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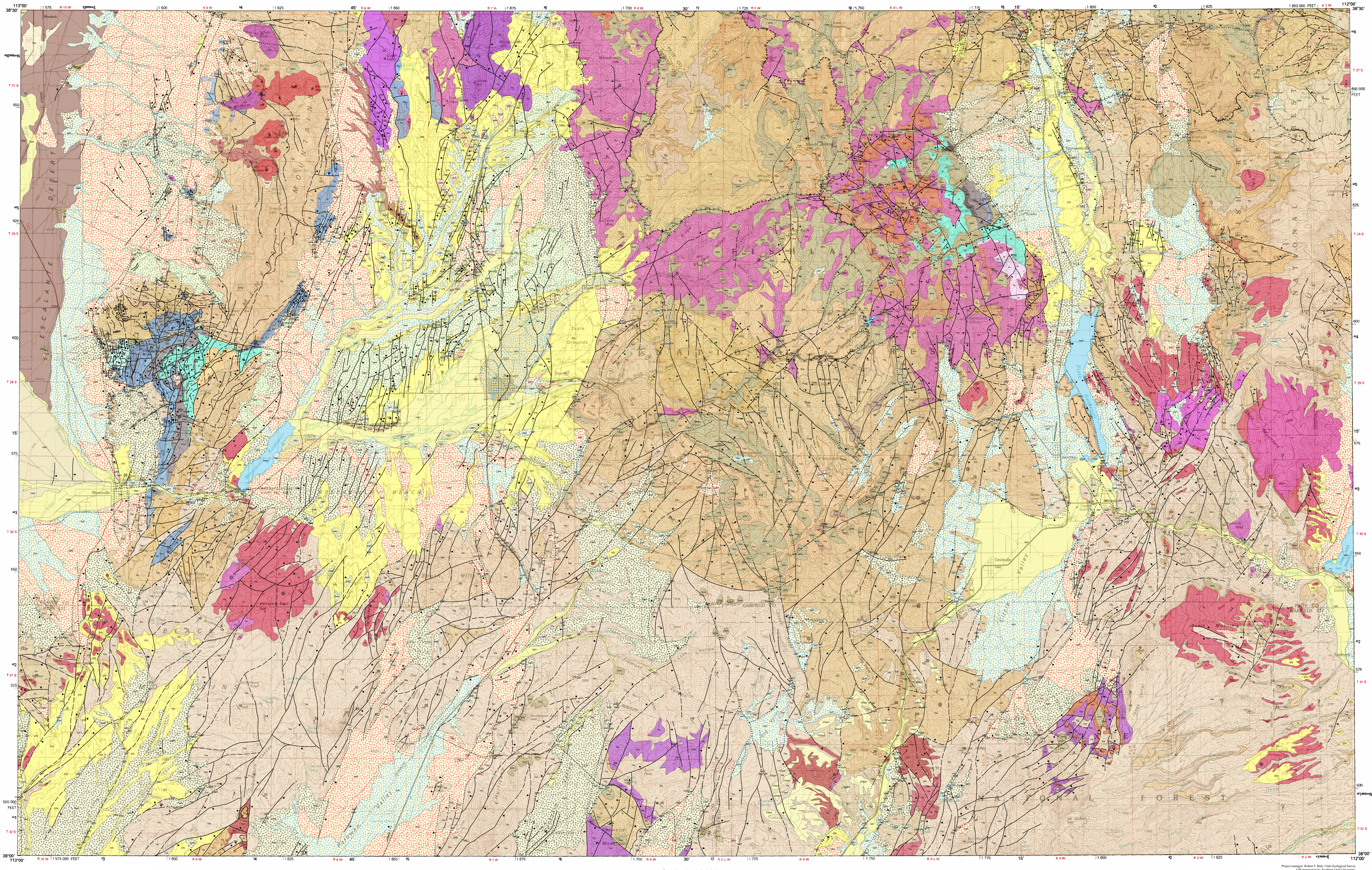

Scale 1:100,000

5 4 3 2 1 0 5 10 Miles

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# Interim Geologic Map of the Beaver 30' x 60' Quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah

By
Peter D. Rowley, Garrett S. Vice, Robert E. McDonald, John J. Anderson, Michael N. Machette, David J. Maxwell, E. Bart Ekren, Charles G. Cunningham, Thomas A. Steven, and Bruce R. Wardlaw

2005

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by
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## NO CROSS SECTIONS ARE AVAILABLE WITH THIS PUBLICATION

### DESCRIPTION OF GEOLOGIC UNITS

**Qf** Artificial-fill deposits—Man-made deposits of artificial fill, for dams.

**$Qal_1$, $Qal_2$** Alluvium—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—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—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—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—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 modern and generally undissected; thickness at least 30 feet (10 m).

**$Qaf_2$, $Qaf_3$, $Qaf_4$** Middle alluvial-fan deposits—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 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 Beaver basin (Machette and others, 1984); thickness at least 50 feet (15 m).

**$QTaf_5$** Old alluvial-fan deposits—Partly consolidated, 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 well dissected by modern streams; mapped only in the Circleville Canyon – Dog Valley area (Anderson, 1987); thickness at least 30 feet (10 m).

**Qmtc** Talus and colluvium—Poorly sorted, mostly angular gravel, sand, and silt deposited by rockfall, sheetwash, and streams along scarps and hillsides; mostly mapped where conceals underlying bedrock; maximum thickness about 30 feet (10 m).

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

**Qmr** Rock-glacier deposits—Unsorted, angular, unstratified rock debris in lobate masses in cirques east of the crest of the Tushar Mountains; includes reworked glacial deposits (moraine) of mostly Pinedale age (late Pleistocene); maximum thickness about 30 feet (10 m).

**Qes** Eolian sand deposits—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—Generally resistant deposits of mostly calcareous tufa from Pleistocene, Holocene, and present springs, including a spring mound 8.5 miles (14 km) north-northeast of Beaver and 4 miles (6 km) north of Minersville; includes siliceous sinter at the Opal Mound, which is controlled by the Opal Mound fault in the northwest part of the map area; also includes 5,000-year-old (middle Holocene) marsh deposits 4 miles (6 km) north of Minersville (report by Beta Analytic, Inc. of Miami, Florida, for the Utah Geological Survey, 2004); maximum thickness about 40 feet (13 m).

**Qlae** Mixed lacustrine, alluvial, and eolian deposits—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 of older Pleistocene lakes; maximum thickness about 20 feet (6 m).

**Qlg** Lacustrine gravel—Silty, fine-to-coarse-grained sand and gravel deposited by the Beaver River in Lake Bonneville and then distributed by waves and currents and deposited in shore-zone deposits as beaches, spits, and offshore bars; maximum thickness about 30 feet (10 m).

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

Rhyolite of Mineral Mountains—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 largely 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, 1980) 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—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 9 domes concentrated along the crest of the north Mineral Mountains; K-Ar age about 0.6 to 0.5 Ma (e.g., Lipman and others, 1978; Sibbett and Nielson, 1980); maximum thickness about 900 feet (300 m).

**Qrt** Tuff—Poorly consolidated, white, unwelded, pumice-rich, crystal-poor, high-silica rhyolite ash-flow and airfall tuff; best exposed in Ranch Canyon, where mined for pumice; overlain by Qrd in the Mineral Mountains, and deposited also eastward throughout the Beaver basin after drainage integration with Escalante Desert (Nash and Smith, 1977; Machette and others, 1984; Machette, 1985); K-Ar age about 0.8 to 0.6 Ma (Lipman and others, 1978); exposed thickness as much as 600 feet (180 m).

**Qrl** Lava flows—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; K-Ar age about 0.8 Ma (Lipman and others, 1978); maximum thickness of each flow is about 300 feet (100 m).

**Qbr** Basaltic andesite of Red Knoll—Resistant, dark-gray and black, blocky, vesicular, crystal-rich basaltic andesite lava flows and red and dark-gray cinder cone of ash and scoria, northwest 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—Resistant, dark-gray and black, blocky, vesicular, crystal-rich basaltic andesite lava flows and red and dark-gray cinder cone of ash and scoria, northwest Beaver basin; has a K-Ar date 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 to the north of the map area (Steven and Morris, 1983; Hintze and others, 2003); maximum thickness about 100 feet (30 m).

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

**QTs** Basin-fill sedimentary rocks—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 related to the youngest basin-range extension that is responsible for the present topography (Rowley and Dixon, 2001; Rowley and others, 2002); 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); the main phase of basin-range faulting took place between 7.6 (unit Trf) and 5.4 Ma (rhyolite of Phonolite Hill, Try) in the Kingston Canyon area (Rowley and others, 1981); thickness of QTs at least 2,000 feet (600 m).

