U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Digital geologic map of the Nevada Test Site and vicinity, Nye, Lincoln, and Clark Counties, Nevada, and Inyo County, California

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INTRODUCTION

This digital geologic map of the Nevada Test Site (NTS) and vicinity, as well as its accompanying digital geophysical maps, are compiled at 1:100,000 scale. The map area covers two 30 x 60-minute quadrangles—the Pahute Mesa quadrangle to the north and the Beatty quadrangle to the south—plus a strip of 7½-minute quadrangles on the east side (Fig. 1). In addition to the NTS, the map area includes the rest of the southwest Nevada volcanic field, part of the Walker Lane, most of the Amargosa Desert, part of the Funeral and Grapevine Mountains, some of Death Valley, and the northern Spring Mountains (Fig. 1). This geologic map improves on previous geologic mapping of the same area (Minor and others, 1993; Sawyer and others, 1995; Carr and others, 1996; Wahl and others, 1997; Fig. 2) by providing new and updated Quaternary and bedrock geology, new geophysical interpretations of faults beneath the basins, and improved GIS coverages. This publication also includes a new isostatic gravity map (Ponce and others, 1999) and a new aeromagnetic map (Ponce, 1999). Data collection, data analysis, and map compilation were funded by the U.S. Department of Energy (DOE) through Interagency Agreement DE–A108–96NV11967 between DOE and USGS.

The primary purpose of the three maps is to provide an updated geologic framework to aid interpretation of ground-water flow through and off the NTS (Laczniak and others, 1996). The NTS is centrally located within the area of the Death Valley regional ground-water flow system of southwestern Nevada and adjacent California. During the last 40 years, DOE and its predecessor agencies have conducted about 900 nuclear tests on the NTS, of which 100 were atmospheric tests and the rest were underground tests (Laczniak and others, 1996). More than 200 of the tests were detonated at or beneath the water table, which commonly is about 500 to 600 m below the surface. Because contaminants introduced by these tests may move into water supplies off the NTS, rates and directions of ground-water flow must be determined. Knowledge about the ground water also is needed to properly appraise potential future effects of the possible nuclear waste repository at Yucca Mountain, adjacent to the NTS. Furthermore, we need to determine the effects of the withdrawal of ground water from upstream parts of the flow system on water levels and thus endangered animal and plant species in springs in downstream areas such as Devils Hole and Death Valley. The overall study is part of a closely coordinated effort by the Geologic Division and Water Resources Division of the USGS, in cooperation with other Federal, State, and county agencies and private contractors (Laczniak and others, 1996; Leahy and Lyttle, 1998; Rowley and others, 1998, 1999; Trudeau and Rowley, 1998; D'Agnese and Faunt, 1999; Faunt and others, 1999). Map compilation is by the Geologic Division, whereas the Water Resources Division uses standard hydrologic methods to study ground-water flow.

Compilation of the surficial geology in the southern half (Slate and Berry, 1999) and eastern 7½-minute strip of the map area deserves special mention because this is the major revision to the previous map of Wahl and others (1997). Contacts of surficial units in the southern half were mapped using 1:80,000-scale diapositive-film air photos, which have significantly better resolution than paper prints at the same scale. Digital files of the contacts were made using a computerized photogrammetric mapping system that consists of *Carl Zeiss Inc.* CADMAP® software and a digital *Kern* model PG-2 stereoplotter. A stereo pair of air photos was mounted on the PG-2 and scaled to the map base. The 1:24,000 digital topographic base came from DLG (digital line graph) files or scanned clear-film positives, where DLG's were not available. We merged the topographic base with the Quaternary-bedrock contacts from Wahl and others (1997) to create a background file. Previously mapped Quaternary geology that was available digitally (see Slate and Berry, 1999) was transferred into the computerized system as an active (editable) layer. This system enabled us to (1) save time and reduce error by eliminating the steps needed to convert data from analog to digital format, and (2) evaluate preexisting geologic mapping while viewing the area in stereo.

Responsibility of the authors is as follows. Slate and Berry did the majority of the Quaternary geologic mapping and compilation; Williams mapped surficial geology in four-and-a-half quadrangles. Rowley and Dixon revised the bedrock geology and map-unit descriptions of Wahl and others (1997), interpreted geophysically based faults, revised caldera boundaries, and initiated and supervised the project. Fridrich and Minor mapped bedrock in nine quadrangles in the central western portion of the map area; Minor also revised bedrock geology of parts of the Pahute Mesa 30 x 60-minute quadrangle. Morgan,

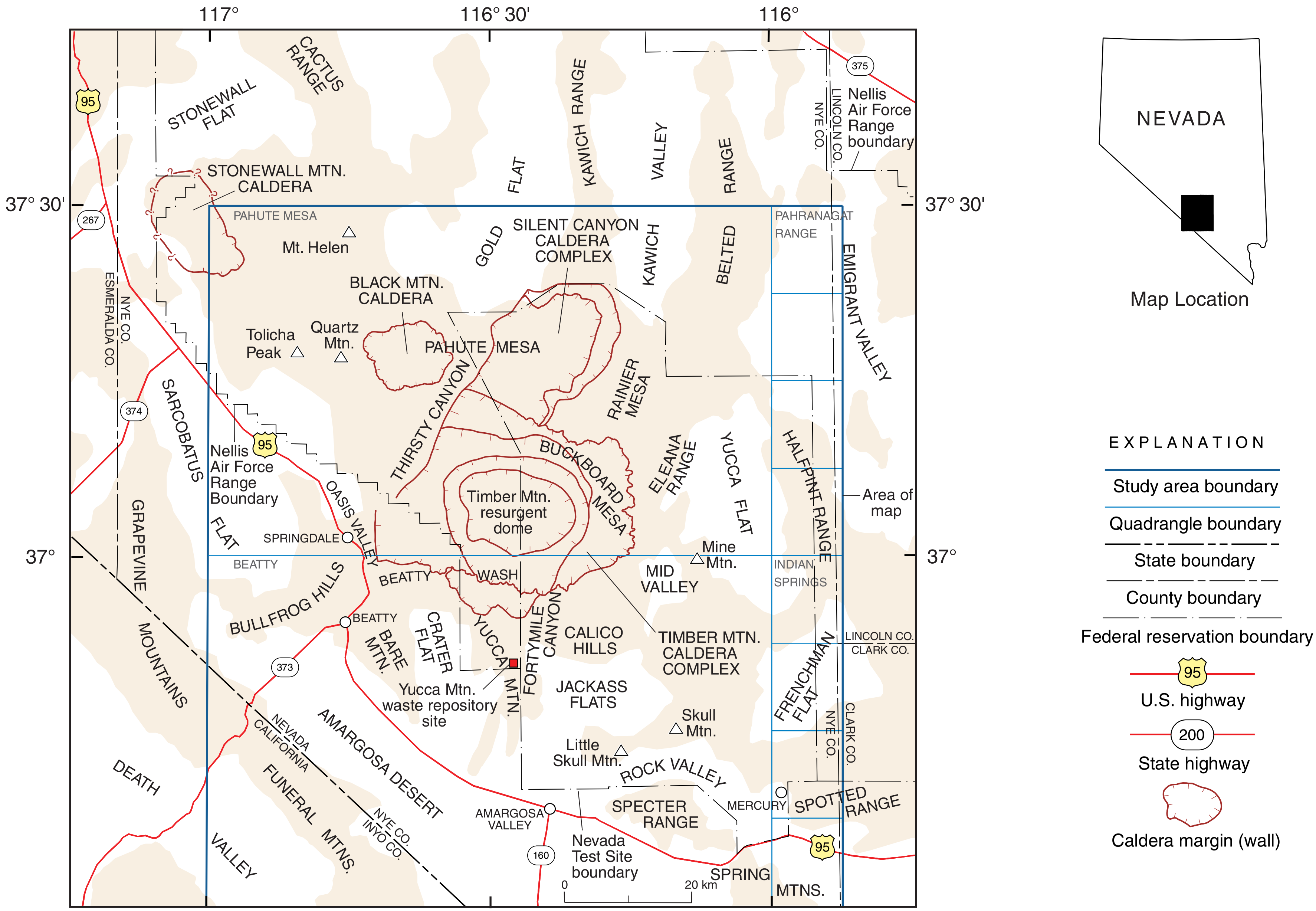

Figure 1. Location map showing the setting of the Nevada Test Site digital geologic map (heavy outer line), which comprises the Pahute Mesa 30 x 60-minute quadrangle on the north and the Beatty 30 x 60-minute quadrangle on the south, plus a one-quad wide strip of 7½-minute quadrangles to the east.

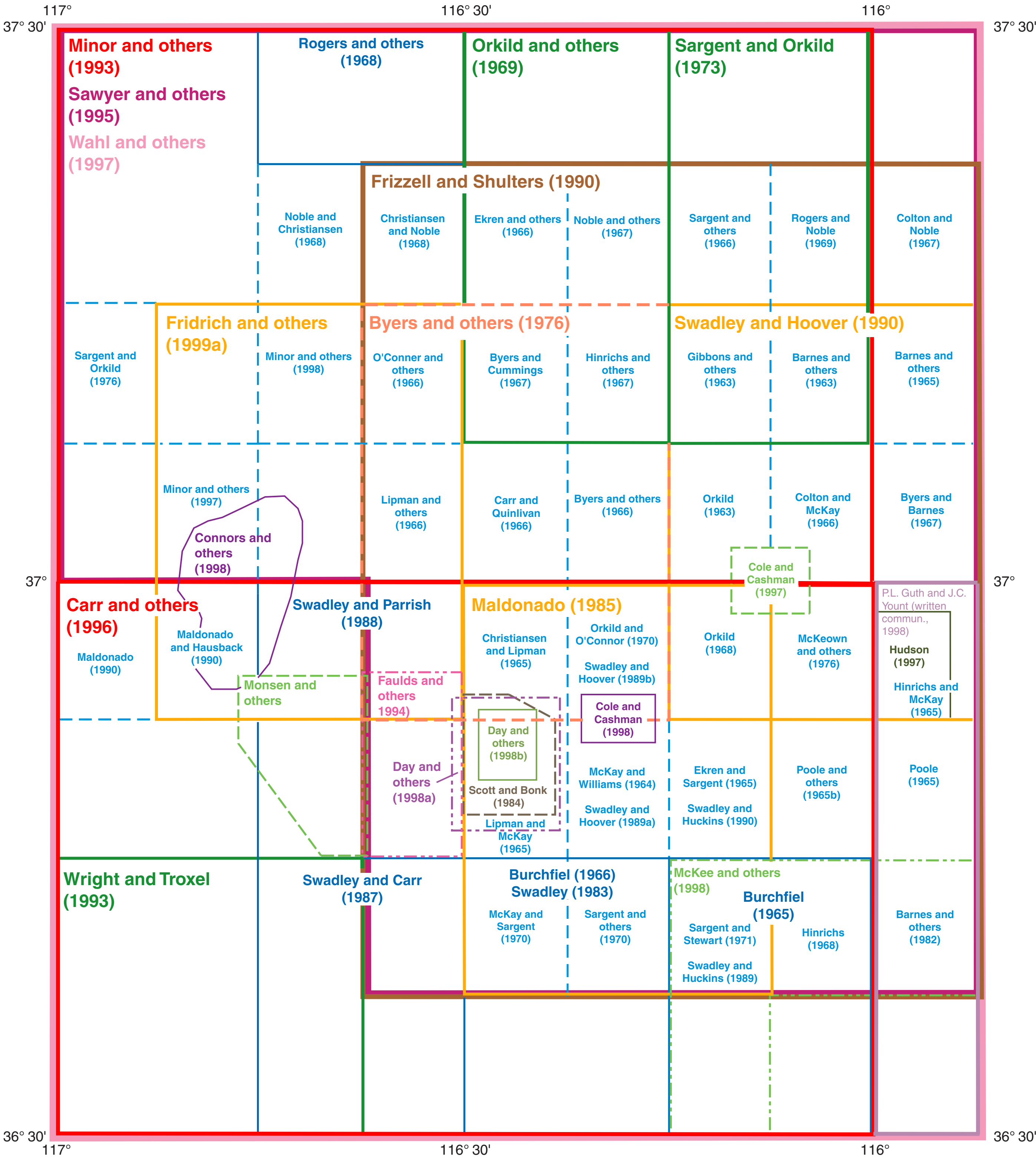

Figure 2. Index map to main sources of data used in compiling the geologic map of the Nevada Test Site area.

Workman, Young, Grunwald, and Laczniak did the digital cartography; Workman also wrote the metadata. Swadley initiated compilation of the Quaternary geology on a portion of the Beatty 30 x 60-minute quadrangle. Lundstrom provided unpublished, digital Quaternary mapping of six quadrangles along a north-south swath in the central portion of the Beatty 30 x 60-minute quadrangle and most of one quadrangle in the southeastern corner of the map. McKee, Ponce, Hildenbrand, and Ekren contributed to interpretations of geophysically based faults and caldera boundaries. Warren and Sawyer described petrographic data and made stratigraphic assignments on which the description of map units is partly based. Cole revised the pre-Tertiary map unit descriptions, and edited bedrock geology of two quadrangles. Fleck, Lanphere, and Sawyer provided new $^{40}Ar/^{39}Ar$ ages. Menges updated depiction of Quaternary faults in the Yucca Mountain area. We adapted unpublished compilations of the Quaternary geology along the western strip of Indian Springs (Yount) and Pahranagat Range (Jayko).

DESCRIPTION OF MAP UNITS

[All volcanic units in the mapped area belong to the southwest Nevada volcanic field (Christiansen and others, 1977), except some pre-15.5-Ma tuffs and other eruptive units derived from distant sources. Figure 1 gives the geographic locations referred to herein. Figure 2 shows main sources of geologic map data. Classifications of volcanic and plutonic rocks are those of IUGS (Le Bas and others, 1986, and Streckeisen, 1976, respectively). Stratigraphic terminology, unless stated, follows Sawyer and others (1994). Subsurface (dotted) traces of some faults shown, including the Carpetbag Fault and Belted Range Thrust in and near Yucca Flat are based on borehole data. Sawyer and others (1994) summarized isotopic ages of units and provided most of the estimates given below of eruptive volumes (as dense rock equivalents) of major volcanic rock units. Where necessary, isotopic ages given here have been recalculated using the IUGS decay constants (Steiger and Jager, 1977). Most magnetic polarities and mineralogies given below are from data from M.R. Hudson (U.S. Geological Survey) and R.G. Warren (Los Alamos National Laboratory), respectively, as cited in Wahl and others (1997). Phenocryst abundances given below are median values determined by Warren and others (1998) by point counting thin sections of samples collected throughout the southwest Nevada volcanic field.

We mapped three alluvial units (Qay, Qai, and QTa), three eolian units (Qed, Qey, and Qeo), two playa units (Qp and Qps), lacustrine beach deposits (Qlb), travertine (Qt), and Quaternary-Pliocene undifferentiated surficial deposits (QTu), colluvium (QTc), and marl (QTm). Alluvial units include deposits from multiple periods of deposition that were not mapped separately because of map scale. Additionally, units may include other surficial deposits that are too small to be shown as separate polygons, or so thin that surface characteristics are controlled by the underlying (mapped) unit. Because of the time constraints of this project, our mapping was principally based on air photo interpretation. We used surface morphology, tone, relative height, and map pattern to differentiate among the alluvial units. The geomorphic attributes of the alluvial units, which make up about 90 percent of the Quaternary part of the map area, are as follows:

Quaternary Alluvial Unit	Surface Morphology	Tone (on air photos)	Relative Height	Map Pattern
Qay – Young alluvial deposits (Holocene)	Bar-and-swale near range fronts; braided sand plains in basins	Light, in general, due to no or little rock varnish; can appear variegated	Lowest where surfaces are incised	Emanate from fan apices; form active channels
Qai – Intermediate alluvial deposits (early Holocene? and Pleistocene)	Planar, smooth appearance; locally dissected	Dark, in general, due to accumulation of rock varnish	Intermediate; higher than Qay, but lower than QTa	Progressively older units flank younger units
QTa – Old alluvial deposits (middle to early Pleistocene and Pliocene?)	Typically ballena (whaleback form), locally planar	Light, in general, due to erosional exposure of soil-carbonate horizon	Highest where surfaces are incised	Older units typically preserved close to the range fronts

These attributes are highly generalized. Surface morphology is a product of both depositional and post-depositional processes. Stream flows, debris flows, or some combination of the two are the main processes that deposit alluvial units. Post-depositional processes include weathering, eolian additions (surface accretion), winnowing by wind (deflation), reworking and erosion by water, creep, and bioturbation. Nevertheless, the variation in alluvial surface morphology with age aids in the mapping and correlation of geomorphic surfaces (Bull, 1991, among others). Lithologic variations across the map area influence the tone of the alluvial units. Although young alluvial units are often light-toned due to an absence or paucity of rock varnish, they may appear dark where the source rocks are dark. Lithology also influences the development of rock varnish; fine-grained or aphanitic rocks, such as quartzite or basalt, tend to become varnished more quickly than rocks such as limestone or granite. Granite commonly disaggregates to grus before becoming varnished. Relative height (topographic position) is useful for mapping in individual drainage basins near range fronts, but basinward, especially in tectonically inactive areas, most surfaces grade to the same base level, and relative height differs little among the alluvial units. Faulting—both the magnitude and location—also affects the map pattern of alluvial units. As faulting uplifts ranges relative to the basins, streams adjust to new base levels, abandoning and incising older alluvial units, thus preserving them. In tectonically inactive areas, streams continue to grade to the same level or aggrade, thus burying older alluvial units. Therefore, map pattern of Quaternary units is an important tool to evaluate late-phase basin evolution.

The following conventions are used in the map unit descriptions of surficial deposits. Stages of secondary calcium-carbonate morphology are those of Gile and others (1966). Soil horizon designations are those of the Soil Survey Division Staff (1993). Grain sizes for surficial deposits are based on visual estimates and follow the modified Wentworth grade scale (American Geological Institute, 1982). Dry colors of the less-than-2-mm fraction of the surficial deposits were determined by comparison with Munsell Soil Color Charts (Munsell Color Company, 1988)]

SURFICIAL DEPOSITS

Qay **Young alluvial deposits (Holocene)**—Gravel, sand, and silt; intermixed and interbedded. Grayish brown, pale yellowish brown, light brownish gray to light gray, unconsolidated to poorly consolidated, poorly to moderately well sorted, nonbedded to well bedded, locally cross-bedded. Clasts are commonly angular to subrounded; locally well rounded. Clasts commonly less than 0.5 m in diameter, but as much as 2 m in diameter at and near base of steep slopes, and close to mountain fronts. Along large alluvial channels, such as Fortymile Wash, boulders are found several kilometers from the mountain front. Sand and silt present as matrix and lenses; rarely form continuous beds. Surface commonly is irregular; bar-and-swale topography and braided channels are common. In places, forms extensive thin sheets of sand with flat, smooth surfaces. Little or no pavement, varnish, or soil development except near dust sources. Maximum thickness about 10 m

Qey **Young eolian sand deposits (Holocene)**—Silty fine to medium sand, pale yellowish brown to yellowish gray, well sorted, massive to poorly bedded; locally includes a few cobbles and pebbles near bedrock outcrops. Forms sheets, ramps, and vegetation-stabilized mounds. Along Fortymile Wash, this unit overlies a low (2 to 3 m high), inset terrace of late Pleistocene age (Lundstrom and others, 1998). Thickness probably less than 10 m

Qed **Eolian dune sand deposits (Holocene)**—Silty fine to medium sand, pale yellowish brown to yellowish gray, well sorted. Forms a dune complex at Big Dune in the Amargosa Desert, south-central part of mapped area. Thickness as much as 80 m

Qp **Playa deposits (Holocene)**—Silt, fine sand, and clay; poorly to moderately well consolidated, light grayish brown, calcareous, moderately well sorted, thinly bedded, polygonal desiccation cracks common. Locally contains sparse thin beds or lenses of pebbly coarse sand. Composed of illite and montmorillonite (50 percent), feldspar, quartz, and amorphous material (glass?) in Yucca Flat, east-central part of mapped area (McKeown and others, 1976). Locally at least 20 m thick

Qps **Saline playa deposits (Holocene)**—Silt, fine sand, and clay; white to light-gray and light-brownish-gray, gypsiferous and calcareous, moderately well sorted, thinly bedded. Includes sandy playa or lake deposits, gypsum and other sulfate salts, sodium carbonate and other carbonate salts, and rock salt (Hunt and Mabey, 1966; Wright and Troxel, 1993). Present in Cotton Ball Basin (floor of north-central Death Valley). Drilled thickness 186 m at Badwater (about 30 km south of the mapped area) in Death Valley (Lowenstein and others, 1999); thickness probably less in the mapped area

Qlb **Lacustrine beach deposits (Holocene and late Pleistocene)**—Two ages of pebbly sand beach deposits are recognized. Deposits of late Pleistocene pluvial lakes form low discontinuous sand ridges near the playas within the mapped area. Sand is yellowish gray, moderately sorted, mostly medium to coarse, weakly consolidated, slightly pebbly. Ridges are 1 to 3 m high, commonly covered with a pebble to coarse-sand lag; surface clasts have a weakly developed desert varnish. One Holocene beach ridge was mapped at the east edge of the Gold Flat playa, north-central part of mapped area. Deposit consists of grayish-orange, thinly crossbedded, unconsolidated, slightly pebbly, calcareous sand. Ridge is about 2 m high and is sparsely covered with a pebble-gravel lag. Thickness less than 3 m

