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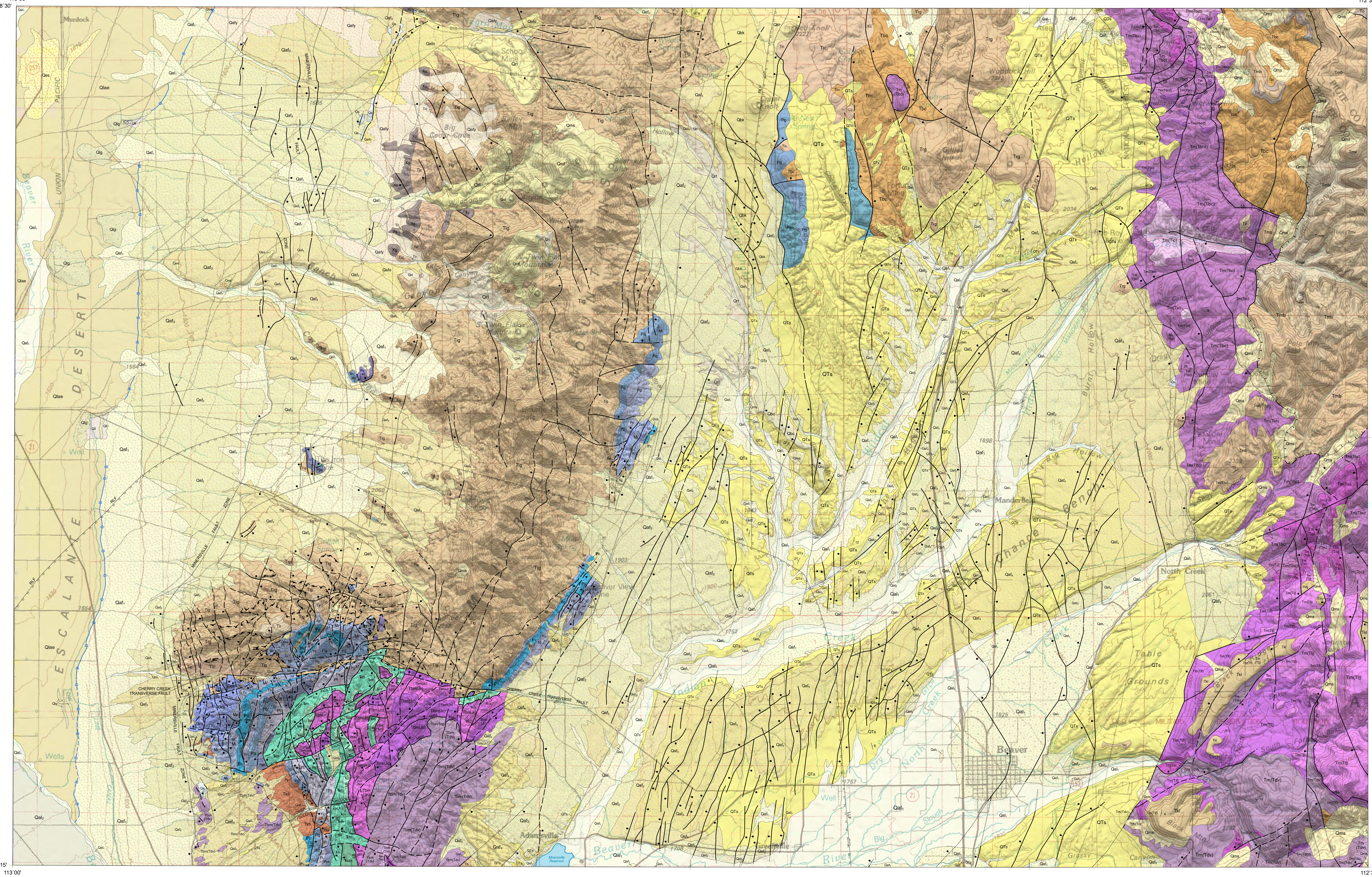
113°00' 38°30'   112°30' 38°30'



38°15' 113°00'   112°30' 38°15'

SCALE 1:62,500

1 0.5 0 1 2 3 4 5 6 Kilometers

1 0.5 0 1 2 3 4 Miles

CONTOUR INTERVAL 40 METERS - SUPPLEMENTARY CONTOURS 10 METERS

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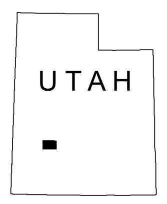
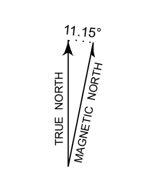


MAP LOCATION



APPROXIMATE MEAN DECLINATION, 2020

INTERIM GEOLOGIC MAP OF THE NORTHWESTERN QUARTER OF THE BEAVER 30' X 60' QUADRANGLE, BEAVER AND PIUTE COUNTIES, UTAH

by

Peter D. Rowley[1], Robert F. Biek[2], David B. Hacker[3], Garrett S. Vice[4], Robert E. McDonald[5], David J. Maxwell[6], Zachary D. Smith[6], Charles G. Cunningham[7], Thomas A. Steven[7], John J. Anderson[8], E. Bart Ekren[9], Michael N. Machette[10], Bruce R. Wardlaw[7], Stephan M. Kirby[2], Tyler R. Knudsen[2], Emily J. Kleber[2], and Adam I. Hiscock[2]

2020

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[7]U.S. Geological Survey, now deceased; [8]Seattle, Washington;
[9]White Sulphur Springs, Montana; and [10]Port Townsend, Washington

RICHFIELD (north) · WAH WAH MOUNTAINS SOUTH (west) · LOA (east) · PANGUITCH (south)

Ranch Canyon	Bearskin Mountain	Gillies Hill	Pole Mountain	Mount Belknap	Mount Brigham	Marysvale	Marysvale Peak
Cave Canyon	Adamsville	Beaver	Black Ridge	Shelly Baldy Peak	Delano Peak	Piute Reservoir	Malmsten Peak
Minersville	Minersville Reservoir	Greenville Bench	Kane Canyon	Circleville Mtn	Circleville	Junction	Phonolite Hill
Dry Willow Peak	Jack Henry Knoll	Buckhorn Flat	Burnt Peak	Fremont Pass	Bull Rush Peak	Mount Dutton	Deep Creek

NORTHWEST QUARTER OF THE BEAVER 30' X 60' QUADRANGLE

Base from USGS Beaver 30' x 60' Quadrangle (1980)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Program Manager: Grant C. Willis (UGS)
Project Manager (GIS): Robert F. Biek (UGS)
GIS and Cartography: GIS Services & Consulting, LLC and Basia Matyjasik (UGS)

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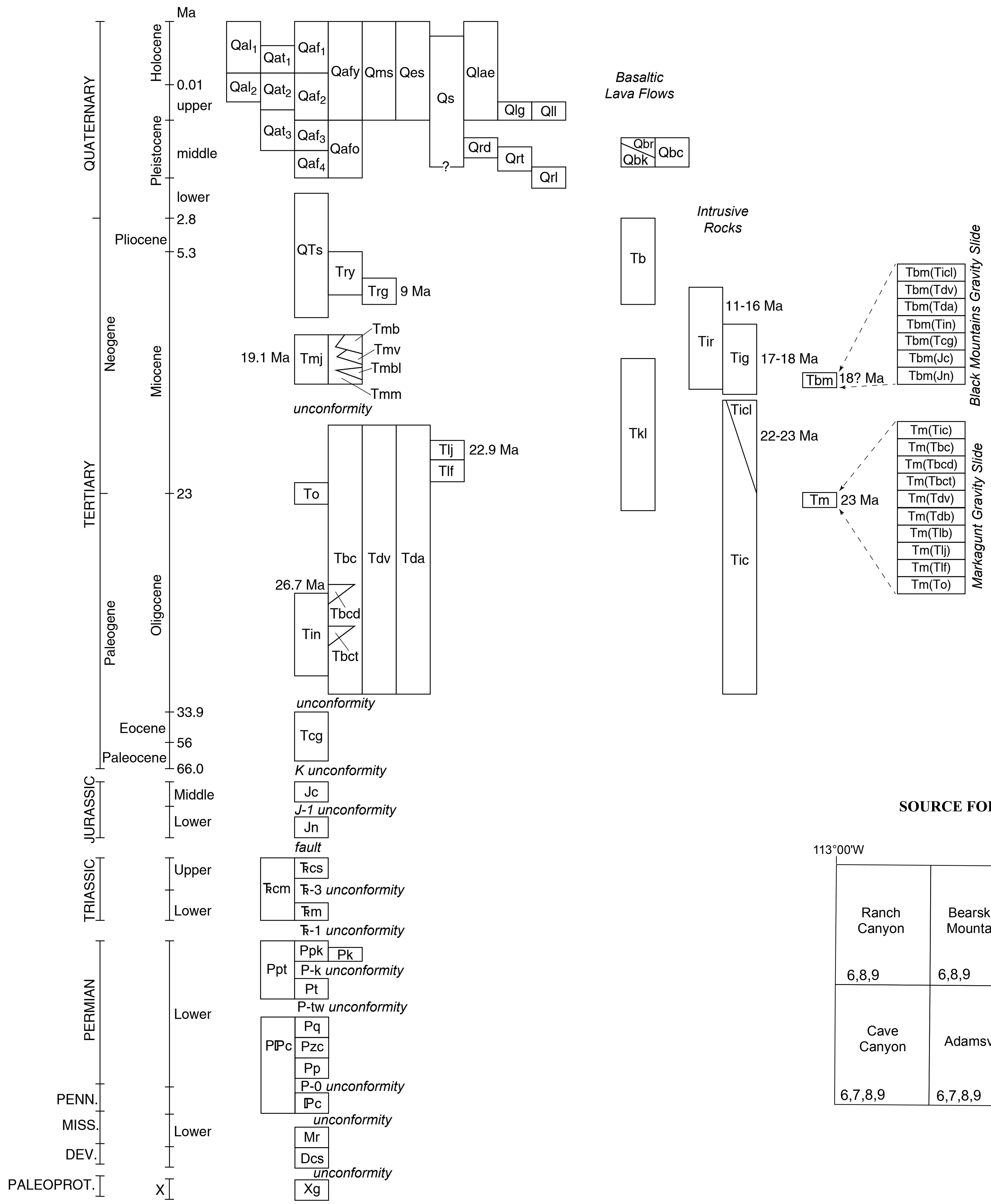
https://doi.org/10.34191/OFR-729DM

This map was created from geographic information system (GIS) data.

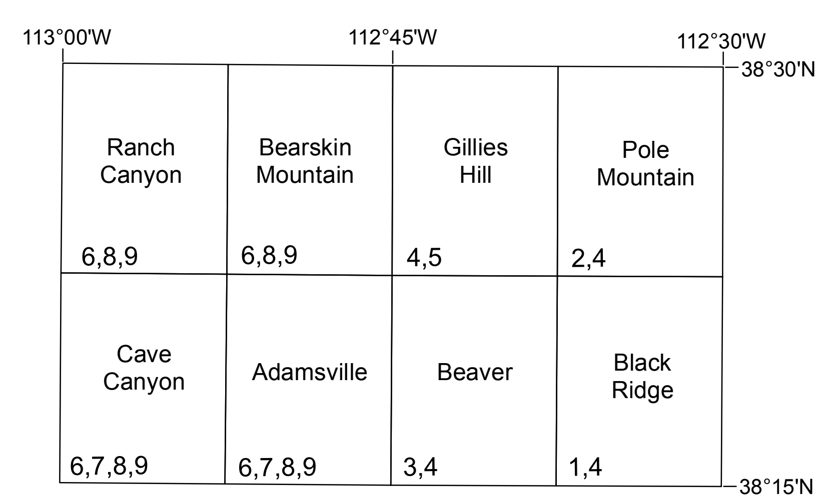
CORRELATION OF MAP UNITS



MAP SYMBOLS

Dashed where approximately located, dotted where concealed;
bar and ball and other line decorations on downthrown side;
arrows show relative movement

SOURCE FOR GEOLOGIC MAPPING



INTERIM GEOLOGIC MAP OF THE NORTHWESTERN QUARTER OF THE BEAVER 30' x 60' QUADRANGLE, BEAVER AND PIUTE COUNTIES, UTAH

by

Peter D. Rowley [1], Robert F. Biek [2], David B. Hacker [3], Garrett S. Vice [4], Robert E. McDonald [5], David J. Maxwell [6], Zachary D. Smith [6], Charles G. Cunningham [7], Thomas A. Steven [7], John J. Anderson [7], E. Bart Ekren [8], Michael N. Machette [9], Bruce R. Wardlaw [7], Stephan M. Kirby [2], Tyler R. Knudsen [2], Emily J. Kleber [2], and Adam I. Hiscock [2]

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Suggested citation:

Rowley, P.D., Biek, R.F., Hacker, D.B., Vice, G.S., McDonald, R.E., Maxwell, D.J., Smith, Z.D., Cunningham, C.G., Steven, T.A., Anderson, J.J., Ekren, E.B., Machette, M.N., Wardlaw, B.R., Kirby, S.M., Knudsen, T.R., Kleber, E.J., and Hiscock, A.I., 2020, Interim geologic map of the northwestern quarter of the Beaver 30' x 60' quadrangle, Beaver and Piute Counties, Utah: Utah Geological Survey Open-File Report 729DM, 25 p., 2 plates, scale 1:62.500, https://doi.org/10.34191/OFR-729DM.

Disclaimer

UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 729DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2020

DESCRIPTION OF GEOLOGIC UNITS

The Interim Geologic Map of the Northwest Quarter of the Beaver 30' x 60' Quadrangle is a revised portion of the entire quadrangle map originally published in 2005 as UGS Open-File Report 454. The revisions reflect our current understanding of the newly discovered Black Mountains and Markagunt gravity slides, parts of perhaps the world's largest terrestrial landslide complex, which we now know spans much of the Beaver 30' x 60' quadrangle. The map also incorporates new mapping of surficial deposits in the Escalante Desert, here simplified for reasons of map scale, done as part of the Utah FORGE (Frontier Observatory for Research in Geothermal Energy) project. We continue to work on revisions of the remainder of the quadrangle and surrounding areas.

Where necessary, previously determined isotopic ages given here have been recalculated using the IUGS (International Union of Geological Sciences) decay constants (Steiger and Jager, 1977) and the tables of Dalrymple (1979).

Qal_1, Qal_2

Alluvium (Holocene and upper Pleistocene) – Sand, gravel, silt, and clay in channels, floodplains, and adjacent low river terraces of rivers and major streams; subscript denotes relative age, with Qal_1 younger and Qal_2 older; maximum thickness about 30 feet (10 m).

Qat_1 **Younger stream-terrace deposits** (Holocene) – Sand and gravel that form dissected surfaces as much as 15 feet (5 m) above the level of adjacent modern streams; maximum thickness about10 feet (3 m).

Qat_2 **Older stream-terrace deposits** (Holocene and upper Pleistocene) – Sand and gravel that form well dissected surfaces 15 to 40 feet (5–13 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qat_3 **Oldest stream-terrace deposits** (upper and middle Pleistocene) – Sand and gravel that form well dissected surfaces 50 to 80 feet (15–25 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qaf_1 **Young alluvial-fan deposits** (Holocene) – Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans and on coalesced alluvial fans and pediments (piedmont slopes); surface is young and generally undissected; thickness at least 30 feet (10 m).

Qaf_2, Qaf_3, Qaf_4

Middle alluvial-fan deposits (Holocene to middle Pleistocene) – Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans and on coalesced alluvial fans and pediments (piedmont slopes); surfaces are moderately dissected by modern streams; subscript denotes relative age, with Qaf_2 youngest and Qaf_4 oldest; unit Qaf_4 is correlated with the gravel of Last Chance Bench in the central and northeast Beaver basin, which is estimated to be about 500,000 years old based on radiometric ages that bracket it and which is incised 100 to 330 feet (30–100 m) by local streams (Machette and others, 1984; Machette, 1985); like our Qaf_4 deposits, gravel of Last Chance Bench has advanced stage III calcic soil horizons characterized by massive accumulations of carbonate and platy structure; thickness at least 50 feet (15 m).

