBR).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.

2) **GRI Digital Maps and Source Map Citations** – A listing of all GRI digital geologic-GIS maps produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.

3) **Map Unit List** – A listing of all geologic map units present on maps for this project, generally listed from youngest to oldest.

4) **Map Unit Descriptions** – Descriptions for all geologic map units. If a unit is present on multiple source maps the unit is listed with its source geologic unit symbol, unit name and unit age followed by the unit's description for each source map.

5) **Geologic Cross Sections** – Geologic cross section graphics with source geologic cross section abbreviations.

6) **Geologic Sample Localities** – Information pertaining to (geologic) sample localities present on both maps.

7) **Ancillary Source Map Information** – Additional source map information presented by source map. For each source map this includes a correlation of map units, stratigraphic column, index map, map legend and map booklet.

8) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document

production credits.

For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Many additional partners participate in the GRI process by contributing source maps or reviewing products.

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: https://www.nps.gov/articles/gri-geodatabase-model.htm

Geologic Reports: GRI reports synthesize discussions from the original scoping meeting, follow up conference call(s), and subsequent research. Chapters of each report discuss the geologic setting of the park, distinctive geologic features and processes within the park, highlight geologic issues facing resource managers, and describe the geologic history leading to the present-day landscape. Each report also includes a poster illustrating these GRI digital geologic-GIS data.

For a complete listing of GRI products visit the GRI publications webpage: https://go.nps.gov/gripubs. GRI digital geologic-GIS data is also available online at the NPS Data Store: https://irma.nps.gov/DataStore/Search/Quick. To find GRI data for a specific park or parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: https://www.nps.gov/subjects/geology/gri.htm. At the bottom of that webpage is a “Contact Us” link if you need additional information. You may also directly contact the program coordinator:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division. Learn more about I&M and the 12 baseline inventories at the I&M webpage: https://www.nps.gov/im/inventories.htm.

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for Cedar Breaks National Monument, Utah (CEBR):

Digital Geologic-GIS Map of Cedar Breaks National Monument and Vicinity, Utah (*GRI MapCode CEBR*)

The map was produced from the following source map and GIS data. Only a partial extent of the source map, the Brian Head, Flanigan Arch, Henrie Knolls, Navajo Lake, Panguitch Lake and Webster Flat 7.5' quadrangles (see Index Map below), was used, however, all geologic features within this extent were captured. Of note, on the source map unit colors for Quaternary volcanic map units frequently shared the same color. In most cases these unit colors were changed to be unique colors using colors from the U.S Geological Survey "Selection of Colors and Patterns for Geologic Map of the U.S. Geological Survey, publication Techniques and Methods 11-B1.

> Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, Florian, Moore, D.W., Hacker, D.B., Eaton, J. G., Hereford, Richard, Sable, E.G., Filkorn, H.F., and Matyjasik, Basia, 2015, Geologic Map of the Panguitch 30' x 60' Quadrangle, Garfield, Iron and Kane Counties, Utah: Utah Geological Survey, Map 270DM, 3 plates and booklet, scale 1:62,500 (Panguitch 30' x 60' Quadrangle). (*GRI Source Map ID 76300*).

Digital Geologic-GIS Map of the Brian Head Quadrangle, Utah (*GRI MapCode BRHE*)

The above GRI digital geologic-GIS map (in reference to it's source map) provides added detail to the northern portion of the monument (personal communication from Robert Biek, co-author on both source maps: "the Brian Head map has value above and beyond the Panguitch 30x60 map, showing different interpretations of some pretty difficult geology".

The above map was produced from the following source map and GIS data. The full extent of the source map was used, and all geologic features within this extent were captured.

> Rowley, Peter D., Biek, Robert F., Sable, Edward G., Boswell, Jonathan T., Vice, Garrett S., Hatfield, Stanley C., Maxwell, David J., and Anderson, John J., 2013, Geologic Map of the Brian Head Quadrangle, Iron County, Utah: Utah Geological Survey, Map 263DM, 2 plates and booklet, scale 1:24,000 (Brian Head Quadrangle). (*GRI Source Map ID 75809*).

Additional information pertaining to each source map is also presented in the GRI Source Map Information (CEBRMAP) table included with the GRI digital geologic-GIS data.

Index Map

The following index map displays the extents of the GRI digital geologic-GIS maps produced for Cedar Breaks National Monument (CEBR). The extent of the park map (*GRI MapCode CEBR*) is defined by the extent of the six 7.5' quadrangles shown, whereas the extent of the Brian Head Quadrangle map (*GRI MapCode BRHE*) is that of the Brian Head quadrangle extent. The boundary for Cedar Breaks National Monument (as of June, 2022) is outlined in green. Bounding 7.5' quadrangle coordinates are also shown.



Index map by Stephanie O'Meara (Colorado State University)

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Cedar Breaks National Monument, Utah (CEBR) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qh - Artificial fill). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (CEBRUNIT) table included with the GRI digital geologic-GIS data.

Cenozoic Era

Quaternary Period

Qh - Artificial fill
Qhd - Disturbed land
Qmsh - Landslides, active
Qal - Stream alluvium
Qaly - Young stream alluvium
Qam - Marsh alluvium
Qaf1 - Young fan alluvium
Qafy - Young and middle fan alluvium, undivided
Qc - Colluvium
Qc/Tbh - Colluvium over Brian Head Formation
Qc/Tcwu - Colluvium over the upper limestone unit of the white member of the Claron Formation
Qed - Eolian dune sand
Qat2 - Stream-terrace deposits, level 2
Qlg - Course-grained lacustrine sediment
Qms - Landslides
Qms(Tm) - Landslides, debris derived from Markagunt gravity slide
Qms(Tql) - Landslides, slump blocks of Leach Canyon Formation
Qms(Ti) - Landslides, slump blocks of Isom Formation
Qms(Kn) - Landslides, slump blocks of Naturita Formation
Qmt - Talus
Qac - Alluvium and colluvium
Qacf - Alluvium, colluvium and fan alluvium
Qae - Alluvium and eolian sand
Qaec - Alluvium, eolian sand and colluvium
Qca - Colluvium and alluvium
Qmtc - Talus and colluvium
Qmsc - Landslides and colluvium
Qla - Lacustrine sediment and alluvium
Qr - Relict Houston Mountain and Blue Spring Mountain lava flows
QTbx - Markagunt gravity slide residuum
Qat - Stream-terrace alluvium
Qlao - Older lacustrine sediment and alluvium
Qlao/Qbmk3 - Older lacustrine sediment and alluvium over Miller Knoll lava flows, oldest
Qalo - Old stream alluvium
Qaf2 - Middle fan alluvium
Qbpl1 - Panguitch Lake lava flows, youngest
Qbpl2 - Panguitch Lake lava flows, older
Qbpl3 - Panguitch Lake lava flows, oldest
Qbdv - Dry Valley lava flow
Qbmkc - Miller Knoll cinder cone
Qbmk2 - Miller Knoll lava flows, older
Qbmk3 - Miller Knoll lava flows, oldest
Qgtp - Glacial till of Pinedale age
Qgop - Glacial outwash of Pinedale age
Qgtou - Older glacial till and outwash, undivided

Qafo - Older fan alluvium
Qaco - Older alluvium and colluvium
Qacfo - Older colluvium and fan alluvium
Qat4 - Stream-terrace deposits, level 4
Qao - Oldest stream alluvium
Qgtu - Older glacial till of uncertain pre-Pinedale age
Qbnlc - Navajo Lake cinder cone
Qbnl - Navajo Lake lava flow
Qbrdc - Red Desert cinder cone
Qbrd - Red Desert lava flows
Qbhkc - Henrie Knolls cinder cone
Qbhk - Henrie Knolls lava flows
Qbmcc - Midway Creek cinder cone
Qbmc - Midway Creek lava flow
Qbdec - Deer Valley cinder cone
Qbde - Deer Valley lava flow
Qbhoc - Horse Pasture cinder cone
Qbho - Horse Pasture lava flow
Qbdc - Duck Creek lava flow
Qbskc - Strawberry Knolls cinder cone
Qbsk - Strawberry Knolls lava flows
Qbefc - East Fork Deek Creek cinder cone
Qbef - East Fork Deep Creek lava flow
Qbbk - Bowers Knoll lava flow
Qbck - Copper Knoll lava flow
Qbpk - Pryor Knoll lava flow
Qbwfc - Webster Flat cinder cone
Qbwf - Webster Flat lava flow
Qbalc - Aspen Lake cinder cone
Qbal - Aspen Lake lava flow
Qblfc - Long Flat cinder cone
Qblf - Long Flat lava flow
Qbwkc - Wood Knoll cinder cone
Qbwk - Wood Knoll lava flow
Qbubc - Upper Bear Springs cinder cone
Qbub - Upper Bear Springs lava flow
Qbbm - Black Mountain lava flow
Qbhpc - Hancock Peak cinder cone
Qbhp1 - Hancock Peak lava flow, younger
Qbhp2 - Hancock Peak lava flow, older

Tertiary Period
Tbbmc - Blue Spring Mountain cinder cone
Tbbm - Blue Spring Mountain lava flow
Tbhm - Houston Mountain lava flow
Tbsp - Sidner Peaks lava flow
Tm - Markagunt Megabreccia, undivided
Tm(Tqcb) - Markagunt Megabreccia, Bauers Tuff Member slide rock
Tm(Tdbv) - Markagunt Megabreccia, Mount Dutton and Bear Valley components, undivided
Tm(Tdm) - Markagunt Megabreccia, Mount Dutton Formation, alluvial facies component
Tm(Ti) - Markagunt Megabreccia, Isom Formation component
Tm(Tnw) - Markagunt Megabreccia, Wah Wah Springs Formation component
Tm(Tbh) - Markagunt Megabreccia, Brian Head Formation component
Ta - Miocene alluvium
Timd - Mafic dikes at the west edge of the Markagunt Plateau
Tqcb - Condor Canyon Formation, Bauers Tuff Member
Td - Mount Dutton Formation, alluvial facies

Tgl - Leach Canyon Formation
Ti - Isom Formation
Tnw - Wah Wah Springs Formation
Tbh - Brian Head Formation
Tc - Claron Formation, undivided
Tcw - Claron Formation, white member, undivided
Tcwt - Claron Formation, white member, uppermost mudstone, siltstone and sandstone unit
Tcwu - Claron Formation, white member, upper limestone unit
Tcwml - Claron Formation, white member, middle mudstone, siltstone and sandstone unit and lower limestone unit, undivided
Tcwm - Claron Formation, white member, middle mudstone, siltstone and sandstone unit
Tcwl - Claron Formation, white member, lower limestone unit
Tcp - Claron Formation, pink member

Mesozoic Era

Cretaceous Period

Km - Cretaceous strata on the Markagunt Plateau
Kgc - Grand Castle Formation (redefined)
Kwcs - Wahweap Formation, capping sandstone member
Kw - Wahweap Formation, upper, middle and lower members, undivided
Ksd - Straight Cliffs Formation, Drip Tank Member
Ksjs - Straight Cliffs Formation, John Henry and Smoky Hollow Members, undivided
Ksj - Straight Cliffs Formation, John Henry Member
Kst - Straight Cliffs Formation, Tibbet Canyon Member
Kt - Tropic Shale
Ktn - Tropic Shale and Naturita Formation, undivided
Kn - Naturita Formation
Kcm - Cedar Mountain Formation

Jurassic Period

Jcw - Carmel Formation, Winsor Member
Jcp - Carmel Formation, Paria River Member
Jcx - Carmel Formation, Crystal Creek Member
Jcc - Carmel Formation, Co-op Creek Limestone Member

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. Some geologic map units are present on both GRI digital geologic-GIS maps, and therefore have a unit description from each source map. For each unit description the source map name, unit name and unit age is first listed. Of note, some unit symbols, unit names and/or the unit ages were changed to either correspond with the other source map, to reflect more up-to-date unit nomenclature and interpretation of a unit's recognized age, or were changed as per GRI protocol regarding unit naming (e.g., "Formation, then Member" not "Member of Formation"), or adopted guidelines listing unit ages with a range, listing oldest age to youngest age (e.g., "Pleistocene to Holocene" and not "Holocene to Pleistocene").

Unit descriptions from the Panguitch 30' x 60' source map were obtained from the source map publication's booklet. Additional information pertaining to these map units and other units present on the source map are in this map's booklet and users of the GRI digital geologic-GIS data are encouraged to explore this document. Of added note, some units mentioned in the unit descriptions may not be present in the extent of the GRI digital geologic-GIS map. These units, when referenced by their map unit symbol (e.g.,Tlbh), are not linked as their unit description is not present in this document. For figures referenced in unit descriptions users should also look for these in the map's booklet.

All units descriptions from the Brian Head Quadrangle were obtained from the source map publication's booklet. Additional information pertaining to these map units are in this map's source map booklet and users of the GRI digital geologic-GIS data are encouraged to explore this document.

Qh - Artificial fill (Historical)

Qh - Artificial fill (Historical)
Engineered fill used to construct the dam at Navajo Lake; fill of variable thickness and composition should be anticipated in all developed or disturbed areas; typically less than 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qhd - Disturbed land (Historical)

Qhd - Disturbed land (Historical)
Disturbed area in Castle Valley (about 5 miles [9 km] southwest of Panguitch Lake) mapped because it obscures extent of glacial deposits and landforms; also includes large sand and gravel pits southeast of Panguitch and northwest of Bryce Canyon. Description from source map: Panguitch 30' x 60' Quadrangle

Qmsh - Landslides, active (Historical)

This unit shares a unit description with other units. Those units and their shared unit description are presented below.

Qms, Qmsh, Qms(Kd), Qms(Ti), Qms(Tql), Qms(Tm) - Landslides (Historical to 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; the largest landslide complexes are several square miles in size and involve tuffaceous strata of the Brian Head (Tbh) and Dakota (Kd and Ktd) Formations,

and to a lesser extent the combined Limerock Canyon and Brian Head Formations (Tlbh); Qmsh denotes landslides known to be active in historical time, but any landslide deposit may have been historically active even if not so identified; large rotational slump blocks of Isom Formation (Qms[Ti]) and Leach Canyon Formation (Qms[Tql]) are mapped in the Yankee Meadows graben and in the lower part of the Lowder Creek basin, and slump blocks of Dakota Formation (Qms[Ktd]) are mapped in Cedar Canyon; Qms(Tm) represents Quaternary landslide debris derived from the Markagunt gravity slide present northwest of Cedar Breaks National Monument; query indicates areas of unusual morphology that may be due to landsliding; thickness highly variable, but typically several tens of feet or more thick and the largest landslides, at Yankee Meadows graben, may be as much as 600 feet (200 m) thick (Maldonado and others, 1997); 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).

The most active and problematic landslide in the map area is in Cedar Canyon where State Highway 14 crosses the upper part of the Dakota Formation. Lund and others (2009) reported on a large rockfall associated with this landslide that closed the highway for six days in January 2009. The landslide moved again on October 8, 2011, destroying the road and closing the highway for nearly a year (Lund and others, 2012).

Dense forests and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as LiDAR may show that many slopes, particularly those developed on the Brian Head (Tbhv) and Bear Valley (Tbv) Formations and on Upper Cretaceous strata, 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. Description from source map: Panguitch 30' x 60' Quadrangle

This unit (below) shares a unit description with other units. Those units and their shared unit description are presented below.

Qms, Qmsh, Qms(Ti) - Landslide deposits (Historical to Pleistocene)
Unsorted, mostly angular, unstratified rock debris moved by gravity from nearby slopes and cliffs; contains youthful, including historical, landslide topography; locally includes talus and colluvium; the reason for most slides in the map area is the combination of high relief and the presence of Brian Head Formation, which contains tuffaceous material that weathers into smectitic clay, which in turn facilitates landsliding when wet or on steep slopes; Qmsh denotes landslides known to be active in historical time, but any landslide deposit may have been historically active even if not so identified; Qms(Ti) denotes a slide made up almost exclusively of the Isom Formation; mostly 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); thickness variable and uncertain but may locally exceed 200 feet (60 m) thick north and northeast of Brian Head. Description from source map: Brian Head Quadrangle

Qal - Stream alluvium (Holocene)

Qal - Stream alluvium (Holocene)
Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active, main-stem stream channels and floodplains of the Sevier River and its few well-graded major tributaries; locally includes minor stream-terrace alluvium as much as about 10 feet (3 m) above current stream level; inferred to overlie older alluvial and fan deposits in the valley of the Sevier River; probably less than 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qal - Alluvium (Holocene)

Youngest alluvium in channels, floodplains, and adjacent low terraces of major streams; interbedded gravel, sand, silt, and clay; grades laterally into alluvium and colluvium (Qac) and alluvial-fan deposits (Qafy, Qacf); maximum thickness about 20 feet (6 m). Description from source map: Brian Head Quadrangle

Qaly - Young stream alluvium (Holocene)

Qaly - Young stream alluvium (Holocene)
Combined stream alluvium (Qal) and the youngest (lowest elevation) part of stream-terrace alluvium (Qat), but undivided here due to limitations of map scale; this lumped unit is commonly mapped in upland drainages where it may include small alluvial-fan deposits from tributary drainages and colluvium from adjacent slopes; commonly grades downslope into alluvial fans; locally includes historical debris-flow and debris-flood deposits derived from tributary drainages, as, for example, the deposits of the 2005 Black Mountain debris flow that entered the upper reaches of Coal Creek in Cedar Canyon (Giraud and Lund, 2010); typically less than 20 feet (<6 m) thick, but deposits in major stream valleys may locally exceed 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qam - Marsh alluvium (Holocene and upper Pleistocene)

Qam - Marsh alluvium (Holocene and upper Pleistocene)
Dark-yellowish-brown clay, silt, sand, and minor gravel lenses deposited in closed depressions on landslides and glacial moraines in the Lowder Creek area east of Brian Head peak; forms small marshy areas characterized by cattails and other hydrophilic vegetation; typically less than 10 feet (3 m) thick, but marsh alluvium of Lowder Creek bog, described in more detail under the unit description for “glacial till of Pinedale age (Qgtp),” is at least 21 feet (7 m) thick (Mulvey and others, 1984). Description from source map: Panguitch 30' x 60' Quadrangle

Qam - Marsh alluvium (Holocene and upper Pleistocene)
Dark-yellowish-brown and brownish-black clay, silt, sand, and minor gravel lenses deposited in closed depressions on glacial moraines in the Lowder Creek area east of Brian Head peak; forms marshy areas; includes water-saturated, partly decomposed plant material and minor clay and silt, with a spongy, soft surface; includes peat, as a dense organic mat of grass roots, moss, and herbaceous annuals; locally contains scarce, light-gray chitinous bivalve shells 0.1 to 0.2 in (3–5 mm) across; mapped only at Lowder Creek bog, but unit forms smaller bogs on landslides and on glacial deposits at and near the top of the Markagunt Plateau that have been consistently saturated with water; 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); thickness 2 to at least 21 feet (0.5–6+ m) (Mulvey and others, 1984). Description from source map: Brian Head Quadrangle

Qaf1 - Young fan alluvium (Holocene)

Qaf1 - Young fan alluvium (Holocene)
Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment containing subangular to subrounded clasts deposited principally by debris flows and debris floods at the mouths of active drainages; equivalent to the upper part of young and middle fan alluvium (Qafy), but differentiated because Qaf1 typically forms smaller, isolated fans; probably less than 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qafy - Young and middle fan alluvium, undivided (Holocene and upper Pleistocene)

Qafy - Young and middle fan alluvium, undivided (Holocene and upper Pleistocene)
Poorly to moderately sorted, non-stratified, boulder- to clay-size sediment containing subangular to subrounded clasts deposited at the mouths of streams and washes; forms both active depositional surfaces (Qaf1 equivalent) and low-level inactive surfaces incised by small streams (Qaf2 equivalent) that are undivided here; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part; small, isolated deposits are typically less than a few tens of feet thick, but large, coalesced deposits in Sevier and Parowan Valleys are much thicker and form the upper part of basin-fill deposits. Description from source map: Panguitch 30' x 60' Quadrangle

Qafy - Fan alluvium (Holocene)
Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans; includes alluvium and colluvium in upper stream courses; surface is modern and generally undissected; maximum thickness at least 30 feet (10 m). Description from source map: Brian Head Quadrangle

Qc - Colluvium (Holocene and upper Pleistocene)

Qc - Colluvium (Holocene and upper Pleistocene)
Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; locally grades downslope into deposits of mixed alluvial and colluvial origin; mapped only where it conceals contacts or fills broad depressions; the Claron and Brian Head Formations and Upper Cretaceous strata shed enormous amounts of colluvium, such that an apron of heavily vegetated colluvium (unmapped because it forms a veneer having poor geomorphic expression) typically envelops at least the lower part of steep slopes along their outcrop belt; typically less than 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qc - Colluvium (Holocene and upper Pleistocene)
Poorly to moderately sorted, clay- to pebble-size, locally derived sediment deposited principally by slope wash and locally reworked by alluvial processes; locally includes Isom Formation boulders derived from weathering of the Markagunt Megabreccia; maximum thickness about 15 feet (5 m). Description from source map: Brian Head Quadrangle

Qc/Tbh - Colluvium over Brian Head Formation (Holocene and upper Pleistocene/Eocene to Oligocene)

Qc/Tbh - Colluvium over the Brian Head Formation (Holocene to Pleistocene/Oligocene to Eocene)
Mapped on the west flank of Houston Mountain (6 miles [10 km] east of Cedar Breaks National Monument) and south of the town of Brian Head, where colluvium, residual deposits, and possibly landslide deposits conceal the underlying Brian Head Formation; at Houston Mountain, colluvium includes large blocks of the Houston Mountain lava flow enclosed in a matrix of colluvium derived from weathered, tuffaceous Brian Head strata; also mapped on the flanks of the Sevier Plateau where colluvium derived mostly from the overlying Mount Dutton Formation obscures underlying Brian Head strata; surficial cover may exceed 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qc/Tbh - Colluvium over the Brian Head Formation (Holocene and upper Pleistocene/ Oligocene to Eocene)
Mapped where colluvium conceals the underlying Brian Head Formation; maximum thickness of surficial deposits is about 15 feet (5 m). Description from source map: Brian Head Quadrangle

Qc/Tcwu - Colluvium over the upper limestone unit of the white member of the Claron Formation (Holocene and upper Pleistocene/Eocene)

Qc/Tcwu - Colluvium over the upper limestone unit of the white member of the Claron Formation (Holocene and upper Pleistocene/Eocene)
Mapped on the southwest side of Houston Mountain (6 miles [10 km] east of Cedar Breaks National Monument) where colluvium conceals the underlying upper limestone unit of the white member of the Claron Formation; colluvium includes large blocks of the Houston Mountain lava flow enclosed in a matrix of colluvium derived from weathered, tuffaceous Brian Head strata and the upper limestone unit of the white member of the Claron Formation; surficial cover may exceed 10 feet (3 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qed - Eolian dune sand (Holocene)

Qed - Eolian dune sand (Holocene)
Grayish-pink to pale-red, well-sorted silt and fine-grained sand largely stabilized by vegetation on the Cedar Breaks escarpment; most of the sand consists of tiny clay pellets eroded from the Claron Formation and carried eastward up the scarp by strong winds; typically less than 15 feet (5 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qes - Wind-blown sand (Holocene and upper Pleistocene)
Well-sorted silt (loess), quartz sand, and clay pellets in vegetated sheets and subdued dunes on the rim of Cedar Breaks National Monument; deposited by winds that ascended the west-facing cliffs; maximum thickness 15 feet (5 m). Description from source map: Brian Head Quadrangle

Qat2 - Stream-terrace deposits, level 2 (Holocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qat2, Qat4 - Stream-terrace deposits, level 2 (Holocene)
Sand, gravel, silt, and clay that form dissected stream-terrace surfaces above the level of adjacent modern streams in the Ashdown Creek drainage basin; maximum thickness about 20 feet (6 m). Subscript denotes relative height above adjacent stream: level-2 terraces are typically 10 to 30 feet (3–9 m) above modern streams; level-3 terraces are not mapped in this quadrangle; and level-4 terraces are typically 100 to 120 feet (30–35 m) above modern streams. Description from source map: Brian Head Quadrangle

Qlg - Course-grained lacustrine sediment (Holocene and upper Pleistocene)

Qlg - Coarse-grained lacustrine sediment (Holocene and upper Pleistocene)
Sand and gravel deposited at the east end of Navajo Lake which formed behind a lava dam created by the Henrie Knolls lava flows; probably 10 to 15 feet (3–5 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qms - Landslides (upper? Pleistocene to Historical)

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Brian Head Quadrangle

Qms(Tm) - Landslides, debris derived from Markagunt gravity slide (upper? Pleistocene to Historical (lower Miocene))

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qms(Tql) - Landslides, slump blocks of Leach Canyon Formation (upper? Pleistocene to Historical (upper Oligocene))

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qms(Ti) - Landslides, slump blocks of Isom Formation (upper? Pleistocene to Historical (upper Oligocene))

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Brian Head Quadrangle

Qms(Kn) - Landslides, slump blocks of Naturita Formation (upper? Pleistocene to Historical (Upper Cretaceous))

This unit shares a unit description with other units. See unit Qmsh for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Of note, the Dakota Formation (Kd) is now named the Naturita Formation (personal communication in 2022 from Utah Geological Survey). The unit's map symbols has therefore been changed to Kn.

Qmt - Talus (Holocene and upper Pleistocene)

Qmt - Talus (Holocene and upper Pleistocene)
Poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rockfall on or at the base of steep slopes; talus that is part of large landslide complexes is not mapped separately; 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; commonly grades downslope into colluvium; typically less than 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qmt - Talus (Holocene and upper Pleistocene)
Loose, angular rock fragments deposited on steeply sloping surfaces by rock falls; fragments range from silt size to blocks 3 to 15 feet (1-5 m) across; downslope, unit includes colluvium and slope wash; along the Black Ledge fault scarp west and northwest of Sidney Peaks, talus locally exhibits a rumpled surface suggestive of relic rock glaciers; thickness about 6 to 30 feet (2–10 m). Description from source map: Brian Head Quadrangle

Qac - Alluvium and colluvium (Holocene and upper Pleistocene)

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. Description from source map: Panguitch 30' x 60' Quadrangle

Qac - Alluvium and colluvium (Holocene and upper Pleistocene)
Alluvium in channels, floodplains, and adjacent low terraces of small streams, and laterally gradational colluvium from weathering of adjacent bedrock hills; interbedded gravel, sand, silt, and clay; locally includes Isom Formation boulders derived from weathering of the Markagunt Megabreccia; maximum thickness about 15 feet (5 m). Description from source map: Brian Head Quadrangle

Qacf - Alluvium, colluvium and fan alluvium (Holocene and upper? Pleistocene)

Qacf - Alluvium, colluvium and fan alluvium (Holocene and upper? Pleistocene)
Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment, deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages, and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalesced apron of fan alluvium and colluvium impractical to map separately at this scale; typically, 10 to 40 feet (3–12, m) thick.

