Text and references to accompany Nevada Bureau of Mines and Geology Map 112

GEOLOGY OF THE NORTHEASTERN BULLFROG HILLS AND VICINITY

SOUTHERN NYE COUNTY, NEVADA

by

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INTRODUCTION

The Bullfrog Hills, located at the western edge of the southwestern Nevada volcanic field, have a complex depositional and structural history, and many of the units of ash-flow tuff erupted from caldera sources to the east are preserved beneath a sequence of locally erupted tuffs and lavas. The map area lies just outside the margin of the Timber Mountain caldera complex and is a complicated, structurally distended terrane that was the focus for syntectonic volcanism at the end of the *Timber Mountain magmatic stage* of the volcanic field. The sequence reflects volcanic activity extending from before eruption of the Crater Flat Tuff at about 13.25 Ma to that of the Spearhead Member of the Stonewall Flat Tuff at about 7.6 Ma. Tertiary volcanic rocks overlie Paleozoic sedimentary rocks that, south of the map area, appear to have been juxtaposed with the volcanic sequence along a low-angle normal fault, first recognized by Ransome and others (1910; see fig 1, this report). In the central Bullfrog Hills, the exposed Paleozoic rocks appear to represent a persistent basement high. Angular discordance between units, fanning (shallowing upward) dips in the upper part of the volcanic sequence and the presence of debris-flow deposits indicate periods of faulting coincident with volcanism after 11.4 Ma.

The map area, encompassing the northeastern part of the Bullfog Hills and the Oasis Valley area (fig. 1), consists primarily of extensionally faulted volcanic rocks of Timber Mountain age and younger, locally overlying older Miocene ash-flow tuffs, and Paleozoic sedimentary rocks. A local sequence of ash-flow tuff, lava, and interlayered breccia that postdates the Timber Mountain caldera is exposed over much of the area. The southern Bullfrog Hills were studied early in this century by Ransome and others (1907, 1910) with a focus on the mineral deposits of the area. The geologic map included with their report, although made without the benefit of modern concepts of volcanic stratigraphy, was largely accurate, and the part of their report on the structural evolution of the area provides a classic discussion on the development of tilted fault blocks. The thick sequence of Tertiary ash-flow tuff in the Bullfrog Hills, as well as the nature of the associated breccia deposits, led some workers (Cornwall, 1962; Cornwall and Kleinhampl, 1964) to propose the existence of a caldera, which they thought was older than the Timber Mountain caldera. Features present in the Bullfrog Hills are now recognized to have resulted from syntectonic volcanism near, but outside, the western margin of the Timber Mountain caldera complex, 1 to 1.5 million years after the last caldera-forming eruption. Several gold deposits including the Barrick-Bullfrog (previously Lac Gold-Bullfrog and Bond-Bullfrog), the Original Bullfrog, the Gold Bar, the Montgomery-Shoshone, and the Mayflower Mines are located in the Bullfrog Hills (fig. 1). Several pulses of hydrothermal activity have affected the rocks of the Bullfrog Hills and all but the youngest volcanic units in the area have been affected by some alteration or mineralization (Weiss and others, 1991).

NOMENCLATURE OF POST-TIMBER MOUNTAIN GROUP ROCKS IN THE BULLFROG HILLS

In the Bullfrog Hills, the Ammonia Tanks Tuff of the Timber Mountain Group is overlain by a thick sequence of near-vent pyroclastic flow and surge deposits of high-silica rhyolite intercalated with lavas of high- and low-silica rhyolite and lithologically variable debris-flow deposits. These rocks are overlain by, and in part interlayered with, quartz latite to latite lava, termed the latite of Donovan Mountain by Minor and others (1993). Part of the silicic portion of this sequence was termed the rhyolite of Rainbow Mountain by Maldonado and Hausback (1990). These authors excluded a lower pyroclastic unit near the base of the sequence at Rainbow Mountain, incorrectly identifying it, in part, as the tuff of Buttonhook Wash, and, in part, as bedded tuff. In addition, they did not recognize that silicic tuff is locally intercalated with the latite of Donovan Mountain, and did not identify the presence of a juvenile volcanic component in the debris-flow deposits. For these reasons, and to follow local usage, the more inclusive name, *the Rainbow Mountain sequence*, is used in this report. Eng and others (1996) informally used *Rainbow Mountain sequence* for most lithologic units included here, but they excluded the basalt flows in the lower part of the sequence (**Tb**$_2$ of this report) and the thinly interbedded mixed pyroclastic and epiclastic rocks near the base of the sequence in the southeastern part of the map area (**Trp**, which overlies **Tb**$_2$). The term *tuffs and lavas of the Bullfrog Hills*, applied by Noble and others (1991) and in subsequent publications by the present authors, refers to the sequence of rocks included here in the Rainbow Mountain sequence, as well as the overlying airfall tuff and basalt units **Tha, Tta, Tb**$_3$, and **Tbs**. Rocks of the Rainbow Mountain sequence represent a discrete episode of bimodal, syntectonic rhyolite-latite and subordinate basaltic volcanism of $\leq$0.3 million years duration from local sources peripheral to the western margin of the Timber Mountain caldera complex.

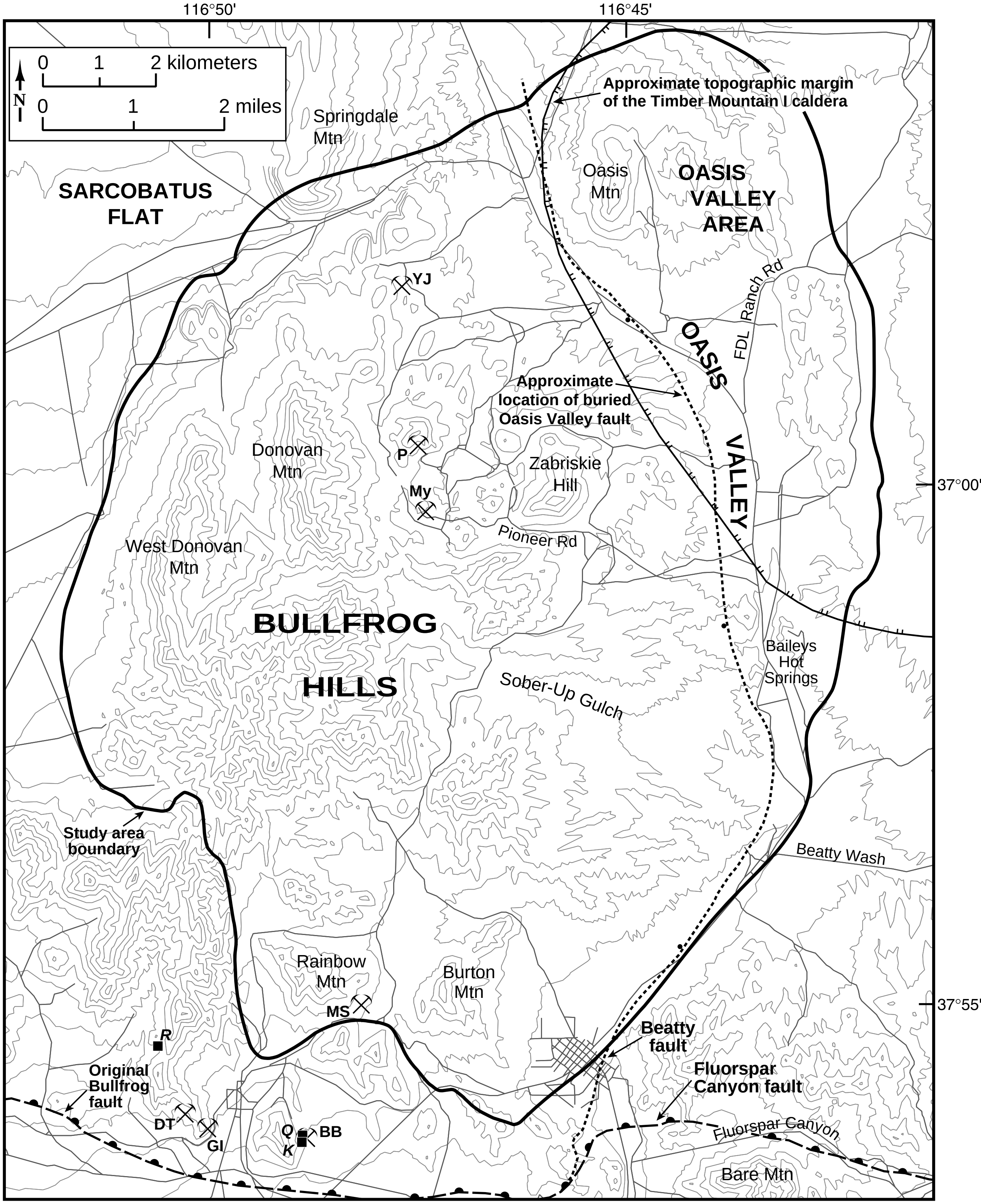

Figure 1. Location map of the Bullfrog Hills–Oasis Valley area showing geographic features discussed in the text as well as major structural features, the approximate topographic margin of the Timber Mountain I caldera, and selected active or historical mines or mining districts. YJ = Yellow Jacket; P = Pioneer district; My = Mayflower district; MS = Montgomery-Shoshone Mine; BB = Barrick-Bullfrog Mine; GI = Gibraltar Mine; DT = Denver-Tramps Mine. The Original Bullfrog and Gold Bar Mines are situated directly west of the southwest corner of the map, north of the Original Bullfrog fault. Filled squares with letter symbols indicate sample locations for those isotopic age determinations listed in table 1 that fall outside the map area.

VOLCANO-TECTONIC EVOLUTION OF THE BULLFROG HILLS AND OASIS VALLEY AREA

The Bullfrog Hills and the Oasis Valley area differ in their stratigraphic sections and volcano-tectonic styles. The two domains are separated by the Oasis Valley fault, which is the principal breakaway for west- to west-northwest-directed extension in the northern Bullfrog Hills (Connors and others, 1995). This fault or fault zone generally follows U.S. Highway 95, trending nearly N-S north of Beatty, Nevada, and is the structural boundary between the highly faulted Bullfrog Hills and the much less faulted western margin of the Timber Mountain I caldera in the Oasis Valley area. The Oasis Valley fault marks the effective eastern limit of late Miocene synvolcanic faulting of the highly extended Bullfrog Hills structural domain. It is the easternmost and best-documented of several subparallel, approximately north-trending "first-order" structures in an area characterized by a pattern of major down-to-the-west normal faults, interspersed with smaller faults having varying amounts of offset (Connors and others, 1995). Isotopic age determinations of the volcanic units in the area provide constraints on timing of tectonic events, as shown schematically for Timber Mountain and younger events in figure 2.