Qt **Travertine and tufa deposits (Holocene and Pleistocene)**—White to light gray to brown, hard to semi-friable, fine grained. Spring-generated calcium carbonate that contains scattered grains of sand and silt. Mapped mostly along the southwest range front of the Funeral Mountains. Thickness generally less than 3 m but locally greater

QTc **Colluvium (Holocene, Pleistocene, and Pliocene)**—Angular to subangular granule- to boulder-sized clasts with variable amounts of sand, silt, and clay as matrix. Generally unsorted and nonbedded to poorly bedded; locally cemented by carbonate. Matrix probably partly of eolian origin. Forms talus deposits and thin mantles of debris along flanks and bases of steep slopes; deposited by rainwash, sheetwash, creep, and mass-wasting processes. Colluvium-mantled surfaces commonly have ribbed or fluted appearance due to gullying and development of stony surface lags. Locally includes bedrock outcrops too small to map separately. Most deposits are probably of Holocene to middle Pleistocene age. In upper Fortymile Canyon, unit includes large blocks of bedrock (greater than 10 m thick) that have slumped into the canyon. Thickness varies, but generally less than 3 m

QTu **Undifferentiated surficial deposits (Holocene, Pleistocene, and Pliocene)**—Gravel, sand, silt, and clay; light gray, light brownish gray, yellowish brown to grayish brown; poorly to moderately well sorted; poorly to well bedded. Includes alluvium, colluvium, and eolian deposits that could not be differentiated from bedrock on aerial photos but were mapped as Quaternary by previous workers. Thickness probably 1 to 3 m and locally less than 1 m

Qai **Intermediate alluvial deposits (early Holocene? and Pleistocene)**—Gravel, sand, and silt; intermixed and interbedded, light gray, pinkish gray, and yellowish to grayish brown, weakly to moderately well consolidated. Clasts are unsorted to moderately well sorted, nonbedded to well bedded, angular to rounded. Clasts commonly less than 0.5 m in diameter, but locally as much as 2 m in diameter; matrix is sandy to silty. Sand is discontinuously to moderately well bedded, locally crossbedded, moderately well sorted; commonly gravelly and locally silty. Surface is planar with moderately packed to densely packed pavement; pavement clasts are moderately to well varnished. In places, thin eolian sand deposits mantle the surface. Soil development varies from a cambic B horizon and a stage I to II carbonate horizon to an argillic B horizon and an approximately 1-m-thick, stage III to IV carbonate horizon. Thickness less than 1 m to 10 m

Qeo **Old eolian sand deposits (Pleistocene)**—Silty fine to medium sand, very pale orange to yellowish or grayish brown, well sorted, massive to poorly bedded. Locally includes cobbles and pebbles near bedrock outcrops that may form a loosely to densely packed pavement of angular clasts. Unit forms large sand ramps flanking bedrock hills along the edge of the Amargosa Desert. Includes varying amounts of eolian sand reworked by slopewash and intermittent streams. Buried soils separate superimposed eolian deposits that form sand ramps in the Yucca Mountain area. Soils formed in these deposits consist of a 1- to 2-m thick, stage III to IV carbonate horizon (Swadley and Carr, 1987). Volcanic ash, identified as the Bishop (Izett, 1982, p. 34, *in* Swadley and Carr, 1987), is present within the unit, 7 km west of Yucca Mountain. Thickness as much as 30 m

QTa **Old alluvial deposits (middle to early Pleistocene and Pliocene?)**—Gravel, sand, and silt; intermixed and interbedded, light brownish gray to light gray. Clasts are angular to subrounded, clasts more than 1 m in diameter are common at and near base of steep slopes. Generally poorly sorted, nonbedded to poorly bedded, and moderately to well cemented with carbonate. Locally consists of moderately well bedded, poorly to moderately well-sorted pebble to cobble gravel in a sand and silt matrix. Surface is eroded and dissected; commonly forms rounded ridges or ballenas. Where preserved, pavement is generally moderately to densely packed and includes tabular fragments cemented by pedogenic carbonate and opaline silica; varnish on pavement clasts is variable but commonly strongly developed. Soils typically consist of a stage III to IV carbonate horizon as much as 2 m thick; argillic horizons, where present, postdate much of the erosion. Thickness may be greater than 40 m

QTm **Marl deposits (Pleistocene and Pliocene)**—Marl, pale yellowish brown, weathers white to very light gray, silty to sandy, soft, plastic when wet. Consists of calcite, various clay minerals, quartz and opaline silica, silt, and sand-sized rock fragments. Includes several thin chalk beds as much as 1 m thick and discontinuous beds of small, irregular limestone nodules. Unit includes yellowish-gray to grayish-orange, locally calcareous silt, in part clayey; mostly unconsolidated; locally interbedded with sandy marl. Locally contains sparse to common pencil-sized calcareous cylinders that probably represent calcified plant stems. This unit is thought to represent deposits and precipitates formed in areas of ground-water discharge, including paludal environments. Reported ages range from Pleistocene (>200 to 90 ka and 60 to 15 ka; Paces and others, 1997) to Pliocene (3.8 to 2.1 Ma based on fission-track and K-Ar ages on interbedded ash; Swadley and Carr, 1987; Marvin and others, 1989). In the Amargosa Desert, exposed thickness as much as 50 m (Hay and others, 1986), but the base of the unit is not exposed

BEDROCK UNITS

Qbu **Youngest basalt (Pleistocene)**—Isolated, generally resistant, black and reddish-brown, scoria cinder cones, lava flows, and feeder dikes from two centers in northern Oasis Valley and one center north of the town of Amargosa Valley (formerly known as Lathrop Wells). Rock composition is mainly crystal-poor trachybasalt containing sparse phenocrysts of olivine and subordinate plagioclase. Distinguished by relatively uneroded geomorphic expression, young isotopic ages, low phenocryst abundance (about 2 percent of rock volume), a predominance of olivine, and normal magnetic polarity. Whole-rock K-Ar ages for basaltic centers at Hidden Cone and Little Black Peak, north of Oasis Valley (Crowe and others, 1995; Minor and others, 1998), are about 350 ka (Fleck and others, 1996). A youthful cinder cone and underlying flows that make up the basalt of Lathrop Wells (Swadley and Carr, 1987) have been well studied because it is only 20 km from the proposed nuclear waste repository at Yucca Mountain. Dates on the volcanic center range predominantly between 140 and 70 ka (Crowe and others, 1995; Turrin and others, 1991, 1992; Fleck and others, 1996; Heizler and others, 1999). Maximum thickness about 200 m

Qbl **Basalt of central Crater Flat (Pleistocene)**—Moderately dissected cinder cones, lava flows, and feeder dikes and plugs of moderately resistant, black to dark-reddish-brown, olivine basalt in the central and western parts of Crater Flat (Faulds and others, 1994). Four eruptive centers form an arcuate, northwest-trending alignment. Whole-rock K-Ar ages are about 1.9 to 0.7 Ma, with a best estimate of 1.1 Ma (Fleck and others, 1996). Magnetic polarity of the rocks is reversed (Rosenbaum and Snyder, 1984). Thickness at least 200 m

QTgf **Funeral Formation (lower Pleistocene? and upper Pliocene)**—Mostly poorly consolidated, tan and gray fanglomerate that locally intertongues with unconsolidated and poorly consolidated, pink and white, silty lacustrine sediments (Wright and Troxel, 1993), basalt and basaltic agglomerate (McAllister, 1973). Clast types vary depending on local provenance; Cambrian and Precambrian quartzose sedimentary rocks were derived from the Funeral Mountains. Age ranges from 5.2 Ma (fission track on tuff; Topping, 1993) to 1.92 to 1.86 Ma (lower Glass Mountain tuff; Knott and others, 1999). A whole-rock K-Ar age of 4.1 Ma was obtained from basalt in the central Black Mountains (south of the mapped area) that intertongues with the map unit (McAllister, 1973). Generally flat lying to gently tilted at the type locality in eastern Furnace Creek Wash; however, significantly tilted and faulted in the immediate vicinity of faults. Unit rests with angular unconformity on older rocks in Furnace Creek Wash, and south of the mapped area in Mud Hills, eastern and southern Black Mountains, and Artists Drive. In fault contact at Mormon Point, south of mapped area. Thickness probably at least 600 m (Wright and Troxel, 1993)

Typ **Basalt of Thirsty Mountain and other areas (Pliocene)**—Moderately dissected, basaltic trachyandesite cinder cones, lava flows, and feeder dikes that make up three volcanic centers in the map area. These are a shield volcano at Thirsty Mountain (north-northeast of Oasis Valley), a mesa-like volcanic edifice on Buckboard Mesa, and a fissure-vent and flow complex in southeastern Crater Flat. Rocks consist of resistant, dark-gray to dark-reddish-brown, lava flows and scoria mounds that contain moderately abundant to sparse phenocrysts of olivine and plagioclase, with subordinate clinopyroxene. Most rocks in Crater Flat erupted from a north-striking fissure (Faulds and others, 1994). Fleck and others (1996) reported whole-rock K-Ar ages that cluster around 4.6 Ma at Thirsty Mountain, 2.9 Ma at Buckboard Mesa, and 3.7 Ma in Crater Flat. Magnetic polarities of the rocks from Thirsty Mountain and Crater Flat are reversed, whereas those from Buckboard Mesa are normal. Maximum thickness at least 200 m at Thirsty Mountain and about 100 m at the other localities

Tgy **Basin-fill sediments, undivided (Pliocene and upper Miocene)**—Poorly consolidated, poorly sorted, poorly to moderately well bedded, light-gray, light-orange, and light-tan, angular to rounded sandy gravel and gravelly sand in a locally tuffaceous matrix. Tuffaceous material and interbeds of landslide breccia are more common in older parts of the unit. Generally coarse grained and of alluvial fan origin, with some clasts as large as 5 m. Locally contains fine-grained deposits (mostly of playa origin) of tuffaceous sandstone, mudstone, and marl. Unit combines deposits that have gone by many informal stratigraphic names and that were deposited over a broad span, with different ages in different places, during extension associated with basin-range faulting. Everywhere younger than the 11.6-Ma Rainier Mesa Tuff (Tmr) and locally as young as middle Pliocene based on the volcanic units they are interbedded with; the oldest of these intertonguing units is the rhyolites of Twisted Canyon (Tmtc) and the youngest is the basalt of Thirsty Mountain and other areas (Typ). Includes deposits west of Sarcobatus Flat, northwest of Tolicha Peak, on Little Skull Mountain, and in the Halfpint Range that were split out separately by Carr and others (1996) and Wahl and others (1997) as the "late synvolcanic sedimentary rocks" (Tgm). Some of these deposits are interbedded with tuffs and basalts synchronous with the Thirsty Canyon Group (called here basalt of Black Mountain, Ttb), but some (conglomerate of Sargent and others, 1970) predate intermediate-age basalt (Tft).

Upper parts of the unit generally untilted and only slightly faulted, but lower parts are locally tilted as much as 20 degrees and significantly faulted. In northern Crater Flat and the Bullfrog Hills, the unit ("gravel of Sober-up Gulch" of Maldonado and Hausback, 1990, and Monsen and others, 1992) contains beds of volcanic ash that yielded K-Ar ages of 8.7 to 7.7 Ma (Monsen and others, 1992). In the Beatty Wash area, basal parts of the map unit are locally interbedded with the 11.55-Ma rhyolite of Tannenbaum Hill (Tmat) and upper parts of the map unit are locally interbedded with the 7.5-Ma Spearhead Member (Tsp) of the Stonewall Flat Tuff. In lower Thirsty Canyon, parts of the unit are locally interbedded with 4.6-Ma flows of the basalt of Thirsty Mountain and other areas (Typ) (Minor and others, 1998). Along Fortymile Wash in northwestern Jackass Flats, this deposit, which contains a 7.5-Ma ash, is inferred to predate the inception of the throughgoing Fortymile Canyon (Lundstrom and Warren, 1994). The unit is probably under Yucca Flat, but included with Tertiary volcanic rocks in the estimate of basin thickness provided by Phelps and others (1999). Maximum thickness at least 300 m

Tgfc **Furnace Creek Formation (lower Pliocene and upper Miocene)**—Mostly poorly consolidated, tan and gray fanglomerate that locally intertongues with unconsolidated silty lacustrine sediments (Wright and Troxel, 1993). Derived from reworked older Tertiary gravels such as those in the upper plate of the Boundary Canyon fault, northern Funeral Mountains. Fleck (1970) and Cemen and others (1985) reported K-Ar ages of 6.5 and 5.5 Ma from volcanic beds in the unit in the Dantes View area, about 25 km south of the mapped area. Diatoms of Hemphillian age were reported from the upper part of the formation in the Furnace Creek area of Death Valley (McAllister, 1970). The base of the unit is probably no older than about 8 Ma. Unit rests in angular unconformity on underlying rocks. Thickness probably at least 2,000 m (Wright and Troxel, 1993)

Tgc **Caldera moat-filling sediments (Miocene)**—Poorly to moderately consolidated, mostly gray, poorly sorted, poorly to moderately well bedded, angular to subrounded, sandy gravel, sand, and minor silt in a locally tuffaceous matrix. Fan alluvium and subordinate lacustrine deposits and nonwelded tuff. Clasts, as large as 1 m, consist of locally derived volcanic rocks. Lacustrine deposits include interbedded, partly tuffaceous sandstone, mudstone, and water-laid tuff. Unit represents deposits that filled low moat parts of the Stonewall Mountain caldera, Black Mountain caldera, Timber Mountain caldera complex, and Claim Canyon caldera (Minor and others, 1993; Sawyer and others, 1995; Carr and others, 1996; Wahl and others, 1997). In the Black Mountain moat, these deposits underlie the Spearhead Member of the Stonewall Flat Tuff (Tsp; 7.5 Ma) and overlie the Gold Flat Tuff (Ttg, 9.15 Ma) (Minor and others, 1998). In the Timber Mountain moat, these deposits underlie the basalt of Buckboard Mesa (unit Typ; 2.9 Ma), overlie the Ammonia Tanks Tuff (Tma; 11.45 Ma), and intertongue with the Trail Ridge Tuff (Ttt; 9.3 Ma), Pahute Mesa Tuff (Ttp; 9.4 Ma), rhyolite of Shoshone Mountain (Tfs; 10.3 Ma), and lava flows of Dome Mountain (Tfd) (Byers and others, 1966; symbols and ages are those given herein). Maximum thickness about 300 m

Stonewall Flat Tuff (Miocene)—Peralkaline ash-flow tuff derived from the Stonewall Mountain caldera, part of which lies in the northwestern corner of the mapped area (Noble and others, 1984; Weiss and Noble, 1989). Consists of two members that generally contain abundant pumice and lithic fragments and locally exhibit rheomorphic flow foliation. Volcanism in and near the Nevada Test Site is progressively younger in a northwest direction (Sawyer and others, 1994), and this caldera is the youngest major eruptive center of this northwest trend in the mapped area

Tsc Civet Cat Canyon Member—Moderately resistant, light-gray, light-purplish-brown, and reddish-brown, nonwelded to densely welded, mostly crystal-poor (2 to 25 percent phenocrysts) ash-flow tuff that is compositionally zoned. Its volume is about

40 km^3. Its composition grades from an upper part that consists of crystal-rich trachyte made up of alkali feldspar (anorthoclase and sodic sanidine) and subordinate plagioclase, biotite, clinopyroxene, and orthopyroxene into a lower part that consists of crystal-poor comendite made up of alkali feldspar and rare clinopyroxene, plagioclase, and fayalitic olivine. $^{40}Ar/^{39}Ar$ age is 7.54 Ma (Hausback and others, 1990). Reversed magnetic polarity. Maximum thickness of outflow deposits about 180 m; intracaldera tuff at least 300 m thick northwest of the mapped area

Tsp — Spearhead Member—Moderately resistant, light-brown and light-gray nonwelded to light- to medium-reddish-brown densely welded, crystal-poor (median 3 percent by volume) ash-flow tuff that is compositionally zoned. It has a volume of about 80 km^3. Its composition grades from an upper part that consists of comendite into a lower part that consists of more crystal-poor comendite. Median amounts are about 2 percent alkali feldspar, less than 0.5 percent each of plagioclase, quartz, and clinopyroxene, and trace amounts of fayalitic olivine, biotite, and hornblende. The upper zone is only locally present. Unit locally intercalated in the basin-fill sediments, undivided (Tgy). $^{40}Ar/^{39}Ar$ age is 7.61 Ma according to Hausback and others (1990) and 7.5 Ma according to Sawyer and others (1994). Normal magnetic polarity. Maximum thickness 50 m

Tsr — **Rhyolite of Stonewall Mountain (Miocene)**—Resistant, mostly red, crystal-rich, flow-foliated rhyolite lava flows and volcanic domes that adjoin the Stonewall Mountain caldera. Contains abundant biotite and subordinate sanidine, plagioclase, and clinopyroxene. Thickness at least 200 m

Trsf — **Rhyolite of Sarcobatus Flat (Miocene)—**Poorly to moderately resistant, gray, yellowish-brown, and light-red, aphyric to crystal-poor, flow-foliated, locally spherulitic rhyolite lava flows and subordinate related pyroclastic and sedimentary rocks. Exposed in the Sarcobatus Flat area and deposited synchronously with initial structural opening of Sarcobatus Flat basin. Formerly called the rhyolite lava flows of Rainbow Mountain and the ash-fall tuffs of Rainbow Mountain by Maldonado (1990). Contains phenocrysts of sanidine, quartz, plagioclase, biotite, and hornblende. Map unit includes the rhyolite of Obsidian Butte of Wahl and others (1997), some flows of which contain about 1 percent phenocrysts consisting of about 1 percent plagioclase, less than 0.5 percent quartz and sanidine, and traces of biotite. The rhyolite of Obsidian Butte contains locally bedded, pumice- and lithic-rich tuff, tuff breccia, and reworked tuff, as well as well-bedded tuffaceous sandstone and conglomerate containing clasts of the rhyolite flows. The rhyolite of Obsidian Butte intertongues with basalt flows of the basalt of Black Mountain (Ttb) and has a K-Ar age of 8.8 Ma (Noble and others, 1991). Maximum exposed thickness of map unit at least 400 m

Tas — **Andesite of Sarcobatus Flat (Miocene)**—Moderately resistant, medium- to dark-gray, commonly flow-foliated, andesite lava flows and subordinate interbedded tuffaceous sedimentary rocks exposed in hills along the eastern edge of Sarcobatus Flat. Flows contain plagioclase and subordinate orthopyroxene and hornblende. Has a K-Ar age of 9.3 Ma (Minor and others, 1997). Maximum exposed thickness about 100 m

THIRSTY CANYON GROUP (MIOCENE)

Peralkaline volcanic rocks erupted as ash-flow tuff, lava flows, and related nonwelded tuff from the Black Mountain caldera (Vogel and others, 1989) between 9.4 and 9.15 Ma (Sawyer and others, 1994). The major ash-flow tuffs associated with caldera collapse are the Pahute Mesa Tuff (Ttp), Trail Ridge Tuff (Ttt), and Gold Flat Tuff (Ttg). The oldest unit derived from the caldera, the comendite of Ribbon Cliff, erupted prior to caldera subsidence. The younger trachyte of Hidden Cliff (Tth) and trachytic rocks of Pillar Spring (Ttc) and Yellow Cleft (Tts) accumulated chiefly within the caldera. Silicic rocks of the Thirsty Canyon Group are distinguished by their peralkaline mineralogy (high alkali feldspar and low plagioclase contents, general absence of biotite and hornblende, presence of Fe-rich clinopyroxene and fayalitic olivine and, less commonly, peralkaline minerals arfvedsonite and aenigmatite) and chemistry (high iron, low alumina, and anomalously high trace-element concentrations of zirconium, rare-earth elements, and other elements). Group also includes basalt of Black Mountain (Ttb)

Ttb **Basalt of Black Mountain (Miocene)**—Basaltic lava flows, cinder cones, and local feeder dikes erupted from numerous sources, most of them centered on the Black Mountain caldera in the northwestern part of the mapped area. Original geomorphic form now deeply dissected. Rocks consist of generally resistant, dark-gray, locally vesicular trachybasalt, basaltic trachyandesite, basalt, and basaltic andesite and subordinate hawaiite and mugearite. Contains variable crystal content, with crystal-rich rocks containing plagioclase and olivine and crystal-poor rocks containing olivine and sparse plagioclase. Less abundant minerals are clinopyroxene, biotite, orthopyroxene, and rare kaersutitic amphibole and apatite. K-Ar ages indicate that the rocks range in age between about 10 and 6 Ma, consistent with field evidence that these basalts were erupted before, during, and after peralkaline rhyolite eruptions of the Black Mountain caldera (Carr and others, 1996; Minor and others, 1998). In the Sleeping Butte area north of Oasis Valley, four samples have K-Ar ages of 9.9 to 9.6 Ma (Fleck and others, 1996). Also includes minor volumes of basalt flows in the western Bullfrog Hills (unit Tb_3, Maldonado, 1990) that have K-Ar ages of 8.1 Ma (discordant because this flow overlies the 7.5-Ma Spearhead Member of the Stonewall Flat Tuff, Tsp) and 7.5 Ma (Marvin and others, 1989). Includes basalt in the northern Funeral Mountains (Tb of Wright and Troxel, 1993) that intertongues with basin-fill sediments, undivided (Tgy) and is dated by $^{40}Ar/^{39}Ar$ methods at 7.5 Ma (M.A. Kunk, unpub. data, 1999). Includes basalt flows and intrusions in the northern Halfpint Range (Byers and Barnes, 1967) that have a K-Ar age of 8.5 Ma (Marvin and others, 1989). Also includes a basalt with a K-Ar age of 8.1 Ma encountered in a drill hole at 240 m depth in southwestern Yucca Flat, where it is intercalated in basin-fill sediments, undivided (Tgy) (Marvin and others, 1989). Maximum exposed thickness about 100 m