Qafy **Young and middle fan alluvium, undivided** (Holocene to upper Pleistocene) – Quaternary alluvial deposits booulder- to clay-size sediment fluvial 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 (Qaf_1 equivalent) and low-level mostly inactive surfaces incised by small streams (Qaf_2 equivalent) that are undivided here; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part adjacent to range fronts; thickness at least 30 feet (10 m).

Qafo **Old fan alluvium** (upper to middle? Pleistocene) – Quaternary alluvial deposits boulder- to clay-size sediment fluvial Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with moderately developed calcic soils (caliche); forms broad, gently sloping, deeply incised surfaces along the west side of the Mineral Mountains; deposited principally as debris flows and debris floods; exposed thickness as much as several tens of feet.

Qms **Landslide deposits** (Holocene and upper Pleistocene) – Unsorted, mostly angular, unstratified rock debris moved by gravity from nearby bedrock cliffs; includes reworked glacial deposits on high scarp of the Tushar Mountains west-northwest of Circleville, just east of the mapped area; maximum thickness about 100 feet (30 m).

Qes **Eolian sand deposits** (Holocene and upper Pleistocene) – Windblown sand in vegetated sheets that generally lack dune form; mapped in the northwest part of the map area; maximum thickness about 10 feet (3 m).

Qs **Spring deposits** (Holocene to middle Pleistocene) – Generally resistant deposits of mostly calcareous tufa from Pleistocene, Holocene, and modern springs, including spring mounds 8.5 miles (14 km) north-northeast of Beaver and 4 miles (6 km) north of Minersville, the latter of which includes marsh deposits that have been dated at 5000 years old (middle Holocene) (UGS unpublished data); also includes siliceous sinter of the Opal Mound, located west of the mouth of Big Cedar Cove, and a series of outcrops of silica-cemented alluvium about a mile (1.6 km) to the north and continuing for more than a mile (1.6 km) to and past the northern edge of the Beaver quadrangle (Sibbett and Nielson, 1980, 2017; Kirby, 2019); Roosevelt hot springs is located just north of the mapped area; all these spring deposits are controlled by the Opal Mound fault (Sibbett and Nielson, 1980, 2017; Allis and Moore, 2019 and references therein) that bounds the western side of the Roosevelt geothermal area in the northwestern part of the mapped area; sinter-cemented alluvium is present at depths of 90 m and 130 m east of the Opal Mound fault (Glenn and Hulen, 1979); paleomagnetic studies of Opal Mound yielded a minimum age on opaline sinter of 12,000 years (Faulder, 1991), and radiocarbon ages of about 1900 and 1600 ^{14}C yr B.P. (Lynne and others, 2004, 2005) for the opal indicate that at least some opal deposition continued into the late Holocene, although spring activity at Opal Mound has not occurred historically; maximum thickness of deposits about 40 feet (13 m).

Qlae **Mixed lacustrine, alluvial, and eolian deposits** (Holocene and upper Pleistocene) – Mixed and reworked gravelly lacustrine and alluvial deposits on piedmont slopes; grades from pebbly sand and silt to sandy pebble gravel; lacustrine material was deposited in Escalante Bay of Lake Bonneville and perhaps in older Pleistocene lakes; maximum thickness about 20 feet (6 m).

Qlg **Lacustrine gravel** (upper Pleistocene) – Sand and gravel in Lake Bonneville shore-zone deposits, forming beaches, spits, and offshore bars; maximum thickness about 30 feet (10 m).

Qll **Lacustrine lagoon deposits** (upper Pleistocene) – Sand, silt, clay, and silty marl that accumulated in lagoons behind (landward from) gravel barrier beaches of Lake Bonneville; present east of Milford; generally less than 10 feet (3 m) thick.

Rhyolite of Mineral Mountains (middle and lower Pleistocene) – High-silica rhyolite made up of three types of deposits erupted from sources in the Mineral Mountains and derived from the vestiges of the same magma chamber that resulted in the Mineral Mountains batholith; rhyolite deposited on the eroded surface and canyons cut in that batholith; the buried rhyolite magma chamber supplies the heat for the Roosevelt geothermal area, which supports an electric power plant (Lipman and others, 1978; Nielson and others, 1978, 1986; Sibbett and Nielson, 1980, 2017; Allis and others, 2015) from wells drilled east of the Opal Mound fault; like other Quaternary and Tertiary rhyolites and basalts in the area, the unit is synchronous with basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001).

Qrd **Volcanic dome** (middle Pleistocene) – Resistant, mostly tan, crystal-poor (sparsely porphyritic), perlite-mantled, flow-foliated, high-silica rhyolite lava flows, flow breccia, and minor tuff that form volcanic domes by deposition around central vents; mostly devitrified but contains a basal vitrophyre zone as much as 30 feet thick (10 m); at least nine domes concentrated along the crest of the north Mineral Mountains; K-Ar ages of three of these domes are 0.75 + 0.10 Ma (obsidian), 0.61 + 0.05 Ma (sanidine), and 0.50 + 0.07 Ma (sanidine), plus another just north of the mapped area of 0.54 + 0.06 Ma (sanidine) (Lipman and others, 1978); maximum thickness about 900 feet (300 m).

Qrt **Tuff** (middle Pleistocene) – Poorly consolidated, white, unwelded, pumice-rich, crystal-poor, high-silica rhyolite ash-flow and airfall tuff; best exposed in Ranch Canyon, where it once was mined for pumice; overlain by Qrd in the Mineral Mountains; deposited also to the east in the Beaver basin after drainage integration with Escalante Desert and before deposition of the gravel of Last Chance Bench (Qaf_4) (Nash and Smith, 1977; Machette and others, 1984; Machette, 1985); K-Ar age of 0.70 + 0.04 Ma (obsidian) on ash-flow tuff in Ranch Canyon (Lipman and others, 1978) and 0.55 + 0.006 Ma (Izett, 1981) in the Beaver basin; exposed thickness as much as 600 feet (180 m).

Qrl **Lava flows** (middle and lower Pleistocene) – Two compound lava flows of resistant, black to light-gray, flow-foliated, aphyric, high-silica rhyolite, most of which is devitrified but much of which is basal vitrophyre (obsidian); overlain by Qrt; the northern flow, the Bailey Ridge flow in Negro Mag Wash, has been mined for perlite, whereas the southern flow, the Wildhorse Canyon flow, is famous for its implement-grade obsidian, artifacts of which have been found in archeological sites throughout the West (see, for example, Jones and others, 2003); K-Ar age 0.79 + 0.08 Ma (obsidian) on the Bailey Ridge flow (Lipman and others, 1978); maximum thickness of each flow is about 300 feet (100 m).

Qbr **Basaltic andesite of Red Knoll** (middle Pleistocene) – Resistant, dark-gray and black, blocky, vesicular, crystal-rich basaltic andesite lava flows and red and dark-gray cinder cone of ash and scoria, northwestern Beaver basin; synchronous with the latest stage of basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001); maximum thickness about 200 feet (60 m).

Qbk **Basaltic andesite of Crater Knoll** (middle Pleistocene) – Resistant, dark-gray and black, blocky, vesicular, crystal-rich basaltic andesite lava flows and red and dark-gray cinder cone of ash and scoria, northwestern Beaver basin; has a K-Ar age of 1.0 Ma (Best and others, 1980) but interpreted to overlie Qrt by Machette and others (1984) and more likely is closer to 0.5 Ma, the age of the lithologically similar basaltic andesite of Cove Fort, just north of the mapped area (Steven and Morris, 1983; Hintze and others, 2003); maximum thickness about 100 feet (30 m).

Qbc **Basalt of Cunningham Hill** (lower Pleistocene) – Resistant, dark-gray, scoriaceous to massive basaltic lava flow that filled the ancestral valley of Cunningham Wash, in the western Beaver basin (Machette and others, 1984); K-Ar age of 1.1 Ma (Best and others, 1980); maximum thickness about 30 feet (10 m).

QTs **Basin-fill sedimentary rocks** (lower Pleistocene to upper Miocene) – Poorly to moderately consolidated, tan and gray, tuffaceous sandstone and subordinate mudstone, siltstone, and conglomerate deposited in basins of different ages (Pliocene to late Miocene) and origins; basins were formed by normal faults and subordinate oblique and strike-slip faults of the episode of basin-range extension, whose beginning is poorly constrained but seems to be at about 20 Ma, if not older; basin-range extension reached maximum intensity and created the present topography largely after 10 Ma (e.g., Rowley and Dixon, 2001; Rowley and others, 2002; Biek and others, 2015a); deposits generally consist of fanglomerate near the present basin margins, piedmont slope deposits farther toward the centers of the basins, and lacustrine deposits near the centers of the basins; includes deposits studied in detail in the Beaver basin (Machette and others, 1984; Machette, 1985), which began to form at about 9 Ma (Evans and Steven, 1982); in the Kingston Canyon area east of the mapped area, the main phase of basin-range faulting is between about 7.6 and 5.4 Ma based on K-Ar ages published by Rowley and others (1981), and recently confirmed by new $^{40}Ar/^{39}Ar$ ages (UGS and NMGRL, 2019a); thickness of overall map unit in the mapped area is variable but locally at least 2000 feet (600 m).

Tb **Basalt lava flows** (Pliocene and upper Miocene) – Resistant, dark-gray and black, locally vesicular or amygdaloidal, crystal-poor (olivine and pyroxene phenocrysts), olivine basalt lava flows, flow breccia, and cinder cones; basaltic rocks and high-silica rhyolite rocks make up an episode of bimodal magmatism that is synchronous with basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001; Biek and others, 2015a); in the northwestern quarter of the Beaver 30' x 60' quadrangle (Rowley and others, 2005), includes basalt west of Minersville Reservoir that has a K-Ar age of 7.6 Ma (Best and others, 1980); elsewhere in the Beaver quadrangle, south of the map area includes basalt in the Black Mountains that has a K-Ar age of 6.4 Ma (Best and others, 1980; Anderson and others, 1990a), southeast of the mapped area basalt southeast of Otter Creek Reservoir has a K-Ar age of 5.0 Ma (Best and others, 1980), basalt in Kingston Canyon has a K-Ar age of 7.8 Ma (Rowley and others, 1981), basalt 2 miles (3 km) west of Piute Reservoir has a K-Ar age of 10.9 Ma (Rowley and others, 1994), and basalt east of Piute Reservoir has K-Ar ages of 12.9 Ma (Damon, 1969) and 12.7 Ma (Best and others, 1980); maximum thickness of lava flows in the mapped area about 200 feet (60 m).

Try **Young rhyolite lava flows** (upper Miocene) – Small, resistant, mostly gray, flow-banded, crystal-poor, high-silica rhyolite volcanic domes and lava flows, and subordinate pyroclastic material; these rocks are part of the episode of bimodal magmatism; in the mapped area, unit only includes a small dome in Corral Canyon, about 2 miles (3 km) upstream from where it joins Ranch Canyon and just west of the western flank of the Mineral Mountains (Sibbett and Nielson, 1980, 2017), that has a K-Ar age (biotite) of 7.90 + 0.30 Ma (Lipman and others, 1978; see also Evans and Steven, 1982); along the southern part of the Beaver 30' x 60' quadrangle, however, eruptive centers of the map unit help define an east-trending structural belt known as the Blue Ribbon transverse zone (Rowley and others, 1978; Rowley, 1998; Rowley and Dixon, 2001); this transverse zone includes east-striking faults that define the north end of the east-trending Black Mountains and separates this range from the southern end of the Mineral Mountains

(Rowley, 1978), as well as extending east of the mapped area (Rowley and others, 2005) and west of the mapped area across the entire Great Basin (Rowley, 1998; Rowley and Dixon, 2001); from east to west in the Beaver quadrangle (Rowley and others, 2005), the rhyolite bodies along the Blue Ribbon transverse zone include the rhyolite of Phonolite Hill in Kingston Canyon east of the mapped area, which consists of several domes with K-Ar ages of 5.4 and 4.8 Ma (Rowley and others, 1981); a dome southwest of Beaver in the Black Mountains that has a K-Ar age of 8.3 Ma (Anderson and others, 1990a); a dome at Teddys Valley in the Black Mountains that has a K-Ar age of 7.9 Ma (Anderson and others, 1990a); and a dome at Blue Ribbon Summit in the Black Mountains that has a K-Ar age of 7.6 Ma (Mehnert and others, 1978; Rowley and others, 1978); in most places the maximum thickness of the rhyolite flows is less than 200 feet (60 m).

Trg **Rhyolite of Gillies Hill** (upper Miocene) – Mostly resistant, white and light-gray, flow-foliated, locally vesicular, aphyric to crystal-rich, high-silica rhyolite lava flows and volcanic domes; includes interlayered soft white ash-flow tuff; map unit exposed at the northern end of the Beaver basin, west of the main basin-range frontal fault that defines the western side of the Tushar Mountains, including along that fault a mile (1.6 km) south of the mouth of Indian Creek (Cunningham and others, 1983, 1984b); map unit has K-Ar and fission-track ages that cluster at 9 Ma, probably synchronous with the main phase of basin-range faulting in the Beaver basin (Evans and Steven, 1982; Cunningham and others, 1984b); K-Ar and fission-track ages of the same age represent resetting of older rocks and formation of the Sheep Rock replacement-alunite deposit (and an adjacent gold deposit) by the same thermal event—perhaps from an underlying granite pluton—extending nearly 7 miles (11 km) south along and east of the main frontal fault from the mouth of Indian Creek to the mouth of North Creek (Cunningham and others, 1984b); base of map unit not exposed but exposed thickness at least 1200 feet (350 m).

Tir **Rhyolite porphyry** (Miocene) – Resistant, mostly small, gray, tan, and pink, commonly hydrothermally altered dikes, sills, plugs, a laccolith(?), and masses of other shapes of mostly crystal-poor (phenocrysts of K-feldspar, quartz, plagioclase, and biotite), mostly high-silica rhyolite and fine-grained granite in the Mineral Mountains (Sibbett and Nielson, 1980, 2017) that intrudes rocks as young as the main granitic batholith of the Mineral Mountains (Tig) and has K-Ar ages of 9.1 and 9.6 Ma (Nielson and others, 1986), a U-Pb zircon age of 11.0 Ma (Coleman and Walker, 1994), and an 40Ar/39Ar age of 11.5 Ma (Coleman and others, 2001; also includes a glassy rhyolite flow and north-striking feeder dike on the western flank of the Tushar Mountains north of Indian Creek (Cunningham and others, 1983; Machette and others, 1984) that has a fission-track age on zircon of 16.1 + 0.8 Ma, as well as another glassy north-striking rhyolite dike 0.9 miles (1.5 km) west of the flow/dike too small to show on the map that has a fission-track age on zircon of 15.6 + 1.1 Ma (Cunningham and others, 1984b, table 1); these dikes host fluorite and secondary uranium minerals and are related to uranium deposits mined at the Mystery-Sniffer mine just east of the flow/dike, likely due to a granite pluton at depth (Cunningham and others, 1984b); most bodies too small to be mapped at this scale but those shown on the map are as much as several hundred feet (100 m) across and more than a mile (1.6 km) long.