This map unit is also mapped in sediment-choked drainages that drain the Paunsaugunt and Sevier Plateaus where it consists of modern alluvium, low-level, terrace alluvium, colluvium, and fan alluvium impractical to differentiate at the map scale. The upper reaches of these deposits are typically characterized by debris-flow deposits partly reworked by braided channels, probably a result of flash-flood runoff on the Claron Formation. The morphology of many of these drainages suggests that they are partly backfilled following an earlier, deeper level of canyon erosion, and in the larger drainages these deposits are likely several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qacf - Alluvium, colluvium and fan alluvium (Holocene and upper Pleistocene?)
Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalesced apron of fan alluvium and colluvium impractical to map separately; typically 10 to 40 feet (3–12 m) thick. Description from source map: Brian Head Quadrangle

Qae - Alluvium and eolian sand (Holocene and upper Pleistocene)

Qae - Alluvium and eolian sand (Holocene and upper Pleistocene)
Moderately to well-sorted, mostly light-reddish-brown silt and sand deposited by sheetwash and ephemeral streams in small drainages and swales on the Henrie Knolls lava flow in the west-central part of the Henrie Knolls quadrangle; probably less than 10 feet (3 m) thick. Description from source

map: Panguitch 30' x 60' Quadrangle

Qaec - Alluvium, eolian sand and colluvium (Holocene and upper Pleistocene)

Qaec - Alluvium, eolian sand, and colluvium (Holocene and upper Pleistocene)
Moderately sorted, light-reddish-brown and moderate- to dark-yellowish-brown silt and sand and locally gravelly lenses deposited in swales and small drainages on and adjacent to the Henrie Knolls lava flow (Qbhk); the margins of the deposits include significant colluvium derived from adjacent hillslopes developed on the Claron Formation and basaltic lava flows; soils developed on this unit have an argillic horizon 1 to 1.5 feet (0.3–0.5 m) thick of moderate-reddish-brown sandy clay and clayey fine-grained sand; typically less than 10 feet (3 m) thick, although deposits in the Cow Lake area, south of the Henrie Knolls flows, are likely as much as 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qca - Colluvium and alluvium (middle Pleistocene to Holocene)

Qca - Colluvium and alluvium (Holocene to middle Pleistocene)
Poorly to moderately sorted, clay- to pebble-size, locally derived sediment deposited principally by slope wash and locally reworked by alluvial processes; typically mapped where lava flows dammed local washes, causing ponding of mixed colluvial and alluvial sediment; distal, finer-grained parts form broad, open meadows; thickness uncertain, but likely less than about 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qmtc - Talus and colluvium (Holocene and upper Pleistocene)

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 rockfall and slope wash on steep slopes throughout the quadrangle; includes minor alluvial sediment at the bottom of washes; generally, less than 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qmsc - Landslides and colluvium (Holocene and upper Pleistocene)

Qmsc - Landslides and colluvium (Holocene and upper Pleistocene)
Landslides and colluvium impractical to differentiate at this scale; as much as several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qla - Lacustrine sediment and alluvium (Holocene)

Qla - Lacustrine sediment and alluvium (Holocene)
Forms the meadow of Blue Spring Valley about 2 miles (3 km) southwest of Panguitch Lake, which we interpret to be a lake deposit made up of moderately to well-sorted, thinly bedded, light-gray and light-brown, fine-grained sand, silt, and clay derived principally from Brian Head strata in the Bunker and Deer Creek drainages; upper surface is marked by numerous small stream channels and meander cutoffs; also mapped near the east end of Navajo Lake where it consists of fine-grained sediment eroded from the pink member of the Claron Formation, and at Co-op Valley Sinks east of Parowan; likely several tens of feet thick in Blue Spring Valley; recent remedial work on the Navajo Lake dam shows that sediments there, as much as 37 feet (11 m) thick along the central portion of the dam, overlie basalt presumably of the Henrie Knolls lava flow (Qbhk) (Carl Ege, Utah Division of

Water Rights, written communication, May 8, 2013).

Blue Spring Valley was flooded to form a shallow reservoir following completion of the Blue Spring Valley dam in the late 1800s or early 1900s; the small dam was breached by 1917 (Ipson and Ipson, 2008). The valley is now drained at its north end by Blue Spring Creek, which may have formed in response to the Miller Knoll lava flows that blocked the original Bunker Creek outlet at the southeast end of the valley, possibly as late as middle Holocene time. Description from source map: Panguitch 30' x 60' Quadrangle

Qr - Relict Houston Mountain and Blue Spring Mountain lava flows (Holocene and Pleistocene)

Qr - Relict Houston Mountain and Blue Spring Mountain lava flows (Holocene and Pleistocene)
Mapped about 4 miles (7 km) north-northeast of Navajo Lake, where blocky remnants of the 5.3 Ma Houston Mountain lava flow (Tbhm) have been let down by sapping and dissolution of underlying beds; angular to subangular blocks of the lava flow, typically 3 feet (1 m) or less in diameter but locally as large as about 12 feet (4 m), locally form a basaltic pavement on the white member of the Claron Formation, but typically they are widely scattered; other than uncommon small fragments of chalcedony (itself likely the remains of the Brian Head Formation once buried by the Houston Mountain lava flow), no other exotic rock types are present; map unit probably formed as former basalt-capped hilltops succumbed to chemical weathering of carbonate beds in the underlying Claron Formation and concomitant hillslope erosion, undermining the lava flow and scattering resistant basalt blocks over the underlying bedrock, processes that began following development of inverted topography now capped by the Houston Mountain lava flow; unmapped colluvium derived from this unit blankets much of the nearby Claron Formation; also mapped on the south side of Blue Spring Mountain (about 5 miles [8 km] southwest of Panguitch Lake) where blocks of the Blue Spring Mountain lava flow (Tbbm) conceal the upper part of the white member of the Claron Formation and possibly the lower part of the Brian Head Formation; typically less than a few feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

QTbx - Markagunt gravity slide residuum (Miocene? to Holocene)

QTbx - Markagunt gravity slide residuum (Holocene to Miocene?)
Mapped south of the Markagunt gravity slide, principally at and near the west rim of the Markagunt Plateau, but also mapped where it caps several small hills south of Panguitch Lake and in the upper reaches of Rock Canyon, south of Haycock Mountain. Consists of two units not mapped separately: (1) large blocks and rubble of the Isom Formation present in the northeast part of Cedar Breaks National Monument, and (2) an unconsolidated mix of Isom boulders and minor Brian Head debris present in the southern part of the monument and in the deposits near Panguitch Lake. In both units, Isom blocks are subangular and locally as much as 16 feet (5 m) long, but in the northeast part of the monument, rafted Isom blocks are as much as several hundred feet in extent; many of the Isom blocks are internally brecciated on a fine scale, then rehealed by silicification to become a resistant rock (Hatfield and others, 2010), presumably by redeposition of silica from ash shards and fine breccia fragments of the Isom ash-flow tuff itself (the brecciation is a direct result of deformation within the Markagunt gravity slide). Maximum thickness is about 150 feet (45 m) at Blowhard Mountain immediately south of Cedar Breaks National Monument, but most deposits are 5 to 30 feet (2–9 m) thick.

Exposures on the west side of Blowhard Mountain reveal large, fractured blocks of Brian Head tuffaceous mudstone, sandstone, micritic limestone, and chalcedony, with some blocks as large as 100 feet (30 m) long, in addition to the ubiquitous, angular Isom boulders. There, the map unit overlies alluvial boulder gravel (undifferentiated from the residuum) as much as about 50 feet (15 m) thick that consists of subrounded Isom Formation clasts, minor Brian Head limestone and chalcedony clasts,

and, near the base of the deposit, rare Claron clasts. Isom clasts are commonly 2 to 3 feet (0.5–1 m) in diameter and locally as much as 9 feet (3 m) long and include at least one large boulder of Isom flow breccias similar to that at Brian Head peak. No other clast types are present. Much of the west side of this outcrop belt at Blowhard Mountain is involved in landslides, many with historical movement, but the gravel is clearly part of a channel eroded into the Claron Formation and overlain by mass-wasting deposits composed of Isom and Brian Head debris.

Between Blowhard Mountain and Long Valley Creek, these residuum deposits form an extensive, hummocky surface draped over the Claron Formation. Elsewhere on Blowhard Mountain and areas to the east and south, the map unit is characterized by abundant or scattered, large, locally internally brecciated, angular Isom boulders that litter the surface. The hummocky surface is mostly due to dissolution and collapse of underlying Claron limestone, which created numerous sinkholes in this area (Moore and others, 2004; Hatfield and others, 2010; Spangler, 2010), but the surface is also likely due in part to ongoing slumping and slope creep that results from admixed tuffaceous Brian Head strata (Moore, 1992).

The large blocks of Isom in this map unit in and near the northeast part of Cedar Breaks National Monument rest unconformably on Brian Head and Claron strata, whereas not far to the north, at a higher elevation, the main mass of the Markagunt gravity slide rests on Leach Canyon Formation. Because the southern margin of the gravity slide (and underlying regional ash-flow tuffs) is erosional in nature, we do not know its southern depositional limit. However, because debris from the Leach Canyon Formation is missing in areas mapped as QTbx in the northeast part of Cedar Breaks National Monument and at and near Blowhard Mountain, it seems likely that the Leach Canyon (and underlying in-place Isom) pinched out southward against paleotopography and did not extend much farther south than its present-day outcrop. Because there is no evidence for a post- Leach Canyon (but pre-Markagunt gravity slide) unconformity that cuts out strata southward across the west edge of the Markagunt Plateau, senior-author Biek interprets the large Isom blocks to be old landslide remnants that are at a lower topographic and structural level than the main mass of the Markagunt gravity slide. In this interpretation, the large Isom blocks and Isom and Brian Head debris are inferred to be derived from northward retreat of the erosional escarpment that stretches from Brian Head peak eastward to Haycock Mountain. Thus in this view, similar to that suggested by Moore (1992) and Sable and Maldonado (1997a), the map unit is a remobilized part of the Markagunt gravity slide, the southern extent of which was emplaced on a paleohigh of Brian Head strata that served to constrain the southern limit of the Isom and Leach regional ash-flow tuffs. The gravity slide has since been let down to its present position principally by landsliding in late Tertiary and Quaternary time, with smectitic clays of the Brian Head Formation initially providing the weak shear surface for downslope movement of the blocks, which were then further dispersed by colluvial and slope-creep processes. An alternative interpretation, however, suggests that all but the southernmost blocks are a bona fide part of the Miocene Markagunt gravity slide (Moore and others, 2004; Hatfield and others, 2010; Rowley and others, 2013), which thus must have been emplaced as far south as Blowhard Mountain; subsequent weathering and sapping of the gravity slide and underlying Claron Formation then spread debris southward to the area beyond State Route 14. Yet another interpretation is that the map unit may be the distal remains of debris avalanche deposits at the south margin of the Markagunt gravity slide. Our differences in interpretation reflect our incomplete understanding of these deposits. Description from source map: Panguitch 30' x 60' Quadrangle

Qat - Stream-terrace alluvium (middle? Pleistocene to Holocene)

Qat - 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 its few well-graded major tributaries; deposited in a stream channel environment, but locally includes colluvium and small alluvial fans; terraces are at elevations of about 10 to 120 feet (3–35 m) above adjacent streams but are not subdivided here due to limitations of map scale; typically, less than 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qlao - Older lacustrine sediment and alluvium (Holocene and upper Pleistocene)

Qlao - Older lacustrine sediment and alluvium (Holocene and upper Pleistocene)
Similar to lacustrine sediment and alluvium (Qla), but forms incised, planar surfaces 5 to 10 feet (2–3 m) above the main meadow of Blue Spring Valley; likely several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qlao/Qbmk3 - Older lacustrine sediment and alluvium over Miller Knoll lava flows, oldest (Holocene and upper Pleistocene/late Pleistocene)

Qlao/Qbmk3 - Older lacustrine sediment and alluvium over the Miller Knoll lava flow (Holocene and upper Pleistocene/Holocene to upper Pleistocene)
Mapped along the southeast edge of Blue Spring Valley (about 2 miles [3 km] southwest of Panguitch Lake) where the oldest Miller Knoll lava flow (Qbmk3) is partly concealed by a veneer of sediment interpreted as a mixture of lacustrine and alluvial, and possibly eolian, sand and silt; Blue Spring Valley likely drained through Black Rock Valley prior to the drainage being blocked by the Miller Knoll lava flows, with lacustrine and alluvial sediment accumulating in the basin upstream of the flows; surficial cover is likely less than 6 feet (2 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qalo - Old stream alluvium (Holocene and upper Pleistocene)

Qalo - Old stream alluvium (Holocene and upper Pleistocene)
Similar to lower- to middle-elevation parts of stream-terrace alluvium (Qat), but these dissected deposits are largely restricted to upland drainages not well graded to the Sevier River; typically, less than 20 feet (6 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qaf2 - Middle fan alluvium (Holocene and upper Pleistocene)

Qaf2 - Middle fan alluvium (Holocene and upper Pleistocene)
Similar in composition and morphology to young fan alluvium (Qaf1), but forms inactive surfaces incised by younger stream and fan deposits; equivalent to the older, lower part of young and middle fan alluvium (Qafy) and coalesced fan alluvium of Parowan Valley (Qafc); these deposits preserve previously unreported fault scarps east and north of Summit in southern Parowan Valley that appear to be the southwest continuation of the Parowan Valley faults that Williams and Maldonado (1995) and Black and Hecker (1999) inferred to be latest Pleistocene to early Holocene in age; probably less than 30 feet (9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbpl1 - Panguitch Lake lava flows, youngest (upper Pleistocene? to upper Holocene?)

This unit shares a unit description with other units. Those units and their shared unit description are presented below.

Qbpl1, Qbpl2, Qbpl3 - Panguitch Lake lava flows (upper Holocene? to upper Pleistocene?)

Mapped as three separate lava flows, with Qbpl1 being the youngest, all three of which are mostly unvegetated and blocky, and exhibit steep flow fronts 100 to 200 feet (30–60 m) high: Qbpl1 is dark-gray to black latite (potassium rich trachyandesite) containing small (1 mm), stubby plagioclase phenocrysts in a glassy to aphanitic groundmass; Qbpl2 and Qbpl3 are dark-gray latite containing small stubby plagioclase and abundant acicular hornblende phenocrysts in a fine-grained groundmass; age uncertain, but may be as young as late Holocene; individual lava flows are typically about 200 feet (60 m) thick. The Qbpl1 lava flow lacks collapsed lava tubes and exhibits blocky flow lines similar to those of the Dry Valley lava flow (Qbdv). The smaller Qbpl2 lava flow has collapsed lava tubes and partly buries the Qbpl3 lava flow. The Qbpl3 flow, which has abundant collapsed lava tubes and branching distributary lobes, erupted from a vent apparently now concealed by the younger vents of the Qbpl1 and Qbpl2 lava flows (immediately northeast of Miller Knoll, which is the large cinder cone [Qbmkc] about 3 miles [5 km] south of Panguitch Lake) and flowed northward about 3 miles (5 km) nearly to Panguitch Lake; this is the “northern Panguitch flow” of Stowell (2006). Description from source map: Panguitch 30' x 60' Quadrangle

Qbpl2 - Panguitch Lake lava flows, older (upper Pleistocene? to upper Holocene?)

This unit shares a unit description with other units. See unit Qbpl1 for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbpl3 - Panguitch Lake lava flows, oldest (upper Pleistocene? to upper Holocene?)

This unit shares a unit description with other units. See unit Qbpl1 for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbdv - Dry Valley lava flow (upper Pleistocene? to upper Holocene?)

Qbdv - Dry Valley lava flow (upper Holocene? to upper Pleistocene?)
Dark-gray latite (potassium-rich trachyandesite) that contains olivine and abundant hornblende phenocrysts in an aphanitic to fine-grained groundmass; forms a thick, blocky, laterally restricted flow west of Black Rock Valley and north of Mammoth Creek that exhibits high, steep flow fronts (except at Dry Valley, immediately west of the vent, where a slightly older more fluid phase erupted); upper surface shows prominent arcuate ridges that reveal flow directions; vent area lacks scoria or cinders and there is no “tuff ring” as stated by Stowell (2006); northern flank of flow is partly vegetated, but upper surface and south-facing slopes are not vegetated; age uncertain, but overlies and is younger than the Miller Knoll lava flow (Qbmk2—the “arcuate andesite flow” of Stowell, 2006); typically 100 to 120 feet (30–35 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbmkc - Miller Knoll cinder cone (upper Pleistocene to middle Holocene?)

This unit shares a unit description with other units. These units and their shared unit description are presented below.

Qbmk1, Qbmk2, Qbmk3, Qbmkc - Miller Knoll lava flows and cinder cone (middle Holocene? to upper Pleistocene)
Mapped as three separate lava flows in the Black Rock Valley area south of Panguitch Lake, with Qbmk1 being the youngest flow: Qbmk1 is dark-gray to black andesite that contains small (1 mm),

stubby plagioclase phenocrysts in a glassy to aphanitic groundmass; Qbmk2 and Qbmk3 are dark- to medium-gray basaltic trachyandesite containing clusters of olivine, plagioclase, and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass and include both sodium-rich (mugearite) and potassium-rich (shoshonite) rock types, locally containing small, thin plagioclase phenocrysts; the Qbmk2 lava flow, the “southern Panguitch flow” of Stowell (2006), yielded cosmogenic exposure ages of about 37,000 years (David Marchetti, Western State Colorado University, written communication, August 4, 2009); the Qbmk2 and Qbmk3 flows are thus likely late Pleistocene in age; the Qbmk1 flow unit may be as young as middle Holocene; lava flows are typically 30 to 100 feet (10–30 m) thick, but may be thicker where they fill paleotopography.

The Qbmk1 lava flow erupted from a vent near the top of the Miller Knoll cinder cone (Qbmkc, at the northwest end of Black Rock Valley) and forms a blocky, mostly unvegetated flow that looks morphologically similar to, and may be chemically transitional with, latite of the Panguitch Lake lava flows (Qbpl). The much larger Qbmk2 lava flow erupted from vents on the south side of the Miller Knoll cinder cone and flowed about 4 miles (6 km) southeast through Black Rock Valley to Mammoth Creek, forming a young-looking, blocky, poorly vegetated flow that has abundant collapsed lava tubes and branching distributary lobes. The Qbmk3 lava flow erupted from a vent now concealed by the Miller Knoll cinder cone; the lava flow is mostly well vegetated and was the first flow to block Blue Spring Valley—the western part of this flow is partly covered by old mixed lacustrine and alluvial deposits (Qlao) that we interpret as having accumulated upstream of the lava-flow dam.

The southern extent of the Qbmk2 lava flow along Mammoth Creek was clearly limited by pre-existing topography of the pink member of the Claron Formation, but the flow now lies at the modern base level of Mammoth Creek. The lava flow once blocked Mammoth Creek, which has since eroded the adjacent, less-resistant Claron strata. Lacustrine sediments are absent upstream of the lava flow along Mammoth Creek, but stream terraces there may record partial infilling and subsequent exhumation of the valley. Description from source map: Panguitch 30' x 60' Quadrangle

Of note, unit Qbmk1 is not present within the extent of the GRI digital geologic-GIS map.

Qbmk2 - Miller Knoll lava flows, older (late Pleistocene)

This unit shares a unit description with other units. See unit Qbmkc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbmk3 - Miller Knoll lava flows, oldest (late Pleistocene)

This unit shares a unit description with other units. See unit Qbmkc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qgtp - Glacial till of Pinedale age (upper Pleistocene)

Qgtp - Glacial till of Pinedale age (upper Pleistocene)
Non-stratified, poorly sorted, sandy pebble to boulder gravel in a matrix of sand, silt, and minor clay; clasts are matrix supported, subangular to subrounded, and derived from the Leach Canyon, Isom, and Brian Head Formations and the Markagunt gravity slide exposed in the headwaters of the Castle Creek and Lowder Creek drainage basins; terminal moraine at the west end of Castle Valley is at an elevation of about 9750 feet (2973 m), whereas the terminal moraine of the smaller Lowder Creek basin is at Long Flat at an elevation of about 10,100 feet (3080 m); recessional and lateral moraines and hummocky, stagnant-ice topography are locally well developed, but sculpted bedrock is absent or inconspicuous, probably owing to the relatively small size and suspected short duration of the glaciers (Mulvey and others, 1984); well-developed terminal and recessional moraines are as much as 120

feet (37 m) thick, but till is much thinner elsewhere and locally consists only of scattered boulders or a veneer of meltout till on bedrock.

The Brian Head–Sidney Peaks area marks the southernmost occurrence of late Pleistocene glaciation in Utah (Mulvey and others, 1984), as first briefly described by Gregory (1950). Agenbroad and others (1996) interpreted glacial deposits and features that they attributed to their “Mammoth Summit glacier” at the southwest side of Brian Head peak and north edge of Cedar Breaks National Monument, but which we interpret as landslide deposits and in-place Brian Head Formation, the latter partly covered by a lag of large blocks of the Isom Formation.

Till is Pinedale age on the basis of distinct, well-preserved morainal morphology and relatively unweathered clasts, and a minimum limiting age of 14,400 ± 850 14C yr B.P. from marsh deposits of the Lowder Creek bog that overlie the till (Mulvey and others, 1984; Currey and others, 1986; see also Anderson and others, 1999). Madsen and others (2002) identified the 14,300 14C yr B.P. Wilson Creek #3 ash (erupted from Mono Craters in California) in the Lowder Creek bog. Marchetti and others (2005, 2007, 2011) and Weaver and others (2006) reported boulder exposure ages from four different moraines that indicate a local last glacial maximum of about 21.1 ka for the main Pinedale advance on Boulder Mountain approximately 80 miles (130 km) to the northeast. Their ages coincide with the global LGM (21 ± 2 ka) and thus likely are the age of the main Pinedale moraines on the Markagunt Plateau. Marchetti and others (2005, 2011) also reported a smaller advance at about 16 ka on Boulder Mountain. Description from source map: Panguitch 30' x 60' Quadrangle

Qgtp - Glacial till of Pinedale age (upper Pleistocene)
Non-stratified, poorly sorted, sandy pebble- to boulder-sized clasts in a matrix of sand, silt, and minor clay; includes scattered subangular bedrock blocks, probably deposited as ground moraine; clasts are matrix supported, subangular to subrounded, and were derived from the Leach Canyon, Isom, and Brian Head Formations and the Markagunt Megabreccia exposed in the headwaters of the Castle Creek and Lowder Creek drainage basins; terminal moraine (shown by map symbol) just south of where Castle Creek crosses the eastern map boundary is at an elevation of about 9750 feet (2973 m), whereas the terminal moraine of the smaller Lowder Creek basin is at Long Flat at an elevation of about 10,100 feet (3080 m); recessional and lateral moraines (shown by map symbol) and hummocky, stagnant ice topography (for example, ponds, kettles, and bogs) are locally well developed and little dissected, but sculpted bedrock is absent or inconspicuous, probably owing to the relatively small size and suspected short duration of the glaciers (Mulvey and others, 1984); well-developed terminal and recessional moraines are as much as 120 feet (37 m) thick, but till is much thinner elsewhere and locally consists only of scattered boulders or a veneer of meltout till on bedrock. Description from source map: Brian Head Quadrangle

Qgop - Glacial outwash of Pinedale age (upper Pleistocene)

Qgop - Glacial outwash of Pinedale age (upper Pleistocene)
Moderately to well-sorted, generally subrounded, clast-supported, pebble to boulder sand and gravel; clasts are typically little weathered and of the same provenance as glacial till (Qgtp); mapped on the east side of Castle Valley where the deposits likely represent the waning stages of Pinedale glaciation; probably about 20 to 30 feet (6–9m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qgop - Glacial outwash of Pinedale age (upper Pleistocene)
Moderately to well-sorted, generally subrounded, clast-supported, pebble to boulder sand and gravel; clasts are typically little weathered and of the same provenance as glacial till (Qgtp); mapped on the eastern side of upper Castle Creek, where the deposits likely represent the waning stages of Pinedale glaciations; probably about 20 to 30 feet (6–9 m) thick. Description from source map: Brian Head Quadrangle

Qgtou - Older glacial till and outwash, undivided (upper and middle Pleistocene)

Qgtou - Older glacial till and outwash, undivided (upper and middle? Pleistocene)
Similar to older glacial till of uncertain pre-Pinedale age, but forms broad, open, boulder-strewn and sage-brush-covered, eastward-sloping surfaces of the Castle Creek and Mammoth Creek areas; exposures just north of the junction of Castle Creek and Mammoth Creek suggest that most of this surface is underlain by till now deeply incised at its eastern end; glacial outwash deposits, especially those graded to the Pinedale terminal moraines, are presumed to be present locally on this till plain, but are not readily differentiated at this map scale; Mulvey and others (1984) and Currey and others (1986) briefly reported on possible ice wedge polygons as evidence for periglacial features on the southwest side of Castle Valley; glacial till is as much as 60 feet (18 m) thick where exposed near the confluence of Castle and Mammoth Creeks. Description from source map: Panguitch 30' x 60' Quadrangle

Qgtou - Older glacial till and outwash, undivided (Pleistocene)
Similar to older glacial till of uncertain pre-Pinedale age, but forms broad, open, boulder-strewn and sage-brush-covered, eastward-sloping surface in the lower Mammoth Creek area and along Castle Creek and Mammoth Creek east of the map area; exposures just north of the junction of Crystal Creek and Mammoth Creek suggest that most of this surface is underlain by till now deeply incised at its eastern end; glacial outwash deposits, especially those graded to the Pinedale terminal moraines, are presumed to be present locally on this till plain, but are not readily differentiated at this map scale; Mulvey and others (1984) and Currey and others (1986) noted possible ice wedge polygons as evidence for periglacial features on the southwestern side of Castle Valley; glacial till is as much as 60 feet (18 m) thick where exposed near the confluence of Castle and Mammoth Creeks. Description from source map: Brian Head Quadrangle

Qafo - Older fan alluvium (upper and middle Pleistocene)

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 in Parowan, Panguitch, and Hatch Valleys; fault scarps locally prominent on these deposits; deposited principally as debris flows and debris floods; exposed thickness as much as several tens of feet. Description from source map: Panguitch 30' x 60' Quadrangle

Qaco - Older alluvium and colluvium (upper? Pleistocene)

Qaco - Older alluvium and colluvium (upper? Pleistocene)
Similar to mixed alluvium and colluvium (Qac), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6–9 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qacfo - Older colluvium and fan alluvium (Pleistocene)

Qacfo - Older colluvium and fan alluvium (Pleistocene)
Mapped in the western Markagunt Plateau, where it consists of poorly sorted, boulder- to clay-size sediment derived mostly from the Claron, Brian Head, and Isom Formations, and locally below the rim of the Paunsaugunt Plateau where it consists principally of reworked Claron debris; deposited principally by debris flows, debris floods, and slope wash; typically forms a resistant cap on isolated hill tops and ridges underlain by Upper Cretaceous strata, remnants of a once larger apron of

sediment shed off the plateaus and now preserved as deeply dissected inverted valleys; also forms a broad bench, preserved in the Iron Peak graben west of the town of Brian Head, where it is locally exposed in the main scarp of a large landslide complex southeast of Sugarloaf Mountain (SE1/4SW1/4 section 8, T. 36 S., R. 9 W.); also forms incised, isolated remnants south of Haycock Mountain, in the upper reaches of the Clear Creek drainage, and a single deposit southeast of Brian Head peak; typically about 20 to 30 feet (6–9 m) thick, but larger deposits may locally exceed 50 feet (15 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qacfo - Older alluvium, colluvium and fan alluvium (Pleistocene)
Mapped along the western edge of the map area and in the Mammoth Creek drainage where it forms dissected, coalesced, higher benches of reworked debris; consists of poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash; maximum thickness about 50 feet (15 m). Description from source map: Brian Head Quadrangle

Qat4 - Stream-terrace deposits, level 4 (upper Pleistocene)

This unit shares a unit description with another unit. See unit Qat2 for this shared unit description. Unit present on source map: Brian Head Quadrangle

Qao - Oldest stream alluvium (Pleistocene)

Qao - Oldest stream alluvium (Pleistocene)
Moderately sorted sand, silt, and pebble to boulder gravel that forms topographically inverted channel deposits at the mouth of Clear Creek, which drains eastward into Panguitch Lake, and on the south side of the lake itself; the deposits of the latter area were well exposed in excavations associated with a new housing development that revealed interbedded sand and pebbly to cobbly, locally iron-stained gravel containing clasts mostly of the Isom Formation (Ti, which is commonly grussy weathering) and subordinate chalcedony and quartzite, but apparently lacking basalt; map unit includes deposits that underlie the nearby Cooper Knoll lava flow (Qbck) just southeast of Panguitch Lake and that consist of subrounded to rounded pebbles to boulders of the Isom Formation, mafic volcanic rocks, chalcedony, and, especially near the base of the deposits, quartzite pebbles and cobbles; the source of the quartzite pebbles and cobbles is unknown, but they are doubtless ultimately recycled from the Grand Castle Formation (redefined) or Drip Tank Member of the Straight Cliffs Formation now exposed in grabens below the western topographic rim of the Markagunt Plateau; Qao deposits record an early phase in the development of the Clear Creek drainage and the related Rock Canyon drainage, which also drains eastward across the central part of the Haycock Mountain quadrangle and the lower part of which is now drained by its markedly underfit northern tributary, Pass Creek; in other words, ancestral Clear Creek apparently used to drain southeast into Rock Canyon, thus giving the canyon a much larger drainage basin before Clear Creek was diverted by the Panguitch Lake lava flows; deposits near Panguitch Lake are 40 to 60 feet (12–18 m) thick and those underlying the Cooper Knoll lava flow are as much as 120 feet (35 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qgtu - Older glacial till of uncertain pre-Pinedale age (upper? and middle? Pleistocene)

Qgtu - Older glacial till of uncertain pre-Pinedale age (upper? and middle? Pleistocene)
Similar to glacial till of Pinedale age, but glacial landforms are poorly preserved or absent; forms a low-relief, rubble- covered, locally hummocky surface both northeast and southwest of the southern Long Flat cinder cone (peak 10,392, north of lower Lowder Creek; map unit Qblfc); the northeast flank

of this cinder cone is conspicuously truncated, perhaps by this glacial advance; also forms low hills south of Castle Valley, in the southwest part of the Panguitch Lake 7.5' quadrangle, that are composed almost entirely of large blocks of Leach Canyon Formation, with minor blocks of Isom Formation and chalcedony, that we infer to be the deeply eroded remains of a medial or recessional moraine; thickness uncertain, but probably about 10 to 30 feet (3–10 m) thick.