In the Oasis Valley area, an unusually thick section of the Ammonia Tanks Tuff of the Timber Mountain Group is overlain by the tuffs and lava of Fleur de Lis Ranch and the tuff of Cutoff Road, which were deposited within the western part of the Timber Mountain I caldera. Near the west side of Oasis Mountain, the Oasis Valley fault closely coincides with the topographic margin of the Timber Mountain I caldera. The entire exposed section, with a composite thickness of more than 1,500 m, is generally concordant and was deposited between about 11.45 and 11.40 Ma (Connors and others, 1991). In contrast, in the Bullfrog Hills the Ammonia Tanks Tuff is much thinner, units of the tuffs and lava of Fleur de Lis Ranch are absent except as blocks in the younger debris-flow deposits, and the exposed section includes units that range in age from Cambrian to late Miocene.

In the Bullfrog Hills a generally conformable sequence of ash-flow sheets of the *main* and *Timber Mountain magmatic stage*s of the southwestern Nevada volcanic field (Noble and others, 1991) is unconformably overlain by the 10.6- to 10.3-Ma Rainbow Mountain sequence, which includes complexly intercalated and lithologically variable synvolcanic debris-flow deposits. The presence of abundant blocks of the tuffs and lava of Fleur de Lis Ranch and their distribution within the debris-flow unit indicate that a principal source for these deposits was in the Oasis Valley area. Volcanic rocks along the eastern side of Oasis Valley were, therefore, exposed and being eroded by about 10.5 Ma. The very large size of some of the blocks in the debris-flow unit, as much as 500 m in length, demonstrates the existence of pronounced topographic relief—most probably steep, west-dipping scarps of the active Oasis Valley fault.

The Bullfrog Hills have undergone several stages of rotational block faulting after eruption of the Paintbrush Group. East of Beatty a pronounced angular uncomformity of as much as 40° is present between the Tiva Canyon Tuff and the Rainier Mesa Tuff, reflecting a major pulse of extensional faulting between 12.7 and 11.6 Ma. The two units are conformable in the map area. Breccia and talus or landslide deposits of inferred tectonic origin, however, have been recognized between the Tiva Canyon and Rainier Mesa Tuffs near the Bullfrog Mine and in nearby drill holes, suggesting that this episode of faulting affected the southeastern Bullfrog Hills (Eng and others, 1996; E.B. Ekren, written commun., 1997).

Throughout the Bullfrog Hills the 11.45-Ma Ammonia Tanks Tuff and underlying units dip more steeply (commonly > 45°) than do nearby rocks of the Rainbow Mountain sequence, which are generally tilted about 15° to 30° to the east. In the map area, field relations suggest that widespread eastward tilting of as much as 35° occurred after deposition of the Ammonia Tanks Tuff and the tuff of Cutoff Road at 11.4 to 11.45 Ma, but prior to the beginning of deposition of the Rainbow Mountain sequence at about 10.5 Ma, probably along numerous down-to-the-west faults, synchronous with and possibly before formation of the Oasis Valley fault. Major late Miocene extensional deformation of the Bullfrog Hills–Oasis Valley area, therefore, began after deposition of the Ammonia Tanks Tuff and the tuff of Cutoff Road and was active throughout deposition of the Rainbow Mountain sequence, as evinced by fanning dips in volcanic units and the presence of coarse, interlayered debris-flow deposits. One or more buried normal faults must also be present east of Oasis Valley to have produced the 20 to 30° eastward tilting of tuffs and lavas exposed in the Oasis Valley area. With time, faulting ceased east of the Oasis Valley fault, but significant movement along the Oasis Valley fault brought about additional tilting of Timber Mountain stage and older units, and rotation of earlier down-to-the-west faults in the northern Bullfrog Hills, as are exposed east of Zabriskie Hill.

The development of the Oasis Valley fault breakaway created a topographic high in the Oasis Valley area, resulting in the westward shedding of blocks and debris-flow deposits synchronous with volcanism in the Bullfrog Hills and deposition of the Rainbow Mountain sequence. In the Bullfrog Hills, the locally very coarse breccias and other clastic deposits were largely derived from west-facing fault scarps produced by contemporaneous normal faulting (Weiss and others, 1990; Connors, 1995; Connors and others, 1995). Curvilinear map patterns suggest that many of the extensional faults are listric, although it is uncertain whether they sole into an underlying detachment surface (c.f. Maldonado, 1990). Some faults have acted as feeders for rhyolite lavas, implying that they extend to considerable depths. Structural and stratigraphic relations constrain Neogene movement along a possible detachment surface to some time prior to and/or during the deposition of the Rainbow Mountain sequence. Continued movement on the Oasis Valley fault and subparallel faults to the west resulted in tilting of the debris-flow deposits and the Rainbow Mountain sequence to dips of as much as 20°–35° E. Extensional faulting had ceased prior to deposition of flat-lying distal parts of the outflow sheets of the 9.4-Ma Pahute Mesa Tuff of the Thirsty Canyon Group and the 7.6-Ma Spearhead Member of the Stonewall Flat Tuff (Connors and others, 1995; 1997; fig. 2).

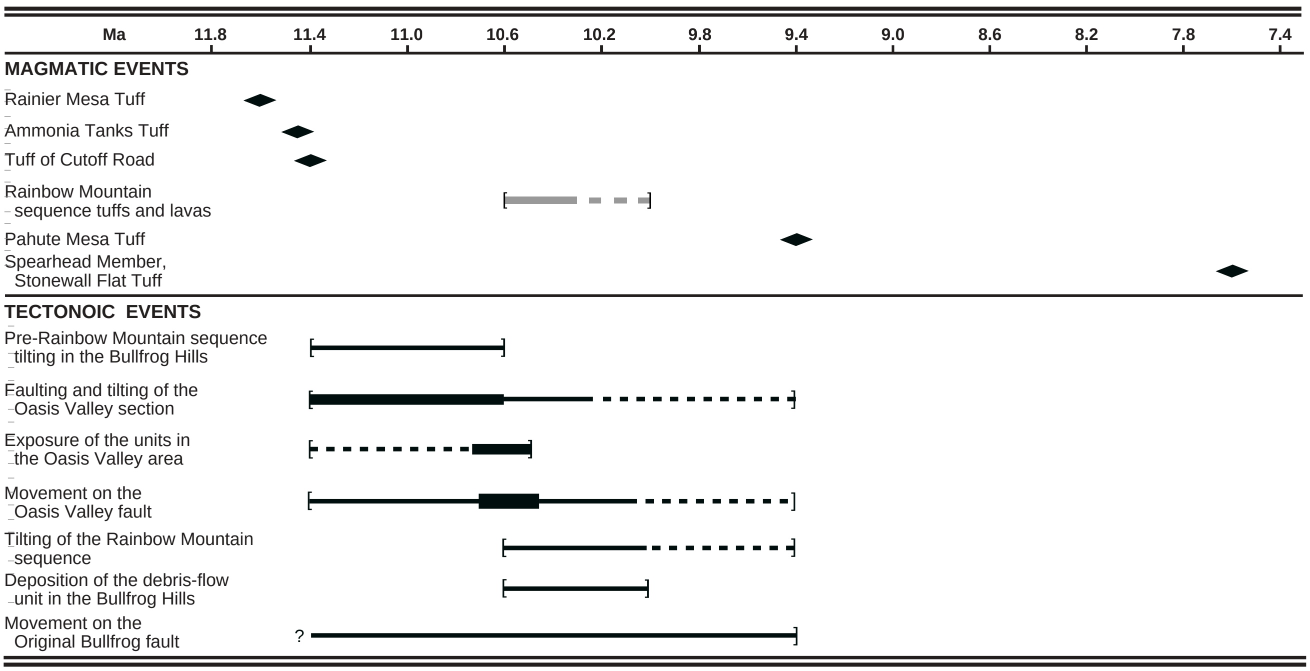

Figure 2. Diagram illustrating control on the timing of volcanic and structural events in the Bullfrog Hills–Oasis Valley area. Magmatic events are based on isotopically dated volcanic units and provide absolute age constraints. Structural events are constrained by geologic relations in the volcanic units; brackets indicate absolute limits, line weight indicates degree of confidence for a period of structural movement, and dashed lines indicate periods where movement is possible, but thought to be less probable. Constraints on the movement of the Original Bullfrog fault are based on the absence of any evidence for rotational faulting of the volcanic section in the Bullfrog Hills prior to deposition of the Timber Mountain Tuff. The possibility of an earlier episode of detachment faulting, before deposition of volcanic rocks from the southwestern volcanic field, cannot be discounted.

The Oasis Valley fault probably represents the northern continuation of the Beatty fault, for which Ransome and others (1910) estimated a throw of some 1,500 m. A minimum of 600 to 900 m of offset on the Oasis Valley fault is required to account for the displacement of the Ammonia Tanks Tuff near Oasis Mountain; total offset could be considerably greater. To the west one, or possibly two, additional major normal faults subparallel to, and probably initiated slightly later than, the Oasis Valley fault, account for most of the stratigraphic offset in the Bullfrog Hills (see cross section G–G').

The Oasis Valley fault was an important element in the later volcano-tectonic evolution of the Bullfrog Hills structural domain, and Oasis Valley marks a persistent boundary between distinct volcano-tectonic zones. This boundary was first the site of an east-facing, probably caldera-related, topographic barrier that restricted deposition of the Ammonia Tanks Tuff, the tuffs and lava of Fleur de Lis Ranch, and the tuff of Cutoff Road, and later, was the edge of a west-facing topographic high that was the source of blocks present within the debris-flow deposits of the Rainbow Mountain sequence.

Isotopic Ages of Volcanic Units

Ages of most of the major ash-flow sheets exposed in the Bullfrog Hills, which range from about 14 to 7.6 Ma, are tightly constrained by K-Ar and $^{40}Ar/^{39}Ar$ dating. In general, the best estimates are ages published by Sawyer and others (1994), based on multiple single-crystal $^{40}Ar/^{39}Ar$ determinations on specimens from outcrops in the Nevada Test Site region of southern Nye County. These ages, given in the map descriptions, in most cases agree closely with K-Ar and $^{40}Ar/^{39}Ar$ ages published by previous workers (e.g., Marvin and Cole, 1978; Marvin and others, 1989; Jackson, 1988; Noble and others, 1991). The ages of the tuff of Cutoff Road (11.4 Ma) and the Spearhead Member of the Stonewall Flat Tuff (7.6 Ma) are based on $^{40}Ar/^{39}Ar$ ages presented by Noble and others (1991; *see* Connors and others, 1991 and Connors, 1995) and by Hausback and others (1990), respectively. The age range of the Rainbow Mountain sequence is best constrained by $^{40}Ar/^{39}Ar$ ages of 10.33 ± 0.1 Ma and 10.56 ± 0.02 Ma on sanidine from map unit Trt_1 and the latite of Donovan Mountain, respectively (Eng and others, 1996). These ages are, in general, consistent with K-Ar ages on various units of the Rainbow Mountain sequence published by Morton and others (1977), Marvin and others (1989) and Noble and others (1991) and summarized in table 1. A K-Ar age of 10.3 ± 0.3 Ma on basalt lava that directly overlies the Ammonia Tanks Tuff in the western Bullfrog Hills (Marvin and others, 1989), probably correlative with Tb_2 in the map area, limits the onset of volcanism of the Rainbow Mountain sequence to after about 10.7 Ma.