Tig **Granitic intrusive rocks** (Miocene) – Mostly resistant, mostly gray, high-alkali and mostly high-silica (of the bimodal igneous episode that is synchronous with basin-range extension) granite and related rocks; as such, granitic plutons probably underlie and are the source for most if not all high-silica rhyolite bodies exposed in the Beaver quadrangle, including beneath the Mount Belknap caldera in the Tushar Mountains (Rowley and others, 2002); makes up the main mass of the Mineral Mountains batholith, which is exposed over most of the Mineral Mountains and is considered the largest exposed batholith in Utah; batholith is made up of individual stocks and sheeted dike-like masses of fine- to coarse-grained or porphyritic, nonfoliated, mostly granite (classification of intrusive rocks from International Union of Geological Sciences) but locally monzonite, syenite, diorite, and granodiorite (Nielson and others, 1978, 1986; Sibbett and Nielson, 1980, 2017; Coleman, 1991; Meschter-McDowell and others, 2004; Jones and others, 2019; Kirby, 2019) because the batholith was likely formed by partial melting (anatexis) of an older, more mafic, calc-alkaline phase (Coleman and Walker, 1992) that is mapped separately as Tic; isotopic (mostly K-Ar) dating of the plutonic rocks of the Mineral Mountains has been problematic because of almost continuous emplacement of intrusive rocks, and consequent resetting of isotopic clocks, since at least about 25 Ma (Aleinikoff and others, 1986; Nielson and others, 1986; Coleman and others, 2001), but Coleman and others (2001) interpreted on the basis of U-Pb zircon and $^{40}Ar/^{39}Ar$ ages that the main granitic batholith in the Mineral Mountains has an age of about 18 to 17 Ma.

Marysvale Gravity Slide Complex (lower Miocene to upper Oligocene) – The Beaver 30' x 60' quadrangle spans much of the northern part of the recently discovered Marysvale gravity slide complex (MGSC), which comprises the Sevier, Markagunt, and Black Mountains gravity slides, three gigantic terrestrial landslides forming one of the largest such complexes known in the world. Each gravity slide continues to be studied by not only some of the authors of this report, but also several from an international group of geologists introduced to the slides during the Thompson Field

Forum that was sponsored by the Geological Society of America and the UGS and held during September 2017 (e.g., Biek and others, 2016, 2017, 2019). Parts of the Markagunt and Black Mountains gravity slides are in this northwest quarter of the Beaver 30' x 60' map area.

Each gravity slide consists of deformed pre-existing, predominantly Miocene and Oligocene calc-alkaline volcanic rocks that erupted in the Marysvale volcanic field as well as calc-alkaline ash-flow tuffs that erupted from calderas in the Great Basin to the west and intertongued with Marysvale rocks (e.g., Lipman and others, 1972). Distinctive gravity slide related deformation is present as breccia, cataclasite and ultracataclasite, rare pseudotachylyte (frictionite), and basal layers and related clastic dikes or injectites, but the northern parts of the slides are noted for huge mountain-sized blocks (megabreccia) of transported yet seemingly intact rock. In addition, south-directed kinematic features such as grooves, striations, and Reidel shears are present on basal and subsidiary slip surfaces, and older-on-younger rock relationships characterize former land surface areas south of this map.

These rocks represent repeated catastrophic failure of the southern Marysvale volcanic field, first as the ca. 25 Ma Sevier gravity slide, then as the ca 23 Ma Markagunt gravity slide, and finally as the post-19.5 Ma Black Mountains gravity slide. The emplacement age of each gravity slide, described in Biek and others (2019) and being refined by on-going research, tracks the westward progression of volcanism in the field. Each gravity slide moved rapidly southward across areas that later, after basin-range tectonism, became the Sevier Plateau, southern Tushar Mountains, southern Mineral Mountains, Black Mountains, Red Hills, northern and central Markagunt Plateau, and valleys in between.

The gravity slides exhibit structural features commonly seen in modern landslides, but on an enormous scale and lithified. These features include: (1) extensional faulting in the source area of the slide, (2) translational movement of the main body of the slide, which is characterized by mountain-size blocks jostled together, (3) thrust faulting at the ramp fault, where the basal slip surface "day lighted" and the slide mass moved up onto the former land surface, (4) thrust faulting in the toe area where the slide came to a stop and blocks piled one atop the other, and (5) debris-avalanche deposits of the distal toe area, where the slide mass completely disaggregated into chaotic blocks. The primary failure plane of each gravity slide was in incompetent tuffaceous sedimentary rocks of the Brian Head Formation, which immediately underlies the volcanic rocks.

The MGSC covers more than 3000 square miles (>8000 km^2). The Markagunt slide is the largest among the three gravity slides having an overall length of about 60 miles (96 km) and breadth of about 20 miles (32 km), making the deposit at least 1350 square miles (>3500 km^3) in extent (revised from initial estimates in Biek and others, 2014, 2015a; Hacker and others, 2014, 2015). It is also over a mile (1.6 km) thick in its northern reaches at the breakaway zone in the modern-day Tushar Mountains, tapering southward to several hundred feet thick on the central Markagunt Plateau. Statistics of the Sevier and Black Mountains gravity slides are similarly impressive, and runout over the former land surface of each slide was at least 20 miles (32 km). Only the 49 Ma Heart Mountain gravity slide in northwestern Wyoming is a terrestrial slide of comparable size and it was considered unique until discovery of the MGSC. The Heart Mountain gravity slide is at least 1300 mi^2 (3400 km^2) in areal extent (e.g., Malone and Craddock, 2008; Craddock and others, 2009, 2012); however, reinterpretation of enigmatic volcanic rocks at Squaw Peaks led Malone and others (2014) to suggest that the Heart Mountain slide may be larger still, at least 2000 mi^2 (5000 km^2).

The first parts of what would come to be known as the Markagunt gravity slide were discovered in the early 1970s during thesis geologic mapping in the northern and central Markagunt Plateau by graduate students of John J. Anderson, then Professor at Kent State University; Biek and others (2019) summarized the history of this discovery. We use the name Markagunt Megabreccia, as proposed by Anderson (1993) with a type section along Panguitch Creek southwest of the town of Panguitch, for the deposits of the Markagunt gravity slide (and similarly adapt this methodology for deposits of the Black Mountains and Sevier gravity slides). Although the Markagunt gravity slide was not recognized to extend as far north as the area of the Beaver 30' x 60' quadrangle during our initial mapping (e.g., Rowley and others, 2005), we now know that it underlies most of the Beaver quadrangle, including most of the Tushar Mountains. Furthermore, we now understand that the western extent of the slide complex comprises the younger Black Mountains gravity slide in and south of the southern Mineral Mountains; based on new age control and other considerations discussed in Biek and others (2019), the Black Mountains slide is not part of the Markagunt gravity slide as we previously envisioned (Rowley and others, 2018). We continue to work at defining their common boundary.

In addition to the Markagunt and Black Mountains gravity slides, two small gravity slides, the Minersville gravity slide and the Showalter Mountain gravity slide, are exposed in the Beaver quadrangle south of the mapped area

(Rowley and others, 2014, 2018); both appear to be slightly older than the Markagunt and Black Mountains gravity slides and therefore were in turn carried along by the younger slides. Therefore, in the mapped area, nearly all exposed rocks except the Late Triassic Petrified Forest Member of the Chinle Formation and older rocks, and those younger than about 18 Ma, have been transported generally southward as part of the Black Mountains or Markagunt gravity slides.

The map units involved in the gravity slides are not deformed or little deformed in many places, so they may be easily correlated with named rock units not involved in the slides or that were mapped and named before recognition of the slides (e.g., Cunningham and others, 1983; Rowley and others, 2002, 2005). Therefore, following the usage of Biek and others (2015a, 2015b), rocks involved in the slides are designated with a symbol consisting of a prefix "Tm," followed in parentheses by the symbol for the named undeformed rock unit, for example, Tm(Tda)—the alluvial facies of the Mount Dutton Formation as part of the Markagunt gravity slide. We use the prefix Tbm for those rocks that are part of the Black Mountains gravity slide. Components of the slides are listed below; for their descriptions, see the named pre-existing (undeformed) rock unit, given elsewhere in the text and in the correlation chart in their proper stratigraphic positions.

Black Mountains Megabreccia (Miocene) – The Black Mountains gravity slide is the most recently discovered part of the Marysvale gravity slide complex, and because the vast bulk of its upper plate rocks are volcanic mudflow breccia and lava flows, it remains the most poorly understood. Presently, we interpret the main slip surface to be at the base of the volcanic section in the southern Mineral Mountains, and we interpret a secondary, deeper failure plane in the upper part of the Upper Triassic Chinle Formation. This deeper slip surface places Lower Jurassic Navajo Sandstone in the upper plate on Lower Triassic Shinarump Member of the Chinle Formation. Nearly 1000 feet (300 m) of Upper Triassic to Lower Jurassic strata—including the upper, non-resistant members of the Chinle Formation, Moenave Formation, and Kayenta Formation—are missing.

Tbm(Ticl)

Black Mountains Megabreccia, Lincoln Stock component

Tbm(Tdv)

Black Mountains Megabreccia, Mount Dutton Formation, vent facies component

Tbm(Tda)

Black Mountains Megabreccia, Mount Dutton Formation, alluvial facies component

Tbm(Tin)

Black Mountains Megabreccia, Isom Formation and the Needles Range Group component

Tbm(Tcg)

Black Mountains Megabreccia, conglomerate component

Tbm(Jc)

Black Mountains Megabreccia, Carmel Formation component

Tbm(Jn)

Black Mountains Megabreccia, Navajo Sandstone component

Mount Belknap Volcanics (lower Miocene) – Large masses of high-silica rhyolite derived from several caldera and volcano eruptive centers in the Tushar Mountains and Marysvale mining district (Callaghan, 1939; Cunningham and Steven, 1979; Rowley and others, 1979, 2002; Cunningham and others, 1983; Steven and others, 1984b); map units and their source plutons (Tig) have considerable mineral potential, primarily uranium, molybdenum, and alunite (Kerr and others, 1957; Callaghan, 1973; Steven and others, 1981, 1984a; Podwysocki and Segal, 1983; Beatty and others, 1986; Steven and Morris, 1987; Cunningham and others, 1982, 1984a, 1984b, 1994, 1998a, 1999, 2005); isotopic ages from many types of analyses range from 21 to 12 Ma (Cunningham and others, 1998b) and show that volcanism occurred in several pulses, not including the rhyolite of Gillies Hill, which is a younger, perhaps more western pulse tied more closely to multiple pulses in the Mineral Mountains; of the Mount Belknap pulses, the most prominent, at least in terms of volume of erupted products, is at about 19 Ma with the initial eruption (Joe Lott Tuff Member), then subsidence, then filling of the Mount Belknap caldera, including emplacement of its intracaldera (resurgent) pluton; only the western part of this caldera and its included rocks is in the mapped area (Cunningham and Steven, 1979); the intracaldera pluton is not exposed in the mapped area (it is just east of the mapped area, in the headwaters of the North Fork of North Creek), although a suggested small apophysis, called the U-Beva stock (Cunningham and others, 1984b), was proposed in the lower part of the North Fork of North Creek, northeast of Beaver, but the senior author revisited the area and reinterpreted the rock here as a crystal-rich ash-flow tuff intertongued with lava flows of the Mount Baldy Member (Tmb); this tuff was dated by fission-track methods on zircon of 19.8 + 1.2 Ma and on apatite of 13.4 + 2.7 Ma, the latter of which was partly reset by a younger pulse of magmatism, perhaps by an underlying pluton that fed the rhyolite of Gillies Hill (Cunningham and others, 1984b); resetting of older ages with similar results is indicated by the calc-alkaline Indian Creek stock (Tm[Tic]), exposed along Indian Creek west of the Mount Belknap caldera, where samples yielded fission track ages on zircon of 19.3 + 1.0 Ma and on apatite of 12.8 + 2.1 Ma; the former of these was reset by the underlying intracaldera intrusion, whereas the latter was partly reset by the pluton that fed the rhyolite of Gillies Hill (Cunningham and others, 1984b).

Tmj **Joe Lott Tuff Member of the Mount Belknap Volcanics** (lower Miocene) – Moderately resistant, light-gray and tan, partly welded, crystal-poor (about 1 percent total crystals of quartz, sanidine, and plagioclase), high-silica rhyolite ash-flow tuff, with a black basal vitrophyre; the main outflow unit derived from the Mount Belknap caldera (Cunningham and Steven, 1979), which is well exposed as several thick cooling units in lower Clear Creek Canyon 24 miles (39 km) northeast of the mapped area (Budding and others, 1987; Rowley and others, 2002; Hintze and others, 2003); rocks of the Mount Belknap Volcanics and their source plutons in the Mount Belknap caldera and the Central mining area near Marysvale are part of the bimodal magmatic episode and contain ore deposits of lithophile elements such as uranium, alunite, and molybdenum in the Beaver and Richfield 30' x 60' quadrangles (Kerr and others, 1957; Callaghan, 1973; Cunningham and others, 1982, 1984a, 1998a, 1998b, 2005, 2007; Hintze and others, 2003; Rowley and others, 2005, 1988a, 1988b; Steven and others, 1981); K-Ar ages on overlying and underlying units indicate an age of the map unit of 19 Ma (Steven and others, 1979), and this interpretation is confirmed by a new $^{40}Ar/^{39}Ar$ age on sanidine of 19.12 + 0.10 Ma (UGS and NMGRL, 2019b); previous K-Ar ages (18.3 + 1.1 Ma on sanidine and 17.2 + 0.7 Ma on vitrophyre) directly on the Joe Lott by Budding and others (1987) are considered too young; as such, this unit is one of the oldest known that postdates emplacement of the Markagunt gravity slide, as discussed below; maximum thickness about 400 feet (120 m).

Tmm **Middle tuff member and lower tuff member of the Mount Belknap Volcanics** (lower Miocene) – Soft, light-gray and tan, poorly welded, crystal-poor intracaldera rhyolite ash-flow tuff that is lithologically similar to Tmj, with which it is locally continuous across the margin of the Mount Belknap caldera; the lithologically similar lower tuff member is exposed beneath the Blue Lake Rhyolite Member (Tmbl) in deep canyons in the eastern part of the caldera (Cunningham and Steven, 1979; Cunningham and others, 1983); the middle tuff member is about 1600 feet (500 m) and the lower tuff member is at least 1500 feet (460 m) thick; the bases of both units are not exposed.

Tmb **Mount Baldy Rhyolite Member of the Mount Belknap Volcanics** (lower Miocene) – Resistant, light-gray, crystal-poor intracaldera rhyolite lava flows and dikes derived from, and deposited mostly within, the Mount Belknap caldera; the fission-track age of 19.8 Ma on zircon noted above on the so-called U-Beva stock probably represents the isotopic age of an ash-flow tuff within the member; thickness about 2600 feet (800 m).

Tmv **Volcaniclastic rocks of the Mount Belknap Volcanics** (lower Miocene) – Soft to moderately resistant, light-gray and white, mostly intracaldera volcanic mudflow breccia derived from, and deposited within, the Mount Belknap caldera; includes landslide debris and fluvial sandstone and conglomerate; thickness about 800 feet (240 m).

Tmbl **Blue Lake Rhyolite Member of the Mount Belknap Volcanics** (lower Miocene) – Lower parts of the intracaldera fill of the Mount Belknap caldera, which in turn is underlain by the lower tuff member (see unit Tmm above); the Blue Lake Member is a moderately resistant, gray, flow-foliated, crystal-poor lava flow about 1100 feet (340 m) thick.

Tkl **Potassium-rich mafic lava flows** (lower Miocene and upper Oligocene) – Resistant, black and dark-gray, locally vesicular and amygdaloidal, crystal-poor lava flows and scoria that resemble basalt but chemical analyses show to be high in K_20 (Best and others, 1980; Cunningham and others, 1983; Rowley and others, 1994, 2002); formerly referred to as "older basalt" (Anderson and Rowley, 1975); Mattox and Walker (1989, 1990), Walker and Mattox (1989), and Mattox (1991, 1992) considered the unit to represent the termination of eruption of the Mount Dutton Formation (Tdv, Tda), but we consider the rocks to represent the initial product of bimodal (extension-related) volcanism (Cunningham and others, 1998b), with K-Ar ages of 25 to 21 Ma; with such ages, it is likely some of the older flows have moved within the Markagunt gravity slide, but we have not found field evidence for this, at least in the mapped area; exposed north and south of the canyon of the Beaver River, east of Beaver; maximum thickness about 500 feet (150 m).