Mulvey and others (1984) and Currey and others (1986) first suggested that glacial till older than Pinedale age may be present in the Brian Head quadrangle, west of Castle Valley. We sampled a sandy till exposed in a bluff northwest of the confluence of Mammoth and Castle Creeks (map unit Qgtou) that yielded an optically stimulated luminescence age of 48.95 ± 19.24 ka (table 5; see also UGS and USULL, 2013), but we remain uncertain how to interpret this age. The deposits may correspond to the Early Wisconsin MIS 3-4 advance (about 59 to 71 ka; Imbrie and others, 1984), and although Laabs and Carson (2005) reported that MIS 3-4 glacial moraines are not known in Utah, such deposits may be more widespread in the west than originally thought (Tammy Rittenour, Utah State University, written communication, August 3, 2010). However, given the widespread extent and degree of incision of Qgtou deposits, we interpret these glacial deposits to be older, more likely of Bull Lake age. Description from source map: Panguitch 30' x 60' Quadrangle

Qgtu - Older glacial till of uncertain pre-Pinedale age (Pleistocene)
Similar to glacial till of Pinedale age, but glacial landforms are poorly preserved or absent; forms a low-relief, rubble-covered, locally hummocky surface both northeast and southwest of the Long Flat cinder cone (peak 10,392, the southernmost map unit Qblfc); the northeast flank of the cinder cone is conspicuously truncated, perhaps by this glacial advance; also forms low hills south of Castle Valley, in the southwestern part of the Panguitch Lake 7.5' quadrangle, that are composed almost entirely of large blocks of Leach Canyon Formation, with minor blocks of Isom Formation and chalcedony, that we infer to be deeply eroded remains of a medial or recessional moraine (Biek and others, 2012); probably about 10 to 30 feet (3–9 m) thick. Mulvey and others (1984) and Currey and others (1986) first suggested that glacial till older than Pinedale age may be present in the Brian Head quadrangle, west of Castle Valley. Biek and others (2012) sampled a sandy till exposed in a bluff northwest of the confluence of Mammoth and Crystal Creeks (map unit Qgtou), in the Panguitch Lake quadrangle, that yielded an OSL age of 48.95 ± 19.24 ka, but we are uncertain how to interpret this age as described above. Given the widespread extent and degree of incision of Qgtou deposits, we interpret these glacial deposits to be older, more likely of Bull Lake age. Description from source map: Brian Head Quadrangle

Qbnlc - Navajo Lake cinder cone (upper Pleistocene?)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbnl, Qbnlc - Navajo Lake lava flows and cinder cone (upper Pleistocene?)
Medium- to dark-gray mugearite (sodium-rich basaltic trachyandesite) containing clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; some lava flows contain common small plagioclase phenocrysts; lava flows (Qbnl) erupted from vents at a cinder cone (Qbnlc) about 3 miles (5 km) north of Navajo Lake (Moore and others, 2004) and coalesced into flow complexes not mapped separately; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3–9 m) high; cinder cone is well vegetated; lava flows are locally well vegetated, but more commonly barren and characterized by a rough, blocky surface; vegetated areas collect wind-blown sediment that forms a sparse soil cover on parts of the flows; age uncertain, but likely late Pleistocene on the basis of degree of incision and weathering, although Moore and others (2004) considered the lava flow as probably Holocene; lava flows are typically several tens of feet thick, but thicker where they fill paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

Qbnl - Navajo Lake lava flow (upper Pleistocene?)

This unit shares a unit description with another unit. See unit Qbnlc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbrdc - Red Desert cinder cone (upper Pleistocene?)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbrd, Qbrdc - Red Desert lava flows and cinder cone (upper Pleistocene?)
Medium- to dark-gray basalt and basaltic andesite that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; some lava flows contain common small plagioclase phenocrysts; lava flows (Qbrd) erupted from vents at a cinder cone (Qbrdc) nearly 6 miles (10 km) north of Navajo Lake (Moore and others, 2004) and from a small vent about 3 miles (5 km) to the southeast, and they coalesced into flow complexes not mapped separately; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3–9 m) high; cinder cone is well vegetated; lava flows are locally well vegetated, but more commonly are barren and have a rough, blocky surface; vegetated areas collect wind-blown sediment that forms a sparse soil on parts of the flows; age uncertain, but lava flows are likely late Pleistocene on the basis of degree of incision and weathering, although Moore and others (2004) considered the lava flows as probably Holocene; lava flows are typically several tens of feet thick, but thicker where they fill paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

Qbrd - Red Desert lava flows (upper Pleistocene?)

This unit shares a unit description with another unit. See unit Qbrdc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbrd - Red Desert lava flow (upper Pleistocene?)
Medium- to dark-gray basalt and basaltic andesite that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; some lava flows contain common small plagioclase phenocrysts; lava flow erupted from a vent at a cinder cone about 2 miles (3 km) south of the map boundary; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3–9 m) high, and the lava flow is mostly unvegetated with a rough, blocky surface; age uncertain, but likely late Pleistocene based on morphology and degree of weathering, although Moore and others (2004) considered the lava flow as probably Holocene. Description from source map: Brian Head Quadrangle

Qbhkc - Henrie Knolls cinder cone (upper Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbhk, Qbhkc - Henrie Knolls lava flows and cinder cones (upper Pleistocene)
Medium- to dark-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; some lava flows, particularly those between Duck Creek Sinks and Dry Camp Valley Spring (about 4 to 5 miles [6–8 km] east and northeast of Navajo Lake), also contain common plagioclase phenocrysts and have a slightly coarser groundmass; lava flows that erupted from the northeasternmost group of cinder cones, including Henrie Knolls, tend to be of basaltic andesite composition; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3–9 m) high; cinder cones are well vegetated; lava flows are locally well vegetated but more commonly barren, exhibiting a rough, blocky surface; age unknown, but probably late Pleistocene because the north end of flow complex is incised by Tommy Creek and capped by level 4 stream-terrace deposits (Biek and others, 2011, here mapped as Qat) inferred to be of late Pleistocene age;

sample HK092106-1 near Henrie Knolls yielded a low-precision 40Ar/39Ar age of 0.058 ± 0.035 Ma (UGS and NMGRL, 2009); lava flows are typically several tens of feet thick, but likely exceed 200 feet (60 m) thick where they fill paleotopographic lows.

The wide chemical variation of the Henrie Knolls lava flows (Qbhk) reflects the fact that these flows erupted from at least 20 separate vents marked by cinder cones (Qbhkc), including the largest two cones at Henrie Knolls, in the northeast part of the flow complex. The cinder cones are strikingly aligned along a northeast trend, subparallel to mapped normal faults in the quadrangle. Although no fault that postdates eruption of the Henrie Knolls lava flows has been identified along this trend, a concealed, unmapped fault likely controls the alignment of vents. The southernmost of the Henrie Knolls lava flows blocked the Navajo Lake and nearby Dry Valley drainages, forming Navajo Lake and intermittent Cow Lake. Description from source map: Panguitch 30' x 60' Quadrangle

Qbhk - Henrie Knolls lava flows (upper Pleistocene)

This unit shares a unit description with another unit. See unit Qbhkc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbmcc - Midway Creek cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbmc, Qbmcc - Midway Creek lava flow and cinder cones (Pleistocene)
Medium- to dark-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; lava flow (Qbmc) erupted from a vent at a cinder cone (Qbmcc) and is partly covered by the Navajo Lake lava flow (Qbnl) (Moore and others, 2004); this cinder cone may also be the source of the Duck Creek lava flow (Qbdc); lava flow is typically several tens of feet thick, but thicker where it fills paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

Qbmc - Midway Creek lava flow (Pleistocene)

This unit shares a unit description with another unit. See unit Qbmcc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbdec - Deer Valley cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbde, Qbdec - Deer Valley lava flow and cinder cone (Pleistocene)
Medium- to dark-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; small lava flow (Qbde) erupted from a vent at a cinder cone (Qbdec) 1.5 miles (2.5 km) north of Navajo Lake; lava flow is typically several tens of feet thick, but thicker where it fills paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

Qbde - Deer Valley lava flow (Pleistocene)

This unit shares a unit description with another unit. See unit Qbdec for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbhoc - Horse Pasture cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbho, Qbhoc - Horse Pasture lava flow and cinder cone (Pleistocene)
Medium- to dark-gray basalt and hawaiite (sodium-rich trachybasalt) containing clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; lava flow (Qbho) erupted from a vent at a cinder cone (Qbhoc) 4 miles (6 km) north of Navajo Lake; this cinder cone may also be the source of the Duck Creek lava flow (Qbdc); lava flow is typically several tens of feet thick, but thicker where it fills paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

Qbho - Horse Pasture lava flow (Pleistocene)

This unit shares a unit description with another unit. See unit Qbhoc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbdc - Duck Creek lava flow (Pleistocene)

Qbdc - Duck Creek lava flow (Pleistocene)
Medium-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts and abundant small plagioclase phenocrysts in a fine-grained groundmass; lava flow is typically partly concealed by a veneer of unmapped surficial deposits of alluvial, colluvial, and eolian origin; maximum exposed thickness is about 15 feet (5 m) near Aspen Mirror Lake, but likely several tens of feet thick where it fills paleotopography in the Duck Creek drainage. The location of the vent of the Duck Creek lava flow is unknown, but it may be concealed by the Henrie Knolls (Qbhk) or Navajo Lake (Qbnl) lava flows. Alternatively, geochemical data suggest that the Duck Creek lava flow may be the distal part of either the Midway Creek or Horse Pasture lava flows. Regardless, the lava flowed east down the ancestral Duck Creek drainage and continued northeastward to at least the Bowers Flat area at the west edge of the Asay Bench quadrangle. The lava flow contains a long, open lava tube near Aspen Mirror Lake, just west of Duck Creek village (U.S. Forest Service restricts access). The age of the Duck Creek flow is uncertain, but it locally covers the Bowers Knoll lava flow (Qbbk) Geologic map of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah 125 and in turn is locally covered by the Henrie Knolls lava flow (Qbhk), thus is probably late to late middle Pleistocene. However, Johnson and others (2010) suggested that the distal end of the Bowers Knoll flow as mapped here, including the part that contains Mammoth Cave, may be the Duck Creek flow—if so, incision there suggests that the Duck Creek flow is about 500,000 years old, far older than indicated by the degree of incision along the upstream part of the flow. Description from source map: Panguitch 30' x 60' Quadrangle

Qbskc - Strawberry Knolls cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbsk, Qbskc - Strawberry Knolls lava flows and cinder cones (Pleistocene)
Medium- to dark-gray potassic trachybasalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; lava flows (Qbsk) erupted from Strawberry Knolls (Qbskc), two cinder cones located about 2 miles (3 km) east of Duck Creek village, and flowed mostly northeast along Strawberry Creek to Uinta Flat; age uncertain, but cinder cones are well vegetated and flow is incised by Strawberry Creek as much as 40 feet (12 m) at its downstream end and so is probably late to middle Pleistocene; lava flows are typically 20 to 30 feet (6–9 m) thick, but doubtless many tens of feet thick near vent areas.

Qbsk - Strawberry Knolls lava flows (Pleistocene)

This unit shares a unit description with another unit. See unit Qbskc for this shared unit description.
Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbefc - East Fork Deek Creek cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbsk, Qbskc - Strawberry Knolls lava flows and cinder cones (Pleistocene)
Medium- to dark-gray potassic trachybasalt that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; lava flows (Qbsk) erupted from Strawberry Knolls (Qbskc), two cinder cones located about 2 miles (3 km) east of Duck Creek village, and flowed mostly northeast along Strawberry Creek to Uinta Flat; age uncertain, but cinder cones are well vegetated and flow is incised by Strawberry Creek as much as 40 feet (12 m) at its downstream end and so is probably late to middle Pleistocene; lava flows are typically 20 to 30 feet (6–9 m) thick, but doubtless many tens of feet thick near vent areas.

Qbef - East Fork Deep Creek lava flow (Pleistocene)

This unit shares a unit description with another unit. See unit Qbefc for this shared unit description.
Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbbk - Bowers Knoll lava flow (middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below. Of note, unit Obbkc is not present within the extent of the GRI digital geologic-GIS map.

Qbbk, Qbbkc - Bowers Knoll lava flow and cinder cones (middle Pleistocene)
Medium-gray mugearite (sodium-rich basaltic trachyandesite) containing abundant clusters of olivine, plagioclase, and clinopyroxene phenocrysts in a fine-grained groundmass; lava flow erupted from Bowers Knoll, a cinder cone (Qbbkc) about 3 miles (5 km) northeast of Duck Creek village, about 10 miles (16 km) south of Panguitch; forms rugged, heavily vegetated, blocky surface having steep flow fronts 40 feet (12 m) or more high; as mapped, contains Mammoth and Bower caves, large open lava tubes, but that part of the flow may belong to the Duck Creek flow (Johnson and others, 2010); age uncertain, but locally underlies the Duck Creek lava flow (Qbdc), so is probably middle Pleistocene; Best and others (1980) reported a K-Ar age of 0.52 ± 0.05 Ma for the nearby Asay Knoll lava flow (Qbak), which exhibits a similar degree of incision and weathering; typically 40 feet (12 m) or more thick near flow margins, but may exceed 100 feet (30 m) thick near the central part of the flow.
Description from source map: Panguitch 30' x 60' Quadrangle

Of note, unit Qbbkc is not present within the extent of the GRI digital geologic-GIS map.

Qbck - Copper Knoll lava flow (lower to middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below. Of note, unit Obckc is not present within the extent of the GRI digital geologic-GIS map.

Qbck, Qbckc - Cooper Knoll lava flow and cinder cone (middle to lower Pleistocene)
Medium-gray basalt that contains clusters of olivine, plagioclase, and clinopyroxene phenocrysts in a fine-grained groundmass; lava flow (Qbck) erupted from a vent at a cinder cone (Qbckc) on the south flank of Cooper Knoll, about 1 mile (1.6 km) southeast of Panguitch Lake; overlies stream gravels containing rounded pebbles and cobbles of the Isom Formation, mafic and intermediate volcanic rocks of the Mount Dutton Formation, chalcedony, and minor quartzite; sample HM101408-1 yielded a discordant age spectrum showing that the flow is less than or equal to 0.92 Ma (UGS and NIGL, 2013); more likely, it may be about 500,000 years old on the basis of comparison with the similarly incised Asay Bench lava flow (Qbak) for which Best and others (1980) reported a K-Ar age of 0.52 ± 0.05 Ma; lava flow is about 20 to 40 feet (6–12 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Of note, unit Qbckc is not present within the extent of the GRI digital geologic-GIS map.

Qbpk - Pryor Knoll lava flow (Pleistocene)

Qbpk - Pryor Knoll lava flow (Pleistocene)
Basaltic lava flow present at the southwest edge of the map area; may have erupted from Pryor Knoll in the adjacent Cedar Mountain quadrangle; age uncertain but may be about 1 Ma on the basis of comparison with nearby dated lava flows and its degree of dissection; lava flow is typically several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbwfc - Webster Flat cinder cone (Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbwf, Qbwfc - Webster Flat lava flow and cinder cone (middle Pleistocene)
Medium-gray, fine-grained olivine basalt with small plagioclase phenocrysts; lava flow (Qbwf) erupted from vent at cinder cone (Qbwfc) about 1 mile (1.6 km) east of Black Mountain in the southwest corner of the map area and flowed mostly south down the Kolob Terrace; age uncertain, but probably about 500,000 years old on the basis of comparison with nearby dated lava flows and its degree of dissection; lava flow is typically several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbwf - Webster Flat lava flow (Pleistocene)

This unit shares a unit description with another unit. See unit Qbwfc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbalc - Aspen Lake cinder cone (middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbal, Qbalc - Aspen Lake lava flow and cinder cone (middle Pleistocene)
Medium-gray, fine-grained olivine basalt with small plagioclase phenocrysts; lava flow (Qbal) erupted from vent at cinder cone (Qbalc) about 1 mile (1.6 km) south of Black Mountain in the southwest corner of the map area and flowed mostly south down the Kolob Terrace; age uncertain, but probably about 500,000 years old on the basis of comparison with nearby dated flows and its degree of dissection; lava flow is typically several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbal - Aspen Lake lava flow (middle Pleistocene)

This unit shares a unit description with another unit. See unit Qbalc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qblfc - Long Flat cinder cone (middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qblf, Qblfc - Long Flat lava flow and cinder cones (middle Pleistocene)
Medium-gray basalt to hawaiite (sodium-rich trachybasalt) that contains clusters of olivine and clinopyroxene phenocrysts; lava flow (Qblf) erupted mostly from hills 10,392 and 10,352 (Brian Head 7.5' topographic quadrangle map; Rowley and others, 2013), which are two cinder cones (Qblfc) near Long Flat about 3 miles (5 km) east of Brian Head peak; a third, smaller cinder cone is near the southeast margin of the flow near State Highway 143; parts of the lava flow are covered by Pinedale-age glacial till and glacial outwash, and the cinder cones appear to be more heavily eroded than the nearby Hancock Peak cinder cone (Qbhpc); the northeast flank of hill 10,392 is conspicuously truncated and it may have been eroded by an earlier glacial advance (if so, likely the Bull Lake [Illinoian or MIS 6] advance); Stowell (2006) reported an 40Ar/39Ar maximum isochron age of 0.60 ± 0.25 Ma for sample LEA71SS2, which is likely from the Long Flat lava flow, but minor- and trace-element signatures of the Long Flat and nearby Hancock Peak flows are similar and Stowell's sample location lacks precision to be properly located, thus the age of the Long Flat flow is uncertain; lava flow is several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

This unit (below) shares a unit description with another unit. These units and their shared unit description are presented below.

Qblf, Qblfc - Long Flat lava flow and cinder cones (middle Pleistocene)
Medium-gray basalt to hawaiite (sodium-rich trachybasalt) that contains clusters of olivine and clinopyroxene phenocrysts; lava flow (Qblf) erupted from hills having elevations of 10,392 and 10,352 feet, two cinder cones (Qblfc) near Long Flat about 3 miles (5 km) east of Brian Head peak, and another probable vent farther southeast along Utah State Highway 143, now the site of a borrow pit; parts of the lava flow are covered by Pinedale-age glacial till and glacial outwash, and the cinder cones appear to be more heavily eroded than the nearby Hancock Peak cinder cone (Qbhpc); the northeast flank of hill 10,392 is conspicuously truncated and it may have been eroded by a pre-Pindale glacial advance (if so, likely the Bull Lake [Illinoian or MIS 6] advance); Stowell (2006) reported an 40Ar/39Ar maximum isochron age of 0.60 ± 0.25 Ma for sample LEA71SS2, which is likely from the Long Flat lava flow, but minor- and trace-element signatures of the Long Flat and nearby Hancock Peak flows are similar and Stowell's sample location lacks precision to be properly located, thus its age is uncertain. Description from source map: Brian Head Quadrangle

Qblf - Long Flat lava flow (middle Pleistocene)

This unit shares a unit description with another unit. See unit Qblf for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with another unit. See unit Qblf for this shared unit description. Unit present on source map: Brian Head Quadrangle

Qbwkc - Wood Knoll cinder cone (middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbwk, Qbwkc - Wood Knoll lava flow and cinder cone (middle Pleistocene)
Medium- to dark-gray, fine-grained olivine basalt; lava flow (Qbwk) erupted from a vent at Wood Knoll, a cinder cone (Qbwkc) about 2 miles (3 km) southwest of Cedar Breaks National Monument, and flowed northwest into Long Hollow; a remnant of the flow, perched 1100 feet (335 m) above the junction of Ashdown Creek and Coal Creek, yielded an 40Ar/39Ar age of 0.63 ± 0.10 Ma and a long-term down-cutting rate of 0.53 mm/yr (about 21 inches per thousand years or 1700 ft/myr), inferred to be a minimum rate of relative uplift on the Hurricane fault to the west (Lund and others, 2007); lava flow is typically several tens of feet thick, but is as much as about 300 feet (90 m) thick where it fills the ancestral Coal Creek channel. Description from source map: Panguitch 30' x 60' Quadrangle

Qbwk - Wood Knoll lava flow (middle Pleistocene)

This unit shares a unit description with another unit. See unit Qbwkc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbubc - Upper Bear Springs cinder cone (lower to middle Pleistocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Qbub, Qbubc - Upper Bear Springs lava flows and cinder cones (middle to lower Pleistocene)
Medium- to dark-gray, fine-grained olivine basalt; lava flows (Qbub) erupted from vents at cinder cones (Qbubc) about 2 miles (3 km) southwest of Navajo Lake and flowed mostly south onto the Kolob Terrace; probably about 750,000 years old because they appear to be the same lava flows as those at Horse Knoll (Sable and Hereford, 2004; Doelling, 2008), which yielded a K-Ar age of 0.81 ± 0.05 Ma and an 40Ar/39Ar age of 0.73 ± 0.02 Ma (Biek and Hylland, 2007; UGS and NMGRL, 2008); lava flows are several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbub - Upper Bear Springs lava flow (lower to middle Pleistocene)

This unit shares a unit description with another unit. See unit Qbubc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Qbbm - Black Mountain lava flow (lower to middle Pleistocene)

Qbbm - Black Mountain lava flow (middle to lower Pleistocene)
Medium-gray, fine-grained olivine basalt with small plagioclase and pyroxene phenocrysts; lava flow caps the northwest-sloping surface of Black Mountain in the southwest corner of the map area; vent unknown but may be concealed by nearby younger lava flows or surficial deposits to the southeast; yielded K-Ar ages of 0.80 ± 0.24 (Anderson and Mehnert, 1979) and 0.87 ± 0.24 Ma (Best and others, 1980); typically, several tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Qbhpc - Hancock Peak cinder cone (lower to middle Pleistocene)

This unit shares a unit description with other units. These units and their shared unit description are presented below.

Qbhp1, Qbhp2, Qbhpc - Hancock Peak lava flows and cinder cone (middle to lower Pleistocene)
Medium-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in a fine-grained groundmass; on the basis of chemistry and morphology, the map unit is divided into two flows, both of which are well vegetated; erupted from Hancock Peak, a large, well-preserved cinder cone (Qbhpc) 5 miles (8 km) southeast of Brian Head peak; Qbhp1 appears to overlie Qbhp2 and extends farther downstream where it caps an inverted valley about 600 feet (180 m) above Mammoth Creek just north of the community of Mammoth Creek; age unknown, but estimated to be middle to early Pleistocene on the basis of comparison with the apparently 60,000-year-old Long Flat lava flow (Qblf) and the 2.8 Ma Blue Spring Mountain lava flow (Tbbm); lava flows are typically several tens of feet thick, but likely exceed 100 feet (30 m) thick where they fill paleotopographic lows. Description from source map: Panguitch 30' x 60' Quadrangle

This unit (below) shares a unit description with other units. These units and their shared unit description are presented below.

Qbhp1, Qbhp2, Qbhpc - Hancock Peak lava flows and cinder cone (middle to lower Pleistocene)
Medium-gray basalt that contains clusters of olivine and clinopyroxene phenocrysts in a fine-grained groundmass; based on chemistry and morphology the map unit is divided into two flows, both of which are well vegetated; erupted from Hancock Peak, a large, well-preserved cinder cone (Qbhpc) in the southeastern corner of the map area; Qbhp1 appears to overlie Qbhp2 and extends farther downstream, where it caps an inverted valley about 600 feet (180 m) above Mammoth Creek just north of the community of Mammoth Creek (Biek and others, 2012); age unknown, but estimated to be middle to early Pleistocene based on comparison with the Long Flat lava flow (Qblf) to the north and the 2.8 Ma Blue Spring Mountain lava flow east of the map area (Biek and others, 2012). Description from source map: Brian Head Quadrangle

Qbhp1 - Hancock Peak lava flow, younger (lower to middle Pleistocene)

This unit shares a unit description with other units. See unit Qbhpc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Qbhpc for this shared unit description. Unit present on source map: Brian Head Quadrangle

Qbhp2 - Hancock Peak lava flow, older (lower to middle Pleistocene)

This unit shares a unit description with other units. See unit Qbhpc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Qbhpc for this shared unit description. Unit present on source map: Brian Head Quadrangle

Tbbmc - Blue Spring Mountain cinder cone (Pliocene)

This unit shares a unit description with another unit. These units and their shared unit description are presented below.

Tbbm, Tbbmc - Blue Spring Mountain lava flow and cinder cone (Pliocene)
Medium-gray hawaiite and mugearite (sodium-rich trachybasalt and basaltic trachyandesite, respectively) lava flow (Tbbm) that contains clusters of olivine and clinopyroxene phenocrysts in an aphanitic to fine-grained groundmass; erupted from vents at a cinder cone (Tbbmc) on Blue Spring Mountain and flowed east and south, mostly toward the ancestral Mammoth Creek drainage; an erosional outlier caps Mahogany Hill, about 500 feet (150 m) above Mammoth Creek east of its intersection with Black Rock Valley; the cinder cone is deeply eroded and the lava flow is well vegetated; between Blue Spring Mountain and Blue Spring Valley the flow is involved in a large landslide complex, which slid on the underlying Brian Head Formation; lava flow is typically several tens of feet thick, but is doubtless thicker near the vent area and where it fills paleotopographic lows.