**Tb** Basalt lava flows—Resistant, dark-gray and black, locally vesicular or amygdaloidal, crystal-poor (olivine and pyroxene phenocrysts) olivine basalt lava flows, flow breccia, and cinder cones; synchronous with basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001); includes basalt southeast of Otter Creek Reservoir that has a K-Ar date of 5.0 Ma (Best and others, 1980), basalt in the Black Mountains that has a K-Ar date of 6.4 Ma (Best and others, 1980; Anderson and others, 1990b), another north of it near Minersville Reservoir that has a K-Ar date of 7.6 Ma, basalt in Kingston Canyon that has a K-Ar date of 7.8 Ma (Rowley and others, 1981), basalt 2 miles (3 km) west of Piute Reservoir that has a K-Ar date of 10.9 Ma (Rowley and others, 1994), and basalt east of Piute Reservoir that has K-Ar dates of 12.9 Ma (Damon, 1969) and 12.7 Ma (Best and others, 1980); maximum thickness of lava flows about 200 feet (60 m).

**Tsr** Sevier River Formation—Poorly to moderately indurated, gray, tan, yellow, white, pink, and light-green tuffaceous sandstone, pebbly to bouldery conglomerate, mudstone, and siltstone of fluvial and locally lacustrine origin; deposited in basins that formed generally prior to the main episode of basin-range faulting (Rowley and others, 1981, 1998, 2002; Rowley, 1998); airfall tuff beds and basalt flows within the formation near the town of Sevier north of the mapped area have K-Ar dates between 14 and 5.6 Ma (Best and others, 1980; Steven and others, 1979; Rowley and others, 1994); mapped south of Junction and on the Sevier Plateau; thickness at least 500 feet (150 m).

**Trd** Rhyodacite of Dry Lake—Resistant light-gray, pink, and tan, flow-foliated, locally spherulitic, moderately crystal-rich rhyodacite volcanic dome and lava flows, locally containing black basal vitrophyre; in the Dry Lake area of the south Sevier Plateau; maximum thickness about 750 feet (230 m).

**Try** Young rhyolite lava flows—Small, resistant, mostly gray, flow-banded, crystal-poor, high-silica rhyolite volcanic domes and subordinate pyroclastic material, most of which help define an east-trending structural belt known as the Blue Ribbon transverse zone (Rowley and others, 1978; Rowley, 1998), including the rhyolite of Phonolite Hill in Kingston Canyon, which consists of several domes with K-Ar dates of 5.4 and 4.8 Ma (Rowley and others, 1981); a dome at Blue Ribbon Summit in the Black Mountains that has a K-Ar date of 7.6 Ma (Mehnert and others, 1978; Rowley and others, 1978); a dome at Teddys Valley in the Black Mountains that has a K-Ar date of 7.9 Ma (Anderson and others, 1990b); and a dome southwest of Beaver in the Black Mountains that has a K-Ar date of 8.3 Ma (Anderson and others, 1990b); also includes a small dome in Corral Canyon, west of the Mineral Mountains, that has a K-Ar date of 7.9 Ma (Lipman and others, 1978; see also Evans and Steven, 1982); although the dome of Phonolite Hill has relief of more than 1,000 feet (300 m), in most other places the maximum thickness of the rhyolites is less than 200 feet (60 m).

**Trf** Rhyolite of Forshea Mountain—Resistant light-gray and white, flow-foliated, spherulitic, crystal-poor, high-silica rhyolite lava flows and volcanic dome capping the Sevier Plateau north of Kingston Canyon; locally includes a black basal vitrophyre and soft, poorly exposed airfall and ash-flow tuff, sandstone, and conglomerate at the base of the unit; has K-Ar dates of 7.6 Ma (Rowley and others, 1981); maximum thickness about 1,000 feet (300 m).

**Trg** Rhyolite of Gillies Hill—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 only at the north end of the Beaver basin; has K-Ar dates that cluster at 9 Ma, probably synchronous with the initiation of basin-range faulting in the Beaver basin (Evans and Steven, 1982); base not exposed but exposed thickness at least 1,200 feet (350 m).

**Tir** Rhyolite porphyry—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) that intrudes rocks as young as the main granitic batholith of the Mineral Mountains (Tig) and has K-Ar dates of 9.1 and 9.6 Ma (Nielson and others, 1986), a U-Pb zircon date of 11.0 Ma (Coleman and Walker, 1994), and an $^{40}Ar/^{39}Ar$ date of 11.5 Ma (Coleman and others, 2001); unit also includes several high-silica rhyolite plugs in the Tushar Mountains younger than 19 Ma and shown by Rowley and others (2002) as late rhyolite dikes, stocks, and volcanic domes; map unit also includes lithologically similar low-silica, altered, crystal-poor (phenocrysts of plagioclase and minor sanidine, biotite, and hornblende) rhyolite dikes and plugs in the south Mineral Mountains that have K-Ar dates of 22.5 and 22.3 Ma (Rowley and others, 1994) and may be associated with the calc-alkaline Lincoln Stock (Ticl); 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.

**Mount Belknap Volcanics—**Large masses of high-silica rhyolite derived from several caldera and volcano eruptive centers in the Tushar Mountains and Marysvale mining district (Callaghan, 1939; Rowley and others, 1979; Cunningham and Steven, 1979a; Cunningham and others, 1983; Steven and others, 1984b; Rowley and others, 2002); 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, b, 1994, 1998a, 1999, 2005); isotopic ages from many types of analyses range from 21 to 12 Ma (Cunningham and others, 1998b).

**Tmg** Upper gray tuff member, Gray Hills Rhyolite Member, upper red tuff member, and porphyritic lava flows—From youngest to oldest, these local resistant units were deposited in an east-trending paleocanyon that is east of, and formerly drained, the Mount Belknap caldera: (1) the upper gray tuff member, a crystal-poor rhyolite ash-flow tuff that was derived from the caldera and has a K-Ar date of 18 Ma (Steven and others, 1979) and is at least 425 feet (130 m) thick; (2) the Gray Hills Rhyolite Member, a crystal-poor dome and related rocks from a local vent that has K-Ar dates of 20.5 to 19.5 Ma (Bassett and others, 1963) and is about 1,600 feet (500 m) thick; (3) the upper red tuff member, a densely welded, crystal-poor rhyolite ash-flow tuff derived from the caldera and about 60 feet (20 m) thick; and (4) porphyritic lava flows of coeval, poorly to moderately crystal-rich rhyolite flows and ash-flow tuff as much as 250 (75 m) thick.

**Tmc** Crystal-rich tuff member—Resistant, dark-reddish-brown, gray, and pink, moderately to densely welded, crystal-rich rhyolite ash-flow tuff that fills channels that radiate outward from its source, the Mount Belknap caldera; K-Ar age about 19 Ma (Steven and others, 1979); thickness about 200 feet (60 m).

**Tmr** Red Hills Tuff Member—Moderately resistant, reddish-brown, tan, and light-gray, crystal-poor, densely welded rhyolite ash-flow tuff derived from the Red Hills caldera north of Marysvale (Cunningham and Steven, 1979a); about 19 Ma based on K-Ar dates on overlying and underlying units; maximum thickness about 600 feet (180 m).

**Tmj** Joe Lott Tuff Member—Moderately resistant, light-gray and tan, partly welded, crystal-poor rhyolite ash-flow tuff, with a black basal vitrophyre; the main outflow unit derived from the Mount Belknap caldera (Budding and others, 1987); K-Ar dates on overlying and underlying units indicate an age of 19 Ma (Steven and others, 1979); maximum thickness about 400 feet (120 m).

**Tmb** Mount Baldy Rhyolite Member—Resistant, light-gray, crystal-poor intracaldera rhyolite lava flows and dikes derived from, and deposited mostly within, the Mount Belknap caldera; thickness about 2,600 feet (800 m).

**Tmv** Volcaniclastic rocks—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).

**Tmm** Middle tuff member—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; thickness about 1,600 feet (500 m).

**Tmbl** Blue Lake Rhyolite Member and lower tuff member—Lower parts of the intracaldera fill of the Mount Belknap caldera, consisting of: (1) the Blue Lake Member, a moderately resistant, gray, flow-foliated, crystal-poor lava flow about 1,100 feet (340 m) thick; and (2) the underlying lower tuff member, lithologically similar to Tmm and Tmj and at least 1,500 feet (460 m) thick, with its base not exposed.

**Tmh** Lower heterogeneous member—Mostly soft, gray rhyolite volcanic domes, lava flows, and subordinate ash-flow tuff and fluvial sandstone; derived from a volcano source northwest of Marysvale; thickness about 230 feet (70 m).

**Tmi** Crystal-rich volcanic domes and plugs—Resistant, tan, pink, and gray, flow-foliated, crystal-rich rhyolite volcanic domes and intrusive feeders for domes since eroded away; crops out northeast of Marysvale; age about 21 Ma based on dates on overlying and underlying units (Steven and others, 1979; Cunningham and others, 1982); maximum thickness of domes about 800 feet (250 m).