Markagunt Megabreccia (lower Miocene) – The Markagunt Megabreccia is mapped in the Tushar Mountains, Markagunt Plateau, and westernmost Sevier Plateau and forms the largest component of the Marysvale gravity slide complex described earlier. The breakaway area is overprinted by the Mount Belknap caldera. In this map area, the basal slip surface is deeply buried and the Markagunt Megabreccia is characterized by little deformed, kilometer-scale blocks.

Tm(Tic)

Markagunt Megabreccia, calc-alkaline intrusive rocks component

Tm(Tbc)

Markagunt Megabreccia, Bullion Canyon Volcanics component

Tm(Tbcd)

Markagunt Megabreccia, Bullion Canyon Volcanics, Delano Peak Tuff Member component

Tm(Tbct)

Markagunt Megabreccia, Bullion Canyon Volcanics, Three Creeks Tuff Member component

Tm(Tdv)

Markagunt Megabreccia, Mount Dutton Formation, vent facies component

Tm(Tdb)

Markagunt Megabreccia, Mount Dutton Formation, Beaver Member component

Tm(Tlb)

Markagunt Megabreccia, Mafic lava flows of Birch Creek Mountain component

Tm(Tlj)

Markagunt Megabreccia, volcanic rocks of Lousy Jim component

Tm(Tlf)

Markagunt Megabreccia, Tuff of Lion Flat component

Tm(To)

Markagunt Megabreccia, Osiris Tuff outflow facies component

Tm(Tbb)

Markagunt Megabreccia, Buckskin Breccia component

Tic **Calc-alkaline intrusive rock** (lower Miocene to lower Oligocene) – Moderately resistant, gray, tan, pink, and brown, crystal-rich monzonite, low-silica granite, granodiorite, and monzodiorite; the calc-alkaline sources of the Mount Dutton Formation (Tdv, Tda), Bullion Canyon Volcanics (Tbc), and other calc-alkaline volcanic units, and the calc-alkaline early intrusive products of the Mineral Mountains batholith; calc-alkaline intrusive rocks and bimodal intrusive rocks (Tig), as well as other intrusive units mapped here, represent the cupolas of a large composite batholith that underlies the east-trending Pioche-Marysvale igneous belt (Rowley, 1998), including the Marysvale volcanic field, and extends westward beyond the Nevada border, as indicated by geophysics (Steven and Morris, 1987; Rowley, 1998; Campbell and others, 1999; Rowley and others, 1998, 2002) and geologic mapping (Steven and others, 1990); isotopic ages of the map unit cluster at about 25 to 23 Ma in the Tushar Mountains (Steven and others, 1979; Cunningham and others, 1984a) and about 26 Ma based on U-Pb zircon analyses (Alienikoff, and others, 1987); intruded by the granite (Tig) in the western Mineral Mountains, resetting all isotopic ages that have been attempted (Nielson and others, 1978, 1986; Aleinikoff and others, 1986; Coleman and others, 2001; McDowell, 2004); exposed in several areas in the western Tushar Mountains, including the Indian Creek stock, where fission-track ages have been reset by plutons that erupted the Mount Belknap Volcanics; upper parts of some plutons, such as the Indian Creek stock, were beheaded by the Markagunt gravity slide and carried in the slide.

Ticl **Lincoln Stock** (lower Miocene) – Resistant, light-gray monzonite and granodiorite porphyry stock in the southern Mineral Mountains (Earll, 1957; Corbett, 1984; Price, 1998), resulting in contact metamorphic lead-zinc-gold ore deposits of the Lincoln and Bradshaw mining districts in the mapped area; pluton is interpreted here to represent a calc-alkaline phase of the Mineral Mountains batholith; the stock itself is in the mapped area, but several dikes thought to be related to the main stock are present in and just south of the mapped area (Rowley and others, 2018); these dikes, which intruded to higher levels than the main part of the stock, were beheaded by the Markagunt gravity slide and carried in the slide, but the main, deeper part of the stock was not affected by the slide; stock has a K-Ar age of 21.9 Ma (Bowers, 1978) and a preliminary U-Pb zircon age of about 23 Ma (Coleman and others, 1997, 2001), and one of the dikes has K-Ar ages of 22.5 + 0.9 (biotite) and 22.3 + 0.8 Ma (sanidine) (Rowley and others, 1994).

Tbc **Bullion Canyon Volcanics** (lower Miocene to lower Oligocene) – Moderately resistant, tan, gray, pink, and light-green lava flows, flow breccia, volcanic mudflow breccia, and minor ash-flow tuff and fluvial conglomerate and sandstone (Callaghan, 1939; Rowley and others, 1979; Steven and others, 1979; Cunningham and others, 1984b, 1994, 1998b, 2007; Rowley and others, 1998, 2002); the product of clustered stratovolcanoes, made up of undivided vent-facies and alluvial-facies rocks; the second-most voluminous stratigraphic unit in the Marysvale volcanic field; mostly crystal-rich dacite, thus more highly evolved than the Mount Dutton Formation, with which it intertongues; unit derived from intrusive sources that are abundantly exposed elsewhere in the Beaver 30' x 60' quadrangle (Rowley and others, 2005) and are much more shallow than those for the Mount Dutton Formation; isotopic dates and stratigraphic relationships indicate an age range of at least 30 to 22 Ma (Steven and others, 1979; Kowallis and Best, 1990; Rowley and others, 1994); rocks of the unit and its source plutons have high potential for mineral resources of the chalcophile elements (Callaghan, 1973; Steven and others, 1979; Steven and Morris, 1987; Cunningham and others, 1984b, 1994, 1998b, 2007); thickness at least 5000 feet (1500 m).

Tbcd **Delano Peak Tuff Member of the Bullion Canyon Volcanics** (upper Oligocene) – Resistant, dark-reddish-brown, densely welded, crystal-rich, dacitic ash-flow tuff best exposed in the central Tushar Mountains (Cunningham and others, 1984b; Steven and others, 1984a, 1984b); exposed in one place in the canyon of the Beaver River east of Beaver and in many places in the Tushar Mountains at the northern edge of the mapped area that have been carried in the Markagunt gravity slide; yielded new $^{40}Ar/^{39}Ar$ ages on the map unit of 26.80 + 0.15 Ma (hornblende) and 26.96 + 0.07 Ma (biotite) (UGS and NMGRL, 2019b); maximum thickness about 600 feet (200 m).

Tbct **Three Creeks Tuff Member of the Bullion Canyon Volcanics** (upper Oligocene) – Resistant, light- to medium-gray and locally pink, moderately welded, crystal-rich, dacitic ash-flow tuff that contains at least several percent each of lithic clasts and collapsed pumice; contains 35 to 45 percent phenocrysts, mostly distinctively large (as much as 5 mm long) plagioclase but also including as much as 10 percent hornblende, less abundant (3 percent) but especially conspicuous biotite, 1.5 percent Fe-Ti oxides, 1 to 2 percent quartz, and trace amounts of sanidine and clinopyroxene (Steven and others, 1979; Best and Grant, 1987); probably the most voluminous tuff in the Marysvale volcanic field, derived from the Three Creeks caldera on the northern side of Clear Creek Canyon (Steven and others, 1979, 1984b, 1990), which is controlled by the Cove Fort transverse zone (Rowley, 1998; Rowley and others, 2002); K-Ar age is about 27 Ma (Steven and others, 1979); forms one small exposure several tens of feet thick north of Wittwer Hill in the northeast corner of the map area; maximum thickness in the Tushar Mountains is about 600 feet (200 m).

Mount Dutton Formation (lower Miocene to lower Oligocene) – Resistant to non-resistant, brown, tan, pink, and gray, volcanic mudflow breccia made up mostly of matrix-supported angular clasts as well as resistant lava flows and flow breccia; the clasts in the mudflow breccia and the lava flows are of crystal-poor, generally pyroxene-bearing, andesitic rock of the same lithology; unit also includes minor fluvial and eolian sandstone and conglomerate whose clasts are the same lithology (Anderson and Rowley, 1975); deposited from clustered stratovolcanoes that form most of the southern Marysvale volcanic field (e.g., Callaghan, 1939; Anderson and Rowley, 1975; Rowley and others, 1979, 1998, 2002; Steven and others, 1979, 1990; Cunningham and others, 1983; Campbell and others, 1999); K-Ar dated at 26 to 21 Ma (Fleck and others, 1975) but some deposits predate the Wah Wah Springs Formation and therefore are 30 Ma or older; the most voluminous unit in the Marysvale volcanic field; thickness in the area at least 6000 feet (1800 m).

Tdv **Vent facies of the Mount Dutton Formation** (lower Miocene to lower Oligocene) – Lava flows, volcanic mudflow breccia, and flow breccia interpreted to represent near-source eruptions (Anderson and Rowley, 1975); many of the source stratovolcanoes are aligned east-west along the east-striking Blue Ribbon transverse zone (Rowley and others, 1978, 1998; Rowley, 1998), which passes across the southeast and southwest quarters of the Beaver 30' x 60' quadrangle west from Kingston Canyon (Rowley and others, 1981) along the break in slope between the Tushar Mountains and Markagunt Plateau (Anderson and others, 1990a, 1990b), then along the northern side of the Black Mountains and on to the west.

Tda **Alluvial facies of the Mount Dutton Formation** (lower Miocene to lower Oligocene) – Primarily volcanic mudflow breccia in which lithologies are more heterogeneous than in the vent facies, representing deposits interpreted to have traveled farther from the source, down the flank of individual stratovolcanoes (Anderson and Rowley, 1975), passing into conglomerate still farther from the source; the unit is by far the most voluminous component of the formation.

Tdb **Beaver Member** – Resistant, gray, pink, tan, green, and reddish-brown, dense, thick-bedded, crystal-rich, andesite porphyry lava flows and flow breccia of several volcanic domes, and local tuffaceous sandstone, volcanic mudflow breccia, and tuff (Anderson and Rowley, 1975); corrected K-Ar ages of 26.2 + 0.8 and 25.0 ± 0.5 Ma (Fleck and others, 1975); exposed only south of Beaver (Rowley and others, 2018); maximum thickness about 600 feet (200 m).

Tlj **Volcanic rocks of Lousy Jim** (lower Miocene) – Resistant, light- to dark-gray, flow-foliated, crystal-rich trachydacite porphyry lava flows and flow breccia forming a volcanic dome east of Beaver that is about 5 miles (8 km) in diameter (Sigmund, 1979); Fleck and others (1975) determined K-Ar ages of 22.6 Ma, but these are supplanted by a new ^{40}Ar/^{39}Ar age on sanidine of 22.88 + 0.02 Ma (UGS and NMGRL, 2019b); thickness about 1000 feet (300 m).

Tlf **Tuff of Lion Flat** (lower Miocene) – Non-resistant, pink, white, tan, and gray, unwelded, crystal-poor, rhyolite ash-flow tuff and minor airfall and water-laid tuff (Wickstrom, 1982; Lanigan and Anderson, 1987); probably tuff-ring deposits related to eruption of the volcanic rocks of Lousy Jim (Tlj), which overlies the tuff of Lion Flat (Rowley and others, 2002); maximum thickness about 300 feet (100 m).

To **Osiris Tuff, outflow facies** (lower Miocene) – Resistant, light-gray (upper vapor phase zone) and brown (lower part), densely welded, moderately crystal-rich, rhyodacitic ash-flow tuff containing prominent euhedral biotite phenocrysts (Williams and Hackman, 1971); one or two cooling units containing black basal vitrophyres; contains drawn-out pumiceous lenticules; upper part locally contains steeply dipping flow-foliated rock caused by secondary flowage of rock fused in the last few tens of feet of movement; derived from the Monroe Peak caldera, the largest in the Marysvale volcanic field (Steven and others, 1984b; Rowley and others, 1986a, 1986b) and just east of the mapped area; the preferred age of the Osiris is about 23 Ma (Fleck and others, 1975; Rowley and others, 1994; Cunningham and others, 2007; Ball and others, 2009; UGS and NMGRL, 2019c; Willis and Doelling, 2019; Rivera, written communication, June 18, 2019); maximum thickness about 200 feet (60 m).

Tlb **Mafic lava flows of Birch Creek Mountain** (lower Miocene and upper Oligocene) – Moderately resistant, dark-gray to black, vesicular to dense lava flows of olivine-bearing basaltic andesite or trachybasalt exposed in and near Birch Creek Mountain in the southeastern Tushar Mountains, east of this map area (Wickstrom, 1982; Anderson and others, 1990a, 1990b); contains typically anhedral phenocrysts of olivine (generally altered to iddingsite), augite, and plagioclase generally less than 1 mm long in a groundmass generally of devitrified glass consisting of microlites of plagioclase, augite, and Fe-Ti oxides; perhaps correlative with an early eruptive sequence of the potassium-rich mafic lava flows exposed east of the mapped area; map unit appears to be a source of the mafic gravels of Gunsight

Flat, exposed just east of the mapped area and interpreted to have been deposited in basins created by north-dipping (antithetic) faults of the Markagunt gravity slide; corrected K-Ar ages from samples of two flows are 22.9 ± 0.4 and 22.4 ± 0.4 Ma ("older basalts" of Fleck and others, 1975), but these are supplanted by a new $^{40}Ar/^{39}Ar$ age of 23.51 ± 0.06 Ma on a groundmass concentrate (UGS & NMGRL, 2019b); thickness typically 200 feet (60 m) to as much as 500 feet (150 m).

Tin **Isom Formation and the Needles Range Group, undivided** (upper and lower Oligocene)

Isom Formation (upper Oligocene) – Resistant, brown and reddish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff (Mackin, 1960; Fryman, 1987) derived apparently from the Indian Peak caldera complex at the Utah-Nevada border (Best and others, 1989a, 1989b); age about 27–26 Ma on the basis of many $^{40}Ar/^{39}Ar$ and K-Ar ages (Best and others, 1989b; Rowley and others, 1994); exposed in the southern Mineral Mountains; maximum thickness about 60 feet (20 m).

Needles Range Group (lower Oligocene) – Resistant, gray, tan, pink, medium-red, and light-purple, crystal-rich, moderately welded, dacite ash-flow tuff (Mackin, 1960) derived from the Indian Peak caldera complex (Best and others, 1989a, 1989b); exposed in the Minersville area, where it consists of both the Lund Formation (27.9 Ma; Best and others, 1989a) and the Wah Wah Springs Formation (about 29.5 Ma; Best and Grant, 1987; Best and others, 1989a, Rowley and others, 1994); maximum thickness about 100 feet (30 m).

Unconformity

Tcg **Conglomerate** (Eocene and/or Paleocene) – Moderately resistant, white, tan, and light-gray, fluvial conglomerate and sandstone characterized by pebbles to boulders of quartzite and carbonates as much as 3 feet (1 m) in diameter, resting unconformably on Mesozoic sedimentary rocks and disconformably overlain by Tertiary volcanic rocks; basal deposits south of Utah Highway 21 locally contain angular blocks of bleached and iron-stained Navajo Sandstone; maximum thickness is about 120 feet (40 m); we interpret that these beds contain the main shear plane of the Black Mountains gravity slide in the southern Mineral Mountains and northern Black Mountains.