Ttg **Gold Flat Tuff**—Moderately resistant, light-bluish-green, yellow, and reddish-brown, partially to densely welded, strongly peralkaline silicic (pantellerite) ash-flow tuff deposited in and adjacent to the moat of the Black Mountain caldera. A single cooling unit with a volume of about 20 km^3. Contains about 13 percent phenocrysts, consisting of about 11 percent of both sodic sanidine and subordinate anorthoclase, 1 percent plagioclase, less than 0.5 percent each of quartz, fayalitic olivine, and biotite, and traces of hornblende and Fe-rich clinopyroxene (Warren and others, 1998). Arfvedsonite occurs as sparse phenocrysts and as a devitrification product in the groundmass; also contains rare primary fluorite and aenigmatite. Contains sparse to abundant lithic inclusions. A sample from the Black Mountain caldera has a $^{40}Ar/^{39}Ar$ age of 9.15 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Normal magnetic polarity. Maximum thickness about 70 m

Tth **Trachyte of Hidden Cliff**—Moderately resistant, locally vesicular, gray trachyte lava flows (Noble and Christiansen, 1968; Orkild and others, 1969). Contains 5 to 20 percent phenocrysts of plagioclase, olivine, and clinopyroxene. Numerous flows form an exogenous volcanic dome in the center of the Black Mountain caldera. Normal magnetic polarity. $^{40}Ar/^{39}Ar$ age is 9.3 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness at least 500 m

Tts **Trachytic rocks of Pillar Spring and Yellow Cleft**—Moderately resistant, crystal rich trachyte to quartz trachyte lava flows, associated ash-flow tuff and tuff breccia, and syenite intrusive rocks that partly fill and overlap the Black Mountain caldera. Where mapped in detail, referred to as the lavas of Pillar Spring, which consist of gray, flow-foliated lava flows that contain abundant alkali feldspar (sanidine and subordinate anorthoclase), subordinate plagioclase, and sparse clinopyroxene, fayalite, and biotite; and the underlying rocks of Yellow Cleft, which consist of dark-gray and reddish-brown lava flows, tuff, and light-gray and brown intrusive rocks that contain abundant anorthoclase and sodic plagioclase and subordinate olivine and clinopyroxene (O'Conner and others, 1966; Noble and Christiansen, 1968; Orkild and others, 1969). Reversed magnetic polarity. Maximum exposed thickness 300 m

Ttt **Trail Ridge Tuff**—Resistant, tan and pink nonwelded and rusty-red and greenish-brown, densely welded, moderately crystal-rich (about 13 percent by volume), comendite ash-flow tuff. A simple cooling unit with a volume of about 50 km^3. Contains about 13 percent phenocrysts, consisting of about 12 percent of both sodic sanidine and subordinate anorthoclase, less than 1 percent plagioclase, less than 0.5 percent each of Fe-rich clinopyroxene and fayalitic olivine, and traces of quartz, hornblende, and orthopyroxene. Contains conspicuous pumice fragments. Reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 9.3 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness 80 m

Ttp **Pahute Mesa and Rocket Wash Tuffs**—Soft to moderately resistant, crystal-poor, comendite ash-flow tuffs that have reversed polarity. Each unit has a volume of about 100 km^3. The younger Pahute Mesa Tuff is tan and pink where unwelded and rusty-red and greenish-brown where moderately welded. It contains about 5 percent phenocrysts, consisting of about 4 percent sanidine, less than 0.5 percent each of plagioclase, quartz, Fe-rich clinopyroxene, and fayalitic olivine. Its maximum thickness is 75 m. The older but lithologically similar Rocket Wash Tuff is a local, gray and pink, partially to densely welded ash-flow tuff with slightly more alkali feldspar and a maximum thickness of 50 m. The Pahute Mesa Tuff has a $^{40}Ar/^{39}Ar$ age of 9.40 Ma (Connors and others, 1998). The Rocket Wash Tuff has a $^{40}Ar/^{39}Ar$ age of 9.4 Ma (Sawyer and others, 1994)

Ttc **Comendite of Ribbon Cliff**—Resistant, medium-gray to brown, locally vesicular, crystal-rich (15 to 30 percent), flow-foliated, comendite and trachyte lava flows and volcanic domes exposed adjacent to the Black Mountain caldera (O'Conner and others, 1966; Noble and Christiansen, 1968; Orkild and others, 1969) and erupted before subsidence of the caldera. Contains abundant alkali feldspar, subordinate plagioclase, sparse clinopyroxene and fayalitic olivine, and rare biotite. Normal magnetic polarity. $^{40}Ar/^{39}Ar$ age is 9.4 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness 320 m

Trc **Rhyolite of Colson Pond (Miocene)**—Moderately resistant, gray and light-purple, flow-foliated, generally crystal-poor (about 3 to 15 percent), rhyolite lava flows and related ashfall and block-and-ash-flow tuff erupted in upper Oasis Valley and lower Thirsty Canyon (O'Conner and others, 1966). Phenocrysts consist of quartz, sanidine, and plagioclase and sparse biotite and hornblende and traces of clinopyroxene. Upper part of map unit intertongues with the basalt of Black Mountain (Ttb). Includes the rhyolite of Boundary Butte (Carr and Quinlivan, 1966), which contains sparse quartz phenocrysts and a $^{40}Ar/^{39}Ar$ age of 9.9 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Map unit has $^{40}Ar/^{39}Ar$ ages of 9.9 to 9.5 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Thickness about 100 m in any one place

Txy **Younger landslide, gravity-slide, and talus breccia (Miocene)**—Mostly soft masses of landslide, talus, and rock-avalanche breccia and megabreccia not related to calderas. Of several widely different ages, origins, and localities in the western part of the mapped area. Probably most are related to landsliding off fault scarps. Includes interbedded subordinate fine-grained sedimentary rocks and tuff. Giant (as much as 3 km long) semi-intact gravity slide blocks are found in the Bullfrog Hills (Maldonado and Hausback, 1990; Minor and others, 1997). The bases of these blocks are undulating but otherwise are fault-like surfaces that cut out section near their source areas but place older rocks on younger rocks (i.e., they duplicate section) farther away. These giant slide blocks locally grade laterally into typical rock-avalanche breccia, which forms the predominant rock type of this unit outside the Bullfrog Hills.

The rock-avalanche deposits are sheets and lenses of locally monolithologic breccia in a crushed rock matrix. Heterolithic breccia as well as breccia with a soil-like sedimentary matrix are also found. All breccias of this map unit appear to have formed in the same time interval as, and most probably are related in origin to, the tectonism that formed the Fluorspar Canyon-Bullfrog Hills-Funeral Mountains detachment fault zone. Most of the breccias of the map unit fall into two age ranges. One is bracketed between the 12.7-Ma Tiva Canyon Tuff and the 11.6-Ma Rainier Mesa Tuff. Breccia of this age is abundant in the western Crater Flat basin (including in the subsurface) at the base of the basin-fill sediments, undivided (Tgy) and in the volcanic hills along the northern side of Bare Mountain and the northeastern flank of the Funeral and Grapevine Mountains. The other age range is between 11.4 and about 10 Ma. Breccia of this younger age is abundant in the eastern and especially the northern Bullfrog Hills, as well as in the same areas where the 12.7- to 11.6-Ma breccias are found. Clasts in all breccias include both Miocene volcanic rocks and Paleozoic sedimentary rocks. At the southern margin of Crater Flat, a sheet of relatively intact slabs of monolithologic breccia (of Bonanza King Formation, ebb, ebp) rests on rocks of the Timber Mountain Group (Swadley and Carr, 1987; Swadley and Parrish, 1988). Also includes monolithologic blocks and breccia sheets derived from Paleozoic rocks that occur near the base of the basin-fill sediments, undivided (Tgy) in northern Crater Flat (Carr and others, 1996). These breccia deposits consist of clasts of the 11.6-Ma Rainier Mesa Tuff and are overlain by an airfall tuff dated at 10.3 Ma (Fridrich and others, 1999b). Other related breccia deposits, interpreted as rock-avalanche deposits, are locally exposed and encountered in the subsurface by drilling in western Crater Flat, both overlying and underlying a basalt flow (intermediate-age basalt, Tft) dated at 11.3 and 10.5 Ma (Carr and Parrish, 1985; Swadley and Carr, 1987; Fridrich and others, 1999b). Fridrich and others (1999b) interpreted all the Crater Flat breccia deposits as being due to development by basin-range tectonism of the Crater Flat basin. Also includes sedimentary rocks east of the Stonewall Mountain caldera that underlie the Rainier Mesa Tuff (Tmr) or Grouse Canyon Tuff (Tbg) (Minor and others, 1993). Includes small breccia masses west of Thirsty Mountain, east of Beatty, west of the mouth of Thirsty Canyon, and locally intercalated with the rhyolite of Fluorspar Canyon (Tmfc) (Carr and Parrish, 1985; Minor and others, 1998; Fridrich and others, 1999a). Thickness of map unit locally more than 400 m

Tfs **Rhyolite of Shoshone Mountain (Miocene)**—Moderately resistant, light-brownish-gray, purplish-gray, and grayish-orange-pink, flow-foliated, generally aphyric lava flows and minor genetically related tuff and tuff breccia of rhyolite (Orkild and O'Connor, 1970). Flows include dark-gray to black basal glasses. Forms a volcanic dome straddling the southeastern topographic margin of the Rainier Mesa caldera. Includes plugs and dikes. Contains rare sanidine, plagioclase, clinopyroxene, and biotite. Normal magnetic polarity. K-Ar age is 10.3 Ma (Noble and others, 1991). Maximum thickness in any one place is about 400 m

Trs **Rhyolite of Springdale Mountain (Miocene)—**Sequence of local, soft to resistant, mostly gray, mostly crystal-rich, low-silica rhyolite volcanic domes, lava flows, and associated pyroclastic rocks exposed west of Springdale and in the Bullfrog Hills, in the western part of the mapped area. Includes nonwelded to moderately welded ash-flow tuff and flow-foliated lava flows that are underlain by bedded tuffaceous sedimentary breccia formed as alluvial fans or mudflows. Flows and tuff contain sanidine, subordinate plagioclase, sparse biotite, and clinopyroxene, and rare hornblende. Distinguished by rhyolite composition combined with an almost complete lack of quartz phenocrysts and an abundance of sanidine; grades downward into the underlying trachyte of Donovan Mountain (Tfn). Erupted at about 10.4 Ma (Marvin and others, 1970). Maximum exposed thickness about 200 m

Tft **Intermediate-age basalt (Miocene)**—Widely scattered, moderately resistant, mostly dark-gray to black and locally red, locally vesicular lava flows, flow breccia, and scoria of basalt, basaltic andesite, trachybasalt, and basaltic trachyandesite. Emplaced in a strong pulse of mafic volcanism that occurred during and shortly after the final stages of the Timber Mountain caldera complex. Original geomorphic form removed by erosion. Locally includes related feeder dikes and local thin interbeds of alluvium, rock-avalanche breccia, as well as volcanic units ranging from the tuff of Cutoff Road (Ttc, the oldest of the volcanic units) to the lower units of the rhyolite of Rainbow Mountain (Tfr, the youngest). Contains moderate amounts of phenocrysts of plagioclase, olivine, and subordinate clinopyroxene. $^{40}Ar/^{39}Ar$ ages of the map unit range from 11.3 to 8.4 Ma. Mapped in the Bullfrog Hills (Maldonado, 1990; Maldonado and Hausback, 1990), on the northeastern flank of the Grapevine Mountains (Marvin and others, 1989), and north of Bare Mountain (Monsen and others, 1992). At Skull Mountain and Little Skull Mountain (Maldonado, 1985; Carr and Parrish, 1985; Marvin and others, 1989), stratigraphic constraints indicate that the actual age range of the basalts is between 11.4 and about 10.5 Ma. Also includes other basalts that are poorly constrained stratigraphically but which have K-Ar ages of the same stratigraphic range (Marvin and others, 1989; Carr and others, 1996). These include basalts in the Mount Helen area in the northwestern part of the mapped area (Rogers and others, 1968). Also includes basalt of 10.5 Ma (Swadley and Carr, 1987) that are exposed on the southwestern side of Crater Flat basin (Swadley and Carr, 1987) and encountered in drill holes in Crater Flat (Carr and Parrish, 1985). A basalt dike on a fault in the western side of Yucca Mountain, though not shown on the map, has a K-Ar age of 10.0 Ma (Maldonado, 1985; Carr and Parrish, 1985; Marvin and others, 1989). A drill hole sited between Red Cone and Black Cone, the two largest Quaternary centers of the basalt of central Crater Flat (Qbc), encountered a 30-m-thick basalt flow at a depth of 360 m, resting on the Ammonia Tanks Tuff (Tma); this basalt flow has K-Ar ages of 11.4 to 11.3 Ma (Carr and Parrish, 1985; Marvin and others, 1989). Maximum thickness about 500 m

Tfn **Trachyte of Donovan Mountain (Miocene)**—Generally resistant sequence of crystal-rich (about 20 percent) lava flows, feeder dikes, and flow-margin pyroclastic rocks exposed along the eastern and southern sides of Sarcobatus Flat (Minor and others, 1997). The lava flows are gray and locally flow-foliated and have normal magnetic polarity. Trachyte flows contain about 10 percent plagioclase, 8 percent sanidine, less than 1 percent each of biotite and clinopyroxene, less than 1 percent olivine, and traces of orthopyroxene. Mapped unit locally includes intertongued basaltic flows. $^{40}Ar/^{39}Ar$ age is 10.4 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness about 300 m

Tgb **Bedded tuff and sedimentary rocks (Miocene)—**Soft, gray and light-green, bedded airfall and water-laid tuff and interbedded volcaniclastic sandstone, siltstone, and local conglomerate (Minor and others, 1997). Conglomerate occurs at base and includes a large paleochannel cut into underlying ash-flow tuff of the underlying rhyolite of Rainbow Mountain (Tfr). Some tuff beds resemble units in the rhyolite of Rainblow Mountain and may be distal equivalents. Maximum exposed thickness 200 m

Tfr **Rhyolite of Rainbow Mountain (Miocene)**—Moderately resistant, gray, brown, and light-red, locally flow-foliated, crystal-poor to crystal-rich lava flows and flow breccia as well as genetically related ash-flow tuff, block-and-ash-flow tuff, airfall tuff, and waterlaid tuff of high- to low-silica rhyolite (Maldonado and Hausback, 1990; Minor and others, 1997). One of the ash-flow units in the northern Bullfrog Hills is thick, densely welded, and crystal-rich. Includes one or more probable crystal-rich shallow intrusions as well as several dikes (Maldonado and Hausback, 1990; Minor and others, 1997). Includes the tuff of Leadfield Road of Maldonado (1990), exposed in the western Bullfrog Hills and northern Funeral Mountains. Map unit erupted from vent areas in the eastern Bullfrog Hills. Beds contain plagioclase and subordinate to rare biotite, quartz, sanidine, and local hornblende and clinopyroxene. Distinguished from other rhyolites of this and younger ages in the southwest Nevada volcanic field by high plagioclase-to-sanidine ratio (sanidine is commonly absent) and by the rarity or absence of hornblende. Includes partly consolidated sand and gravel beds that are interbedded with the tuffs. Flows have normal magnetic polarity. Sequence is stratigraphically bracketed between about 11 and 10.4 Ma and is locally interbedded at the base of the intermediate-age basalt (Tft). Maximum thickness at least 400 m

Tfd **Lava flows of Dome Mountain (Miocene)**—Resistant, gray, light-brown, and black, dense to scoriaceous, mostly crystal-poor lava flows of trachybasalt, basaltic trachyandesite, and trachyandesite southeast of Timber Mountain (Luft, 1964). Basaltic rocks contain abundant plagioclase, subordinate olivine, and sparse clinopyroxene; trachyandesites contain moderately abundant to sparse clinopyroxene, rare olivine and orthopyroxene, and local rare hornblende. Normal magnetic polarity. Age between 11 and 10.35 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum thickness about 300 m

Tfb **Beatty Wash Formation**—Soft to moderately resistant, light-gray, purple, light-red, and brown, flow-foliated lava flows and genetically related reddish-brown ash-flow tuff and white, gray, and light-orange, pumice-rich, bedded airfall tuff and nonwelded ash-flow tuff of rhyolite erupted largely within the moat of the Ammonia Tanks caldera. Unit has a volume of at least 110 km^3. Identifying features of the map unit are its quartz-poor mineralogy and relative abundance of sphene. Unit includes tuffaceous sandstone. Also includes subunits of the same lithology and petrology that have been separated in more detailed previous mapping. One of these is the rhyolite of Beatty Wash, which consists of lava flows that have normal magnetic polarity and which has a $^{40}Ar/^{39}Ar$ age of 11.4 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Another is the tuff of Cutoff Road, a 120-m-thick, gray and pink, poorly to densely welded rhyolite ash-flow cooling unit that has normal magnetic polarity and about 11 percent phenocrysts, consisting of about 5 percent each of plagioclase and sanidine, less than 1 percent each of biotite, sphene, and hornblende, and traces of quartz (Lipman and others, 1966; Byers and others, 1976a). The tuff of Cutoff Road, which has a $^{40}Ar/^{30}Ar$ age of 11.45 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998), is the youngest unit in the hogback west of Oasis Valley basin and west of the Ammonia Tanks caldera. Another rock unit included in the Beatty Wash Formation map unit is the rhyolite of Chukar Canyon, which contains pumice of both rhyolite and basalt composition in its upper part. Others are the rhyolite of Max Mountain, which has reversed polarity and a $^{40}Ar/^{39}Ar$ age of 11.3 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998); and the rhyolite of Fortymile Canyon (Byers and others, 1966; Carr and Quinlivan, 1966; Orkild and O'Connor, 1970), a gray, crystal-poor lava flow and basal bedded tuff. Local deposits of the rhyolite of Rainbow Mountain (Trr) are included in the map unit. Lava flow sequences are as much as 430 m thick; tuff sequences are as much as 60 m thick

Tff **Rhyodacite of Fleur-de-lis-Ranch**—Two moderately resistant, light-brown, gray, and purple, crystal-poor, densely welded, rhyodacite ash-flow cooling units separated by flow-foliated lava flows. Includes the rhyolite lavas of West Cat Canyon, a gray, brown, and red lava flow that locally overlies the Ammonia Tanks Tuff on Timber Mountain (Byers and others, 1976a). Exposed in the moat of the Ammonia Tanks caldera and west of the caldera. All rocks of the sequence are petrographically indistinguishable, containing about 16 percent phenocrysts that consist of about 13 percent plagioclase, 2 percent biotite, and less than 1 percent each of sanidine and clinopyroxene; distinctive by its abundant plagioclase and lack of sphene. Unit has a $^{40}Ar/^{39}Ar$ age of 11.45 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Upper tuff and the lava flow have normal magnetic polarity and the lower tuff has reversed polarity. Thickness as much as 300 m

TIMBER MOUNTAIN GROUP (MIOCENE)

Metaluminous igneous rocks that erupted as rhyolite ash-flow tuff and subordinate rhyolite lava flows and volcanic domes, as well as genetically related intrusions and intracaldera breccia. The igneous rocks were derived from the Timber Mountain caldera complex between 11.6 and 11.45 Ma (Sawyer and others, 1994). The most significant units of the group are the Ammonia Tanks Tuff (Tma, 11.45 Ma) and the voluminous Rainier Mesa Tuff (Tmr, 11.6 Ma). Prior to their eruption, a broad structural dome formed that was centered on, but larger than, the area of the later calderas; extension of the roof of this broad dome was accommodated by concentric normal faults (Christiansen and others, 1965). Eruption of the Rainier Mesa and Ammonia Tanks Tuffs resulted in collapse of, respectively, the Rainier Mesa and Ammonia Tanks calderas of the Timber Mountain caldera complex (Christiansen and others, 1965, 1977). The Ammonia Tanks caldera is nested entirely within the larger Rainier Mesa caldera and is centered about Timber Mountain, which formed during resurgence of the Ammonia Tanks caldera (Christiansen and others, 1965, 1977). The structural margin (ring fault) of the Ammonia Tanks caldera is exposed on the eastern margin of Timber Mountain and inferred elsewhere around it (Sawyer and others, 1994), with its longest diameter nearly 20 km. Intracaldera Rainier Mesa Tuff and intertongued caldera-collapse breccia are exposed in the Transvaal Hills, which Sawyer and others (1994) interpreted as the western part of the resurgent dome of the Rainier Mesa caldera before it was partly destroyed by the Ammonia Tanks eruptions and caldera collapse. A topographic margin of a caldera, about 35 km in longest diameter and presumably the Rainier Mesa caldera, is clearly exposed in many places as far as a radial distance of 10 km outside the structural margin of the Ammonia Tanks caldera. Inasmuch as most of the topographic margin of the Ammonia Tanks caldera and the structural margin of the Rainier Mesa caldera are not exposed, we have used geophysics to infer their locations, which are shown as dotted caldera margins on the map. As used here, the rock units making up the Timber Mountain Group range between post-caldera volcanic rocks, the youngest of which is the resurgent intrusive rocks of Timber Mountain (Tmi). Rocks of the group are distinguished by abundance of quartz phenocrysts in rhyolite and by abundant ferromagnesian minerals in upper parts of zoned ash-flow units. Group includes basalt of the Bullfrog Hills (Tmt)