Stowell (2006) reported an 40Ar/39Ar plateau age of 2.78 ± 0.16 Ma for what is likely the Blue Spring Mountain lava flow, but Stowell's sample location lacks precision to be properly located, thus age is uncertain. On the basis of their similar chemistry, the map unit includes a northeast-trending dike at the north end of Blue Spring Valley and a small remnant a few tens of feet above Blue Spring Creek (Biek and others, 2014). If the Blue Spring Creek remnant is indeed part of the 2.8-million-year-old Blue Spring Mountain lava flow, it means that the Blue Spring Valley area has been a topographic low for nearly the past 3 million years, an unlikely scenario. Alternately, this remnant may be a small basaltic sill. Description from source map: Panguitch 30' x 60' Quadrangle

Tbbm - Blue Spring Mountain lava flow (Pliocene)

This unit shares a unit description with another unit. See unit Tbbmc for this shared unit description. Unit present on source map: Panguitch 30' x 60' Quadrangle

Tbhm - Houston Mountain lava flow (upper Miocene to lower Pliocene)

Tbhm - Houston Mountain lava flow (lower Pliocene to upper Miocene)
Medium-gray basalt containing clusters of olivine and clinopyroxene phenocrysts in a fine-grained groundmass; unconformably overlies the Brian Head Formation (Tbhv) and Leach Canyon Formation (Tql) along the west edge of Blue Spring Mountain; an erosional outlier on the south side of Clear Creek, about 3 miles (5 km) west-northwest of Panguitch Lake, contains abundant 1- to 2-mm-long plagioclase phenocrysts, but is otherwise chemically similar to and included in the Houston Mountain flow map unit; unit also caps Houston Mountain (about 6 miles [10 km] east of Cedar Breaks National Monument) and other hills of lower elevation to the south (about 3 miles [5 km] northeast of Navajo Lake), where it is typically platy weathering; source vent unknown and margins of lava flow are entirely eroded away, but elevation of remnants suggests flow was derived from the west of its current exposures, probably in the Brian Head quadrangle, likely at a vent now eroded and concealed by younger deposits; sample HK092006-3 yielded an 40Ar/39Ar whole-rock age of 5.27 ± 0.14 Ma (UGS

and NMGRL, 2009); maximum thickness is about 140 feet (43 m) at Houston Mountain. Description from source map: Panguitch 30' x 60' Quadrangle

Tbsp - Sidner Peaks lava flow (upper Miocene? to lower Pliocene?)

Tbsp - Sidney Peaks lava flow (lower Pliocene? to upper Miocene?)
Medium-gray basalt containing clusters of olivine and clinopyroxene phenocrysts as much as 0.25 inch (5 mm) in diameter in a fine-grained groundmass; forms deeply dissected flow and flow breccia that unconformably overlie the Markagunt gravity slide; deposit just northeast of Sidney Peaks, which unconformably overlies the Leach Canyon Formation, consists of lava blocks in a cinder matrix, is locally cut by basaltic dikes, and may be a deeply eroded vent area; age uncertain, but probably early Pliocene or late Miocene on the basis of comparison with dated flows elsewhere on the Markagunt Plateau; as much as 80 feet (25 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Tbsp - Sidney Peaks lava flow (lower Pliocene to upper Miocene)
Medium-gray basalt containing clusters of olivine and clinopyroxene phenocrysts as much as ¼ inch (5 mm) in diameter in a fine-grained groundmass; forms deeply dissected flow and flow breccia remnants that unconformably overlie the Markagunt Megabreccia; deposit just northeast of Sidney Peaks, where it unconformably overlies the Leach Canyon Formation and the Markagunt Megabreccia, consists of lava blocks in a cinder matrix, is locally cut by basaltic dikes, and may be a deeply eroded vent area; age uncertain, but probably early Pliocene or late Miocene based on comparison with dated flows elsewhere on the Markagunt Plateau; about 40 feet (12 m) thick. Description from source map: Brian Head Quadrangle

Tm - Markagunt Megabreccia, undivided (lower Miocene)

Tm - Markagunt Megabreccia, undivided
The Markagunt gravity slide is undivided where exposures are insufficient to delineate bedrock units at the map scale and in more remote areas due to time constraints. Most areas mapped as Tm consist predominantly of the Isom Formation, but locally includes Wah Wah Springs and Brian Head strata, and, north of Panguitch Lake, large amounts of volcanic mud flow breccia, volcaniclastic sandstone, and minor pebbly conglomerate of the Bear Valley and Mount Dutton Formations; it locally includes conglomeratic strata of the pink member of the Claron Formation on the east flank of Jackrabbit Mountain. On the Markagunt Plateau, north of the latitude of Panguitch Lake, Tm was emplaced on the resistant, planar surface of the Isom Formation, but south of the lake it was emplaced on the Leach Canyon Formation. At the west edge of the plateau, south of Iron Peak, Tm was locally emplaced on Brian Head strata. The Markagunt gravity slide locally exceeds 2000 feet (600 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

This unit (below) shares a unit description with other units. These units and their shared unit description are presented below.

Tm, Tm(Tqcb), Tm(Ti), Tm(Tnw), Tm(Tbh) - Markagunt Megabreccia (Miocene)
Poorly exposed, structurally chaotic assemblage of angular clasts and sheared, brecciated, and broken masses of older rock units spread by a large gravity slide over what is now the northern and central Markagunt Plateau (Sable and Anderson, 1985; Anderson, 1993; Sable and Maldonado, 1997b; Biek and others, 2012). Slide rocks in the map area are dominated by the Isom Formation (Ti; see discussion below), a resistant, regional ash-flow tuff (Mackin, 1960; Fleck and others, 1975; Best and others, 1989a), but older rocks of the resistant Wah Wah Springs Formation (Tnw) and the soft Brian Head Formation (Tbh) are also exposed in the upper plate of the Markagunt Megabreccia. Where they are part of the gravity slide mass, both the Isom and Wah Wah Springs Formations are lithologically different from nearby in-place outcrops in the map area, as discussed below, indicating

distant transport. The upper plate rocks were variably emplaced on the Mount Dutton Formation (Td), Leach Canyon Formation (Tql), and Isom Formation (Ti) in the northern and central part of the map area, and on the Brian Head and Claron Formations in the southern part of the map area. In the central and eastern parts of the map area, the Markagunt Megabreccia is locally well exposed and mapped by its individual components Tm(Tqcb, Ti, Tnw, Tbh), but where poorly exposed or where it consists of brecciated rocks of more than one unit, it is mapped as Markagunt Megabreccia (Tm).

In the southern part of the map area and in the Navajo Lake quadrangle, the unit consists of poorly exposed hills of breccia, mapped as Markagunt Megabreccia (Tm and Tm[Ti]) sitting on Brian Head or Claron Formation. South of Mammoth Creek, the Markagunt Megabreccia consists locally only of scattered, isolated, angular blocks of Isom Formation and minor agatized limestone of the Brian Head Formation unconformably on the Brian Head and Claron Formations. Being thin and scattered, these latter deposits are not mapped or are included within alluvium and colluvium deposits (Qac) or colluvium deposits (Qc). In the Navajo Lake quadrangle, they are similarly not mapped or are included in volcanic gravel colluvium (Qcv) or gravelly decomposition residuum and colluvium (QTrg). The isolated, angular blocks overwhelmingly consist of the Isom Formation and are as large as 16 feet (5 m) long (Hatfield and others, 2000b, 2010, figure 6), resembling glacial erratics. Many blocks of the Isom Formation are autobrecciated, that is internally brecciated (figure 6; see also Hatfield and others, 2000b, 2010, figure 7), then “healed” into hammer-ringing resistant rock presumably by devitrification and silicification of the tuff. Where appearing as unconsolidated rubbly outcrops or isolated blocks, Hatfield and others (2000b, 2000c, 2010) and Moore and others (2004) attributed it to being let down from a higher-level surface by sapping and dissolution of the underlying limestone in the Brian Head and Claron Formations, which formed abundant sinkholes in and south of the map area. Maximum thickness in the map area is about 450 feet (140 m); in the places where they are components of the slide mass, the Isom Formation is as much as 300 feet (90 m) thick, the Wah Wah Springs Formation is as much as 40 feet (12 m) thick, and the Brian Head Formation is as much as 150 feet (45 m) thick. Description from source map: Brian Head Quadrangle

Tm(Tqcb) - Markagunt Megabreccia, Bauers Tuff Member slide rock (lower Miocene)

Tm(Tqcb) - Markagunt Megabreccia, Bauers Tuff Member of Condor Canyon Formation component
Mapped northwest of Navajo Ridge in the northwestern corner of the Brian Head quadrangle (Rowley and others, 2013) and south of Jackrabbit Wash in the northwestern Red Hills (Maldonado and Williams, 1993a); exposed thickness about 100 feet (30 m). Description from source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Tm for this shared unit description. Unit present on source map: Brian Head Quadrangle

Tm(Tdbv) - Markagunt Megabreccia, Mount Dutton and Bear Valley components, undivided (lower Miocene)

Tm(Tdbv) - Markagunt Megabreccia, Mount Dutton and Bear Valley components, undivided
Mapped north of Panguitch Lake where exposures are inadequate to readily differentiate these formations; exceeds 500 feet (150 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Tm(Tdm) - Markagunt Megabreccia, Mount Dutton Formation, alluvial facies component (lower Miocene)

Tm(Tdm) - Markagunt Megabreccia, Mount Dutton Formation, mafic alluvial facies component
Dark-gray, vesicular, basaltic andesite and basalt present as angular cobble- to boulder-size blocks floating in a light-gray sandy and muddy matrix of the same composition; monolithic; interpreted to be volcanic mudflow deposits; a small area of basaltic scoria is present north of Bunker Creek in the NE1/4 NE1/4 section 12, T. 36 S., R. 8 W., about 3 miles (5 km) west of Panguitch Lake; maximum thickness is about 80 feet (24 m).

Mapped between Panguitch Lake and Sidney Peaks where it overlies 23.8 Ma Leach Canyon Formation (Tql), and north of Panguitch Lake, where it overlies the Isom Formation (Tm[Ti]). In the Bunker Creek drainage west of Panguitch Lake, the map unit is overlain by Isom Formation or locally by Wah Wah Springs Formation, each as part of the Markagunt gravity slide. Description from source map: Panguitch 30' x 60' Quadrangle

Tm(Ti) - Markagunt Megabreccia, Isom Formation component (lower Miocene)

Tm(Ti) Markagunt Megabreccia, Isom Formation component
Medium-gray, crystal-poor, densely welded, trachydacitic ashflow tuff; small (1–3 mm) euhedral crystals constitute 15 to 20% of the rock and are mostly plagioclase (90%) and minor pyroxene, magnetite, and rare quartz set in a devitrified glassy groundmass; unlike autochthonous Isom Formation, most outcrops and blocks weather to grussy soils and rounded hills; except locally along the south edge of Haycock Mountain, rarely forms cliffs as is typical of the autochthonous Isom; maximum thickness about 400 feet (120 m).

Although generally poorly exposed, the Isom Formation constitutes the great bulk of the gravity slide along its southern margin, roughly between Haycock Mountain, Brian Head, and Horse Valley, and in downfaulted blocks at the plateau's west margin. The map unit locally includes components of the Brian Head Formation, Wah Wah Springs Formation, and volcanic mudflow breccia that are difficult to delineate given extensive forest cover and inconspicuous outcrop habit. It generally slid over the Leach Canyon Formation west of Panguitch Lake, over Isom Formation north of Panguitch Lake, and over thin lower Miocene conglomerate that unconformably overlies the Brian Head Formation east of Panguitch Lake. Description from source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Tm for this shared unit description. Unit present on source map: Brian Head Quadrangle

Tm(Tnw) - Markagunt Megabreccia, Wah Wah Springs Formation component (lower Miocene)

Tm(Tnw) - Markagunt Megabreccia, Wah Wah Springs Formation component
Palered, grayish-orange-pink, and pale-red purple, crystal-rich, moderately welded, dacitic ash-flow tuff; phenocrysts of plagioclase, hornblende, biotite, and quartz (with minor Fe-Ti oxides and sanidine) comprise about 40% of the rock; locally exhibits intense cataclasis and shearing; about 40 feet (12 m) thick on the Markagunt Plateau and as much as about 100 feet (30 m) thick on Jackrabbit Mountain and northern Red Hills. Description from source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Tm for this shared unit description. Unit present on source map: Brian Head Quadrangle

Tm(Tbh) - Markagunt Megabreccia, Brian Head Formation component (lower Miocene)

Tm(Tbh) - Markagunt Megabreccia, Brian Head Formation component
Poorly exposed but distinctive white to light-gray volcaniclastic mudstone, pebbly sandstone, micritic limestone, and chalcedony clasts commonly present in colluvium, thus betraying the formation's presence northwest of Castle Valley (about 5 miles [8 km] west-southwest of Panguitch Lake), where it rests out-of-sequence on autochthonous Leach Canyon Formation; on the ridge at the common border of sections 9 and 16, T. 36 S., R. 8 W., pebbly volcaniclastic sandstone of the Brian Head Formation is well exposed at the head of a small landslide, dips 27° northeast, and is overlain by similarly dipping Wah Wah Springs Formation; on the hill to the south, however, Brian Head strata appear to be subhorizontal; thickness uncertain but outcrop patterns suggest that displaced Brian Head strata likely exceed 100 feet (30 m) thick.

Unit on the southeast side of Haycock Mountain is characterized by white and light-gray, locally tuffaceous, volcaniclastic sandstone, pebbly sandstone, mudstone, minor tuffaceous limestone, and local multi-hued chalcedony that are faulted and folded, indicative of deformation as part of the Markagunt gravity slide (alternately, deformation may be due to south-vergent thrust faulting associated with the westward extension of the Rubys Inn thrust); exposed thickness as much as 150 feet (45 m). Description from source map: Panguitch 30' x 60' Quadrangle

This unit shares a unit description with other units. See unit Tm for this shared unit description. Unit present on source map: Brian Head Quadrangle

Ta - Miocene alluvium (lower Miocene)

Ta - Miocene alluvium (lower Miocene)
Moderately sorted, moderately consolidated, pebble to boulder gravel mapped in three areas across the quadrangle: (1) on the south side of Haycock Mountain, (2) at the southeast end of Flake Mountain, and (3) at Miners Peak in the southwest corner of the map area. Deposits at Haycock Mountain contain rounded volcanic clasts and lesser quartzite and Claron limestone clasts; importantly, they also contain rounded clasts of Isom and possibly of Harmony Hills Tuff (though the latter may be derived from the Needles Range Group) and so are at least as young as 26–27 Ma and may be younger than 22 Ma; regardless, the Markagunt gravity slide overlies the map unit at Haycock Mountain; maximum exposed thickness about 80 feet (25 m).

Deposits at the southeast end of Flake Mountain are poorly exposed but consist of pebble to boulder gravel; contains well-rounded volcanic clasts, Claron Formation limestone clasts, and common recycled quartzite clasts; interpreted to be stream channel deposits eroded into the white member of the Claron Formation; structurally overlain by the Flake Mountain megabreccia; maximum exposed thickness about 40 feet (12 m).

Deposits at Miners Peak on Cedar Mountain are unconsolidated, poorly sorted, clay- to very large boulder-size sediment characterized by large quartz monzonite boulders. Quartz monzonite boulders as much as about 30 feet (10 m) in diameter constitute about 90% of the deposits. These deposits also contain large boulders of Claron Formation limestone as much as 18 feet (6 m) long, as well as recycled, rounded pebbles and small cobbles of Precambrian and Cambrian quartzite, lesser Cretaceous sandstone boulders, and rare cobbles and boulders of pebbly sandstone of uncertain origin. Except for the quartzite, most clasts at Miners Peak are subangular to subrounded. These deposits are about 90 feet (27 m) thick and were probably deposited by debris flows originating in the ancestral Pine Valley Mountains from erosion of the 20.5 Ma Pine Valley Latite or Pine Valley laccolith (see Biek and others [2009] for a discussion of the provenance and age of these unusual deposits). Description from source map: Panguitch 30' x 60' Quadrangle

Timd - Mafic dikes at the west edge of the Markagunt Plateau (lower Miocene)

Timd - Mafic dikes at the west edge of the Markagunt Plateau (lower Miocene)
Highly altered, greenish-gray to brownish-gray, aphanitic to fine-grained mafic dikes that trend mostly north in the Cottonwood Mountain quadrangle northeast of Paragonah; some dikes contain small plagioclase phenocrysts; typically deeply weathered and so poorly exposed, but most dikes fill joints and small-displacement faults, which are especially well developed in a horst of gently northwest-tilted Claron strata at the west edge of the plateau, west of Iron Peak (the bar and ball symbol on these dikes indicates relative sense of displacement of the fault); a sample from one of the northwest-trending dikes west of the Iron Peak laccolith yielded a K-Ar age of about 20 Ma (H.H. Mehnert and R. E. Anderson, written communication to F. Maldonado, 1988), consistent with an interpretation that the dikes are related to the laccolith; dikes range from about 1 to 20 feet (0.3–6 m) wide.

Map unit symbol Timd also used to denote basaltic and andesitic dikes in the adjacent Little Creek Peak quadrangle to the east, which Anderson and others (1987) interpreted as feeder dikes for the Mount Dutton and Bear Valley Formations and which Maldonado and others (1997, 2011) interpreted as related to the Iron Peak laccolith. Description from source map: Panguitch 30' x 60' Quadrangle

Of note, this unit is mapped as a linear feature and therefore is represented in the source GIS data as a line feature. In the GRI digital geologic-GIS map data these linear unit features are present in the Linear Dikes data layer. The unit is not present as a mapped area feature in the extent of the GRI digital geologic-GIS map.

Tqcb - Condor Canyon Formation, Bauers Tuff Member (lower Miocene)

Tqcb - Bauers Tuff Member of Condor Canyon Formation (lower Miocene)
Resistant, light-brownish gray to pinkish-gray, densely welded, rhyolitic ashflow tuff; contains about 10 to 20% phenocrysts of plagioclase (40–70%), sanidine (25–50%), biotite (2–10%), Fe-Ti oxides (1–8%), and pyroxene (<3%), but lacks quartz phenocrysts (Rowley and others, 1995); bronze-colored biotite and light-gray flattened lenticules are conspicuous in the upper, vapor-phase part of the tuff, and a basal vitrophyre 10 to 20 feet (3–6 m) thick is normally present; typically about 50 to 100 feet (15–30 m) thick

The Bauers Tuff Member is exposed in Parowan Canyon where it is as much as 50 feet (15 m) thick and overlies volcaniclastic sandstone and mudflow breccia of the Mount Dutton Formation. It overlies the Leach Canyon Formation in Summit Creek canyon. It is also exposed in a fault block in the northwestern Red Hills, where it is as much as about 100 feet (30 m) thick (Maldonado and Williams, 1993a).

The Bauers Tuff Member erupted from the northwest part (Clover Creek caldera) of the Caliente caldera complex and covered an area of at least 8900 square miles (23,000 km2) (Best and others, 1989b; Rowley and others, 1995) with an estimated volume of 740 cubic miles (3200 km3) (Best and others, 2013). The preferred 40Ar/39Ar age of the Bauers Tuff Member is 22.7 Ma (Best and others, 1989a) or 22.8 Ma (Rowley and others, 1995), which is also the 40Ar/39Ar age of its intra-caldera intrusion exposed just north of Caliente, Nevada (Rowley and others, 1994b). Fleck and others (1975) reported a K-Ar age (corrected according to Dalrymple, 1979) of 22.7 ± 0.6 Ma (plagioclase) for what they interpreted as Bauers Tuff Member on the Markagunt Plateau, east of Fivemile Ridge, but that we re-interpret as Haycock Mountain Tuff. Description from source map: Panguitch 30' x 60' Quadrangle

Td - Mount Dutton Formation, alluvial facies (upper Oligocene)

Td - Mount Dutton Formation, alluvial facies (upper Oligocene)
Light- to dark-gray and brown, andesitic to dacitic volcanic mudflow breccia and lesser interbedded volcaniclastic conglomerate and tuffaceous sandstone; also contains subordinate lava flows, flow breccia, and minor felsic tuff; Anderson and Rowley (1975) defined the Mount Dutton Formation as consisting of most of the rocks exposed on the south flank of the Marysvale volcanic field, and divided it into complexly interfingering and cross-cutting vent and alluvial facies derived from clustered stratovolcanoes and dikes; except for the Kingston Canyon Tuff Member, only those rocks associated with the alluvial facies are present in the map area, where they typically overlie the Bear Valley Formation on the Markagunt Plateau and the Brian Head Formation on the Sevier Plateau.

The Marysvale volcanic field is one of several voluminous calc-alkaline, subduction-related volcanic centers and underlying source batholiths that characterized the West from Oligocene to Miocene time at this latitude (Lipman and others, 1972; Rowley and Dixon, 2001). Fleck and others (1975) and Rowley and others (1994a) reported several K-Ar ages of 23 to 30 Ma on rocks of the coeval vent facies, not including an anomalously young age (corrected according to Dalrymple, 1979) of 21.2 ± 0.5 Ma (sample R-27 of Fleck and others, 1975) ascribed by Anderson and Rowley (1975, p. 28) and Rowley and others (1994a) to a local volcano, perhaps from the Iron Peak intrusion east of Paragonah. The alluvial facies is at least 1000 feet (300 m) thick in the map area in the northern Markagunt Plateau (Anderson and Rowley, 1987) where we re-interpret it to be part of the Markagunt gravity slide, about 2000 feet (600 m) thick on the southern end of the Sevier Plateau (Rowley and others, 1987), and is at least 6000 feet (2000 m) thick in the Sevier Plateau north of the Panguitch 30' x 60' quadrangle (Anderson and others, 1990a, 1990b; Rowley and others, 2005). Individual mudflows and other rock units pinch out radially from an east-trending string of stratovolcanoes along the southern part of the Marysvale volcanic field. Description from source map: Panguitch 30' x 60' Quadrangle

Td - Mount Dutton Formation (Miocene)
Moderately resistant, light- to medium-gray, volcanic mudflow breccia made up of dark-gray and black, matrix-supported, angular and subangular clasts of crystal-poor dacitic and andesitic flow rock in a fine-grained matrix (former mud) (Anderson and Rowley, 1975); mapped northeast of Sidney Peaks, where it forms small patches that postdate the Leach Canyon Formation (Tql) and predate emplacement of the Markagunt Megabreccia (Tm); maximum thickness about 10 feet (3 m).

Anderson and Rowley (1975) defined the Mount Dutton Formation as consisting of most of the rocks exposed on the south flank of the Marysvale volcanic field, and divided it into complexly interfingering and cross-cutting vent and alluvial facies derived from clustered stratovolcanoes and dikes. The Marysvale volcanic field is one of several voluminous calc-alkaline, subduction-related volcanic centers and underlying source plutons that characterized the West from Oligocene to Miocene time at this latitude (Lipman and others, 1972; Rowley and Dixon, 2001). Fleck and others (1975) and Rowley and others (1994a) reported several K-Ar ages of 23 to 30 Ma on rocks of the coeval vent facies, but only the youngest part of the formation is present in the map area. The alluvial facies is at least 1000 feet (300 m) thick in the map area in the northern Markagunt Plateau (Anderson and Rowley, 1987) and is at least 6000 feet (2000 m) thick farther north (Anderson and others, 1990a, 1990b; Rowley and others, 2005). It pinches out radially from an east-trending string of stratovolcanoes along the southern part of the Marysvale volcanic field. Description from source map: Brian Head Quadrangle

Tql - Leach Canyon Formation (upper Oligocene)

Tql - Leach Canyon Formation (upper Oligocene)
Grayish-orange-pink to pinkish-gray, poorly to moderately welded, crystal-rich to crystal-poor rhyolite tuff that contains abundant white or light-pink collapsed pumice fragments and several percent lithic clasts, many of which are reddish brown; contains as much as 25 to 35% total phenocrysts of plagioclase, slightly less but subequal amounts of quartz and sanidine, and minor biotite, hornblende,

Fe-Ti oxides, and a trace of pyroxene; forms the resistant cap rock of Brian Head peak and the southern part of Black Ledge, is exposed eastward nearly to the Panguitch Lake area, and is also exposed in fault blocks at the west edge of the Markagunt Plateau and in the northern Red Hills, as described below; source is unknown, but it is probably the Caliente caldera complex because isopachs show that it thickens toward the complex (Williams, 1967; Rowley and others, 1995); the total volume of the Leach Canyon is estimated to be 830 cubic miles (3600 km3), representing the largest and apparently the initial eruption of the Caliente caldera complex (Best and others, 2013); typically about 100 feet (30 m) thick in the map area.

At Brian Head peak, the Leach Canyon Formation, which unconformably overlies the Isom Formation, consists of four parts, the lower three of which are rarely exposed elsewhere. At the base is non-resistant, 6- to 10-foot-thick (2–3 m), unwelded, white, rhyolite tuff that is overlain by a 10-foot-thick (3 m) moderate- orange-pink rhyolite tuff that has sparse reddish-brown lithic clasts, which becomes slightly more indurated in the upper part of the unit. This is overlain by a massive, 12-foot-thick (4 m) black vitrophyre, which is in turn overlain by a 25-foot-thick (8 m) resistant, pale-red, moderately welded rhyolite tuff that contains pale-lavender flattened pumice lenticules and as much as 1% distinctive, small, reddish-brown lithic clasts of flow rock torn from the vent walls. This resistant upper unit forms the cap rock of Black Ledge northward to beyond the Sidney Peaks area.

To the east, west of Panguitch Lake, the Leach Canyon Formation unconformably overlies the Brian Head Formation or, locally, stream gravel too thin to map that contains clasts of Isom Formation (for example, on the southeast side of Prince Mountain at sample location PL061708-3). A non-resistant, moderate-orange-pink ash-fall tuff identical to that at Brian Head peak is present at the base of the unit on the southeast side of Prince Mountain. The main part of the cooling unit contains only rare, small, reddish-brown lithic fragments.

The Leach Canyon Formation and the Haycock Mountain Tuff are petrographically and chemically similar, which led Sable and Maldonado (1997a) to suggest that the latter is a distal facies of Leach Canyon. While it is true that the two formations are not reliably distinguishable on the basis of their major and trace-element chemistry, the Haycock Mountain Tuff is typically less welded than the Leach Canyon and contains conspicuous black lithic fragments, unlike the reddish-brown lithic fragments of the Leach Canyon, facts previously noted by Anderson (1993), Rowley and others (1994a), and Hatfield and others (2010). Detailed mapping of the Panguitch Lake and Haycock Mountain quadrangles (Biek and others, 2014a, 2014b) reconfirms that these are indeed two different units. The Leach Canyon Formation can be traced in continuous outcrop from Brian Head peak northward to the head of Bunker Creek and then east to the east end of Prince Mountain just west of Panguitch Lake. It is structurally overlain by the Markagunt gravity slide, which here consists mostly of the Isom Formation. Samples from the south side of Prince Mountain yielded K-Ar ages of 22.8 ± 1.1 Ma (biotite) and 24.8 ± 1.0 Ma (sanidine) (Rowley and others, 1994a, sample 89USa-1a, which they mistakenly called Haycock Mountain Tuff) and a duplicate K-Ar age of 24.3 ± 1.0 Ma (sanidine) as well as an 40Ar/39Ar age of 23.86 ± 0.26 Ma (biotite) (Sable and Maldonado, 1997a, on the same sample 89USa-1a). The Leach Canyon Formation is widely agreed to be about 23.8 Ma (Best and others, 1993; Rowley and others, 1995). As noted by Hatfield and others (2010), both Rowley and others (1994a) and Sable and Maldonado (1997a) misinterpreted this tuff to be the Haycock Mountain Tuff, which yielded a slightly younger 40Ar/39Ar age of 22.75 ± 0.12 Ma (sanidine) at its type section about one mile (1.6 km) northeast of Panguitch Lake (Sable, unpublished data, 1996; see also Hatfield and others, 2010) and our new U-Pb age on zircon of 21.63 ± 0.73 Ma. The facts that the tuff at Prince Mountain yielded an age analytically indistinguishable from the Leach Canyon Formation, and that it can be traced continuously to classic Leach Canyon outcrops at Brian Head peak, are irrefutable evidence that it is the Leach Canyon Formation and not the Haycock Mountain Tuff.

