U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary Digital Geologic Map Database of the Nevada Test Site area, Nevada

By

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Open-File Report 95-0567

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1995

INTRODUCTION

Work on geologic compilation of the Nevada Test Site (NTS) map and Pahute Mesa 30' x 60' quadrangle was conceptually proposed in 1984 as part of a U.S. Geological Survey (USGS) programmatic initiative to conduct a geologic synthesis of the southern Great Basin in Nevada. One of the central objectives of the program was to compile the geology of four contiguous 1:100,000-scale, 30' x 60' minute quadrangles that cover the region of interest (Pahute Mesa, Beatty, Pahranagat Range, and Indian Springs quadrangles), and to produce a separate 1:100,000-scale geologic map of the NTS that overlaps all four quadrangles. Digital compilation of the Pahute Mesa quadrangle began in 1990, with support coming entirely from the USGS Rad Waste Program. Work on the digital compilation of the NTS has largely been funded by the DOE NTS Weapons Program. Two of the other proposed 1:100,000-scale geologic maps have been completed, the NTS map (Frizzell and Shulters, 1990) and the Pahranagat Range quadrangle map (Jayko, in press), and a preliminary digital geologic map of the Pahute Mesa 30' x 60' quadrangle has been released (Minor and others, 1993).

The Nevada Test Site/Pahute Mesa digital geologic map database allows for accurate and rapid updating of geologic information, generation of derivative maps at various scales, and layering with other Geographic Information System (GIS) databases to produce integrated thematic maps and 3-D models. The digital database is available, in GRASS ascii vector, DLG-3 (optional), and in Arc/Info ASCII (Generate) and export formats, from the USGS, Denver, on-line repository on Internet (via 'anonymous ftp') at greenwood.cr.usgs.gov [136.177.48.5], path (/pub/open-file-reports/ofr-95-0567).

COMPILATION METHODS

The current map database incorporates geologic data from: (1) digitized (scanned) polygon, fault, and structural attitude layers of the published 1:100,000-scale geologic map of the NTS (Frizzell and Shulters, 1990, and Figure 1a, Sources of Compiled Geologic Data); (2) the recent digital 1:100,000-scale geologic compilation of the Pahute Mesa 30' by 60' quadrangle (Minor and others, 1993); and (3) recent field studies of stratigraphy and structure by the authors and others . Sawyer was lead compiler for the NTS part of the combined database; Minor was lead compiler of the Pahute Mesa sheet outside of the NTS area; Cole compiled the new geology and stratigraphy of the Pre-Tertiary sedimentary rocks in the NTS area. New geologic field data were digitized directly from field-annotated aerial photographs using a digital photogrammetric plotter or from scale-stable author-prepared maps using a digitizing tablet or scanner. Numerous revisions of the of the NTS area were also made by adding new field and stratigraphic data to the published 1:24,000-scale geologic data (see Figure 1b; Sources of Original Geologic Data). All new digital files as well as the pre-existing Pahute Mesa and NTS geologic map files were imported into the raster processing software LT4X for cleaning, editing, and, in the case of scan files, vectorization. The new map data were also imported into AutoCAD for editing and simplification for depiction at a scale of 1:100,000. Geographic Resource Analysis Support System (GRASS), a public domain GIS developed by the U. S. Army Corps of Engineers, was used to transform all of the new component map files to Universal Transverse Mercator projections, merge the files in the appropriate composite map-data layers, conduct final editing and modification of map elements, build and tag polygons, and assign attributes to map elements.

The map dataset may produce some minor display conflicts that reflect limitations of the algorithms used to automatically generate the labels; unit labels of some narrow polygons extend into adjoining polygons, and faults or fault decorations (e.g., ball and bars) locally overlap map unit labels or structural attitude symbols. These labeling conflicts were not resolved for this version of the map because they do not affect the quality or resolution of the database when used in a GIS. The reader is referred to published copies of the component U.S. Geological Survey base maps (Pahute Mesa, Beatty, Indian Springs, Pahranagat Lakes 1:100,000-scale maps) for clarification of placenames and other geographic base map features. The geologic map dataset is considered an accurate compilation at the line-width and simplified polygon geometry depicted at 1:100,000-scale level of detail. Enlarging or viewing the dataset at scales greater than about 1:50,000 (in particular with comparison to 1:24,000-scale topographic or published geologic maps) will in some cases show polygon contacts or structural features to be inaccurately located at the larger scales of resolution.

DESCRIPTION OF MAP UNITS

The Tertiary map unit descriptions were largely compiled using recent petrographic, chemical, stratigraphic, and geochronologic data by Sawyer, Minor, and Warren. The pre-Tertiary unit descriptions were largely compiled by Cole, and descriptions of Quaternary and other surficial units were based on information contributed by Cole and W C Swadley (USGS, 1994, written communincation).

Volcanic rock names are based on the IUGS total alkali-silica classification scheme of Le Bas and others (1986). Phenocryst content modifiers of volcanic rock names are based on the modal percentages shown in table 1 below; in basaltic rocks the modifiers "phenocryst-rich" and "-poor" are substituted for "crystal-rich" and "-poor", respectively, to distinguish phenocrysts and microphenocrysts from coarse groundmass crystals common in those rocks. Phenocrystic mineral abundances are from unpublished median data compiled for individual SWNVF units by R. G. Warren. Table 2 below shows terms used to indicate median abundances for felsic phenocrysts (quartz, K-feldspar=sanidine + anorthoclase, and plagioclase), for mafic minerals (biotite, hornblende, arfvedsonite, orthopyroxene, clinopyroxene, acmite, and olivine), and for accessory minerals (chiefly sphene) in intermediate to silicic volcanic rocks. Mineral abundance terms for basaltic rocks are listed in table 3 below, which differ only for mafic phenocrystic abundances; these median abundances include both phenocrysts and microphenocrysts. Generally, mineral contents are listed in order of decreasing abundance. Although the relative abundance terms shown in the tables are appropriate for descriptions of volcanic rocks from the SWNVF, they may be inappropriate when applied to other volcanic fields.

Table 1. Total phenocryst content

Term	(median modal %)
aphyric	<0.5
crystal-poor	0.5-5
(no modifier)	5-15
crystal-rich	15-25
very crystal-rich	>25

Table 2. Phenocrystic mineral abundances in intermediate to silicic volcanic ro:ks

Term	Felsics (median modal %)	Mafics (median modal %)	Accessories (median ppm/V)
rare	<0.5	<0.1	<20
sparse	0.5-2	0.1-0.5	20-150
common	2-10	0.5-1	150-300
abundant	10-20	1-2	>300
very abundant	>20	>2	

Table 3. Phenocrystic mineral abundances in basaltic volcanic rocks

Term	Felsics (median modal %)	Mafics (median modal %)	Accessories (median ppm/V)
rare	<0.5	<0.5	<20
sparse	0.5-2	0.5-2	20-150
common	2-10	2-5	150-300
abundant	10-20	5-10	>300
very abundant	>20	>10	

Tertiary volcanic stratigraphic nomenclature is from Sawyer and others (1994) and the Los Alamos National Laboratory GEODES database (Warren and others, 1989; Ferguson and others, 1994). Some map unit descriptions and informal unit names cited within them are derived from descriptions in published USGS Geologic Quadrangle (1:24,000-scale) and Miscellaneous Investigations (1:48,000-scale) Series maps (see Sources of Geologic Data figures), from the GEODES data, or, in the case of central Nevada volcanic units, from Scott and others (in press). The revised SWNVF stratigraphic framework used in this report is builds upon the reports of Ekren and others (1971), Byers and others (1976b,1989), and Carr and others (1986), and from the regional compilation maps of Orkild and others (1969), Sargent and Orkild (1973), Byers and others (1976a), and Minor and others (1993).

Stratigraphic nomenclature used for the pre-Tertiary sedimentary units is outlined in Cole and others (1989), Guth (1986, 1990), Cashman and Trexler (1994), and Minor and others (1993), and is based on many published studies cited by them. Descriptions of these units are largely summarized from published geologic map descriptions (see Sources of Geologic Data figures), and supplemented by Cole and others (1989, 1994) Miller (1989), Monsen and others (1992), Cole (1991), Cashman and Trexler (1991, 1994), and some unpublished data. Plutonic rock names are based on the IUGS classification scheme of Streckeisen (1976).

Reported ages for volcanic units are based mainly on new 40Ar/39Ar age determinations (Best and others, 1989; Fleck and others, 1991; Noble and others, 1991; Sawyer and others, 1994). Published 40Ar/39Ar ages from Hausback and others (1990) were recalculated using a 513.9 Ma monitor age for MMHB-1 (Lanphere and others, 1990; Dalrymple and others, 1993). 40Ar/39Ar ages are supplemented by published K/Ar results of Kistler (1968) and Marvin and others (1970, 1973, 1979, 1989), recalculated using current IUGS constants (Steiger and Jaeger, 1977; Dalrymple, 1979). Additional sources of radiometric ages are cited specifically in the map unit descriptions.

Magnetic polarity data are from published sources (Bath, 1968; Byers and others, 1976a and 1976b; Rosenbaum and Snyder, 1984; Noble and others, 1984; Carr and others, 1986; Rosenbaum and others, 1991; Hudson, 1992; Hudson and others, 1994). Normal polarity magnetizations have northerly declinations and moderate downward inclinations. Reverse polarity magnetizations have southerly declinations and moderate upward inclinations. Anomalous normal and reverse polarity magnetizations have downward or upward inclinations, respectively, but their directions lie at great (>45o) angles to time-averaged late Tertiary expected direction for the area.

Some geographic place names mentioned in the descriptions are not labeled on the 1:100,000-scale topographic base maps but are present on the larger-scale component topographic and geologic quadrangle maps that have been published. Where cited place names are not labeled on the base maps, locations of the named geographic features are described with respect to features that are labeled on these maps.