Tmi **Intrusive rocks of Timber Mountain**—Moderately resistant, gray, crystal-rich intrusions of rhyolite and microgranite porphyry emplaced into the Ammonia Tanks Tuff (Tma) on the southeastern flank of the Timber Mountain resurgent dome (Carr and Quinlivan, 1966). Intrusive rhyolite contains abundant alkali feldspar, subordinate quartz, and sparse biotite, plagioclase, and sphene; lithologically and chemically resembles the rhyolite compositional zone of the Ammonia Tanks Tuff. Microgranite porphyry is a gray, crystal-rich syenite with abundant sanidine and subordinate plagioclase and biotite and minor clinopyroxene (Carr and Quinlivan, 1966; Byers and others, 1976a). Considered to represent exposed fingers of the intracaldera intrusion that closely followed eruption of the Ammonia Tanks Tuff and collapse of the Ammonia Tanks caldera. The main mass of the intrusion, which is inferred to be at depth, intruded into the caldera fill and bowed up the structural dome, which now is about 18 km in longest diameter

Tmay **Trachyte of East Cat Canyon**—Resistant, light-gray and purplish-gray, crystal-rich quartz trachyte lava flows on the southeastern margin of the Timber Mountain dome. Contains abundant plagioclase and biotite, subordinate clinopyroxene, sparse sanidine and orthopyroxene, and rare quartz, hornblende, and apatite. A genetic association with the older Ammonia Tanks Tuff (Tma) is suggested by the petrologic similarity between the map unit and the youngest part of the zoned Ammonia Tanks Tuff. Unit is domed, indicating that it postdates caldera collapse but predates resurgence. Called rhyodacitic and mafic lavas by Byers and others (1976a). Includes rhyolite of Parachute Canyon, on the northern margin of the Timber Mountain dome; this rhyolite is a gray, crystal-rich (sanidine, subordinate quartz and plagioclase, and minor clinopyroxene and biotite) volcanic dome (Carr and Quinlivan, 1966). Maximum thickness 150 m

Tmaw **Tuff of Buttonhook Wash**—Moderately resistant, mostly crystal-poor, gray nonwelded to reddish-brown densely welded, rhyolite ash-flow tuff and subordinate bedded airfall tuff on the flank of the Timber Mountain dome (Carr and Quinlivan, 1966; Lipman and others, 1966). Contains about 15 percent phenocrysts of sanidine, plagioclase, and quartz, sparse biotite, clinopyroxene, and sphene, and local rare hornblende. Contains abundant purple lithic inclusions. Compound cooling unit that is lithologically similar to intracaldera Ammonia Tanks Tuff (Tma) but separated from it by a cooling break. Normal magnetic polarity. $^{40}Ar/^{39}Ar$ age is about 11.45 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Includes petrographically indistinguishable tuff of Crooked Canyon (Byers and others, 1976a). Deformed as part of the resurgent dome. Maximum thickness about 250 m

Tma **Ammonia Tanks Tuff**—Voluminous (about 900 km^3), moderately resistant, light-red, lavender-gray, light-gray, light-brown, and black, nonwelded to densely welded, generally crystal-rich, metaluminous ash-flow tuff derived from the Ammonia Tanks caldera. Compositionally zoned from an upper quartz trachyte (about 25 percent phenocrysts), consisting of about 13 percent sanidine, 8 percent plagioclase, 3 percent quartz, 1 percent biotite, less than 1 percent clinopyroxene, and traces of sphene, to a lower rhyolite (about 18 percent phenocrysts), consisting of about 11 percent sanidine, 4 percent quartz, 2 percent plagioclase, less than 1 percent biotite, and traces of sphene and clinopyroxene. Contains sparse collapsed pumice and moderately abundant small lithic inclusions. Map unit distinguished by its high content of quartz and mafic minerals, sparse sphene, and normal magnetic polarity. Includes a local basal bedded tuff that resembles the lower rhyolitic part of the ash-flow sheet but contains sparse hornblende and rare orthopyroxene, clinopyroxene, and Mg-rich olivine. This bedded tuff also contains lapilli of basalt. $^{40}Ar/^{39}Ar$ age is 11.45 Ma (Sawyer and others, 1994). Intracaldera tuff, as exposed on the Timber Mountain dome, is at least 900 m thick, and its base is not exposed. Outflow tuff generally less than 150 m

Tmc **Caldera-collapse breccia of Timber Mountain caldera complex**—Mostly soft, brown and gray, locally bedded, poorly sorted breccia and basal megabreccia in a tuff matrix. Made up of dark angular clasts as much as 6 m across and a matrix of ground-up material of the same lithology and of variable amounts of tuff (Orkild, 1963; Byers and others, 1966; Lipman and others, 1966; Hinrichs and others, 1967). Derived from volcanic units exposed on the topographic wall of the calderas and deposited in the calderas as landslides, rock avalanches, mudflows, and fans. Mostly deposited during and after subsidence of the Rainier Mesa caldera, where they occur as an intracaldera fill that includes intertongued intracaldera Rainier Mesa Tuff and is overlain by the Ammonia Tanks Tuff (Tma). Some deposits are from collapse of the margins of the Ammonia Tanks and Twisted Canyon calderas. Exposed thickness at least 300 m

Tmt **Basalt of the Bullfrog Hills (Miocene)**—Widely scattered, mostly thin, moderately resistant, gray, black, and reddish-brown, locally vesicular, generally crystal-poor, basaltic lava flows and local scoria beds that stratigraphically occur between the Ammonia Tanks Tuff (Tma) and the Tiva Canyon Tuff (Tpc). Exposed in the Bullfrog Hills and west of Thirsty Canyon. Typically consists of 5 percent or less phenocrysts of olivine and subordinate plagioclase and orthopyroxene. Formerly mapped as basalts in Timber Mountain Group by Minor and others (1993), Carr and others (1996), and Wahl and others (1997). Exposed primarily in the Bullfrog Hills (unit Tb_1 of Maldonado, 1990; units Tb and Tb_1 of Maldonado and Hausback, 1990). Includes a small patch southwest of Mid Valley (Orkild, 1968), as well as a thin flow not mapped at this scale in the Shoshone Mountain area (Orkild and O'Connor, 1970). Magnetic polarity of individual flows may be either normal or reversed. Maximum thickness about 60 m

Tmat **Rhyolite of Tannenbaum Hill**—Resistant, light-gray and purplish-gray, locally vesicular, crystal-poor (about 8 percent), locally flow-foliated, rhyolite lava flows and genetically related subordinate nonwelded ash-flow tuff that erupted from volcanic domes in the moat of the Rainier Mesa caldera (O'Conner and others, 1966; Byers and Cummings, 1967). Consists of about 5 percent sanidine, 3 percent quartz, and less than 1 percent each of plagioclase, sphene, and biotite. Distinguished by sphene content, normal magnetic polarity, and stratigraphic position between the Ammonia Tanks (Tma) and Rainier Mesa (Tmr) Tuffs. Includes the rhyolite of Buried Canyon, which consists of gray, crystal-poor flows and tuff (Orkild and O'Connor, 1970) and has a $^{40}Ar/^{39}Ar$ age of 11.6 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Chemically and petrographically similar to the Ammonia Tanks Tuff, and for this reason only is considered to be younger than the rhyolite of Twisted Canyon (Tmtc). $^{40}Ar/^{39}Ar$ age of 11.55 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Thickness at least 180 m

Tmtc **Rhyolites of Twisted Canyon**—Soft to resistant, mostly pink, rhyolite ash-flow tuff and gray and tan lava flows largely erupted from the Twisted Canyon caldera. The intracaldera deposits are a complex sequence of volcanic rocks and caldera-collapse breccia and interbedded conglomerate. Also includes two small dissected cinder cones of olivine basalt. The Twisted Canyon caldera, recently recognized by Fridrich (1999) and Fridrich and others (1999a), is about 4 km in diameter and is exposed 8 km north of Beatty, Nev. The tuff is interbedded between the Ammonia Tanks (Tma) and Rainier Mesa (Tmr) Tuffs and is lithologically intermediate between the rhyolite of Fluorspar Canyon (Tmrf) and the Rainier Mesa Tuff. The deposits therefore are included within the Timber Mountain Group. The Twisted Canyon caldera—although it is outside the Timber Mountain caldera complex—is interpreted as a satellite volcanic center to the main caldera complex (Fridrich and others, 1999a). Thickness at least 100 m

Tmr **Rainier Mesa Tuff**—Voluminous (about 1,200 km^3), generally resistant, pink, brown, light-red, and light-gray, nonwelded to densely welded, generally crystal-rich, metaluminous ash-flow tuff derived from the Rainier Mesa caldera. Nonwelded base is characteristically salmon pink. Compositionally zoned from an upper crystal-rich (about 24 percent) trachyte, consisting of about 10 percent sanidine, 9 percent plagioclase, 3 percent quartz, 1 percent biotite, less than 1 percent clinopyroxene, and traces of orthopyroxene and hornblende, to a lower, less crystal-rich (about 10 percent) rhyolite, consisting of about 4 percent each of sanidine and quartz, 2 percent plagioclase, and less than 1 percent biotite. Locally underlain by thin (about 10 cm) distinctive beds of dacite and overlying trachybasalt tephra that contain hornblende, subordinate plagioclase, and sparse orthopyroxene. Contains sparse lithic fragments. Unit distinguished by its high content of quartz and mafic minerals, by rare accessory monazite, by lack of sphene, and by reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 11.6 Ma (Sawyer and others, 1994). In Bullfrog Hills, unit may include some Ammonia Tanks Tuff (Tma) where distinction between it and Rainier Mesa Tuff was not possible owing to hydrothermal alteration and brecciation. Maximum exposed thickness of intracaldera tuff about 500 m, but its base is not exposed. Outflow tuff generally less than 150 m but locally as much as 400 m where it ponded in topographically low areas

Tmrf **Rhyolite of Fluorspar Canyon**—Mostly soft, light-gray, pink, and white, nonwelded rhyolite ash-flow, airfall, surge, and waterlaid tuff and subordinate, locally resistant, gray, petrographically identical rhyolite lava flows. Deposits occur throughout the west-central part of the mapped area. Younger beds within the map unit have progressively smaller dips (as much as a 35 degree difference between younger and older units) and deformation. Some of the tuffs and lava flows are petrographically similar to lower parts of the Rainier Mesa Tuff (Tmr), but most are more evolved as well as being crystal poor. The crystal-poor varieties have about 6 percent phenocrysts, consisting of about 2 percent each of quartz and sanidine, 1 percent plagioclase, and less than 1 percent biotite. Distinguished by relatively high quartz content, reversed magnetic polarity, and rare accessory monazite. $^{40}Ar/^{39}Ar$ ages are between 11.7 and 11.6 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Includes tuff of Holmes Road, which is a distinctive brown, pink, and white phreatomagmatic deposit, and the rhyolite of Pinnacles Ridge (Christiansen and Lipman, 1965), which is exposed south of Beatty Wash and has a $^{40}Ar/^{39}Ar$ age of 11.7 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum thickness at least 250 m

Tgs **Sedimentary rocks and landslide deposits (Miocene)**—Soft to moderately resistant, pink, gray, tan, and variegated sandstone, conglomerate, siltstone, and mudstone, as well as landslide breccia and airfall tuff. Largely fills basins formed during the initiation of detachment faulting in the western part of the map area. Locally includes airfall tuff of the Wahmonie Formation (Tw) at its base in the Point of Rocks area just northwest of the Spring Mountains. Ranges in age between about 13 and 11.6 Ma. Thickness at least 300 m

PAINTBRUSH GROUP (MIOCENE)

Metaluminous sequence of alkali rhyolite tuff and lava flows, with the rhyolite of Windy Wash (Tpw) at the top and the Topopah Spring Tuff (Tpt) at the base, erupted from the Claim Canyon caldera. Detailed stratigraphy described by Dickerson and Drake (1995, 1998), Moyer and Geslin (1995), Buesch and others (1996), and Moyer and others (1996). Only the southern part of the Claim Canyon caldera is preserved, on the southern side of the Timber Mountain caldera complex. The caldera wall shown here has been interpreted as a structural margin (Christiansen and Lipman, 1965) but it also includes segments of the topographic margin. Most of the mapped margin of the caldera has been resurgently domed (Sawyer and others, 1994). Eruption of rocks of the group took place between 12.8 and 12.7 Ma (Sawyer and others, 1994). One of two large ash-flow units in the group is the Tiva Canyon Tuff (Tpc), whose eruption was followed by subsidence of the Claim Canyon caldera. The older, even more voluminous Topopah Spring Tuff (Tpt) appears to have also erupted from the area of the Claim Canyon caldera, or beneath the younger Timber Mountain caldera complex. The Yucca Mountain Tuff (Tpy) and Pah Canyon Tuff (Tpp), which are two smaller tuffs that predate the Tiva Canyon Tuff and postdate the Topopah Spring Tuff, probably also were derived from the Claim Canyon caldera. Rocks of the Paintbrush Group are characterized by an absence or rarity of quartz phenocrysts, even in the rhyolite units, and by—with the main exception of the Topopah Spring Tuff—the presence of sphene. Biotite is present in the rocks and, in the upper part of the group, it is accompanied by hornblende whereas, in the lower part of the group, it is accompanied by clinopyroxene

Tpw **Rhyolite of Windy Wash**—Mostly resistant, light-gray and black, crystal-rich, rhyolite volcanic domes, lava flows, and subordinate nonwelded ash-flow and airfall tuff, tuff breccia, and feeder dikes exposed primarily within the moat of the Claim Canyon caldera (Christiansen and Lipman, 1965). The main mass of flows consists of about 20 percent phenocrysts, consisting of about 10 percent sanidine, 5 percent each of plagioclase and quartz, and less than 1 percent each of biotite, sphene, and hornblende. A volumetrically subordinate series of upper flows have about 15 percent phenocrysts, consisting of about 5 percent each of sanidine and quartz, 4 percent plagioclase, less than 1 percent biotite, and an absence of sphene. Includes feeder dikes of the domes that were mapped separately within the Claim Canyon caldera by Fridrich and others (1999a) and that cut the Tiva Canyon Tuff (Tpc) and older rocks. These dikes have both lithic-rich tuff and lava-like flow-banded facies and were emplaced in faults formed during resurgence of the Claim Canyon caldera. Unit formerly mapped as transitional Timber Mountain rhyolites (Tmn) by Carr and others (1996) and Wahl and others (1997). The age of this unit (only 0.1 to 0.2 m.y.

younger than the Tiva Canyon Tuff, Tpc) and the localization of this unit to the moat of the Claim Canyon caldera indicates that it is part of the Paintbrush Group, emplaced after subsidence of the Claim Canyon caldera (C.J. Fridrich, unpub. data, 1998). Includes the rhyolite of Water Pipe Butte (Christiansen and Lipman, 1965; Orkild and O'Connor, 1970), which consists of gray, crystal-rich lava flows and airfall tuff as much as 170 m thick and has a $^{40}Ar/^{39}Ar$ age of 12.5 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998), and rhyolite of the Loop, which has a volume of about 40 km^3 and a $^{40}Ar/^{39}Ar$ age of 12.5 Ma (Sawyer and others, 1994). $^{40}Ar/^{39}Ar$ ages of the rhyolite of Windy Wash are 12.6 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). Maximum thickness about 110 m

Tpr **Rhyolite of Comb Peak**—Mostly resistant, light-gray, grayish pink, and black, mostly crystal-rich rhyolite and quartz trachyte lava flows and associated ash-flow tuff, airfall tuff, and tuff breccia. Exposed largely in the Fortymile Canyon area, just south of the Claim Canyon caldera (Dickerson and Drake, 1995). Contains plagioclase, alkali feldspar, hornblende, and quartz, minor biotite, and traces of sphene. Very closely resembles the last eruptive phases of the Tiva Canyon Tuff (Tpc). Maximum thickness about 340 m. Includes the rhyolite of Vent Pass (Orkild and O'Connor, 1970), which is exposed in Fortymile Canyon and which consists of a 200-m thick sequence of mostly resistant, gray, pink, and purple rhyolite lava flows and associated ash-flow tuff, airfall tuff, and tuff breccia containing phenocrysts of alkali feldspar and plagioclase, minor hornblende, and traces of sphene (Christiansen and Lipman, 1965). Also includes, just northeast of the topographic margin of the Rainier Mesa caldera, upper parts of the crystal-rich to crystal-poor rhyolite of Scrugham Peak quadrangle (Byers and Cummings, 1967) and the rhyolite of Benham, which has a $^{40}Ar/^{39}Ar$ age of 12.7 Ma (R.J. Fleck, M.A. Lanphere, and D.A. Sawyer, unpub. data, 1998). The rhyolite of Scrugham Peak quadrangle contains sanidine and subordinate to minor plagioclase and biotite, and traces of sphene; the younger rhyolite of Benham contains sanidine, subordinate to minor plagioclase and biotite, and rare quartz and hornblende. Map unit formerly called the post-Tiva Canyon rhyolites (Tpu of Carr and others, 1996; Wahl and others, 1997). Interpreted to have been deposited after formation of the Claim Canyon caldera. Reversed magnetic polarity. Maximum thickness of the overall sequence in any one spot is about 300 m

Tpc **Tiva Canyon Tuff**—Voluminous (about 1,000 km^3), resistant, gray to reddish-brown, moderately crystal-rich, locally lithophysal, nonwelded to densely welded, ash-flow tuff. Two compositional units, an upper brown, red, and dark-purplish-gray, crystal-rich densely welded trachyte with about 14 percent phenocrysts, consisting of about 10 percent sanidine, 3 percent plagioclase, less than 1 percent each of biotite and clinopyroxene, and traces of sphene, fayalite, hornblende, and quartz, and a lower light-gray and light-red, lithic-poor, crystal-poor, densely welded, crystal-poor rhyolite with about 3 percent phenocrysts, consisting of about 3 percent sanidine and traces of clinopyroxene, plagioclase, sphene, biotite, hornblende, and quartz. Lower part commonly platy and locally underlain by beds of white airfall pumice. Contains moderately abundant collapsed pumice. Unit distinguished by its dominance of sanidine among felsic phenocrysts, presence of sphene, and reversed magnetic polarity. Includes an upper separate cooling unit (tuff of Pinyon Pass), which has about 6 percent phenocrysts, consisting of about 5 percent sanidine, less than 1 percent each of plagioclase, biotite, clinopyroxene, and hornblende, and traces of quartz and sphene. In the Bullfrog Hills, map unit includes the Topopah Spring Tuff (Tpt) (Maldonado, 1990; Maldonado and Hausback, 1990). Also includes intracaldera deposits (formerly called tuff of Chocolate Mountain, Christiansen and Lipman, 1965). $^{40}Ar/^{39}Ar$ age is 12.7 Ma (Sawyer and others, 1994). Maximum thickness of outflow deposits 120 m; thickness of intracaldera deposits at least 1.5 km, with the base not exposed

Tpcc **Caldera-collapse breccia of Claim Canyon caldera**—Soft to moderately resistant, multicolored breccia and megabreccia consisting of angular clasts of pre-Tiva Canyon rocks. Interfingers with, and has a matrix of, the Tiva Canyon Tuff (Tpc). Formed as landslides derived from the walls of the caldera and deposited inside the caldera. Thickness at least 300 m

Tpy **Yucca Mountain Tuff**—Moderately resistant, gray, pink, brown, and light-orange, almost aphyric (with traces of sanidine, biotite, plagioclase, and sphene), locally lithophysal, nonwelded to densely welded, high-silica rhyolite ash-flow tuff. Resembles the lower rhyolitic part of the Tiva Canyon Tuff (Tpc) but distinguished by its low phenocryst content, stratigraphic position beneath the Tiva Canyon Tuff, and reversed magnetic polarity. A simple cooling unit of relatively small volume (25 km^3) whose similarity with the lower Tiva Canyon suggests that it was derived from the same magma chamber as this tuff (Sawyer and others, 1994). As much as 335 m thick in the western part of the exposed part of the Claim Canyon caldera. Includes local 3-m-thick, white airfall pumice at the base of the ash-flow cooling unit. $^{40}Ar/^{39}Ar$ ages show evidence of xenocrystic contamination of the tuff. Maximum thickness of outflow tuff is 75 m