The Leach Canyon Formation unconformably overlies the Isom Formation at Brian Head peak and the southern part of Black Ledge. North of Castle Valley and at Prince Mountain, however, the Leach Canyon unconformably overlies Brian Head strata. This distribution suggests that the Prince Mountain–Castle Valley area was a paleohigh of Brian Head strata during Isom time, and that, once the resistant Isom was in place in flanking areas, this paleohigh was preferentially eroded to form a broad, east-trending stream valley in which the Leach Canyon accumulated. Except for outcrops in

Bear Valley north of Utah Highway 20, the Leach Canyon is not present on the Markagunt Plateau north of Clear Creek, a northwest-trending tributary to Panguitch Lake. Description from source map: Panguitch 30' x 60' Quadrangle

Tql - Leach Canyon Formation (upper Oligocene)
Resistant, tan, poorly welded, crystal-poor (15 to 20 percent phenocrysts), low-silica rhyolite ash-flow tuff; single cooling unit whose lower part consists of a resistant, platy, dark-brown and black basal vitrophyre as much as 20 feet (7 m) thick that is locally underlain by a non-resistant, pale-orange, unwelded ash-fall tuff as much as 15 feet (5 m) thick (figure 7); characterized by as much as 1 percent bright-red and gray lithic clasts (rock fragments) of flow rock torn from the magma chamber or vent, and common, little-collapsed, cognate pumice fragments, each as much as 0.5 inch (1.5 cm) long; probably derived from the Caliente caldera complex based on isopachs that show the Leach Canyon Formation thickening toward the complex (Williams, 1967; Rowley and others, 1995); 40Ar/39Ar age is about 23.8 Ma (Best and others, 1993; Rowley and others, 1995); 55 to 100 feet (17–30 m) thick. Description from source map: Brian Head Quadrangle

Ti - Isom Formation (upper Oligocene)

Ti - Isom Formation (upper Oligocene)
Medium-gray, crystal-poor, densely welded, trachydacitic ash-flow tuff, typically having distinctive rheomorphic features including flow folds, elongated vesicles, and flow breccias and thus commonly known as a tufflava (Mackin, 1960; Cook, 1965, 1966; Anderson and Rowley, 1975, 2002); small (1–3 mm) euhedral crystals constitute 10 to 15% or less of the rock and are mostly plagioclase (90%) and minor pyroxene and Fe-Ti oxides set in a devitrified-glass groundmass; exhibits pronounced platy outcrop habit and is thus accompanied by extensive talus deposits; rarely, a black basal vitrophyre is exposed, and locally fracture surfaces and elongated vesicles (lenticules, described below) are dark reddish brown to dusky red; query indicates uncertain correlation in the upper reaches of the Clear Creek drainage northwest of Panguitch Lake; the Isom Formation is about 26 to 27 Ma on the basis of many 40Ar/39Ar and K-Ar ages (Best and others, 1989b; Rowley and others, 1994a), and because it is locally interbedded with the 26 Ma Buckskin Breccia (Anderson and others, 1987); maximum exposed thickness is about 350 feet (110 m) at Black Ledge and about 250 feet (75 m) along Ipson Creek.

The best and most extensive exposures of the Isom Formation in the map area are at Brian Head peak and to the northeast along Black Ledge where at least three cooling units are locally present. At Brian Head peak, the lower part of the formation is classic tufflava about 80 feet (24 m) thick, whereas the upper part is a flow breccia 60 to 90 feet (18–27 m) thick. Along Black Ledge, about 7 miles (11 km) northeast of Brian Head peak, the flow breccia is absent and the Isom there appears to consist of a single cooling unit about 350 feet (100 m) thick. The Isom also forms prominent cliffs north of Clear Creek and Panguitch Lake. East of Yankee Meadows Reservoir, the base of the Isom is unusual in that Isom ash-flow tuff overlies as much as 30 feet (9 m) of coarse sandstone with angular Isom pebbles and planar and low-angle cross-stratification that in turn overlies calcite-cemented Isom breccia.

Regionally, many outcrops of all cooling units in the Isom Formation reveal secondary flow characteristics, including flow breccias, contorted flow layering, and linear vesicles such that the unit was considered a lava flow until Mackin (1960) mapped its widespread distribution (300 cubic miles [1300 km3] today spread over an area of 9500 square miles [25,000 km2] [Best and others, 1989a]) and found evidence of glass shards in its basal vitrophyre, thus showing its true ash-flow tuff nature. Such an ashflow tuff is also called a tufflava or rheomorphic ignimbrite, one sufficiently hot to move with laminar flow as a coherent ductile mass—see, for example, Cook (1966), Anderson and Rowley (1975, 2002), Ekren and others (1984), Andrews and Branney (2005), and Geissman and others (2010). Exhibits pronounced subhorizontal lamination or platiness, which Mackin (1960) called “lenticules.” Fryman (1986, 1987), Anderson and others (1990c), and Anderson and Rowley (2002) also described the light gray, pancake-shaped lenticules, which are typically spaced 4 to 8 inches

(10–20 cm) apart and may extend for 30 feet (10 m) or more, and which are locally contorted, suggesting turbulence in the flow as it moved over uneven topography. Fryman (1986, 1987) also described fumaroles in the Isom of the northern Markagunt Plateau, a result of degassing of the flow as it came to rest.

The source of the Isom is unknown, but isopach maps and pumice distribution suggest that it was derived from late-stage eruptions of the 27–32 Ma Indian Peak caldera complex that straddles the Utah- Nevada border, possibly in an area now concealed by the western Escalante Desert (Rowley and others, 1979; Best and others, 1989a, 1989b, 2013). Estimated crystallization temperature and pressure of Isom phenocrysts are 950°C and <2 kbar (Best and others, 1993), and this relatively high temperature is supported by its degree of welding and secondary flow features. At its type area in the Iron Springs district west of the map area, Mackin (1960) defined three members, a lower unnamed member, the Baldhills Tuff Member, and the upper Hole-in-the-Wall Tuff Member; Rowley and others (1975) redefined the Baldhills Tuff Member to include Mackin's lower unnamed member, and noted that the Baldhills consists of at least six cooling units. Maldonado and Williams (1993a, 1993b) described nine apparent cooling units in the northern Red Hills at the west edge of the map area. In the northern Markagunt Plateau, Anderson and Rowley (1975) defined the Blue Meadows Tuff Member, which underlies the Baldhills Tuff Member, but it is possible that the Blue Meadows Tuff is part of the Mount Dutton Formation, and thus a local tuff derived from the Marysvale volcanic field (Rowley and others, 1994a). Maldonado and others (2011) mapped the Blue Meadows Tuff Member of the Isom Formation at the east edge of the Cottonwood Mountain quadrangle. For this map, we simply call this ash-flow tuff the Isom Formation, noting our uncertainty in dividing the Isom on the Markagunt Plateau. Description from source map: Panguitch 30' x 60' Quadrangle

Ti - Isom Formation (Oligocene)
Resistant, medium- to dark-brown, black, reddish-brown, brick-red, and greenish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff; comprises at least three cooling units in the map area, some of which have black basal vitrophyres and local flow-breccia bases; below Brian Head peak, the top of the Isom is at least 40 feet (13 m) of breccia, interpreted to be flow breccia. Together with the Leach Canyon Formation, the Isom Formation (figures 8 and 9) forms the prominent cliff of Black Ledge that trends northeast from Brian Head peak. All Isom cooling units are densely welded and show evidence of rheomorphic flow (flowed during the last several dozens of feet of emplacement), as indicated by steep flow folds common west of the map area, by basal flow breccias, and by linear vesicles (figure 10); thus the map unit was considered to be a lava flow until Mackin (1960) and Williams (1960) traced it widely over western Utah and eastern Nevada and found petrographic evidence in the basal glass that the matrix consists of welded glass shards. Where in place in the map area, cooling units contain distinctive linear vesicles 0.08 inch (2 mm) to 0.3 inch (1 cm) in diameter and drawn out laterally 1 to 2 inches (3–6 cm) during flow, and the tuffs contain only 5 to 15 percent phenocrysts. In contrast, however, where included in the Markagunt Megabreccia, the Isom Formation consists of several cooling units with linear vesicles and an upper distinctive cooling unit that is recognizable as the main cooling unit of the Baldhills Tuff Member in the formation's type area in the Iron Springs mining district west of Cedar City (Mackin, 1960; Anderson and Rowley, 1975). In that area, the Baldhills Tuff Member is a massive, more crystal-rich (15 to 25 percent phenocrysts) tuff that lacks linear vesicles but contains lighter colored, vesicular, planar lenticules as much as 1.5 feet (0.5 m) long in the plane of bedding and 1 inch (2 cm) thick. The closest this cooling unit is recognized in place is several miles north of the map area, the likely source of the slide mass of the Markagunt Megabreccia (Sable and Maldonado, 1997b). The Isom Formation is probably derived from the Indian Peak caldera complex (Best and others, 1989a, 1989b); the age appears to be about 26–27 Ma on the basis of many 40Ar/39Ar and K-Ar ages (Best and others, 1989b; Rowley and others, 1994a). The maximum thickness where in place is about 350 feet (107 m) along Black Ledge; its maximum thickness within the Markagunt Megabreccia about 300 feet (100 m). Description from source map: Brian Head Quadrangle

Tnw - Wah Wah Springs Formation (lower Oligocene)

Tnw - Wah Wah Springs Formation (lower Oligocene)
Pale-red to grayish-orange-pink, moderately welded, crystal-rich, dacitic ash-flow tuff that rests on Brian Head strata and, on the Markagunt Plateau, is overlain by the Isom Formation; phenocrysts of plagioclase, hornblende, and biotite (plus minor quartz, Fe-Ti oxides, and sanidine) constitute about 40% of the rock; the abundance of hornblende over biotite is unique among Great Basin ash-flow tuffs; elongate collapsed pumice is common; exposed west of Cottonwood Mountain and west of Bear Valley in the northern Markagunt Plateau, at the head of Bunker Creek west of Panguitch Lake, and in the Red Hills; exhibits reversed magnetic polarity (Best and Grant, 1987); derived from the Indian Peak caldera of the 27 to 32 Ma Indian Peak caldera complex that straddles the Utah- Nevada border (Best and others, 1989a, 1989b, 2013); today, the Wah Wah Springs covers at least 8500 square miles (22,000 km2) with an estimated volume of as much as about 720 cubic miles (3000 km3) (Best and others, 1989a); about 30 Ma on the basis of many K-Ar and 40Ar/39Ar age determinations (Best and Grant, 1987; Best and others, 1989a, 1989b; Rowley and others, 1994a); about 40 feet (12 m) thick in the northern Markagunt Plateau and as much as 130 feet (40 m) thick in the Sevier Plateau; map patterns show that it is about 200 feet (60 m) thick in the Red Hills, about half the thickness reported by Maldonado and Williams (1993a, 1993b).

A small exposure on Lowder Creek (east of Brian Head peak) is deeply weathered, non-resistant, white, crystal-rich ash-flow tuff about 6 feet (2 m) thick. Phenocrysts of plagioclase, hornblende, biotite, and quartz (plus minor Fe-Ti oxides and sanidine) make up about 30 to 40% of the rock. The color and degree of welding contrast sharply with typical Wah Wah Springs, which led Rowley and others (2013) to suggest that the tuff at Lowder Creek was deposited in a lake. Biotite-hornblende pairs from two samples from the same bed at Lowder Creek yielded K-Ar ages of 29.1 to 32.4 Ma (Rowley and others, 1994a). The Lowder Creek exposure is overlain by 3 to 6 feet (1–2 m) of volcanic mudflow breccia, which is in turn overlain by 10 to 15 feet (3–5 m) of deeply weathered, non-resistant, crystal-poor ash-flow tuff(?) of uncertain provenance, which is itself overlain by autochthonous Isom Formation. Description from source map: Panguitch 30' x 60' Quadrangle

Tnw - Wah Wah Springs Formation (Oligocene)
Resistant to non-resistant, light-red, medium-gray, and pink, crystal-rich (30 to 40 percent phenocrysts), moderately welded, dacite ash-flow tuff that contains sparse lithic clasts and partly collapsed, cognate pumice fragments. Where in place, it is exposed only along the upper part of Lowder Creek, where it is non-resistant and overlain by about 10 feet (3 m) of tuffaceous sandstone mapped with Wah Wah Springs, but identical to sandstone of the Brian Head Formation below it; the poorly welded nature of the ash-flow tuff and its stratigraphic position here suggests that it was emplaced into a lake. The Wah Wah Springs Formation is present in the Markagunt Megabreccia only in the eastern part of the map area, where it is resistant and moderately welded and was derived from areas to the north (Sable and Maldonado, 1997b; Biek and others, 2012) by gravity sliding. It erupted from the Indian Peak caldera complex (Best and others, 1989a, 1989b) along the Utah-Nevada border; Best and others (1989a) considered it to have an age of 29.5 Ma, and Rowley and others (1994a) reported four K-Ar ages of 29 to 32 Ma from biotite-hornblende pairs from two samples collected from Lowder Creek. Its thickness where in place along Lowder Creek is 3 to 8 feet (1–3 m), and maximum thickness in the Markagunt Megabreccia is as much as 40 feet (12 m). Description from source map: Brian Head Quadrangle

Tbh - Brian Head Formation (middle Eocene to lower Oligocene)

Tbh - Brian Head Formation, Middle volcaniclastic unit, undivided (middle Eocene to lower Oligocene)
White to light-gray volcaniclastic mudstone, siltstone, silty sandstone, sandstone, conglomerate, volcanic ash, micritic limestone, and multi-hued chalcedony; near Mineral Canyon and northwest of Little Salt Lake (hill 7292), conglomerate consists of pebble- to boulder-size, rounded clasts of intermediate volcanic rocks of unknown affinity and quartzite pebbles and cobbles; sandstone is

commonly bioturbated with pencil-size root or burrow casts that weather out in relief; soft-sediment slump features are locally common; chalcedony is various shades of white, gray, yellow, red, black, and brown, typically has a white weathering rind, is commonly highly brecciated and resilicified, typically occurs in beds 1 to 3 feet (0.3–1 m) thick but locally as much as 8 feet (2.5 m) thick, and is locally stained by manganese oxides; chalcedony beds probably reflect silicification of limestone beds (Maldonado, 1995; Sable and Maldonado, 1997b; Schinkel, 2012) as silica is leached from glass shards in the volcanic ash beds; Bakewell (2001) suggested that the chalcedony may have resulted from silicification of the tuff beds themselves; Maldonado (1995) suggested a hydrothermal source for the generally low metal values in the chalcedony; chalcedony is almost always highly fractured, but some is useful for lapidary purposes (Strong, 1984); Brian Head strata are about 500 feet (150 m) thick at Brian Head peak; on the southwest flank of the Sevier Plateau, they are readily divisible into four informal parts that collectively total about 1000 feet (300 m) thick, described below. The formation is typically non-resistant, poorly exposed, and extensively covered by colluvium, but locally well exposed near Panguitch Lake and on the southwest side of Brian Head peak. Because of abundant bentonitic clay derived from weathered volcanic ash, this unit weathers to strongly swelling soils (unlike the underlying Claron Formation) and forms large landslide complexes; it was the principal detachment surface for the Markagunt gravity slide and for the Red Hills shear zone of Maldonado (1992, 1995) and Maldonado and others (1994, 1997). The Brian Head Formation was deposited in low-relief fluvial, floodplain, and lacustrine environments in which large amounts of volcanic ash accumulated (Sable and Maldonado, 1997b). Description from source map: Panguitch 30' x 60' Quadrangle

Tbh - Brian Head Formation (Oligocene and Eocene)
Mostly poorly resistant, pink and light-gray, tuffaceous, fluvial sandstone, siltstone, shale, and minor conglomerate and locally resistant 2- to 6-foot-thick (1–2 m) ledges of white lacustrine micritic limestone that has characteristically been partly to mostly replaced by tan, light-gray, orange, yellow, green, red, and brown agate (chalcedony); formation rests unconformably upon the Claron Formation, which is not tuffaceous. The Brian Head Formation was first defined by Gregory (1944) to describe a thick package of sedimentary and volcanic rocks that included at its base the white member of the Claron Formation; the name was 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 interval, and Anderson (1993) reintroduced the name “Brian Head Formation” for the same restricted unit in the Markagunt Plateau. Sable and Maldonado (1997a) provided a detailed discussion and type section of the redefined Brian Head Formation at Brian Head peak, which they divided into three units: (1) an upper volcanic unit, locally present in the northern Markagunt Plateau but not in the map area, characterized by volcanic mudflow breccia, mafic lava flows, volcaniclastic sandstone and conglomerate, and ash-flow tuff; (2) a middle unit of thick, soft, gray, greenish-gray, and yellowish-gray, bioturbated, thin-bedded, volcaniclastic clayey sandstone, conglomeratic sandstone, claystone, micritic limestone (commonly replaced by chalcedony), and ash-fall tuff; and (3) a lower unit of soft, thin-bedded, reddish-brown and pink, nontuffaceous, calcareous siltstone and mudstone with minor silty sandstone and micritic limestone and a thin, capping, non-volcaniclastic pebble conglomerate, reassigned by Biek and others (2012) to a new uppermost unit (Tcwt) of the white member of the Claron Formation. Largely because of the ash-fall tuff, which has weathered to bentonitic clay, the middle member of Sable and Maldonado (1997a) is weak and prone to landsliding virtually wherever exposed; the Markagunt Megabreccia is interpreted to have slid primarily on this unit in the map area.

The Brian Head Formation is early Oligocene to latest middle Eocene in age, about 30 to 36 million years old. The upper part of the middle unit in Lowder Creek is overlain by the 29.5-Ma Wah Wah Springs Formation (Tnw) (Rowley and others, 1994a; Sable and Maldonado, 1997a; Hatfield and others, 2000b, 2010). Davis and others (2009) reported U-Pb (SHRIMP-RG) ages of 35.2 ± 0.8 Ma and 34.7 ± 0.6 Ma from the Brian Head Formation at Brian Head peak. Biek and others (2012; see also UGA and A-to-Z, 2013) obtained U-Pb ages on zircon from an ash-fall tuff at the base of the formation at Cedar Breaks National Monument of 35.77 ± 0.28 Ma, and from the Sevier Plateau of 36.51 ± 1.69 Ma. In the Red Hills to the west, Maldonado and Moore (1995) reported 40Ar/39Ar ages

of 33.00 ± 0.13 Ma (plagioclase) and 33.70 ± 0.14 Ma (biotite) on an ash-flow tuff that lies in the upper part of the formation, and in the Panguitch Lake area, tuffs in the upper part of the formation yielded 40Ar/39Ar ages on sanidine of 35.04 ± 0.23 Ma and 33.80 ± 0.05 Ma (Biek and others, 2012; UGS and NIGL, 2012). As mapped, the Brian Head Formation is rarely exposed because it is largely buried beneath a residual and colluvial mantle of debris let down from the overlying Isom and Leach Canyon Formations and the Markagunt Megabreccia. The Brian Head Formation is about 500 feet (150 m) thick at its type section on Brian Head peak. Description from source map: Brian Head Quadrangle

Tc - Claron Formation, undivided (Paleocene to Eocene)

Tc - Claron Formation, undivided (Eocene and Paleocene)
Mapped west of Brian Head where we are unable to differentiate pink and possible white member strata; exposed thickness is about 400 feet (120 m). Description from source map: Panguitch 30' x 60' Quadrangle

Tcw - Claron Formation, white member, undivided (Eocene)

Tcw - Claron Formation, white member, undivided (Eocene)
Lithologies are described below for individual units. On the Markagunt Plateau, used for areas south of Blue Spring Mountain (southwest of Panguitch Lake) and west of Brian Head peak where incomplete and isolated exposures preclude subdivision; also used on the southeastern Sevier Plateau where intervening clastic intervals lose character and most of the member appears to be white micritic limestone, and at Flake Mountain, where what we map as the white member may in fact be the pink member. We also map the white member at Boat Mesa and northward along the escarpment in the northeast part of Bryce Canyon National Park; Bowers (1990), however, mapped these strata as the pink member. Ledge-forming white limestone typical of the white member is present on hill 8155 west of Boat Mesa but appears to grade east and north into interbedded varicolored mudstone, siltstone, and limestone that weathers to distinctly lighter colored slopes than the underlying pink member. In aggregate, the white member maintains a relatively uniform thickness of about 350 to 450 feet (105–135 m) on the Markagunt and Paunsaugunt Plateaus. However, the member thickens to the east where it is dominated by white micritic limestone and is about 550 feet (170 m) thick on the Table Cliff Plateau (Bowers, 1973). The entire white member is about 340 feet (100 m) thick in Rock Canyon southeast of Panguitch Lake. Hatfield and others (2010) reported that it is 360 feet (110 m) thick at Cedar Breaks National Monument but including the lower sandstone and conglomerate unit of Sable and Maldonado (1997b), as suggested here, the thickness is 440 feet (135 m) (regardless, the white member is truncated south of Cedar Breaks National Monument by late Tertiary and Quaternary erosion associated with development of the Markagunt Plateau). Moore and others (1994) reported significant facies changes in the white member near Asay Bench, but there, in aggregate, it is 448 feet (137 m) thick. The white member is about 350 feet (105 m) thick on the southern Sevier Plateau. Ott (1999) measured an incomplete section of 233 feet (71 m) of the white member near Bryce Point, but it is unclear if her lower contact is the same as that used on this map. Description from source map: Panguitch 30' x 60' Quadrangle

Tcw - Claron Formation, white member, undivided (Eocene)
The white member, individual units of which are described below, is undivided in the northwest part of the map area due to incomplete, poor exposures. In aggregate, Hatfield and others (2000b, 2010) reported that the white member is 360 feet (110 m) thick at Cedar Breaks National Monument, but including the lower sandstone and conglomerate unit of Sable and Maldonado (1997b), as suggested here, the thickness is 440 feet (135 m). Description from source map: Brian Head Quadrangle

Tcwt - Claron Formation, white member, uppermost mudstone, siltstone and sandstone unit (upper and middle Eocene)

Tcwt - Claron Formation, uppermost mudstone, siltstone, and sandstone unit of white member (upper and middle Eocene)
Varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, and grayish-pink calcareous mudstone and siltstone, locally with minor fine-grained silty sandstone and micritic limestone; indistinguishable in lithology and color from the middle white (Tcwm) and pink members (Tcp) of the Claron Formation. Forms a brightly colored slope at the top of the upper white member of the Claron Formation in the northern part of Cedar Breaks National Monument, where it is best exposed near the North View Overlook. There, it is 109 feet (33 m)

(Schneider, 1967) of mudstone and siltstone capped by a thin calcareous sandstone and pebbly conglomerate, described below. Also exposed immediately south of Panguitch Lake, where it is about 50 feet (15 m) thick, and in the upper reaches of Rock Canyon. This unit is queried near Winn Gap at the south end of the Red Hills, where, on the basis of a similar four-part limestone-clastic- limestone-clastic section above the pink member, we infer that the white member may be present. The unit is thin or absent on the southeastern Markagunt Plateau and on the Sevier Plateau. Schneider (1967) reported biotite in some of these beds, and while some beds exhibit slightly expansive soils, we found no biotite— even so, it was the apparent presence of biotite-bearing strata, and possible correlation to variegated strata on the southern Sevier Plateau (see Feist and others, 1997), that led Sable and Maldonado (1997b) to provisionally include these strata as a basal part of their Brian Head Formation. However, in light of the absence of tuffaceous material in these beds, these same exposures strongly suggest to us that the nontuffaceous sandstone and conglomerate as defined by Sable and Maldonado (1997b) is simply an uppermost unit of the Claron Formation (Tcwt) and the overlying conglomerate at Boat Mesa (Tbm, Tbml). We place an unconformity at the base of the thin sandstone and conglomerate (not at the top of the limestone ledge of the white member), thereby including the Claron-like red beds as a new upper unit of the white member. Similar strata are present above the conglomerate at Boat Mesa on the southwest flank of the Sevier Plateau, but because they lie above, not below, the conglomerate, we assign them to the basal unit (variegated unit, Tbhv) of the Brian Head Formation. Description from source map: Panguitch 30' x 60' Quadrangle

Tcwt - Claron Formation, uppermost mudstone, siltstone, and sandstone unit of white member (upper and middle Eocene)
Varicolored and commonly mottled, light-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, and grayish-pink calcareous mudstone and siltstone, locally with minor fine-grained silty sandstone and micritic limestone; indistinguishable in lithology and color from the middle white (Tcwm) and pink members (Tcp) of the Claron Formation. Forms a brightly colored slope at the top of the upper white member of the Claron Formation in the northern part of Cedar Breaks National Monument (figure 11), where it is best exposed near the North View Overlook. There, it is 109 feet (33 m) (Schneider, 1967) of mudstone and siltstone capped by a thin calcareous sandstone and pebbly conglomerate, described below.

Schneider (1967) reported biotite in some of these beds, and while some beds exhibit slightly expansive soils, we found no biotite- even so, it was the apparent presence of biotite-bearing strata, and possible correlation to variegated strata on the southern Sevier Plateau (see Feist and others, 1997), that led Sable and Maldonado (1997b) to provisionally include these strata on the Markagunt Plateau as part of their Brian Head Formation. However, the Markagunt Plateau exposures strongly suggest to us that the nontuffaceous sandstone and conglomerate as defined by Sable and Maldonado (1997b) is simply our uppermost facies of the Claron Formation (Tcwt) and the overlying conglomerate at Boat Mesa. We place an unconformity at the base of the thin sandstone and conglomerate (not at the top of the limestone ledge of the white member), thereby including the Claron-like red beds as a new upper unit of the white member. Description from source map: Brian Head Quadrangle

Tcwu - Claron Formation, white member, upper limestone unit (Eocene)

Tcwu - Claron Formation, upper limestone unit of white member (Eocene)
White, pale-yellowish-gray, pinkish-gray, and very pale orange micritic limestone and uncommon pelmicritic limestone, locally containing intraformational rip-up clasts; locally contains sparse charophytes and planispiral snails; typically poorly bedded and knobby weathering; locally vuggy with calcite spar and commonly cut by calcite veinlets; resistant and so forms prominent ledges and flat ridge tops; upper conformable contact with Tcwt corresponds to a pronounced color change from white to very pale orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above; queried at the south end of the Red Hills.