Two, and perhaps three, periods of hydrothermal activity can be recognized in the Bullfrog Hills and the Oasis Valley area (Weiss and others, 1991; Weiss, 1996). The older episode at about 11.2 Ma is documented by K-Ar and $^{40}Ar/^{39}Ar$ ages of 11.0 ± 0.4 on adularia from north of the Pioneer Mine, and 11.3 ± 0.3 on adularia collected at the Yellow Jacket Mine (E and F on table 1). A second episode at about 10.0 Ma is defined by $^{40}Ar/^{39}Ar$ ages of 9.99 ± 0.04, 9.8 ± 0.3 and 10.07 ± 0.05 on adularia from the Bullfrog Mine and the Rush fault zone (Eng and others, 1996; Weiss, 1996), and a K-Ar age of 9.5 ± 0.2 Ma (recalculated) on adularia from the Montgomery Shoshone Mine (Morton and others, 1977). A third period of mineralization at about 9.0 Ma is suggested by K-Ar and $^{40}Ar/^{39}Ar$ ages of 8.7 ± 0.4 and 9.2 ± 0.3 on adularia from the Original Bullfrog Mine (Weiss, 1996; sample locations not shown on map).

DESCRIPTION OF MAP UNITS

Qa **Alluvium (Quaternary)** Unconsolidated to poorly consolidated, poorly to well sorted, weakly to well stratified gravel, sand, and sandy silt in active stream channels**.**

Qac **Alluvium and colluvium, undivided (Quaternary)** Unconsolidated gravel, sand, and silt with locally derived clasts, poorly to moderately sorted and poorly to well stratified. Locally includes talus deposits.

Qc **Colluvium (Quaternary)** Unconsolidated gravel, sand, and silt of local derivation forming thin surficial veneers that obscure bedrock. Locally includes talus deposits.

Qoa **Older alluvium (Quaternary)** Light-brown- to brown-weathering, poorly consolidated conglomeratic alluvium. Consists of coarse to fine, mostly poorly sorted fluvial and slope-wash debris containing locally derived clasts of Cenozoic volcanic and pre-Cenozoic sedimentary rocks, and abundant pumice and tuffaceous sand, probably in part reworked from map unit Tps.

Table 1. SELECTED ISOTOPIC AGE DETERMINATIONS ON VOLCANIC ROCKS AND HYDROTHERMAL MINERALS WITHIN AND NEAR THE MAP AREA

Locality	Map unit	Sample No.	Mineral Dated	Analysis Type*	Age (Ma ± 1σ)	Source
A	Trt_2	3DN9-20	biotite	K-Ar	10.1 ± 0.3	1
B	Tmr	3SW-247	sanidine	$^{40}Ar/^{39}Ar$, TF	11.7 ± 0.3	1
C	vein in Tdfrh	Mayflower	adularia	K-Ar	10.0 ± 0.3	2
		Mayflower	adularia	$^{40}Ar/^{39}Ar$, TF	9.9 ± 0.3	2
D	Tmr	3DN9-35	biotite	K-Ar	11.8 ± 0.3	3
E	vein in Tc	Bullfrog Hills	adularia	K-Ar	11.0 ± 0.4	2
F	vein in Tc	3SW-357	adularia	$^{40}Ar/^{39}Ar$, TF	11.3 ± 0.3	2
G	Tma	3SW-269	sanidine	$^{40}Ar/^{39}Ar$, TF	11.9 ± 0.7	1
H	vein/Tma	3MJ-74a	adularia	K-Ar	10.6 ± 0.3	4
I	Tcr	3DN-75	sanidine	$^{40}Ar/^{39}Ar$, SC	11.4 ± 0.1	1, 5
J	Tma	3DN9-1	biotite	K-Ar	11.3 ± 0.3	1
K**	vein/Tmr	BBSF-2	adularia	$^{40}Ar/^{39}Ar$, TF	9.8 ± 0.3	2
L	Trl	BF-591	biotite	K-Ar	10.0 ± 0.4	6
M	Trl	MLS-73-1	biotite	K-Ar	10.7 ± 0.3	7
N	vein	MLS-73-2	adularia	K-Ar	9.5 ± 0.2	7
O	Trl	DB-7B-RM	sanidine	$^{40}Ar/^{39}Ar$, SC	10.33 ± 0.098	8
P	Trt_1	DB-1-RM	sanidine	$^{40}Ar/^{39}Ar$, SC	10.56 ± 0.022	8
Q**	vein	DB-952-FW-1	adularia	$^{40}Ar/^{39}Ar$, SC	9.99 ± 0.04	8
R**	vein	DB-1-BC	adularia	$^{40}Ar/^{39}Ar$, TF	10.07 ± 0.050	8
				$^{40}Ar/^{39}Ar$, SH	10.04 ± 0.054	8
S	Ttp	Pahute Mesa	sanidine	$^{40}Ar/^{39}Ar$, SH	9.40 ± 0.036***	9

Sources: 1. Noble and others, 1991; 2. Weiss, 1996; 3. previously unpublished age, analytical data: K_2O = 8.39 wt%; $^{40}Ar_{rad} = 1.4248\times10^{-10}$ mole/g; $^{40}Ar_{rad}/^{40}Ar$ = 63.5%, analysis performed under the supervision of E.H. McKee, U.S. Geological Survey, Menlo Park, CA; 4. Jackson, 1988; 5. Connors and others, 1991; 6. Marvin and others, 1989; 7. Morton and others, 1977; 8. Eng and others, 1996; 9. Connors and others, 1997: analytical data: n=13, K/Ca = 38.4 ± 7.7 age = 9.403 ± 0.036 (2σ) Ma, relative to 27.84 Ma for Fish Canyon sanidine, 520.4 Ma for MMhb-1, analysis performed by C.D. Henry at the New Mexico Geochronology Research Laboratory courtesy of W.C. McIntosh.

* $^{40}Ar/^{39}Ar$ age determination methods: TF = total fusion, SC = multiple laser fusion single crystal, SH = step heating.
** Sample locations are southwest of the map area, see figure 1.
*** Analytical uncertainty reported as two sigma.

Tgs Gravels of Sober-Up Gulch (late Miocene and Pliocene?) Alluvial deposits of unconsolidated to poorly consolidated, poorly to well stratified silt, sand and conglomerate. Contains angular to well-rounded pebbles, cobbles and boulders of locally derived volcanic and pre-Cenozoic rocks. Corresponds to map unit Tgs of Swadley and Parrish (1988) and Monsen and others (1992).

Tps Pumiceous siltstone, sandstone, conglomerate, and tuff (late Miocene) White, light-gray, greenish-gray, buff, and orangish-buff, weakly indurated, tuffaceous sandstone and conglomerate, typically with fluvial bedding, with interbeds of reworked and air-fall(?) tuff. Well to moderately sorted, with abundant small pumice fragments and shards. Contains abundant subrounded to angular grains of volcanic quartz, feldspar, and biotite. Unit intertongues with, and underlies, map unit Tgs. Thickness reflects varying paleo-topography, and ranges from 0 to more than 40 m.

Tss Spearhead Member of the Stonewall Flat Tuff (late Miocene) Light-gray to buff, nonwelded to poorly welded, largely glassy, shard- and pumice-rich rhyolite ash-flow tuff; light orange-pink where devitrified. In most places consists of a single pyroclastic flow. Contains about 3–5% phenocrysts about 1–3 mm in maximum dimension including characteristically platy sanidine accompanied by much smaller quantities of plagioclase and clinopyroxene, and trace amounts of fayalitic olivine, sodic amphibole, and Fe-Ti oxides. Traces of xenocrystic(?) quartz are locally present. In various localities the unit is interbedded with rocks of map units Tgs and Tps. Age is 7.6 ± 0.03 Ma (Hausback and others, 1990). Thickness 0 to about 20 m.

Ttp Pahute Mesa Tuff of the Thirsty Canyon Group (late Miocene) Light-gray to grayish-brown, nonwelded glassy to poorly welded devitrified comendite ash-flow tuff. Contains approximately 3–5% large, platy phenocrysts of alkali feldspar, with sparse distinctive clinopyroxene, rare plagioclase, and quartz rare to absent based on one small exposure in the map area, approximately 2 miles northeast of Beatty in Oasis Valley. An isotopic age determination of a sample from this location yielded an age of 9.40 ± 0.04 Ma (see table 1), an age consistent with identification of the unit as the Pahute Mesa Tuff.

Tbs Basalt of Springdale Mountain (late Miocene) Flows of dark-gray vesicular to dense basaltic lava containing 3–5% phenocrysts of plagioclase 1–3 mm in length, and altered olivine and clinopyroxene. Large vesicles are commonly filled with white fibrous zeolite.

Tb_3 Basalt lava flows and intrusive rocks Flows, dikes and plugs of dark-gray dense, to reddish vesicular, basaltic lava containing 3–5% phenocrysts of plagioclase, olivine, and pyroxene.

Tta Air-fall tuff of Oasis Valley White to yellowish, thin-bedded, interbedded air-fall and surge deposits that may correlate with map unit Tha. The tuffs are porous, nonresistant and locally zeolitically altered, and overlie rocks of the Fleur de Lis area in angular unconformity. Contains sparse phenocrysts of plagioclase, sanidine, and biotite. Exposed thickness ranges from 0 to about 100 m.

Tha Air-fall tuff of Bullfrog Hills White, pale-gray to yellowish, thin- to thick-bedded air-fall, welded air-fall and thin interlayered surge deposits. Individual layers are petrographically variable; most contain 2–3% phenocrysts of plagioclase, biotite, hornblende, and minor sanidine, whereas others are composed of aphyric pumice. Lithic fragments of latite, rhyolite lava, and tuff, 0.5–2 cm in diameter, are common in some layers and one bed contains as much as 10% biotite. Unit drapes paleotopography, ranging in thickness from 0 to about 75 m. May include air-fall deposits of map unit Trt_3 where stratigraphic position is uncertain.

Rainbow Mountain Sequence

A complex sequence of tuffs, lavas, and debris-flow deposits emplaced between about 10.7 and 10.3 Ma. The rhyolite tuffs and lavas appear to have been derived from vent areas within the Bullfrog Hills and the deposits of the debris flow unit were largely derived from sources in the Bullfrog Hills and the Oasis Valley area. (See section on Nomenclature of Post-Timber Mountain Group Rocks in the Bullfrog Hills.)