QTa **Quaternary surficial deposits**--undivided (Holocene, Pleistocene, and Pliocene?)-- Includes younger, middle, and older alluvium; younger and middle eolian deposits; colluvial deposits; and playa and playa beach deposits. Alluvial deposits consist of unconsolidated gravel, gravelly sand, silty sand, and sandy silt. Clasts are locally derived. Angular to subrounded, poorly to moderately consolidated gravel, generally with sparse sand and silt in matrix. Light gray to light brownish gray to yellowish brown to grayish brown, poorly to moderately well sorted, poorly to well bedded. Alluvium is deposited as discontinuous beds and lenses forming alluvial-fan aprons adjacent to range fronts, thin sheet-like deposits on valley floors, low terraces in large washes, and bottoms of active washes. Middle and older alluvium form terraces in washes and dissected alluvial fans, and fan remnants. Eolian deposits are wind-blown sand and silt forming dunes, sheets, mounds stabilized by vegetation, and ramps. Colluvium is unconsolidated angular boulders, gravel, and sand of local derivation, forming talus aprons and thin surficial veneers that obscure bedrock. Commonly also contains admixtures of wind-blown sand and silt. Older deposits have strong desert varnish. Playa deposits consist of compacted, poorly to moderately consolidated clay, silt, and fine sand; thinnly bedded; calcareous; light grayish brown. Locally contains sparse thin beds or lenses of pebbly coarse sand. Deposited in intermittently flooded bottoms of closed drainage basins such as Yucca Lake, Kawich Lake, Gold Flat Lake, Frenchman Lake, and Death Valley. Playa beach deposits consist of low discontinuous sand ridges near some playas within the map area. Playa beach sand is yellowish gray, moderately sorted, mostly medium to coarse, weakly consolidated, slightly pebbly. Ridges are 1-3 m high, commonly covered with a pebble to coarse sand lag; surface clasts have a weakly developed desert varnish

Qby **Younger Quaternary basalt (Pleistocene)**--Isolated cinder cones, lava flows, and feeder dikes at Little Black Peak and on the flank of Sleeping Butte about 12 km north of Oasis Mtn., and at Lathrop Wells, about 10 km northwest of the town of Amargosa Valley (formerly known as Lathrop Wells). Rock compositions are mainly phenocryst-poor trachybasalt and basalt; more sodic samples, including hawaiite, are uncommon. Phenocrysts consist of common olivine and sparse plagioclase. Distinguished by a low phenocryst abundance, predominance of olivine, by young ages [about 350 Ka for Sleeping Butte area basalts (Fleck and others, in press) and about 130 Ka for Lathrop Wells basalt (Turrin and others 1991)] and geomorphic appearance of cinder cone vents, and by normal magnetic polarity

Qbo **Older Quaternary basalt (Pleistocene)**--Basalt flows and moderately dissected scoria mounds of black to dark reddish-brown olivine basalt. Includes volcanic centers at Red, Black, and Little Cones in Crater Flat (Faulds and others, 1994). Basalt has yielded whole-rock potassium-argon dates of about 1.1 Ma

(Fleck and others, in press). Magnetic polarity is reverse (Rosenbaum and Snyder, 1984)

Typ **Pliocene and youngest Miocene basalt (Pliocene)**--Basaltic trachyandesite cinder cones, lava flows, and feeder dikes erupted from volcanic centers at Buckboard Mesa (2.87 +/-0.06 Ma; normal magnetic polarity), rocks in southeastern Crater Flat (3.73 +/- 0.02 Ma; reverse polarity), and at the broad shield volcano at Thirsty Mountain about 10 km north of Oasis Valley (4.63 +/- 0.02 Ma; reverse polarity) [ages from Fleck and others, in press]. Lithologies consist of lava flows and eroded scoria mounds of dark gray to dark-reddish-brown basalt. Phenocrysts vary from common to abundant olivine, sparse plagioclase, and variably sparse clinopyroxene in Buckboard Mesa area; to common to abundant olivine in southeast Crater Flat; to phenocryst poor with rare plagioclase in Thirsty Mountain area. Distinguished by marked preservation of constructional volcanic geomorphology, Pliocene age, and characteristic magnetic polarity of each center. Maximum thickness of more than 200 m at the Thirsty Mountain shield volcano; thickness as much as 100 m at other localities.

Tgy **Younger sedimentary deposits (Pliocene and Miocene)**--Consists of basin-fill deposits and fan alluvium composed mainly of poorly sorted, poorly to moderately bedded, angular to rounded gravel and sand in a locally tuffaceous matrix; typically weakly cemented. Unit locally contains interbedded, partly tuffaceous sandstone and mudstone and layers of nonwelded vitric tuff and limestone; such interbedded, finergrained deposits form a 65-m-thick interval within gravel deposits north of Beatty Wash. Clasts in unit composed of locally derived Tertiary volcanic rocks and lesser Pre-Tertiary sedimentary rocks, and include boulders up to 3 m across. Monolithologic landslide breccia derived from nearby bedrock is locally present within unit. Unit forms very strongly dissected alluvial fans in Oasis Valley, Beatty Wash, northern Crater Flat, and northwest of Tolicha Wash that include several levels of younger gravel deposits comprising small pediment remnants. Unit distinguished from temporally overlapping caldera moat-filling sedimentary deposits by extracaldera distribution of unit, and from younger landslide and sedimentary breccias and late synvolcanic sedimentary deposits by the higher stratigraphic position of the unit. Unit deposited during a period of at least 3 m.y.; deposits in northern Crater Flat contain beds of volcanic ash that yielded an ages of 8.2 Ma (Monsen and others, 1992); to the north 7.5-Ma Spearhead Member of Stonewall Flat Tuff is intercalated with or underlies basal part of sedimentary deposits, whereas basalt flows of the 4.63-Ma Thirsty Mountain shield volcano intertongue with gravels in lower Thirsty Canyon. Maximum known thickness of about 180 m in Oasis Valley area. Equivalent in part to gravel of Sober-up Gulch of Maldonado and Hausback (1990) and the gravels of Oasis Valley mapped by Minor and others (1993)

Tsc **Civet Cat Canyon Member of Stonewall Flat Tuff (Miocene)**--Comendite welded ash-flow tuff erupted from Stonewall Mountain caldera at 7.45 Ma. Compositionally zoned from lower comendite, containing common alkali feldspar (anorthoclase and sodic sanidine) and rare clinopyroxene, plagioclase, and fayalitic olivine, to upper crystal-rich trachyte containing abundant alkali feldspar, common plagioclase, sparse biotite and clinopyroxene, and rare orthopyroxene; acmite or arfvedsonite is present in groundmass. Magnetic polarity reverse. Maximum exposed thickness 180 m

Tsp **Spearhead Member of Stonewall Flat Tuff (Miocene)**--Welded ash-flow tuff erupted from Stonewall Mountain caldera at 7.5 Ma. Lithology consists of grayish- pink, nonwelded to partly welded ash-flow tuff containing abundant glass shards. Compositionally zoned from lower crystal-poor comendite, containing common alkali feldspar, sparse clinopyroxene, and rare fayalitic olivine, plagioclase, and quartz, to upper comendite containing abundant alkali feldspar, sparse plagioclase, clinopyroxene, and fayalitic olivine, and rare quartz, biotite, and hornblende; upper zone is only locally present. Magnetic polarity normal. Maximum exposed thickness about 50 m

Tsr **Rhyolite of Stonewall Mountain (Miocene)**--Lava flows and domes adjoining Stonewall Mountain caldera (Weiss and Nobele, 1989). Rhyolite is crystal-rich, containing abundant biotite and common sanidine, plagioclase, and clinopyroxene; flow laminated and flow folded. Maximum preserved dome height exceeds 200 m

Tyb **Thirsty Canyon and younger basalts (Miocene)**--Widespread trachybasalt, basaltic trachyandesite, basalt, and basaltic andesite lava flows, eroded cinder cones, and feeder dikes erupted from several centers between 9.9 and 6.3 Ma. Distribution is generally north and west of Timber Mountain in areas adjoining Black Mountain caldera and Stonewall Mountain volcanic center; unit includes two local basalt centers in northern Pahute Mesa located both at Basalt Ridge and to the east of it (8.8-9.1 Ma). Basalts erupted just prior to, during, and following the peralkaline volcanic rocks (Thirsty Canyon Group) of the Black Mountain caldera . Basalts adjoining Black Mountain caldera in west part of map area are variable in composition from basalt and alkali basalt to trachybasalt and trachybasaltic andesite, and include subordinate hawaiite, mugearite, and basaltic andesite. Petrography is also variable; phenocryst-rich varieties contain very abundant plagioclase and abundant olivine phenocrysts; subordinate phenocrystpoor varieties contain sparse to common olivine, sparse plagioclase; sparse to rare clinopyroxene, biotite, and orthopyroxene, rare kaersutitic amphibole, and very abundant apatite are locally present. Numerous basalt feeder dikes (unmapped at 1:100,000-scale) were emplaced southwest of Black Mountain caldera and in the Basalt Ridge area. Olivine and plagioclase contents, and stratigraphic range are distinctive. Maximum exposed thickness about 100 m

Tys **Andesite of Sarcobatus Flat (Miocene)**--Local sequence of andesitic lava flows and subordinate interflow tuffaceous sedimentary rocks exposed in low hills along edge of Sarcobatus Flat in western part of map area. Andesitic flows contain common plagioclase and sparse to common orthopyroxene and hornblende. Includes intermediate-composition rocks of peralkaline affinity, probably close in age to rocks of Thirsty Canyon Group, exposed locally east of Black Mountain. Maximum exposed thickness about 100 m

Tyr **Rhyolite of Obsidian Butte (Miocene)**--Flow-laminated and -folded rhyolite lava flows and subordinate related pyroclastic and sedimentary rocks in Obsidian Butte area in northwestern part of map area. Generally aphyric, but some flows contain sparse plagioclase, biotite, or olivine, or rare clinopyroxene, locally rhyolite is conspicuously spherulitic. Pyroclastic rocks mainly consist of variously bedded, pumice- and lithic-rich tuff, tuff breccia, and reworked tuff; sedimentary rocks are generally well-bedded tuffaceous sandstone and conglomerate; clasts are predominantly locally derived rhyolite. Intertongues with and is at least in part comagmatic with basalt flows of unit Tyb. Age of 8.8 Ma (Noble and others, 1991). Maximum exposed thickness about ?75 m

Tgm **Late synvolcanic sedimentary rocks (Miocene)**--Weakly to moderately consolidated, generally well-bedded pebble to cobble conglomerate, breccia, sandstone, siltstone, and locally reworked nonwelded tuff. Variously rounded clasts, predominantly of Miocene volcanic and Proterozoic/Paleozoic sedimentary (Halfpint Range) provenance, supported in tuffaceous matrix; tuffs form thin (less than 1 m), generally isolated beds, are commonly vitric, and contain pumice lapilli. Unit distinguished from younger landslide and sedimentary breccias by higher stratigraphic position, typically smaller size and greater rounding of clasts, and higher proportion of tuffaceous clasts and matrix, and from caldera moat-filling sedimentary deposits by extracaldera distribution. Late synvolcanic sedimentary rocks deposited in local paleobasins and paleochannels in northwestern part of map area, in the Halfpint Range east of Yucca Flat, and in the Little Skull Mountain area in the southern part of map area; deposition of unit occurred following eruption of Timber Mountain units but before, during, and after eruption of the Thirsty Canyon Group and temporally associated basalts with which unit is locally interlayered. Maximum exposed thickness about 125 m

Tgc **Caldera moat-filling sedimentary deposits (Miocene)**--Consists of intercalated fan alluvium and subordinate lacustrine deposits and nonwelded tuff. Fan alluvium composed of coarse, poorly sorted, unevenly bedded, angular to rounded gravel, sand, and minor silt in a locally tuffaceous matrix; clasts, as large as 1 m, consist of locally derived volcanic rocks; weakly to moderately cemented. Lacustrine deposits include interbedded, partly tuffaceous sandstone and mudstone and water-laid tuff. Tuff beds, as much as 0.5 m thick, consist of pumice-bearing ash-fall and ash-flow tuff. Unit poorly exposed; most slopes mantled by gravelly sand. Caldera sedimentary deposits distinguished from younger sedimentary deposits by the limited extent within the Timber Mountain caldera complex and the Black Mountain caldera. Timber Mountain deposits overlie intracaldera, 11.45 Ma Ammonia Tanks Tuff, intertongue with Pahute Mesa and Trail Ridge Tuffs, and underlie 2.82 Ma basalt at Buckboard Mesa; in Black Mountain caldera unit postdates 9.15 Ma Gold Flat Tuff and underlies 7.5 Ma Spearhead Member of the Stonewall Flat Tuff. Maximum thickness about 300 m in Timber Mountain caldera complex

