

UNITED STATES DEPARTMENT OF INTERIOR

U.S. GEOLOGICAL SURVEY

**PRELIMINARY GEOLOGIC MAP OF SOUTHERN YUCCA
MOUNTAIN, NYE COUNTY, NEVADA**

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

DESCRIPTION OF MAP UNITS

Descriptions of colors of bed rock units are from the Rock-Color Chart (Rock-Color Chart Committee, 1951). Descriptions of volcanic units are based upon megascopic and binocular microscope inspection; abundances of phenocrysts are based upon handlens and binocular microscope estimates except where otherwise indicated. Numerous, small-offset, west-dipping normal faults that cut east-dipping strata generally are not depicted because of scale limitations or because of poor exposure; thus, stratigraphic thicknesses of intervals affected by these structures are unrealistically high, whether measured by geometric reconstruction from the map or measured in the field. This and other general structural relationships are further described in Scott (1990).

- QTac** **Alluvium and colluvium (Quaternary and late Tertiary)**—Alluvium, consisting of pale-yellowish-brown to very pale orange boulders, gravel, sandy gravel, sand, and silt; unconsolidated to consolidated, poorly to moderately bedded, and, poorly to moderately well sorted. Clasts consist of volcanic units; clasts generally are coarser closer to bedrock exposures. Soil development ranges from no visible soil on youngest alluvium to a vesicular A horizon, a cambic to argillic B horizon, and a Stage III to Stage IV carbonate horizon on oldest alluvium (Gile and others, 1966). On and adjacent to Busted Butte, alluvium includes reworked eolian deposits that locally contain abundant root casts. Colluvium consists of unconsolidated to moderately consolidated debris consisting chiefly of talus; angular pebble- to boulder-sized clasts, with minor amounts of silt and sand; typically poorly sorted. Colors are inherited from bedrock source. Colluvium is generally nonbedded and locally cemented by secondary carbonate; occurs along base of steep slopes developed on Tertiary volcanic rocks. No distinctions of age, genesis, or lithology of alluvial or colluvial units are depicted on this map. Thickness greater than 100 m locally. [More detailed information on surficial deposits in the area is given by Swadley (1983), Swadley and Parrish (1988), and Swadley and Hoover (1989)]
- Qbf** **Basalt flow (Early Holocene(?) to Pleistocene(?))**—Olivine basalt, consisting of grayish-black to brownish-black scoriaceous flows forming the eastern side of a lava-flow apron under the Lathrop Wells cinder cone, located 600 m west of the map area. Olivine phenocrysts form about 2 percent of the rock. Exposed in southwest part of map area. Precise age of basalt is uncertain; age reported as less than 250,000 years (Crowe and others (1983), but the overlying cinder cone may be as young as latest Pleistocene or early Holocene (Wells and others (1990). Maximum thickness is 27 m
- Tts** **Tuffaceous sandstone (Pliocene(?) or Miocene(?))**—Poorly to moderately consolidated, poorly to moderately sorted conglomeratic sandstone, consisting of tuffaceous boulders, cobbles, pebbles, and sand in a very pale orange and yellowish-gray tuffaceous matrix. Thin layers of yellowish-gray tuff occur between thick beds of sandstone. Larger clasts are angular to subrounded and were derived from the Paintbrush Tuff. Map unit locally contains fluvial crossbeds and channel fill. Locally as much as 12 m thick

Timber Mountain Tuff (Miocene)--Ash-flow tuff, consisting of compound two cooling units, in descending order, the Ammonia Tanks and Rainier Mesa Members. Although each ash-flow tuff is chemically zoned from a quartz latitic top to a rhyolitic base on a regional scale (Broxton and others, 1989), only the rhyolitic zone of each unit is represented in the map area. Combined maximum thickness about 30 m