The upper limestone unit of the white member thickens irregularly to the east and ranges from about

30 to 180 feet (10–55 m) thick, but some of this variation may be due to difficulties in placing the locally gradational contacts. The unit is 45 to 60 feet (14–18 m) thick at Cedar Breaks (Schneider, 1967; Moore and others, 2004; Rowley and others, 2013) and about 30 feet (10 m) thick in the southern Red Hills (Threet, 1952). It is about 80 to 100 feet (24–30 m) thick in the Black Rock Valley area south-southeast of Panguitch Lake, 80 to 165 feet (24–50 m) thick southwest of Hatch in the Asay Bench quadrangle (Moore and others, 1994), and about 150 to 180 feet (45–55 m) thick near Houston Mountain northnortheast of Navajo Lake (Biek and others, 2011). It is typically about 80 to 100 feet (25–30 m) thick on the southern flank of the Sevier Plateau, but north of the latitude of Limekiln Creek it grades into a mudstone-dominated interval similar to that of the underlying middle unit. Description from source map: Panguitch 30' x 60' Quadrangle

Tcwu - Claron Formation, upper limestone unit of white member (upper and middle Eocene)
White, light-yellowish-gray, pinkish-gray, and light-orange micritic limestone and uncommon pelmicritic limestone, locally containing intraformational rip-up clasts; locally contains sparse charophytes and planispiraled snails; typically poorly bedded and knobby weathering; locally vuggy with calcite spar and commonly cut by calcite veinlets; resistant, forms prominent ledge and flat ridge tops; upper conformable contact with Tcwt corresponds to a pronounced color change from white to light-orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above. The upper limestone unit of the white member thickens irregularly to the east and ranges from about 30 to 180 feet (10–55 m) thick across the Markagunt Plateau, but some of this variation may be due to difficulties in placing the locally gradational contacts (Biek and others, 2012). The unit is 45 to 60 feet (14–18 m) thick at Cedar Breaks (Schneider, 1967; Moore and others, 2004). Description from source map: Brian Head Quadrangle

Tcwml - Claron Formation, white member, middle mudstone, siltstone and sandstone unit and lower limestone unit, undivided (Eocene)

Tcwml - Claron Formation, middle mudstone, siltstone, and sandstone unit and lower limestone unit of white member, undivided (Eocene)
Locally undivided at Cedar Breaks National Monument due to map scale, and about 5 miles (8 km) to the east at Houston Mountain due to poor exposure. As mapped, less than about 250 feet (75 m) thick. Description from source map: Panguitch 30' x 60' Quadrangle

Tcwm - Claron Formation, white member, middle mudstone, siltstone and sandstone unit (upper middle Eocene)

Tcwm - Claron Formation, 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; queried at the south end of the Red Hills.

As mapped on the southwest side of the Sevier Plateau, consists of a deep reddish-orange siltstone and mudstone interval about 60 feet (18 m) thick that becomes difficult to identify north of Limekiln Creek. About 120 feet (36 m) thick near Cameron Troughs south of Panguitch Lake, but appears to thin abruptly to about 50 feet (15 m) thick about one mile (1.6 km) to the east. At Cedar Breaks National Monument, Schneider (1967) measured 227 feet (69 m) of strata we assign to Tcwm, but Rowley and others (2013) reported that this interval is 310 feet (94 m) thick in this same area. 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 southwest of Hatch. 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. Description from source map: Panguitch 30' x 60' Quadrangle

Tcwm - Claron Formation, middle mudstone, siltstone, and sandstone unit of white member (upper middle Eocene)
Varicolored and commonly mottled, light-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 slope-forming, brightly colored reddish-orange mudstone and siltstone below to ledge-forming, white to light-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. At Cedar Breaks National Monument, Schneider (1967) measured 227 feet (69 m) of strata we assign to Tcwm, but we find that this interval is 310 feet (94 m) thick in this same area. Description from source map: Brian Head Quadrangle

Tcwl - Claron Formation, white member, lower limestone unit (Eocene)

Tcwl - Claron Formation, lower limestone unit of white member (Eocene)
Micritic limestone similar to the upper white limestone interval (Tcwu); forms cliff or steep, ledgy, white slope above more colorful but typically subdued slopes of the pink member (Tcp); 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; query indicates uncertain identification on Navajo Ridge northwest of Brian Head peak, at the south end of the Red Hills, and near Willow Creek northeast of Paragonah.

As mapped on the southwest flank of the Sevier Plateau, the lower limestone interval is multi-hued mudstone, siltstone, and limestone that weathers to white and pink, subdued slopes. As such, its lower and upper contacts are difficult to pick except from a distance or on aerial photographs, and we are uncertain of correlation to exposures on the Markagunt Plateau.

The lower limestone unit attains its maximum thickness of about 300 feet (90 m) at Bryce Point in Bryce Canyon National Park (Bowers, 1990), but is only about 160 feet (50 m) thick to the north on the southwest flank of the Sevier Plateau. To the west, on the Markagunt Plateau, it is about 100 to 120 feet (30–35 m) thick in the upper reaches of Rock Canyon. 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. This unit is only about 47 feet (14 m) thick at Cedar Breaks National Monument, where it is informally called the “lower white limestone” (Schneider, 1967; Rowley and others, 2013), and about 30 feet (10 m) thick in the southern Red Hills (Threet, 1952). Description from source map: Panguitch 30' x 60' Quadrangle

Tcwl - Claron Formation, lower limestone unit of white member (Eocene)
Micritic limestone similar to the upper white limestone interval (Tcwu); 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 light-orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above. Like the upper limestone unit, the lower limestone unit of the white member thickens irregularly to the east (Biek and others, 2012). This unit is only about 47 feet (14 m) thick at Cedar Breaks National Monument (Schneider, 1967). Description from source map: Brian Head Quadrangle

Tcp - Claron Formation, pink member (Eocene and Paleocene)

Tcp - Claron Formation, 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 minor pebbly conglomerate that weather to colluvium-covered ledgy slopes. 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, 1988b; 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 and that locally contain 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 forms lenticular beds typically 5 to 15 feet (2–5 m) thick containing rounded quartzite, limestone, and chert pebbles, cobbles, and, locally, small boulders; conglomerate is uncommon on the Markagunt Plateau south of Parowan Canyon, but lower pink member strata are abundantly conglomeratic in the Red Hills and at the northwest edge of the Markagunt Plateau north of Parowan; at Sugarloaf Mountain west of Brian Head, several tens of feet of conglomerate (or several thinner beds within this interval) overlie the basal Claron limestone; Gregory (1951) and Bowers (1990) reported conglomeratic basal Claron strata on the Paunsaugunt Plateau. Upper, conformable contact corresponds to a pronounced color and lithologic change from brightly colored reddish-orange mudstone and siltstone below to white to very pale orange micritic limestone above.

Sinkholes are common in the pink member in the central Markagunt Plateau (Moore and others, 2004; Biek and others, 2011; Hatfield and others, 2010; Rowley and others, 2013). Large sinkholes visible on 1:20,000-scale aerial photographs are plotted on the geologic map, and doubtless many smaller sinkholes are present. These sinkholes capture local runoff and serve to shunt shallow groundwater rapidly down dip where it emerges as springs, including the large Mammoth and Asay Springs (Wilson and Thomas, 1964; Spangler, 2010).

The pink member is mostly non-fossiliferous and its age is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994) as described above. Measurements from the map suggest that the pink member is about 1000 feet (300 m) thick at Cedar Breaks National Monument, similar to the measured thickness of Schneider (1967), who reported that the pink member there was 993 feet (303 m) thick (however, the lower 56 feet [17 m] of his section includes beds we assign to Km, thus the pink member there is 937 feet [286 m] thick), considerably less than the 1300 feet (400 m) reported by Sable and Maldonado (1997b). Strata that we include in the pink member are likely of similar thickness in more structurally complicated outcrops of the Red Hills (Threet, 1952, 1963a). The pink member is about 600 feet (180 m) thick at Bryce Canyon National Park. Description from source map: Panguitch 30' x 60' Quadrangle

Tcp - Claron Formation, pink member (Eocene and Paleocene)
Alternating beds of light-red, pink, grayish-orange, and dark-yellowish-orange, calcite-cemented sandstone, calcareous mudstone and siltstone, sandy limestone, and minor pebble conglomerate. Based on precedence and a long informal usage of the term “pink” when referring to the uppermost part of the Grand Staircase and its strata, we retain Bowers’ (1972) term “pink member” for the lower Claron, noting that these strata have been informally known as the red member on the Markagunt Plateau.

Most limestone beds are massive (3 to 6 feet [1–2 m] thick), structureless micrite that is locally argillaceous and generally sandy (2 to 20 percent uniformly dispersed fine quartz sand); much of the pink member was greatly modified by bioturbation and pedogenic processes, creating a stacked series of paleosols (Mullett and others, 1988a, 1988b; Mullett, 1989; Mullett and Wells, 1990; see also Bown and others, 1997); limestone commonly contains calcite spar-filled vugs and thin branching veinlets of calcite spar, with crystals 0.02 to 0.08 inch (0.5–2 mm) long, as well as stylolites; calcite

spar- and micrite-filled vertical burrows 0.2 to 2 inches (0.5–4 cm) in diameter and 4 to 20 inches (10–50 cm) long are abundant in some limestone beds, and some contain pebble-sized intraclasts that are in places angular and chaotically juxtaposed and so impart a breccia-like appearance to the rock; rare limestone beds contain oncolites, micrite balls 0.08 to 1 inch (0.2–2 cm) in diameter that have concentric laminations, or "onion-like" structure.

Interbedded throughout the unit is sandstone and mudstone; the sandstone forms ledges and is a varicolored, thick-bedded, calcite-cemented quartz arenite that is cross-bedded in places; the 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 feet (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 feet (9 m), 39 feet (12 m), 138 feet (42 m), and 207 feet (63 m) above the base of the pink member in the Navajo Lake quadrangle (Moore and others, 2004); conglomerate beds persist 300 to 1000 feet (100–300 m) laterally before pinching out; they apparently are fluvial point-bar and channel deposits. The member is locally cavernous, with abundant dissolution cavities and surficial sinkholes. These sinkholes capture local runoff and serve to shunt shallow groundwater rapidly down dip where it emerges as springs, including the large Mammoth and Asay Springs (Wilson and Thomas, 1964; Spangler, 2010).

The base of the pink member is placed at the bottom of the lowest limestone (calcic paleosol) bed following Moore and Straub (2001). The pink member is mostly nonfossiliferous and its age is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994), but Nichols (1997) reported Late Cretaceous (Santonian?) pollen from underlying strata here mapped as Km south and west of Blowhard Mountain; Biek and others (2012) recovered late Campanian to Maastrichtian pollen from this same interval. We see no evidence of a significant unconformity between these apparently Upper Cretaceous strata and overlying Claron Formation, suggesting that the lower part of the Claron Formation may be older than previously thought. Measurements from the map suggest that the pink member is about 1000 feet (305 m) thick at Cedar Breaks National Monument, similar to the measured thickness of Schneider (1967), who reported that the pink member there was 993 feet (303 m) thick (the lower 56 feet [17 m] of his section includes beds we assign to Km, thus the pink member there is 937 feet [286 m] thick), considerably less than the 1300 feet (400 m) reported in Sable and Maldonado (1997b). Description from source map: Brian Head Quadrangle

Km - Cretaceous strata on the Markagunt Plateau (Upper Cretaceous (upper Campanian to Mastrichtian(?)))

Km - Cretaceous strata on the Markagunt Plateau (Upper Cretaceous, Maastrichtian[?] to upper Campanian)
Consists of yellowish-brown, commonly stained dark-reddish-brown, fine-grained sandstone and lesser interbedded, similarly colored mudstone and siltstone; bedding is thin to very thick and appears tabular from a distance; weathers to ledgy slope or cliff; outcrop habit and surficial color make it look like the pink member of the Claron Formation from a distance; not mapped in Parowan Canyon and areas to the north, where basal Claron strata are conglomeratic and identification of this interval, if present, is uncertain; upper contact placed at the base of the lowest sandy limestone bed (calcic paleosol) of the pink member of the Claron Formation, following Moore and Straub (2001); about 200 feet (60 m) thick near State Highway 14 at the west edge of the Markagunt Plateau, but apparently thins to the north where it may be about 60 feet (20 m) thick in Parowan Canyon.

These Markagunt Plateau strata represent fluvial and floodplain environments apparently gradationally overlain by the Claron Formation. Like Moore and Straub (2001), we recognize no significant erosion beneath the Claron Formation at the west edge of the Markagunt Plateau, leading to uncertainty as to the age of this interval and the age of basal Claron strata. Nichols (1997) reported Late Cretaceous (Santonian?) pollen from strata we map as Km south and west of Blowhard Mountain, and we recovered late Campanian to Maastrichtian pollen from this same interval (table 1). The stratigraphic position of Km strata precludes it being Santonian in age. The apparently

gradationally overlying basal Claron Formation is widely believed to be late Paleocene(?) (Goldstrand, 1994) on the basis of one report of late Paleocene palynomorphs from basal Claron strata on the east flank of the Pine Valley Mountains and the gastropods Viviparus trochiformis, Goniobasis, and Physa from the pink Claron on the Table Cliff Plateau, eastern Pine Valley Mountains, and Bryce Point, respectively (Goldstrand, 1991). We treat Km strata as a separate informal unit, but it is possible that they are better assigned to the base of the Kaiparowits Formation. Description from source map: Panguitch 30' x 60' Quadrangle

Km - Cretaceous strata on the Markagunt Plateau (Upper Cretaceous, Maastrichtian? to Santonian?)
Yellowish-brown, commonly stained dark-reddish-brown, fine-grained sandstone and lesser interbedded, similarly colored mudstone and siltstone; bedding is thin to thick and appears tabular from a distance; weathers to ledgy slope or cliff; outcrop habit and surficial color make it look like the pink member of the Claron Formation from a distance (figure 12); not mapped in Parowan Canyon, where basal Claron strata are conglomeratic and identification of this interval, if present, is uncertain; farther south, along the western part of the map area, the upper contact is placed at the base of the lowest sandy limestone bed (calcic paleosol) of the pink member of the Claron Formation, following Moore and Straub (2001). Map unit represents fluvial and floodplain environments apparently gradationally overlain by the Claron Formation. Like Moore and Straub (2001), we recognize no significant erosion beneath the Claron Formation at the western edge of the Markagunt Plateau, leading to uncertainty as to the age of this interval and the age of basal Claron strata. However, Nichols (1997) reported Late Cretaceous (Santonian?) pollen from strata we map as Km south and west of Blowhard Mountain, and Biek and others (2012) reported Maastrichtian to late Campanian pollen from this same interval. The apparently gradationally overlying basal Claron Formation is widely believed to be late Paleocene(?) (Goldstrand, 1994) based on one report of late Paleocene palynomorphs from basal Claron strata on the eastern flank of the Pine Valley Mountains and the gastropods Viviparus trochiformis, Goniobasis, and Physa from the pink Claron on the Table Cliff Plateau, eastern Pine Valley Mountains, and Bryce Point, respectively (Goldstrand, 1991). We treat these strata as a separate informal unit, but it is possible that they are better assigned to the base of the Kaiparowits Formation (Biek and others, 2012). The unit is about 200 feet (60 m) thick near State Highway 14 at the western edge of the Markagunt Plateau (about 3 miles [5 km] south of the map area), where it correlates with the “dirty salt-and-pepper sandstone” of Moore and Nealey (1993), but thins to the north where it may be about 60 feet (20 m) thick in Parowan Canyon (Biek and others, 2012). Description from source map: Brian Head Quadrangle

Kgc - Grand Castle Formation (redefined) (Upper Cretaceous (upper Campanian to Mastrichtian(?)))

Kgc - Grand Castle Formation (redefined) (Upper Cretaceous?, Maastrichtian? to upper Campanian?)
Light-gray and light-red massive conglomerate; clasts are well-rounded, pebble- to boulder-size quartzite, limestone, sandstone, and chert; redefined and restricted to only the upper member of three informal members (resistant upper conglomerate, non-resistant middle sandstone, and resistant lower conglomerate) of the Grand Castle Formation of Goldstrand and Mullett (1997); cliff-forming in the Parowan Canyon area, where it locally weathers to form hoodoos similar to those of the Drip Tank Member (formerly lower conglomerate member of the Grand Castle Formation); thins dramatically south of Parowan Canyon where it is mapped as a poorly exposed marker bed; we also map Grand Castle Formation (redefined) locally on the Paunsaugunt Plateau, where it is typically thin and poorly exposed at the base of the Claron Formation.

Grand Castle strata are as much as about 200 feet (60 m) (Threet, 1952, 1963a) to 300 feet (90 m) (Maldonado and Williams, 1993a) thick near Parowan Gap; Anderson and Dinter (2010) reported that there it is about 230 feet (70 m) thick. On the Markagunt Plateau, thins abruptly to the south from 183 feet (56 m) thick at the type area in First Left Hand Canyon southeast of Parowan (Goldstrand and Mullet, 1997) and the conglomerate may locally be absent south of Navajo Ridge (where it was not

recognized in the measured sections of Goldstrand, 1991), but this interval is typically mantled in talus and colluvium that may obscure its presence. However, our mapping of Upper Cretaceous strata between Parowan and Cedar Canyons shows this conglomerate to be present at Sugarloaf Mountain (about 8 miles [13 km] south of Summit), in Last Chance Canyon (a tributary to Cedar Canyon) where it is about 25 feet (8 m) thick, in the upper reaches of Spring Creek Canyon below Cedar Breaks National Monument, west of Blowhard Mountain, and west of Navajo Lake where it is no more than a few feet thick. We thus conclude that though dramatically thinner than at its type section, the upper conglomerate member is, apart from a few local areas, present along the entire west margin of the Markagunt Plateau.

The upper contact with strata here mapped as Km on the Markagunt Plateau and mapped as basal pink member of the Claron Formation in the Red Hills and northwestern Markagunt Plateau, appears gradational. On the Markagunt Plateau south of Parowan, the upper contact corresponds to the base of ledge and cliff-forming, tabular-bedded sandstone stained dark-reddish-brown from overlying Claron strata. Elsewhere, the upper contact corresponds to the top of the cliff-forming conglomerate, above which is interbedded reddish-brown siltstone, sandstone, mudstone, sandy limestone, and pebbly conglomerate of the Claron Formation.

The Grand Castle Formation (redefined) was deposited in a braided fluvial environment with paleoflow principally to the east to south-southeast, suggesting source areas in the Wah Wah, Blue Mountain, and Iron Springs thrust sheets of southwest Utah (Goldstrand and Mullett, 1997). Goldstrand and Mullett (1997) inferred a Paleocene age for their entire Grand Castle Formation on the basis of distant correlations with Canaan Peak and Pine Hollow Formations on the Table Cliff Plateau, but we found evidence that the lower two members are Late Cretaceous and are thus reassigned as the Drip Tank Member of the Straight Cliffs Formation and the capping sandstone member of the Wahweap Formation as described below. The age of their upper conglomerate member of the Grand Castle Formation (here, the Grand Castle Formation [redefined]) is not well constrained, but we suggest that it is indeed Late Cretaceous. A debris flow deposit within the upper conglomerate member at its type section yielded Late Cretaceous (Santonian?) pollen that Goldstrand and Mullett (1997) interpreted as recycled from older strata. However, Nichols (1997) reported Late Cretaceous Proteacidites sp. pollen, which he interpreted as Coniacian and Santonian, from overlying beds here mapped as Km west and south of Blowhard Mountain, and we recovered late Campanian to Maastrichtian pollen from this same interval (table 1).

In the northern Red Hills, the Grand Castle Formation (redefined) was earlier referred to informally as the conglomerate of Parowan Gap by Maldonado and Williams (1993a). However, like Goldstrand and Mullet (1997), we infer this interval to be their upper conglomerate member of the Grand Castle Formation because it is gradationally overlain by the pink member of the Claron Formation and their underlying middle Grand Castle sandstone is absent. Anderson and Dinter (2010) reported a 10- to 15-foot-thick (3–5 m), poorly sorted, matrix-supported conglomerate at the base of the Grand Castle that they informally called their conglomerate of Parowan Gap. They described this unit, which is apparently restricted to the hanging wall of the Iron Springs thrust, as distinct from overlying Grand Castle conglomerate, but we found mostly clast-supported conglomerate identical to the Grand Castle conglomerate at this horizon. The basal few feet of Grand Castle Formation are locally iron stained throughout the Parowan Gap area, likely a result of a strong permeability contrast between underlying Upper Cretaceous strata and the overlying Grand Castle conglomerate. Description from source map: Panguitch 30' x 60' Quadrangle

Kgc - Grand Castle Formation, redefined (Upper Cretaceous)
Light-gray and light-red massive conglomerate; clasts are well-rounded, pebble- to boulder-size quartzite, limestone, sandstone, and chert; cliff-forming in the Parowan Canyon area where it locally weathers to form hoodoos; redefined and restricted to only the upper of three informal members (resistant upper conglomerate, nonresistant middle sandstone, and resistant lower conglomerate) of the Grand Castle Formation of Goldstrand and Mullett (1997), with their type section in First Left Hand Canyon southeast of Parowan and 3 miles (5 km) north of the map area. The upper contact with strata here mapped as Km appears gradational and corresponds to the base of ledge- and cliff-

forming, tabular bedded sandstone that is stained dark reddish brown from overlying Claron strata (figure 12).

Map unit deposited in a braided fluvial environment with paleoflow principally to the east to south-southeast, suggesting source areas in the Wah Wah, Blue Mountain, and Iron Springs thrust sheets of southwest Utah (Goldstrand and Mullett, 1997). Goldstrand and Mullett (1997) inferred a Paleocene age for their entire Grand Castle Formation based on distant correlations with the Canaan Peak and Pine Hollow Formations on the Table Cliff Plateau. Biek and others (2012), however, reported evidence that the lower two members of the originally defined Grand Castle Formation are Late Cretaceous and thus were reassigned, in descending order, as the capping sandstone member of the Wahweap Formation (Kwcs) and the Drip Tank Member of the Straight Cliffs Formation (Ksd), as described below. The age of the remaining, restricted Grand Castle Formation (redefined) is not well constrained, but must be Late Cretaceous because it is overlain by strata that yielded Late Cretaceous palynomorphs as described below. A debris-flow deposit within the map unit at its type section yielded Late Cretaceous (Santonian?) pollen that Goldstrand and Mullett (1997) interpreted as recycled from older strata. However, this pollen is more likely to be in place and to represent the age of the map unit because Nichols (1997) reported Late Cretaceous Proteacidites sp. pollen, which he interpreted as Coniacian and Santonian, from overlying beds here mapped as Km west and south of Blowhard Mountain, and Biek and others (2012) recovered late Campanian to Maastrichtian pollen from that same interval. About 183 feet (56 m) thick at the type section (Goldstrand and Mullet, 1997), and about 200 feet (60 m) thick in Parowan Canyon in the northern part of the map area, from where it thins abruptly to the south and may locally be absent in Rattlesnake Canyon at the west-central edge of the map area (where it was not recognized in the measured sections of Goldstrand, 1991), but this interval is typically mantled in talus and colluvium that may obscure its presence. In fact, Biek and others (2012) found the map unit at five places just west, southwest, and south of the map area: at Sugarloaf Mountain (about 3 miles [5 km] west of Brian Head), in Last Chance Canyon (a tributary to Cedar Canyon), in the upper reaches of Spring Creek Canyon below Cedar Breaks National Monument, west of Blowhard Mountain, and west of Navajo Lake; this unit ranges in thickness from several feet (1 m) west of Navajo Lake to 25 feet (8 m) in Last Chance Canyon. Thus, although the Grand Castle Formation (redefined) is dramatically thinner in, west, and south of the map area than at its type section, apart from a few local areas, it is present along the entire western margin of the Markagunt Plateau; because it is thin, it is mapped as a marker bed in the southwestern part of the map area. Description from source map: Brian Head Quadrangle

Kwcs - Wahweap Formation, capping sandstone member (Upper Cretaceous (middle Campanian))

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; see also UGS and AtoZ, 2013b); 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; attains its maximum thickness 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 Grand Castle Formation), and elsewhere, map patterns show that the member is about 200 feet (60 m) thick.

Among the best exposures of the capping sandstone on the Markagunt Plateau are those about 2 miles (3.5 km) southwest of Parowan, at the mouth of Summit Creek canyon, at the type area in First Left Hand Canyon (southeast of Paraowan), and in a State Highway 14 road cut west of Blowhard

Mountain. We discovered Campanian to Santonian palynomorphs and a theropod dinosaur track (the latter found by Eric Roberts, formerly with Southern Utah University and now at James Cook University, Australia) in the lower part of the interval in an unnamed canyon about 2 miles (3 km) southwest of Parowan, confirming our suspicion of a Late Cretaceous age for this member on the Markagunt Plateau (Hunt and others, 2011a). As defined in the Kaiparowits basin, includes yellowish-brown, fine-grained sandstone locally with thin lenses of mudstone (similar to parts of Eaton's lower Wahweap strata), but as mapped here restricted to distinctive white quartz arenite facies. Equivalent to the middle member of the Grand Castle Formation as suggested by Lawton and others (2003), confirmed by this mapping, and supported by preliminary detrital zircon analyses of Johnson and others (2011) who examined detrital zircon populations of three samples from the Markagunt and Paunsaugunt Plateaus and concluded that they represent sediments of a Late Cretaceous braided stream system that drained thrust sheets of the Sevier orogenic belt to the west. Goldstrand and Mullett (1997) and Lawton and others (2003) also showed that the member was deposited in a braided fluvial environment with a paleoflow direction principally to the east to south-southeast, suggesting source areas in Navajo Sandstone exposed in the upper plate of the Iron Springs thrust, now exposed in the Red Hills.

Along much of the west flank of the Markagunt Plateau south of Parowan Canyon, the capping sandstone member is commonly covered by talus and colluvium derived from overlying Claron Formation. There, we used a dashed lower contact to indicate our uncertainty as to its true thickness. Our mapping confirms the finding of Goldstrand and Mullet (1997), who first correlated the sandstone at the Websters Flat turnoff with their middle sandstone member of the Grand Castle Formation. Description from source map: Panguitch 30' x 60' Quadrangle

Kwcs - Wahweap Formation, capping sandstone member (Upper Cretaceous, middle? Campanian)
White to light-orange, locally iron stained, fine to coarse-grained, mostly medium-grained, trough cross-bedded quartz arenite that "caps" the Wahweap Formation; upper part contains abundant pebble stringers and conglomeratic beds with rounded quartzite, dolostone, 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; 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 and therefore poorly exposed in this map area.

Hunt and others (2011) and Biek and others (2012) reported Campanian to Santonian palynomorphs and a theropod dinosaur track (the latter found by Eric Roberts, formerly with Southern Utah University and now at James Cook University, Australia) in the lower part of the member in an unnamed canyon about 2 miles (3 km) southwest of Parowan, confirming a Late Cretaceous age for this interval on the Markagunt Plateau.

The unit is equivalent to the now-abandoned middle member of the original Grand Castle Formation, as suggested by Lawton and others (2003), confirmed by the mapping of Biek and others (2012), and supported by preliminary detrital zircon analyses of Johnson and others (2011) who examined detrital zircon populations of three samples from the Markagunt and Paunsaugunt Plateaus and concluded that they represent sediments of a Late Cretaceous braided stream system that drained thrust sheets of the Sevier orogenic belt to the west. Goldstrand and Mullett (1997) and Lawton and others (2003) also showed that the member was deposited in a braided fluvial environment with a paleoflow direction principally to the east to south-southeast, suggesting source areas in Navajo Sandstone exposed in the upper plate of the Iron Springs thrust, now exposed in the Red Hills.