K unconformity

Jc **Carmel Formation, undivided** (Middle Jurassic) – Slope- and ledge-forming, light-gray, reddish-brown, and tan, thin-bedded limestone and calcareous shale underlain by resistant, light-gray, thin- to medium-bedded, locally fossiliferous limestone (Earll, 1957); exposed in the southern Mineral Mountains south of the Cherry Creek fault; as described by Earll (1957) likely consists of the resistant basal Co-op Creek Member capped by its distinctive oolitic and fossiliferous limestone ledge, an inconspicuous and thin Crystal Creek Member, and the Paria River Member, here apparently lacking gypsum; incomplete section is about 600 feet (200 m) thick as measured near the head of structurally complicated Cherry Creek Canyon (Earll, 1957).

We follow Carmel Formation nomenclature of Sprinkel and others (2011a) and Doelling and others (2013). The Carmel Formation was deposited in a shallow sea of a back-bulge basin and, together with the underlying Temple Cap Formation, provides the first clear record of the effects of the Sevier orogeny in southwestern Utah (Sprinkel and others, 2011a; Phillips and Morris, 2013). Middle Jurassic age is from Imlay (1980), Sprinkel and others (2011a), and Doelling and others (2013). Pipiringos and O'Sullivan (1978) interpreted that Temple Cap and Carmel strata were separated by their J-2 unconformity, but new radiometric ages and palynomorph data suggest that the J-2 does not exist or is a very short hiatus in southern Utah (Sprinkel and others, 2011a; Doelling and others, 2013).

Jt **Temple Cap Formation, undivided** (Middle Jurassic) – Not present or not exposed, but regionally in western exposures consists of a thin interval of reddish-brown, thin-bedded sandstone and siltstone of the Manganese Wash Member (Sprinkel and others, 2011a).

J-1 unconformity (Pipiringos and O'Sullivan, 1978) formed prior to 173 million years ago in southwest Utah (Sprinkel and others, 2011a).

Jn **Navajo Sandstone** (Lower Jurassic) – Resistant, pale-reddish-orange and light-gray or white, cross-bedded, fine- to medium-grained, eolian sandstone (Earll, 1957; Price, 1998); white color is due to alteration, remobilization, and bleaching of limonitic and hematitic (iron-bearing) cement, probably due to hydrocarbon migration (see, for example, Chan and others, 2000; Beitler and others, 2003; Potter and Chan, 2011); typically highly fractured; bedding consists of high-angle, large-scale cross-bedding in tabular planar, wedge planar, and trough-shaped sets 10 to 45 feet or more (3–14+ m) thick; upper, unconformable contact is the J-1 regional unconformity, here corresponding to a subtle break in slope, with cross-bedded sandstone below and micritic limestone above (the intervening, thin Manganese Wash Member of the Temple Cap Formation is either not exposed or is missing; deposited in a vast coastal and inland dune field with prevailing winds principally from the north (Blakey, 1994, 2008; Peterson, 1994); zircon studies show that much of the sand was derived from the Appalachian (475–525 Ma) and Grenville (1125–1225 Ma) orogens of eastern North America (Dickinson and Gehrels, 2003, 2009a, 2009b; Rahl and others, 2003; Reiners and others, 2005); a transcontinental river system transported the sand to areas north and northwest of Utah (Marzolf, 1988), which was subsequently blown southward into what is commonly thought to be the world's largest coastal and inland paleodune field (Milligan, 2012; Rodríguez-López and others, 2014); correlative in part with the Nugget Sandstone of northern Utah and Wyoming and the Aztec Sandstone of southern Nevada and adjacent areas (see, for example, Kocurek and Dott, 1983; Riggs and others, 1993; Sprinkel and others, 2011b); exposed northeast of Minersville and east of the mapped area in the central Tushar Mountains; maximum exposed thickness about 1500 feet (450 m) northeast of Minersville (Earll, 1957) and 2000 feet (600 m) in the central Tushar Mountains (Rowley and others (2005).

Fault cuts out the Kayenta Formation, the Moenave Formation, and most of the Chinle Formation. Earll (1957, p. 33) was the first to notice that Chinle strata were missing in the southern Mineral Mountains, which he interpreted as a slight angular unconformity between Navajo and underlying Moenkopi strata. We interpret this "unconformity" as the lowest slip surface of the Black Mountains gravity slide, with highly fractured Navajo Sandstone in the upper plate resting on pebbly conglomerate of the Shinarump Member of the Chinle Formation. Smectitic mudstone of the upper Chinle facilitated down-to-the-south movement on this gently south-dipping low-angle normal fault.

TRcm **Chinle Formation and Moenkopi Formation, undivided** (Lower to Upper Triassic) – Undivided at southern map boundary due to structural complexity and map scale.

Chinle Formation (Upper Triassic) – The nearest well-studied Chinle exposures are about 75 miles (120 km) east (at Capitol Reef National Park) and south (in the St. George basin) of the map area. At Capitol Reef, Kirkland and others (2014) provided a comprehensive summary of the formation where they recognized five members: from oldest to youngest these are the Shinarump, Monitor Butte, Moss Back, Petrified Forest, and Owl Rock Members (the Church Rock Member, commonly the uppermost member throughout the region, is not recognized in the Capitol Reef area). In this map area, we recognize only part of the Shinarump Member, the upper members having been cut out along a low-angle normal fault.

The Chinle Formation was deposited in a variety of fluvial, floodplain, palustrine, and lacustrine environments of a back-arc basin formed inland of a magmatic arc associated with a subduction zone along the west coast of North America; resistant, locally conglomeratic sandstones, including the Shinarump Member, were deposited in braided and meandering streams that flowed north and northwest, whereas mudstone intervals were deposited in floodplains, lakes, and swamps (e.g., Stewart and others, 1972a; Blakey and Gubitosa, 1983, 1984; Lucas, 1993; Dubiel, 1994; Lucas and Tanner, 2007; Dubiel and Hasiotos, 2011). Chinle strata are among the most productive of fossilized continental plants and vertebrates in the world (Benton, 1995). Swelling, smectitic mudstone and claystone are common in the Chinle and although typically poorly exposed, their bright purple, grayish-red, dark-reddish-brown, light-greenish-gray, brownish-gray, olive-gray, and similar hues locally show through to the surface—these clay-rich beds weather to a "popcorn" surface and are responsible for numerous building foundation problems and landslides across its outcrop belt. The Chinle Formation represents a span of about 25 million years, from about 228 to 203 Ma, during the Late Triassic (Irmis and others, 2011; Ramezani and others, 2011, 2014).

TRcs **Shinarump Member of the Chinle Formation** (Upper Triassic) – Moderately resistant, light-gray and tan sandstone and subordinate pebble conglomerate typically poorly exposed in the southern Mineral Mountains; clasts are subrounded quartz, quartzite, and chert; locally contains minor gray to greenish-gray siltstone and mudstone lenses; medium- to thick-bedded with both planar and low-angle cross-stratification and common scour and fill structures; regionally, upper contact with other members of the Chinle Formation is gradational and interfingering (Stewart and others, 1972a), but here a covered interval as much as a few tens of feet thick locally separates the Shinarump Member below from the Navajo Sandstone above—a fault cuts out the Kayenta Formation, the Moenave Formation, and most of the Chinle Formation; locally, highly fractured Navajo Sandstone appears to rest on the Shinarump Member but is distinguished from the Shinarump in that it has no pebbles and has eolian rather than fluvial sedimentary structures;

this covered interval is interpreted to contain a major shear plane of the Black Mountains gravity slide; lower Norian age from the likely correlative Mesa Redondo Member of northern Arizona (Ramezani and others, 2014); an incomplete section of Shinarump strata is likely as much about 30 feet (9 m) thick.

TR-3 unconformity (Pipiringos and O'Sullivan, 1978), a widespread episode of erosion across the western U.S. that spans about 10 Ma during late Middle and early Late Triassic time (e.g., Kirkland and others, 2014).

Ћm **Moenkopi Formation, undivided** (Lower Triassic) – The Moenkopi Formation is undivided here following Earll (1957) who recognized lower and upper non-resistant red bed units separated by a ledge- and slope-forming middle limestone and calcareous shale unit; red bed units are reddish-brown and yellowish-brown, calcareous, fine-grained sandstone, siltstone, and shale with common ripple marks and local thin interbedded limestone; the middle limestone interval is typically medium bedded, gray or brownish gray, locally fossiliferous, and interbedded with calcareous shale; the base of the formation is a chert pebble conglomerate as much as about 15 feet (5 m) thick; the entire formation is about 1300 to 1700 feet (400–500 m) thick (Earll, 1957).

Regionally, the Moenkopi consists of three transgressive members (the Timpoweap, Virgin Limestone, and Shnabkaib Members that each record an interval of sea-level rise), each of which is overlain by an informally named regressive red-bed member (the lower, middle, and upper red members, respectively, which record sea-level fall); the Rock Canyon Conglomerate Member locally forms the base of the Moenkopi Formation (Reeside and Bassler, 1921; Stewart and others, 1972b; Dubiel, 1994). These members thus record a series of incursions and retreats of a shallow ocean across a gently sloping continental shelf, where sea-level changes of several feet translated into shoreline changes of many miles (Blakey and others, 1993; Dubiel, 1994). Earll's (1957) lower red bed unit comprises the Rock Canyon, Timpoweap, and lower red members, his middle limestone unit comprises the Virgin Limestone, likely thin middle red member, and Shnabkaib Member (where Price [1988] recognized two main limestone intervals), and his upper red bed unit comprises the upper red member. In the greater St. George area, the Shnabkaib Member is characterized by interbedded reddish-brown mudstone and white gypsum, giving the member its classic "bacon striped" appearance, but here this interval is mostly limestone.

TR-1 unconformity (Pipiringos and O'Sullivan, 1978) spans 10 to 20 million years during Late Permian and Early Triassic time in southwestern Utah (Nielson, 1981, 1991; Sorauf and Billingsley, 1991). The unconformity represents an episode of dramatic, worldwide sea-level drop and the largest global extinction event in Earth's history (see, for example, Ward, 2004).

Ppt **Plympton, Kaibab, and Toroweap Formations, undivided** (Lower Permian) – Undivided in the southern Mineral Mountains due to structural complexity and map scale.

Ppk **Plympton and Kaibab Formations, undivided** (Lower Permian) – Undivided in the southern Mineral Mountains due to structural complexity and map scale.

Plympton Formation (Lower Permian) – Moderately resistant, white, light- to medium-gray, and tan, thin- to medium-bedded (weathers to light-tan plates), hackly and ledgy, marine dolomite and limestone that contain sparse yellow and brown chert beds and stringers; interbedded with subordinate to minor, poorly exposed siltstone and sandstone; includes a thin coquina of unidentified fossil shells; at the south end of Yellow Mountain, J.E. Welsh (unpublished data, 1978) measured the unit at 244 feet (74 m) thick, but we consider only about the upper 100 feet (30 m) of his section, consisting of thin-bedded dolomite and sandstone, to be Plympton, and the underlying ledges of brown cherty dolomite to be the Kaibab Formation.

Pk **Kaibab Formation** (Lower Permian) – Resistant, light- to dark-gray, medium-grained, thin- to thick-bedded, highly fossiliferous (mostly crinoids, also bryozoa and brachiopods), shallow-marine limestone and, at the top, dolomite that are intertongued with minor, poorly exposed, buff, fine-grained sandstone and siltstone; limestone and dolomite characterized by cliffs and ledges and by abundant dark-brown and tan chert concretions, lacy stringers, and beds, giving especially the upper part of the formation a banded, "zebra stripe" appearance; limestone includes white sparry calcite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); in southwestern Utah, divided into the lower Fossil Mountain Member and upper Harrisburg Member (see, for example, Biek and others, 2009), but undivided here as it lacks gypsum (Corbett, 1984) characteristic of the Harrisburg Member; deposited in a shallow-marine environment when southwestern Utah lay just north of the equator, at the western margin of the supercontinent Pangea (McKee, 1938; Nielson, 1981, 1986; Sorauf and Billingsley, 1991); Earll (1957) reported a thickness of about 700 feet (210 m), which appears to include all Permian carbonates at Yellow Mountain; J.E. Welsh (unpublished data, 1978) reported a maximum thickness for Kaibab strata of about 400 feet (120 m) at Yellow Mountain.

P-k unconformity (Blakey, 1996)

Pt **Toroweap Formation** – Generally resistant, mostly light- to medium-gray, locally dark-gray, light-blue-gray, light-greenish-gray, and black, fine-grained, thin- to medium-bedded, ledgy, marine limestone (exhibits a phosphatic smell from phosphate pisolites) and subordinate interbedded, light-gray, thin-bedded, locally cross-bedded, fine-grained sandstone; contains sparse, lacy, white and brown chert concretions, stringers, and beds; locally fossiliferous (mostly crinoids, some horn corals, bryozoa, and productid brachiopods, as noted by J.E. Welsh); in several places in the Lincoln and southern Bradshaw districts, near the intrusive contact with the Lincoln Stock (Til), veined light- and blue-gray, black, red, and yellow, fine-grained marble and limestone are mined as "Picasso stone" for polished facings on buildings and for sculptures; in southwestern Utah, divided into the lower Seligman Member, middle Brady Canyon Member, and upper Woods Ranch Member (see, for example, Biek and others, 2009), but undivided here as it lacks gypsum (Corbett, 1984) characteristic of the lower and upper members; deposited in a shallow-marine environment when southwestern Utah lay just north of the equator, at the western margin of the supercontinent Pangea (McKee, 1938; Rawson and Turner-Peterson, 1979, 1980; Nielson, 1981, 1986); well exposed at Yellow Mountain where it is about 280 feet (85 m) thick (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978), and on and east of Bradshaw Mountain, where it is about 300 feet (100 m) thick.

P-tw unconformity (Blakey, 1996)

PIPc **Queantoweap Sandstone, Pakoon Dolomite, and Callville Limestone, undivided** (Lower Permian and Pennsylvanian) – Mapped above the Cave Canyon low-angle normal fault west of Soldier Pass in the southern Mineral Mountains; combined thickness about 300 feet (100 m) although the base is not exposed.

Pq **Queantoweap Sandstone** (Lower Permian) – Resistant, tan and pink, medium- to thick-bedded, ledgy, cross-bedded, fine-grained sandstone and orthoquartzite and minor dolomite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); deposited in shallow-marine, beach, and dune environments (Nielson, 1981; Johansen, 1988); Leonardian to Wolfcampian (Early Permian) age from Blakey (1996); caps Bradshaw Mountain, where J.E. Welsh (unpublished data, 1978) measured an incomplete section of about 500 feet (150 m).

Pzc **Paleozoic carbonate rocks** (Lower Permian to Lower Mississippian) – Mapped only west of Gillies Hill (Machette and others, 1984) where it is intensely metamorphosed by the Mineral Mountains batholith; unit appears to conformably underlie the Queantoweap Sandstone so likely is the Pakoon Dolomite but could include the Callville Limestone and/or Redwall Limestone.

Pp **Pakoon Dolomite** (Lower Permian) – Alternating ledges and slopes made up of sandy, marine dolomite and subordinate limestone and sandstone; of these rock types, the dolomite and limestone are mostly light- to medium-gray and locally dark-gray, medium-grained, thick-bedded, locally bioclastic, and locally contain tan chert and horn corals, bryozoa, and chaetetid corals, whereas the sandstone is light brown and pink and fine grained; ledges are of limestone and some sandstone beds, whereas slopes are most commonly the dolomite; map unit locally contains a yellowish-brown shale at the base; deposited in a shallow-marine environment (McNair, 1951); well exposed at Bradshaw Mountain, where J.E. Welsh (unpublished data, 1978) noted that the lower 100-feet (30 m) is relatively non-resistant interbedded limestone, fine-grained sandstone, and dolomite; thickness about 800 feet (240 m) at Bradshaw Mountain and at Black Mountain (Rowley and others, 2018) 3 miles (5 km) southeast of Minersville.