- Tma** **Ammonia Tanks Member**--Grayish-orange-pink to pinkish-gray, rhyolitic, ash-flow tuff consisting of a nonwelded to partially welded simple (?), vitric to devitrified cooling unit. Few to abundant lithophysal cavities, about 20 percent pumice fragments that range from 0.2 to 3.5 cm long, and sparse lithic fragments are present. Rock contains about 18 percent phenocrysts consisting of about 20 percent quartz, 60 percent adularic sanidine, 15 percent plagioclase, 2 percent biotite, and traces of other ferromagnesian phases, Fe-Ti oxides, and sphene. Map unit forms gentle rounded slopes, is exposed in the southwest part of the map area, and is preserved only in low-standing areas. A $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date for the Ammonia Tanks Member is 11.45 Ma (Sawyer and others, 1990). Maximum thickness is 20 m
- Tmr** **Rainier Mesa Member, undivided**--Very light gray, grayish-orange, grayish-orange-pink, to pinkish-gray, rhyolitic, ash-flow tuff, consisting of a nonwelded to moderately welded, vitric to devitrified cooling unit. Few lithophysal cavities, about 15 percent cognate pumice fragments (0.2 to 2 cm long), and sparse to 2 percent lithic fragments are present. Rock contains about 10 to 20 percent phenocrysts, consisting of about 40 percent quartz, 30 percent adularic sanidine, 15 percent plagioclase, 2 percent biotite, and traces of other ferromagnesian phases and Fe-Ti oxides. Map unit forms gentle rounded slopes and is preserved only in low-standing areas. The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date for the map unit is 11.6 Ma (Sawyer and others, 1990). Maximum thickness is 20 m
- Tmrw** **Welded zone**--Distinguished from nonwelded zone (Tmrn) by slightly grayer shades of colors described for the undivided member (Tmr), slightly greater abundance of phenocrysts, devitrified state, and partially to moderately welded character. Thickness less than 20 m
- Tmrn** **Nonwelded zone**--Distinguished from welded zone (Tmrw) by slightly pinker shades of colors described for the undivided member (Tmr), slightly smaller abundance of phenocrysts, vitric state, and nonwelded character. In the adjoining area to the north (Scott and Bonk, 1984), map unit forms envelope around more welded interior of Rainier Mesa Member; upper part of envelope probably eroded here. Thickness less than 10 m

Tybt **Young bedded tuff (Miocene)**--Very pale orange, very light gray, to light-gray, pumiceous, poorly bedded ash-fall tuff and less abundant tuffaceous sandstone; bedded tuff is generally poorly consolidated but locally moderately consolidated. Pumice fragments are as long as 3 cm. Bedded tuff contains about 10 percent phenocrysts that consist predominately of quartz, sanidine, plagioclase, and biotite. Tuffaceous sandstone contains as much as 25 percent reworked, slightly rounded phenocrysts and minor lithic fragments in a shaly matrix. Sandstone shows weak layering parallel to bedding. In some localities, pumice fragments occur as clasts within a tuffaceous sandstone matrix. At one locality on the western side of Yucca Mountain, 1-2-m-diameter boulders of the upper zones of the Tiva Canyon Member occur in a tuffaceous sandstone matrix; here, the map unit has the resembles a mud flow. Map unit locally exposed in valleys west of major west-dipping, generally concealed, normal faults and on the downthrown side of the major normal fault zone that cuts the crest of Busted Butte. Thickness less than 10 m

Paintbrush Tuff (Miocene)--The formation consists of two ash-flow tuff members, separated by a bedded tuff member; in descending order the members are the Tiva Canyon, bedded tuff member, and Topopah Spring Members. Each ash-flow tuff is a compound cooling unit that is chemically zoned from a quartz-latic top to a rhyolitic base (Broxton and others, 1989; Lipman and others, 1966). The Paintbrush Tuff forms the resistant ridges of Yucca Mountain. Combined maximum thickness about 400 m (Scott and Castellanos, 1984) in the northern part and less than 140 m in the southern part of the map area

[Map symbols used for map units of the Paintbrush Tuff omit the first two letters typically used for Paintbrush designation (Tp) to save space because of necessity of showing details of complex structure]

Tiva Canyon Member--Ash-flow tuff, consisting of one compound cooling unit. Evidence that the tuff consists of multiple flows, even where partial cooling breaks are absent, is given below in the description of individual zones. The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date for the Tiva Canyon Member is 12.7 Ma (Sawyer and others, 1990). Maximum thickness is about 100 m in the northern part and 30 m in the southern part of the map area