Trt_3 Rhyolite tuff #3 White to buff, nonwelded to poorly welded pumice- and crystal-rich ash-flow, surge and air-fall tuff. Surge and ash-flow tuffs contain 15–25% phenocrysts of sanidine, quartz, plagioclase, biotite, and hornblende 0.2–2 mm in diameter. Ash-flow and surge layers are generally lithic, containing pebble- to boulder-size fragments, predominantly of latite and tuff of map unit **Trt**, but also including fragments of map units **Tmr**, **Tma**, **Tp** and several Paleozoic units. The air-fall layers of **Trt_3** are poor in crystals and rich in pumice and lithic fragments, yellowish-buff to white, and contain phenocrysts of plagioclase, biotite, and minor quartz, sanidine, and hornblende. Ash-flow tuffs have locally undergone vapor-phase crystallization. Originally glassy rocks are largely zeolitically altered. **Trt_3** intertongues with and overlies the upper lava flows of map unit **Trl**. **Trt_3** is distinguished from tuffs of **Trt_2** on the basis of stratigraphic position and the presence of lithic fragments of **Trt_2** and **Trl**. Thickness ranges from 0 to about 80 m.

Trl Latite of Donovan Mountain Flows and interlayered flow breccia of dark-gray, black to reddish-brown, compositionally variable latite lava. Contains 5–20% phenocrysts, and ranges from rocks containing plagioclase, olivine, and clinopyroxene to rocks containing plagioclase, sanidine, biotite, clinopyroxene, hornblende, and olivine. The matrix is devitrified or locally glassy, commonly with abundant microlitic feldspar crystals. Upward-shallowing dips within the sequence of flows are observed in the southern part of the map area. In the northern part of the map area some of these lavas are near basalt in composition and are commonly slightly to highly vesicular. Chemical analyses of two samples from the latite unit were reported by Cornwall and Kleinhampl (1964); these indicate compositions with about 60–63% SiO_2 and K_2O approximately equal to, or slightly higher than, Na_2O(SiO_2 = 60.58% and 63.34%, K_2O= 4.59% and 5.31%; Na_2O = 4.27% and 3.89%, respectively). This unit includes the "quartz basalt" of Ransome and others (1910) and Cornwall and Kleinhampl (1964), which is petrographically similar to the other latite flows but contains anhedral quartz xenocrysts. A thin, underlying unit of bluish-gray, pumice-rich, crystal-poor air-fall tuff shown by a **t** on the map is included in one locality in the northern Bullfrog Hills. Best estimate of age is 10.33 ± 0.10 Ma (Eng and others, 1996). Thickness ranges from 0 to 425 m.

This unit was first termed *latite of Donovan Mountain* by Minor and others (1993); other nomenclature for the unit has included *latite and andesite lava flows* by Maldonado and Hausback (1990), *latite* by Cornwall and Kleinhampl (1964), and *quartz latite* by Ransome and others (1910). We have adopted the use of *latite of Donovan Mountain* for continuity, recognizing that there is significant compositional variation in the unit.

Trri Rhyolite dikes, plugs, and stocks Light-gray, pale-bluish-gray to buff, medium-grained porphyritic dikes, plugs, and stocks of massive to weakly flow-banded rhyolite lava. Contains 15–35% phenocrysts, generally 1–3 mm in diameter, of quartz, sanidine, plagioclase, and biotite in dense glassy to devitrified groundmass. Sanidine phenocrysts are locally as large as 5 mm, similar to those in the ash-flow tuff of unit **Trt**. In some localities, intrusive rocks of this unit are transitional upwards and laterally to flow-banded lava flows of map units **Trr** and/or **Trr$_2$**. Locally includes pumiceous to vesicular rhyolite (**Trrt**) of possible pyroclastic origin, with steeply dipping foliation.

Trr Rhyolite lava flows, domes, and plugs, undivided Flow-banded to massive, bluish-gray, pale-brown to dark-reddish-brown, lava flows, domes, and hypabyssal feeder plugs and dikes of rhyolitic composition mapped in uncertain stratigraphic position relative to **Trr$_1$** and **Trr$_2$**. Contains thin, laterally discontinuous interlayered lenses of pyroclastic surge and ash-flow deposits interpreted as related to the rhyolite lavas and shown on the map as **t** within the **Trr** unit. Dikes and plugs locally intrude fault zones, which served as feeders for lava flows. Map unit includes rocks assigned by Maldonado and Hausback (1990) to the rhyolite of Rainbow Mountain.

Trr$_2$ Rhyolite lava flows and domes Dark-bluish-gray, pale-bluish-gray, to dark-brown and reddish-brown lava flows of rhyolitic composition. Flows contain 5–20% phenocrysts of quartz, sanidine, plagioclase, biotite and hornblende, and glomeroporphyritic intergrowths of magnetite and zircon. Phenocrysts are generally 1–1.5 mm, but some are as much as 4 mm in diameter. Unit includes small irregular lenses of intrusive rhyolite that crosscut subhorizontal flow banding and thin, laterally discontinuous lenses of pyroclastic material shown as **t** within **Trr$_2$**. Irregular zones of pale- to medium-blue, flow-banded vitrophyre and vitrophyre breccia are common. Thickness varies from 0 m at the north end of Donovan Mountain to a minimum of 380 m.

Trt Rhyolite tuff undivided Buff, pinkish-gray to reddish-brown, nonwelded to densely welded crystal- and pumice-rich ash-flow tuff and interbedded surge deposits of rhyolitic composition. Originally glassy tuffs are commonly zeolitically altered. Contains 15–25% phenocrysts of quartz, sanidine, plagioclase, biotite, hornblende, and zircon. May include rocks of map units **Trt$_1$** and/or **Trt$_2$** in areas where stratigraphic position is uncertain.

Trt$_2$ Rhyolite tuff #2 Pale-buff to light-pink, nonwelded, porous glassy to vapor-phase crystallized ash-flow tuff and surge deposits. Originally glassy ash-flow tuffs are in part zeolitically altered. Unit forms rounded, commonly cavernous ledges and slopes. Contains 20–25% phenocrysts of quartz, sanidine, and plagioclase, generally 1–2 mm in diameter but not uncommonly as large as 5–6 mm. Accessory biotite and trace magnetite, zircon, and magnetite-zircon intergrowths are present, as well as Fe-Ti oxides. Upper part includes discontinuous beds of fine-grained surge and air-fall tuff. Small lithic fragments of rhyolite lava are present throughout, and the lower part of the unit commonly contains zones very rich in cobble- and boulder-sized blocks of reddish-brown, devitrified, crystal-poor rhyolite lava. In the area directly north of Burton Mountain the base of map unit **Trt$_2$** contains as much as 50% lithic fragments of dark-reddish-brown rhyolite lava. These rhyolite lava fragments distinguish the lower part of the unit from underlying debris-flow deposits, which in this area contain abundant clasts of tuff of the Timber Mountain Group. Exposed thickness ranges from about 30 m at Rainbow Mountain to about 300 m north of Burton Mountain.

Trr$_1$ Rhyolite lava flows #1 Flows of pale-brown, reddish-brown, yellow to bluish-gray, flow-banded lava and thin, interlayered pyroclastic flow deposits, all of rhyolitic composition. Contains 2–5% phenocrysts of plagioclase with sieve texture, sanidine, hornblende, biotite, and quartz, 0.3–1 mm in diameter. In devitrified rocks coarse anhedral quartz infills vesicles. Lava flows commonly possess a pale- to medium-bluish-gray, flow-banded basal vitrophyre or vitrophyre breccia, and irregular bodies of vitrophyre possibly reflecting partial cooling breaks are present throughout the sequence. Thickness ranges from 0 m to about 200 m.

Tdf Debris-flow (megabreccia) deposits Reddish-brown, light-brown, bluish-gray, yellowish-gray, and pinkish-gray, coarse, poorly sorted, unstratified to weakly stratified, unconsolidated to well-lithified breccia and intertonguing coarse volcanic conglomerate. Breccia and conglomerate are predominantly composed of angular to slightly rounded pebble- to boulder-size clasts of Miocene volcanic rocks of the southwestern Nevada volcanic field, including ash-flow tuff of the Ammonia Tanks Tuff, the tuffs of Fleur de Lis Ranch and the tuff of Cutoff Road, and contain interbeds of tuffaceous sandstone and thin pyroclastic surge deposits. Some layers are rich in fragments of pre-Cenozoic quartzite, sandstone, shale, and limestone. Breccia varies from clast- to matrix-supported and from heterolithologic to monolithologic, and includes slide blocks as much as 450 m in length. In certain exposures the debris-flow deposits consist mainly of clasts derived from an individual unit. Where present, these areas of dominant clast types within the **Tdf**, are annotated with lowercase letters as follows: Paleozoic sedimentary rock (**q**), Crater Flat Group (**c**), Paintbrush Group (**p**), Rainier Mesa Tuff (**r**), Ammonia Tanks Tuff (**a**) Timber Mountain Group tuffs, undivided (**m**), and tuffs of Fleur de Lis Ranch, undivided (**f**). Bodies of monolithologic breccia that appear to constitute layers within the debris-flow sequence are indicated by **Tdf** followed by unit suffix within stipple pattern. Map-scale blocks within megabreccia are indicated by stipple and lack of a Period/Epoch prefix (e.g., **ft**$_2$ rather than **Tft**$_2$). Areas of brecciated, but apparently in-place, bedrock of Crater Flat and Paintbrush units of uncertain relation to debris-flow deposits are shown by stipple and subscript "b" suffix (**Tc**$_b$ and **Tp**$_b$). Local intercalated bedded tuffs are labeled **bt**. Much of the unit has a tuffaceous matrix, and crude columnar jointing and irregular bodies of porous crystal-rich rhyolite tuff are locally present. Thickness of the megabreccia and conglomerate sequence between the Pioneer and Mayflower Mines is estimated to be about 320 m. In other areas, thickness cannot be reliably estimated because bedding is poorly defined and, therefore, amounts of offset along normal faults are unknown.

Trt$_1$ **Rhyolite tuff #1** Pale-yellowish-buff to pink pumice- and crystal-rich, poorly to moderately welded ash-flow tuff and interlayered surge deposits; locally grades into reddish brown, devitrified, densely welded ash-flow tuff. Pore spaces in glassy lower portion are filled with secondary calcite. Forms resistant, light-colored, rounded slopes and ledges, commonly cavernous. Contains 10–20% phenocrysts of quartz, sanidine, and plagioclase, generally about 2 mm in diameter, with some quartz phenocrysts as much as 5 mm in diameter, and smaller amounts of biotite and relict hornblende. Generally contains 3–5% lithic fragments, predominantly of Timber Mountain Group and older ash-flow units. Also contains sparse clasts of schist and gneiss. Age = 10.56 ± 0.02 Ma (table 1). Thickness ranges from 0 to 230 m.