Tgyx **Younger landslide and sedimentary breccias (Miocene)**--Brecciated slide blocks and sheets, sedimentary breccia and conglomerate, and subordinate finer-grained tuffaceous sedimentary rocks and tuff. Unit present only in western part of map area. In Bullfrog Hills area largely consists of crudely bedded to massive, polymictic, matrix- and block-supported breccia containing lenses, blocks, and sheets of monolithologic breccia up to 1 km or more in length. Slide sheets commonly bounded along lower contacts by thin zones of sheared and comminuted tuff that are subparallel to local bedding. Conglomerate is poorly to well bedded and contains matrix-supported, poorly sorted, locally well-rounded pebbles, cobbles, and rare boulders. Sedimentary breccia and conglomerate clasts, locally derived from competent Miocene volcanic rocks and pre-Tertiary sedimentary rocks, are enclosed in partly tuffaceous, sandy to silty matrix. Breccia and conglomerate probably deposited syntectonically as landslide debris, colluvium, and proximal fan alluvium adjacent to uplifted fault blocks. In Bullfrog Hills, breccias are concordantly(?) overlain by rhyolite of Rainbow Mountain tuff and have a maximum exposed thickness exceeding 400 m. Unit also present in isolated exposures north of Tolicha Peak

Thirsty Canyon Group (Miocene)--Peralkaline assemblage of ash-flow sheets, lavas, and related nonwelded tuffs erupted from Black Mountain caldera in north-central part of map area between 9.4 and 9.15 Ma. The Pahute Mesa and Trail Ridge Tuffs likely are the major units associated with caldera collapse. Following caldera collapse, the Pillar Spring, Yellow Cleft, and Hidden Cliff lavas and associated rocks and the Gold Flat Tuff accumulated within the caldera; the Gold Flat also overflowed the caldera mainly to the north and south. Late caldera collapse associated with the Gold Flat is uncertain. Thirsty Canyon Group is distinguished by its peralkaline mineralogy and chemistry; petrographically it is characterized by high alkali feldspar and low plagioclase contents, general absence of biotite and hornblende, and presence of Fe-rich clinopyroxene and fayalitic olivine; chemically it is distinguished by high iron and low aluminum contents for rhyolitic compositions, and anomalously high trace-element concentrations of zirconium, rare-earths, and other elements. Subdivided into:

Ttg **Gold Flat Tuff**--Strongly peralkaline (pantellerite) welded ash-flow tuff erupted at 9.15 Ma from Black Mountain caldera. Contains abundant alkali feldspar (anorthoclase and sodic sanidine), sparse plagioclase, Fe-rich clinopyroxene, and fayalitic olivine, and rare biotite, quartz, and hornblende. Arfvedsonite occurs both as sparse phenocrysts and as a devitrification product in groundmass. Contains rare primary fluorite and aenigmatite. Anomalous normal magnetic polarity. Deposited in caldera moat and present outside of it

Tth **Trachyte of Hidden Cliff**--Sequence of very crystal-rich trachyte lavas containing very abundant plagioclase(distinctive) and common to very abundant olivine and clinopyroxene. Normal magnetic polarity. Exogenous dome emplaced within a collapse depression nested within Black Mountain caldera (exposed part exceeds 500 m)

Tts **Trachytic rocks of Pillar Spring and Yellow Cleft**--Crystal-rich to very crystal rich trachyte to rhyolite lava flows, associated tuff and tuff breccia, and porphyritic syenite intrusive rocks; rocks partly fill and overlap Black Mountain caldera. Lavas contain abundant to very abundant alkali feldspar (mainly anorthoclase), common plagioclase, sparse clinopyroxene and olivine, and local rare biotite; phenocrysts in syenite consist of abundant alkali feldspar (anorthoclase and sodic plagioclase) and lesser olivine and clinopyroxene. The magnetic polarity of Pillar Spring rocks is reverse. Maximum exposed thickness 180 m

Ttt **Trail Ridge Tuff**--Widespread welded, moderately crystal rich, comendite ash-flow tuff erupted from Black Mountain caldera. Contains abundant sodic sanidine, sparse Fe-rich clinopyroxene and fayalitic olivine, and rare plagioclase. Anomalous reverse magnetic polarity. Maximum exposed thickness about 65 m

Ttp **Pahute Mesa and Rocket Wash Tuffs**--Widespread Pahute Mesa Tuff consists of welded, moderately crystal-poor, comendite ash-flow tuff erupted from Black Mountain caldera. Contains common alkali feldspar, sparse Fe-rich clinopyroxene and fayalitic olivine, and rare plagioclase and quartz. Pahute Mesa has anomalous reverse magnetic polarity; maximum thickness about 60 m. Unit locally includes the Rocket Wash Tuff, a subjacent cooling unit erupted 9.4 Ma that has slightly more common alkali feldspar and a typical reverse magnetic polarity; maximum exposed thickness about 50 m

Ttc **Comendite of Ribbon Cliff**--Pre-caldera crystal-rich to very crystal rich comendite and trachyte lava flows and domes exposed marginal to the Black Mountain caldera. Contains abundant alkali feldspar, local common plagioclase, sparse clinopyroxene and fayalitic olivine, and local rare biotite. Normal magnetic polarity. Maximum exposed thickness 320 m

Tfu **Upper Fortymile rhyolite lavas (Miocene)**--Lava flows containing abundant sanidine, sparse biotite, and rare clinopyroxene. Includes rhyolite flows, domes, plugs, and associated tephra overlying trachyte of Donovan Mountain in northernmost Bullfrog Hills, rhyolite of Boundary Butte lava on the south rim of the Ammonia Tanks caldera of the Timber Mountain caldera complex, and isolated lava and associated tephra exposures along the lower Thirsty Canyon drainage. Age ranges from about 10.5 Ma to 9.5 Ma. Maximum exposed thickness about 175 m

Tft **Post-Timber Mountain basaltic rocks (Miocene)**--Basalt, basaltic andesite, trachybasalt, and basaltic trachyandesite lava flows and dikes erupted between 11.45 and approximately 10 Ma. Includes rocks mapped as trachyandesite in the northwest moat of the Timber Mountain caldera complex. Flows generally contain common olivine, sparse plagioclase, and rare clinopyroxene. Maximum exposed thickness about 30 m

Tfn **Trachyte of Donovan Mountain (Miocene)**--Crystal-rich trachyte lava flows and subordinate feeder dikes, sills, and flow-margin tephra present in Bullfrog Hills area. Flows contain abundant plagioclase, common sanidine, biotite, and clinopyroxene, and sparse olivine. Flow foliations and laminations locally conspicuous. Lava flows have normal magnetic polarity; age 10.4 Ma. Maximum exposed thickness exceeds 200 m. Flows overlie rhyolite of Rainbow Mountain with local angular discordance and locally are overlain by some upper Fortymile rhyolite lavas

Tfs **Rhyolite of Shoshone Mountain (Miocene)**--Generally aphyric rhyolite lavas and minor related tuffs containing rare plagioclase, sanidine, clinopyroxene, and biotite. Erupted at about 10.3 Ma from center southeast of Timber Mountain caldera complex; normal magnetic polarity; age 10.3 Ma. Maximum exposed thickness in map area 150 m

Tfd **Lavas of Dome Mountain (Miocene)**--Interstratified trachybasalt, basaltic trachyandesite, and trachyandesite lava flows overlapping southern moat of Timber Mountain caldera complex. Different lava types are petrographically distinguishable; basaltic rocks contain abundant plagioclase, common olivine, and sparse clinopyroxene; trachyandesites contain sparse to common clinopyroxene, rare olivine and orthopyroxene, and local rare hornblende. Normal magnetic polarity; age older than 10.35 Ma, younger than about 11 Ma. Maximum exposed thickness in map area about 200 m

Tiy **Younger intrusive rocks (Miocene)**--Intrusive rhyolite and microgranite porphyry emplaced in the southeast flank of Timber Mountain dome following collapse of Ammonia Tanks caldera. Intrusive rhyolite is crystal-rich and contains abundant alkali feldspar, common quartz, sparse biotite and plagioclase, and sphene; strongly resembles rhyolite compositional zone of Ammonia Tanks Tuff. Unit termed microgranite porphyry (Byers and others, 1976a) is very crystal rich syenite and contains very abundant sanidine, abundant biotite, and common plagioclase and clinopyroxene. Rhyoite that intrudes the Rhyolite of Rainbow Mountain in the Bullfrog Hills is compiled in this unit

Tfr **Rhyolite of Rainbow Mountain (Miocene)**--Intercalated rhyolite and minor dacite/trachyte nonwelded ash-flow tuff and subordinate lava flows, ash-fall tuff, and tuffaceous sedimentary rocks. Present in the northern part of the Bullfrog Hills where it is a thick (150 m), crystal-rich ash-flow tuff containing common plagioclase, quartz, sanidine, and biotite. Lava flows are predominant in the southern Bullfrog Hills and contain common plagioclase and biotite, sparse quartz, and local rare hornblende and clinopyroxene. The lowest lava flow is equivalent to tuff in the northern Bullfrog Hills and contains sparse sanidine. Rests with angular discordance upon older volcanic units; concordantly(?) overlies proximal sedimentary rocks (breccia) of unit Tgx. Lavas have normal magnetic polarity; age about 11 Ma. Maximum exposed thickness in map area about 250 m. Equivalent to rhyolite lava flows and tuffs of Rainbow Mountain of Maldonado and Hausback (1990)

Tfb **Beatty Wash Formation (Miocene)**--Post-caldera rhyolite lavas and related tuff erupted from 11.4 to 11.2 Ma within moat of Timber Mountain caldera complex. Includes rhyolite of Beatty Wash (normal magnetic polarity) and tuff of Cutoff Road (anomalous reverse magnetic polarity), which contain common sanidine and plagioclase, sparse to common biotite, local sparse hornblende, local rare quartz, and common sphene. Petrographically similar tephras are white and very pumice-rich in lower part and consist of brown basalt-rhyolite mixes in rhyolite of Chukar Canyon subunit of upper part. Quartz-poor character and abundance of sphene are diagnostic. Also includes overlying rhyolites of Max Mountain (reverse magnetic polarity) and Boundary Butte, which contain sparse quartz phenocrysts. Lavas as much as 300-430 m thick; tuff layers as much as 60 m thick

Tff **Rhyolite of Fleur-de-lis Ranch (Miocene)**--Post-caldera rhyolite lavas and welded ash-flow tuff erupted at about 11.4 Ma on west side of Timber Mountain caldera complex. Contains abundant plagioclase and biotite, sparse clinopyroxene, and local sparse hornblende. Distinguished by abundance of plagioclase and lack of sphene, especially in welded ash-flow subunits. Magnetic polarity normal. Stacked lavas and welded tuffs as much as 300 m thick. Includes rhyolite of West Cat Canyon

Timber Mountain Group (Miocene)--Calc-alkaline assemblage erupted from the Timber Mountain caldera complex between about 11.6 and 11.45 Ma. Group consists predominantly of rhyolite ash-flow tuff and includes subordinate, related rhyolite lava flows and domes that erupted before, between, and after emplacement of ash-flow units. Eruption of the voluminous Rainier Mesa Tuff and Ammonia Tanks Tuff resulted in collapse of the Rainier Mesa and younger Ammonia Tanks calderas (Christiansen and others, 1977), respectively, which form the Timber Mountain caldera complex. The latter caldera is centered about Timber Mountain, which consists of the Ammonia Tanks resurgent dome. Rocks of this group are distinguished by high content of quartz phenocrysts in rhyolite units and high mafic contents in upper parts of zoned units. Subdivided into:

Tmay **Trachyte of East Cat Canyon**--Immediately post-caldera, very crystal-rich trachyte lavas erupted prior to resurgence on margin of Ammonia Tanks resurgent dome. Contains very abundant plagioclase and biotite, abundant clinopyroxene, sparse sanidine and orthopyroxene, rare quartz and hornblende, and abundant apatite. Close temporal and compositional association with Ammonia Tanks Tuff is distinctive, as is the presence of sanidine and quartz, which is unusual for an intermediate lava. Maximum thickness about 125 m. Includes rhyolite of Parachute Canyon

Tmaw **Tuff of Buttonhook Wash**--Post-caldera, crystal-rich rhyolite ash-flow tuff and subordinate bedded tuff erupted immediately after Ammonia Tanks subsidence, and confined within Timber Mountain caldera complex. Contains common sanidine, plagioclase, and quartz, sparse biotite and clinopyroxene, local rare hornblende, and abundant sphene. Virtually identical to intracaldera facies of unit Tma, but separated from it by a cooling break. Magnetic polarity normal. Maximum exposed thickness about 250 m. Includes petrographically indistinguishable tuff of Crooked Canyon

Tma **Ammonia Tanks Tuff**--Widespread metaluminous, welded ash-flow tuff sheet erupted at 11.45 Ma from younger Ammonia Tanks caldera of Timber Mountain caldera complex, and resurgently domed to form Timber Mountain. Compositionally zoned from lower, volumetrically dominant rhyolite (abundant sanidine, common quartz and plagioclase, sparse biotite, rare clinopyroxene, and sparse sphene) to upper crystal-rich trachyte (abundant sanidine and biotite, common plagioclase and quartz, and sparse clinopyroxene and sphene). Local basal bedded tuff unit resembles lower rhyolite but contains sparse hornblende and rare orthopyroxene, clinopyroxene, and Mg-rich olivine in association with basaltic lapilli. Distinguished by high quartz and mafic contents, sparse sphene, and normal magnetic polarity. Maximum intracaldera thickness more than 900 m on Timber Mountain resurgent dome; outflow widely distributed in all directions, with a typical thickness of less than 150 m

Tmx **Timber Mountain landslide breccia**--Thickly bedded, poorly sorted breccia grading downward into megabreccia. Composed of angular, mainly pre-Ammonia Tanks volcanic clasts as much as 6 m across and variable proportions of coarse-grained tuffaceous matrix; clasts locally derived from rock units exposed on topographic wall of Timber Mountain caldera complex. Lower part of unit locally intertongues with upper Rainier Mesa Tuff, and breccia is overlain by intracaldera Ammonia Tanks Tuff. Breccia, limited to caldera moat and base of caldera wall, emplaced as debris flows and rock avalanches shed off topograhic wall of caldera(s) following Rainier Mesa and, perhaps, Ammonia Tanks collapse. Maximum thickness exceeds 300 m

Tmat **Rhyolites of Tannenbaum Hill/Buried Canyon**--Rhyolite lavas and related subordinate nonwelded tuff erupted between emplacement of Rainier Mesa Tuff and Ammonia Tanks Tuff in northwest Timber Mountain caldera complex moat; chemically and petrographically similar to Ammonia Tanks. Contains common quartz and sanidine, rare plagioclase and biotite, and common sphene. Distinguished by sphene content, normal magnetic polarity, and stratigraphic position between major tuff units. Isotopic age of 11.54 +/- 0.03 Ma (Fridrich, Sawyer, Fleck, and Lanphere, unpublished data) Maximum thickness greater than 180 m

Tmt **Basalts in Timber Mountain Group**--Flows containing common olivine, common plagioclase, and local sparse clinopyroxene. Includes preRainier Mesa basalt of Tierra [normal magnetic polarity (Lawrence Livermore National Lab, unpublished data)] and basalt of Oasis Valley (reverse magnetic polarity) that occurs stratigraphically between Rainier Mesa and Ammonia Tanks Tuffs. Maximum exposed thickness less than 30 m

Tmr **Rainier Mesa Tuff**--Widespread metaluminous welded ash-flow tuff sheet erupted at 11.6 Ma from older Rainier Mesa caldera of Timber Mountain caldera complex. Compositionally zoned from lower, volumetrically dominant rhyolite (common sanidine and quartz, sparse plagioclase, and rare biotite) to upper crystal-rich trachyte (abundant biotite, common sanidine, plagioclase, and quartz, sparse clinopyroxene, and rare orthopyroxene and hornblende). Distinctive thin (about 10 cm) tephra layers directly beneath main eruptive unit consist of paired dacite and overlying trachybasalt tuff containing abundant hornblende, common plagioclase, and sparse orthopyroxene. Unit distinguished by high quartz and mafic contents, rare accessory monazite, and reverse magnetic polarity; lower nonwelded to partly welded zones are characteristically salmon pink. Maximum intracaldera thickness more than 500 m; outflow, which is widely distributed in all directions, has a typical maximum thickness of 150 m and locally is ponded to a thickness of as much as about 400 m. Includes minor overlying bedded Rainier Mesa Tuff locally; in Bullfrog Hills unit may include some Ammonia Tanks Tuff where distinction could not be made due to brecciation and alteration

Tmrf **Rhyolite of Fluorspar Canyon**--Pre-caldera rhyolite lava and nonwelded tuff erupted prior to eruption of Rainier Mesa Tuff. Contains common quartz and sanidine, sparse plagioclase, and rare biotite. Locally consists of thick nonwelded tuff deposits. Distinguished by high quartz content, reverse magnetic polarity, and rare accessory monazite, and from petrographically similar mafic-poor Rainier Mesa Tuff by lower lithic content. Maximum thickness about 200 m. Includes tuff of Holmes Road, a distinctive interlayered brown and pink to white phreatomagmatic deposit. Isotopic age 11.62 +/- 0.03 Ma (Fridrich, Sawyer, Fleck, and Lanphere, unpublished data) Includes Rhyolite of Pinnacles Ridge, on the divided between Beatty Wash and Yucca Wash

Tgn **Transitional Timber Mountain sedimentary rocks (Miocene)**--volcaniclastic sedimentary rocks associated with the Transitional Timber Mountain rhyolite lava flows

Tmn **Transitional Timber Mountain rhyolites (Miocene)**--Widespread crystal-rich to very crystal-rich rhyolite lavas and related nonwelded tuffs, ponded in the Claim Canyon caldera of Paintbrush age at 12.5 Ma, but representing the initial eruptions of Timber Mountain-type petrography (common quartz and biotite, but lacking in monazite). Contains common to abundant sanidine and plagioclase, and common quartz, and common biotite. Includes the rhyolites of Windy Wash and Waterpipe Butte, which contain rare to common hornblende and abundant sphene, and the rhyolite of the Loop which lacks both. Rhyolite of the Loop is dated at 12.49 +/- 0.03 Ma (Fridrich, Sawyer, Fleck, and Lanphere, unpublished data). Small-volume rhyolite lava flows, related breccia and intrusive dikes, and tephra

Paintbrush Group (Miocene)--Metaluminous assemblage of alkali rhyolite tuffs and lavas was erupted from the vicinity of the Timber Mountain caldera complex between 12.8 and 12.7 Ma. The Claim Canyon caldera, well-established source of the Tiva Canyon Tuff, adjoins the southern part of the Timber Mountain caldera complex and is exposed in the south of the map area, whereas the source of the older Topopah Spring Tuff is uncertain. The westernmost exposures of thick Pah Canyon and Yucca Mountain Tuffs located just south of the intersection of the Transvaal Hills and Beatty Wash, are interpreted by some to be a part of the southwest outer topographic wall of the Topopah Spring caldera. Paintbrush Group rocks are distinguished by an absence or rarity of quartz phenocrysts in rhyolite units and the presence of sphene, except in the lower Topopah Spring. In addition to biotite, units in the upper part of the Paintbrush contain hornblende, whereas the lower units contain clinopyroxene. Subdivided into:

Tpu **Post-Tiva Canyon rhyolites**--Post-caldera rhyolite lavas and related nonwelded tuff exposed on northern topographic wall of Timber Mountain caldera complex. Contains common sanidine and common to sparse plagioclase and biotite. Includes the rhyolite of Scrugham Peak, which also contains abundant sphene, and the younger rhyolite of Benham, which additionally contains rare quartz and hornblende. Unit also includes the rhyolites of Vent Pass and Comb Peak. Erupted immediately after the Tiva Canyon Tuff; reverse magnetic polarity. Maximum exposed thickness 300 m

Tpc **Tiva Canyon Tuff**--Widespread metaluminous welded ash-flow tuff sheet erupted at 12.7 Ma from Claim Canyon caldera. Compositionally zoned from lower crystal-poor rhyolite (common sanidine, sparse hornblende, and abundant sphene) to upper trachyte (common sanidine and plagioclase, sparse biotite and clinopyroxene, rare hornblende, and sparse sphene). Distinguished by dominance of sanidine among felsic phenocrysts, presence of sphene, and reverse magnetic polarity; lower part commonly is conspicuously platy. Locally hydrothermally altered and brecciated in Bullfrog Hills. Exposures consist of outflow in Pahute Mesa map area, where unit is widely distributed with maximum exposed thickness about 110 m. In the NTS map area, a piece of the intracaldera Tiva Canyon is exposed, and was called the tuff of Chocolate Mountain on the Topopah Spring NW quadrangle (Christiansen and Lipman, 1965). In the Claim Canyon caldera area and in northern Crater Flat, there is an upper separate cooling unit, the tuff of Pinyon Pass which shows a similar compositional zonation to the Tiva Canyon

Tpx **Paintbrush caldera-collapse breccias**--Caldera collapse landslide breccias interfingering with the intracaldera Tiva Canyon Tuff on and adjoining the Chocolate Mountain resurgent caldera dome. Consists of varied pre-Tiva Canyon volcanic lithologies

Tpy **Yucca Mountain Tuff**--Welded aphyric rhyolite ash-flow tuff, present as a simple cooling unit in the vicinity of the Claim Canyon caldera and Yucca Mountain. Distinguished by its virtually phenocrystfree composition and reverse magnetic polarity; and stratigraphic position immediately beneath the Tiva Canyon Tuff, which it appears to be related as a precursory eruption. Maximum thickness of 335 m within the Claim Canyon caldera, and 75 m outside

Tpm **Middle Paintbrush Group rhyolites**--Lava flows and related nonwelded tuff present at Pahute Mesa that were erupted between deposition of the two major Paintbrush ash-flow tuff units (Tiva Canyon Tuff and Topopah Spring Tuff). Lavas contain common sanidine, common to rare plagioclase and biotite, and rare quartz. The lowest unit, the rhyolite of Silent Canyon, has the highest plagioclase content, common biotite as the only mafic mineral, and lacks sphene; overlying rhyolite of Echo Peak is characterized by sparse to common biotite, rare clinopyroxene, and abundant sphene; uppermost crystal-poor rhyolite of Delirium Canyon has sparse plagioclase, rare hornblende and biotite, and abundant sphene. Additional units include the rhyolite of Black Glass Canyon and rhyolite of Z. Distinguished by stratigraphic position both above and below the Pah Canyon Tuff and by reverse magnetic polarity of lava flows. Maximum thickness for individual flow units ranges from 140 to 390 m