**Tig** Granitic intrusive rocks—Mostly resistant, mostly gray, high-alkali and mostly high-silica (bimodal igneous episode that is synchronous with basin-range extension) granite and related rocks; includes small, fine-grained intracaldera stocks within the Mount Belknap caldera in the Tushar Mountains (Rowley and others, 2002); to the west, in the Mineral Mountains, includes the main mass of the Mineral Mountains batholith, the largest exposed batholith in Utah, which 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 and syenite (Sibbett and Nielson, 1980; Nielson and others, 1978, 1986; Coleman, 1991; Meschter McDowell and others, 2004) 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 (Nielson and others, 1986; Aleinikoff and others, 1986; Coleman and others, 2001), but Coleman and others (2001) interpreted on the basis of U-Pb zircon and $^{40}Ar/^{39}Ar$ dates that the main granitic batholith in the Mineral Mountains has an age of about 18 to 17 Ma.

**Tml** Potassium-rich mafic lava flows—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 Tml 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 dates of 25 to 21 Ma; maximum thickness about 500 feet (150 m).

**Tmgg** Mafic gravels of Gunsight Flat—Moderately resistant, black and dark-gray fluvial conglomerate made up of clasts of Tml, locally intercalated with Tml and interpreted to represent fanglomerate shed northward from Miocene fault scarps (Anderson and others, 1990a); exposed only in the south Tushar Mountains; maximum thickness 1,000 feet (300 m).

**Thv** Horse Valley Formation—Mostly soft, gray and pink, crystal-poor, dacitic lava flows and volcanic mudflow breccia of a probable stratovolcano complex that erupted in the west to central Black Mountains, most vents of which are just west of the map area (Anderson and Rowley, 1975; Rowley, 1978); dated at 22-19 Ma (Fleck and others, 1975) but is calc-alkaline and unlikely to be much younger than 22 Ma; the significance of calc-alkaline igneous rocks, which make up all Tertiary igneous rocks listed below, is that they precede basin-range extension and are the youngest part of the subduction regime that affected North America (Lipman and others, 1972; Rowley and Dixon, 2001); maximum thickness about 1,000 feet (300 m), thickening westward.

**Rocks of the Monroe Peak caldera**—Includes the Osiris Tuff, whose eruption caused the subsidence of the caldera (Cunningham and others, 1983; Steven and others, 1984b; Rowley and others, 1986a, b, 1988a, b), as well as calc-alkaline intracaldera volcanic, sedimentary, and intrusive rocks of 23 to 22 Ma; north edge of caldera (Rowley and others, 2002; Hintze and others, 2003), like several other calderas and igneous and structural features of the north Marysvale volcanic field, is controlled by the east-striking Cove Fort transverse zone (Rowley, 1998; Rowley and others, 1998; Campbell and others, 1999; Rowley and Dixon, 2001).

**Tmpu** Late intracaldera deposits of the Monroe Peak caldera, undivided—Moderately resistant lava flows, airfall tuff, and fluvial and lacustrine sedimentary rocks that were deposited in the Monroe

Peak caldera after subsidence; the volcanic rocks represent the effusive products of intracaldera intrusions; unit mapped only where rocks are intensely hydrothermally altered.

**Tmps** Sedimentary rocks—Mostly soft, tan, gray, brown, pink, and green, thin- to medium-bedded, fine- to coarse-grained tuffaceous sandstone and airfall tuff deposited in the caldera basin, with minor intertongued lava flows, siltstone, and conglomerate; commonly hydrothermally altered and silicified; maximum thickness about 200 feet (60 m).

**Tmpn** Lava flows of Indian Flat—Resistant, compositionally heterogeneous sequence of lava flows in east part of caldera; mostly purplish-gray and light-gray, crystal-poor, rhyodacitic lava flows; about 150 feet (50 m) thick, but east of map area, unit thickens to 600 feet (200 m) against the caldera wall and includes andesite and dacite flows.

**Tmpl** Lava flows of Monroe Peak—Mostly resistant, gray, pink, greenish-brown, and dark-green, vesicular, generally crystal-rich rhyodacitic lava flows, flow breccia, volcanic mudflow breccia, fluvial sandstone, and airfall tuff; K-Ar age of 21.3 (Rowley and others, 1988b); maximum thickness 500 feet (150 m).

**Tmpf** Lava flows of Monkey Flat Ridge—Moderately resistant, reddish-brown, gray, and greenish-brown, vesicular, crystal-poor dacitic to rhyodacitic lava flows, minor fluvial sandstone and conglomerate, and minor crystal-rich lava flows; maximum exposed thickness 500 feet (150 m).

Osiris Tuff—Ash-flow tuff derived from the Monroe Peak caldera, the largest in the Marysvale volcanic field (Steven and others, 1984b); K-Ar age is about 23 Ma (Fleck and others, 1975; L.W. Snee, U.S. Geological Survey, written commun., 1998).

**Toi** Intracaldera facies—Soft to resistant, orange and tan, densely welded ash-flow tuff that is petrologically the same as outflow facies but is generally partly hydrothermally altered to clay by emplacement of Ticm and Ticmc; facies confined to its source, the Monroe Peak caldera; includes interbedded intracaldera-collapse breccia (“caldera megabreccia”) derived from landslides from the caldera walls into the caldera; thickness at least 1,000 feet (350 m) but base not exposed.

**To** Outflow facies—Resistant, light-gray (upper vapor phase zone) and brown (lower part), densely welded, moderately crystal-rich, rhyodacitic ash-flow tuff (Williams and Hackman, 1971); one or two cooling units with black basal vitrophyres; contains drawn-out pumaceous lenticules; upper part locally contains steeply-dipping flow-foliated rock caused by secondary flowage of rock fused in the last few tens of meters of movement; maximum thickness about 200 feet (60 m).

**Ticm** Intracaldera intrusions of the Monroe Peak caldera, undivided—Resistant, tan, light-gray, and light-green, locally flow-foliated monzonite porphyry (calc-alkaline) intrusive masses that were the source for, and are intruded into, intracaldera volcanic deposits of the Monroe Peak caldera; fine-grained chilled margin locally resembles Toi, into which they intrude, except that they are fresh rather than altered; commonly called “resurgent intrusions” in other calderas (Smith and Bailey, 1968) because they dome up the cover (intracaldera) tuffs above them in the caldera, but the Monroe Peak caldera exhibits no such structural dome; K-Ar dates suggest an age of 22 to 21 Ma (Rowley and others, 1988a, b).

**Ticmc** Intracaldera intrusions of the Monroe Peak caldera, Central intrusion—Resistant, gray and green, porphyritic to equigranular monzonite (calc-alkaline) stock that exhibits a fine-grained chilled margin as wide as 200 feet (60 m); isotopic age about 22 Ma (Rowley and others, 1988a, b); pluton was eroded and unroofed by about 19 Ma, when it was unconformably overlain by Tmr.

**Ticc** Concordant intrusions—Resistant, gray, monzonite (calc-alkaline) intrusions in the Markagunt Plateau (Anderson and Rowley, 1975; Anderson and others, 1990a, b); probably laccoliths that intrude into Tc; one, the Spry Intrusion in Circleville Canyon, is of batholith size in outcrop (Grant and Anderson, 1979) and extends well to the south in the subsurface (Blank and Kucks, 1989; Bankey and others, 1998); the Spry intrusion has an age of 25 Ma (Anderson and others, 1990a), and erupted Tbb and Tbr.

**Tvl** Local volcanic rocks of the Lincoln Stock—Soft, mostly reddish-brown, hydrothermally altered, dacitic to andesitic lava flows and volcanic mudflow breccia located just west of, and adjacent to, Ticl; about 300 feet (100 m) thick, but its base is not exposed; possibly vented products of the Lincoln Stock.

**Ticl** Lincoln Stock—Resistant, light-gray, monzonite and granodiorite porphyry stock in the south Mineral Mountains (Earll, 1957; Corbett, 1984; Price, 1998), resulting in contact metamorphic lead-zinc-gold ore deposits of the Lincoln and Bradshaw mining districts; interpreted here to represent a calc-alkaline phase of the Mineral Mountains batholith; has a K-Ar date of 21.9 Ma (Bowers, 1978) and a preliminary U-Pb zircon date of about 23 Ma (Coleman and others, 1997, 2001).

**Mount Dutton Formation**—Mostly soft, brown, tan, pink, and gray, volcanic mudflow breccia made up of angular clasts of crystal-poor andesitic rock, subordinate resistant lava flows and flow breccia of the same lithology, and 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 south 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); dated at 26 to 21 Ma (Fleck and others, 1975); the most voluminous unit in the Marysvale volcanic field; thickness in the area at least 6,000 feet (2,000 m).