Trp **Pyroclastic and epiclastic deposits** Buff, light-gray, pink, brown, bluish-gray, and grayish-green, thick- to thin-bedded, tuffaceous siltstone, sandstone, and conglomerate with interbedded thin pyroclastic flow deposits petrographically similar to **Trt**$_1$. Contains lenses of coarse breccia dominated by clasts of map units **Tmr** and **Tma**. These lenses may represent early deposits of the debris flow sequence (**Tdf**). **Trp** is mappable as a separate unit only at Burton Mountain, but epiclastic and surge deposits that form about 1–2 m of the poorly exposed base of **Trt**$_1$ at Rainbow Mountain are probably correlative.

Tb$_2$ **Lava flow(s) of basaltic composition** One or more flows of dark-greenish-gray, dense to vesicular porphyritic basaltic lava containing about 10% phenocrysts, <4 mm in length, of olivine, plagioclase, and Fe-Ti oxides in a fine-grained trachytic to hyalopilitic groundmass of plagioclase, olivine, Fe-Ti oxides ± glass. Probably correlative with basaltic lavas overlying the Ammonia Tanks Tuff in the western Bullfrog Hills dated at 10.3 ± 0.3 Ma (Marvin and others, 1989). Thickness 0 to about 120 m.

Tcr **Tuff of Cutoff Road (middle Miocene)** Pinkish-brown, bluish-gray, and medium-brown, moderately to densely welded, pumice- and shard-rich, rhyolite ash-flow tuff. Contains 5–15% phenocrysts of plagioclase and sanidine, 1–1.5 mm in diameter, hornblende and biotite as much as 2 mm in diameter, and sphene generally 0.3–0.5 mm in diameter; quartz phenocrysts are rare to absent. Small lithic fragments are moderately abundant. Dark-colored, densely welded zones contain abundant, pale-pink to buff pumice fragments 0.5–2 cm in length. In some locations the contact between **Tcr** and underlying unit **Tft**$_2$ is marked by a complete cooling break; elsewhere this break is equivocal due to poor exposure and weak alteration. Age = 11.4 ± 0.1 Ma (table 1). Exposed thickness is as much as 200 m, but top of unit is not preserved. A thin fault and talus breccia composed entirely of Tcr is developed within the unit east of Oasis Valley.

Tuffs and Lava of Fleur de Lis Ranch (middle Miocene)

Tft$_2$ **Tuff of Fleur de Lis Ranch #2** Dark-brown to black, pale- to medium-brown, and pale-bluish-gray porous to densely welded, crystal-rich, rhyolitic ash-flow tuff. Persistent dark vitrophyre near base is overlain by densely to moderately welded devitrified and vapor-phase crystallized tuff, commonly with large, light-colored pumice fragments. Upper part of unit is moderately to poorly welded and vapor-phase crystallized. Contains 20–25% of unusually small (average diameter about 0.4 mm) phenocrysts of plagioclase, sanidine, and biotite, with lesser amounts of clinopyroxene and trace zircon, magnetite, and apatite. Quartz phenocrysts are rare to absent. Small inclusions of originally molten mafic magma are common. Maximum exposed thickness is about 190 m.

Tfr **Rhyolite lava of Fleur de Lis Ranch** Flow-banded rhyolite lava, bluish gray to black where glassy and bluish gray, pale reddish brown, to dark brown where devitrified. A well-developed basal vitrophyre several meters thick is generally developed where the unit overlies unit **Tft**$_1$, but is absent where overlying **Tfb**. Irregular glassy zones are present throughout the unit. Contains 3–20% phenocrysts of plagioclase, sanidine, and biotite with lesser amounts of hornblende and clinopyroxene; quartz phenocrysts are rare to absent. Glomeroporphyritic intergrowths of plagioclase+biotite and plagioclase+biotite+clinopyroxene are present. Thickness ranges from 0 to 360+ m.

Tfb **Breccia** Bluish-gray to reddish-brown breccia composed almost exclusively of blocks of units **Tft**$_1$, **Tma**, and **Tfr**(?).In places the matrix is composed of milled tuff and lava and elsewhere consists of dense, glassy to devitrified, rhyolite lava(?) petrographically similar to contained rhyolite lava blocks and overlying lava flow. Overlies and crosscuts **Tma**, is in apparent fault contact with **Tft**$_1$ to the north, and is overlain by **Tfr**. In one location, east of Oasis Mountain, a poorly exposed glassy dike (too narrow and discontinuous to map) with vertical flow banding crosscuts this breccia; this dike may be a feeder for lava of overlying unit **Tfr**. Although exposures are not conclusive, this unit appears to be composed of flow and/or explosion breccia related to the emplacement of unit **Tfr**; alternatively, it could consist of older colluvium, talus and/or perhaps landslide material.

Tft_1 Tuff of Fleur de Lis Ranch #1 Simple cooling unit of ash-flow tuff; pale-greenish-white porous glassy base is overlain by densely welded orangish-buff to brown devitrified tuff grading upward to bluish- to pinkish-gray, moderately welded, vapor-phase crystallized tuff that is capped by several meters of lithic-rich surge deposits. Generally pumice-rich, containing 10–20% phenocrysts of plagioclase, sanidine, biotite and accessory apatite, zircon, and magnetite. Rare quartz phenocrysts are irregular and deeply embayed. Phenocrysts are generally 0.5 to 1 mm, but some are as much as 2 mm in diameter. Contains lithic fragments and cognate melt inclusions of mafic composition. Exposed thickness ranges from 0 m to 175+ m.

Tol Marl, sandstone, and limestone of Oasis Mountain (Miocene) Ocher-yellow to pale-tan, brown, or greenish, thinly laminated, calcareous silty claystone to silty sandstone with interlayered beds of laminated lacustrine limestone. Ripple marks and mud cracks are locally preserved. Clastic material is mostly volcanic and includes thin, poorly exposed beds of waterlaid air-fall tuff. Maximum thickness is 60 m.

Timber Mountain Group (middle Miocene)

In this area consists of two major ash-flow sheets, the Rainier Mesa and the Ammonia Tanks Tuffs, as well as several local informal units of tuff and lava.

Tma Ammonia Tanks Tuff Pale-buff, gray, bluish-gray to pinkish-tan, poorly to densely welded rhyolite ash-flow tuff. In the Bullfrog Hills, consists of a simple cooling unit with a porous glassy base that grades upward into discontinuous vitrophyre, in turn overlain by moderately to densely welded, devitrified to vapor-phase crystallized ash-flow tuff. In the Oasis Mountain–Oasis Valley area, the unit is more complex, with laterally discontinuous ledges of densely welded tuff alternating with slightly to moderately welded, lithic tuff; a discontinuous medial vitrophyre is locally present. Large white collapsed pumice fragments, commonly as much as 15 cm in length, contain abundant phenocrysts of sanidine and quartz 2–3 mm in diameter. At Oasis Mountain, densely welded, granophyrically crystallized tuff contains stretched pumice indicating rheomorphic flowage. Throughout the map area the unit contains 10–20% phenocrysts of chatoyant sanidine, quartz, and lesser amounts of plagioclase and biotite, 1–2.5 mm in diameter, and trace to accessory sphene. **Tma** is generally moderately rich in small lithic fragments, but in the Oasis Valley area commonly contains as much as 30% fragments, some as long as 5 m. Age is 11.45 ± 0.03 Ma (Sawyer and others, 1994). Thickness ranges from >650 m in the Oasis Mountain–Oasis Valley area to about 20 m in Sober-Up Gulch.

Tmpa Ash-flow tuff and lava Single cooling unit of pale-purplish-gray to purplish-brown, rhyolitic ash-flow tuff characterized by the presence of two distinct pumice types. Unit also includes a thin underlying flow of rhyolite lava. Dark-purple pumice fragments, 1–5 cm in length, are most abundant and contain crystals of plagioclase and sanidine; pale gray aphryic pumice 0.5–1 cm are less abundant. Tuff contains 10–15% phenocrysts, 0.5–1 mm in diameter, of sanidine, plagioclase, quartz, accessory hornblende and biotite, trace magnetite, and zircon. Rare relict sphene suggests that the unit could be related to **Tma**. The underlying lava is flow banded, white or greenish white where hydrothermally altered, to bluish gray or pale purple, and contains <5% phenocrysts of sanidine, plagioclase, quartz, and relict accessory mafic minerals.

Tmr Rainier Mesa Tuff Single cooling unit of slightly to densely welded rhyolite ash-flow tuff. Consists of slightly welded, pumice-rich buff-colored glassy ash-flow tuff that grades upwards into several meters of pink, partly welded glassy tuff that is in turn overlain by moderately to densely welded, dark-reddish-brown devitrified ash-flow tuff. Densely welded tuff locally contains spherulites and lithophysae. Most of the unit contains about 15–20% phenocrysts, <1–3 mm in diameter, of quartz (commonly dipyramidal), subequal amounts of sanidine and plagioclase, accessory biotite, and trace hornblende and zircon. A resistant vitrophyric caprock, containing about 25% phenocrysts, is present locally. Nonwelded to slightly welded lower part locally includes as much as 30+ m of buff to light-gray and light-pinkish-red, pumice-rich, bedded tuff consisting of interbedded surge and thin ash-flow deposits with somewhat fewer phenocrysts of the same assemblage as the overlying ash-flow sheet. Age is 11.6 Ma ± 0.03 (Sawyer and others, 1994). Thickness is variable throughout the map area, ranging from about 320 m in Sober-Up Gulch to about 220 m northeast of Sawtooth Mountain. Maldonado and Hausback (1990) reported a thickness of about 425 m, but intraformational faults north of the town of Rhyolite probably have produced apparent thicknesses greater than the true thickness.

Tprr Pre-Rainier Mesa lava flows Pale-gray, gray-blue, bluish- to dark-purple, flow-banded to massive lavas of rhyolitic composition containing approximately 3–7% phenocrysts, 0.2–1 mm in diameter, of sanidine, quartz, plagioclase, and accessory biotite. Commonly dense and flow-banded, but microvesicular in part with fine-grained vapor-phase crystals lining irregular cavities. Locally includes intercalated pyroclastic surge, ash-flow, and air-fall deposits. Exposed thickness about 170 m.

Tprt Pre-Rainier Mesa tuff Buff to light-gray and light-pinkish-red, pumice-rich and generally crystal-poor interbedded surge and thin ash-flow deposits of rhyolitic composition. Contains about 5–7% phenocrysts of quartz, sanidine, plagioclase, and accessory biotite, and commonly, abundant pale-green, altered pumice fragments. Small, dark-brown lithic fragments of rhyolitic lava are common. Probably represents apron of pyroclastic deposits associated with eruption of lavas of map unit Tppr.

Tb$_1$ Basalt lava flows (middle Miocene) Dark-greenish-gray, dense to vesicular flow or flows of porphyritic basalt. Contains about 10% phenocrysts of plagioclase, olivine, and pyroxene, <2 mm in diameter, in a fine-grained, partly glassy groundmass. Thickness about 15 m.