P-0 unconformity (Blakey, 1996)

IPc **Callville Limestone** (Pennsylvanian) – Ledge-forming, white, light-gray, and tan, fine-grained, thin- to medium-bedded, homogeneous, locally sandy and bioclastic, marine limestone (with a phosphatic smell) that contains fossils (horn corals, crinoids, and chaetetid corals; also brachiopods noted by J.E. Welsh) and uncommon nodules and beds of white and tan chert, and poorly exposed slopes of limestone and interbedded minor gray, purple, and brown siltstone and fine-grained sandstone; mapped in the southern Mineral Mountains where the top of the unit in the Bradshaw district is a limestone cliff; sections measured where well exposed on the upper part of Bradshaw Mountain (J.E. Welsh, unpublished data, 1978; Wardlaw, 1980) and on Black Mountain southeast of Minersville (Wardlaw, 1980); conodont fossils indicate an Early to Late Pennsylvanian age and a depositional environment as a transgressive deposit on a shallow-marine shelf (Welsh and Bissell, 1979; Wardlaw, 1980); thickness about 200 feet (60 m) at Bradshaw Mountain and Black Mountain.

Unconformity

Mr **Redwall Limestone, undivided** (Lower Mississippian) – Resistant, medium- to dark-gray, medium-grained, thick-bedded, bioclastic and fossiliferous (mostly crinoids, horn corals, bryozoans, and brachiopods) limestone that contains uncommon light-gray, tan, and black chert nodules and thin beds, and, in the lower 375 feet (114 m) of the unit, less resistant, light- to dark-gray dolomite (J.E. Welsh, unpublished data, 1978); forms massive cliffs; upper part has a phosphatic smell from small black pisolites; mapped in the southern Mineral Mountains and well exposed on the western flank of Bradshaw Mountain, where it is about 1250 feet (380 m) thick (J.E. Welsh unpublished data, 1978).

Divided into four members in the Grand Canyon by McKee (1963; see also McKee and Gutschick, 1969), in descending order the Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members, which remain undivided in southwestern Utah (Biek and others, 2009). Known as the Monte Cristo Limestone in the Basin and Range (Hewitt, 1931), with its Yellowpine and Arrowhead Members (Horseshoe Mesa lithologic equivalent), Bullion Member (Mooney Falls lithologic equivalent), Anchor Member (Thunder Springs lithologic equivalent), and Dawn Member (Whitmore Wash lithologic equivalent). Deposited on a gently sloping shallow-marine shelf, in a foreland basin associated with the Antler orogeny of central Nevada, as two transgressive (Whitmore Wash and Mooney Falls Members) and two regressive (Thunder Springs and Horseshoe Mesa Members) sequences (McKee and Gutschick, 1969).

Dcs **Crystal Pass Member of the Sultan Limestone, Simonson Dolomite, and Sevy Dolomite, undivided** (Devonian) – Mapped only in the southern Mineral Mountains where it is undivided due to map scale and structural complexity. Each was deposited in a shallow-marine environment (Hintze and Kowallis, 2009 and references therein).

Crystal Pass Member of the Sultan Limestone (Upper Devonian) – Relatively poorly resistant and poorly exposed, ledgy, light- to medium-gray and white, tan-weathering, thin- to medium-bedded, dolomite interbedded with subordinate but generally more resistant beds of brown and white, fine-grained sandstone; dolomite contains sparse white and brown chert; base of map unit identified by a tan-weathering, white, 10-foot-thick (3 m) sandstone or orthoquartzite; exposed on the western side of Bradshaw Mountain where J.E. Welsh (unpublished data, 1978) measured a thickness of 160 feet (50 m).

Simonson Dolomite (Lower to Middle Devonian) – Resistant, light- to dark-gray and light-bluish-gray, mostly thick-bedded, mostly homogeneous, sugary, dolomite that contains sparse brown and tan, lacy and bedded chert, especially in the lower part; stromatoporoids (sponges including the spaghetti-like *Amphipora*) and gastropods identified by J.E. Welsh (unpublished data, 1978), who measured the upper part of the unit at 337 feet (103 m); B.R. Wardlaw found sparse half-inch-long (1 cm) ovoidal fossils that he thought might be *gervanella* (algal balls); well exposed in incomplete faulted sections along the lower western flank of Bradshaw Mountain, where the cumulative thickness is at least 500 feet (150 m), although no complete section is exposed.

Sevy Dolomite (Lower Devonian) – Mostly resistant, light- to dark-green and light- to dark-gray, thin-bedded siltstone, cross-bedded sandstone, dolomite, and algal limestone at the top of the map unit, underlain by resistant, light-gray and blue-gray, thick-bedded, dolomite; correlation uncertain because only the upper 200 feet (60 m) of the unit is exposed, in a fault block just northwest of the Cave Mine, at the base of Bradshaw Mountain in the Bradshaw mining district.

Unconformity

Xg **Banded gneiss** (Paleoproterozoic) – Resistant, light- to dark-gray biotite, quartz, K-feldspar, hornblende, and plagioclase gneiss and local schist exposed along the west frontal fault of the Mineral Mountains (Sibbett and Nielson, 1980, 2017; Alienikoff, and others, 1986; Coleman, 1991); gneissic banding is commonly folded and ptygmatic in character; accessory minerals include rounded zircon and apatite; muscovite is locally present, and sphene is absent, which helps to distinguish this unit from the granodiorite (Tig) that makes up much of the Mineral Mountains;

as mapped, unit includes local dikes and apophyses of Tertiary intrusive rocks of the Mineral Mountains batholith (Nielson and others, 1986), which are shown on the more detailed map of Kirby (2019); Rb-Sr and U-Pb dating shows that the unit was last metamorphosed at about 1720 Ma (Aleinikoff and others, 1986).

ACKNOWLEDGMENTS

We are grateful to the late John Welsh for providing unpublished measured sections of Paleozoic rocks in the Mineral Mountains. Larry Snee and Drew Coleman provided unpublished ages. Bill McIntosh and Lisa Peters, both retired from the New Mexico Geochronology Research Laboratory at the New Mexico Institute of Mining and Technology, Socorro, New Mexico, provided $^{40}Ar/^{39}Ar$ ages. Jeanne Wardlaw assisted in identifying, measuring, and sampling Paleozoic units. Ernie Anderson, Milt Childers, and Brian Spillane assisted with structural problems and field reviews in the Mineral Mountains. Dawna Ferris assisted with fieldwork. Grant Willis of the UGS provided constant advice and assistance on stratigraphic and structural problems as well as technical reviews; we also appreciate the reviews of Stephanie Carney and Mike Hylland (UGS). Kent Brown (UGS) supplied base maps and Basia Matyjasik (UGS) assisted with many aspects of the GIS coverage and map preparation.

REFERENCES

Aleinikoff, J.M., Nielson, D.L., Hedge, C.E., and Evans, S.H., Jr., 1986, Geochronology of Precambrian and Tertiary rocks in the Mineral Mountains, south-central Utah: U.S. Geological Survey Bulletin 1622-A, p. 1–12.

Allis, R.G., Gwynn, M., Hardwick, C., Kirby, S., Moore, J., and Chapman, D., 2015, Re-evaluation of the pre-development thermal regime of Roosevelt Hot Springs geothermal system, Utah: Stanford Geothermal Reservoir Engineering Workshop, https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=8019519.

Allis, R., and Moore, J.N., 2019, Geothermal characteristics of the Roosevelt hot springs system and adjacent FORGE EGS site, Milford, Utah: Utah Geological Survey Miscellaneous Publication 169, 245 p., 8 appendices, 2 plates, https://doi.org/10.34191/MP-169.

Anderson, J.J., 1993, The Markagunt Megabreccia—large Miocene gravity slides mantling the northern Markagunt Plateau, southwestern Utah: Utah Geological Survey Miscellaneous Publication 93-2, 37 p., https://doi.org/10.34191/MP-93-2.

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

Anderson, J.J., Rowley, P.D., Blackman, J.T., Mehnert, H.H., and Grant, T.C., 1990b, Geologic map of the Circleville Canyon area, southern Tushar Mountains and northern Markagunt Plateau, Beaver, Garfield, Iron, and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2000, scale 1:50,000.

Anderson, J.J., Rowley, P.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990a, Geologic map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1999, scale 1:50,000.

Ball, J.L., Bailey, C., and Kunk, M.J., 2009, Volcanism on the Fish Lake Plateau, central Utah: Geological Society of America Abstracts with Programs, v. 41, no. 6, p. 17.

Beaty, D.W., Cunningham, C.G., Rye, R.O., Steven, T.A., and Gonzalez-Urien, Eliseo, 1986, Geology and geochemistry of the Deer Trail Pb-Zn-Ag-Cu manto deposits, Marysvale district, west-central Utah: Economic Geology, v. 81, p. 1932–1952.

Beitler, B., Parry, W.T., and Chan, M.A., 2003, Bleaching of Jurassic Navajo Sandstone on Colorado Plateau Laramide highs—evidence of exhumed hydrocarbon supergiants?: Geology, v. 31, p. 1041–1044.

Benton, M.J., 1995, Diversification and extinction in the history of life: Science v. 268, p. 52–58.

Best, M.G., Christiansen, E.H., and Blank, R.H., Jr., 1989a, Oligocene caldera complex and calc-alkaline tuffs and lavas of the Indian Peak volcanic field, Nevada and Utah: Geological Society of America Bulletin, v. 101, p. 1076–1090.

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

Best, M.G., and Grant, S.K., 1987, Stratigraphy of the volcanic Oligocene Needles Range Group in southwestern Utah: U.S. Geological Survey Professional Paper 1433-A, 28 p.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035–1050.

Biek, R.F., Eaton, J.G., Rowley, P.D., and Mattox, S.R., 2015b, Interim geologic map of the western Loa 30' x 60' quadrangle, Garfield, Piute, and Wayne Counties, Utah (year 2): Utah Geological Survey Open-File Report 648, scale 1:100,000, https://doi.org/10.34191/OFR-648.

Biek, R.F., Hacker, D.B., and Rowley, P.D., 2014, New constraints on the extent, age, and emplacement history of the early Miocene Markagunt Megabreccia, southwest Utah—one of the World's largest subaerial gravity slides, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, CD, p. 565–598.

Biek, R.F., Hacker, D.B., and Rowley, P.D., 2016, Catastrophic mega-scale landslide failure of large volcanic fields (Thompson Field Forums announcement): GSA Today, v. 26, no. 11, p. 22–24.

Biek, R.F., Hacker, D.B., and Rowley, P.D., 2017, Catastrophic mega-scale landslide failure of large volcanic fields (Thompson Field Forums report): GSA Today, v. 27, no. 12, p. 30–31.

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, 2015a, Geologic map of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Map 270DM , CD, 162 p., scale 1:62,500, https://doi.org/10.34191/M-270dm.

Biek, R.F., Rowley, P.D., and Hacker, D.B., 2019, The gigantic Markagunt and Sevier gravity slides resulting from mid-Cenozoic catastrophic mega-scale failure of the Marysvale volcanic field, Utah, USA: Geological Society of America Field Guide 56, 121 p., https://lccn.loc.gov/2019045272.

Biek, R.F., Rowley, P.D., Hayden, J.M., Hacker, D.B., Willis, G.C., Hintze, L.F., Anderson, R.E., and Brown, K.D., 2009, Geologic map of the St. George and east part of the Clover Mountains 30' x 60' quadrangles, Washington and Iron Counties, Utah: Utah Geological Survey Map 242DM, 2 plates, 101 p., scale 1:100,000, https://doi.org/10.34191/M-242dm.

Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 273–298.

Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau, *in* Longman, M.W., and Sonnenfeld, M.D., editors, Paleozoic systems of the Rocky Mountain region: Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 405–426.

Blakey, R.C., 2008, Pennsylvanian–Jurassic sedimentary basins of the Colorado Plateau and Southern Rocky Mountains, *in* Miall, A.D., editor, The Phanerozoic sedimentary basins of the United States and Canada: Amsterdam, Elsevier, Sedimentary Basins of the World, v. 5, p. 245–296.

Blakey, R.C., Bashem, E.L., and Cook, M.J., 1993, Early and Middle Triassic paleogeography, Colorado Plateau and vicinity, *in* Morales, M., editor, Aspects of Mesozoic geology and paleontology of the Colorado Plateau: Museum of Northern Arizona Bulletin 59, p. 13–26.

Blakey, R.C., and Gubitosa, R., 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of west-central United States: Denver, Colorado, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 57–76.

Blakey, R.C., and Gubitosa, R., 1984, Controls of sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: Sedimentary Geology, v. 38, p. 51–86.

Bowers, D., 1978, Potassium-argon age dating and petrology of the Mineral Mountains pluton,Utah: Salt Lake City, University of Utah, unpublished M.S. thesis, 76 p.

Budding, K.E., Cunningham, C.G., Zielinski, R.A., Steven, T.A., and Stern, C.R., 1987, Petrology and chemistry of the Joe Lott Tuff Member of the Mount Belknap Volcanics, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1354, 47 p.

Callaghan, E., 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: American Geophysical Union Transactions, 20th Annual Meeting, Washington, D.C., 1939, p. 438–452.

Callaghan, E., 1973, Mineral resources potential of Piute County, Utah and adjoining areas: Utah Geological and Mineralogical Survey Bulletin 102, 135 p., https://doi.org/10.34191/B-102.

Campbell, D.L., Steven, T.A., Cunningham, C.G., and Rowley, P.D., 1999, Aeromagnetic and gravity maps of the central Marysvale volcanic field, southwestern Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2645-B, scale 1:100,000.

Chan, M.A., Parry, W.T., and Bowman, J.R., 2000, Diagenetic hematite and manganese oxides and fault-related fluid flow in Jurassic sandstones, southeastern Utah: American Association of Petroleum Geologists Bulletin, v. 84, p. 1281–1310.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate tectonic evolution of the western United States—II. Late Cenozoic: Royal Society of London Philosophical Transactions (A), v. 271, p. 249–284.

Coleman, D.S., 1991, Geology of the Mineral Mountains batholiths, Utah: Lawrence, University of Kansas, unpublished Ph.D. dissertation, 219 p.

Coleman, D.S., Bartley, J.M., Walker, J.D., Price, D.E., and Friedrich, A.M., 1997, Extensional faulting, footwall deformation and plutonism in the Mineral Mountains, southern Sevier Desert: Brigham Young University Geology Studies, v. 42, p. 203–233.

Coleman, D.S., and Walker, J.D., 1992, Evidence for the generation of juvenile granitic crust during continental extension, Mineral Mountains batholith, Utah: Journal of Geophysical Research, v. 97, no. B7, p. 11,011–11,024.

Coleman, D.S., and Walker, J.D., 1994, Modes of tilting during extensional core complex development: Science, v. 263, p. 215–218.

Coleman, D.S., Walker, J.D., Bartley, J.M., and Hodges, K.V., 2001, Thermochronologic evidence for footwall deformation during extensional core complex development, Mineral Mountains, Utah, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin—a symposium and field guide (The Mackin Volume): Utah Geological Association and Pacific Section of the American Association of Petroleum Geologists: Utah Geological Association Publication 30, p. 155–168.

Corbett, M.D., 1984, Stratigraphy, structure, and skarn deposits within the Toroweap, Kaibab, and Moenkopi section, Lincoln mining district, southern Mineral Range, Beaver County, Utah: Golden, Colorado, Colorado School of Mines, unpublished M.S. thesis, 180 p.

Craddock, J.P., Geary, Jesse, and Malone, D.H., 2012, Vertical injectites of detachment carbonate ultracataclasite at White Mountain, Heart Mountain detachment, Wyoming: Geology, v. 40, p. 463–466.