Tpm **Middle Paintbrush Group rhyolites—**Rhyolite lava flows and genetically related nonwelded tuff from several eruptive centers, all active during the interval between the major ash-flow eruptions of the Tiva Canyon Tuff (Tpc) and Topopah Spring Tuff (Tpt). Lava flows contain sanidine, subordinate plagioclase and biotite, and sparse quartz. The youngest known unit is the gray, crystal-poor rhyolite of Delirium Canyon, which consists of lava flows and ash-flow and airfall tuff as much as 300 m thick; exposed just southeast of the Claim Canyon caldera (Christiansen and Lipman, 1965) and in Fortymile Canyon (Orkild and O'Connor, 1970). This unit is underlain by the rhyolite of Echo Peak, exposed in the western part of the Claim Canyon caldera, which consists of lava flows and petrographically similar, overlying ash-flow tuff that contains about 11 percent phenocrysts, consisting of about 6 percent sanidine, 4 percent plagioclase, and less than 1 percent each of biotite, quartz, sphene, and clinopyroxene. The lowermost unit is the rhyolite of Silent Canyon, exposed on the northeastern topographic margin of the Rainier Mesa caldera and consisting of plagioclase, minor biotite, and an absence of sphene. The map unit also includes the lower crystal-poor part of the rhyolite flows of Scrugham Peak quadrangle (Byers and Cummings, 1967). Unit also includes the rhyolite of Black Glass Canyon, exposed south of the Claim Canyon caldera (Christiansen and Lipman, 1965), which is about 30 m thick and consists of a gray to brown lava flows containing alkali feldspar, plagioclase, and hornblende as well as related airfall tuff and tuff breccia. It also includes the rhyolite of Z. Units have reversed magnetic polarity. Maximum thickness of individual units ranges from 140 to 390 m

Tpp **Pah Canyon Tuff**—Moderately resistant, pink, light-brown, light-orange, and gray, crystal-poor, nonwelded to moderately welded, low-silica rhyolite ash-flow tuff. Its volume is about 35 km^3. Contains about 7 percent phenocrysts, consisting of about 4 percent plagioclase, 3 percent sanidine, less than 1 percent each of biotite and clinopyroxene, and traces of quartz and sphene. Contains moderately abundant small pumice and lithic inclusions. Reversed magnetic polarity. Locally ponded in the Claim Canyon caldera but in most places is a single cooling unit with two partial cooling units with a total maximum thickness of about 90 m

Tpt **Topopah Spring Tuff—**Voluminous (about 1,200 km^3), resistant, light-orange, dark-olive-brown, reddish-brown, and black, crystal-poor, locally lithophysal, moderately to densely welded, rhyolitic ash-flow tuff. Caldera source is the Claim Canyon. A compound cooling unit that is compositionally zoned from an upper trachyte with about 12 percent phenocrysts, consisting of about 7 percent sanidine, 4 percent plagioclase, and less than 1 percent each of biotite, clinopyroxene, and quartz, to a lower high-silica rhyolite with about 1 percent phenocrysts, consisting of less than 1 percent each of plagioclase, sanidine, quartz, and biotite. Contains abundant collapsed pumice and lithic inclusions. Includes overlying beds of gray airfall pumice. Distinguished from the Tiva Canyon Tuff (Tpc) by an absence of sphene, lower phenocryst abundances, and large lithophysae. $^{40}Ar/^{39}Ar$ age is 12.8 Ma (Sawyer and others, 1994). Normal magnetic polarity. Maximum thickness about 350 m

Tac **Calico Hills Formation (Miocene)**—Soft to resistant, light- to medium-gray, light-purple, pink, and grayish-green, flow-foliated, crystal-poor, high-silica rhyolite lava flows and related, petrographically similar, light-yellow, gray, and brown, block-and-ash-flow tuff, bedded airfall tuff, and tuff breccia. Includes small feeder intrusions. Detailed stratigraphy described by Moyer and Geslin (1995) and Dickerson and Drake (1998). Erupted from widely scattered areas outside the Rainier Mesa caldera, notably in the Calico Hills and the Silent Canyon caldera complex. It has a volume of about 160 km^3. Hydrothermally altered in the Calico Hills. Flow sequence ranges in lithology from crystal-poor to crystal-rich rhyolites that contain quartz and sanidine and minor plagioclase and biotite, to rhyolites that contains quartz, plagioclase, and sanidine, and sparse biotite. Tuffs in the western part of the mapped area contain about 2 percent phenocrysts of quartz, sanidine, subordinate plagioclase, and minor biotite. Tuffs contain abundant lithic fragments of the flow rock. Distinguished by high relative quartz content, Fe-rich mafic minerals, bedded pyroclastic character, and normal magnetic polarity. Sawyer and others (1994) interpreted the unit to represent a post-caldera sequence genetically related to the Crater Flat Group. Map unit includes rocks formerly called the volcanics of Area 20 (Sawyer and Sargent, 1989), which is confined to the Silent Canyon caldera complex (Area 20 caldera), and has an apparent thickness in the subsurface of 1,850 m. In the Hampel Hill-Pavits Spring area southwest of Frenchman Flat, map unit includes pre-Rainier Mesa, gray and yellow, bedded eolian sandstone, conglomerate, and rhyolite airfall tuff (some correlated with the Calico Hills Formation) and local nonwelded rhyolite ash-flow tuff that Poole and others (1965b) mapped as "sandstone and tuff of Hampel Hill." Map unit also occurs as a bedded tuff, too thin to map at this scale, in the Halfpint Range (Hudson, 1997). $^{40}Ar/^{39}Ar$ age is 12.9 Ma (Sawyer and others, 1994). Maximum exposed thickness about 200 m, but drilling indicates that rhyolite in the subsurface of Pahute Mesa, which appears correlative with the Calico Hills Formation based on similar age and composition, ponded within the Silent Canyon caldera complex to a thickness of 1,850 m (Sawyer and others, 1994)

Tw **Wahmonie Formation (Miocene)**—Moderately resistant, purple, brown, olive-gray, black, gray, and red, crystal-rich andesite, dacite, and rhyodacite lava flows, flow breccia, and volcanic mudflow breccia, as well as white, gray, pink, green, and brown, generally well bedded tuff, tuff breccia, and tuffaceous sandstone and conglomerate (Ekren and Sargent, 1965; Poole and others, 1965a, b). Volume of the formation about 90 km^3. Contains abundant plagioclase, conspicuous biotite, and minor hornblende, orthopyroxene, clinopyroxene, and olivine, and sparse quartz. Plagioclase and orthopyroxene increase upward in the sequence, and biotite decreases upward. Locally hydrothermally altered. Poole and others (1965a, b) defined the map unit and the Salyer Formation (Tws), which underlies the Wahmonie, and they noted that the two formations locally intertongue at their contact. We retain the original usage because the units are somewhat different lithologically and seem to make up different eruptive sequences from centers of different ages. The distribution of the rocks of both formations is similar (Poole and others, 1965a), west of Frenchman Flat. The source area of the Wahmonie appears to be a cluster of apparent stratovolcanoes centered near Wahmonie, which is a ghost town north of Skull Mountain. Intrusive rocks of Wahmonie (Twi) cored the centers of some volcanoes. $^{40}Ar/^{39}Ar$ age is 13.0 Ma (Sawyer and others, 1994). Includes, north of Frenchman Flat, thin bedded tuff of the Calico Hills Formation (Tac) in upper part (Hudson, 1997). Maximum thickness about 1,100 m

Twi **Intrusive rocks of Wahmonie (Miocene)**—Moderately resistant, light-gray, porphyritic granite, granodiorite, rhyolitic, and andesitic intrusions north of Wahmonie (Ekren and Sargent, 1965). Includes intrusive breccia. Some intrusions too small to be shown at map scale (Poole and others, 1965b). Unit intrudes the Salyer Formation (Tws) and believed to be the source intrusions of the Wahmonie Formation (Tw) (Frizzell and Shulters, 1990). Contains plagioclase, pyroxene, and biotite phenocrysts in a groundmass of quartz and alkali feldspar. Includes, in the Kawich Range at the northern edge of the mapped area, a small rhyolite intrusion whose age is poorly known and which contain sparse phenocrysts of quartz, alkali feldspar, and biotite (Orkild and others, 1969)

Tws **Salyer Formation (Miocene)**—Soft to moderately resistant, purple, red, gray, and green, volcanic mudflow breccia; lavender, purple, red, and gray, crystal-rich, dacitic lava flows, flow breccia, and lahars; gray, green, yellow, pink, and orange lithic-rich ash-flow tuff and tuff breccia; and reddish-brown, pink, gray, and red, tuffaceous sandstone and claystone (Ekren and Sargent, 1965; Poole and others, 1965a, b). Source area interpreted to be several kilometers east of the Wahmonie center. Contains plagioclase, subordinate biotite, hornblende, orthopyroxene, and clinopyroxene. Maximum thickness about 600 m

Tgp **Pre-basin-range sedimentary rocks, undivided (Miocene)**—Soft to moderately resistant, fluvial and lacustrine conglomerate, claystone, siltstone, sandstone, limestone, and tuff of several sequences that predate the basin-fill sediments, undivided (Tgy) and that generally rest unconformably on older rocks. The map unit predates rocks of the Timber Mountain Group (Minor and others, 1993; Sawyer and others, 1995; Carr and others, 1996; Wahl and others, 1997). Unit is synextensional but is interpreted to predate the major basin-range extensional episode in the area, which created the modern topography. The most extensively exposed sequence is the rocks of Pavits Spring, which is exposed in the Rock Valley area of the southern Nevada Test Site. This unit is a light-gray, light- to dark-brown, yellow, greenish-gray, locally tuffaceous conglomerate, claystone, siltstone, and sandstone, as well as minor amounts of limestone, bedded airfall tuff, and two nonwelded crystal-poor, rhyolitic ash-flow tuff units (Hinrichs, 1968). Unit contains sparse plant and fish fossils. The upper ash-flow tuff, as much as 60 m thick, is a light-yellowish-gray nonwelded tuff containing sparse lithic clasts and about 5 percent phenocrysts of plagioclase, sanidine, and quartz and minor biotite. The lower ash-flow tuff, as much as 25 m thick, is a light-gray, nonwelded tuff containing abundant lithic clasts and about 3 percent phenocrysts of plagioclase, sanidine, and quartz and minor biotite and hornblende (Hinrichs, 1968). Clasts in sedimentary beds consist of Paleozoic quartzite and limestone as well as Tertiary ash-flow tuff and lava flows. The provenance of clasts of Tertiary ash-flow tuffs, which are as young as the 18.3-Ma Hiko Tuff (Carr and others, 1996), in the base of the rocks of Pavits Spring suggest that the clasts in the map unit were derived from the east and were transported in west- or southwest-flowing streams (Barnes and others, 1982; J.C. Yount and G.L. Dixon, unpub. data., 1997). Whereas the rocks of Pavits Spring must be younger than 18.3 Ma, airfall tuff near the base of the unit has a K-Ar age of 15.8 Ma (J.C. Yount, unpub. data, 1989). The rocks of Pavits Spring contains interbedded tuff correlated with the 12.9-Ma Calico Hills Formation and the 13.5- to 13.1-Ma Crater Flat Group (Carr and others, 1996). Parts of the map unit probably are the lateral equivalents of the Tunnel Formation (Tn) and tuff of Sleeping Butte (Tqs). Map unit includes light-brown to yellowish-brown sandstone, siltstone, and tuff south of Crater Flat (Swadley and Carr, 1987; their unit Tts, southeast of Black Marble) that contain an ash bed that has a K-Ar age of 14.9 Ma (J.C. Yount, unpub. data, 1989). Map unit also includes, 10 km east of Beatty, Nev., the rocks of Joshua Hollow of Monsen and others (1992), made up of ash-flow tuff and lacustrine, siltstone, and fluvial conglomerate. These rocks, which contain fossil wood, are intruded in this area by a quartz latite dike that has a K-Ar age of 13.9 Ma (Monsen and others, 1992). In the Bullfrog Hills, includes the sedimentary rocks (Ts_3, Ts_2, Ts_1), bedded tuff (Tba), and ash-fall tuff (Tas) of Maldonado (1990). About 15 km southwest of Big Dune, in the southeastern Funeral Mountains, unit includes sandstone, conglomerate, and siltstone (Tcs unit of Swadley and Carr, 1987; Tsa unit of Wright and Troxel, 1993) that rests in fault contact with older rocks, that contain a tuff bed dated by K-Ar at 14.9 Ma (Swadley and Carr, 1987), and that is overlain by a channel fill of Rainier Mesa Tuff (Tmr). In the eastern Grapevine and northern Funeral Mountains, map unit includes sandstone, conglomerate, siltstone, and tuff (Tsa and Tss) of Wright and Troxel (1993) as well as the "unnamed tuff sequence" and "green conglomerate facies" of Reynolds (1969); the latter contains a tuff that yielded a K-Ar age of about 17 Ma (Carr and others, 1996). Near Mount Helen in the northwestern part of the mapped area, map unit also includes a 300-m-thick, tan and brown, fluvial and lacustrine, locally tuffaceous, cross-bedded conglomeratic sandstone, siltstone, and limestone, as well as ash-flow tuff; the ash-flow tuff includes the tuff of Tolicha Peak (Tqt) and the dacite of Mount Helen (Tqm) and is mineralogically similar to the lower rhyolite of Quartz Mountain (Tqe) (Rogers and others, 1968; Wahl and others, 1997). Ekren and others (1971) interpreted this unit as an upper intracaldera sedimentary fill to their Mount Helen caldera. Map unit includes 60 m of gray, brown, and yellow tuffaceous sandstone and bedded tuff north of the Black Mountain caldera (Noble and Christiansen, 1968). Thickness of the rocks of Pavits Spring about 1,800 m (Hinrichs, 1968), whereas the thickness of the rocks in the Funeral Mountains may be about 1,200 m (Wright and Troxel, 1993)

Txo **Older landslide and talus breccia (Miocene)**—Monolithologic breccia, heterolithic angular gravel, and coarse sandstone. Depending on the local source rock, breccia debris is commonly Paleozoic dolomite or Precambrian quartzite. Includes small landslide masses north of Springdale that predate Tiva Canyon Tuff (Tpc) and postdate Grouse Canyon Tuff (Tbg) and are interpreted to have slid off scarps caused by mapped faults in the area (Minor and others, 1998). Unit overlies the 13.7-Ma Grouse Canyon Tuff (Tbg) southeast of Tolicha Peak. Unit consists of well-bedded boulder conglomerate and sandstone that overlie the 15.3-Ma Redrock Valley Tuff (Tfr) at the northern end of Mine Mountain. Locally as much as 50 m thick

CRATER FLAT GROUP (MIOCENE)

A calc-alkaline assemblage of ash-flow tuff and related lava flows and airfall tuff. The rocks of the group are distinguished in their phenocrysts by high relative quartz and by Fe-rich mineralogy. Rocks of the group were erupted between 13.5 and 13.1 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). The sources of the ash-flow sheets are not well known. Most are exposed south of the Timber Mountain caldera complex and this evidence in part led to the suggestion (Carr and Parrish, 1985; W.J. Carr and others, 1986; Carr, 1988, 1990) that their source was a caldera complex beneath Crater Flat. The southward distribution could be explained by an alternative conclusion, however, drawn from studying provenance of clasts in sedimentary rocks of comparable age, that the regional slope was southward during Crater Flat eruptions. The principal ash-flow sheet of the group is the Bullfrog Tuff (Tcb), but it was recognized early (Byers and others, 1976a, among others) that it resembled and had a similar stratigraphic position to outflow tuffs ("Stockade Wash Tuff" of Byers and others, 1976b) exposed east and northeast of the Timber Mountain caldera complex (Frizzell and Shulters, 1990) and to thick tuffs ("lithic-rich ash-flow tuff" of Orkild and others, 1969) exposed within a buried caldera ("Silent Canyon caldera") on Pahute Mesa, north of the Timber Mountain caldera complex. Peralkaline tuffs of the Belted Range Tuff (Sargent and others, 1965), which formerly were defined to consist of the Grouse Canyon Member and the underlying Tub Spring Member (Sargent and others, 1965), were suggested to have been derived from the Silent Canyon caldera (Byers and others, 1976a). Later work interpreted that the lithic-rich ash-flow tuff represented intracaldera tuffs also derived from the Silent Canyon caldera complex and that they were best correlated with the Stockade Wash Tuff (Sawyer and Sargent, 1989). Correlation of the Bullfrog Tuff with the Stockade Wash Tuff, the lithic-rich ash-flow tuff, and the volcanics of Area 20 led to recognizing that the Bullfrog Tuff (Tcb) was derived from a separate caldera, called the Area 20 caldera, inset into the Silent

Canyon caldera complex (Sawyer and Sargent, 1989; Minor and others, 1993; Sawyer and others, 1994, 1995). At least three drill holes show that the Bullfrog was ponded to a thickness of at least 600 m in the caldera. The Bullfrog Tuff was, at least in part, erupted from the Area 20 caldera, and its margin was portrayed on the regional maps of Minor and others (1993), Sawyer and others (1995), and Wahl and others (1997) based on drill data east and north of holes UE-20f and UE-18r. Early geophysical studies (Kane and others, 1981) suggested that the Area 20 caldera margin extends southward beneath the Timber Mountain caldera complex, whose eruption partly obliterated and concealed the southern margin. The large gravity anomaly in the Pahute Mesa area, and the distribution of many tuffs that center on Pahute Mesa, however, indicate that more tuffs besides the Grouse Canyon Tuff (Tbg) were derived from the area (McKee and others, 1999). Although it appears likely that the Bullfrog Tuff was not derived from the Crater Flat area (Scott, 1990; Sawyer and others, 1994), conceivably its source caldera could extend south of the Timber Mountain dome (Sawyer and others, 1994). Sawyer and others (1994), in fact, suggested that the northern half of a caldera may be exposed near Tram Ridge, north of Bare Mountain (Snyder and Carr, 1984); if so, this caldera may be the source of the Tram Tuff (Tct) (W.J. Carr and others, 1986). Fridrich (1999) saw no evidence that Crater Flat represents a caldera and interpreted the basin as a graben that formed after emplacement of the Crater Flat Group; he noted, however, that a caldera of Crater Flat Tuff age or older cannot be ruled out under the basin. On the basis of a seismic profile across Crater Flat, as well as other geophysical data, Brocher and others (1998) also interpreted Crater Flat to be underlain by a north-striking graben within the Amargosa Desert rift zone, which extends southward beneath Amargosa Desert. The Prow Pass Tuff (Tcp) does not have an identified source, but it may be too small to have formed a caldera (W.J. Carr and others, 1986)

Tcp **Prow Pass Tuff**—Local, soft to moderately resistant, light-olive gray, light-gray, reddish-orange, light-red, crystal-poor, partly to moderately welded, crystal-rich rhyolite ash-flow tuff (Maldonado, 1985; Moyer and Geslin, 1995). Its volume is about 45 km^3. Compound cooling unit that contains about 10 percent phenocrysts, consisting of about 4 percent each of plagioclase and sanidine, 1 percent quartz, and less than 1 percent each of biotite and orthopyroxene. Location of source unknown. Includes airfall tuff at base. Contains sparse brown lithic inclusions. Distinguished from other units by its orthopyroxene and biotite abundance and by normal magnetic polarity. Most exposures are in a small area just northwest of Yucca Mountain, but drilling indicates that it is more extensive in the subsurface. Also encountered in drill holes and exposed between Crater Flat and Frenchman Flat (Carr and others, 1984; Moyer and Geslin, 1995). $^{40}Ar/^{39}Ar$ age is 13.1 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Exposed thickness at least 100 m; as much as 160 m thick in drill holes

Tcg **Latite of Grimy Gulch**—Local moderately resistant, dark-gray and black, crystal-poor, dacitic lava flows erupted on the flank of the Silent Canyon caldera complex at the southern end of Kawich Valley. Contains plagioclase and olivine, sparse clinopyroxene, and rare sanidine and quartz. Includes feeder dike. Formerly called latite lavas of South Kawich Valley (Sargent and Orkild, 1973). Normal magnetic polarity. Maximum thickness 80 m

Tcb **Bullfrog Tuff**—Voluminous (about 650 km^3), moderately resistant, generally lavender, light-orange, and red, crystal-poor, poorly to densely welded, rhyolite ash-flow tuff. Outflow tuff is generally a simple cooling unit with about 13 percent phenocrysts, consisting of about 6 percent plagioclase, 5 percent sanidine, 3 percent resorbed quartz, and less than 1 percent each of biotite and hornblende. Has sparse to abundant lithic clasts. Widely distributed south, southwest, southeast, and north of the Timber Mountain caldera complex (Carr and others, 1984) but also includes, on the eastern side of the Timber Mountain caldera complex, an outflow lobe that was formerly (Byers and others, 1976a, b; Frizzell and Shulters, 1990) called the Stockade Wash Tuff. Sawyer and others (1994) correlated it with the Bullfrog Tuff based on their identical petrology and paleomagnetic signature (Hudson and others, 1994). Intracaldera Bullfrog Tuff in the Area 20 caldera is compositionally zoned, from an upper rhyolite that contains sanidine, plagioclase, and quartz, sparse biotite, and rare hornblende, to a lower rhyolite that contains sanidine and quartz, sparse plagioclase, and rare biotite. The intracaldera tuff contains abundant lithic inclusions and is intertongued with caldera-collapse breccia (Sawyer and others, 1994). Map unit is distinguished by its high relative quartz content, sparse to rare biotite and hornblende, Fe-rich mafic minerals, general absence of sphene, and normal magnetic polarity. $^{40}Ar/^{39}Ar$ age is 13.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Normal magnetic polarity. On the western side of Yucca Flat and in Rainier Mesa and the southern Belted Range, thin bedded tuff of the Deadhorse Flat Formation (Tbd), the Wahmonie Formation (Tw), Calico Hills Formation (Tac), Tiva Canyon Tuff (Tpc), rhyolites of middle Paintbrush Group (Tpm), Topopah Springs Tuff (Tpt), and rhyolite of Fluorspar Canyon (Tmrc) are included in the mapped unit. Maximum thickness of outflow tuff generally about 120 m, but it is 220 m thick in the Bullfrog Hills (Maldonado and Hausback, 1990); maximum thickness in drill holes into intracaldera tuff about 680 m