Tp Paintbrush Group (Miocene) Light-grayish-yellow to brownish-gray and dark-reddish-brown rhyolitic ash-flow tuff; mostly shard-rich and phenocryst-poor. Basal nonwelded, pumice- and shard-rich, grayish-yellow, altered, originally glassy tuff as much as 30 m in thickness grades upwards to dark-gray, brown to reddish-brown, densely welded, devitrified, very phenocryst-poor ash-flow tuff. In some locations 5 m or less of dark-grayish-brown vitrophyre is present at the base of the densely welded zone. Abundant lithophysal cavities as much as 10 cm in diameter are developed in the upper part of the densely welded zone. Phenocrysts, generally 1–3 mm in maximum dimension, consist mainly of alkali feldspar, plagioclase, and biotite, with traces of hornblende, clinopyroxene, and subhedral quartz. In more complete sections, densely welded, lithophysal tuff grades upwards into brownish-gray, moderately welded, strongly vapor-phase crystallized ash-flow tuff with abundant large pumice fragments and about 15% phenocrysts, including subequal amounts of sanidine and plagioclase, accessory biotite, hornblende, clinopyroxene, and trace broken, subhedral quartz. In some locations the upper, crystal-rich subunit includes a dense caprock. Densely welded parts of the unit are commonly intensely brecciated and hydrothermally altered, particularly south and east of Zabriskie Hill, as shown by stipple and suffix (**Tp$_b$**). Between Pioneer Road and Sober-Up Gulch no sphene was found in relatively fresh crystal-rich caprock and a thin (<10 m), brownish-red, shard-rich, ash-flow cooling unit (**Tp$_2$**), containing as much as 10–15% phenocrysts of sanidine subequal to plagioclase, biotite, hornblende, and clinopyroxene, overlies the main tuff unit. This suggests that at this locality the lower unit (**Tp$_1$**) is possibly the Topopah Spring Tuff rather than the Tiva Canyon Tuff as shown by Maldonado and Hausback (1990). Ages of the Topopah Spring and Tiva Canyon Tuffs are 12.8 ± 0.03 and 12.7 ± 0.03 Ma, respectively (Sawyer and others, 1994). Thickness about 190 m to >240 m.

Tfpi Silicic dikes and plugs (middle Miocene) Aphyric to porphyritic, massive to flow-banded, in part pumiceous, largely hydrothermally altered dikes and small plugs of rhyolite and dacite(?). Includes glassy, devitrified, and locally spherulitic rocks. Rhyolitic bodies are brownish red, light grayish pink, and light gray and contain as much as 3% phenocrysts of feldspar 1–3 mm in diameter. Dacitic(?) bodies are green and porphyritic, containing about 15% phenocrysts, including subequal quantities of sanidine and plagioclase as much as 5–7 mm in diameter, and biotite, hornblende, and apatite 1–3 mm in diameter. Bodies of rhyolite locally intrude discontinuous thin wedges of related(?), crystal-poor pyroclastic flow and surge(?) deposits (map unit **Tfpt**).

Trpi Rhyolite plug (middle Miocene) Dark- to pale- to reddish-brown, massive rhyolite lava with dense granophyric interior and spherulitic border zones; mostly hydrothermally altered. Contains 10–15% phenocrysts, 1–1.5 mm in diameter, of feldspar, quartz, biotite, and relict hornblende.

Tc Crater Flat Tuff (middle Miocene) Nonwelded to densely welded rhyolite ash-flow tuff. Consists mostly of light-purplish-gray, grayish-red and grayish-purple, moderately to densely welded, devitrified tuff containing abundant collapsed pumice fragments and about 15% phenocrysts, 1–3 mm in diameter, of sanidine and plagioclase in subequal amounts, quartz (commonly highly embayed), accessory biotite, and trace zircon and sphene. In some areas the welded part grades upward into a few tens of meters of light-gray to grayish-yellow or yellowish-green, nonwelded shard and pumice-rich ash-flow tuff. At some localities dense, devitrified tuff grades downward into underlying green, hydrothermally altered, originally glassy, partly welded, lithic, pumice-rich ash-flow tuff containing about 15–20% small (1–2 mm in length) phenocrysts of plagioclase, sanidine, quartz, and accessory biotite and sphene(?). Locally, two separate cooling units (**Tc$_1$** and **Tc$_2$**) are present. Most exposures probably belong to the lower cooling unit, which is most similar in phenocryst mineralogy and field appearance to the Bullfrog Tuff exposed in Fluorspar Canyon, southern Yucca Mountain and at Bullfrog Mountain. Much of the unit exposed at Pioneer Hill is intensely brecciated (shown by stipple and suffix **b**), but is apparently in place and is in uncertain relation to nearby monolithologic debris-flow deposits of **Tdf$_c$**. The Bullfrog Tuff has an age of 13.25 ± 0.04 Ma (Sawyer and others, 1994). Maximum exposed thickness is up to 185 m.

Td Lava flows and flow breccia (middle Miocene) Dark-grayish-purple to purplish-brown, dense to vesicular, porphyritic lava flows, flow breccia and hypabyssal intrusive(?) rocks of dacitic to low-silica rhyolitic (?) composition. Contains about 15–20% phenocrysts of plagioclase >> sanidine, clinopyroxene, hornblende, and accessory quartz, 1–4 mm in diameter, in a dark, fine-grained groundmass of plagioclase, potassium feldspar, quartz, and Fe-Ti oxides. May correlate with map unit Ta of Maldonado and Hausback (1990). Thickness 0 to 60+ m.

Tlr Lithic Ridge Tuff (middle Miocene) Single cooling unit of light-gray partly welded to dark-purplish-gray densely welded, low-silica rhyolite ash-flow tuff. Distinguished by abundant lithic fragments and small phenocrysts, including abundant biotite and hornblende, and macroscopically visible sphene. Contains about 15–20% phenocrysts of plagioclase >> sanidine, quartz, biotite, hornblende, and sphene <2 mm in length. Includes distinctive subunit of partially welded, very lithic tuff. Upper part of unit locally consists of dark-purplish lithic tuff containing very abundant biotite and hornblende. Age is 14.0 ± 0.06 Ma (Sawyer and others, 1994). Estimated thickness 0 to 100+ m.

Tql Quartz latite to low-silica rhyolite (?) lava flows and flow-breccia (Miocene) Mottled light gray, medium purplish gray, and reddish brown where devitrified, dark to light bluish gray where glassy. Porphyritic and texturally variable, contains about 5–15% phenocrysts of plagioclase > sanidine, accessory biotite and hornblende, and trace quartz, 1–5 mm in diameter. Corresponds to map unit Tql of Maldonado and Hausback (1990). Thickness 0 to 250 m.

Tpd Felsic porphyry dike (Miocene?) Pale yellow, golden brown to brownish red with porphyritic texture; hydrothermally altered, with local presence of abundant euhedral adularia crystals. Contains about 25–30% phenocrysts of plagioclase, sanidine, quartz, relict biotite and hornblende, and trace zircon in a granophyrically crystallized groundmass of feldspar and quartz. Phenocrysts are generally 1–2 mm in diameter, but scattered potassium feldspar phenocrysts as much as 5 cm in length are common.

Tri Rhyolite dike or plug (Miocene) Pale-grayish-pink to medium brownish-red, massive to coarsely flow-banded porphyritic rhyolite dike or plug, largely hydrothermally altered. Contains about 30% phenocrysts, generally 1–2 mm in length, of subequal amounts of sanidine and plagioclase, with lesser amounts of quartz, biotite, hornblende, and apatite. Feldspar phenocrysts are euhedral and commonly as much as 7 mm in length, but quartz is 1–2 mm in maximum dimension, anhedral, and generally highly embayed.

Tai Porphyritic dikes of intermediate composition (Miocene) Dark-greenish-gray to reddish-brown, dense to vesicular porphyritic dikes of andesitic and/or basaltic andesitic composition; unit contains about 30–35% phenocrysts, <1 mm to 5 mm in length, of plagioclase, clinopyroxene and hornblende in a fine-grained groundmass of trachytic texture.

Tot Older ash-flow tuffs and subordinate sedimentary rocks, undifferentiated (Miocene?) Includes at least three cooling units of silicic ash-flow tuff, separated in places by thin interbedded units of tuffaceous sandstone, conglomerate, lacustrine limestone and, locally, by a thin unit of andesitic or dacitic lava. Sequence is locally subdivided into **Tot_1**, **Tot_2**, **Tot_3**. Exposed combined thickness of at least 140 m. In part corresponds to map units Ts_1, Tsl, and Tsu of Maldonado and Hausback (1990). May also include hydrothermally altered, phenocryst-poor, originally glassy parts of the Lithic Ridge Tuff and/or tuffs of the Crater Flat Group. The following subunits are locally recognized:

Tot_3 Hydrothermally altered; one or more cooling units of generally pale-purplish- and greenish-gray to light-grayish-pink and medium-reddish-brown, moderate to densely welded, originally glassy(?) shard- and pumice-rich, phenocryst-poor ash-flow tuff. Contains about 1–5% small phenocrysts, mostly feldspar with sparse anhedral quartz. No meaningful estimate of thickness.

Tot_2 Single(?) cooling unit of hydrothermally altered ash-flow tuff. Light-pinkish-gray, partly welded upper part with about 15% phenocrysts, <2 mm in length, of feldspar, quartz and accessory biotite; grades downward into dark brownish-red and orange-brown, densely welded, devitrified tuff containing 20–25% phenocrysts of sanidine(?), plagioclase, quartz, and biotite, 2–4 mm in diameter. South of Pioneer Road includes underlying beds of dark-gray lacustrine limestone 2–10 m in aggregate thickness. North of Pioneer Road, includes underlying unit of reddish-brown to brownish-gray andesitic or dacitic lava about 20 m thick.

Tot_1 Single(?) cooling unit of partly to densely welded, pale pinkish-buff and grayish-pink to reddish-brown, hydrothermally altered ash-flow tuff. Contains 5–15% phenocrysts, 1–2 mm in diameter, of feldspar, quartz, and biotite. Partly welded tuff contains abundant green, originally glassy, collapsed pumice fragments <1 cm in diameter. Locally includes similar tuff having somewhat larger phenocrysts of feldspar and trace quartz, which directly overlies the Titus Canyon Formation. May correspond to tuff of Buck Spring of Maldonado and Hausback (1990).

Ttc Titus Canyon Formation (Oligocene) Dark-gray, light-pinkish- to greenish-gray and dark-red interbedded coarse sandstone, fine to coarse, commonly poorly sorted conglomerate, and sparse, dark-gray lacustrine limestone. Conglomerate contains distinctive, well-rounded, commonly polished pebbles and cobbles of quartzite, chert-pebble conglomerate and cherty quartzite, chert, limestone, and mafic volcanic rock that have been tectonically fractured and healed subsequent to deposition. Corresponds to Titus Canyon Formation as discussed by Cornwall and Kleinhampl (1964). Incomplete sections exposed near Zabriskie Hill vary in thickness from 0 to about 100 m.