Craddock, J.P., Malone, D.H., Cook, A.L., Rieser, M.E., and Doyle, J.R., 2009, Dynamics of emplacement of the Heart Mountain allochthon at White Mountain—constraints from calcite twinning strains, anisotropy of magnetic susceptibility and thermodynamic calculations: Geological Society of America Bulletin, v. 121, no. 5/6, p. 919–938.

Cunningham, C.G., Ludwig, K.R., Naeser, C.W., Weiland, E.K., Mehnert, H.H., Steven, T.A., and Rasmussen, J.D., 1982, Geochronology of hydrothermal uranium deposits and associated igneous rocks in the eastern source area of the Mount Belknap Volcanics, Marysvale, Utah: Economic Geology, v. 77, no. 2, p. 453–463.

Cunningham, C.G., Rasmussen, J.D., Steven, T.A., Rye, R.O., Rowley, P.D., Romberger, S.B., and Selverstone, Jane, 1998a, Hydrothermal uranium deposits containing molybdenum and fluorite in the Marysvale volcanic field, west-central Utah: Mineralium Deposita, v. 33, p. 477–494.

Cunningham, C.G., Rasmussen, J.D., Steven, T.A., Rye, R.O., Rowley, P.D., Romberger, S.B., and Selverstone, Jane, 1999, Reply to the Comment by C.S. Spirakus: Mineralium Deposita, v. 34, p. 725–726.

Cunningham, C.G., Rowley, P.D., Steven, T.A., and Rye, R.O., 2007, Geologic evolution and mineral resources of the Marysvale volcanic field, west-central Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah, diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 143–162.

Cunningham, C.G., Rye, R.O., Steven, T.A., and Mehnert, H.H., 1984a, Origins and exploration significance of replacement and vein-type alunite deposits in the Marysvale volcanic field, west-central Utah: Economic Geology, v. 79, p. 50–71.

Cunningham, C.G., Rye, R.O., Rockwell, B.W., Kunk, M.J., and Councell, T.B., 2005, Supergene destruction of a hydrothermal replacement alunite deposit at Big Rock Candy Mountain, Utah—mineralogy, spectroscopic remote sensing, stable-isotope, and argon-age evidences: Chemical Geology, v. 215, p. 317–337.

Cunningham, C.G., and Steven, T.A., 1979, Mount Belknap and Red Hills calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Bulletin 1468, 34 p.

Cunningham, C.G., Steven, T.A., Campbell, D.L., Naeser, C.W., Pitkin, J.A., and Duval, J.S., 1984b, Multiple episodes of igneous activity, mineralization, and alteration in the western Tushar Mountains, Marysvale volcanic field, west-central Utah, *in* Steven, T.A., editor, Igneous activity and related ore deposits in the western and southern Tushar Mountains, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1299-A, 22 p.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Glassgold, L.B., and Anderson, J.J., 1983, Geologic map of the Tushar Mountains and adjoining areas, Marysvale volcanic field, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1430-A, scale 1:50,000.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Naeser, C.W., Mehnert, H.H., Hedge, C.E., and Ludwig, K.R., 1994, Evolution of volcanic rocks and associated ore deposits in the Marysvale volcanic field, Utah: Economic Geology, v. 89, p. 2003–2005.

Cunningham, C.G., Unruh, D.M., Steven, T.A., Rowley, P.D., Naeser, C.W., Mehnert, H.H., Hedge, C.E., and Ludwig, K.R., 1998b, Geochemistry of volcanic rocks in the Marysvale volcanic field, west-central Utah, *in* Friedman, J.D., and Huffman, A.C., Jr., coordinators, Laccolith complexes of southeastern Utah—time of emplacement and tectonic setting—workshop proceedings: U.S. Geological Survey Bulletin 2158, p. 223–232.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

Damon, P.E., 1969, Correlation and chronology of ore deposits and volcanic rocks: Tucson, Arizona University, Geochronology Laboratory, U.S. Atomic Energy Commission Contract AT(11-1)-689, Annual Progress Report COO-689-120, 90 p.

Dickinson, W.R., and Gehrels, G.E., 2003, U-Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA—paleogeographic implications: Sedimentary Geology, v. 163, issues 1–2, p. 29–66.

Dickinson, W.R., and Gehrels, G.E., 2009a, U-Pb ages of detrital zircons in Jurassic eolian and associated sandstones of the Colorado Plateau—evidence for transcontinental dispersal and intraregional recycling of sediment: Geological Society of America Bulletin, v. 121, nos. 3 and 4, p. 408–433.

Dickinson, W.R., and Gehrels, G.E., 2009b, Insights into North American paleogeography and paleotectonics from U-Pb ages of detrital zircons in Mesozoic strata of the Colorado Plateau USA: International Journal Earth Science, DOI 10.1007/s00531-009-0462-0, 19 p.

Doelling, H.H., Sprinkel, D.A., and Kuehne, P.A., 2013, Temple Cap and Carmel Formations in the Henry Mountains Basin, Wayne and Garfield Counties, Utah, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 279–318 with appendices.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, p. 133–168.

Dubiel, R.F., and Hasiotis, S.T., 2011, Deposystems, paleosols, and climatic variability in a continental system—the Upper Triassic Chinle Formation, Colorado Plateau, U.S.A.: SEPM Special Publication, v. 97, p. 393–421.

Earll, F.N., 1957, Geology of the central Mineral Range, Beaver County, Utah: Salt Lake City, Utah, University of Utah, unpublished Ph.D. dissertation, 112 p.

Evans, S.H., Jr., and Steven, T.A., 1982, Rhyolites in the Gillies Hill—Woodtick Hill area, Beaver County, Utah: Geological Society of America Bulletin, v. 93, p. 1131–1141.

Faulder, D.D., 1991, Conceptual geologic model and native state model of the Roosevelt Hot Springs hydrothermal system: Proceedings, 16th Workshop on Geothermal Reservoir Engineering, Stanford University, p. 131–142.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in High Plateaus region of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 53–62.

Fryman, M.D., 1987, The Isom Formation of the Markagunt Plateau in southwestern Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 86 p.

Glenn, W.E., and Hulen, J.B., 1979, Interpretation of well log data from four drill holes at Roosevelt Hot Springs KGRA: unpublished report prepared by Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah, for U.S. Department of Energy, Division of Geothermal Energy, 74 p.

Hacker, D.B., Biek, R.F., and Rowley, P.D., 2014, Catastrophic emplacement of the gigantic Markagunt gravity slide, southwest Utah (USA)—implications for hazards associated with sector collapse of volcanic fields: Geology, v. 42, no. 11, p. 943–946.

Hacker, D.B., Biek, R.F., and Rowley, P.D., 2015, Earth's largest terrestrial landslide (the Markagunt gravity slide of southwest Utah)—insights from the catastrophic collapse of a volcanic field: American Geophysical Union abstracts, https://agu.confex.com/agu/fm15/meetingapp.cgi/Paper/76934.

Hewitt, D.F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U.S. Geological Survey Professional Paper 162, 172 p.

Hintze, L.F., Davis, F.D., Rowley, P.D., Cunningham, C.G., Steven, T.A., and Willis, G.C., 2003, Geologic map of the Richfield 30′ x 60′ quadrangle, southeast Millard County and parts of Beaver, Piute, and Sevier Counties, Utah: Utah Geological Survey Map 195DM, scale 1:100,000, https://doi.org/10.34191/M-195dm.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 9, 225 p.

Imlay, R.W., 1980, Jurassic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Irmis, R.B., Mundil, R., Martz, J.W., and Parker, W.G., 2011, High-resolution U-Pb ages from the Upper Triassic Chinle Formation (New Mexico, USA) support a diachronous rise of dinosaurs: Earth and Planetary Science Letters, v. 309, p. 258–267.

Izett, G.A., 1981, Volcanic ash beds—recorders of upper Cenozoic silicic pyroclastic volcanism in the Western United States: Journal of Geophysical Research, v. 86, no. B11, p. 10,200–10,222.

Johansen, S.J., 1988, Origins of upper Paleozoic quartzose sandstones, American southwest: Sedimentary Geology, v. 56, p. 153–166.

Jones, C.G., Moore, J.N., and Simmons, S., 2019, Petrography of the Utah FORGE site and environs, Beaver County, Utah, *in* Allis, R., and Moore, J.N., editors, Geothermal characteristics of the Roosevelt Hot Springs system and adjacent FORGE EGS site, Milford, Utah: Utah Geological Survey Miscellaneous Publication 169-K, 23 p., 2 appendices, https://doi.org/10.34191/MP-169-K.

Jones, G.T., Beck, C., Jones, E.E., and Hughes, R.E., 2003, Lithic source use and Paleoarchaic foraging territories in the Great Basin: American Antiquity, v. 68, no. 1, p. 5–38.

Kerr, P.F., Brophy, G.P., Dahl, H.M., Green, Jack, and Woolard, L.E., 1957, Marysvale, Utah, uranium area—geology, volcanic relations, and hydrothermal alteration: Geological Society of America Special Paper 64, 212 p.

Kirby, S.M., 2019, Revised mapping of bedrock geology adjoining the Utah FORGE site, *in* Allis, R., and Moore, J.N., editors, Geothermal characteristics of the Roosevelt Hot Springs system and adjacent FORGE EGS site, Milford, Utah: Utah Geological Survey Miscellaneous Publication 169-A, 6 p., 2 plates, scale 1:24,000, https://doi.org/10.34191/MP-169-A.

Kirkland, J.I., Martz, J.W., DeBlieux, D.D., Santucci, V.L., Madsen, S.K., Wood, J.R., and Payne, N.M., 2014, Paleontological resource inventory & monitoring, Chinle and Cedar Mountain Formations, Capitol Reef National Park, Utah: Utah Geological Survey Contract Report to the National Park Service prepared under cooperative agreement #P13AC00601 Task #P13AC01248, 128 p. plus appendices.

Kocurek, G., and Dott, R.H., Jr., 1983, Jurassic paleogeography and paleoclimate of the central and southern Rocky Mountains region, *in* Reynolds, M.W., and Dolley, E.D., editors, Mesozoic paleogeography of the west-central United States: Denver, Colorado, Rocky Mountain Section Society of Economic Paleontologists and Mineralogists, p. 101–116.

Kowallis, B.J., and Best, M.G., 1990, Fission track ages from volcanic rocks in southwestern Utah and southeastern Nevada: Isochron/West, no. 55, p. 24–27.

Lanigan, J.C., Jr., and Anderson, J.J., 1987, Geology of the lower canyon of Beaver River, southwestern Tushar Mountains, Utah, *in* Kopp, R.S., and Cohenour, R.E., editors, Cenozoic geology of western Utah: Utah Geological Association Publication 16, p. 417–428.

Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1972, Cenozoic volcanism and evolution of the western United States—I. Early and middle Cenozoic: Royal Society of London, Philosophical Transactions (A), v. 271, p. 217–248.

Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H. Jr., Nash, W.P., and Brown, F.H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah—geothermal and archeological significance, *with sections on* Fission-track dating, by Izett, G.A., and Naeser, C.W., *and on* Obsidian-hydration dating, by Irving Friedman: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133–147.

Lucas, S.G., 1993, The Chinle Group—revised stratigraphy and biochronology of Upper Triassic nonmarine strata in the western United States: Museum of Northern Arizona Bulletin, v. 59, p. 27–50.

Lucas, S.G., and Tanner, L.H., 2007, Tetrapod biostratigraphy and biochronology of the Triassic-Jurassic transition on the southern Colorado Plateau, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 242–256.

Lynne, B.Y., Campbell, K.A., Moore, J.N., and Browne, P.R.L., 2004, Siliceous sinter diagenesis at the Opal Mound, Roosevelt Hot Springs, Utah, USA: Proceedings, 26th New Zealand Geothermal Workshop, p. 12–17.

Lynne, B.Y., Campbell, K.A., Moore, J.N., and Browne, P.R.L., 2005, Diagenesis of 1900 year-old siliceous sinter (opal-A to quartz) at Opal Mound, Roosevelt Hot Springs, Utah: Sedimentary Geology, v. 179, p. 249–278.

Machette, M.N., 1985, Late Cenozoic geology of the Beaver basin, southwestern Utah: Brigham Young University Studies in Geology, v. 32, pt. 1, p. 19–37.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, no. 2, p. 81–131.

Malone, D.H., and Craddock, J.P., 2008, Recent contributions to the understanding of the Heart Mountain detachment, Wyoming: Northwest Geology, v. 37, p. 21–40.

Malone, D.H., Craddock, J.P., and Mathesin, M.G., 2014, Origin of allochthonous volcanic rocks at Squaw Peaks, Wyoming—a distal remnant of the Heart Mountain slide?: Mountain Geologist, v. 51, p. 321–336.

Marzolf, J.E., 1994, Reconstruction of the early Mesozoic cordilleran cratonal margin adjacent to the Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 181–216.

Mattox, S.R., 1991, Origin of potassium-rich mafic lava flows, Marysvale volcanic field, Utah [abs.]: Eos (American Geophysical Union) Program and Abstracts, v. 72, no. 44, p. 561.

Mattox, S.R., 1992, Geochemistry, origin, and tectonic implications of mid-Tertiary and late Tertiary and Quaternary volcanic rocks, southern Marysvale volcanic field, Utah: DeKalb, Northern Illinois University, Ph.D. dissertation, 502 p.

Mattox, S.R., and Walker, J.A., 1989, Geochemistry and tectonism of lavas erupted during the transition from compression to extension, southern Marysvale complex, southwestern Utah [abs.]: IAVCEI Abstracts, New Mexico Bureau of Mines and Mineral Resources Bulletin 131, p. 178.

Mattox, S.R., and Walker, J.A., 1990, Late Cenozoic lavas of the Utah transition zone [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 65.

McDowell, S.M., 2004, Construction of the Mineral Mountains sheet complex, Mineral Mountains batholith, southwestern Utah: Chapel Hill, University of North Carolina, unpublished M.S. thesis, 79 p.

McKee, E.D., 1938, The environment and history of the Toroweap and Kaibab Formations of northern Arizona and southern Utah: Carnegie Institute of Washington Publication 492, 268 p.

McKee, E.D., 1963, Nomenclature for lithologic subdivisions of the Mississippian Redwall Limestone, Arizona: U.S. Geological Survey Professional Paper 475-C, p. C21–C22.

McKee, E.D., and Gutsckick, R.C., 1969, History of the Redwall Limestone of northern Arizona, with chapters on paleontology of the Redwall Limestone by B. Skipp, W.J. Sando, H. Duncan, E.L. Yochelson, W.M. Furnish, D.B. Macurda, Jr., and J.C. Brower: Geological Society of America Memoir 114, 726 p.

McNair, A.H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: American Association of Petroleum Geologists Bulletin, v. 35, no. 3, p. 503–541.

Mehnert, H.H., Rowley, P.D., and Lipman, P.W., 1978, K-Ar ages and geothermal implications of young rhyolites in west-central Utah: Isochron/West, no. 21, p. 3–7.

Meschter-McDowell, S.M., Coleman, D.S., and Geissman, J.W., 2004, Development of the Mineral Mountains sheet complex, Mineral Mountain batholith, southwestern Utah: Geological Society of America Abstracts with Programs, v. 36, no. 4, p. 71.

Milligan, M., 2012, Sizing up titans—Navajo erg vs. Sahara ergs, which was the larger sand box?: Utah Geological Survey, Survey Notes, v. 44, no. 3, p. 8–9, https://doi.org/10.34191/SNT-44-3.

Nash, W.P., and Smith, R.P., 1977, Pleistocene volcanic ash deposits in Utah: Utah Geology, v. 4, no. 1, p. 35–42.

Nielson, D.L., Evans, S.H., Jr., and Sibbett, B.S., 1986, Magmatic, structural, and hydrothermal evolution of the Mineral Mountains intrusive complex, Utah: Geological Society of America Bulletin, v. 97, p. 765–777.