- ccr** **Caprock zone**—Quartz-latic ash-flow tuff, forming the stratigraphic cap on many ridges of Yucca Mountain. Consists of as many as five subzones, which are in descending order: 1) moderate-orange-pink to moderate-reddish-orange, nonwelded to partially welded, vitric tuff; 2) grayish-brown to brownish-black, densely welded, partly devitrified and partly vitrophyre; 3) pale-brown to moderate-brown, densely welded, devitrified tuff; 4) pale-yellowish-brown, moderately to densely welded, devitrified tuff; and 5) light-gray to light-brownish-gray, moderately welded, devitrified tuff. Two, and locally three, different types of pumice fragments are distinguished; the more mafic type is medium gray, the more silicic type is very light gray to white, an intermediate type is intermediate in color (Flood and others, 1989); pumice fragments range from 1 to 40 cm in length and form about 10 percent of tuff; more mafic pumice fragments are predominate in upper three subzones, whereas more silicic are predominate in lower two subzones. Lithophysal cavities are sparse to absent in upper subzones but 5- to 10-cm-length, highly oblate cavities form about 15 percent of lowest subzone. Lithic fragments form less than 1 percent of caprock zone. Rock contains 5-20 percent phenocrysts that consist of less than 1 percent quartz, 64-88 percent sanidine, 7-28 percent plagioclase, 3-5 percent biotite, less than 1 percent hornblende, clinopyroxene, and orthopyroxene, 1 percent opaque phases, and accessory zircon, apatite, sphene, allanite, and either perrierite and/or chevkinite (Scott and Bonk, 1984). Subzones of map unit are present locally; upper three subzones are commonly eroded except where protected in downdropped fault blocks; lower two subzones form cliffs. A decrease in the degree of welding of the base of the caprock zone indicates that a partial cooling break occurred before emplacement of the caprock zone. Also, north of this map in Yucca Mountain, blocks of the upper lithophysal zone (cul) are included within the caprock (Scott and Bonk, 1984), indicating that the upper lithophysal zone had cooled sufficiently to be eroded by caprock emplacement mechanisms without internal deformation of lithophysae in the blocks). Maximum thickness estimated to be 20 m
- cuc** **Upper cliff zone**—Light-gray to light-brownish-gray, moderately to densely welded, devitrified, rhyolitic tuff; contains 2-10 percent pumice fragments that range from 0.1 to 4 cm long, 5-10 percent oblate lithophysal cavities that range from 10 to 50 cm long, and less than 1 percent lithic fragments about 0.5 cm in diameter. Rock contains 3-5 percent phenocrysts that consist of nearly 100 percent sanidine with only traces of plagioclase, biotite, hornblende, opaque phases, and accessory zircon and sphene (Scott and Bonk, 1984). Zone forms base of cliff under caprock (ccr) and commonly exhibits exfoliation on steep surfaces. Map unit exposed in northern part of map area and pinches out southward. Maximum thickness is about 10 m
- cul** **Upper lithophysal zone**—Light-gray to grayish-pink, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains 5-10 percent pumice fragments than range from 0.2 to 5 cm long, 10-20 percent oblate and convolute lithophysal cavities that range from 5 to 35 cm long, and less than 1 percent lithic fragments. Rock contains 2.5-5 percent phenocrysts that consist of nearly 100 percent sanidine and only traces of plagioclase, biotite, hornblende, opaque phases, and accessory zircon and sphene (Scott and Bonk, 1984). Map unit forms moderate to steep slopes with exfoliated surface, is present in the northern part of the map area, but pinches out southward. Maximum thickness is 15 m