Cc Carrara Formation (Middle and Lower Cambrian) Predominantly thin- to medium-bedded light-to dark-gray limestone; lower part contains intercalated beds of olive-green to gray micaceous shale, siltstone, and thin phyllitic sandstone. Probably an incomplete section; exposed thickness is about 280 m on east side of Zabriskie Hill.

Cz Zabriskie Quartzite (Lower Cambrian) White to pinkish-gray, fine- to medium-grained quartzite; commonly intensely brecciated and silicified. Bedding is poorly preserved. Probably an incomplete section; exposed thickness about 370 m at Zabriskie Hill.

Cwu Wood Canyon Formation, Upper member (Lower Cambrian) Grayish-green, olive-gray, brown and reddish-brown shale, siltstone, micaceous sandstone and quartzite, and thin beds of finely laminated limestone. Probably equivalent to the upper part of the Upper Member of the Wood Canyon Formation at Bare Mountain (Monsen and others, 1992). Minimum thickness about 350 m at Zabriskie Hill.

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GEOLOGIC MAP OF THE NORTHEASTERN BULLFROG HILLS AND VICINITY, SOUTHERN NYE COUNTY, NEVADA

Katherine A. Connors, Steven I. Weiss, and Donald C. Noble

1998

Scale 1:24,000

CONTOUR INTERVAL 20 FEET, Springdale and Thirsty Canyon SW 7.5' Quadrangles
CONTOUR INTERVAL 40 FEET, Beatty and Beatty Mountain 7.5' Quadrangles

Topographic base map from the Beatty 1987, Beatty Mountain 1987, Springdale 1986, and Thirsty Canyon SW 1986 7.5' Quadrangles.

Contact Dashed where approximately located.

Fault Showing dip of fault; ball on downthrown side; dashed where approximately located; dotted where concealed.

Syncline Trace of axial surface, dashed where approximately located.

Strike and dip of bedding.

Inclined

Strike and dip of foliation in volcanic rocks.

Compaction foliation and layering in tuffs

Inclined — Vertical — Approximate

Horizontal — Overturned

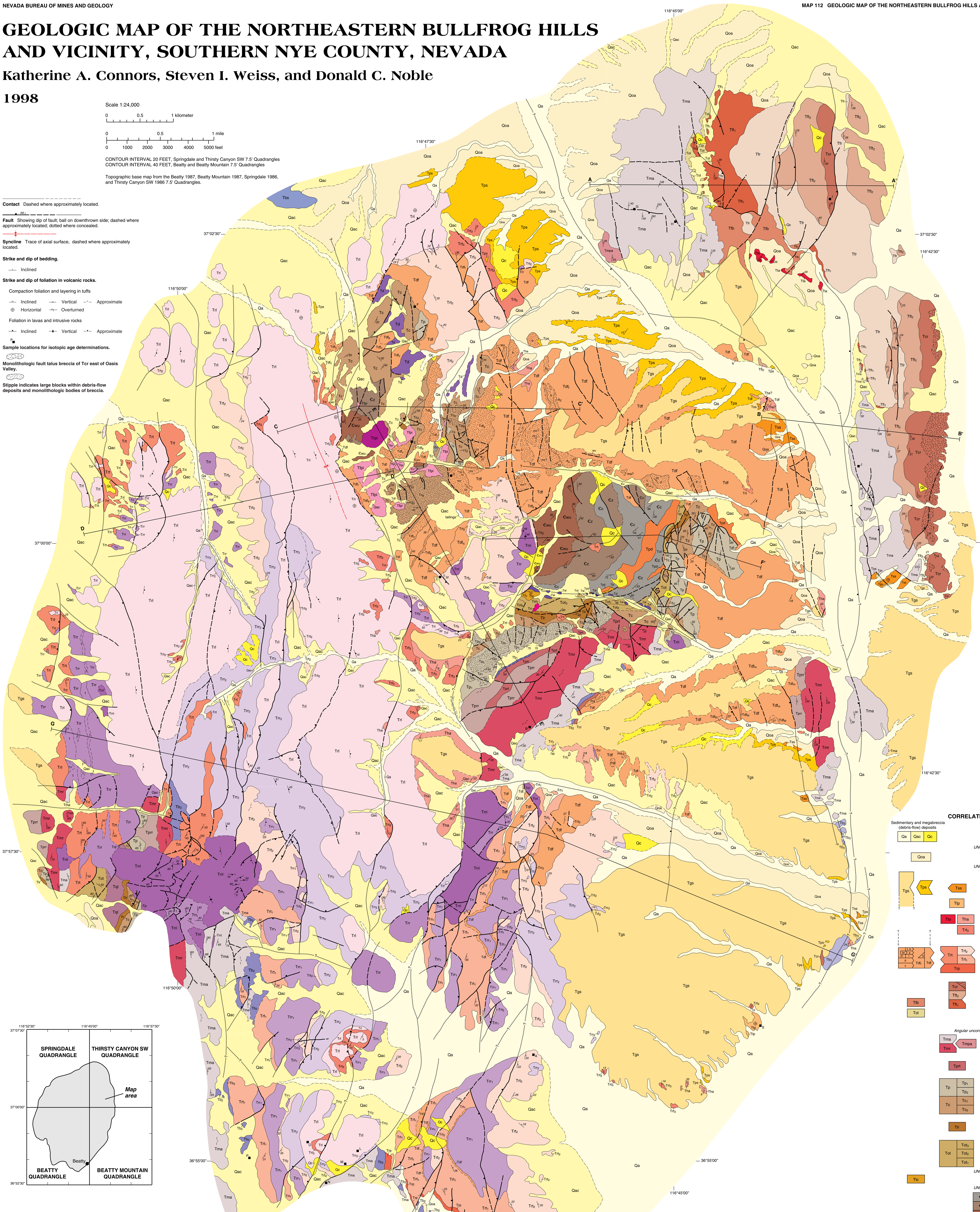
Foliation in lavas and intrusive rocks

Inclined — Vertical — Approximate

Sample locations for isotopic age determinations.

Monolithologic fault talus breccia of Tcr east of Oasis Valley.

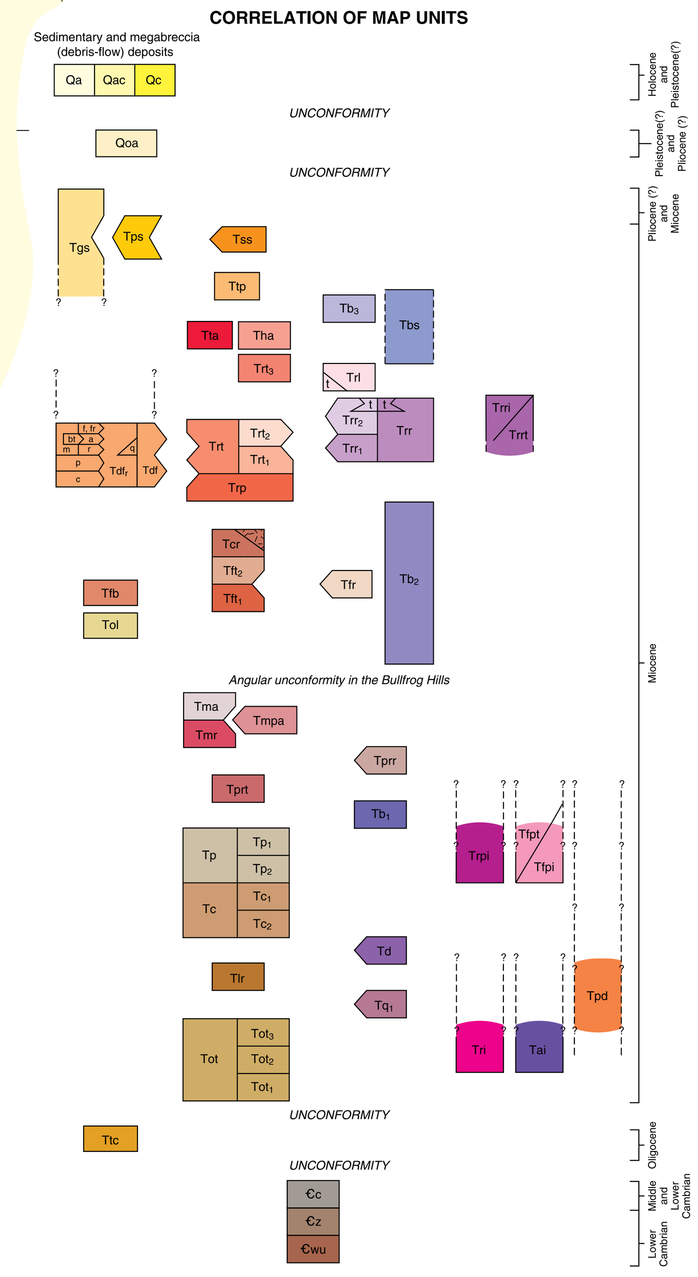
Stipple indicates large blocks within debris-flow deposits and monolithologic bodies of breccia.