**Tdv** Vent facies—Volcanic mudflow breccia, flow breccia, and lava flows 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 west from Kingston Canyon along the break in slope between the Tushar Mountains and Markagunt Plateau, then along the north side of the Black Mountains and on across the entire Great Basin.

**Tda** Alluvial facies—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.

**Tdp** Plugs and dikes—Small source calc-alkaline magma bodies (vents) of the formation (e.g., Blackman, 1985); the crystal-poor (poorly differentiated) nature of the rock, coupled with the low volume of its source plutons, indicate that the intrusive sources of the volcanic rocks of the formation are deep.

**Tdan** Antimony Tuff Member—Resistant, mostly red, densely welded, crystal-poor, trachytic ash-flow tuff intertongued within the upper part of the formation (Anderson and Rowley, 1975); source vent may underlie Sevier Valley near the town of Sevier; K-Ar age is 25 Ma (Rowley and others, 1994); exposed mostly in the Sevier Plateau; maximum thickness 50 feet (15 m).

**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); K-Ar dates of 26.2 and 25.0 Ma (Fleck and others, 1975); exposed only south of Beaver; maximum thickness about 600 feet (200 m).

**Tdl** Local tuff—Several, mostly resistant, reddish-brown and tan, densely welded, crystal-poor, trachytic ash-flow tuffs intertongued within the formation; maximum thickness of any one unit is about 200 feet (60 m).

**Tdk** Kingston Canyon Tuff Member—Resistant, mostly purple, densely welded, crystal-poor, trachytic ash-flow tuff intertongued within the lower part of the formation (Anderson and Rowley, 1975); perhaps derived from the same source area as Tdan; K-Ar date of 26 Ma (Fleck and others, 1975); exposed mostly in the Sevier Plateau; maximum thickness about 50 feet (15 m).

**Toa** Antimony Tuff Member of the Mount Dutton Formation and Osiris Tuff, undivided.

**Tlf** Tuff of Lion Flat—Soft, 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 Tlj (Rowley and others, 2002); age between 23 and 22 Ma; exposed only in the east Black Mountains and west Tushar Mountains; maximum thickness about 300 feet (100 m).

**Tlj** Volcanic rocks of Lousy Jim—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 13 miles (8 km) in diameter (Sigmund, 1979); K-Ar age 22.6 Ma (Fleck and others, 1975); thickness about 1,000 feet (300 m).

**Tbc** **Bullion Canyon Volcanics—**Moderately resistant, tan, gray, pink, and light-green volcanic mudflow breccia, lava flows, flow breccia, ash-flow tuff, and fluvial conglomerate and sandstone (Callaghan, 1939; Rowley and others, 1979; Steven and others, 1979; Cunningham and others, 1984; Rowley and others, 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, and derived from intrusive sources (Tic) that are abundantly exposed and much more shallow than those for the Mount Dutton Formation; isotopic dates and stratigraphic relationships indicate an age 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 (Tic) 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; Cunningham and others, 1998b); thickness at least 5,000 feet (1,500 m).

**Tic** Calc-alkaline intrusive rock—Moderately resistant, gray, tan, pink, and brown, crystal-rich monzonite, low-silica granite, granodiorite, and monzodiorite; the calc-alkaline sources of Tbc and several other volcanic units, and the calc-alkaline early products of the Mineral Mountains batholith; plutons of Tic, Tig, and other intrusive units represent cupolas of a large composite batholith that underlies the east-trending Pioche-Marysvale igneous belt (Rowley, 1998), including the central and north part of 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, 2002) and geologic mapping (Steven and others, 1990); isotopic ages of Tic cluster at about 25 to 23 Ma (Steven and others, 1979; Cunningham and others, 1984a; Nielson and others, 1978, 1986; Aleinikoff and others, 1986; Coleman and others, 2001).

**Tbcd** Delano Peak Tuff Member—Resistant, dark-reddish-brown, densely welded, crystal-rich, dacitic ash-flow tuff; derived from the Big John caldera in the central Tushar Mountains (Cunningham and others, 1984; Steven and others, 1984a, b); K-Ar age is 23 Ma, and mapping shows that it is older than To; maximum thickness about 600 feet (200 m).

**Tbct** Three Creeks Tuff Member—Resistant, light-gray and tan, moderately welded, crystal-rich, dacitic ash-flow tuff (Steven and others, 1979); derived from the Three Creeks caldera in the south Pahvant Range (Steven, 1981), whose location was likely controlled by the Cove Fort transverse zone (Rowley, 1998); K-Ar age is 27 Ma; the most voluminous ash-flow tuff in the Marysvale volcanic field and formerly was included within the Needles Range Group; maximum thickness about 700 feet (220 m).

**Tkcn** Kingston Canyon Tuff Member of the Mount Dutton Formation, Buckskin Breccia, Three Creeks Tuff Member of the Bullion Canyon Volcanics, and Needles Range Group, undivided.

**Ttm** Tuff of Minersville—Small-volume, moderately resistant, tan, gray, and pink, poorly welded, crystal-poor (conspicuous sanidine and subordinate plagioclase and biotite), rhyolite ash-flow tuff and apparent source dikes; most exposures east of Minersville; maximum thickness of tuff about 100 feet (30 m).

**Tlt** Volcanic rocks of Little Table—Mostly resistant, tan, brown, gray, brownish-red, and green, amygdaloidal, crystal-poor, andesite lava flows and flow breccia and intertongued volcanic mudflow breccia; of vent-facies and alluvial-facies origin (Anderson and Rowley, 1975), separated in detailed mapping (Cunningham and others, 1983); a shield-volcano complex that intertongues with Tda, Tdv, and Tlm; maximum thickness 2,500 feet (750 m).

**Tlm** Volcanic rocks of Langdon Mountain—Soft to resistant, pink, tan, gray, and red dacitic lava flows, flow breccia, volcanic mudflow breccia, and minor fluvial conglomerate and sandstone; mostly alluvial-facies deposits and some vent-facies deposits derived from clustered stratovolcanoes in the central Sevier Plateau, separated in detailed mapping (Cunningham and others, 1983); deposits extend eastward of the map area (Williams and Hackman, 1971), where an unusual nepheline-syenite breccia pipe of 24.4 Ma was emplaced into it (Agrell and others, 1999); maximum thickness in the map area about 1,300 feet (400 m), thickening northward.

**Tql** Leach Canyon Formation of the Quichapa Group—Moderately resistant, tan and gray, crystal-poor, poorly welded, low-silica rhyolite ash-flow tuff; part of a series of regional ash-flow tuffs (Quichapa Group; Mackin, 1960; Williams, 1967) derived from the Great Basin; source probably the Caliente caldera complex of eastern Nevada, as suggested by isopachs (Williams, 1967; Rowley and others, 1995); $^{40}Ar/^{39}Ar$ age about 23.8 Ma (Best and others, 1993); exposed only west of Parowan Valley; maximum thickness about 150 feet (50 m), thickening southwestward.

**Tws** Volcanic rocks of Willow Spring—Soft to moderately resistant, reddish-brown, light-gray, and black, crystal-poor, dacitic volcanic mudflow breccia and subordinate lava flows, flow breccia, and fluvial conglomerate and sandstone; primarily alluvial-facies rocks of a stratovolcano in the Sevier Plateau; maximum exposed thickness about 1,600 feet (500 m).

**Tbv** Bear Valley Formation—Generally soft, characteristically light-green but locally gray and yellow, moderately to well sorted, commonly cross bedded, fine- to medium-grained, tuffaceous sandstone of mostly eolian but locally fluvial origin, interbedded volcanic mudflow breccia, airfall tuff, and poorly and highly welded ash-flow tuff (Anderson, 1971); has K-Ar dates of about 25 Ma (Fleck and others, 1975); maximum thickness about 1,000 feet (300 m).

**Tbr** Volcanic rocks of Bull Rush Creek—Soft to moderately resistant, tan, gray, pink, and greenish-yellow, dacitic volcanic mudflow breccia, conglomerate, sandstone, lava flows, poorly welded ash-flow tuff, dikes, and flow breccia (Anderson and others, 1990a); lava flows and clasts have an identical, distinctive lithology of crystal-rich quartz monzonite porphyry identical to the Spry Intrusion (Ticc); stratovolcano deposits on the roof of, and derived from the Spry Intrusion, which subsequently domed up Tbr; K-Ar date of 26.4 Ma; base not exposed but about 800 feet thick (250 m).

**Tbb** Buckskin Breccia—Moderately resistant, gray and pink, poorly to moderately welded, crystal-poor, dacitic ash-flow tuff, flow breccia, volcanic mudflow breccia, conglomerate, and sandstone (Anderson and Rowley, 1975; Yannacci, 1986); characterized by as much as 50 percent rock volume of crystal-rich lithic clasts identical to Tbr and the Spry Intrusion (Ticc), from which it was derived; intertongues with the Isom Formation (Tin) and considered about 26 Ma; exposed between Buckskin Valley and Circleville Canyon (Markagunt Plateau); maximum thickness about 250 feet (80 m).