- cks** **Clinkstone zone**—Light-brownish-gray, light-gray, to pale-red, moderately to densely welded, devitrified, rhyolitic tuff; contains 10-15 percent pumice fragments that range from 0.1 to 5 cm long, sparse or no lithophysal cavities, and less than 1 percent lithic fragments. A thin discontinuous unmapped subzone containing 5-10 percent lithophysal cavities occurs near the middle of the clinkstone zone and appears to become thicker southward. Rock contains 2-3.5 percent phenocrysts that consist of about 94 percent sanidine, 2 percent plagioclase, a trace of biotite, 2 percent hornblende, 1 percent opaque phases, and accessory zircon, apatite, sphene, allanite, perrierite and/or chevkinite (Scott and Bonk, 1984). Conchoidal fractures and uniform, fine-grained surface textures characterize rock. Map unit forms moderate to steep slopes and is present in northern part of the map area but grades southward into three laterally equivalent zones, the upper slope zone (cus), the spotted upper lithophysal zone (csul), and the crs (rounded step zone), in descending order. Maximum thickness of the clinkstone zone is 50 m
- cus** **Upper slope zone**—Light-brownish-gray to light-gray, moderately to densely welded, devitrified, rhyolitic tuff; contains 10-15 percent pumice fragments that range from 0.1 to 5 cm long, sparse or no lithophysal cavities, and less than 1 percent lithic fragments. Rock contains about 3.5 percent phenocrysts that consist of about 95 percent sanidine, a few percent plagioclase, biotite, and hornblende. Conchoidal fractures and uniform, fine-grained surface textures are common in the rock. Map unit forms moderate to steep slopes and is mapped in central and southern part of the map area but grades laterally northward into an upper subzone of clinkstone zone (cks) above unmapped lithophysal subzone. Maximum thickness is about 40 m
- csul** **Spotted upper lithophysal zone**—Pale-red-purple, light-brownish-gray, to pinkish-gray, moderately to densely welded, devitrified ash-flow tuff; contains about 10 percent pumice fragments that range from 0.2 to 2 cm long, 10-15 percent spherical to slightly oblate lithophysal cavities that range from 1 to 4 cm in diameter, and less than 1 percent lithic fragments. Lithophysal cavities commonly contain very light gray concentric shell-like layers separated by partially open spaces giving the rock a spotted appearance. Rock contains about 3 percent phenocrysts that consist of about 95 percent sanidine and few percent plagioclase, biotite, and hornblende. Map unit forms moderate slopes and is present in central and southern part of the map area but is interpreted to grade laterally northward into the unmapped lithophysal subzone in middle of clinkstone zone (cks). Maximum thickness is about 20 m
- crs** **Rounded step zone**—Light-brownish-gray to pale-red, moderately to densely welded, devitrified, rhyolitic tuff; contains about 10-15 percent pumice fragments that range from 0.1 to 4 cm long, sparse or no lithophysal cavities, and less than 1 percent lithic fragments. Rock contains about 3 percent phenocrysts that consist of about 95 percent sanidine and a few percent plagioclase, biotite, and hornblende. Conchoidal fractures and uniform, fine-grained surface textures are common. Map unit forms moderate to steep slopes formed by a series of step-like ledges, is mapped in central part of the map area, and grades laterally northward into lower subzone of clinkstone zone (cks) below the unmapped lithophysal subzone. Rounded step zone pinches out southward. Maximum thickness is about 10 m