Tpp **Pah Canyon Tuff**--Partly welded to welded rhyolite ash-flow tuff, erupted in the vicinity of the Claim Canyon caldera. Contains common plagioclase, sanidine, and biotite, and rare clinopyroxene and sphene. Distinguished by stratigraphic position and reverse magnetic polarity; maximum thickness of 90 m

Tpt **Topopah Spring Tuff**--Widespread metaluminous welded ash-flow tuff sheet erupted at 12.8 Ma from as yet uncertain caldera source located in general vicinity of Timber Mountain caldera complex. Compositionally zoned from lower crystal-poor rhyolite (sparse plagioclase and rare sanidine, biotite, and quartz) to upper trachyte (common sanidine and plagioclase, sparse biotite and clinopyroxene, and local rare quartz). Local overlying bedded tuff is zoned in similar fashion. Unit is distinguished by high sanidine content but lower sanidine/plagioclase ratio than that of Tiva Canyon Tuff, trace quartz content, absence of sphene, and normal magnetic polarity. Exposures are entirely outflow; no inctracaldera tuff has been recognized. The tuff is widely distributed in southern part of map area, including the Yucca Mountain repository area; it has a maximum exposed thickness of about 350 m

Tac **Calico Hills Formation (Miocene)**--Sequence of metaluminous rhyolite lavas and related tuff erupted from vents in the Calico Hills area and in the Area 20 caldera in subsurface of Pahute Mesa (Sawyer and Sargent, 1989) at 12.9 Ma. Lavas represent post-collapse eruptions generally related to Crater Flat Group magmatism. Lava sequence is compositionally zoned from lower rhyolite (contains common quartz, plagioclase, and sanidine and sparse biotite) to upper crystal-poor rhyolite (contains sparse quartz and sanidine, and rare plagioclase and biotite). Also includes crystal-rich rhyolites of Pool (sparse biotite and hornblende) and Inlet (common biotite and sparse hornblende) in subsurface of Pahute Mesa. On the west side of Yucca Flat, in the Rainier Mesa/southern Belted Range area, and north of Silent Canyon the map unit may include undivided bedded tuff associated with the Bullfrog Tuff, the Wahmonie Formation, the Paintbrush Group, and (or) pre-Rainier Mesa rhyolites. Normal magnetic polarity, high relative quartz content, Fe-rich mafic mineral chemistry, common bedded tuff character, and local zeolitization are distinctive. Maximum exposed thickness approximately 200 m; ponded to more than 2200 m within Area 20 caldera

Tio **Older intrusive rocks (Miocene)**-- Andesitic, hydrothermally altered, hypabyssal intrusion poorly exposed in Bullfrog Hills. Contains common plagioclase and clinopyroxene phenocrysts. Intrudes pre-Tertiary basement rocks and predates or is coeval with overlying older basalt unit. Unit also includes the granitic and rhyolitic plutons that intrude the Wahmonie volcanic center

Tw **Wahmonie Formation (Miocene)**--13.0 Ma--Metaluminous very crystalrich andesite and crystal-rich dacite lavas, tephra, and related volcaniclastic deposits erupted at 13.0 Ma from the Wahmonie volcano, located southeast of the main cluster of SWNVF calderas. Contains abundant to very abundant plagioclase (increasing upward in the sequence of lavas), very abundant to common biotite (decreasing upward), abundant to sparse hornblende (except where rare in lower tuff of Mara Wash), rare to very abundant orthophyroxene (increasing upward), very abundant clinopyroxene in middle and upper members, abundant olivine in the middle member, and sparse quartz in the lower Member and tuff of Mara Wash. Distinguished by mafic-rich mineralogy, and dominance of plagioclase, and complete absence of sanidine. Includes widespread Wahmonie tephra distributed throughout Yucca Flat and most of Rainier Mesa, that is similar in mineralogy to lower Member

Tws **Salyer Member (Miocene)**--Volcaniclastic facies of lower Wahmonie, including lahars, bedded and reworked tuffs, "tuff breccia" and other volcaniclastic breccia layers

Crater Flat Group (Miocene)--Calc-alkaline assemblage of ash-flow sheets, lavas, and related nonwelded tuff erupted from Area 20 caldera and possibly from the vicinity of the proposed Prospector Pass caldera in the northern Crater Flat area (Carr and others, 1986) between about 13.5 and 13.1 Ma. The Bullfrog Tuff, the major exposed Crater Flat unit, erupted from Area 20 caldera where it is ponded to a thickness of more than 600 m in the subsurface of Pahute Mesa; the larger part of the caldera may have been obliterated by younger Timber Mountain caldera complex. The Crater Flat Group is distinguished by high relative quartz contents among the felsic minerals and Fe-rich mafic mineralogy. Subdivided into:

Tcp **Prow Pass Tuff (Miocene)**--Youngest welded ash-flow tuff sheet in Crater Flat Group, erupted from an unknown source at about 13.1 Ma. Rhyolite tuff contains common plagioclase and sanidine, sparse quartz, and rare orthopyroxene and biotite. Distinguished by orthopyroxene content and relatively low biotite, and normal magnetic polarity. Principal surface exposures are in a small area just northwest of the "Prow" of Yucca Mountain, but much more extensive in the subsurface of Yucca Mountain

Tcg **Latite of Grimy Gulch**--Local intermediate-composition, mainly crystal-poor lava flows erupted on flank of Silent Canyon caldera complex at south end of Kawich Valley. Contains common plagioclase and olivine, sparse clinopyroxene, and rare sanidine and quartz (both with reaction rims). Normal magnetic polarity. Maximum thickness 76 m

Tcb **Bullfrog Tuff**--Widespread metaluminous, variably welded, rhyolite ash-flow tuff sheet. Regional variations in lithic content from lithicpoor welded tuff south of quadrangle at Yucca Mountain to thick, compositionally zoned, lithic-rich nonwelded tuff in central part of map area in the buried Area 20 caldera Outflow Stockade Wash lobe east of caldera, previously called Stockade Wash Tuff, has common sanidine, quartz, plagioclase, and biotite, rare hornblende, and maximum thickness of 120 m. Intracaldera facies in Area 20 caldera is compositionally zoned, from lower rhyolite (common sanidine and quartz, sparse plagioclase, and rare biotite) to upper rhyolite (common sanidine, plagioclase and quartz, sparse biotite, and rare hornblende); it has a high lithic content, is intercalated with landslide breccia deposits, and has maximum thickness of about 680 m. Bullfrog Tuff is hydrothermally altered and locally brecciated in Bullfrog Hills. Distinguished by high relative quartz content among the felsics, sparse to rare biotite and hornblende, Fe-rich mafic minerals, general absence of sphene, and normal magnetic polarity. About 13.25 Ma in age. Includes a related subunit (tuff of Rickey) in subsurface of Pahute Mesa. On the west side of Yucca Flat, and in Rainier Mesa/southern Belted Range area may include undivided bedded tuff of Deadhorse Flat Formation, Wahmonie Formation, Calico Hills Formation, the Paintbrush Group, and (or) the rhyolite of Fluorspar Canyon

Tcr **Rhyolites in the Crater Flat Group (Miocene)**--Thick rhyolitic flows and minor related breccia and tephra. Includes rhyolite of Prospector Pass on the East of Beatty Mountain quadrangle (Fridrich and others, 1994). Petrographically very similar to rhyolite of Inlet: common felsic phenocrysts of plagioclase, quartz, and sanidine; common biotite and sparse hornblende. Unit also includes rhyolite lava and related tuffs of Jorum (rare biotite and hornblende), Sled (crystal-poor, and having rare quartz, biotite, and hornblende), and Kearsarge (crystal-rich, having common biotite and clinopyroxene, sparse orthopyroxene, and rare quartz); these units are known only from the subsurface of Pahute Mesa.

Tct **Tram Tuff (Miocene)**--Widespread welded rhyolite ash-flow tuff, possibly erupted from source in the northern part of the Prospector Pass caldera complex. Age about 13.4 Ma, stratigraphically bracketed between the Bullfrog Tuff and the Deadhorse Flat Formation rhyolite lava flows. Distinguished by mineralogy of subequal common quartz, plagioclase, and sanidine; sparse biotite as the only mafic mineral, and reverse magnetic polarity

Tgo **Older synvolcanic sedimentary rocks (Miocene)**--Nonwelded tuff and fluvial to lacustrine, locally tuffaceous sedimentary rocks; mostly bedded. Sedimentary rocks largely consist of volcaniclastic conglomeratic sandstone, siltstone, shale, and sandy limestone; contains fossil fish and plants. Tuffs, mostly of ash-fall origin, partly related to upper and lower rhyolites of Quartz Mountain. Present in northwestern part of map area in the Mount Helen area and north of Black

Mountain caldera. In Mt Helen area includes tuff and reworked tuff that may be associated with tuff of Tolicha Peak and tuffaceous breccias derived from dacite of Mount Helen. Locally zeolitized. Maximum exposed thickness more than 600 m, but no adequate, unfaulted sections have been carefully measured

Tgox **Older landslide and sedimentary breccias (Miocene)**--sedimentary rocks directly overlie or underlie Grouse Canyon Tuff at two local exposures south of Quartz Mtn; south of Syncline Ridge in Yucca Flat area unit includes well-bedded boulder conglomerate that directly overlies Redrock Valley Tuff

Belted Range Group (Miocene)--Peralkaline assemblage of ash-flow sheets, lavas, and related nonwelded tuff erupted from the older Grouse Canyon caldera of the Silent Canyon caldera complex between 13.85 and 13.5 Ma. Grouse Canyon Tuff, the major caldera-forming unit, has a strong petrologic affinity with the pre-caldera Comendite of Split Ridge. Following eruption of Grouse Canyon Tuff and its ponding within caldera, further caldera collapse occurred, and a thick sequence of post-caldera peralkaline lavas and related tuff, the Deadhorse Flat Formation, accumulated within Grouse Canyon caldera in the subsurface of Pahute Mesa and overflowed it to the north into the Saucer Mesa area. Belted Range Group is distinguished by its peralkaline mineralogy and chemistry; petrographically, it is characterized by high alkali feldspar and low plagioclase contents, absence of biotite and hornblende, and presence of Fe-rich clinopyroxene and fayalitic olivine; quartz is common to sparse in some units, and absent in others; chemically, Belted Range Group is distinguished by high iron and low aluminum in rhyolitic compositions, and high concentrations of zirconium and rare-earth elements. Subdivided into:

Tbd **Deadhorse Flat Formation**--Post-caldera lavas and related tuff erupted and ponded within Grouse Canyon caldera between 13.7 and 13.5 Ma. Mineralogy is variable among the different stratigraphic subunits of formation, which range from crystal-rich comendite (peralkaline rhyolite) and trachyte to crystal-poor and aphyric comendite. Common alkali feldpsar (sodic sanidine) is the dominant felsic phenocryst phase, whereas clinopyroxene and fayalitic olivine are the only mafic phenocryst minerals. Unit includes comendite of Lambs Canyon (with common quartz), aphyric comendite of Kaw Station, comendite and lowsilica comendite of Saucer Mesa, comendite of Chartreuse (with sparse quartz and rare plagioclase), and trachyte of Muenster (with abundant alkali feldpspar and rare plagioclase). Formation distinguished by phenocryst mineralogy (general absence of biotite, hornblende, and plagioclase) and distinctive geochemistry. Comendite of Lambs Canyon has reverse magnetic polarity, and has been dated at 13.5 Ma; the comendite of Saucer Mesa has normal polarity. Maximum thickness about 1600 m in subsurface of Pahute Mesa; maximum exposed thickness about 150 m. Locally includes:

Tbdb **Comendite of Basket Valley**--Comendite lava and welded to nonwelded tuff present stratigraphically between overlying comendite of Saucer Mesa and underlying comendite of Chartreuse in the subsurface. Separated from rest of Deadhorse Flat Formation only northeast of Grouse Canyon caldera where it forms a distinct mappable unit at base of formation. Distinguished by petrography (abundant alkali feldspar and rare quartz, clinopyroxene, and fayalitic olivine), strong light rareearth element enrichment, and rheomorphic character of lava. Includes a low-silica comendite lava north of Apache Tear Canyon. Normal magnetic polarity. Maximum exposed thickness about 150 m

Tbg **Grouse Canyon Tuff**--Widespread peralkaline welded ash-flow tuff sheet erupted at 13.7 Ma from Grouse Canyon caldera of Silent Canyon caldera complex. Compositionally zoned from lower aphyric comendite to upper moderately crystal-rich comendite (common alkali feldspar and rare quartz, plagioclase, clinopyroxene, and fayalitic olivine). Groundmass arfvedsonite is common in devitrified, welded upper part. Basal aphyric comendite bedded tuff is more widely distributed to east and southeast than ash-flow tuff, and consists of multiple normally graded, 0.5-5 m thick beds each containing basal pyroclastic shards and pumice grading upward to fine ash. Unit distinguished by high alkali feldspar content relative to other felsic phases, absence of biotite, strong zonation in geochemistry, conspicuous greenish- to bluish-gray color of lower welded tuff and bedded tuff, and anomalous normal magnetic polarity. Maximum intracaldera thickness about 575 m in subsurface of Pahute Mesa; outflow is widely distributed to northeast (in Belted Range) and west of caldera complex; distribution to south poorly constrained because of younger calderas and outflow tuff sheets; maximum exposed outflow thickness about 110 m; maximum thickness of bedded tuff 150 m

Tbgs **Comendite of Split Ridge**--Pre-caldera aphyric comendite and porphyritic trachyte lava flows and related tuff erupted at 13.85 Ma. Comendite exposed at Split Ridge southeast of Silent Canyon caldera complex; inlcudes trachyte lavas locally exposed along western margin of Kawich Valley and Saucer Mesa. Trachytes contain common sanidine, olivine, and clinopyroxene. Comendite lava has normal magnetic polarity; maximum thickness about 380 m

Trl **Lithic Ridge Tuff (Miocene)**--Regional, partly welded to welded metaluminous ash-flow tuff erupted at 14.0 Ma from unknown caldera source possibly in vicinity of Crater Flat south of quadrangle. Contains common plagioclase and sanidine, and sparse quartz, biotite, and sphene. Distinguished by high plagioclase content relative to other felsic phases and anomalous reverse magnetic polarity. Maximum exposed thickness in map area 30 m

Trd **Dikes of Tram Ridge (Miocene)**-- Intrusive feeders for rhyolite of Picture Rock and local related tuff erupted at 14.0 Ma. Dikes occur widely over the region from Bare Mountain to north of Timber Mountain. Contains abundant plagioclase and biotite, sparse sanidine, hornblende, and sphene, and rare quartz. Distinguished by abundant plagioclase and biotite, and reverse magnetic polarity

Trr **Rhyolite of Picture Rock (Miocene)**—Widespread metaluminous, crystal-rich dacite lava flows, intrusive feeders, and local related tuff erupted at 14.0 Ma. Contains abundant plagioclase and biotite, sparse sanidine, hornblende, and sphene, and rare quartz. Distinguished by abundant plagioclase and biotite, and reverse magnetic polarity. Partly equivalent to units in subsurface of Yucca Mountain south of quadrangle (andesites and dacites in drill holes G-1 and G-2, and tuff of Units B and C). Correlative with metaluminous tephra in bed 4JK (Carroll, 1989, fig. 2) of Tunnel Formation. Includes rhyolitic lavas near Quartz Mountain and Tolicha Peak which contain very abundant to abundant plagioclase and biotite, common to sparse alkali feldspar and hornblende, rare quartz, and very abundant to sparse sphene. Also includes intermediate, hydrothermally altered lavas in Bullfrog Hills that probably correlate with Unit B in the subsurface of Yucca Mountain. Maximum exposed thickness about 450 m

Tn **Tunnel Formation (Miocene)**—Diverse sequence of dominantly red and white bedded and nonwelded rhyolite tuff; possibly includes subordinate, reworked, epiclastic tuff. It is a mappable unit where it ponded in local paleobasins mainly in eastern part of map area, most notably at Rainier Mesa, but also on west side and in the subsurface of Yucca Flat. Upper beds (4JK) [see Carroll (1989, fig. 2) for stratigraphic context of number/letter-designated subunits of formation] consist of interfingering metaluminous and peralkaline tephra; peralkaline, aphyric comendite tuff is apparently related to comendite of Quartet Dome, whereas metaluminous 4K tuff is associated with the rhyolite of Picture Rock, or the tuff of Sleeping Butte as a slightly older metaluminous source (bed 4GH). Non-peralkaline middle beds (3D, 4A-F) contain common sanidine and sparse quartz and plagioclase, and are very mafic-poor (rare clinopyroxene and biotite); crystal content of middle beds increases slightly down section. Bed 3D includes rare hornblende. Lower beds consist of crystal-poor tuff (sparse plagioclase and rare sanidine, quartz, and biotite [bed 3BC]) underlain by crystal-rich tuff (common plagioclase, sanidine, quartz, and biotite, and rare hornblende [bed 3A]). Top of unit is defined as base of Grouse Canyon Tuff or Lithic Ridge Tuff; base of formation is top of Tub Spring Tuff. Unit may locally include Lithic Ridge Tuff north of Redrock Valley. Formation distinguished by its significant local thickness (as much as 200 m), typical zeolitic alteration, and internal variations in petrography and chemistry. Unit mapped as Tunnel Formation in Belted Range may consist laregly of bedded Comendite of Quartet Dome

Tbq **Comendite of Quartet Dome (Miocene)**—Peralkaline crystal-rich comendite lava domes and related tephra mainly exposed around south margin of Kawich Valley. Contains abundant sanidine, common quartz, sparse fayalitic olivine, and rare clinopyroxene. Distinguished by peralkaline mineralogy (absence of plagioclase and biotite), high relative quartz content, and normal magnetic polarity. Maximum exposed thickness 250 m. Correlative with bed 4J of Tunnel Formation and temporally associated with Grouse Canyon magmatic system rather than Tub Spring Tuff

Tqc **Tuff of Cache Cave Draw / Rhyolite of Coyote Cuesta (Miocene)**—Two similar, but probably unrelated, rhyolites exposed in Gold Flat/Tolicha Peak area (Coyote Cuesta) and southern Belted Range (Cache Cave Draw). Tuff of Cache Cave Draw consists of aphyric ash-flow tuff with reverse magnetic polarity

Tqs **Tuff of Sleeping Butte (Miocene)**—Sequence of two metaluminous rhyolite ash-flow tuffs and associated bedded tephra predominantly exposed in Sleeping Butte area about 12 km north of Oasis Valley; tuffs erupted at 14.3 Ma probably from caldera source in this area. Small isolated exposures on east sides of Gold Flat and Kawich Valley and near Tolicha Peak; in latter area distal facies of unit may be locally present in bedded tuffs of upper rhyolite of Quartz Mountain. Upper tuff is partly welded, massive, lithic rich, and crystal poor, with sparse alkali feldspar and rare biotite. Underlying, more densely welded tuff is strongly zoned from lower mafic-poor rhyolite with common sanidine and quartz, sparse plagioclase, and rare pseudomorphs of clinopyroxene and (or) hornblende, to upper crystal-rich rhyolite with abundant sanidine and plagioclase, sparse pseudomorphs of hornblende and (or) clinopyroxene and biotite, and rare quartz. Upper tuff apparently laps onto lower densely welded tuff east of Sleeping Butte. Lower welded tuff distinguished by high sanidine content, locally abundant granitoid inclusions, stratigraphic position, and normal magnetic polarity. Maximum exposed cumulative thickness about 400 m. Unit may include tuff related to rhyolite of Picture Rock, and possibly correlative with beds 4GH of Tunnel Formation

Tqh **Middle rhyolite of Quartz Mountain (Miocene)**—Calc-alkaline rhyolite to dacite lava flows, small dome intrusions, and related tephra intercalated with ompositionally similar bedded tuffs and local sedimentary rocks; exposed in western part of map area. Two types of petrographic modes occur in the lava flows, domes, and intrusions: (1) common sanidine and plagioclase, sparse biotite, rare clinopyroxene, and abundant sphene, and (2) common sanidine, plagioclase, and quartz, and sparse hornblende. Bedded rhyolite tuff is nonwelded, crystal- and lithic-rich, and partly zeolitized, and locally includes tuff breccia; lithic fragments typically composed of upper Quartz Mountain lava. Lava flows have reverse magnetic polarity. May locally include distal tuff of Sleeping Butte. Maximum exposed thickness of lava flows more than 250 m; of bedded tuffs more than 300 m

Tqt **Tuff of Tolicha Peak (Miocene)**--Distinctive metaluminous, very crystal poor, welded rhyolite ash-flow tuff exposed in western part of map area and erupted at 14.3 Ma from unknown source. Contains rare plagioclase, sanidine, and quartz, and no mafics (except very local rare biotite). Conspicuous platy to hackly, orangish- to pinkish-brown appearance in outcrop; typically forms a colluvial scree. Normal magnetic polarity. Maximum exposed thickness exceeds 300 m. Correlative in part with beds 3BC of Tunnel Formation

Tqe **Early rhyolite of Quartz Mountain (Miocene)**--Calc-alkaline rhyolite to dacite lava flows and domes intercalated with subordinate, compositionally similar tephra and bedded tuffs, and tuffaceous sedimentary rocks; exposed in western part of map area stratigraphically below tuff of Tolicha Peak. Two types of petrographic modes are identified in the lavas and small domes and intrusions: (1) common quartz, plagioclase, sanidine, and biotite, rare hornblende, and sparse sphene, and (2) sparse alkali feldspar and biotite. Bedded rhyolite tuff is nonwelded and partly zeolitized, and locally includes tuff breccia; lithic fragments typically composed of lower Quartz Mountain rhyolite lava. Unit commonly hydrothermally altered

Tqm **Dacite of Mount Helen (Miocene)**--Lava flows and intrusive masses exposed in Mt Helen area in northwestern part of map area; crystal-rich with abundant plagioclase, biotite, and hornblende, and common large (more than 1 cm) quartz phenocrysts

Tuo **Comendite of Ochre Ridge (Miocene)**--Peralkaline lava flows and related tephra present at Ocher Ridge and elsewhere along the southern margin of Kawich Valley and in the southern Belted Range. Comendite lavas are moderately crystal-poor, containing common sanidine and quartz, and rare clinopyroxene. Distinguished from comendite of Emigrant Valley by stratigraphic position of Ocher Ridge comendite above Tub Spring Tuff. Normal magnetic polarity