**Tin** Isom Formation and the Needles Range Group, undivided

Isom Formation—Resistant, brown and reddish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff (Mackin, 1960; Fryman, 1987) derived perhaps from the Indian Peak caldera complex at the Utah-Nevada border (Best and others, 1989a, b); age about 27-26 Ma on the basis of many $^{40}Ar/^{39}Ar$ and K-Ar dates (Best and others, 1989b; Rowley and others, 1994); maximum thickness about 30 feet (10 m).

Needles Range Group—Resistant, gray, tan, pink, and light-purple, crystal-rich, moderately welded, dacite ash-flow tuff (Mackin, 1960) derived from the Indian Peak caldera complex (Best and others, 1989a, b); near Minersville, consists of both the Lund Formation (27.9 Ma; Best and others, 1989a) and the Wah Wah Springs Formation (30.5 Ma; Best and others, 1989a) of the Needles Range Group; in the Markagunt Plateau, consists of the Wah Wah Springs Formation; maximum thickness about 100 feet (30 m).

**Tvs** Local volcanic and sedimentary rocks—Heterogeneous assemblage of mostly resistant lava flows, ash-flow tuff, flow breccia, volcanic mudflow breccia, and tuffaceous sandstone (Anderson and Rowley, 1975); a K-Ar date of 31.9 Ma was determined on an ash-flow tuff (Fleck and others, 1975); exposed only between Buckskin Valley and Circleville Canyon; maximum thickness about 450 feet (140 m).

**Tcg** Conglomerate—Moderately resistant, white, tan, and light-gray, fluvial conglomerate and sandstone characterized by pebbles of quartzite and carbonates as much as 3 feet (1 m) in diameter, resting unconformably on Mesozoic sedimentary rocks; where exposed in the south Mineral Mountains and Minersville area, its maximum thickness is about 120 feet (40 m); exposed also as a patch that includes tuffaceous sandstone as much as 30 feet thick (10 m) in the central Tushar Mountains.

**Tc** Claron Formation—Soft to resistant, mostly white and gray (upper part) and red (lower part), lacustrine and fluvial limestone, calcrete, sandstone, siltstone, mudstone, and conglomerate; maximum thickness about 1,000 feet (300 m).

**Ja** Arapien Shale—Soft to moderately resistant, multicolored but generally light-gray, marine siltstone, shale, mudstone, limestone, sandstone, and minor conglomerate; contains evaporite beds north of the map area; exposed in the central Tushar Mountains, in the southwest part of the Arapien basin of central Utah (Hintze, 1993); thickness more than 1,150 feet (350 m), with its top not exposed.

**Jc** Carmel Formation—Soft to resistant, light-gray, reddish-brown, and tan thin-bedded limestone and shale underlain by resistant, light-gray, thin- to medium-bedded, locally fossiliferous limestone (Earll, 1957); exposed in the Mineral Mountains; maximum thickness about 600 feet (200 m).

**Jn** Navajo Sandstone—Resistant, red, yellow, and gray, locally spectacularly cross bedded, fine- to medium-grained, eolian sandstone (Earll, 1957; Price, 1998); exposed northeast of Minersville and in the central Tushar Mountains; maximum exposed thickness about 1,500 feet (450 m) northeast of Minersville and 2,000 feet (600 m) in the central Tushar Mountains.

**TRc** Chinle Formation—Fluvial and lacustrine rocks of the upper Petrified Forest Member and the underlying Shinarump Conglomerate Member; the Petrified Forest Member is of soft to moderately resistant, red, maroon, brown, tan, and white mudstone, and a basal bed of purple, coarse-grained sandstone; the Shinarump Conglomerate Member is moderately resistant, red to brownish-red, fine- to medium-grained conglomerate; exposed only in the central Tushar Mountains, where the combined thickness is about 600 feet (200 m).

**TRm** Moenkopi Formation—Soft and locally resistant, red, brown, pink, light- and dark-gray, and greenish-gray, marine and continental, thin-bedded siltstone, shale, and subordinate locally fossiliferous limestone (Earll, 1957; Price, 1998); exposed east and northeast of Minersville and in the central Tushar Mountains; thickness about 1,300 feet (400 m) to 1,700 feet (500 m).

**Ppt** Plympton, Kaibab, and Toroweap Formations, undivided—Mapped only north of Minersville.

**Ppk** Plympton and Kaibab Formations, undivided—Mapped only east and north of Minersville. Plympton Formation—Moderately resistant, gray and tan, thin bedded, ledgy, chert-bearing, marine dolomite and limestone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); maximum thickness about 200 feet (60 m).

**Pkt** Kaibab and Toroweap Formations, undivided—Mapped only in the central Tushar Mountains, where their combined thickness is 500 to 800 feet (150 to 250 m).

**Pk** Kaibab Formation—Resistant, light- to dark-gray, medium-grained, thin- to thick-bedded, fossiliferous marine limestone characterized by cliffs and ledges and by abundant dark-brown chert concretions and beds (Earll, 1957; J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984; Price, 1998); maximum thickness about 550 feet (170 m) in the northwest part of the map area.

**Pt** Toroweap Formation—Generally resistant, light- to dark-gray, black, and tan, fine-grained, mostly thin-bedded, ledgy, locally cherty and fossiliferous, marine limestone and subordinate sandstone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984); mapped in the northwest part of the map area, where the maximum thickness is about 300 feet (100 m).

**PIPqc** Queantoweap Sandstone, Pakoon Dolomite, and Callville Limestone, undivided—Mapped only in the central Tushar Mountains, where their combined thickness is about 300 feet (100 m) although the base is not exposed.

**Pq** Queantoweap Sandstone—Resistant, tan and pink, thin-bedded, ledgy, fine-grained sandstone and quartzite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); mapped in the northwest part of the map area; maximum thickness about 500 feet (150 m).

**Pzc** Paleozoic carbonate rocks—Mapped only in the Gillies Hill area (Machette and others, 1984) and Mineral Mountains where intensely metamorphosed.

**Pp** Pakoon Dolomite—Alternating soft and resistant, light- to dark-gray and pink, ledgy and cliffy, medium-grained, thick-bedded, locally chert-bearing, marine dolomite and subordinate to minor sandstone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984; Price, 1998); mapped in the northwest part of the map area; thickness about 800 feet (240 m).

**IPc** Callville Limestone—Soft to moderately resistant, white and light-gray, fine-grained, thin- to medium-bedded, ledgy, locally fossiliferous, rarely cherty, marine limestone and minor gray, purple, and brown siltstone and fine-grained sandstone capped by an upper limestone cliff in the Bradshaw district (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Wardlaw, 1980; Corbett, 1984; Price, 1998); mapped in the northwest part of the map area; thickness about 400 feet (120 m).

**Mr** Redwall Limestone—Resistant, light-gray to black, medium-grained, thick-bedded, highly fossiliferous, rarely cherty, spar-rich, marine limestone and, in the lower part, dolomite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); forms massive cliffs; mapped in the northwest part of the map area; thickness about 1,250 feet (380 m).

**Dcs** Crystal Pass Formation, Simonson Dolomite, and Sevy Dolomite, undivided—Mapped only in the northwest part of the map area along the west fault scarp of the south Mineral Mountains.
Crystal Pass Formation—Mostly soft, light-gray, thin- to medium-bedded, interbedded marine dolomite and sandstone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); thickness about 160 feet (50 m).
Simonson Dolomite—Resistant, light- to medium-gray, mostly thick-bedded, marine dolomite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); thickness at least 500 feet (150 m) but no complete section is exposed.
Sevy Dolomite—Mostly resistant, light-gray siltstone and cross-bedded sandstone at the top, underlain by light-gray marine dolomite; thickness less than 100 feet (30 m) but only the top of a complexly faulted section in the Bradshaw mining district is exposed.

**pCg** Banded gneiss—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; as mapped, unit includes local dikes and apophyses of Tertiary intrusive rocks of the Mineral Mountains batholith (Nielson and others, 1986); Rb-Sr and U-Pb dating shows that the unit was last metamorphosed at about 1,750 Ma (Aleinikoff and others, 1986).

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## REFERENCES CITED (those not included in the Source List for Geologic Mapping)

Agrell, S.O., Chinner, G.A., and Rowley, P.D., 1999, The black skarns of Pine Canyon, Piute County, Utah: Geological Magazine, v. 136, no. 4, p. 343-359.

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.

Anderson, J.J., 1971, Geology of the southwestern High Plateaus of Utah—Bear Valley Formation, and Oligocene-Miocene volcanic arenite: Geological Society of America Bulletin, v. 82, p. 1179-1205.