Nielson, D.L., Sibbett, B.S., McKinney, D.B., Hulen, J.B., Moore, J.N., and Samberg, S.M., 1978, Geology of Roosevelt hot springs KGRA, Beaver County, Utah: Salt Lake City, University of Utah Research Institute, Earth Science Laboratory, 120 p.

Nielson, R.L., 1981, Depositional environment of the Toroweap and Kaibab Formations of southwestern Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 495 p.

Nielson, R.L., 1986, The Toroweap and Kaibab Formations, southwestern Utah, *in* Griffen, D.T., and Phillips, W.R., editors, Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 37–53.

Nielson, R.L., 1991, Petrology, sedimentology and stratigraphic implications of the Rock Canyon Conglomerate, southwestern Utah: Utah Geological Survey Miscellaneous Publication 91-7, 65 p., https://doi.org/10.34191/MP-91-7.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas—Jurassic paleogeography in the southern part of the Western Interior basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 233–272.

Phillips, S.P., and Morris, T.H., 2013, Identification of an extensive paleotopographic high on the Navajo Sandstone by surface to subsurface correlation of the Temple Cap Formation and time-equivalent portions of the Page Sandstone, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains Basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 261–278.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.

Podwysocki, M.H., and Segal, D.B., 1983, Mapping of hydrothermally altered rocks using air-borne multispectral data, Marysvale, Utah, mining district: Economic Geology, v. 78, p. 675–687.

Potter, S.L., and Chan, M.A., 2011, Joint controlled fluid flow patterns and iron mass transfer in Jurassic Navajo Sandstone, southern Utah, USA: Geofluids, v. 11, p. 184–198.

Price, D.E., 1998, Timing, magnitude, and three-dimensional structure of detachment-related extension, Mineral Mountains, Utah: Salt Lake City, University of Utah, unpublished M.S. thesis, 67 p., scale 1:24,000.

Rahl, J.M., Reiners, P.W., Campbell, I.H., Nicolescu, S., and Allen, C.M., 2003, Combined single-grain (U-Th)/He and U-Pb dating of detrital zircons from the Navajo Sandstone, Utah: Geology, v. 31, no. 9, p. 761–764.

Ramezani, J., Hoke, G.D., Fastovsky, D.E., Bowring, S.A., Therrien, F., Dworkin, S.I., Atchley, S.C., and Nordt, L.C., 2011, High-precision U-Pb zircon geochronology of the Late Triassic Chinle Formation, Petrified Forest National Park (Arizona, USA)—temporal constraints on the early evolution of dinosaurs: Geological Society of America Bulletin, v. 123, no. 11/12, p. 2142–2159.

Ramazani, J., Fastovsky, D.E., and Bowring, S.A., 2014, Revised chronostratigraphy of the lower Chinle Formation strata in Arizona and New Mexico (USA)—high-precision U-Pb geochronological constraints on the Late Triassic evolution of dinosaurs: American Journal of Science, v. 314, p. 981–1008.

Rawson, R.R., and Turner-Peterson, C.E., 1979, Marine-carbonate, sabkha, and eolian facies transitions within the Permian Toroweap Formation, northern Arizona, *in* Baars, D.L., editor, Permianland: Four Corners Geological Society Guidebook, 9th Field Conference, p. 87–99.

Rawson, R.R., and Turner-Peterson, C.E., 1980, Paleogeography of northern Arizona during the deposition of the Permian Toroweap Formation, *in* Fouch, T.D., and Magathan, E.R., editors, Paleozoic paleogeography of the west-central United States, Rocky Mountain Symposium 1: Denver, Colorado, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 341–352.

Reeside, J.B., Jr., and Bassler, H., 1921, Stratigraphic sections in southwestern Utah and northwestern Arizona: U.S. Geological Survey Professional Paper 129-D, p. 53–77.

Reiners, P.W., Campbell, I.H., Nicolescu, S., Allen, C.M., Hourigan, J.K., Garver, J.I., Mattinson, J.M., and Cowan, D.S., 2005, (U-Th)/(He-Pb) double-dating of detrital zircons: American Journal of Science, v. 305, p. 259–311.

Riggs, N.R., Mattinson, J.M., and Busby, C.J., 1993, Correlation of Jurassic eolian strata between the magmatic arc and the Colorado Plateau—new U-Pb geochronologic data from southern Arizona: Geological Society of America Bulletin, v. 105, p. 1231–1246.

Rodríguez-López, J.P., Clemmensen, L.B., Lancaster, N., Mountney, N.P., and Veiga, G.D., 2014, Archean to Recent aeolian sand systems and their sedimentary record—current understanding and future prospects: Sedimentology, v. 61, p. 1487–1534.

Rowley, P.D., 1978, Geologic map of the Thermo 15-minute quadrangle, Beaver and Iron Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1493, scale 1:62,500.

Rowley, P.D., 1998, Cenozoic transverse zones and igneous belts in the Great Basin, western United States—their tectonic and economic implications, *in* Faulds, J.E., and Stewart, J.H., editors, Accommodation zones and transfer zones—the regional segmentation of the Basin and Range province: Geological Society of America Special Paper 323, p. 195–228.

Rowley, P.D., Biek, R.F., Hacker, D.B., Vice, G.S., McDonald, R.E., Maxwell, D.J., Smith, Z.D., Cunningham, C.G., Steven, T.A., Anderson, J.J., Ekren, E.B., Machette, M.N., and Wardlaw, B.R., 2018, Interim geologic map of the southwestern quarter of the Beaver 30' x 60' quadrangle, Beaver, Iron, and Garfield Counties, Utah: Utah Geological Survey Open-File Report 686DM, 18 p., 1 plate, scale 1:100,000, https://doi.org/10.34191/OFR-686dm.

Rowley, P.D., and Dixon, G.L., 2001, The Cenozoic evolution of the Great Basin area, U.S.A.—new interpretations based on regional geologic mapping, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin—a symposium and field guide (The Mackin Volume): Utah Geological Association and Pacific Section of the American Association of Petroleum Geologists: Utah Geological Association Publication 30, p. 169–188.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1988a, Geologic map of the Antelope Range quadrangle, Sevier and Piute Counties, Utah: Utah Geological and Mineral Survey Map 106, scale 1:24,000, https://doi.org/10.34191/M-106.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1988b, Geologic map of the Marysvale quadrangle, Piute County, Utah: Utah Geological and Mineral Survey Map 105, scale 1:24,000, https://doi.org/10.34191/M-105.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1998, Cenozoic igneous and tectonic setting of the Marysvale volcanic field, and its relation to other igneous centers in Utah and Nevada, *in* Friedman, J.D., and Huffman, A.C., Jr., coordinators, Laccolith complexes of southeastern Utah—time of emplacement and tectonic setting—workshop proceedings: U.S. Geological Survey Bulletin 2158, p. 167–202.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Workman, J.B., Anderson, J.J., and Theissen, K.M., 2002, Geologic map of the central Marysvale volcanic field, southwestern Utah: U.S. Geological Survey Geologic Investigations Series Map I-2645-A, scale 1:100,000.

Rowley, P.D., Lipman, P.W., Mehnert, H.H., Lindsey, D.A., and Anderson, J.J., 1978, Blue Ribbon lineament, an east-trending structural zone within the Pioche mineral belt of southwestern Utah and eastern Nevada: U.S. Geological Survey Journal of Research, v. 6, no. 2, p. 175–192.

Rowley, P.D., Mehnert, H.H., Naeser, C.W., Snee, L.W., Cunningham, C.G., Steven, T.A., Anderson, J.J., Sable, E.G., and Anderson, R.E., 1994, Isotopic ages and stratigraphy of Cenozoic rocks of the Marysvale volcanic field and adjacent areas, west-central Utah: U.S. Geological Survey Bulletin 2071, 35 p.

Rowley, P.D., Norlin, Keith, Maxwell, J.A., and Maxwell, D.J., 2014, The Minersville gravity slide and metallic mineral potential at Black Mountain, northern Black Mountains, Beaver County, Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, CD, p. 599–616; includes 1:6,000-scale geologic map as Plate 1.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geological Survey Professional Paper 1149, 22 p.

Rowley, P.D., Steven, T.A., and Mehnert, H.H., 1981, Origin and structural implications of upper Miocene rhyolites in Kingston Canyon, Piute County, Utah: Geological Society of America Bulletin, Pt. I, v. 92, p. 590–602.

Rowley, P.D., Vice, G.S, McDonald, R.E., Anderson, J.J., Machette, M.N., Maxwell, D.J., Ekren, E.B., Cunningham, C.G., Steven, T.A., and Wardlaw, B.R., 2005, Interim geologic map of the Beaver 30′ x 60′ quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological Survey Open-File Report 454, 32 p., scale 1:100,000, https://doi.org/10.34191/OFR-454.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986a, Geologic map of the Greenwich quadrangle, Piute County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1589, scale 1:24,000.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986b, Geologic map of the Koosharem quadrangle, Sevier and Piute Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1590, scale 1:24,000.

Sibbett, B.S., and Nielson, D.L., 1980, Geology of the central Mineral Mountains, Beaver County, Utah: U.S. Department of Energy DOE/ET/28392-40, 42 p., scale 1:24,000.

Sibbett, B.S., and Nielson, D.L., 2017, Geologic map of the central Mineral Mountains (GIS of 1980 map), Beaver County, Utah: Utah Geological Survey Miscellaneous Publication 17-2DM, 42 p., scale 1:24,000, https://doi.org/10.34191/MP-17-2dm.

Sigmund, J.M., 1979, Geology of a Miocene rhyodacite lava flow, southern Tushar Mountains, Utah: Kent, Ohio, Kent State University, M.S. thesis, 35 p.

Sorauf, J.E., and Billingsley, G.H., 1991, Members of the Toroweap and Kaibab Formations, Lower Permian, northern Arizona and southwestern Utah: The Mountain Geologist, v. 28, no. 1, p. 9–24.

Sprinkel, D.A., Doelling, H.H., Kowallis, B.J., Waanders, G., and Kuehne, P.A., 2011a, Early results of a study of Middle Jurassic strata in the Sevier fold and thrust belt, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey. T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 151–172.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011b, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Steiger, R.H., and Jager, E., 1977, Subcommission on Geochronology—convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984a, Geologic history and uranium potential of the Big John caldera, southern Tushar Mountains, Utah, *in* Steven, T.A., editor, Igneous activity and related ore deposits in the western and southern Tushar Mountains, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1299-B, 33 p.

Steven, T.A., Cunningham, C.G., and Machette, M.N., 1981, Integrated uranium systems in the Marysvale volcanic field, west-central Utah, *in* Goodell, P.C., and Waters, A.C., editors, Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists Studies in Geology, no. 13, p. 111–122.

Steven, T.A., Cunningham, C.G., Naeser, C.W., and Mehnert, H.H., 1979, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40 p.

Steven, T.A., and Morris, H.T., 1983, Geologic map of the Cove Fort quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1481, scale 1:50,000.

Steven, T.A., and Morris, H.T., 1987, Summary mineral resource appraisal of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Circular 916, 24 p.

Steven, T.A., Morris, H.T., and Rowley, P.D., 1990, Geologic map of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1901, scale 1:250,000.

Steven, T.A., Rowley, P.D., and Cunningham, C.G., 1984b, Calderas of the Marysvale volcanic field, west-central Utah: Journal of Geophysical Research, v. 89, no. B10, p. 8751–8764.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region, with a section on sedimentary petrology by R.A. Cadigan and on conglomerate studies by W. Thordarson, H.F. Albee, and J.H. Stewart: U.S. Geological Survey Professional Paper 690, 336 p.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region, with a section on sedimentary petrology by R.A. Cadigan: U.S. Geological Survey Professional Paper 691, 195 p.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2019a, $^{40}Ar/^{39}Ar$ geochronology results for the Burnt Peak and Phonolite Hill quadrangles, Utah: Utah Geological Survey Open-File Report 707, variously paginated, https://doi.org/10.34191/OFR-707.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2019b, $^{40}Ar/^{39}Ar$ geochronology results for the Black Ridge, Circleville Canyon, Government Point, Marysvale Canyon, and Shelly Baldy Peak quadrangles, Marysvale volcanic field, Utah: Utah Geological Survey Open-File Report 705, variously paginated, https://doi.org/10.34191/OFR-705.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2019c, $^{40}Ar/^{39}Ar$ geochronology results for the Koosharem and Sigurd quadrangles, Utah: Utah Geological Survey Open-File Report 709, variously paginated, https://doi.org/10.34191/OFR-709.

Walker, J.A., and Mattox, S.R., 1989, The influences of subduction on mid-late Cenozoic volcanism in southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 6, p. A57.

Ward, P.D., 2004, Gorgon—paleontology, obsession, and the greatest catastrophe in Earth's history: New York, Viking, 257 p.

Wardlaw, B.R., 1980, The Pennsylvanian Callville Limestone in Beaver County, southwestern Utah, *in* Fouch, T.D., and Magatham, E.R., editors, Paleozoic paleogeography of west-central United States: S.E.P.M. West-Central United States Paleogeography Symposium, Rocky Mountain Section, Denver, Colorado, p. 175–179.

Welsh, J.E., and Bissell, H.J., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Utah: U.S. Geological Survey Professional Paper 1110-Y, p. Y1–Y35.

Wickstrom, L.H., 1982, Geology of a Miocene felsic tuff and overlying basalts, southwestern Tushar Mountains, Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 61 p.

Williams, P.L., and Hackman, R.J., 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-591, scale 1:250,000.

Willis, G.C., and Doelling, H.H., 2019, Interim geologic map of the Burrville quadrangle, Sevier and Piute Counties, Utah: Utah Geological Survey Open-File Report 696, 19 p., 1 plate, scale 1:24,000, https://doi.org/10.34191/OFR-696.

SOURCE LIST FOR GEOLOGIC MAPPING (Numbers correspond to those on index map)

1. Anderson, J.J., Lanigan, J.C., Cunningham, C.G., and Naeser, C.W., 1981, Geologic map of the Beaver SE quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1274, scale 1:24,000.

2. Cunningham, C.G., and Steven, T.A., 1980, Geologic map of the Beaver NE quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1191, scale 1:24,000.

3. Machette, M.N., 1983, Geologic map of the southwest-quarter of the Beaver quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1444, scale 1:24,000.

4. Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

5. Machette, M.N., and Steven, T.A., 1983, Geologic map of the northwest-quarter of the Beaver quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1445, scale 1:24,000.

6. Price, D.E., 1998, Timing, magnitude, and three-dimensional structure of detachment-related extension, Mineral Mountains, Utah: Salt Lake City, Utah, University of Utah, unpublished M.S. thesis, 67 p., scale 1:24,000.

7. Rowley, P.D., Vice, G.S., Biek, R.F., and McDonald, R.E., 2003–2016, unpublished mapping of bedrock and surficial geology of the Cave Canyon and Adamsville quadrangles, scale 1:24,000.

8. Sibbett, B.S., and Nielson, D.L., 1980, Geology of the central Mineral Mountains, Beaver County, Utah: U.S. Department of Energy DOE/ET/28392-40, 42 p., scale 1:24,000.

   Sibbett, B.S., and Nielson, D.L., 2017, Geologic map of the central Mineral Mountains (GIS of 1980 map), Beaver County, Utah: Utah Geological Survey Miscellaneous Publication 17-2DM, 42 p., scale 1:24,000, https://doi.org/10.34191/MP-17-2dm.

9. Kirby, S.M., 2019, Revised mapping of bedrock geology adjoining the Utah FORGE site, in Allis, R., and Moore, J.N., editors, Geothermal characteristics of the Roosevelt Hot Springs system and adjacent FORGE EGS site, Milford, Utah: Utah Geological Survey Miscellaneous Publication 169-A, 6 p., 2 plates, scale 1:24,000, https://doi.org/10.34191/MP-169-A.