Tcr **Rhyolite of the Crater Flat Group**—Moderately resistant, commonly flow banded, crystal-poor rhyolite lava flows and associated tephra and ash-flow tuff. Rocks typically contain plagioclase, quartz, and sanidine, subordinate biotite, and sparse hornblende. The only rocks in the map unit that are exposed were called the rhyolite of Prospector Pass in northwestern Crater Flat (Fridrich and others, 1999a), which consists of light-olive-gray, black, medium-greenish-gray, and brick-red lava flows and interbedded, petrographically similar block-and-ash-flow tuff that contains abundant lithic fragments of the flow rock. The rhyolite of Prospector Pass is petrographically similar to the Bullfrog Tuff (Tcb) except that hornblende contents in the Prospector Pass are more variable. This unit has a $^{40}Ar/^{39}Ar$ age of 13.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Other rocks included in the rock unit are local lava flows encountered in drill holes in Pahute Mesa (Carr and others, 1996; Wahl and others, 1997). Thickness at least 100 m

Tct **Tram Tuff**—Resistant, light-brown, light-olive-gray, and light-brownish-gray, mostly densely welded but locally nonwelded to partially welded, crystal-poor, rhyolite ash-flow tuff. Best exposed and encountered in drill holes in the Tram Ridge, Crater Flat, and Yucca Mountain areas (Carr and others, 1984). Its volume is about 170 km^3. Generally consists of about 11 percent phenocrysts, consisting of about 4 percent quartz, 3 percent each of plagioclase and sanidine, and less than 1 percent biotite. Contains abundant lithic fragments of rhyolite and intermediate-composition flow rocks. Distinguished by subequal amounts of quartz, plagioclase, and sanidine and by reversed magnetic polarity. Possibly erupted from northern Crater Flat (W.J. Carr and others, 1986). $^{40}Ar/^{39}Ar$ age is 13.45 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness about 250 m; maximum thickness in drill holes about 270 m (Carr and others, 1984)

BELTED RANGE GROUP (MIOCENE)

A voluminous assemblage of peralkaline ash-flow tuff and related lava flows and airfall tuff. Eruption of rocks of the group took place between 13.85 and 13.5 Ma (Sawyer and others, 1994). Early eruptions of the group resulted in the comendite of Split Ridge (Tbgs), consisting of lava flows and related tuffs petrologically related to the succeeding eruptions. The main unit in the group is the Grouse Canyon Tuff (Tbg), whose eruption at 13.7 Ma resulted in collapse of the Grouse Canyon caldera. The Grouse Canyon caldera is buried by younger deposits but coincides with the northeastern part of a major gravity low (accompanying gravity map by Ponce and others, 1999). Existence of the Grouse Canyon caldera has been further verified by many drill holes (greater than 600 m depth) in Pahute Mesa (Byers and Cummings, 1967; Orkild and others, 1968, 1969; Byers and others, 1976b; R.G. Warren, unpub. data, 1998). Because the Grouse Canyon caldera is buried, the locations of its structural and topographic margins are poorly constrained (Sawyer and Sargent, 1989; Sawyer and others, 1994); in this map we apply geophysical data to interpret these relations. The Grouse Canyon caldera, as well as the Area 20 caldera, are parts of the Silent Canyon caldera complex (Sawyer and Sargent, 1989; Minor and others, 1993; Sawyer and others, 1995). We use the name Silent Canyon caldera complex for the large gravity low as well as the distribution of outflow tuffs surrounding it, which indicate that the complex is the source of several regional ash-flow sheets. The northwestern topographic wall of the Grouse Canyon caldera is expressed at the surface by inward dips of younger tuffs of the Timber Mountain Group that were plastered on the walls. After subsidence of the Grouse Canyon caldera, thick peralkaline lava flows and related tuff of the Deadhorse Flat Formation (Tbd) accumulated in the caldera and overflowed northward. Rocks of the Belted Range Group are distinguished by their peralkaline mineralogy (high alkali feldspar and low plagioclase content, absence of biotite and hornblende, and presence of Fe-rich clinopyroxene and fayalitic olivine) and chemistry (high iron and low alumina; high concentrations of zirconium and rare-earth elements)

Tbd **Deadhorse Flat Formation**—Mostly resistant, mostly gray, lava flows and related tuff. Sequence has a volume of about 120 km^3. Deposited after collapse of the Grouse Canyon caldera, filling the upper part of the caldera, then overflowing the caldera to the north, where it is exposed mostly in the southern Kawich Range. Mineralogy is variable among the various rock types, ranging between crystal-rich comendite and trachyte to crystal-poor to aphyric comendite. Phenocrysts include sodic sanidine and subordinate clinopyroxene and fayalitic olivine. Map unit locally includes the comendite of Basket Valley (Tbdb) near its base where this unit is not mapped separately. Map unit also includes the comendite of Lambs Canyon, which contains abundant quartz phenocrysts, has reversed magnetic polarity, and a $^{40}Ar/^{39}Ar$ age of 13.5 Ma (Sawyer and others, 1994). Also includes the comendite of Kaw Station, which is aphyric; the comendite and low-silica comendite of Saucer Mesa, which has normal polarity; the comendite of Chartreuse, which contains sparse quartz and rare plagioclase; and the trachyte of Muenster, which contains abundant alkali feldspar and rare plagioclase (Wahl and others, 1997). Formation distinguished by phenocryst mineralogy, particularly the general absence of biotite, hornblende, and plagioclase, and by geochemistry. Formerly called the upper lava flows of the rhyolite of Saucer Mesa (Orkild and others, 1969; Sargent and Orkild, 1973) and the volcanics of Saucer Mesa (Sawyer and Sargent, 1989). Map unit has isotopic ages that range from 13.85 to 13.5 Ma (Sawyer and others, 1994). Most subunits of the formation occur in the subsurface of Pahute Mesa, where they have been penetrated by drilling and individually have a thickness of as much as 1,600 m. Maximum exposed thickness about 150 m

Tbdb Comendite of Basket Valley—Resistant, brownish-red, light-brown, and gray, crystal-rich to crystal-poor comendite lava flows and related black, brown, reddish-brown, and green, crystal-poor, nonwelded to densely welded ash-flow tuff and airfall tuff. Locally mapped in the southern Kawich Range near the base of the Deadhorse Flat Formation (Tdb); subsurface drilling indicates that only the comendite of Chartreuse (included in the Deadhorse Flat Formation) is older. Distinctive by the rheomorphic character of the lava flows. Contains alkali feldspar and rare quartz, clinopyroxene, and fayalitic olivine. Chemical analyses indicate that the map unit is strongly enriched in light rare-earth elements. Map unit includes low-silica comendite lava flows north of Apache Tear Canyon. Mapped by Orkild and others (1969) and Sargent and Orkild (1973) as the lower lava flows of the rhyolite of Saucer Mesa and the underlying tuff of Basket Valley. Normal magnetic polarity. Maximum thickness 150 m

Tbg **Grouse Canyon Tuff**—Moderately resistant, typically greenish-gray, bluish-gray, and rusty-red, densely welded, crystal-poor (less than 1 percent), comendite ash-flow tuff. Includes a greenish-black basal vitrophyre. Lower part prominently flow-foliated and contains abundant compacted pumice that has been drawn out a meter or more. Erupted from the Grouse Canyon caldera, with a volume of about 210 km^3. Compositionally zoned from an upper comendite, containing less than 1 percent each of alkali feldspar and quartz, to a lower aphyric comendite (Sawyer and Sargent, 1989). Groundmass arfvedsonite is common in the upper welded part of the tuff. Includes a basal aphyric bedded tuff (“tunnel bed 5” of Carroll, 1989, fig. 2; bedded member of the Grouse Canyon Tuff of Sawyer and others, 1994) that consists of multiple normally graded, 3- to 15-m thick beds, each of which contain basal ash and pumice grading upward to fine ash. The bedded member is a distinctive marker and is more widely distributed to the east and southeast of the caldera than the ash-flow sheet. Unit characterized by its high content of alkali feldspar relative to other phenocrysts, its strong geochemical zonation, its color, and its normal magnetic polarity. $^{40}Ar/^{39}Ar$ age is 13.7 Ma (Sawyer and others, 1994). Based on drill-hole data, its maximum intracaldera thickness is 575 m. The maximum exposed thickness of the outflow facies of the ash-flow tuff is 110 m, whereas the maximum exposed thickness of the underlying bedded tuff is 150 m

Tbgs **Comendite of Split Ridge**—Moderately resistant, greenish-gray and brown, flow-foliated, aphyric comendite and flow-foliated, crystal-rich to crystal-poor, trachyte lava flows and minor related tuff (Hinrichs and others, 1967; Orkild and others, 1969). Volume at least 20 km^3. Unit represents precursor deposits of the Grouse Canyon caldera that are exposed mostly at Split Ridge, southeast of the Grouse Canyon caldera. Trachyte lava flows, which are locally exposed along the western margin of southern Kawich Valley, contain sanidine, olivine, and clinopyroxene. $^{40}Ar/^{39}Ar$ age is 13.85 Ma (Sawyer and others, 1994). Comendite has normal magnetic polarity. Maximum thickness about 380 m. Includes pyroclastic deposits as much as 500 m thick, mapped as ash-flow tuff and minor bedded reworked tuff by Orkild and others (1969), intercalated with the lava flows

Tob **Older basalt (Miocene)**—Resistant, gray to black, basalt and basaltic andesite lava flows. Locally crystal rich, with olivine and clinopyroxene, and subordinate to rare plagioclase. Underlying the tuff of Twin Peaks (Tot) on the northern rim of Yucca Flat, and underlying the Grouse Canyon Tuff (Tbg) west of Black Mountain. Basalt near Yucca Flat has normal magnetic polarity. Maximum exposed thickness at least 50 m

Trl **Lithic Ridge Tuff (Miocene)**—Moderately resistant, grayish-yellow-green, light-brownish-gray, light-olive-gray, and light-yellow, crystal-poor, partly welded, rhyodacitic ash-flow tuff containing abundant (as much as 50 percent by volume) distinctive lithic clasts of intermediate-composition flow rocks (W.J. Carr and others, 1986). Best exposed in the Shoshone Mountain area and the Bullfrog Hills, and well known in drill holes in the Yucca Mountain area (Carr and others, 1984). Volume about 250 km^3. Contains about 10 percent phenocrysts, consisting of about 5 percent plagioclase, 3 percent sanidine, less than 1 percent each of quartz and biotite, and traces of sphene. Includes reworked bedded tuff at the base. Locally intercalated with the rocks of Pavits Spring in the Skull Mountain area (Poole and others, 1965b). Caldera source unknown but has been suggested to be near northern Crater Flat (W.J. Carr and others, 1986), on the east side of which it is thickest. Based on similar age and petrology, genetically related to the rhyolite of Picture Rock (Trr) and dikes of Tram Ridge (Trd), which appear to be precursor units to the Lithic Ridge Tuff (W.J. Carr and others, 1986). Distinguished by its mineralogy and its reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 14.0 Ma (Sawyer and others, 1994). Reported by W.J. Carr and others (1986) to be as much as 300 m thick in drill holes at Yucca Mountain and to have a maximum exposed thickness of about 275 m

Trr **Rhyolite of Picture Rock (Miocene)**—Resistant, dark-grayish-green, maroon, and dark-brown, crystal-rich, dacitic and subordinate rhyolite and latite lava flows and genetically related ochre and light-green, bedded airfall tuff. Its volume is about 60 km^3. First recognized from exposures in a small area on Tram Ridge, north of Bare Mountain (W.J. Carr and others, 1986; Minor and others, 1993), and therefore formerly called the lava of Tram Ridge (Minor and others, 1993; Sawyer and others, 1994). Encountered extensively in drill holes in Yucca Mountain, where it was called andesite and dacite in drill holes G-1 and G-2; also correlated with the calc-alkaline tephra in beds 4K and 4J of the Tunnel Formation (Tn) (see Carroll, 1989, fig. 2;

Sawyer and others, 1994). Formerly more widespread inasmuch as the dikes of Tram Ridge (Trd) record probable vents for the unit at Bare Mountain. Also probably genetically related to the Lithic Ridge Tuff (Trl) based on their similar age and petrology. Contains about 17 percent phenocrysts, consisting of about 15 percent plagioclase, 1 percent sanidine, less than 1 percent each of quartz and hornblende, and traces of sphene. Interpreted to be genetically related to, as a precursor flow sequence, the eruption of the Lithic Ridge Tuff (Trl), based on similar petrology (W.J. Carr and others, 1986). Reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 14.0 Ma (Sawyer and others, 1994). Map unit includes hydrothermally altered, intermediate-composition lava flows in the Bullfrog Hills, which may correlate with unit B in the subsurface of Yucca Mountain (Carr and others, 1996). Map unit includes 250 m of gray, orange, and reddish-brown, crystal-poor, quartz-latite lava flows mapped just north of the topographic wall of the Rainier Mesa caldera (Hinrichs and others, 1967). Map unit also includes crystal-rich rhyolitic lava flows near Quartz Mountain and Tolicha Peak because these also contain plagioclase, subordinate biotite, alkali feldspar, and hornblende, rare quartz, and traces of sphene. Maximum exposed thickness about 450 m

Trd **Dikes of Tram Ridge (Miocene)**—Moderately resistant, mostly tan and locally red, crystal-rich rhyolite and dacite dikes that cut Paleozoic rocks at Bare Mountain. Contains plagioclase and subordinate biotite, sparse sanidine, hornblende, and sphene, and rare quartz. Characterized by its relatively abundant plagioclase and biotite and its reversed magnetic polarity. Interpreted on the basis of its similar petrology, age, and location to be the feeders for the rhyolite of Picture Rock (Trr) and to have a tuff phase, the Lithic Ridge Tuff (Trl). $^{40}Ar/^{39}Ar$ age is 14.0 Ma (Sawyer and others, 1994)

Tn **Tunnel Formation (Miocene)—**Soft to moderately resistant, multicolored (mostly shades of red, orange, ocher, black, and white) sequence of bedded airfall tuff and nonwelded ash-flow tuff of several, mostly rhyolitic compositions. Its volume is about 50 km^3. Exposed mostly in the eastern part of the mapped area, especially Rainier Mesa, but encountered in drill holes in the subsurface of Yucca Flat and locally exposed in the western part of the mapped area, where it fills valleys in pre-existing topography. Unit name formalized by Sawyer and others (1994) for “tunnel beds 3 and 4” (see Carroll, 1989, fig. 2) encountered in a series of tunnels used for underground nuclear tests on the eastern side of Rainier Mesa (Gibbons and others, 1963; Hansen and others, 1963); the lower part of these rocks are mapped herein as the older Tunnel Beds (Ton). Map unit underlies the Lithic Ridge Tuff (Trl) and overlies the Tub Spring Tuff (Tub). Upper beds (units 4K and 4J of Carroll, 1989) consist of interlayered tephra associated with peralkaline sources (comendite of Quartet Dome, Tfq) and metaluminous sources (rhyolite of Picture Rock, Trr). Underlying beds 4H and 4G (Carroll, 1989) may be derived from calc-alkaline sources (tuff of Sleeping Butte, Tgs) (Carr and others, 1996). Beds 4H and 4G have a $^{40}Ar/^{39}Ar$ age of 14.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). The middle beds (4F through 4A, also 3D of Carroll, 1989), which have slightly greater quantities of phenocrysts progressively lower in the stratigraphic section, contain sanidine, sparse quartz and plagioclase, and rare clinopyroxene and biotite, and for bed 3D, also rare hornblende. Lower beds are crystal-poor, containing plagioclase and rare sanidine, quartz, and biotite (Minor and others, 1993). In northwestern Yucca Flat, Lithic Ridge Tuff (Trl) is locally included where this unit is too thin to be mapped separately. In the Belted Range, the map unit consists largely of bedded tuff derived from the comendite of Quartet Dome (Tfq). A section of tuffs that underlies the 14-Ma rhyolite of Picture Rock (Trr) in the western part of the map area is tentatively assigned to the Tunnel Formation based on similar lithology and age range. Maximum thickness about 200 m in eastern part of map area and at least 500 m in the Grapevine Mountains and Bullfrog Mountains in western part of map area

Tfq **Comendite of Quartet Dome (Miocene)**—Soft to resistant, gray and grayish-red, flow-foliated, crystal-poor to crystal-rich, comendite volcanic domes, lava flows, and related airfall tuff exposed at the southern margin of Kawich Valley (Sargent and Orkild, 1973) and northwest of Rainier Mesa (Hinrichs and others, 1967; Orkild and others, 1969). Contains sanidine, subordinate quartz, and sparse fayalitic olivine, and rare clinopyroxene. Distinguished by peralkaline mineralogy, high relative quartz content, and normal magnetic polarity. Correlates with bed 4J of Carroll (1989, fig. 2) of the Tunnel Formation (Tn). Possibly related to the magmatism that later culminated in the eruption of the Grouse Canyon Tuff (Tbg). Unit has a $^{40}Ar/^{39}Ar$ age of 13.9 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Maximum thickness about 250 m

Volcanic rocks of Quartz Mountain (Miocene)—Sequence of mostly local metaluminous rhyolite to quartz trachyte lava flows, ash-flow tuff, and airfall tuff that are exposed in the northwestern part of the mapped area but whose relationship to each other is not well known and whose sources, though local, are mostly buried by younger rocks (Minor and others, 1998). Also includes mineralogically similar units from other parts of the mapped area. As noted by Wahl and others (1997), many subunits of the volcanic rocks of Quartz Mountain were formerly mapped as the tuff of Sawtooth Mountain and the tuff of Buck Springs by Maldonado (1990) and Maldonado and Hausback (1990). Geophysical maps presented as part of this report show many circular features that may belong to one or more calderas in the northwestern part of the mapped area, but no geophysical data provide sufficient evidence to draw the Mount Helen caldera on the geologic map of this report. Erupted between about 14.6 and 14.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998)

Tqu Upper rhyolite—Soft to moderately resistant, mostly gray, rhyolite lava flows and related ash-flow tuff and airfall tuff from several vents that postdate the tuff of Sleeping Butte (Tqs). Includes the late rhyolite of Quartz Mountain of Fridrich and others (1999a), which is the upper part of the rhyolite of Quartz Mountain of Minor and others (1993). Also includes, in the eastern part of the mapped area, the tuff of Cache Cave Draw, which is an aphyric ash-flow tuff with reversed magnetic polarity, and the rhyolite of Coyote Cuesta (Wahl and others, 1997). Maximum thickness about 60 m

Tqs Tuff of Sleeping Butte—Two soft to moderately resistant, grayish-brown, lithic-rich, metaluminous rhyolite ash-flow cooling units and associated bedded airfall tuff exposed in the western part of the mapped area (Minor and others, 1998). The upper tuff is partly welded and crystal poor, containing alkali feldspar and rare biotite. The lower tuff is thicker, more widespread, more densely welded, and is zoned from an upper crystal-rich, low-silica rhyolite to a lower relatively crystal-poor rhyolite. The lower has 19 percent phenocrysts, consisting of about 10 percent sanidine, 5 percent plagioclase, 4 percent quartz, and less than 1 percent each of biotite and hornblende. It is distinguished by its high relative sanidine, alaskitic granite lithic clasts, and normal magnetic polarity. Source area is a probable buried caldera near Sleeping Butte, which is about 12 km north of Oasis Valley. Age is 14.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Maximum thickness of both tuffs about 400 m

Tqh Middle rhyolite—Moderately resistant, gray, flow-foliated, rhyolite to dacite lava flows, volcanic domes, and related feeder dikes and plugs, block- and ash-flow tuff, airfall tuff, reworked airfall tuff, and local sedimentary rocks (Noble and Christiansen, 1968; Minor and others, 1998). Contains sanidine, plagioclase, and quartz, sparse biotite and local hornblende, rare clinopyroxene, and abundant traces of sphene. Bedded tuff is crystal- and lithic-rich. Includes local tuff breccia. Map unit locally includes distal parts of the tuff of Sleeping Butte. Lava flows have reversed magnetic polarity. Erupted at about 14.3 Ma (Minor and others, 1998; M.A.

Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Maximum thickness in any one place of the lava flows is at least 250 m, and maximum thickness of the bedded tuff is at least 300 m

Tqt Tuff of Tolicha Peak—Distinctive, soft, orange, pinkish-brown, gray, and white, crystal-poor and lithic-poor, partially welded rhyolite ash-flow tuff with a platy and hackly weathered appearance. Contains about 0.5 percent phenocrysts, consisting of plagioclase, sanidine, and quartz. Has an age of about 14.3 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Map unit contains lithic blocks as long as 100 m on the southern side of Tolicha Peak, just south of a fault that may be the northern margin of its source caldera (C.J. Fridrich, unpub. data, 1999). May correlate with beds 3B and 3C (Carroll, 1989) of the Tunnel Formation (Tn). Normal magnetic polarity. Maximum thickness 300 m

Tqe Lower rhyolite—Moderately resistant, mostly gray, mostly crystal-rich, rhyolite to dacite lava flows and genetically related and compositionally similar tuff and tuffaceous sedimentary rocks. Contains quartz, plagioclase, sanidine, minor biotite, rare hornblende, and traces of sphene. Commonly hydrothermally altered. Maximum thickness about 200 m

Tqm Dacite of Mount Helen—Moderately resistant, gray, crystal-rich, dacitic lava flows, flow breccia, and hypabyssal intrusions in the Mount Helen area (Rogers and others, 1968). Makes up a clear vent area in the center of a possible caldera (Ekren and others, 1971). Contains plagioclase, biotite, and hornblende, and subordinate large (maximum size at least 1 cm) quartz. Maximum thickness about 300 m

Tuo **Comendite of Ocher Ridge (Miocene)**—Local unit of resistant, light-gray to reddish-gray, moderately crystal-poor, peralkaline lava flows and related airfall tuff along the southern margin of Kawich Valley. Partly made up of the rhyolite of Ocher Ridge of Sargent and Orkild (1973). Contains sanidine and quartz and rare clinopyroxene. Normal magnetic polarity. Maximum thickness at least 300 m

Tub **Tub Spring Tuff (Miocene)**—Moderately resistant, gray, tan, and red, partially to densely welded, peralkaline compound ash-flow cooling unit well exposed in the Belted Range and northeast of Yucca Flat (Noble and others, 1968). Its volume is estimated at 130 km^3. Compositionally zoned from an upper crystal-rich comendite, containing sanidine, subordinate quartz, and sparse clinopyroxene and fayalitic olivine, to a lower crystal-poor comendite, containing sanidine and quartz and rare plagioclase and biotite. Distinguished by its high relative quartz content. Formerly a member of the Belted Range Formation (Sargent and others, 1965; Noble and others, 1968) because of its peralkaline composition, but it was removed from the formation and elevated to separate formation status by Sawyer and others (1994) because it is not comagmatic with the Grouse Canyon Tuff (Tbg) (Sawyer and Sargent, 1989) and is 1.3 m.y. older than the Grouse Canyon. Caldera source unknown but may be buried beneath the eastern part of Pahute Mesa (Noble and others, 1968) or beneath southern Kawich Valley. $^{40}Ar/^{39}Ar$ age is 14.9 Ma (Sawyer and others, 1994). Normal magnetic polarity. Maximum thickness 90 m

Tue **Comendite of Emigrant Valley (Miocene)**—Moderately resistant, gray, moderately crystal-poor, flow-foliated, peralkaline lava flows and related airfall tuff exposed along the eastern flank of the Belted Range. Includes feeder dikes. Contains sanidine and quartz and rare clinopyroxene. Formerly mapped as the rhyolite lava of Kawich Valley (Sargent and Orkild, 1973). Maximum thickness about 230 m

Ton **Older tunnel beds (Miocene)**—Mostly soft, dominantly white, gray, and tan, thin- to thick-bedded, reworked rhyolite airfall tuff, nonwelded ash-flow tuff, and tuffaceous sediments. Contains abundant lithic fragments. Exposed only in the northern margin of Yucca Flat and southern margin of Kawich Valley, but extensive in the subsurface of Rainier Mesa and Yucca Flat. This is an informal name for the lower part of a sequence of tuffs (see Carroll, 1989, fig. 2) encountered in a series of tunnels used for underground nuclear tests on the eastern side of Rainier Mesa (Gibbons and others, 1963; Hansen and others, 1963); the upper part of this sequence, the Tunnel Formation (Tn), was formalized by Sawyer and others (1994). Includes tunnel beds 1 and 2 of Carroll (1989) and may locally include nonwelded tuff equivalent to older calc-alkaline tuffs of the region, including the tuff of Yucca Flat (Toy), Redrock Valley Tuff (Tor), tuff of Twin Peaks (Tot), and tuff of Whiterock Spring (included here with the tuff of Twin Peaks, Tot). Maximum exposed thickness about 500 m

Toy **Tuff of Yucca Flat (Miocene)**—Mostly soft, white, light-red, and light-olive-gray, moderately crystal-rich (about 12 percent), nonwelded to partly welded, calc-alkaline rhyolite ash-flow tuff. Its volume is about 50 km^3. Exposed around the margins of Yucca Flat and encountered in drill holes in the subsurface of Yucca Flat and Pahute Mesa. Interbedded with the rocks of Pavits Spring (Carr and others, 1984). As noted by Carr and others (1996), it was included within the tuff of Buck Spring of Maldonado (1990) and Maldonado and Hausback (1990). Consists of about 6 percent plagioclase, 3 percent sanidine, 2 percent quartz, and less than 1 percent each of biotite and hornblende. Also contains lithic fragments of rhyolite flow rock. Reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 15.1 Ma (Sawyer and others, 1994). Maximum thickness in the Yucca Flat area about 80 m

Tor **Redrock Valley Tuff (Miocene)**—Moderately resistant, orange to reddish-brown, moderately crystal-rich (about 16 percent), generally densely welded, calc-alkaline rhyolite ash-flow tuff exposed along the western and northern margins of Yucca Flat and the Gold Flat area. Volume about 360 km^3. Derived from a presumed caldera source whose location is unknown but may be in the Timber Mountain area. Consists of about 9 percent plagioclase, 6 percent sanidine, less than 1 percent each of biotite, quartz, and hornblende, and traces of sphene. Distinguished by high relative content of plagioclase and low relative content of quartz, by reversed magnetic polarity, by high welding (atypical of older ash-flow tuffs in the southwestern Nevada volcanic field), and by its red color where hydrothermally altered. $^{40}Ar/^{39}Ar$ age is 15.4 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Maximum exposed thickness about 125 m but as much as 250 m thick in a drill hole on the southern side of Rainier Mesa (Sargent and Orkild, 1973)

Tot **Tuff of Twin Peaks (Miocene)**—Moderately resistant, light-gray and medium-brown, crystal-rich, partially to densely welded, rhyolitic to dacitic compound ash-flow cooling unit exposed along the northern margin of Yucca Flat. Distinctive because it is rich in lithic fragments of lava flows, gneiss, schist, granite, and sedimentary rocks as well as small pumice fragments (Ekren and others, 1971). Contains plagioclase, sanidine, quartz, and biotite, sparse hornblende, rare clinopyroxene, and abundant traces of sphene. Ekren and others (1971) mapped this unit in and just north of the Nevada Test Site but correlated it with the Fraction Tuff of the Tonopah area, about 30 km north of the mapped area. The tuff in and north of the Nevada Test Site was called the tuff of Twin Peaks by Wahl and others (1997) because, where exposed in the mapped area, it has a different mineralogy and is younger than the Fraction Tuff of the Tonopah area, which has an age of between 20.5 and 18.7 Ma and a source probably at Tonopah (Best and others, 1989). Map unit has reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age of tuff of Twin Peaks is 15.5 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998). Has a maximum exposed thickness in the mapped area of about 150 m; maximum thickness in drill holes in Yucca Flat is 475 m (Test Wells 1 and 8). Map unit includes the tuff of Whiterock Spring, a brown, densely welded, crystal-rich, dacitic ash-flow tuff as much as 40 m thick in the southern Belted Range (Sargent and Orkild, 1973) and which has a $^{40}Ar/^{39}Ar$ age of 16.1 Ma (M.A. Lanphere, R.J. Fleck, and D.A. Sawyer, unpub. data, 1998)

Tgu **Volcanic rocks of Gold Flat, undivided (Miocene)**—Soft to moderately resistant, light-gray and red, flow-foliated, rhyolitic lava flows and nonwelded to moderately welded ash-flow tuff exposed in the Gold Flat area and north of Springdale (Ekren and others, 1971). Unit includes several mappable units that have been split up in detailed mapping, including the rhyolite of Gold Flat, tuff of Gold Flat, and rhyolite of O'Briens Knob (Rogers and others, 1968; Ekren and others, 1971; Minor and others, 1998). Units contain variable amounts of plagioclase, alkali feldspar, quartz, biotite, hornblende, clinopyroxene, and traces of sphene. Maximum thickness about 100 m

Tkr **Rhyolite of Belted Peak (Miocene)—**Moderately resistant, light- to reddish-gray and reddish-brown, moderately crystal-rich rhyolite lava flows and related airfall tuff exposed in the Belted Range. Contains variable amounts of quartz, alkali feldspar, plagioclase, biotite, and hornblende. Includes rhyolite of Belted Peak (normal magnetic polarity) and rhyolite of Johnnies Water (reversed magnetic polarity) where mapped in detail (Sargent and Orkild, 1973). Maximum thickness about 600 m

Tgo **Older sedimentary rocks, undivided (Miocene and Oligocene)**—Mostly soft, coarse-grained sedimentary rocks of widely scattered units of different poorly constrained ages, all rocks of which appear to predate the volcanic rocks of the southwest Nevada volcanic field. Locally the main rock type is conglomerate, which generally is poorly bedded and poorly cemented and which contains poorly sorted, subangular to well rounded pebbles, cobbles, and boulders of pre-Tertiary rocks, especially quartzite. The lack of volcanic clasts is diagnostic of the map unit. Includes, on the northern side of the Spotted Range, the rocks of Winapi Wash (J.C. Yount, unpub. data, 1991). This unit consists of at least 250 m of light-gray, white, and pink lacustrine argillaceous limestone, sandstone, and siltstone, and fluvial conglomerate as well as beds of interbedded white and light-gray airfall tuff (Barnes and others, 1982), the oldest of which has a K-Ar age of 30.2 Ma (Marvin and others, 1970) and on the basis of petrography may be correlative with ash-flow tuffs of the Needles Range Group (Barnes and others, 1982), whose caldera complex straddles the Nevada-Utah border (Best and others, 1989). Includes, in the southwestern part of the mapped area, the Titus Canyon Formation, as originally defined by Stock and Bode (1935), namely a moderately consolidated, variegated sedimentary sequence, at least 500 m thick, that includes an upper part of green tuffaceous sandstone and a lower part of red and brown rounded cobble conglomerate. Cobbles consist of quartzite and lesser carbonates and argillites, with rare rhyolite flow rock in the upper part of the mapped unit (Fridrich and others, 1999a). The part of the Titus Canyon in the mapped area is generally the lower part (the "variegated and brown conglomerate facies" of Reynolds, 1969) and it contains airfall tuff beds with K-Ar ages of about 29 to 20 Ma (Carr and others, 1996). At its base, the Titus Canyon consists of breccia made up of large blocks of Paleozoic rocks (Wright and Troxel, 1993). The overall map unit was formerly designated the 300-m-thick Horse Spring Formation (Hinrichs and McKay, 1965; Hinrichs, 1968; Barnes and others, 1982), a name that is abandoned because these rocks are clearly older than the Miocene Horse Spring Formation of the Lake Mead area of southern Nevada (Bohannon, 1984). Also includes a coarse-grained unit, more than 100 m thick, in and near the northwestern part of the mapped area that is overlain by the Oligocene tuff of Antelope Spring; this unit is equivalent to the fanglomerate unit of Ekren and others (1971)

Tka **Rhyolite of Wheelbarrow Peak (Miocene)**—Moderately resistant, light- to reddish-gray, flow-foliated, crystal-poor, alkalic rhyolite lava flows and related airfall tuff exposed in the Belted Range. Contains variable amounts of quartz, alkali feldspar, plagioclase, biotite, and hornblende. Includes an intrusive phase. Some parts mapped as rhyolite of Ocher Ridge by Sargent and Orkild (1973). Maximum thickness about 300 m

Tkl **Latite of Kawich Valley (Miocene)—**Moderately resistant, brown and brownish-gray, crystal-rich, andesitic to rhyodacitic lava flows exposed in the western Belted Range. Contains quartz, clinopyroxene, and hornblende but generally lacks biotite. Normal magnetic polarity. Maximum thickness about 250 m

Tep **Pahranagat Formation (Miocene)**—Soft to moderately resistant, gray, brown, pink, and pinkish-tan, moderately crystal-rich, nonwelded to densely welded, calc-alkaline rhyolite ash-flow tuff. Volume at least 2,600 km^3 (Best and others, 1995). Contains conspicuous and abundant pumice fragments and sparse lithic clasts. Locally includes basal bedded airfall tuff. Exposed as two compound cooling units in the northeastern part of the mapped area. Probable source is the Kawich caldera in the central Nevada caldera complex (Best and others, 1989, 1995). Contains quartz, subordinate sanidine, plagioclase, minor biotite, rare hornblende, and abundant traces of sphene. Equivalent to the upper tuff of White Blotch Spring and to part of the tuff of Antelope Springs of Ekren and others (1971) and to several other named units (Deino and Best, 1988). Reversed magnetic polarity. $^{40}Ar/^{39}Ar$ age is 22.39 Ma (Best and others, 1995). Maximum thickness about 200 m

Tes **Shingle Pass Tuff (Oligocene)**—Resistant, light-purplish-gray, light-brown, and pink, crystal-poor, densely welded, calc-alkaline rhyolite ash-flow tuff. Exposed as one to six cooling units in the northeastern part of the mapped area. Probable caldera source is in the Quinn Canyon Range of central Nevada (Best and others, 1989). Contains distinctive white ash-flow tuff lenticules as long as 0.5 m and as thick as 2 cm. Contains sanidine, plagioclase, and quartz, minor pyroxene and biotite, and rare hornblende and fayalitic olivine. Normal magnetic polarity measured in the mapped area indicates that the unit is the lower cooling unit of the type Shingle Pass, which has a $^{40}Ar/^{39}Ar$ age of 26.7 Ma; an upper cooling unit of the formation has a $^{40}Ar/^{39}Ar$ age of 26.0 Ma (Best and others, 1989). Maximum thickness about 200 m

Tem **Monotony Tuff (Oligocene)**—Soft to moderately resistant, light-gray, tan, brownish-red, and light-green, crystal-rich, moderately welded, dacite compound ash-flow cooling unit (Ekren and others, 1971). Volume at least 3,000 km^3 (Best and others, 1989). Contains a dark-gray basal vitrophyre. Exposed in the northeastern part of the mapped area. Probable caldera source is in the southern Pancake Range and Reveille Range, about 70 km north of the mapped area (Ekren and others, 1971; Best and others, 1989). Contains plagioclase and much subordinate quartz, biotite, and sanidine, and minor hornblende and clinopyroxene. Distinguished by its extremely crystal-rich nature, normal magnetic polarity, and brownish hummocky outcrop appearance. $^{40}Ar/^{39}Ar$ age is about 27.3 Ma (Best and others, 1989). Maximum thickness about 200 m

TKg **Gabbro dikes (Oligocene and/or Cretaceous)**—Dark-green hornblende gabbro and diorite dikes that cut pre-Tertiary rocks on the western side of Bare Mountain and in the northern Funeral Mountains. These porphyritic dikes, with a fine- to medium-grained groundmass, consist of about 75 percent plagioclase, 10 percent hornblende, 7 percent clinopyroxene, 5 percent biotite, 3 percent Fe-Ti oxides, and traces of epidote (Carr and others, 1996). In the Bare Mountain area, the dikes have K-Ar ages of 26.1 and 16.6 Ma (Monsen and others, 1992). The relatively coarse-grained nature of these dikes, however, resembles the textures of some Cretaceous plutons of the granitic rocks (Kg) in the mapped area, one of which is north of Bare Mountain. In addition, lithologically similar dikes (too small to be shown on the map) that cut Paleozoic rocks in the northern margin of Yucca Flat have $^{40}Ar/^{39}Ar$ ages of about 102 Ma (Cole and others, 1993). In the Funeral Mountains, a "Tertiary diorite dike" that has a K-Ar age of 34.4 Ma (Wright and Troxel, 1993) is actually composed of amphibolite and, therefore, probably is Mesozoic (C.J. Fridrich, unpub. data, 1999). Therefore, the map unit may be pre-Oligocene, most likely Cretaceous, and the existing Miocene and Oligocene K-Ar dates might have been reset

Kg **Granitic rocks (Cretaceous)**—Moderately resistant, light-orange, tan, and gray, medium-grained equigranular intrusive rocks, chiefly hornblende-biotite granodiorite, biotite monzogranite, quartz monzonite, and leucratic granite. Includes the gray, zoned, equigranular to porphyritic Climax stock (about 101 Ma; Naeser and Maldonado, 1981) on the northern side of Yucca Flat (Houser and Poole, 1960;

Barnes and others, 1963). Also includes the equigranular Gold Meadows stock (93.6 Ma; Naeser and Maldonado, 1981) north of Rainier Mesa (Gibbons and others, 1963); and the light-orange, weakly foliated, equigranular granite at the mouth of Fluorspar Canyon north of Bare Mountain (about 98 Ma; Monsen and others, 1992). Also includes small, poorly exposed bodies of muscovite-bearing leucogranite on the eastern flank of the southern Kawich Range ("leucogranite," Mzg, of Orkild and others, 1969, and of Ekren and others, 1971), which have a K-Ar age of 98.4 Ma (Marvin and others, 1989), and in the northern Halfpint Range (Barnes and others, 1965)

Pht **Tippipah Limestone (Lower Permian and Pennsylvanian)**—Ledgy, light- to medium-gray and light-brown, well-bedded, marine limestone, calcareous mudstone, and minor chert-pebble conglomerate and sandy limestone. Unit contains a diverse macrofossil fauna in its biohermal middle and upper parts. Top of the unit everywhere eroded; base is an indistinct unconformity (Gordon and Poole, 1968) that is on top of the Chainman Shale and cuts out part of the Scotty Wash Quartzite (hMsc). Unit exposed in cores of moderately to strongly overturned synclines at CP Hills and Syncline Ridge, west and southwest of Yucca Flat (McKeown and others, 1976). Maximum thickness about 1,250 m thick (Miller, 1989; Trexler and others, 1996b)

hMsc **Scotty Wash Quartzite and Chainman Shale (Upper Mississippian)**—Scotty Wash Quartzite at top is distinguished by abundance of lensoid and tabular quartz sand bodies containing local gray fossiliferous limestone beds. Top of the unit is irregular due to erosion prior to deposition of the Tippipah Limestone (Pht). Chainman Shale is homogeneous black pyritic shale containing sparse siltstone, fine-grained quartz sandstone, quartzite, and bioclastic limestone. Base of the Chainman is not exposed in the mapped area, but is known from subsurface data in the CP Hills to lie disconformably on the Guilmette Formation (Dg) (Trexler and others, 1996a). Unit is exposed around Syncline Ridge, in the CP Hills, and in the southern Calico Hills. The Scotty Wash Quartzite was deposited in shallow water (deltaic environment), and it records the influx of mature quartz sand derived from eastern cratonic sources (Trexler and others, 1996a). Most of the Chainman was deposited in a deep marginal shelf basin that was isolated from the Eleana Formation turbidite trough to the west. Thickness indeterminate due to structural complications, but locally exceeds 1,200 m south of Syncline Ridge (Cashman and Trexler, 1994; Trexler and others, 1996a)

MDe **Eleana Formation (Mississippian and Upper Devonian)**—Chert-rich sandstone and pebble conglomerate, siliceous siltstone, and minor bioclastic limestone and bedded chert. A laterally variable unit containing thick-bedded lenticular sandstone-conglomerate turbidite complexes, laminated bioturbated siltstone, and discrete carbonate turbidite beds in the upper part. Unit varies considerably, both laterally and vertically, and it was deposited in deep-water marine turbidite trough and submarine fan environments. Informally described as nine subunits by Poole and others (1961; reinterpreted by Cashman and Trexler, 1991, and Trexler and others, 1996a); base of type section in Carbonate Wash is disconformable on upper Middle Devonian slope-facies carbonate rocks (Dsf). Upper 150 m consists of bioclastic limestone in thin tabular beds and of chert litharenite sand. Middle 1,700 m consists of chert litharenite sand, conglomerate, and siltstone. Lower 190 m consists of debris-flow limestone breccia beds, silty and sandy limestone, and beds of clean quartzite. Top of unit is everywhere truncated by the Belted Range thrust or by duplex thrusts in the Belted Range footwall (Cole and Cashman, 1999). Strata assigned to the Eleana Formation in the Calico Hills are generally thinner, more varied, and finer grained than the type Eleana, contain older and more common limestone beds, and probably are no older than latest Devonian (Trexler and others, 1996a; Cole and Cashman, 1999). Strata assigned to the Eleana at Bare Mountain are finer grained and more calcareous than the type Eleana and contain abundant siliceous argillite and chert (Monsen and others, 1992; Trexler and others, 1996a). Strata assigned to the Eleana at Shoshone Mountain and Mine Mountain are generally similar to type Eleana but are no older than middle Early Mississippian at their base. They differ from other Eleana deposits in that they are deposited on karst-weathered shelf-facies Guilmette Formation (Dg) and they are consistently finer grained and contain clasts from more heterogeneous sources (Trexler and others, 1996a; Cole and Cashman, 1999)

MDu **Mississippian and Devonian rocks, undivided**—Limestone, clayey to silty limestone, quartzite, and calcareous siltstone that make up a heterogeneous unit of shelf- and inner slope-facies carbonate-shelf deposits in the Spotted Range east of Mercury, Nev. These units were defined (bottom to top) as the Narrow Canyon Limestone, Mercury Limestone, limestone of Timpi Canyon, and overlying shale, siltstone, and quartzite beds correlated with the Chainman Shale based on age (Barnes and others, 1982; Poole and Claypool, 1984; Stevens and others, 1996). The carbonate units (total thickness 330 m) are similar in sequence, depositional environment, and age to units of the Monte Cristo Group to the east (Stevens and others, 1996; Trexler and others, 1996a). The siliciclastic units at the top of the Spotted Range section are Upper Mississippian and probably correlate with the Indian Springs Formation based on age and lithologic diversity (Trexler and others, 1996a) rather than with the Chainman Shale (Poole and Sandberg, 1977; Poole and Claypool, 1984; Stevens and others, 1996). Top of unit is truncated by the Spotted Range thrust