Anderson, J.J., 1987, Late Cenozoic drainage history of the northern Markagunt Plateau, Utah, *in* Kopp, R.S., and Cohenour, R.E., editors, Cenozoic geology of western Utah: Utah Geological Association Publication 16, p. 271-278.

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.

Bankey, Viki, Grauch, V.J.S., and Kucks, R.P., 1998, Utah aeromagnetic and gravity maps and data—A web site for distribution of data: Online, U.S. Geological Survey Open-File Report 98-761, http://pubs.usgs.gov/of/1998/ofr-98-0761/index.utml.

Bassett, W.A., Kerr, P.F., Schaeffer, O.A., and Stoenner, R.W., 1963, Potassium-argon dating of the late Tertiary volcanic rocks and mineralization of Marysvale, Utah: Geological Society of America Bulletin, v. 74, p. 213-220.

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.

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., 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.

Best, M.G., Scott, R.B., Rowley, P.D., Swadley, W C, Anderson, R.E., Gromme, C.S., Harding, A.E., Deino, A.L., Christiansen, E.H., Tingey, D.G., and Sullivan, K.R., 1993, Oligocene-Miocene caldera complexes, ash-flow sheets, and tectonism in the central and southeastern Great Basin, *in* Lahren, M.M., Texler, J.H., Jr., and Spinosa, Claude, editors, Crustal evolution of the Great Basin and Sierra Nevada: Field Trip Guide, Geological Society of America, Cordilleran and Rocky Mountain Sections Meeting, p. 285-311.

Blackman, J.T., 1985, Geology of a vent of the Mount Dutton Formation (Miocene), southwest Tushar Mountains, Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 80 p.

Blank, H.R., and Kucks, R.P., 1989, Preliminary aeromagnetic, gravity, and generalized geologic maps of the USGS Basin and Range – Colorado Plateau transition zone study area in southwestern Utah, southeastern Nevada, and northwestern Arizona (the "BARCO" project): U.S. Geological Survey Open-File Report 89-432, 27 p., scale 1:250,000.

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, Eugene, 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.

________1973, Mineral resources potential of Piute County, Utah and adjoining areas: Utah Geological and Mineralogical Survey Bulletin 102, 135 p.

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.

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., 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.

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.

________1999, Reply to the Comment by C.S. Spirakus: Mineralium Deposita, v. 34, p. 725-726.

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., 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., and Steven, T.A., 1979a, 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., ed., 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.

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

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.

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.

Grant, T.C., and Anderson, J.J., 1979, Geology of the Spry intrusion, Garfield County, Utah: Utah Geology, v. 6, p. 5-24.

Hintze, L.F., 1993, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 7, 202 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 195, scale 1:100,000.

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.

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.

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.

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

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.

________1992, Geochemistry, origin, and tectonic implications of mid-Tertiary and late Tertiary and Quaternary volcanic rocks, southern Marysvale volcanic field, Utah: DeKalb, Illinois, 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.

________1990, Late Cenozoic lavas of the Utah transition zone (abs.): Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 65.

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.

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., 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.

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.

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., 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.

________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., 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., 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., Nealey, L.D., Unruh, D.M., Snee, L.W., Mehnert, H.H., Anderson, R.E., and Gromme, C.S., 1995, Stratigraphy of Miocene ash-flow tuffs in and near the Caliente caldera complex, southeastern Nevada and southwestern Utah, *in* Scott, R.B., and Swadley, W C, editors, Geologic studies in the Basin and Range—Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1992: U.S. Geological Survey Bulletin 2056, p. 43-88.

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., 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.

________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.

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.

Smith, R.L., and Bailey, R.A., 1968, Resurgent cauldrons, *in* Coats, R.R., Hay, R.L., and Anderson, C.A., editors, Studies in volcanology: Geological Society of America Memoir 116, p. 612-662.

Steven, T.A., 1981, Three Creeks caldera, southern Pavant Range, Utah: Brigham Young University Geology Studies, v. 28, part 3, p. 1-7.

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.

________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.

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.

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.

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., 1967, Stratigraphy and petrography of the Quichapa Group, southwestern Utah and southeastern Nevada: Seattle, University of Washington, unpublished Ph.D. dissertation, 182 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.

Yannacci, D.S., 1986, The Buckskin Breccia—A block and ash-flow tuff of Oligocene age in the southwestern High Plateaus of Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 107 p.

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


1. Anderson, J.J., 1965, Geology of northern Markagunt Plateau, Utah: Austin, University of Texas, unpublished Ph.D. dissertation, 194 p., scale 1:62,500.

2. _______1986, Geologic map of the Circleville Mountain quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 80, scale 1:24,000.

3. Anderson, J.J., and Grant, T.C., 1986, Geologic map of the Fremont Pass quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 81, scale 1:24,000.

4. 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.

5. Anderson, J.J., Sigmund, J.M., Cunningham, C.G., Steven, T.A., Lanigan, J.C., and Rowley, P.D., 1980, Geologic map of the Delano Peak SW quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1255, scale 1:24,000.

6. Anderson, J.J., Rowley, P.D., and Blackman, J.T., 1986, Geologic map of the Circleville quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 82, scale 1:24,000.

7. Anderson, J.J., Rowley, P.D., Blackman, J.T., Mehnert, H.H., and Grant, T.C., 1990a, 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.

8. Anderson, J.J., Rowley, P.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990b, 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.

9. Coleman, D.S., 1991, Geology of the Mineral Mountains batholith, Utah: Lawrence, University of Kansas, unpublished Ph.D. thesis, 219 p, scale 1:12,000.

10. Cunningham, C.G., Anderson, J.J., and Steven, T.A., 1979, Geologic map of the Delano Peak SE quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1139, scale 1:24,000.

11. Cunningham, C.G., and Steven, T.A., 1978, Geologic map of the Delano Peak NW quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-967, scale 1:24,000.

12. ________1979b, Uranium in the Central Mining Area, Marysvale district, west central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1177, scale 1:24,000.

13. ________1979c, Geologic map of the Deer Trail Mountain--Alunite Ridge mining area, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1230, scale 1:24,000.

14. ________1979d, Geologic map of the Delano Peak NE quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1105, scale 1:24,000.

15. ________1979e, Geologic map of the Marysvale NW quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1106, scale 1:24,000.

16.  ________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.

17.  Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H., Jr., Nash, W.P., Brown, F.H., Izett, G.A., Naeser, C.W., and Friedman, Irving, 1978, Pleistocene rhyolite of the Mineral Mountains, Utah—Geothermal and archeological significance:  U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133-147, scale about 1:80,000.

18.  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.

19.  Machette, M.N., and Steven, T.A., 1982, 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.

20.  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.

21.  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, scale about 1:30,000 and 1:60,000.

22.  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.

23.  Rowley, P.D., 1968, Geology of the southern Sevier Plateau, Utah:  Austin, University of Texas, unpublished Ph.D. dissertation, 385 p., scale 1:62,500.

24.  ________1979, Geologic map of the Marysvale SE quadrangle, Piute County, Utah:  U.S. Geological Survey Miscellaneous Field Studies Map MF-1115, scale 1:24,000.

25.  Rowley, P.D., Cunningham, C.G., Anderson, J.J., and Steven, T.A., 1979, Geologic map of the Marysvale SW quadrangle, Piute County, Utah:  U.S. Geological Survey Miscellaneous Field Studies Map MF-1116, scale 1:24,000.

26.  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.

27.  Rowley, P.D., Steven, T.A., and Cunningham, C.G., 1980-82, unpublished mapping of bedrock and surficial geology, scale 1:50,000.

28.  Rowley, P.D., Vice, G.S., and McDonald, R.E., 2003-2004, unpublished mapping of bedrock and surficial geology, scale 1:100,000.

29.  _______2003-2005, unpublished mapping of bedrock and surficial geology, scale 1:24,000.

30.  Rowley, P.D., Wardlaw, B.R., and Machette, M.N., 1970-1980, unpublished mapping of bedrock and surficial geology of the Minersville 15’ quadrangle, scale 1:62,500.

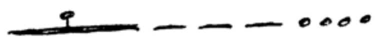
31.  Rowley, P.D., Williams, P.L., Anderson, J.J., and Kaplan, A.M., 1981, Geologic map of the Marysvale NE quadrangle, Piute County, Utah;  U.S. Geological Survey Miscellaneous Field Studies Map MF-1329, scale 1:24,000.

32. 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.