Tub **Tub Spring Tuff (Miocene)**--Widespread peralkaline welded ash-flow tuff present in Belted Range and northeast side of Yucca Flat; erupted at 14.9 Ma from a buried and poorly constrained caldera source, possibly in eastern Pahute Mesa or southern Kawich Valley. Compositionally zoned from lower crystal-poor comendite containing common sanidine and quartz, and rare plagioclase and biotite, to upper crystal-rich comendite containing abundant sanidine, common quartz, and sparse clinopyroxene and fayalitic olivine. Distinguished from peralkaline Grouse Canyon Tuff and younger units by high relative quartz content. Normal magnetic polarity. Maximum exposed outflow thickness 90 m

Tue **Comendite of Emigrant Valley (Miocene)**--Peralkaline lava flows and related tephra that are present along eastern flank of Belted Range. Lavas are moderately crystal poor, containing common sanidine and quartz, and rare clinopyroxene. Distinguished from comendite of Ocher Ridge by the stratigraphic position of Emigrant Valley comendite below the Tub Spring Tuff

Ton **Older tunnel beds (Miocene)**--Lower sequence of zeolitized, dominantly white, bedded and nonwelded rhyolite tuff and reworked epiclastic tuff. Limited exposures around north end of Yucca Flat and southern Kawich Valley; extensive in subsurface of Rainier Mesa and Yucca Flat. Distinguished from overlying Tunnel Formation by stratigraphically intervening Tub Spring Tuff. Includes tunnel beds 1 and 2 of Carroll (1989, fig. 2), and may locally include nonwelded tuff equivalent to tuff or Yucca Flat, Redrock Valley Tuff, tuff of Twin Peaks, and tuff of Whiterock Spring

Toy **Tuff of Yucca Flat (Miocene)**--Subregional, nonwelded to partly welded, metaluminous rhyolite ash-flow sheet erupted at 15.05 Ma from unknown source. Present in subsurface and along margins of Yucca Flat. Contains common plagioclase, sanidine, and biotite, and sparse quartz and hornblende; typically zeolitized. Reverse magnetic polarity. Maximum thickness 80 m

Tor **Redrock Valley Tuff (Miocene)**--Subregional, welded, metaluminous, crystal-rich rhyolite ash-flow sheet erupted at 15.3 Ma from unknown source probably near Timber Mountain; exposed along west and north margins of Yucca Flat. Contains common plagioclase, sanidine, and biotite, rare quartz and hornblende, and sparse sphene; some samples contain common hornblende in excess of biotite. Distinguished by high relative plagioclase and low relative quartz contents, reverse magnetic polarity, common dense welding (atypical in lower tuff units), and red color where altered. Maximum exposed thickness about 125 m

Tot **Tuff of Twin Peaks (Miocene)**--Crystal-rich rhyolite ash-flow tuff containing common plagioclase, sanidine, quartz, and biotite, sparse hornblende, rare clinopyroxene, and very abundant sphene. Magnetic polarity reverse. Erupted at about 15.5 Ma from unknown source; exposed along northern margin of Yucca Flat; maximum thickness in drillholes Test Well 1 and Test Well 8 of 475 m. Formerly called the Fraction Tuff, but it has been demonstrated not to correlate with the type Fraction Tuff in the Tonopah district. It is also temporally distinct from the mapped Fraction Tuff in the Cathedral Ridge area of the Kawich Range. Unit includes the tuff of Whiterock Spring

Tob **Older basalt (Miocene)**--Local basalt and (or) basaltic andesite lava flows exposed near base of Miocene volcanic sequence at north end of Yucca Flat and beneath Grouse Canyon Tuff in the area west of Black Mountain. Locally very crystal rich, containing common olivine and clinopyroxene, and common to rare plagioclase. Basalt microporphyritic near Yucca Flat; contains very abundant west of Black Mountain. Distinguished from other basalt units by its low stratigraphic position. Basalt near Yucca Flat has normal magnetic polarity. Maximum exposed thickness exceeds 50 m

Tkr **Rhyolites of Belted Peak (Miocene)**--Calc-alkaline lava flows and related tephra exposed in Belted Range. Contains variable phenocryst abundances of quartz, alkali feldspar, plagioclase, biotite, and hornblende. Variable magnetic polarity; includes rhyolites of Belted Peak (normal polarity) and Johnnies Water (reverse polarity). Distinguished from rhyolites of Wheelbarrow Peak by stratigraphic position and petrographic characteristics. Maximum exposed composite thickness about 600 m

Tka **Rhyolites of Wheelbarrow Peak (Miocene)**--Alkalic lava flows and related tephra exposed in Belted Range. Contains variable phenocryst abundances of quartz, alkali feldspar, plagioclase, biotite, and hornblende. Distinguished from rhyolites of Belted Peak by stratigraphic position

Tkl **Latite of Kawich Valley (Miocene)**--Crystal-rich lava flows containing abundant plagioclase and common biotite and hornblende. Some flows contain quartz, clinopyroxene, and hornblende and lack biotite. Present along margin of Kawich Valley. Maximum exposed thickness about 250 m; normal magnetic polarity

Tqo **Older rhyolite tuffs and lavas (Miocene)**--Rhyolite of Gold Flat and other units on the northern Black Mountain quadrangle. Three or more, probably unrelated, rhyolitic welded ash-flow tuff sheets exposed in Gold Flat area. Contains variable phenocryst abundances of plagioclase, alkali feldspar, quartz, biotite, hornblende, clinopyroxene, and sphene. Includes tuff of Wilsons Camp, tuff of Gold Flat, and rhyolite of O'Briens Knob

Tge **Prevolcanic sedimentary rocks (Oligocene-Early Miocene)**--Weakly cemented, poorly bedded and poorly exposed fanglomerate containing poorly sorted, angular to subrounded pebbles, cobbles, and boulders composed of quartzite and subordinate sedimentary rocks of pre-Tertiary age. Lack of Tertiary volcanic clasts is diagnostic, and, in conjunction with depositional lower contact with probable Wood Canyon Formation and upper contact with tuff of Antelope Spring, indicates an Oligocene or older age in the limited area west of Mt Helen where unit is more than 100 m thick. Equivalent to fanglomerate unit of Ekren and others (1971); compiled unit also includes fanglomerate deposits and bedded sedimentary breccia that overlie the Cretaceous granite in the Climax stock area. Compiled unit includes Rocks of Winapi Wash of Yount (USGS, oral communication, 1991) on the north side of the Spotted Range that are present only in eastern part of quadrangle and that were formerly correlated with the Horse Spring Formation (Hinrichs, 1965; Barnes and others, 1982). However, bedded tuffs in the Winapi Wash section produce a biotite potassium-argon of 30.2 Ma bedded tuff (Marvin and others, 1970) which is clearly older and makes them a better temporal and mineralogic equivalent to the Needles Range Group

Tep **Pahranagat tuff (Miocene)**--Calc-alkaline, crystal-rich, rhyolite welded ash-flow tuff sheet erupted at 22.65 Ma from probable caldera source in Kawich Range in central Nevada caldera complex. Contains abundant quartz, common sanidine, plagioclase, and biotite, rare hornblende, and common sphene. Locally includes basal bedded tuff. Reverse magnetic polarity. Exposed near northeastern corner and in northwestern part of map area; maximum exposed thickness about 200 m. Equivalent to tuff of White Blotch Spring and to part of tuff of Antelope Springs of Ekren and others (1971)

Tes **Shingle Pass Tuff (Oligocene)**--Widespread metaluminous rhyolite ash-flow tuff sheet erupted at 26.7 Ma probably from caldera source in Quinn Canyon Range in central Nevada caldera complex. Contains common sanidine, plagioclase, and pyroxene, sparse quartz and biotite, and rare hornblende and fayalitic olivine. Normal magnetic polarity, indicating that only lower Shingle Pass cooling unit is present in map area. Exposed in Belted Range and Rhyolite Hills in northeastern part of map area; maximum exposed thickness about 200 m

Tem **Monotony Tuff (Oligocene)**--Widespread metaluminous, very crystalrich dacite welded ash-flow tuff sheet erupted at 27.31 Ma from caldera source in southern Pancake and northern Reveille Ranges in central Nevada caldera complex. Contains very abundant plagioclase and biotite, abundant hornblende, and common quartz, sanidine, and clinopyroxene. Extremely crystal-rich nature, anomalous normal magnetic polarity, and brownish, hummocky outcrop appearance are distinctive. Exposed in Belted Range and Rhyolite Hills in northeastern part of map area; maximum exposed thickness about 200 m

Kg **Granitic rocks (Cretaceous)**--Equigranular and porphyritic intrusive rocks, chiefly hornblende-biotite granodiorite and biotite monzogranite, and minor leucocratic granite. Includes the zoned, porphyritic Climax stock (101 Ma; Naeser and Maldonado, 1981) north of Yucca Flat, and the equigranular Gold Meadows stock (93.6 Ma; Naeser and Maldonado, 1981) north of Rainier Mesa. Small, poorly-exposed bodies of undated muscovite-bearing leucogranite crop out in the southern Kawich Range and in the northern Halfpint Range.

P*Pt **Tippipah Limestone (Early Permian and Pennsylvanian)**--Limestone, calcareous mudstone, and minor chert-pebble conglomerate and sandy limestone; forms well-bedded, ledgy, medium-gray outcrop; diverse fauna preserved in middle and upper parts of the unit. Base marked by an indistinct erosional paraconformity on top of Chainman Shale that cuts out variable amounts of the Scotty Wash Quartzite; top not preserved. Unit exposed in the cores of moderately to strongly overturned synclines at CP Hills and Syncline Ridge, west and southwest of Yucca Flat. Maximum thickness 1250 m (Miller, 1989).

***PMcs Chainman Shale and Scotty Wash Quartzite (Early Pennsylvanian and Mississippian)**--Homogeneous black shale with sparse siltstone, fine quartz sandstone, quartzite, and bioclastic limestone; Scotty Wash forms upper part of unit and is distinguished by abundance of lensoid and tabular quartz sand bodies with local gray fossiliferous limestone beds. Base of Chainman Shale is not exposed in the map area; top of the unit is irregular due to erosion prior to deposition of Tippipah Limestone. Unit is exposed around Syncline Ridge, in the CP Hills, and in the southern Calico Hills. Thickness unknown, but probably exceeds 900 m (Cashman and Trexler, 1994).

Mm Monte Cristo Group and equivalents (Mississippian)--Limestone, clayey-silty limestone, and quartzite; heterogeoeous unit of shelf- and inner-slope-facies calcareous deposits that were defined (bottom to top) as the Narrow Canyon Limestone, Mercury Limestone, limestone of Timpi Canyon, and overlying shale and quartzite beds attributed to the "Chainman Shale" in the Spotted Range east of Mercury (Barnes and others, 1982). Top of unit truncated by Spotted Range thrust, but combined thickness of limestone section about 250 m.