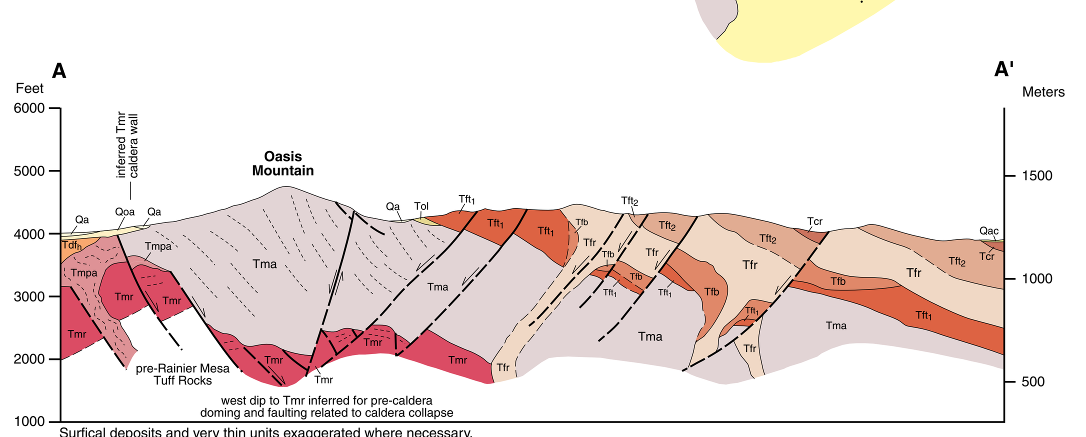


DESCRIPTION OF MAP UNITS

Qa	Alluvium (Quaternary)
Qac	Alluvium and colluvium, undivided (Quaternary)
Qc	Colluvium (Quaternary)
Qoa	Older alluvium (Quaternary)
Tgs	Gravels of Sober-Up Gulch (late Miocene and Pliocene?)
Tps	Pumiceous siltstone, sandstone, conglomerate and tuff (late Miocene)
Tss	Spearhead Member of the Stonewall Flat Tuff (late Miocene)
Ttp	Pahute Mesa Tuff of the Thirsty Canyon Group
Tbs	Basalt of Springdale Mountain (late Miocene)
Tb_3	Basalt lava flows and intrusive rocks
Tta	Air-fall tuff of Oasis Valley
Tha	Air-fall tuff of Bullfrog Hills
	Rainbow Mountain Sequence
Trt_3	Rhyolite tuff #3
Trl	Latite of Donovan Mountain
Trri	Rhyolite dikes, plugs, and stocks
Trr	Rhyolite lava flows, domes, and plugs, undivided
Trr_2	Rhyolite lava flows and domes
Trt	Rhyolite tuff, undivided
Trt_2	Rhyolite tuff #2
Trr_1	Rhyolite lava flows #1
Tdf	Debris-flow (megabreccia) deposits
Trt_1	Rhyolite tuff #1
Trp	Pyroclastic and epiclastic deposits
Tb_2	Lava flow(s) of basaltic composition
Tcr	Tuff of Cutoff Road (middle Miocene)
	Tuffs and Lava of Fleur de Lis Ranch (middle Miocene)
Tft_2	Tuff of Fleur de Lis Ranch #2
Tfr	Rhyolite lava of Fleur de Lis Ranch
Tfb	Breccia
Tft_1	Tuff of Fleur de Lis Ranch #1
Tol	Marl, sandstone, and limestone of Oasis Mountain (Miocene)
	Timber Mountain Group (middle Miocene)
Tma	Ammonia Tanks Tuff
Tmpa	Ash-flow tuff and lava
Tmr	Rainier Mesa Tuff
Tprr	Pre-Rainier Mesa lava flows
Tprt	Pre-Rainier Mesa tuff
Tb_1	Basalt lava flows (middle Miocene)
Tp	Paintbrush Group (Miocene)
Tfpi	Silicic dikes and plugs (middle Miocene)
Trpi	Rhyolite plug (middle Miocene)
Tc	Crater Flat Tuff (middle Miocene)
Td	Lava flows and flow breccia (middle Miocene)
Tlr	Lithic Ridge Tuff (middle Miocene)
Tql	Quartz latite to low-silica rhyolite(?) lava flows and flow-breccia (Miocene)
Tpd	Felsic porphyry dike (Miocene ?)
Tri	Rhyolite dike or plug (Miocene)
Tai	Porphyritic dikes of intermediate composition (Miocene)
Tot	Older ash-flow tuffs and subordinate sedimentary rocks, undifferentiated (Miocene?)
Ttc	Titus Canyon Formation (Oligocene)
Єc	Carrara Formation (Middle and Lower Cambrian)
Єz	Zabriskie Quartzite (Lower Cambrian)
Єwu	Wood Canyon Formation, Upper member (Lower Cambrian)

CORRELATION OF MAP UNITS





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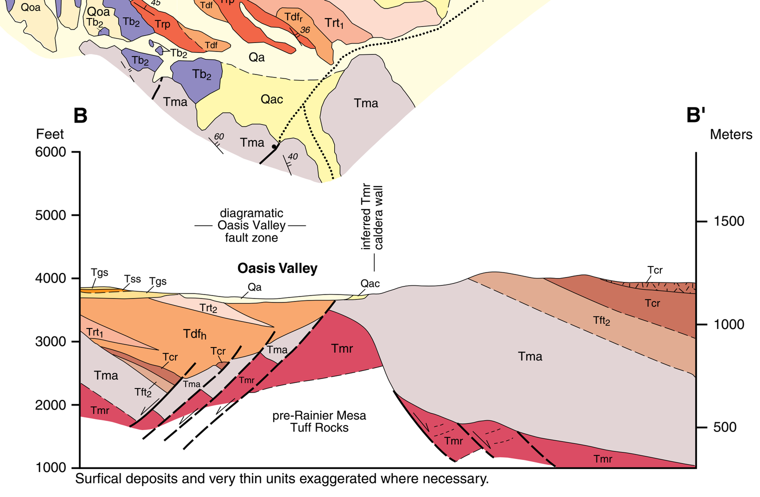

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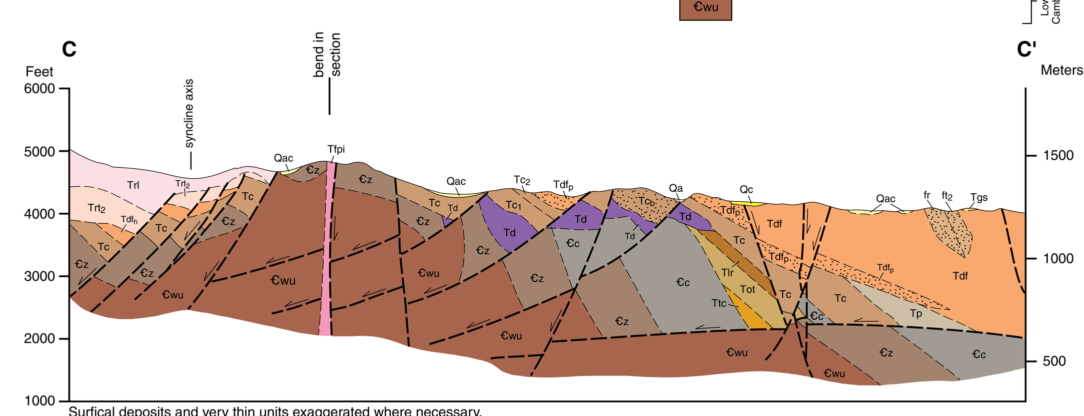

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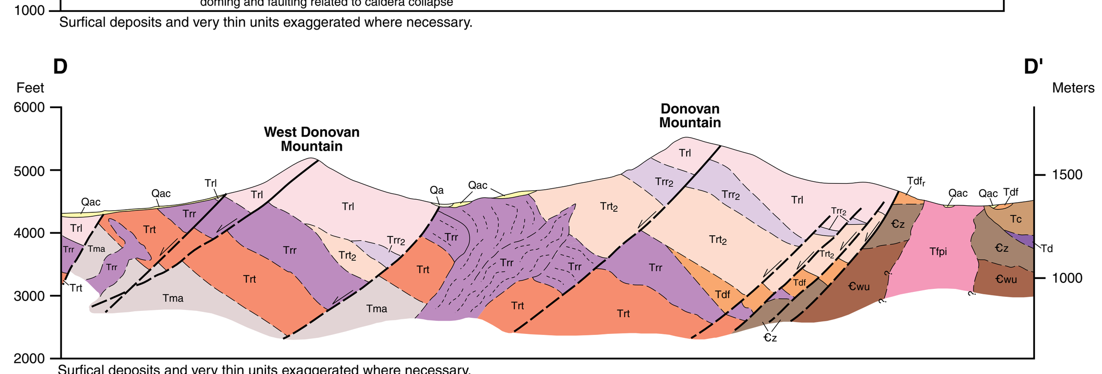

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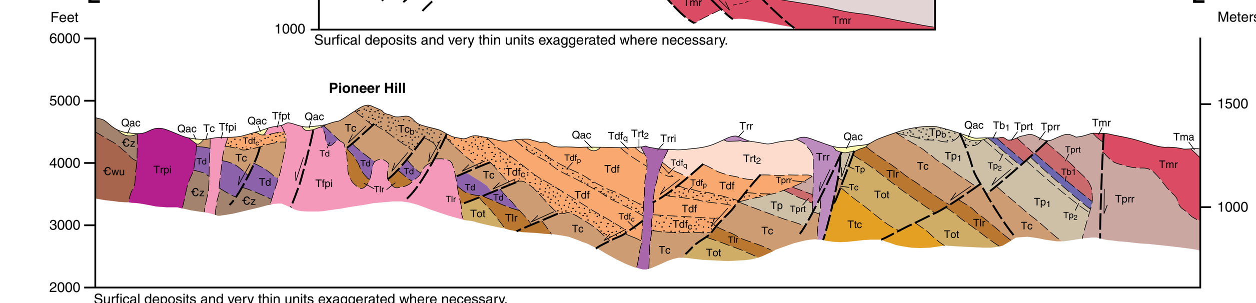

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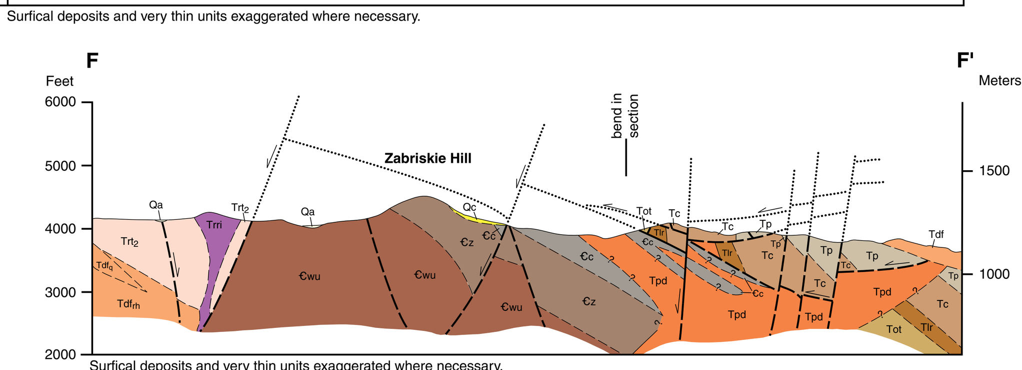

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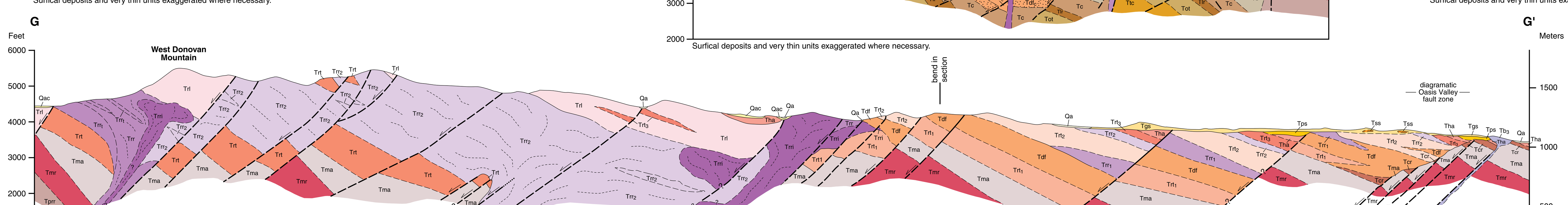

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