- c11** **Lower lithophysal zone**--Pale-red to grayish-red, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains 5-10 percent pumice fragments that range from 0.1 to 1.5 cm long, 10-15 percent spherical to oblate lithophysal cavities that range from 1 to 5 cm long with pinkish-gray margins, and less than 1 percent lithic fragments. Rock contains about 3.3 percent phenocrysts that consist of about 94 percent sanidine, 4 percent hornblende, 2 percent orthopyroxene, a trace of opaque phases, and accessory zircon, apatite, sphene, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms moderate to steep slopes and weathered surface is characterized by exfoliation; exposed in northern part of map area but pinches out southward. Maximum thickness is about 5 m
- ch** **Hackly zone**--Grayish-red to pale-red, densely welded, devitrified, rhyolitic ash-flow tuff; contains about 10 percent pumice fragments that range from 0.2 to 2 cm long, sparse to absent lithophysal cavities. Rock contains about 4 percent phenocrysts that consist of nearly 100 percent sanidine, with only traces of hornblende, opaque phases, zircon, apatite, sphene, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms moderate to steep slopes, is distinguished from the columnar zone (cc) in the northern part of the map area, but is combined with the columnar zone in the southern part of the area. Map unit is characterized by hackly fractures forming 1-5 cm diameter fragments on hackly weathered surfaces. Maximum thickness is about 15 m
- cc** **Columnar zone**--Consists of three gradational subzones, which are in descending order: 1) dark-gray to grayish-black, locally developed, densely welded, rhyolitic, partly devitrified tuff and partly vitrophyre; 2) blackish-red to pale red, moderately to densely welded, vitric, rhyolitic tuff with prominent flattened pumice fragments; and 3) pale-red to grayish-orange, partially welded to nonwelded, vitric, rhyolitic tuff with conspicuous black glass shards. Subzones contain about 15-20 percent pumice fragments that range from 0.2 to 2 cm long, less than 1 percent lithic fragments, and generally sparse lithophysal cavities; locally as much as 10 percent lithophysal cavities occur. Rock contains 4 percent phenocrysts that consist of nearly 100 percent sanidine, with only traces of hornblende, opaque phases, and accessory zircon, apatite, sphene, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Commonly map unit forms small cliffs or steep slopes; cliffs exhibit columnar jointing and slopes have thin, shingle-like partings parallel to foliation. Zone contains thin (< 5 mm) crystal-rich layers that appear to be horizons, where fine shards were winnowed during minor volcanic hiatuses, separating thick ash-flow tuff. These layers indicate multiple-flow emplacement even though no partial cooling breaks occur. Map unit is distinguished from hackly zone (ch) in northern part of map area but is combined with it in the southern part. Maximum thickness is about 10 m
- cch** **Columnar and hackly zone**--Undistinguished hackly (ch) and columnar zones (cc) combined into one map unit because zones are too thin to map separately. Map unit occurs in central and southern part of map area. Maximum thickness is about 25 m but generally less than 10 m

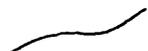
- bt** **Bedded tuff member**--White, pale-yellowish-orange, to light brown, nonwelded, bedded, vitric, rhyolitic to quartz latitic tuff; includes primarily ash- and pumice-fall tuff, secondary thin ash-flow tuffs, and sparse reworked crossbedded tuffs. Only reworked tuff is well bedded; other tuff is moderately to poorly bedded; beds are commonly 0.5-2 m thick. Small erosion channels are locally cut in partially welded upper part of Topopah Springs Member and filled with ash-fall and ash-flow pumiceous lapilli tuff. Upper parts of bedded tuff member are distal facies of the rhyolitic Yucca Mountain and Pah Canyon Members of the Paintbrush Tuff. These ash-flow tuffs form mappable units where they are thicker in the northern part of Yucca Mountain (Scott and Bonk, 1984). Lower parts of the bedded tuff member are nonwelded quartz-latitic and represent the last eruptive events from of the magmatic source of the Topopah Spring Member. Rhyolitic tuff contains less than 5 percent phenocrysts that are dominated by sanidine; quartz-latitic tuff contains plagioclase and biotite in addition to sanidine. Map unit forms an eroded bench. Thickness ranges from 5 to 35 m
- tu** **Topopah Spring Member, undivided**--Compound cooling unit, consisting of a compositionally zoned ash-flow tuff. The tuff contains a quartz-latitic caprock underlain by a rhyolitic lower part. Individual zones are described below. The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date of the Topopah Spring Member is 12.75 Ma (D.A. Sawyer, written comm., 1990). Maximum thickness of the exposed part of the map unit is estimated to be about 220 m in the northern part, is nearly 300 m in a drill hole 1 km north of the map area (Scott and Castellanos, 1984), and 90 m in the southern part of the map area
- tpwu** **Partially welded upper zone**--Light-brown to brownish-gray, nonwelded to partially welded pumice-rich, vitric, quartz latitic tuff, containing 10-20 percent pumice fragments that range from 0.5 to 10 cm long, sparse lithophysal cavities, and about 3 percent lithic fragments. Rock contains about 15 percent phenocrysts that consist of about 60 percent sanidine, 35 percent plagioclase, and 5 percent biotite. Map unit forms moderate slope to bench. Exposures are limited to southern part of map area; in the northern area map unit is included in either caprock zone (tc) or caprock vitrophyric zone (tcv). Maximum thickness is about 10 m
- tc** **Caprock zone**--Quartz-latite ash-flow tuff; consisting of as many as three subzones, which are in descending order: 1) light-brown to brownish-gray, pumiceous, vitric, nonwelded to partially welded tuff; 2) black to brownish-black, moderately to densely welded, vitrophyric tuff containing lenses of moderate-red vitrophyric tuff; and 3) pale-red, densely welded, partly devitrified, dark-grayish-brown to brownish-black, densely welded tuff. At least two different types of pumice fragments are distinguished; more mafic type is medium gray, and more silicic type is light gray; pumice fragments range from 1 to 20 cm long and form about 10 percent of tuff; more mafic pumice fragments predominate in upper two subzones, whereas more silicic predominate in lowest subzone. Lithophysal cavities are sparse in the caprock zone, and lithic fragments form about 3 percent of the rock. Rock contains 6-17 percent phenocrysts that consist of less than 1 percent quartz, 47-56 percent sanidine, 43-38 percent plagioclase, 4 percent biotite, trace of hornblende, trace to 2 percent clinopyroxene, 1-3 percent opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms steep slopes and cliffs. Maximum thickness is about 25 m