## GEOLOGIC SYMBOLS



CONTACT



NORMAL FAULT

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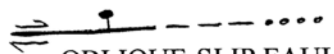

OBLIQUE-SLIP FAULT

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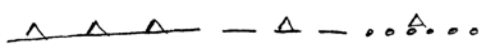

LOW-ANGLE NORMAL FAULT

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GRAVITY-SLIDE SURFACE

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CALDERA MARGIN

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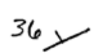


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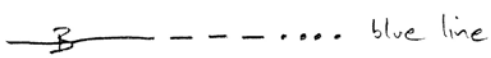


LAKE BONNEVILLE SHORELINE

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DEEP EXPLORATION WELL

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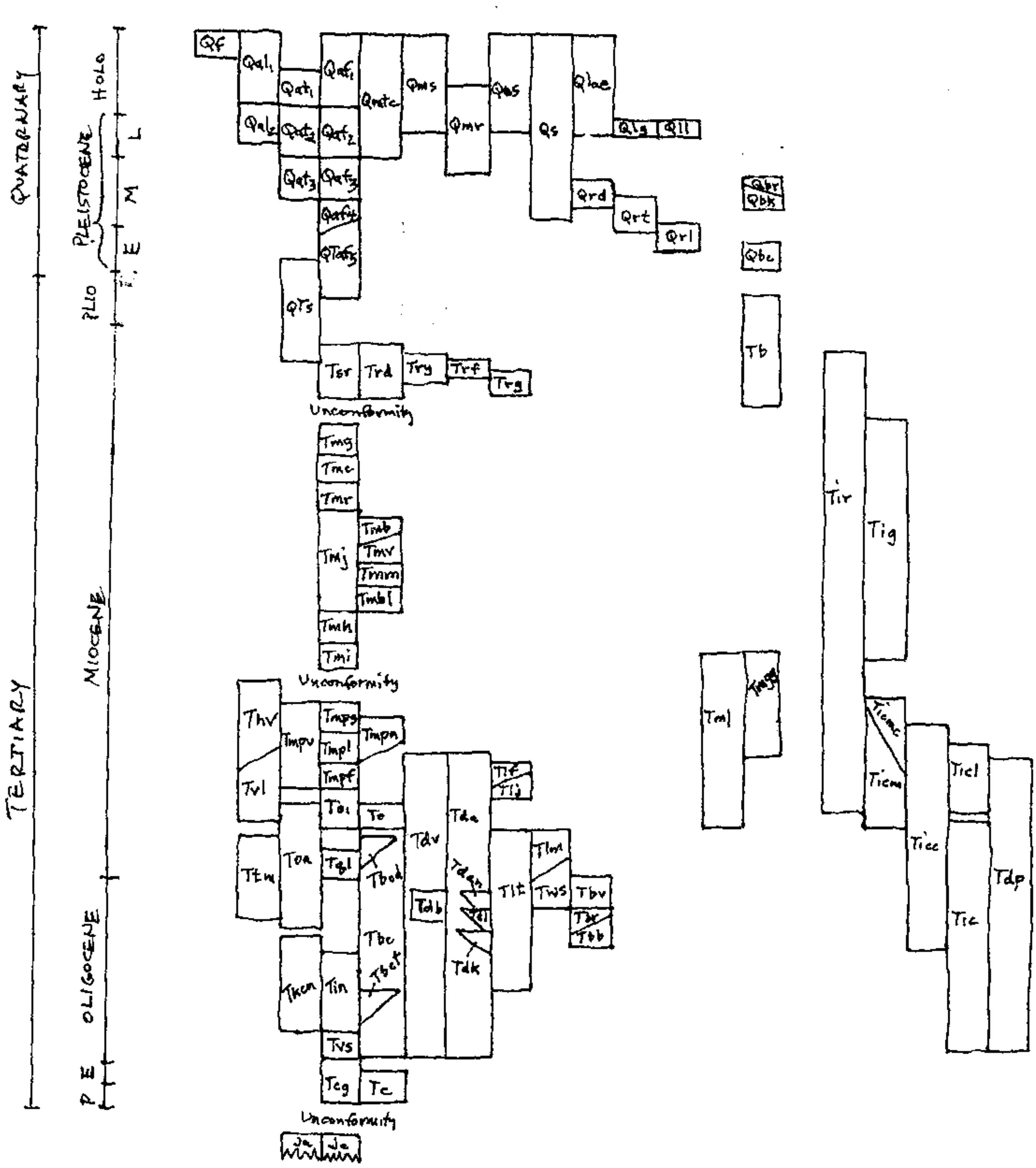
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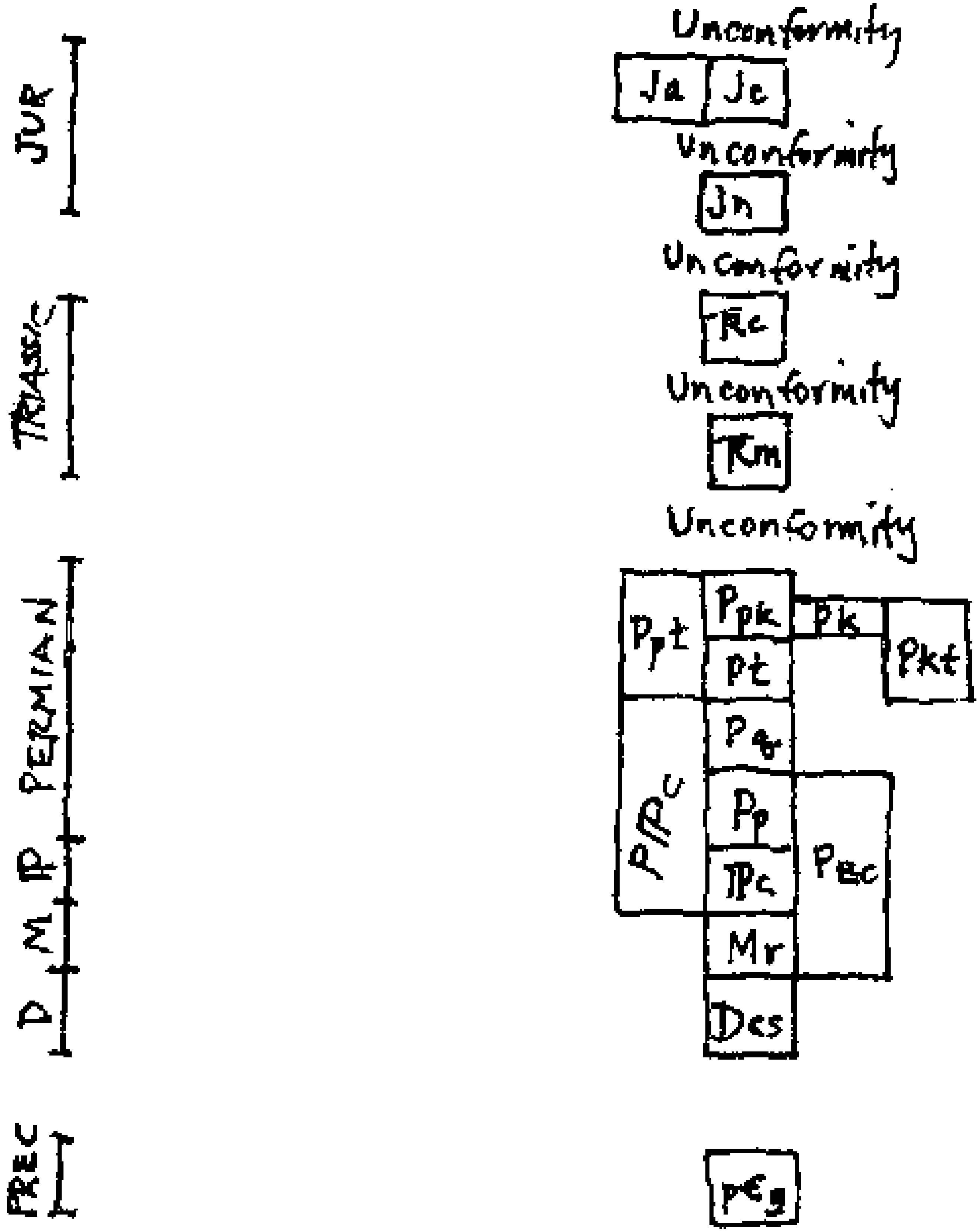
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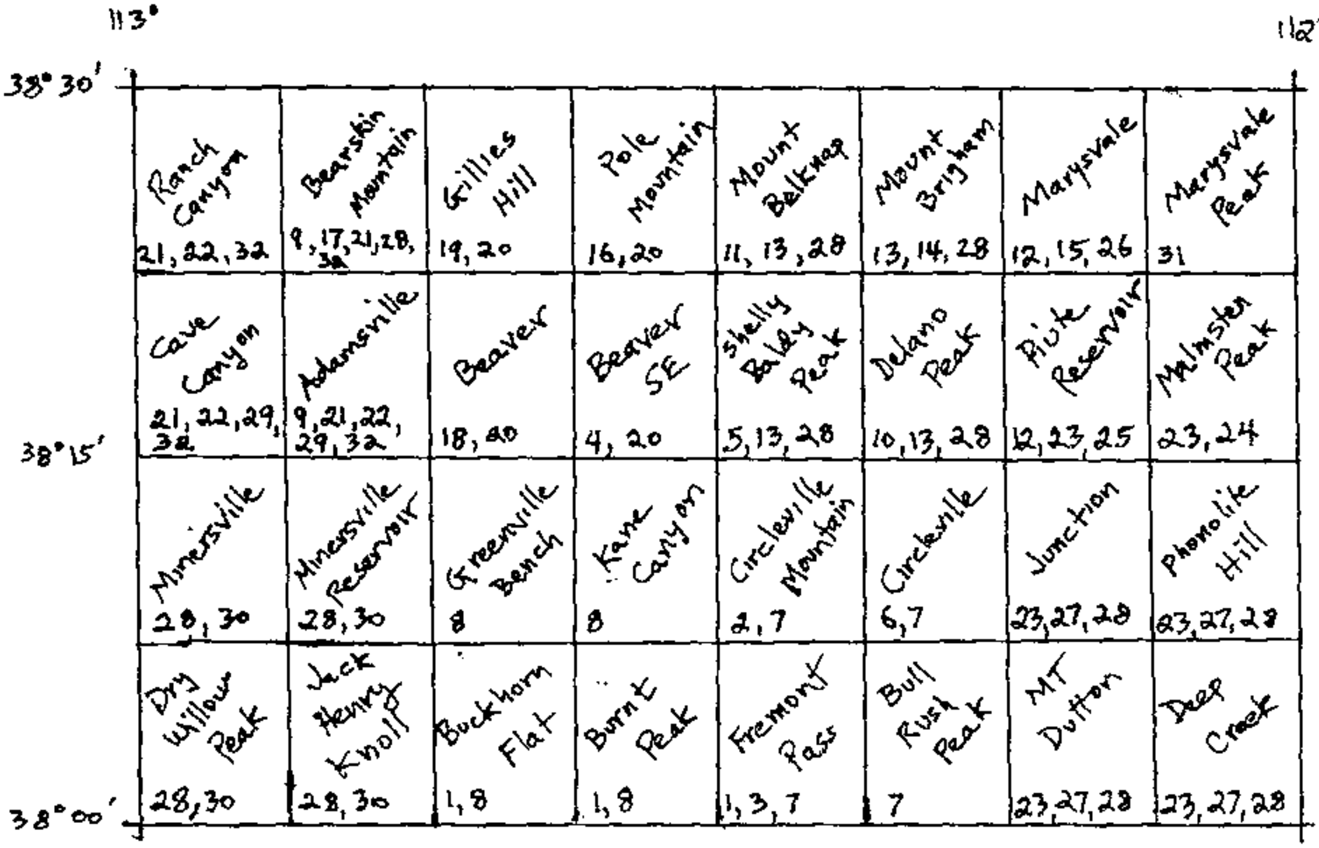