Along much of the west flank of the Markagunt Plateau south of Parowan Canyon, the capping sandstone member is commonly covered by talus and colluvium derived from the overlying Claron Formation. There, we use a dashed lower contact to indicate our uncertainty as to its true thickness. Our mapping confirms the finding of Goldstrand and Mullet (1997), who first correlated the sandstone

at the Webster Flat turnoff with their middle sandstone member of the Grand Castle Formation. The capping sandstone member attains its maximum thickness of 277 feet (85 m) at the type section of the equivalent and now-abandoned middle member of the Grand Castle Formation in First Left Hand

Canyon southeast of Parowan, about 3 miles (5 km) north of the map area. Description from source map: Brian Head Quadrangle

Kw - Wahweap Formation, upper, middle and lower members, undivided (Upper Cretaceous (upper Campanian))

Kw - Wahweap Formation, upper, middle, and lower members, undivided (Upper Cretaceous, middle Campanian)
Varicolored and mottled mudstone of brown, gray, reddish-brown, and pinkish hues, and yellowish-brown fine-grained sandstone and silty sandstone.

Exposures on Markagunt Plateau: Typically heavily vegetated and poorly exposed on the Markagunt Plateau, but likely equivalent to the upper, middle, and lower members as defined by Eaton (1991). The upper part, below the capping sandstone member, contains more sandstone than mudstone, also noted by Moore and Straub (2001) and Moore and others (2004). Measurements from the map show that the Wahweap Formation, excluding the capping sandstone member, is about 800 feet (245 m) thick below Cedar Breaks National Monument and south of Blowhard Mountain, and Moore and Straub (2001) measured 760 feet (230 m) of strata in Cedar Canyon that we assign to the Wahweap Formation (not including the capping sandstone member). Only a few tens of feet of Wahweap Formation, undivided are present at the base of the capping sandstone member (formerly middle sandstone member of the Grand Castle Formation) in Parowan Canyon, illustrating a dramatic southward thickening of the unit south of Parowan Canyon. Eaton and others (1999a) and Moore and Straub (2001) initially proposed correlation of Cedar Canyon strata in the map area with early to middle Campanian Wahweap strata on the Kaiparowits Plateau. Description from source map: Panguitch 30' x 60' Quadrangle

Kw - Wahweap Formation, lower, middle, and upper members, undivided (Upper Cretaceous, Campanian)
Varicolored and mottled mudstone of brown, gray, reddish-brown, and pinkish hues, and yellowish-brown fine-grained sandstone and silty sandstone. Typically heavily vegetated and poorly exposed on the Markagunt Plateau, but likely equivalent to the lower, middle, and upper members as defined by Eaton (1991). The upper third, below the capping sandstone member, contains more sandstone than mudstone, also noted by Moore and Straub (2001) and Moore and others (2004). Measurements from the map show that the Wahweap Formation, excluding the capping sandstone member, is about 800 feet (245 m) thick below Cedar Breaks National Monument, and Moore and Straub (2001) measured 760 feet (230 m) of strata in Cedar Canyon that Biek and others (2012) assigned to the Wahweap Formation (not including the capping sandstone member). The Wahweap (undivided) is only a few tens of feet thick beneath the capping sandstone member in Parowan Canyon, illustrating a dramatic southward thickening of the unit south of Parowan Canyon (Biek and others, 2012). Eaton and others (1999a) and Moore and Straub (2001) initially proposed correlation of Cedar Canyon strata in the map area with early to middle Campanian Wahweap strata on the Kaiparowits Plateau.

Jinnah and others (2009) reported an 40Ar/39Ar age of 80.6 ± 0.3 Ma (Campanian) for 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. Eaton and others (1999a) and Eaton (2006) reported enigmatic fossil mammals from near the base and top of the formation in Cedar Canyon that may be Campanian, and Lawton and others (2003) reported middle Campanian pollen from the upper part of the formation near Webster Flat, just southwest of Blowhard Mountain on the western rim of the Markagunt Plateau. Biek and others (2012) also recovered Campanian to Santonian pollen immediately below the capping sandstone near Webster Flat, just south of the map area. Description from source map: Brian Head Quadrangle

Ksd - Straight Cliffs Formation, Drip Tank Member (Upper Cretaceous (lower Campanian))

Ksd - Straight Cliffs Formation, Drip Tank Member (Upper Cretaceous, lower Campanian)
On the Paunsaugunt Plateau, Drip Tank strata are white to light-gray, fine- to medium-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, but 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 form cliffs and ledges; upper contact with the Wahweap Formation appears to be conformable and corresponds to the top of a white sandstone and pebbly sandstone, above which is yellowish-brown, fine-grained sandstone and lesser interbedded, varicolored and mottled mudstone of brown, gray, reddish- brown, and pinkish hues; as mapped, restricted to the white quartz arenite and pebbly conglomerate facies and thus ranges from about 100 to 200 feet (30–60 m) thick on the Paunsaugunt Plateau; Tilton (2001a) reported that the member is 185 to 215 feet (56–66 m) thick on the southern Paunsaugunt Plateau, in the Alton quadrangle immediately south of the map area.

On the Markagunt Plateau, the Drip Tank Member (formerly lower conglomerate member of the Grand Castle Formation) is a massive, cliff-forming, light-gray conglomerate with well-rounded, pebble- to boulder-sized clasts of quartzite, limestone, and minor sandstone and chert. It is 135 feet (41 m) thick at the type section in First Left Hand Canyon southeast of Parowan (Goldstrand and Mullet, 1997) and of similar thickness southwest to Sugarloaf Mountain (about 3 miles [5 km] west of Brian Head). South of this area, however, the Drip Tank thins irregularly southward, ranging from a few feet thick to nearly 100 feet (30 m) thick, and locally appears as two conglomerate intervals separated by a few feet to a few tens of feet of yellowish-brown, fine-grained sandstone or variegated mudstone. The Drip Tank Member typically overlies stacked or amalgamated sandstone beds, but locally, as along Ashdown Creek in the southwest corner of the map area, overlies variegated mudstone. On the northern Markagunt Plateau, the member locally weathers to form conically shaped hoodoos that resemble old-fashioned beehives known as bee skeps, but south of Summit it forms a resistant ledge in the upper reaches of Summit Creek canyon and the upper reaches of Pickering Creek canyon.

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 we find that it is remarkably similar in lithology and outcrop habit to the capping sandstone member of the Wahweap Formation. The Drip Tank was deposited by east- and northeast-flowing braided streams (Tilton, 1991, 2001a, 2001b; Lawton and others, 2003); age from Jinnah and others (2009, 2011). Description from source map: Panguitch 30' x 60' Quadrangle

Ksd - Straight Cliffs Formation, Drip Tank Member (Upper Cretaceous, late Santonian)
Massive, typically cliff-forming, light-gray conglomerate with well-rounded, pebble- to boulder-sized clasts of quartzite, limestone, and minor sandstone and chert. On the Markagunt Plateau, unit was formerly referred to as the lower conglomerate member of the Grand Castle Formation (Goldstrand and Mullet, 1997), but shown by Biek and others (2012) to be the same unit as the Drip Tank, whose name has nomenclatural priority. It is 135 feet (41 m) thick at the type section in First Left Hand Canyon southeast of Parowan (Goldstrand and Mullet, 1997), and is of similar thickness southwest to Sugarloaf Mountain (about 3 miles [5 km] west of Brian Head). South of this area, however, the Drip Tank thins irregularly southward, ranging from a few feet to nearly 100 feet (30 m) thick, and locally, as in the Ashdown Creek drainage, appears as two conglomerate intervals separated by a few feet to a few tens of feet of yellowish-brown, fine-grained sandstone or variegated mudstone; where thin, we map it simply as a marker bed. The Drip Tank Member typically overlies stacked or amalgamated sandstone beds, but locally overlies variegated mudstone, as along Ashdown Creek. On the northern Markagunt Plateau, the member locally weathers to form conically shaped hoodoos that resemble old-fashioned beehives known as bee skeps, but it forms a resistant ledge in the northwestern corner of

the map area and a typically poorly exposed slope in the Ashdown Creek drainage. The Drip Tank was deposited by east- and northeast-flowing braided streams (Tilton, 1991, 2001a, 2001b; Lawton and

others, 2003); its age is constrained by the ages of enclosing well-dated strata. Description from source map: Brian Head Quadrangle

Ksjs - Straight Cliffs Formation, John Henry and Smoky Hollow Members, undivided (Upper Cretaceous (Turonian to Santonian))

Ksjs - Straight Cliffs Formation, John Henry and Smoky Hollow Members, undivided (Upper Cretaceous, Santonian to Turonian)
Undivided on the Markagunt Plateau, where the Calico bed is poorly exposed and apparently only locally well developed; Smoky Hollow strata are described below and John Henry strata are described separately; combined unit is about 1250 to 1350 feet (380–410 m) thick on the Markagunt Plateau (Eaton and others, 2001; Moore and Straub, 2001).

Smoky Hollow strata are slope-forming, brown and gray mudstone, shale, and interbedded yellowish-brown fine-grained sandstone; lower part contains a few thin coal beds, common carbonaceous shale, and several thin oyster coquina beds; upper contact corresponds to the top of the Calico bed, a stacked series of fluvial channel deposits of white to light-gray, fine- to medium-grained sandstone and conglomeratic sandstone; Smoky Hollow strata are middle to upper Turonian on the basis of a diverse assemblage of mollusks, benthic foraminifera, and ostracods from exposures in Cedar Canyon (Eaton and others, 2001; Tibert and others, 2003); Moore and Straub (2001) assigned 313 feet (95 m) of strata in Cedar Canyon as likely equivalent to the Smoky Hollow Member; Eaton and others (2001) measured 364 feet (110 m) of strata that likely belong to the Smoky Hollow Member in Cedar Canyon, the lower 167 feet (54 m) of which were deposited in brackish-water environments and that are an order of magnitude thicker than equivalent brackish-water strata on the Kaiparowits Plateau, reflecting greater subsidence rates in the western part of the foredeep basin.

Moore and Straub (2001, their subunit 4 of interval A) suggested that the Calico bed may be present in Cedar Canyon about 285 feet (87 m) above the base of the formation. Subunit 4 is sandstone about 30 feet (9 m) thick but it is not distinctive in as much as it lacks pebbles and we were unable to use this bed as a marker horizon. However, we did locally map a thin pebble conglomerate about 330 feet (100 m) above the base of the formation on the Kolob Terrace in the southwest corner of the map area, which may be the Calico bed. Bobb (1991) noted that sediments of the Calico bed were deposited by braided and meandering streams that tapped both the Sevier orogenic belt and the Mogollon Highlands. Description from source map: Panguitch 30' x 60' Quadrangle

Ksj - Straight Cliffs Formation, John Henry Member (Upper Cretaceous (upper Turonian to Santonian))

Ksj - Straight Cliffs Formation, John Henry Member (Upper Cretaceous, Santonian to upper Turonian)
Slope-forming, variegated, gray, brown, and reddish-brown mudstone and thin- to thick-bedded, grayish-orange to yellowish-brown, fine-grained subarkosic sandstone; forms ledgy slopes; sandstone is commonly bioturbated and locally stained by iron-manganese oxides; stacked or amalgamated sandstone beds make up most of the upper part of the unit; upper contact corresponds to a break in slope at the base of the Drip Tank Member (on the Markagunt Plateau, formerly the lower conglomerate of the Grand Castle Formation); biotite from an ash bed about 800 feet (245 m) above the base of the member in Cedar Canyon yielded an 40Ar/39Ar age of 86.72 ± 0.58 Ma (late Coniacian), and biotite from an ash bed 700 feet (213 m) below the top of the member in Parowan Canyon yielded an 40Ar/39Ar age of 83.0 ± 1.1 Ma (early Campanian to late Santonian) (Eaton and others, 1999c); Eaton (2006) reported on mammal fossils in Cedar Canyon that suggest the lower part of the member there is late Turonian; about 900 to 1000 feet (275–300 m) thick in Cedar Canyon (Moore and Straub, 2001), 800 to 1100 feet (240–335 m) thick at Bryce Canyon National Park

(Bowers, 1990), and about 670 feet (200 m) thick at the south end of the Paunsaugunt Plateau (Tilton, 2001a). Description from source map: Panguitch 30' x 60' Quadrangle

Ksj - Straight Cliffs Formation, John Henry Member (Upper Cretaceous, Santonian to upper Coniacian)
Slope-forming, variegated, gray, brown, and reddish-brown mudstone and thin- to thick-bedded, grayish-orange to yellowish-brown, fine-grained subarkosic sandstone; forms ledgy slopes; sandstone is commonly bioturbated and locally stained by iron-manganese oxides; stacked or amalgamated sandstone beds make up most of the upper part of the unit; upper contact corresponds to a break in slope at the base of the Drip Tank Member; biotite from an ash bed about 800 feet (245 m) above the base of the member in Cedar Canyon yielded an 40Ar/39Ar age of 86.72 ± 0.58 Ma (early Coniacian) (Eaton, 1999; Eaton and others, 1999b); Eaton and others (1999b) also reported an 40Ar/39Ar age of 83.0 ± 1.1 Ma for an ash bed that is 712 feet (217 m) below the top of the member in Parowan Canyon; incomplete section is about 400 feet (120 m) thick in the map area, but the entire member is about 900 to 1000 feet (275–300 m) thick to the west in Cedar Canyon (Moore and Straub, 2001),

In the adjacent Navajo Lake quadrangle (Moore and others, 2004), where the upper unit is better exposed, John Henry strata consist predominantly of light-gray, yellowish-gray, light-yellowish-brown, and reddish-brown, silty and sandy mudstone containing numerous thin (1 to 6 feet [0.3–2 m]) lenticular sandstone beds; a few light-orange, grayish-orange, and yellowish-brown, lenticular, trough cross-bedded, feldspathic sandstone beds as thick as 20 feet (6 m), and one or two similar but 50-foot-thick (15 m) cliff-forming sandstone beds, are exposed in the upper quarter of the unit; the rocks in this part of the section contain iron oxide-cemented laminations, nodules, and fossil leaf impressions, silicified fossil wood pieces, carbonaceous plant fragments and films, and local mud-pellet conglomeratic lenses. Description from source map: Brian Head Quadrangle

Kst - Straight Cliffs Formation, Tibbet Canyon Member (Upper Cretaceous (Turonian))

Kst - Straight Cliffs Formation, Tibbet Canyon Member (Upper Cretaceous, Turonian)
Grayish-orange to yellowish-brown, generally medium- to thick-bedded, planar-bedded, fine- to medium-grained quartzose sandstone and minor interbedded, grayish-orange to gray mudstone and siltstone; locally contains pelecypods, gastropods, and thin to thick beds of oyster coquina; forms bold cliffs in Cedar Canyon and in the West and East Forks of Braffits Creek south of Summit, and a prominent though thinner cliff on the east flank of the Paunsaugunt Plateau; upper contact corresponds to a pronounced break in slope and is placed at the top of a coquinoid oyster bed and base of overlying thin coal and carbonaceous shale interval that caps the member; forms the riser of the Gray Cliffs part of the Grand Staircase; 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, 2001a, 2001b; Tibert and others, 2003); thins eastward from about 650 to 800 feet (200–245 m) thick on the west flank of the Markagunt Plateau, 120 to 160 feet (37–50 m) thick at the south end of the Paunsaugunt Plateau (Tilton, 2001a, 2001b), and only 40 to 50 feet (12–15 m) thick on the east flank of the Paunsaugunt Plateau. Description from source map: Panguitch 30' x 60' Quadrangle

Kt - Tropic Shale (Upper Cretaceous (Cenomanian to Turonian))

Kt - Tropic Shale (Upper Cretaceous, Turonian to Cenomanian)
Gray to olive-gray, very thin bedded shale and silty shale in eastern exposures, but thins dramatically westward where it is dark-gray and yellowish-brown sandy mudstone, silty fine-grained sandstone, and minor shale; weathers to form badlands in the type area near Tropic; on the Markagunt Plateau, the base of the formation is locally characterized by a lag of septarian nodules, and Titus and others (2005) noted that the nodules are characteristic of the lower and middle parts of the formation east of

the Paunsaugunt Plateau; numerous smectitic volcanic ash beds occur throughout the formation (Titus and others, 2005); contains locally abundant, well-preserved fossils, including ammonites, inoceramid and mytiloidid bivalves, gastropods, and oysters, as well as vertebrate fossils of sharks, fish, marine turtles, and plesiosaurs, all indicative of an open shallow-marine environment (see, for example, Eaton and others, 2001; Titus and others, 2005); on the Markagunt Plateau, typically poorly exposed, but forms subtle, vegetated slope at the base of the Straight Cliffs Formation and above the prominent “sugarledge sandstone” (Cashion, 1961) at the top of the Dakota Formation; upper, conformable contact placed at the base of the cliff-forming, planar beds of the Straight Cliffs Formation; deposited in shallow-marine environment dominated by fine-grained clastic sediment, marking the maximum incursion of the Western Interior Seaway (Tibert and others, 2003); age well constrained from ammonite and inoceramid biostratigraphy and dated interbedded volcanic ash beds (see, for example, Titus and others, 2013); thins westward across the map area, from about 700 feet (215 m) thick in the east near Tropic, to 40 feet (12 m) thick in the southwest part of the map area, to just a few feet thick in Cedar Canyon; Doelling and Willis (1999a) reported that it is 600 to 900 feet (180– 275 m) thick in the southeast corner of the Panguitch 30' x 60' quadrangle. Description from source map: Panguitch 30' x 60' Quadrangle

Ktn - Tropic Shale and Naturita Formation, undivided (Upper Cretaceous (Cenomanian to Turonian))

Ktd - Tropic Shale and Dakota Formation, undivided (Upper Cretaceous, Turonian to Cenomanian)
Undivided in Cedar Canyon where the Tropic Shale is a few feet to at most a few tens of feet thick. Description from source map: Panguitch 30' x 60' Quadrangle

Of note, the Dakota Formation (Kd) is now named the Naturita Formation (personal communication in 2022 from Utah Geological Survey). This unit's map symbols has therefore been changed to Ktn (from Ktd)

Kn - Naturita Formation (Upper Cretaceous (Cenomanian))

Kd - Dakota Formation (Upper Cretaceous, Cenomanian)
Interbedded, slope- and ledge-forming sandstone, siltstone, mudstone, claystone, carbonaceous shale, coal, and marl; sandstone is yellowish brown or locally white, thin to very thick bedded, fine to medium grained; includes several prominent cliff-forming sandstone beds each several tens of feet thick in the upper part of the formation, the upper one of which may correspond to the “sugarledge sandstone” of Cashion (1961); mudstone and claystone are gray to yellowish brown and commonly smectitic; the Dakota Formation contains two significant coal zones on the Paunsaugunt Plateau, the lower Bald Knoll zone and the upper Smirl zone (Doelling and Graham, 1972; Quick, 2010); oyster coquina beds, clams, and gastropods, including large Craginia sp., are common, especially in the upper part of the section; thin marl beds above the “sugarledge sandstone” locally contain small, distinctive gastropods with a beaded edge (Admetopsis n. sp., indicative of a latest Cenomanian brackish water environment [Eaton and others, 2001]); thins dramatically eastward, from about 1300 to 1400 feet (400– 425 m) thick on the Markagunt Plateau at the south end of Jones Hill west of Maple Canyon, to about 80 to 275 feet (24–85 m) thick on the Paunsaugunt Plateau (Doelling and Willis, 1999a; Tilton, 2001a).

Dakota strata are typically poorly exposed and involved in large landslides on the Markagunt Plateau; they are the culprit in recent landslides that damaged Utah Highway 14 in Cedar Canyon (Lund and others, 2009, 2012). Most workers divide the Dakota Formation into three members, the lower one of which we re-assign to the Cedar Mountain Formation and the upper two of which we combine given the difficulty of mapping their mutual contact. The upper contact with the Tropic Shale is conformable. On the Markagunt Plateau, the contact corresponds to the top of the thin marl beds overlying the

“sugarledge sandstone,” whereas on the Paunsaugunt Plateau, it is placed at the top of the highest coal bed, which has locally burned, creating baked mudstone (clinker) at this horizon. The Dakota Formation is not correlative with the type Dakota in Nebraska, but the term is used loosely in Utah for deposits of an overall transgressive sequence below the Tropic Shale, the lower part of which was deposited in floodplain and river environments, whereas the upper part represents estuarine, lagoonal, and swamp environments of a coastal plain (Gustason, 1989; Eaton and others, 2001; Laurin and Sageman, 2001a, 2001b; Tibert and others, 2003). Gustason (1989), based in part on study of exposures in Cedar Canyon, correlated fluvial packages of the Dakota with orbital cycles of marine sedimentation of the deeper parts of the Western Interior Sea. Laurin and Sageman (2001a, 2001b) expanded on that work, constructing a high-resolution temporal and stratigraphic framework of middle Cretaceous marginal-marine deposits—they documented changes in shoreline position and also linked these changes to rhythmic, Milankovitch-driven deposition of marine limestone in the Western Interior Seaway. Invertebrate and palynomorph fossil assemblages in the Dakota indicate shallow-marine, brackish, and freshwater deposits of Cenomanian age (Nichols, 1997; Eaton, 2009); Dyman and others (2002) reported a Cenomanian 40Ar/39Ar age of 96.06 ± 0.30 Ma from middle Dakota strata about 2 miles (4 km) south of Tropic. Description from source map: Panguitch 30' x 60' Quadrangle

Of note, the Dakota Formation (Kd) is now named the Naturita Formation (personal communication in 2022 from Utah Geological Survey). The unit's map symbols has therefore been changed to Kn.

Kcm - Cedar Mountain Formation (Upper Cretaceous (Albian to Cenomanian))

Kcm - Cedar Mountain Formation (Cretaceous, Cenomanian to Albian)
Consists of a basal pebble conglomerate overlain by brightly colored variegated mudstone in Cedar Canyon. Mudstone is variegated gray, purplish-red, and reddish-brown, distinctly different from the gray and yellowish-brown hues of overlying Dakota strata; clay is smectitic and weathers to “popcorn-like” soils; includes minor light-gray to dark-yellowish-brown, fine- to medium-grained channel sandstone. Basal conglomerate is grayish brown and typically poorly cemented and non-resistant; clasts are subrounded to rounded, pebble- to small-cobble-size quartzite, chert, and limestone; red quartzite clasts are common; entire formation is about 60 feet (18 m) thick in Cedar Canyon, and the conglomerate ranges from less than one foot (0.3 m) to about 10 feet (3 m) thick.

Except for the thin conglomerate ledge at its base, weathers to generally poorly exposed slopes covered with debris from the overlying Dakota Formation. Upper contact is poorly exposed and corresponds to a color and lithologic change, from comparatively brightly colored smectitic mudstone below to gray and light-yellowish-brown mudstone and fine-grained sandstone above, but regionally, the Cedar Mountain Formation is unconformably overlain by the Dakota Formation (see, for example, Kirkland and others, 1997). Volcanic ash from correlative strata on the Kolob Plateau yielded a single-crystal 40Ar/39Ar age of 97.9 + 0.5 Ma on sanidine (Biek and Hylland, 2007), pollen analyses indicate an Albian or older age (Doelling and Davis, 1989; Hylland, 2010), and Dyman and others (2002) obtained an 40Ar/39Ar age of 101.7 + 0.42 Ma (latest Albian) on similar strata near Gunlock, Utah. Additionally, palynomorphs including rare occurrences of Trilobosporites humilis and possibly Pseudoceratium regium, collected from a thin mudstone interbed within basal conglomerate beds in Cedar Canyon immediately to the west of the map area (NW1/4 NW1/4 SE1/4 section 17, T. 36 S., R. 10 W., Cedar City 7.5' quadrangle) suggest a late Albian age for this horizon (M.D. Hylland, Utah Geological Survey, unpublished data, November 9, 2001). The Cedar Mountain Formation was deposited in a floodplain environment of a broad coastal plain (Tschudy and others, 1984; Kirkland and others, 1997; Cifelli and others 1997; Kirkland and Madsen, 2007). This interval was previously mapped as the lower part of the Dakota Formation, but the lithology, age, and stratigraphic position of these beds suggest correlation to the Cedar Mountain Formation (Biek and Hylland, 2007; Biek and others, 2009). Specifically, the mudstone interval appears to be time-correlative with the Mussentuchit Member of the Cedar Mountain Formation of central and eastern Utah (Hylland, 2010). Description from source map: Panguitch 30' x 60' Quadrangle

Jcw - Carmel Formation, Winsor Member (Middle Jurassic (Bathonian to Callovian))

Jcw - Carmel Formation, Winsor Member (Middle Jurassic, Callovian to Bathonian)
Light-reddish-brown, fine- to medium-grained sandstone and siltstone; uppermost beds typically bleached white under the Cretaceous unconformity; poorly cemented and so weathers to vegetated slopes, or, locally, badland topography; Baer and Steed (2010) separated the member into two informal units at Kodachrome Basin State Park, a lower sandstone and shale unit and an upper gypsiferous unit; upper contact on the Markagunt Plateau is at the base of a pebble conglomerate, which marks the Cretaceous unconformity, whereas it is conformably overlain by the Entrada Sandstone in the southeast part of the map area; deposited on a broad, sandy mud flat (Imlay, 1980; Blakey and others, 1983); 250 feet (75 m) thick in Cedar Canyon and 50 to 150 feet (15–45 m) thick in the southeast part of the Panguitch 30' x 60' quadrangle (Doelling and Willis, 1999a). Description from source map: Panguitch 30' x 60' Quadrangle

Jcp - Carmel Formation, Paria River Member (Middle Jurassic (Bathonian))

Jcp - Carmel Formation, Paria River Member (Middle Jurassic, Bathonian)
Consists of three parts not mapped separately: (1) upper part is about 50 feet (15 m) of cliff-forming, olive-gray, micritic and argillaceous limestone and calcareous mudstone; laminated in very thick beds; locally contains small pelecypod fossils; (2) middle part is about 20 feet (6 m) of reddish-brown and greenish-gray shale that forms slope; and (3) lower part is gypsum and minor interbedded shale as much as 80 feet (25 m) thick in nodular, highly fractured and contorted beds and as thin, laminated beds. Upper contact is sharp and planar; deposited in shallow-marine and coastal-sabkha environments (Imlay, 1980; Blakey and others, 1983); Sprinkel and others (2011a) reported an 40Ar/39Ar age on zircon from a volcanic ash of 165.9 ± 0.51 Ma on lower Paria River strata in south-central Utah; 173 feet (53 m) thick in Cedar Canyon and 150 to 400 feet (45–120 m) thick in the southeast part of the Panguitch 30´ x 60´ quadrangle (Doelling and Willis, 1999a). Description from source map: Panguitch 30' x 60' Quadrangle

Jcx - Carmel Formation, Crystal Creek Member (Middle Jurassic (Bathonian))

Jcx - Carmel Formation, Crystal Creek Member (Middle Jurassic, Bathonian)
Thin- to medium-bedded, reddish- brown siltstone, mudstone, and fine to medium-grained sandstone; commonly gypsiferous and contains local contorted pods of gypsum; forms vegetated, poorly exposed slopes; upper contact is sharp and broadly wavy and corresponds to the base of the thick Paria River gypsum bed; Kowallis and others (2001) reported two 40Ar/39Ar ages of 166 to 167 Ma for altered volcanic ash beds within the member near Gunlock that were likely derived from a magmatic arc in what is now southern California and western Nevada; deposited in coastal-sabkha and tidal-flat environments (Imlay, 1980; Blakey and others, 1983); 294 feet (90 m) thick in Cedar Canyon. Description from source map: Panguitch 30' x 60' Quadrangle

Jcc - Carmel Formation, Co-op Creek Limestone Member (Middle Jurassic (Bajocian))

Jcc - Carmel Formation, Co-op Creek Limestone Member (Middle Jurassic, Bajocian)
Thin- to medium- bedded, light-gray micritic limestone and calcareous shale; locally contains Isocrinus sp. crinoid columnals, pelecypods, and gastropods; forms sparsely vegetated, ledgy slopes and cliffs; Kowallis and others (2001) reported several 40Ar/39Ar ages of 167 to 168 Ma for altered volcanic ash

beds within the lower part of the member in southwest Utah that were likely derived from a magmatic arc in what is now southern California and western Nevada; Sprinkel and others (2011a) reported 40Ar/39Ar ages of 169.2 ± 0.51 Ma and 169.9 ± 0.49 Ma on two ash beds in the lower part of the member in southwestern Utah; deposited in a shallow-marine environment (Imlay, 1980; Blakey and others, 1983); probably about 400 feet (120 m) thick; the member is as much as about 350 feet (105 m) thick on the Kolob Terrace north of Zion National Park (Biek and Hylland, 2007). Description from source map: Panguitch 30' x 60' Quadrangle

Geologic Cross Sections

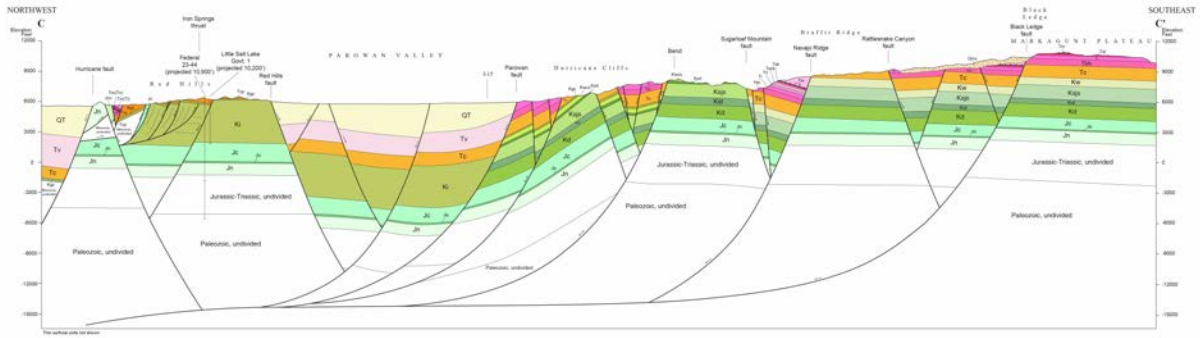
The geologic cross sections present in the GRI digital geologic-GIS data produced for Cedar Breaks National Monument, Utah (CEBR) are presented below. Note that some cross section abbreviations (e.g., A - A') may have been changed from their source map abbreviation in the GRI data so that each cross section abbreviation in the GRI data is unique. Cross section graphics were scanned at a high resolution and can be viewed in more detail by zooming in (if viewing the digital format of this document). Of added note, cross sections are not to source map scale as they've been scaled to fit on a portrait page within this document.