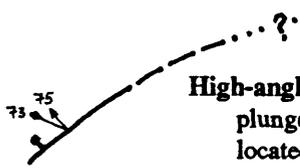
- tcv** **Caprock vitrophyric zone**--Quartz-latite ash-flow tuff; laterally equivalent to caprock zone (tc) and uppermost rounded zone (tr) but differs by consisting entirely of black, brownish-black, and very dark red, densely welded vitrophyre. Rock contains 6-17 percent phenocrysts that consist of less than 1 percent quartz, 47-56 percent sanidine, 43-38 percent plagioclase, 4 percent biotite, trace of hornblende, trace to 2 percent clinopyroxene, 1-3 percent opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms moderate to steep slopes in southern part of map area, and becomes laterally equivalent to the caprock zone (tc) to the north. Maximum thickness is about 30 m
- tr** **Rounded zone**--Light-gray to light-brownish-gray, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains 10-20 percent light-gray to very light gray, highly flattened pumice fragments that range from 1 to 12 cm long, sparse lithophysal cavities, except locally where 10-15 percent lobate cavities are 1-5 cm long, and less than 1 percent lithic fragments. Rock contains 5-14 percent phenocrysts that consist of 65-70 percent sanidine, 23-24 percent plagioclase, 3-4 percent biotite, trace to 2 percent clinopyroxene, 4-5 percent opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms steep slopes with rounded exfoliated surfaces; toward southern part of map area map unit grades laterally into the upper part of the vitrophyric zone (tcv-tv). Maximum thickness is about 25 m
- tu1** **Upper lithophysal zone**--Light-gray and pinkish-gray, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains 5-10 percent pumice fragments that range from 2 to 20 cm long, 10-15 percent lobate lithophysal cavities that range from 4 to 30 cm long, and less than 1 percent lithic fragments. Locally near the top of the unit, moderate-red pumice fragments are distinctive. Devitrified matrix has a slightly coarser texture toward top of map unit. Rock contains about 1 percent phenocrysts that consist of about 40 percent sanidine, 55 percent plagioclase, and a few percent biotite. Map unit forms moderate to steep slopes and grades laterally into the quartz-lined lithophysal zone (tql) and the central part of the vitrophyric zone (tcv-tv) toward the southern part of map area. Maximum thickness is about 55 m
- tql** **Quartz-lined lithophysal zone**--Light-gray to grayish-yellow, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains about 10 percent pumice fragments that range from 1 to 5 cm long and less than 1 percent lithic fragments. About 10 percent of the rock consists of lobate, quartz-lined, lithophysal cavities from 4 to 10 cm long. Rock contains about 1 percent phenocrysts that consist of about 30 percent sanidine, 65 percent plagioclase, and a few percent biotite. Map unit forms moderate to steep slopes; grades laterally from central part of map area northward into the lower part of the upper lithophysal zone (tu1) and southward into the vitrophyric zone (tvc-tv). Maximum thickness is about 75 m