Index map showing 7.5-minute quadrangles and sources of geologic mapping

# LITHOLOGIC COLUMN

| AGE | | MAP SYMBOLS | MAP UNIT | THICKNESS FEET | THICKNESS METERS | SCHEMATIC COLUMN | OTHER INFORMATION |
|---|---|---|---|---|---|---|---|
| QUAT | P-H | Q-various | Alluvial, mass wasting, eolian, lacustrine deposits | 0-100 | 0-30 | | |
| | | Qrd, Qrt, Qrl | Rhyolite of the Mineral Mountains | 1,500 | 500 | | 0.5-0.8 Ma<br>Source of geothermal power<br>Implement-grade obsidian |
| | | Qbr, Qbk, Qbc | Basalt lava flows | 30-200 | 10-60 | | 0.5-1.1 Ma |
| | PL | QTs | Basin-fill sedimentary rocks | 0-2,000+ | 0-600+ | | In basins from main-phase basin-range extension<br>0-8 Ma |
| TERTIARY | MIOCENE | Tb | Basalt lava flows | 30-200 | 10-60 | | 5-13 Ma |
| | | Tsr | Sevier River Formation | 0-500 | 0-150 | | In basins from early (6-15 Ma) basin-range extension |
| | | Trd, Try, Trf, Trg | Rhyolite lava flows | 1200+ | 400+ | | 5-10 Ma |
| | | Tir | Rhyolite porphyry intrusions | – | – | | 9-22 Ma |
| | | Tmg, Tmc, Tmr, Tmj, Tmb, Tmv, Tmm, Tmbl, Tmh, Tmi | Mount Belknap Volcanics | 200-2,600 | 60-800 | | 18-21 Ma<br>From Mount Belknap and Red Hills calderas and local domes<br>Uranium, molybdenum |
| | | Tig | Granitic intrusive rocks | – | – | | 17-21 Ma<br>Main mass of Mineral Mountains batholith |
| | | Tml, Tmgg | Potassium-rich mafic lava flows, gravels | 500-1,000 | 100-300 | | 21-25 Ma<br>Start of basin-range extension |
| | | Thv | Horse Valley Formation | 1,000 | 300 | | 19-22 Ma<br>End of calc-alkaline magmatism |
| | | Tmpo, Tmps, Tmpa, Tmpl, Tmpf, Toi, To | Rocks of Monroe Peak caldera, including Osiris Tuff | 200-1,000+ | 60-300+ | | 22-23 Ma<br>From Monroe Peak caldera |
| | | Ticm, Ticmc | Intracaldera intrusions of Monroe Peak caldera | – | – | | 22-23 Ma |
| | | Ticc | Concordant intrusions | – | – | | Includes Spry intrusion<br>As old as 25 Ma |
| | | Tvl | Local volcanic rocks of the Lincoln Stock | 300 | 100 | | |
| | | Ticl | Lincoln Stock | | | | 22-23 Ma |
| | | Tdv, Tda, Tdp, Tdan, Tdb, Tdl, Tdk | Mount Dutton Formation | 6,000 | 2,000 | | 21-26 Ma<br>Mostly volcanic mudflow breccia from clustered stratovolcanoes<br>Andesite |

| | | | | | | |
|---|---|---|---|---|---|---|
| TERTIARY | MIOCENE | Tlf | Tuff of Lion Flat | 300 | 100 | |
| | | Tlj | Volcanic rocks of Lousy Jim | 1,000 | 300 | 22.6 Ma |
| | | Tbc, Tbcd, Tbct | Bullion Canyon Volcanics | 5,000 | 1,500 | 22-30 Ma<br>Lava flows, mudflow breccia, and tuff from clustered stratovolcanoes<br>Dacite |
| | | Tic | Calc-alkaline intrusive rock | — | — | Source of Bullion Canyon Volcanics<br>Chalcophile mineral resources |
| | | Ttm | Tuff of Minersville | 100 | 30 | |
| | | Tlt | Volcanic rocks of Little Table | 2,500 | 800 | Shield-volcano complex |
| | | Tlm | Volcanic rocks of Langdon Mountain | 1,300 | 400 | Stratovolcano |
| | | Tql | Leach Canyon Formation | 150 | 50 | 23.8 Ma |
| | OLIGOCENE | Tws | Volcanic rocks of Willow Spring | 1,600 | 500 | Stratovolcano |
| | | Tbv | Bear Valley Formation | 1,000 | 300 | Mostly eolian |
| | | Tbr | Volcanic rocks of Bull Rush Creek | 800 | 250 | From Spry intrusion |
| | | Tbb | Buckskin Breccia | 250 | 80 | |
| | | Tin | Isom Formation and Needles Range Group | 100 | 30 | 26-30.5 Ma |
| | | Tvs | Local volcanic and sedimentary rocks | 450 | 140 | |
| | EO | Tcg | Conglomerate | 30 | 10 | |
| | PAL | Tc | Claron Formation | 1,000 | 300 | Fluvial and lacustrine<br>Unconformity |
| JURASSIC | | Ja | Arapien Shale | 1,150+ | 350+ | |
| | | Jc | Carmel Formation | 600 | 200 | |
| | | Jn | Navajo Sandstone | 1,500-2,000 | 450-600 | Mostly red eolian sandstone |
| TRIASSIC | | TRc | Chinle Formation | 600 | 200 | |
| | | TRm | Moenkopi Formation | 1,300-1,700 | 400-500 | |
| PERMIAN | | Ppt, Ppk, Pkt, Pk, Pt | Plympton, Kaibab, and Toroweap Formations | 500-800 | 150-250 | Cherty marine limestone |
| | | Pq | Queantoweap Sandstone | 500 | 150 | |
| | | Pp, Pzc | Pakoon Dolomite | 800 | 240 | Marine dolomite |
| PEN | | IPc, Pzc | Callville Limestone | 400 | 120 | |
| MISS | | Mr, Pzc | Redwall Limestone | 1,250 | 380 | Highly fossiliferous |
| DEV | | Dcs | Crystal Pass Formation, Simonson and Sevy Dolomite | 760 | 230 | |
| PROT | | p€g | Banded gneiss | — | — | Unconformity<br>1,750 Ma |