Cross Section A-A'

Double-click the following link to access this embedded document: Cross Section A-A'.

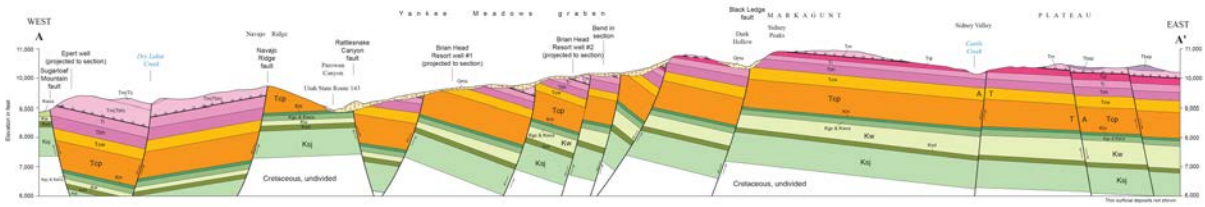
Graphic from source map: Panguitch 30' x 60' Quadrangle. The cross section is B-B' on the source map. Note that only a portion of the full cross section is within the extent of the GRI digital geologic-GIS data. This extent is from B to Black Rock Valley (as denoted on the cross section).

Cross Section B-B'



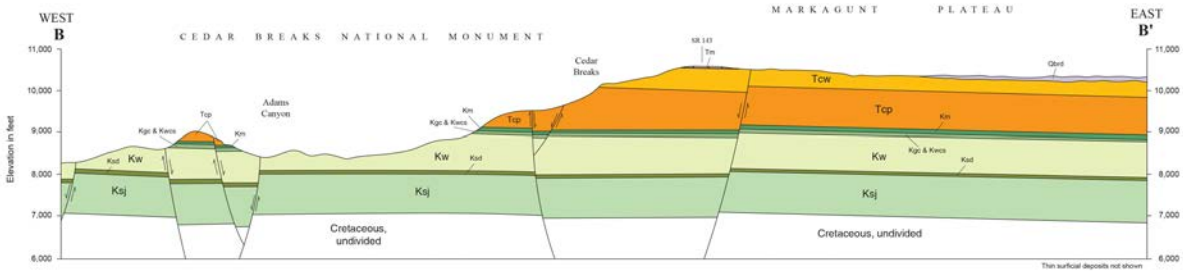
Graphic from source map: Panguitch 30' x 60' Quadrangle. The cross section is C-C' on the source map. Note that only a portion of the full cross section is within the extent of the GRI digital geologic-GIS data. This extent is from just east (right) of the Navajo Ridge fault (as denoted on the cross section) to C'.

Cross Section C-C'



Graphic from source map: Brian Head Quadrangle. The cross section is A-A' on the source map.

Cross Section D-D'



Graphic from source map: Brian Head Quadrangle. The cross section is B-B' on the source map.

Geologic Sample Localities

Additional information pertaining to (geologic) sample localities (palynomorph/microscopic fossil, and various age-dating samples) is found within each source map's booklet.

For the Panguitch 30' x 60' source map this document can be accessed from the following link: Panguitch booklet. Refer to tables 1, 2, 3 and 5 and related text within this booklet.

For the Brian Head Quadrangle source map this document can be accessed from the following link: Brian Had Quadrangle booklet. Refer to references Biek (2013), Utah Geological Survey and A-to-Z (2013) in this booklet.

Ancillary Source Map Information

The following sections present ancillary source map information associated with sources used for this project.

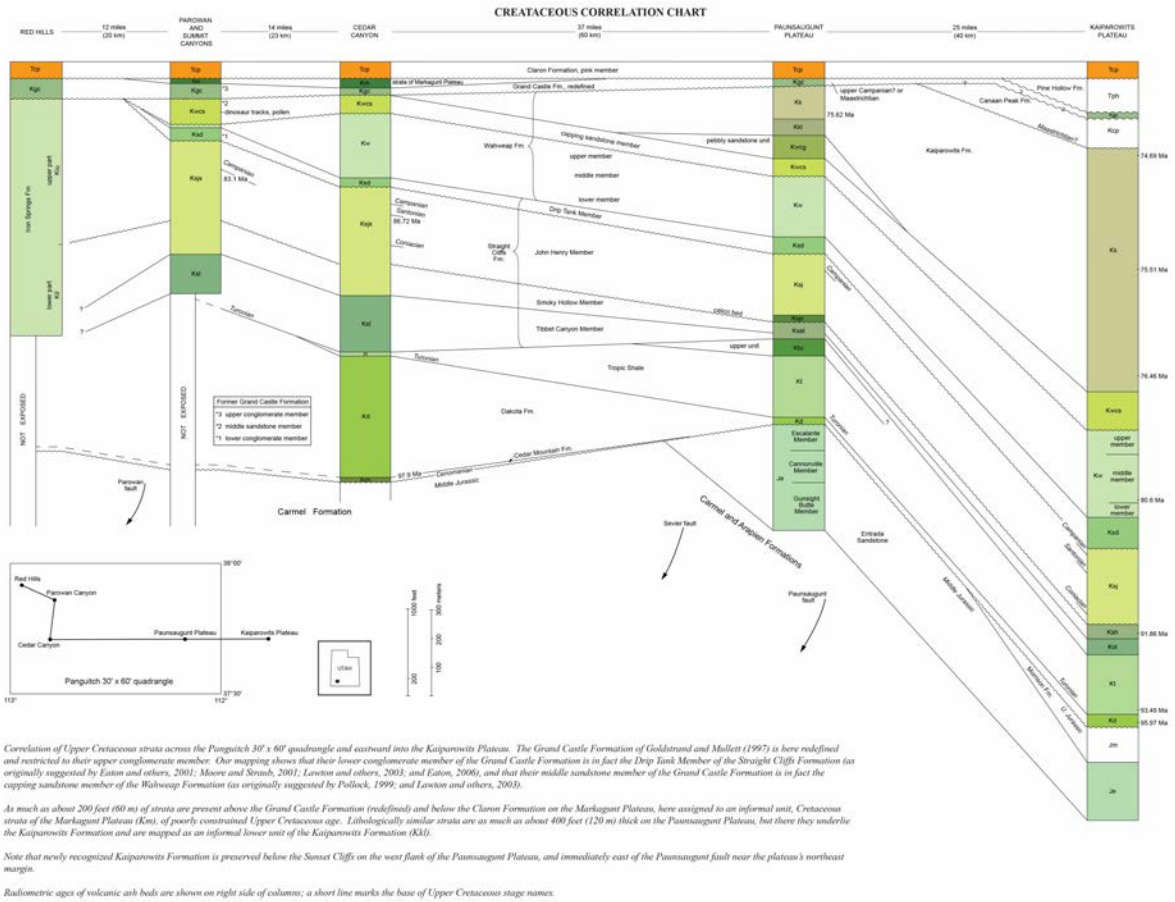
Panguitch 30' x 60' Quadrangle

The formal citation for this source.

> Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, Florian, Moore, D.W., Hacker, D.B., Eaton, J. G., Hereford, Richard, Sable, E.G., Filkorn, H.F., and Matyjasik, Basia, 2015, Geologic Map of the Panguitch 30' x 60' Quadrangle, Garfield, Iron and Kane Counties, Utah: Utah Geological Survey, Map 270DM, 3 plates and booklet, scale 1:62,500 (*GRI Source Map ID 76300*).

Prominent graphics and text associated with this source, as well as the source map's booklet are presented below.

Cretaceous Correlation Chart



Graphic from source map: Panguitch 30' x 60' Quadrangle. Of note, as the GRI digital geologic-GIS data was produced from only a portion of the full source map extent not all units presented are present in the GRI digital geologic-GIS data.

Stratigraphic Column

Stratigraphic Column (double-click link to open the embedded document).

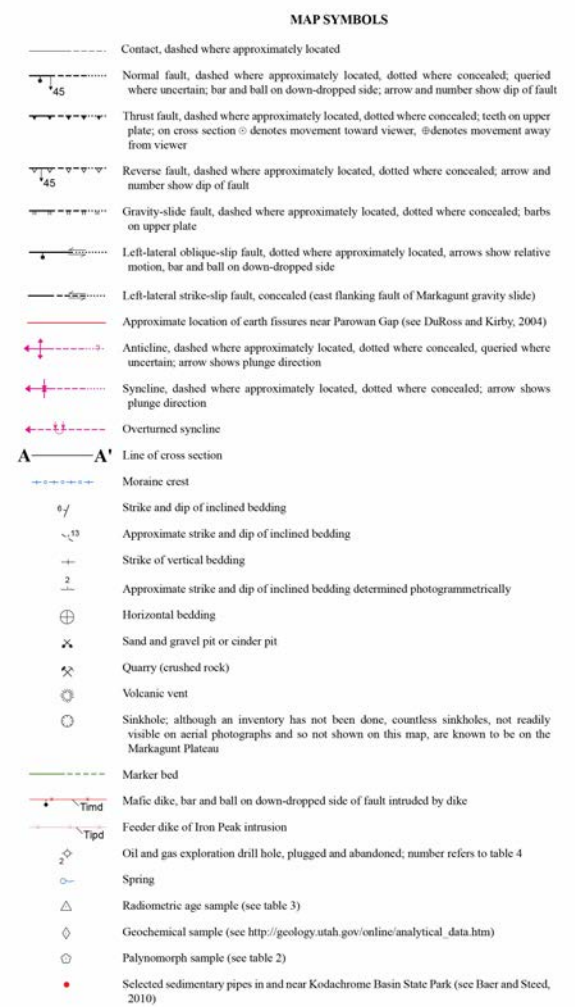
Graphic from source map: Panguitch 30' x 60' Quadrangle

Correlation of Map Units

Correlation of Map Units (double-click link to open the embedded document).

Graphic from source map: Panguitch 30' x 60' Quadrangle. Of note, as the GRI digital geologic-GIS data was produced from only a portion of the full source map extent not all units presented are present in the GRI digital geologic-GIS data.

Map Symbols



Graphic from source map: Panguitch 30' x 60' Quadrangle

Table 4: Wildcat Exploration Drill Holes

Table 4. Wildcat exploration drill holes, all plugged and abandoned, in the Panguitch 30' x 60' quadrangle.

Map ID Number	API Well Number	Operator	Well Name	Year Abandoned	County	7.5' Quadrangle	Qtr/Qtr	Section	Township-Range	Ft. NS*	NS	Ft. EW*	EW	UTM Eastings	UTM Northings	Latitude	Longitude	TD (feet)
1	43-021-30009	DELTA PETROLEUM CORP	FEDERAL 23-44	2007	IRON	Parowan Gap	SESE	23	33S-10W	1062	S	1073	E	329132	4198227	37.91555	-112.94384	12094
2	43-021-10758	MOUNTAIN FUEL SUPPLY CO	LITTLE SALT LAKE GOVT 1 (WSW)	1963	IRON	Summit	NESE	9	34S-10W	2310	S	330	E	325975	4192037	37.8592	-112.97825	4400
3	43-021-30011	CEDAR MOUNTAIN GAS LLC	CLARK 1-28	2009	IRON	Webster Flat	SWNW	28	37S-10W	665	S	655	W	323920	4157241	37.54721	-112.99318	2017
4	43-017-30068	MAY PETROLEUM INC	PANGUITCH 1	1978	GARFIELD	Panguitch Lake	NESW	33	36S-7W	2546	S	2171	W	355193	4166654	37.63746	-112.64119	11610
5	43-017-10902	PHILLIPS PETROLEUM CO	HATCH FEE B-1	1963	GARFIELD	Asay Bench	SESE	2	37S-7W	820	S	549	E	359150	4164461	37.61832	-112.59593	4971
6	43-017-10901	PHILLIPS PETROLEUM CO	HATCH FEE A-1	1964	GARFIELD	Asay Bench	NESE	16	37S-6W	1980	S	660	E	365454	4161419	37.59185	-112.52397	4917
7	43-017-30106	NORTHWEST EXPLORATION CO	PANGUITCH 1	1981	GARFIELD	Panguitch	SWNW	7	35S-5W	2287	N	670	W	370747	4182717	37.78267	-112.46781	6752
8	43-017-30104	TEXAS INTERNATIONAL PETRO	DIXIE UNIT 1-19	1981	GARFIELD	Casto Canyon	NESW	19	34S-4.5W	1391	S	1910	W	380978	4188520	37.83635	-112.35261	14075
9	43-017-30115	ARCO OIL & GAS COMPANY	DIXIE UNIT 2	1982	GARFIELD	Blind Spring Mtn.	SWSW	2	33S-4.5W	960	S	1060	W	386527	4202827	37.96598	-112.29182	15251
10	43-017-30146	FELLOWS ENERGY LTD	10-33C2	2004	GARFIELD	Cow Creek	NWSE	33	33S-2W	1986	S	1782	E	411273	4194102	37.89011	-112.00907	1716
11	43-017-30112	SOUTH LOUISIANA PROD CO	CLAY CREEK FEDERAL 13-29	1982	GARFIELD	Flake Mtn. East	SWSW	29	34S-2W	660	S	660	W	408711	4185659	37.81377	-112.03714	12894
12	43-017-30084	CHAMPLIN PETROLEUM CO	CLAY CREEK FED 11-32	1982	GARFIELD	Flake Mtn. East	NWNW	32	34S-2W	660	N	661	W	408693	4185257	37.81014	-112.03729	8785
13	43-017-10375	FOREST OIL CORP	GOVT 1 (RED CANYON)	1959	GARFIELD	Wilson Peak	SENE	1	36S-4.5W	2970	S	990	E	387227	4173692	37.70353	-112.27931	6242
14	43-017-10662	LION OIL COMPANY	BRYCE-MONSANTO 1	1957	GARFIELD	Bryce Canyon	NWNW	10	36S-4W	990	N	990	W	392688	4172411	37.69264	-112.21718	11221
15	43-017-20350	BRYCE CANYON OIL CO	1	1928	GARFIELD	Tropic Canyon	NENE	36	36S-3W	2640	N	2640	E	406076	4165090	37.62998	-112.06441	400
16	43-017-30117	U R C CORPORATION	TROPIC STATE 1-29	1983	GARFIELD	Cannonville	NWNE	29	37S-2W	660	N	1980	E	409288	4157825	37.56299	-112.02712	6260
17	43-025-30009	TEXACO INC	GOVT SCHNEIDER A NCT-1	1971	KANE	Cannonville	SESW	5	38S-2W	1320	S	1320	W	408655	4153600	37.52485	-112.03376	5958
18	43-017-30126	ARCO OIL & GAS COMPANY	BUCK KNOLL U 1	1985	GARFIELD	Tropic Reservoir	SESW	36	37S-4.5W	880	S	1885	W	386488	4155281	37.53938	-112.28483	10119

Source: Utah Division of Oil, Gas, and Mining; http://oilgas.ogm.utah.gov/Data_Center/LiveData_Search/well_data_lookup.cfm; accessed March 13, 2012.

Note: Location of wells 9, 15, and 17 as reported above are slightly off true location, which is shown on plate 1.

* denotes feet north, south, east, or west from section boundary

Graphic from source map: Panguitch 30' x 60' Quadrangle

Booklet

The booklet associated with this source map is available as an embedded document. Double-click the following link to access this document: Panguitch M-270DM_Booklet.pdf

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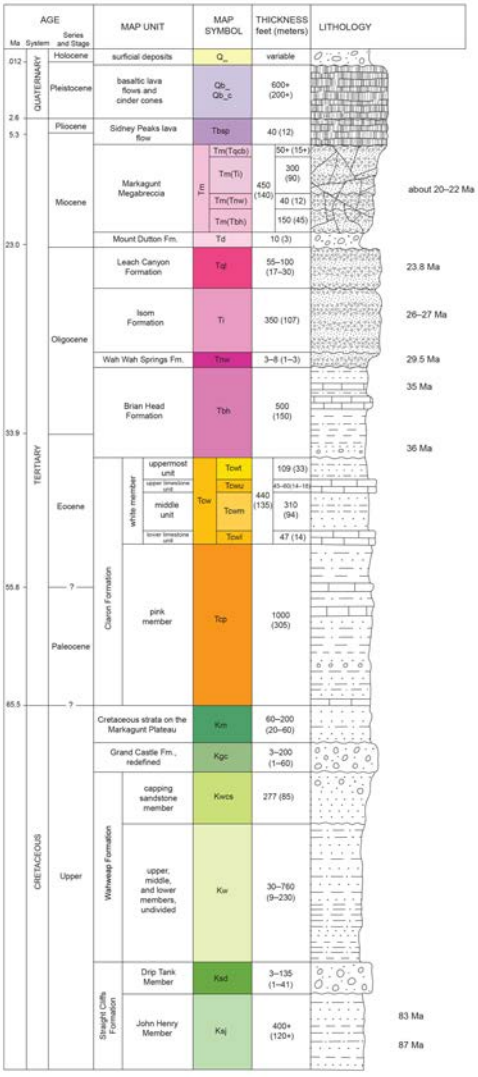
Brian Head Quadrangle

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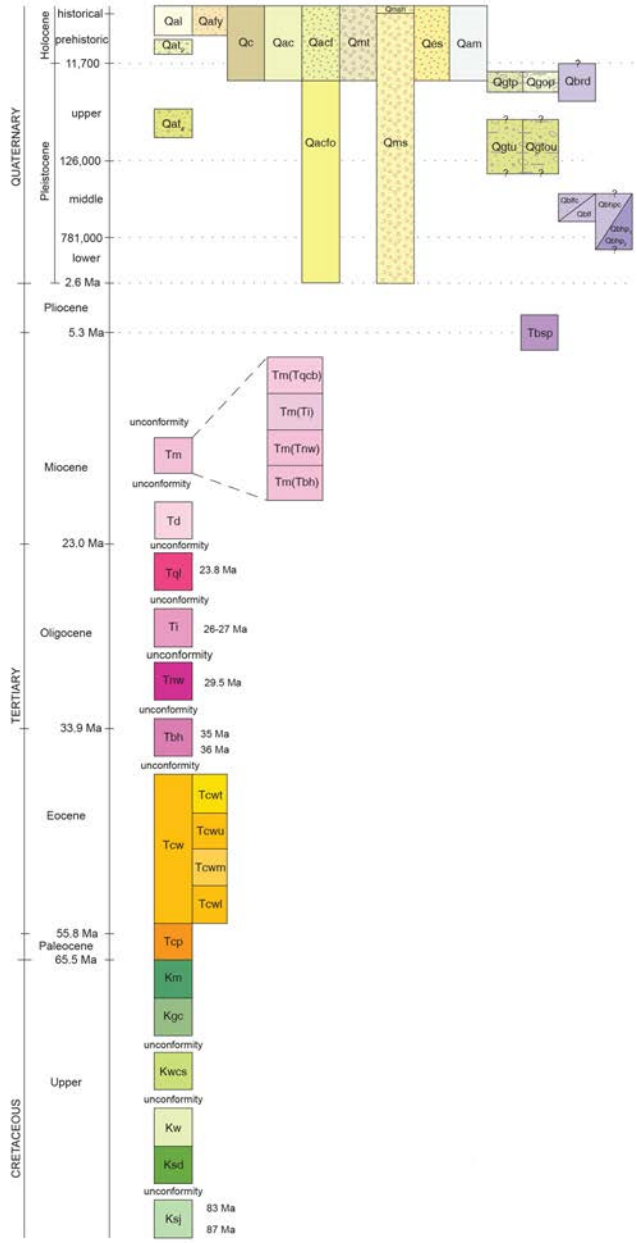
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Stratigraphic Column



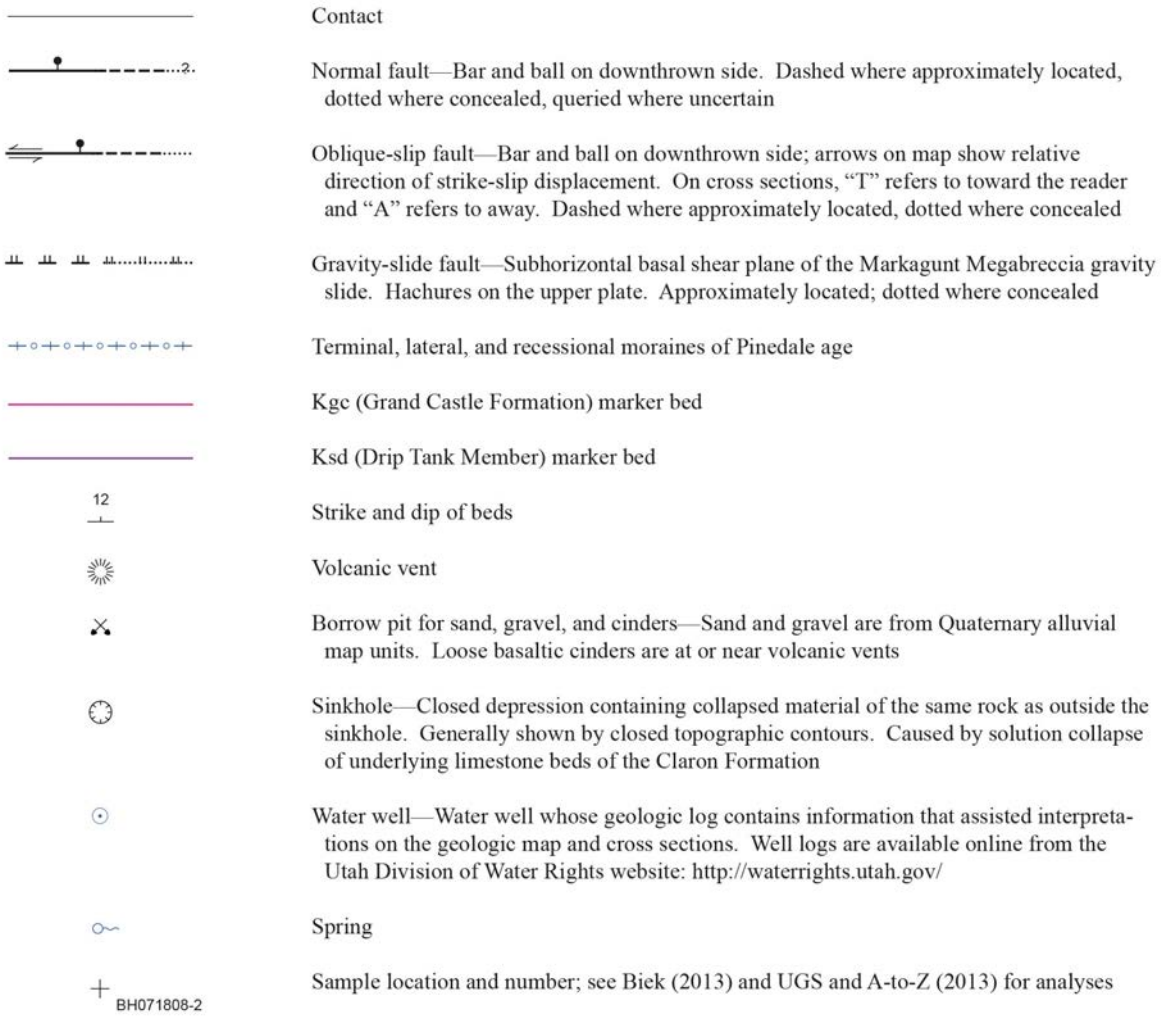
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Correlation of Map Units



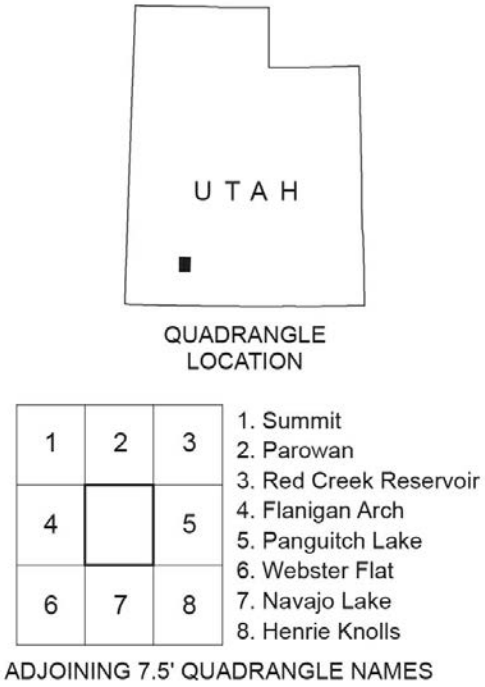
Graphic from source map: Brian Head Quadrangle

Map Symbols



Graphic from source map: Brian Head Quadrangle

Quadrangle Location and Adjoining 7.5' Quadrangles



Graphic from source map: Brian Head Quadrangle

Booklet

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This document was developed and completed by Stephanie O'Meara (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Ron Karpilo (Colorado State University).

The information in this document was compiled from GRI source maps, and is intended to accompany the digital geologic-GIS maps and other digital data for Cedar Breaks National Monument, Utah (CEBR) developed by Stephanie O'Meara with assistance from Ron Karpilo (see the GRI Digital Maps and Source Map Citations section of this document for all sources used by the GRI in the completion of this document and related GRI digital geologic-GIS maps).

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