- tb** **Brick zone**--Light-gray, grayish-orange, pale-red, and grayish-red to mottled pale-red, grayish-orange and moderate-orange-pink, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains about 2-10 percent indistinct pumice fragments, sparse lithophysal cavities, and less than 1 percent lithic fragments. Devitrified matrix has a very fine, uniform brick-like texture. Rock contains about 1 percent phenocrysts that consist of a trace of quartz, 5-20 percent sanidine, 60-90 percent plagioclase, a trace to 5 percent biotite, a trace to 20 percent opaque phases, and accessory zircon, apatite, allanite, and perrerrite and/or chevkinite (Scott and Bonk, 1984). Map unit forms moderate to steep slopes; grades laterally southward into part of the vitrophyric zone (tvc-tv) and into the lower lithophysal zone (tl).. Maximum thickness is about 75 m
- tl** **Lower lithophysal zone**--Light-gray, moderately to densely welded, devitrified, rhyolitic ash-flow tuff; contains sparse pumice fragments, 5-10 percent lithophysal cavities that range from 2 to 6 cm long, and about 4 percent lithic fragments. Rock contains about 1 percent phenocrysts that consist of about 10 percent quartz, 30 percent sanidine, 60 percent plagioclase, and a trace of biotite. Map unit forms moderate to steep slopes. Map unit exposed only is central eastern part of map area and grades laterally into the brick zone (tb) and possibly into the vitrophyric zone (tvc-tv). Maximum thickness is about 50 m
- tv** **Basal vitrophyric zone**--Dark-gray to brownish-black, moderately to densely welded, rhyolitic, vitrophyric ash-flow tuff. Pumice fragments form abundant to common black fiamme; lithophysal cavities are locally abundant and oblate near the southern end of the map area but elsewhere are generally sparse; and rock contains about 2 percent lithic fragments. Rock contains 1.5 percent phenocrysts that consist of 8 percent quartz, 38 percent sanidine, 42 percent plagioclase, and 4 percent biotite, 8 percent opaque phases, and accessory zircon, apatite, allanite, and perrerrite and/or chevkinite (Scott and Bonk, 1984). Map unit forms steep slopes and cliffs; grades laterally into the vitrophyric zone (tvc-tv) in the southern part of map area. Maximum thickness is about 35 m
- tvc-tv** **Vitrophyric zone**--Dark-gray to brownish-black, moderately to densely welded, quartz latitic to rhyolitic vitrophyric ash-flow tuff; laterally equivalent to caprock vitrophyre (tvc), basal vitrophyre (tv), and all intervening units (tr to tb). Map unit forms steep to moderate slopes; exposed only at southern part of map area. Maximum thickness is about 45 m
- tpw1** **Partially welded lower zone**--Moderate-orange-pink to grayish-orange-pink and very pale orange moderately welded to nonwelded, vitric, rhyolitic ash-flow tuff; contains common to sparse pumice fragments that grade downward from black through moderate brown, light brown, grayish orange to very pale orange. Black to brownish-black glass shards are common in moderately welded and partially welded upper part. Lithophysal cavities are absent and lithic fragments are sparse. Rock contains less than 1 percent phenocrysts that consist of about 25 percent quartz, 30 percent sanidine, 40 percent plagioclase, 5 percent biotite, and traces of hornblende and opaque phases (Scott and Bonk, 1984). Map unit forms gentle slopes; mapped only in southern part of map area; too thin to map where exposed to north. Thickness as great as 30 m