Dg **Guilmette Formation (Upper and Middle Devonian)**—Light- to dark-gray, mostly thick-bedded, finely to coarsely crystalline marine limestone (Sandberg and others, 1988). Forms massive cliffs and steep ledgy slopes in upper part and ledgy slopes in lower part. Contains sandy limestone and thick beds of tan quartzite in upper part and common biohermal beds in middle part. Basal beds are yellow and silty (“yellow slope-forming (argillaceous) unit,” Tschanz and Pampeyan, 1970), above an apparent conformable contact with the Simonson Dolomite (Ds). At Shoshone Mountain and Mine Mountain, quartzite beds in the upper part are brecciated by post-depositional collapse above karst sinkholes; karst features were not developed in rocks now exposed in the Spotted Range and elsewhere in the map area. Map unit in the study area lacks evidence of bolide impact during deposition, as has been shown in areas to the east (Warme and Sandberg, 1996). About 350 m thick

Dsf **Slope-facies carbonate rocks (Upper, Middle, and Lower Devonian)**—Moderately resistant, light- to dark-gray limestone, dolomite, and silty carbonate rocks. Moderately well bedded, locally laminated, locally fossiliferous, and typified by debris-flow deposits that contain clasts of quartzite, limestone, dolomite, chert, and coarse fossil fragments; the matrix of some debris-flow deposits is quartzose sand. Includes laminated beds that commonly contain intraformational breccia beds. Exposed at Bare Mountain (rocks of Tarantula Canyon of Monsen and others, 1992), Carbonate Wash (Eleana Range), eastern Rainier Mesa, and northern Calico Hills (rocks of Calico mines of Cole and Cashman, 1998). Fossils of probable late Middle Devonian age were reported from “near the top” of the unit by Cornwall and Kleinhampl (1961). A conodont fauna from 15 m below the top of the unit is Middle Devonian (Carr and others, 1996). Maximum thickness in the map area is about 300 m; top is eroded below the base of the Eleana Formation (MDe)

Ds **Simonson Dolomite (Middle Devonian)**—Ledge-forming, medium- to dark-gray, conspicuously bedded dolomite and local sandy dolomite. Includes distinctive yellow, silty, cherty dolomite at the base (“cherty argillaceous unit”). Basal contact, in which yellow, platy, silty beds rest upon the sandy upper part of the Sevy Dolomite (DSsl), is widespread and distinct (Poole and Sandberg, 1977; Johnson and others, 1988). Unit distinguished by its uniform bedding, alternating light and dark beds, and common dolomitized relict brachiopods, tubular corals, and stromatoporoids. Formerly mapped as part of the Nevada Formation (Burchfiel, 1965, 1966; Hinrichs, 1968; Orkild, 1968) or the Fluorspar Canyon Formation (Monsen and others, 1992). Maximum thickness about 300 m

DSsl **Sevy Dolomite and Laketown Dolomite (Lower Devonian and Silurian)**—Mostly thick bedded dolomite, commonly brecciated. Formerly mapped as an informal dolomite sequence (dolomite of Spotted Range) in the Ranger Mountains and Spotted Range (Poole, 1965; Barnes and others, 1982) or as an unnamed sequence north of Yucca Flat (Rogers and Noble, 1969). The Sevy Dolomite is about 275 m thick and is a cliff-forming, mostly light-gray, aphanitic to finely crystalline dolomite containing beds of quartz sand in the upper 15 m. The Laketown Dolomite, which is about 250 m thick, is a cliff-forming, dominantly dark-gray, mostly aphanitic to finely crystalline, laminated to thinly bedded, fossiliferous dolomite that contains abundant chert lenses, layers, and blebs, especially in the upper part (unit C of Poole, 1965). Basal contact is sharp and conformable but may mark a hiatus (Poole and Christiansen, 1966; Poole and Sandberg, 1977; Poole and others, 1992). Compilation map unit includes the Devonian and Silurian Hidden Valley Dolomite (McAllister, 1974), exposed in the southeastern Funeral Mountains. This 440-m thick unit consists mostly of light-gray, poorly bedded dolomite in the upper two-thirds, and medium- to dark-gray, well-bedded, locally cherty, locally fossiliferous dolomite in the lower third (McAllister, 1974)

DSlm **Lone Mountain Dolomite (Lower Devonian and Upper Silurian)**—Craggy exposures on Bare Mountain of light-gray dolomite containing a distinctive 60-m thick sequence of medium-gray dolomite near the middle of the unit. Dolomite is fine- to medium-grained, indistinctly bedded, and commonly brecciated. Lower contact gradational with underlying unit, by which the dolomite is progressively darker downward and the bedding is progressively better defined downward. Unit is sparsely fossiliferous, although poorly preserved crinoid debris is moderately common. Drill hole UE25p#1 at Yucca Mountain yielded Late Silurian conodonts in the rock unit (M.D. Carr and others, 1986). Thickness about 490 m (Cornwall and Kleinhampl, 1961)

Sr **Roberts Mountain Formation (Silurian)**—Slope-forming, light-brownish-gray to medium-gray dolomite and limestone beds, interbedded silty and sandy dolomite, and sparse beds of dolomite-pebble conglomerate. Bed thickness is variable, commonly flaggy splitting. Locally contains dark-gray chert layers and nodules. Base is regionally disconformable on the Ely Springs Dolomite (Oes). Contains Early to Late Silurian fossils, including brachiopods, corals, graptolites, and conodonts (Cornwall and Kleinhampl, 1961; Berry and Boucot, 1970; Miller, 1976; M.D. Carr and others, 1986). Occurs only in the northern Bare Mountain area, where its thickness is 200 m (Monsen and others, 1992)

Oes **Ely Springs Dolomite (Upper Ordovician)**—Consists of two major lithologic units (Poole and Christiansen, 1966). The upper unit forms a medium- to light-gray ledge slope of aphanitic to fine-grained dolomite containing zones of yellowish-gray silty and clayey dolomite; a persistant thin sandy zone, locally oölitic, is near the top. The lower unit, two-thirds to three-quarters of the formation, forms a dark-gray cliff of fine-grained, commonly cherty dolomite. A thin unit of limy or dolomitic sandstone is present at the base of the formation. Lower contact is disconformable on underlying units. Thickness 50 to 150 m

Oe **Eureka Quartzite (Middle Ordovician)**—Consists of two major parts. The upper part is a white very fine to medium-grained, locally cross laminated, sandstone and quartzite. The lower part is a varicolored red, white, gray, orange, yellow, and brown very fine- to medium-grained quartzite interval that includes a thin gray limestone and dolomite subunit. Thickness 75 to 145 m

Op **Pogonip Group (Middle and Lower Ordovician)**—Moderately resistant, medium- to dark-gray, well bedded, silty limestone, dolomite, and subordinate chert and siltstone. Marked by brownish-orange silt and chert zones. Fossil content is variable, with trilobites, brachiopods, oncolites, ostracods, sponges, algae, locally conspicuous. Made up, from top to base, of the Antelope Valley Limestone, Ninemile Formation, and Goodwin Limestone (Byers and Barnes, 1967). The Antelope Valley Limestone consists of medium-gray, nodular, finely to coarsely crystalline, massive to laminated limestone and silty limestone, as much as 550 m thick, and it contains distinctive sandy beds in its upper part. The Ninemile Formation consists of light- to moderate-brown shaly siltstone and claystone and black and gray, laminated to thick-bedded, silty limestone and dolomite that is about 150 m thick. The Goodwin Limestone consists of resistant, gray, laminated to thick-bedded limestone and minor silty limestone, that is as much as 350 m thick

en **Nopah Formation (Upper Cambrian)**—Resistant, light- to dark-gray, poorly to well bedded limestone, dolomite, and subordinate yellow and brown shale and siltstone. Made up, from top to base, of the Smoky Member, Halfpint Member, and Dunderberg Shale Member. The Smoky Member is a cliff-forming, light- to dark-gray, medium- to thick-bedded dolomite that is about 300 m thick (Barnes and Christiansen, 1967; Byers and Barnes, 1967; Hinrichs, 1968). The Halfpint Member is a medium- to dark-gray, thin- to thick-bedded, finely to coarsely crystalline dolomite that locally contains abundant black chert nodules and layers totaling about 320 m thick. The Dunderberg Shale Member is a reddish-brown and greenish-brown, fissile shale that contains subordinate medium-gray and light-brown, thinly bedded limestone that totals about 100 m thick. Phosphatic brachiopod fossils occur sparsely in the Smoky and Halfpint Members, and trilobite fossils are common in the Dunderberg

Bonanza King Formation (Upper and Middle Cambrian)—Well-bedded dolomite and limestone with beds that commonly have alternating shades of gray

ebb Banded Mountain Member—Cliff-forming, generally light- to dark-gray, medium- to thick-bedded dolomite and limestone. Alternating light-, medium-, and dark-gray beds give a distinctive banded appearance to the member; in the upper part of the unit, the bands are thick, whereas in the lower part, the bands are thin. Thickness generally about 580 m, but 740 m in the Halfpint Range (Barnes and others, 1963, 1965; Byers and Barnes, 1967), and at least 1,000 m west of Yucca Flat (McKeown and others, 1976)

ebp Papoose Lake Member—Cliff-forming, dark-gray limestone and light-gray dolomite and thin beds of yellowish-orange silty limestone and dolomite. Local dolomitization of massive limestone beds in the lower part produces distinctive birds-eye texture. Gradational into the underlying Carrara Formation (ec). Thickness variable, generally about 700 m

ec **Carrara Formation (Middle and Lower Cambrian)**—Heterogeneous sequence of mostly soft, greenish-gray, thin- to medium-bedded shale, siltstone, sandstone, limestone, and silty limestone. Clastic rocks predominate in the lower part, but cliff-forming, orange and medium- to dark-gray, thin-bedded silty limestone beds are prominent in the upper part. The limestone beds contain abundant oncolite, oolite, and stromatolith fossils as well as wavy silty partings of orange calcareous silt. The lower part consists of thin-bedded, micaceous shale and siltstone containing trilobite fossils and several distinctive limestone beds. Separated into seven units in the Halfpint Range (Barnes and others, 1965). A partial section mapped on the western side of the Belted Range consists mostly of limestone and sandy limestone, may be a deeper water facies than elsewhere in the mapped area, and includes some debris-flow limestone equivalent in age to the Bonanza King Formation (ebb, ebp) (Cole and Cashman, 1999). Upper contact is gradational with the overlying Bonanza King Formation; lower contact is conformable on the Zabriskie Quartzite (ez). Thickness about 470 m in the northern Halfpint Range, indeterminate in the CP Hills due to complex structure, and about 350 m at Bare Mountain ez **Zabriskie Quartzite (Lower Cambrian)—**Resistant, massive, white, pink, and red, laminated to thick-bedded, commonly cross bedded, densely cemented, fine- to medium-grained orthoquartzite. Contains conspicuous vertical tubular burrows (Skolithos). Thickness ranges from about 350 m at Bare Mountain, to about 150 m west of the Specter Range, to 30 to 50 m in the Halfpint Range and Belted Range

eZw **Wood Canyon Formation (Lower Cambrian and Late Proterozoic)**—Mostly resistant, thin- to medium-bedded orthoquartzite, micaceous quartzite, arkosic sandstone, siltstone, and subordinate dolomite. Upper and lower third of unit consists of interbedded red and brown orthoquartzite and brownish-green micaceous siltstone beds, with minor prominent orange dolomite beds. Middle third consists of light-green interbedded coarse-grained, micaceous quartzite and siltstone, with minor distinctive beds of arkosic granule conglomerate. Locally metamophosed to subgreenschist to lower greenschist facies in the southern part of the mapped area. Includes Stirling Quartzite (Zs) where mapped north of Rainier Mesa (Gibbons and others, 1963). Thickness ranges from about 1,150 m at Bare Mountain to about 700 m in the Halfpint Range

Zs **Stirling Quartzite (Late Proterozoic)**—Resistant, red, purple, white, light-yellowish-brown, and light-green, medium- to thick-bedded but commonly laminated, locally cross-bedded, fine-grained orthoquartzite, micaceous quartzite, arkosic sandstone, and pebbly sandstone, and subordinate to minor light-green siltstone, light-gray and light-orange limestone and dolomite, and dolomitic siltstone. Locally metamorphosed to subgreenschist to lower greenschist facies in the southern part of the mapped area. Thickness ranges from about 2,000 m in the Funeral Mountains to about 1,500 m in the Belted Range and about 700 m at Bare Mountain

Zj **Johnnie Formation (Late Proterozoic)—**Mostly resistant, brown, gray, and red, thick-bedded, indistinctly cross-bedded, locally pebbly quartzite and variegated, laminated, conspicuously micaceous siltstone, limestone, and calcareous siltstone. Upper part contains numerous limestone and calcareous siltstone beds. Metamorphosed to subgreenschist to lower greenschist facies in the northern Spring Mountains, Bare Mountain, and Funeral Mountains. Thickness estimated to exceed 900 m near the Halfpint Range (Barnes and Christiansen, 1967) and may be as thick as 2,000 m in the Funeral Mountains (Wright and Troxel, 1993)

Yk **Kingston Peak Formation (Middle? Proterozoic)**—Upper part consists of metaconglomerate containing clasts of quartzite and calcitic marble supported by a matrix of staurolite- and biotite-bearing pelitic schist. Lower part consists of staurolite- and biotite-bearing pelitic schist containing subordinate layers of laminated calcitic marble. Exposed only in the Funeral Mountains, where its thickness is estimated as 700 m (Wright and Troxel, 1993)

Yb **Beck Spring Dolomite (Middle? Proterozoic)—**Well laminated, calcitic marble exposed only in the Funeral Mountains. Thickness estimated as 70 m (Wright and Troxel, 1993)

Yc **Crystal Spring Formation (Middle? Proterozoic)—**Upper part consists of mostly staurolite- and biotite-bearing pelitic schist and micaceous quartzite, with subordinate layers of calcitic marble and amphibolite. Middle part consists mostly of calcitic marble and subordinate layers of staurolite- and biotite-bearing pelitic schist. Lower part consists of mostly staurolite- and biotite-bearing pelitic schist with abundant tabular bodies of amphibolite and several distinctive marker beds of calcitic marble. Exposed only in the Funeral Mountains, where its thickness is estimated as 800 m (Wright and Troxel, 1993)

Xmi **Metamorphic and intrusive rocks (Early Proterozoic)**—Light-gray and brown biotite schist, biotite-hornblende schist, and biotite-epidote schist that are intruded by gneissic monzogranite in the Trappman Hills, at the northern edge of the mapped area and just north of western Gold Flat; the schist and monzogranite are intruded by aplite and pegmatite dikes that show no planar fabric. Muscovite from schist there has a K-Ar age of 14.0 Ma, interpreted to represent a cooling age for the Proterozoic rocks during uplift of the lower plate of a metamorphic core complex during Miocene regional extension (McKee, 1983). Consists of mylonitic quartzofeldspathic gneiss and biotite schist and minor metaconglomerate and marble in the Bullfrog Hills (Maldonado, 1990). Muscovite from schist there has a K-Ar age of 11.2 Ma, similarly interpreted to represent cooling of Proterozoic rocks during uplift of a metamorphic core complex and Miocene regional extension (McKee, 1983). The mylonitic fabric was suggested by Maldonado (1990) to be the midcrustal response of a core complex that formed an adjacent mapped Tertiary detachment fault based on K-Ar ages of 16.3 to 10.5 Ma from the mylonites (Marvin and others, 1989). Also includes sillimanite-grade metasedimentary rocks, commonly migmatized, in the Funeral Mountains. These metasedimentary rocks are intruded by abundant pegmatite dikes and small silicic plutons; one of these plutons, a two-mica granite, yielded a U-Pb zircon age of 1.7 Ga (Wright and Troxel, 1993)

Contact

Fault—Solid line where location is known; dashed where approximately located; dotted where concealed. Consists of the following:

High-angle normal fault—Bar and ball on downthrown side

High-angle strike-slip fault—Opposing arrows indicate relative lateral slip

High-angle oblique-slip fault—Bar and ball on downthrown side and opposing arrows indicate relative strike slip movement

Thrust fault—Barbs on upper plate. In part from Cole (1997)

Low-angle normal (detachment) fault—Half-balls on upper plate

Buried fault interpreted from geophysics—Bar and ball on inferred downthrown side, where probable; arrows show inferred strike-slip movement, where probable. These lineaments are largely inferred from locations of maximum horizontal gravity gradients from Ponce and others (1999) supplemented by McCafferty and Grauch (1997). Because the magnitude of the horizontal gradient is a measure of the steepness of the gradient, maximum magnitudes occur at anomaly inflection points, which are located near-vertical density boundaries (Grauch and Cordell, 1987; Cordell and McCafferty, 1989). Horizontal gradient analysis is an objective lithologic and structural mapping tool used here to highlight interpreted major crustal rock-unit boundaries (Blakely and Simpson, 1986). In the Pahute Mesa and Oasis Valley region, identification of the lineaments is based largely on the work of Grauch and others (1997) and Hildenbrand and others (1999). In these areas, the identification was also supplemented by aeromagnetic data (Mankinen and others, 1998, 1999) and by electrical data (Schenkel and others, 1999). One of these lineaments, which we call the Hogback fault, is indicated by the symbol HF

Probable fault—Dotted magenta line

Less certain fault—Dotted orange line

Thirsty Canyon lineament—Dotted green line. Lineament first identified by gravity and aeromagnetic data (Grauch and others, 1997). Because of its possible significance as a barrier or a pathway for ground water, its location was constrained by later detailed gravity, aeromagnetic, and electrical studies (Hildenbrand and others, 1999; Mankinen and others, 1999; Schenkel and others, 1999). Inferred to be a buried fault zone, overlain largely by volcanic rocks of the Thirsty Canyon Group. This fault zone likely is one or more kilometers wide in places. This fault zone is interpreted to have constrained and bounded the western sides of the Silent Canyon and Timber Mountain caldera complexes

Axis of an east-striking lineament—Dotted bluish-green line. Lineament whose western part was first identified by gravity and aeromagnetic data (Grauch and others, 1997). Current location based partly on residual gravity, aeromagnetic, and electrical data (Hildenbrand and others, 1999; Mankinen and others, 1999; Schenkel and others, 1999). Lineament may represent the axis of a transverse zone, which is a wide (several kilometers or more), mostly east-striking structural zone of offset and accommodation, separating areas north and south of the zone that underwent different amounts, rates, and types of regional crustal extension (Rowley, 1998)

Caldera margin (wall)—Hachured blue line, with hachures on the caldera side. Solid line where location is known; dashed where approximately located; dotted where concealed. Consists of the following calderas: topographic margin of the Stonewall Mountain caldera (SMC) in the northwestern corner of the mapped area; topographic margin of the Black Mountain caldera (BMC) on western Pahute Mesa; topographic margin of the Silent Canyon caldera complex (SCCCT) on Pahute Mesa; structural margin of the Silent Canyon caldera complex (SCCCS) on Pahute Mesa; topographic margin of the Rainier Mesa caldera (RMCT) on southern Pahute Mesa and areas to the south; structural margin of the Rainier Mesa caldera (RMCS) in the center of the mapped area; topographic margin of the Ammonia Tanks caldera (ATCT) surrounding Timber Mountain; structural margin of the Ammonia Tanks caldera (ATCS) surrounding Timber Mountain; topographic margin of the Claim Canyon caldera (CCCT) south of Timber Mountain; and topographic margin of the Twisted Canyon caldera (TCC) northeast of Beatty. Usage of topographic and structural margins follows the definitions of Lipman (1997). Margins of the Silent Canyon caldera complex and parts of the Rainier Mesa and Ammonia Tanks calderas based largely on residual gravity data and locally on aeromagnetic and electrical data (Grauch and others, 1997; Hildenbrand and others, 1999; Mankinen and others, 1999; McKee and others, 1999; Schenkel and others, 1999)

Axial trace of fold—Solid line where location is known; dashed where approximately located; dotted where concealed

Anticline—Showing plunge

Syncline—Showing plunge

Metamorphic rocks (green overprint)—Metamorphic rocks of subgreenschist facies and higher grade. Shown only in the Funeral Mountains (Hoisch and Simpson, 1993; Wright and Troxel, 1993) and Bare Mountain area

Strike and dip of beds

Inclined

Horizontal

Strike and dip of foliation—Metamorphic foliation in metamorphic rocks and flow foliation in lava flows and compaction foliation in ash flows

Inclined

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PLATE 1 (OF 2)

Base from U. S. Geological Survey, 1979
Projection zone 11: Universal Transverse Mercator
1927 North American Datum

SCALE 1:120 000

1 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

1 0 1 2 3 4 5 MILES

CONTOUR INTERVAL 50 METERS
WITH SUPPLEMENTARY CONTOURS AT 10-METER INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

DIGITAL GEOLOGIC MAP OF THE NEVADA TEST SITE AND VICINITY, NYE, LINCOLN, AND CLARK COUNTIES, NEVADA AND INYO COUNTY, CALIFORNIA

by

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PLATE 2 (OF 2)

CORRELATION OF MAP UNITS