- Tct** **Tuff of Calico Hills (Miocene)**--Very pale orange to pinkish-gray, nonwelded, vitric, rhyolitic ash-flow tuff and ash-fall tuff; contains 10-30 percent pumice fragments as much as 3 cm in diameter and 2-15 percent silicic volcanic lithic fragments as much as 2 cm in diameter. Rock contains 2-3 percent phenocrysts that consist of 7-24 percent quartz, 29-63 percent sanidine, 30-48 percent plagioclase, trace to 4 percent biotite, 0-4 percent hornblende, trace of orthopyroxene and opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Exposures limited to small areas on northern and eastern sides of Busted Butte. Map unit forms gentle step-like slopes. The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date for the tuff of Calico Hills is 12.9 Ma (Sawyer and others, 1990). Maximum exposed thickness is about 8 m
- Tw** **Wahmonie Tuff (Miocene)**--Pinkish-gray, pale-red to grayish-red, nonwelded, devitrified, dacitic to andesitic ash-flow and ash-fall tuff; very friable. Pumice and lithic fragments are sparse. Rock contains about 15 percent phenocrysts that consist of traces of quartz and sanidine, predominate plagioclase, 20 percent biotite and hornblende, and traces of pyroxene. Map unit forms benches and is exposed at Busted Butte and in the central part of the map area. The $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine date for the Wahmonie Tuff is 13.0 Ma (D.A. Sawyer, written comm., 1990). Maximum thickness is about 10 m
- Crater Flat Tuff (Miocene)**--Rhyolitic volcanic formation consisting of two members that are in descending order: the Prow Pass Member and the Bullfrog Member. Combined maximum thickness about 75 m where both members are exposed in the central part of the map area
- Tcp** **Prow Pass Member**--Medium-light-gray, pinkish-gray, brownish-gray, to very pale orange nonwelded to partially welded, vitric to devitrified, rhyolitic ash-flow tuff; contains 5-10 percent pumice fragments that range from 0.5 to 2 cm long and 1-3 percent distinctive moderate-red to pale-reddish-brown argillic fragments and pale-red and light-gray, silicic volcanic lithic fragments. Rock contains 7-11 percent phenocrysts that consist of 6-16 percent quartz, 30-45 percent sanidine, 39-54 percent plagioclase, trace to 1.5 percent biotite, trace of hornblende, trace to 3 percent orthopyroxene, trace to 3 percent opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms gentle slopes and is exposed at the north end of Busted Butte and in the central and southwestern parts of the map area. Maximum thickness is about 40 m
- Tcb** **Bullfrog Member**--Very light gray, medium-light-gray, grayish-pink, pinkish-gray, brownish-gray, to pale-red nonwelded to partially welded, vitric to devitrified, rhyolitic ash-flow tuff; contains sparse to common pumice 0.5-1.5 cm long and about 1 percent lithic fragments. Map unit consists of two lithologically similar cooling units separated by a thin nonwelded bedded tuff (Tcbs) representing a complete cooling break. Rock contains 9-12 percent phenocrysts that consist of 16-19 percent quartz, 29-35 percent sanidine, 43-46 percent plagioclase, 3-4 percent biotite, trace to 1 percent hornblende, 1-3 percent opaque phases, and accessory zircon, apatite, allanite, and perrierite and/or chevkinite (Scott and Bonk, 1984). Map unit forms gentle slopes and is exposed only in the central part of the map area. The base of the Bullfrog is unexposed; exposed upper part is about 35 m thick

Tcbt **Bedded tuff zone--Very pale orange to yellowish-gray, nonwelded, bedded, rhyolitic ash-fall tuff. Represents a complete cooling break within the Bullfrog Member (Tcb). Map unit forms a narrow bench and is less than 2 m thick**

 **Contact**

 **High-angle normal and reverse faults**--Showing dip (barbed arrow) and trend and plunge of slickenlines (diamond-shaped arrow). Dashed where approximately located, dotted where concealed, and queried where location uncertain. Bar and ball on downthrown side

 **Strike- or oblique-slip fault**--Arrows show relative direction of lateral offset. Dashed where approximately located, dotted where concealed, and queried where location uncertain. Bar and ball on apparent downthrown side

 **Low-angle normal fault**--Below slump block. Sawteeth on upper plate

 **Fault scarp along which younger unit has been deposited**--Hachures on side of postfault deposit

 **Fracture in surficial deposits**

 **Aerial photograph lineament**

 **Syncline**--Showing trace of syncline axis and arrow pointing in direction of plunge of structure in bedrock

Strike and dip of sedimentary beds and of compaction foliation of ash-flow tuffs

 **Inclined**

 **Horizontal**

 **Vertical**

$\overline{\times}$
80 **Overtured**

Strike and dip of flow foliation (post-emplacment flow) in ash-flow tuff

\nearrow
34 **Inclined**

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Correlation of Map Units