MDe Eleana Formation (Mississippian and Late Devonian)--Chert-rich sandstone and pebble conglomerate, siliceous siltstone, and minor bioclastic limestone and bedded chert; laterally variable unit containing thick-bedded lenticular sandstone-conglomerate turbidite complexes, laminated bioturbated siltstone, and discrete carbonate turbidite beds in the upper part. Informally described as 9 subunits by Poole and others (1961); base of type section in Carbonate Wash is disconformable on Late Devonian slope-facies carbonate rocks. Lower 100 m consists of debris-flow limestone breccia beds and sandy limestone and quartzite; middle 1700 m consists of chert litharenite sand, conglomerate, and siltstone; upper 150 m consists of bioclastic limestone in thin tabular beds; top is everywhere faulted against Chainman Shale. Strata compiled as Eleana Formation at Bare Mountain and in the Calico Hills are generally thinner and finer grained than the type Eleana, but show similar stratigraphic organization.

Strata compiled as Eleana Formation at Shoshone Mountain and Mine Mountain are distinct but have not been formally defined. They differ from Eleana in that they are deposited on karst-weathered shelf-facies Devonian Guilmette Formation and they are consistently finer-grained and contain clasts from more heterogeneous sources.

Dsf **Slope-facies rocks (Devonian)**--Moderately resistant, light to dark gray limestone, dolomite, and silty carbonate rocks. Moderately wellbedded, locally laminated or fossiliferous, and typified by debris flows with clasts of quartzite, limestone, dolomite, and coarse fossil fragments; some debris flows have quartzitic matrix sand. Laminated intervals commonly contain intraformational breccia beds. Exposed at Carbonate Wash and northern Calico Hills; maximum thickness in map area about 300 m; base not exposed; top is eroded slightly below base of Eleana Formation.

Dg **Guilmette Formation (Late and Middle Devonian)**--Predominantly thick-bedded, dark- to light-gray, coarse-crystalline limestone. Contains sandy limestone and thick beds of tan quartzite in upper part; biohermal beds are common in middle section; basal beds are yellow and silty above an apparently conformable contact with Simonson Dolomite. Quartzite beds in upper part at Shoshone Mountain and Mine Mountain are brecciated by collapse over karst features. Thickness approximately 350 m.

Ds **Simonson Dolomite (Middle Devonian)**--Dolomite and local sandy dolomite; medium- to dark-gray, conspicuously bedded, ledge-forming unit that includes a distinctive yellow, silty, cherty dolomite at the base; distinguished by uniform bedding, alternating dark and light layers, and by common dolomitized relics of brachiopods, tubular corals, and stromatoporoids. Basal contact is distinct where yellow platy-silty beds of lower Simonson rest on sandy upper Sevy Dolomite. Maximum thickness in map area about 300 m.

DSsl **Sevy Dolomite and Laketown Dolomite, undivided (Early Devonian and Silurian)**--Dolomite, thick bedded, strongly brecciated in many areas; sandy in uppermost part; light- to medium-gray in middle part; lower part contains two conspicuous dark gray bands. Basal contact is sharp and conformable, but may be a hiatus (Poole and others, 1977); upper contact is paraconformable at base of Simonson Dolomite. Lower part equivalent to units A to C of dolomite of Spotted Range; upper part equivalent to units D to F of dolomite of Spotted Range (Poole, 1965; Barnes and others 1982). Thickness not well defined in many areas due to complex structure, but approximately 450 m in Spotted Range.

Sr **Roberts Mountain Formation (Silurian)**--Slope-forming, light brownish-gray to medium gray dolomite and limestone, with interbedded silty and sandy dolomite and sparse beds of dolomite-pebble conglomerate. Thin to thickly bedded, commonly flaggy splitting; dark gray chert layers and nodules occur locally. Base is regionally disconformable on the Ely Springs Dolomite. Occurs only in northern Bare Mountain where the thickness is 198 m (Monsen and others, 1992).

Oes **Ely Springs Dolomite (Late Ordovician)**--Medium- to dark-gray, fine- to medium-grained dolomite and limy dolomite; conspicuously fossiliferous. Moderately thick bedded; contains sparse to abundant irregular layers and nodules of dark-gray chert. Basal contact conformable on Eureka Quartzite. Thickness 30 to 130 m

Oe **Eureka Quartzite (Late and Middle Ordovician)**--Orthoquartzite; conspicuous white to pale-orange unit that appears massive in outcrop but is internally laminated and locally cross bedded; fine-grained, well-sorted quartz sand with variable silica cement. Thickness 75 to 145 m.

Op **Pogonip Group (Middle and Early Ordovician)**--Silty limestone, dolomite, and subordinate chert and siltstone; well-bedded, unit marked by medium- to dark-gray carbonate beds and brown-orange silty or cherty zones; fossil content is variable, but brachiopods, oncolites, and corals are locally conspicuous. Unit consists of thin-bedded silty Goodwin Limestone at the base (about 350 m), an indistinct silty zone in the middle (time-equivalent of the Ninemile Formation), and the Antelope Valley Limestone (about 550 m) at the top that contains distinct sandy beds near the contact with overlying Eureka Quartzite.

€n **Nopah Formation (Late Cambrian)**--Limestone, dolomite, and subordinate chert, shale, and siltstone; well-bedded, light- to darkgray, massive-weathering carbonate beds with yellow to brown, fissile silty partings. The basal red-brown Dunderberg Shale Member (about 100 m) is overlain by the middle Halfpint member of thin-bedded cherty limestone (about 320 m), which is overlain by the Smoky member of thickbedded dark-gray limestone (about 200 m) at the top (Barnes and Christiansen, 1967).

€b **Bonanza King Formation (Late and Middle Cambrian)**-- Limestone, dolomite, and subordinate chert, shale, and siltstone; well-bedded, thick unit that consists of light- to dark-gray, massive-weathering carbonate beds, yellow to brown, fissile silty carbonate, and red-brown calcareous shale. Total thickness about 1300 m. Locally divided into:

€bb **Banded Mountain Member**--Medium to thick beds of light to dark gray dolomite and limestone Alternation of light-, medium- and dark-hued beds produce distinctive banded appearance; upper part of unit shows more massive color banding of medium gray, pale yellow, and dark gray dolomite in descending order. Thickness about 580 m.

€bp **Papoose Lake Member**--Dark-gray limestone and light gray dolomite with thin zones of yellowish-orange silty limestone and dolomite. Spotty dolomitization of lower massive limestone beds produces distinctive birdseye texture. Basal contact is conformable and gradational to Carrara Formation. Thickness variable, but about 700 m.

€c **Carrara Formation (Middle and Early Cambrian)**--Limestone, siltstone, and shale; clastic rocks predominate in lower 350 m, limestone becomes more prominent in the upper 120 m. Lower contact is conformable on the Zabriskie Quartzite; upper contact is gradational into overlying Bonanza King Formation. Lower shale-siltstone section is thin-bedded, micaceous, and contains several distinctive limestone beds; trilobite debris is locally conspicuous. Limestone beds in upper Carrara show common oncolites, oolites, and stromatoliths and wavy silty partings of orange calcareous silt. Total thickness about 470 m in northern Halfpint Range, but indeterminate in the CP Hills due to complex structure. The partial section compiled as Carrara on the west side of the Belted Range is chiefly limestone and sandy limestone and may be a deeper water facies.

€z **Zabriskie Quartzite (Early Cambrian)**--Orthoquartzite; massive, white to pink, laminated and cross-bedded, densely cemented orthoquartzite with conspicuous tubular trace fossils (burrows); locally intensely brecciated Basal contact is conformable on micaceous siltstone of the Wood Canyon Formation. Maximum thickness about 150 m in the Striped Hills, but less than 30 m in the Halfpint Range and Belted Range.

€Zw **Wood Canyon Formation (Early Cambrian and Late Proterozoic)**--Orthoquartzite, micaceous quartzite, arkosic sandstone, siltstone, and subordinate dolomite. Upper third of unit consists of interbedded red orthoquartzite and brown-green micaceous siltstone with several prominent orange dolomite beds; middle third contains distinctive beds of arkosic granule conglomerate in micaceous quartzite and siltstone; lower third is similar to the upper third. Total thickness variable across the region, but generally 1100 m to 700 m; no complete sections are preserved in the map area

Zs **Stirling Quartzite (Late Proterozoic)**--Micaceous quartzite, siltstone, and orthoquartzite. Unit chiefly consists of medium-grained red and purple quartz-rich sandstone, arkosic sandstone, and pebbly sandstone. Informally divided into 4 informal units based on relative proportions of micaceous siltstone and shale and on presence of sparse limestone beds (Barnes and Christiansen, 1967). Total thickness variable across the region, but generally 700 m to more than 1500 m; no complete sections are preserved in the map area.

Zj **Johnnie Formation (Late Proterozoic)**--Brown and red quartzite, variegated siltstone, limestone, and calcareous siltstone; quartzites are thick-bedded and indistinctly cross-bedded and locally pebbly; siltstones are laminated and conspicuously micaceous. Upper part contains numerous limestone beds in calcareous siltstone; base is not exposed in the map area; thickness is estimated to exceed 900 m (Barnes and Christiansen, 1967).

Xmi Metamorphic and intrusive rocks (Early? Proterozoic)--Biotite schist, biotite-hornblende schist, and biotite-epidote schist, intruded by gneissic monzogranite. Schist and monzogranite are intruded by aplite and pegmatite dikes that show no planar fabric; absolute age of dikes unknown. Unit poorly exposed in Trappman Hills in the northwestern map area. Muscovite from schist yielded K-Ar age of 14.0 Ma (McKee, 1983), which is interpreted to date uplift and cooling in middle Miocene resulting from regional crustal extension

ACKNOWLEDGMENTS

We wish to acknowledge several individuals from the U.S. Geological Survey for their contributions to this compilation. We thank R.E. Sabala for methodically and carefully drafting numerous tracings of geologic map layers prior to scanning, and J.R. Estabrook for his persistent, successful efforts in locating and supplying archival map materials used in the compilation. Staff of the U.S. Geological Survey Central Region GIS laboratory provided expert assistance in operating Tektronics and Anatech scanners. A preliminary digital polygon coverage of the NTS geologic map was generated under the direction of D.S. Aitken of the Western Region GIS laboratory. V.S. Williams kindly developed and shared custom software to transfer GS Map files to AutoCAD. Discussions in the field and office with U.S. Geological Survey colleagues M.D. Carr, F. Maldonado, P.P. Orkild, M.A. Lanphere, R.J. Fleck, M.R. Hudson, V.A. Frizzell, Jr., R.E. Anderson, W.B. Hamilton, C.J. Fridrich, D.W. O'Leary, F.W. Simonds, J. C. Yount, as well as B.P. Hausback (Calif. State Univ., Sacramento), and S.I. Weiss (Univ. of Nevada, Reno) were helpful in developing an understanding and appreciation of the varied geology of the area. C.J. Fridrich and R.B. Scott generously provided unpublished map data and extensive input on parts of the digital map compilation in the Yucca Mountain-Crater Flat area. Collaborative work in the Mississippian and Devonian rocks by P.H. Cashman and J.H. Trexler, Jr., both of the University of Nevada at Reno, has been critical to understanding the complex structure and stratigraphy in the Eleana Range, Mine Mountain, and the Calico Hills. Air Force Sgt. D. Welch, Capt. R. Durham, and Shelby Friend kindly arranged access and served as escorts on several trips into geologically critical areas of Nellis Air Force Bombing and Gunnery Range. Paul Williams and G.N. Green provided timely and helpful reviews of the manuscipt and database. This work was prepared in cooperation with the Department of Energy under interagency agreement DE-AI08-91NV11040.

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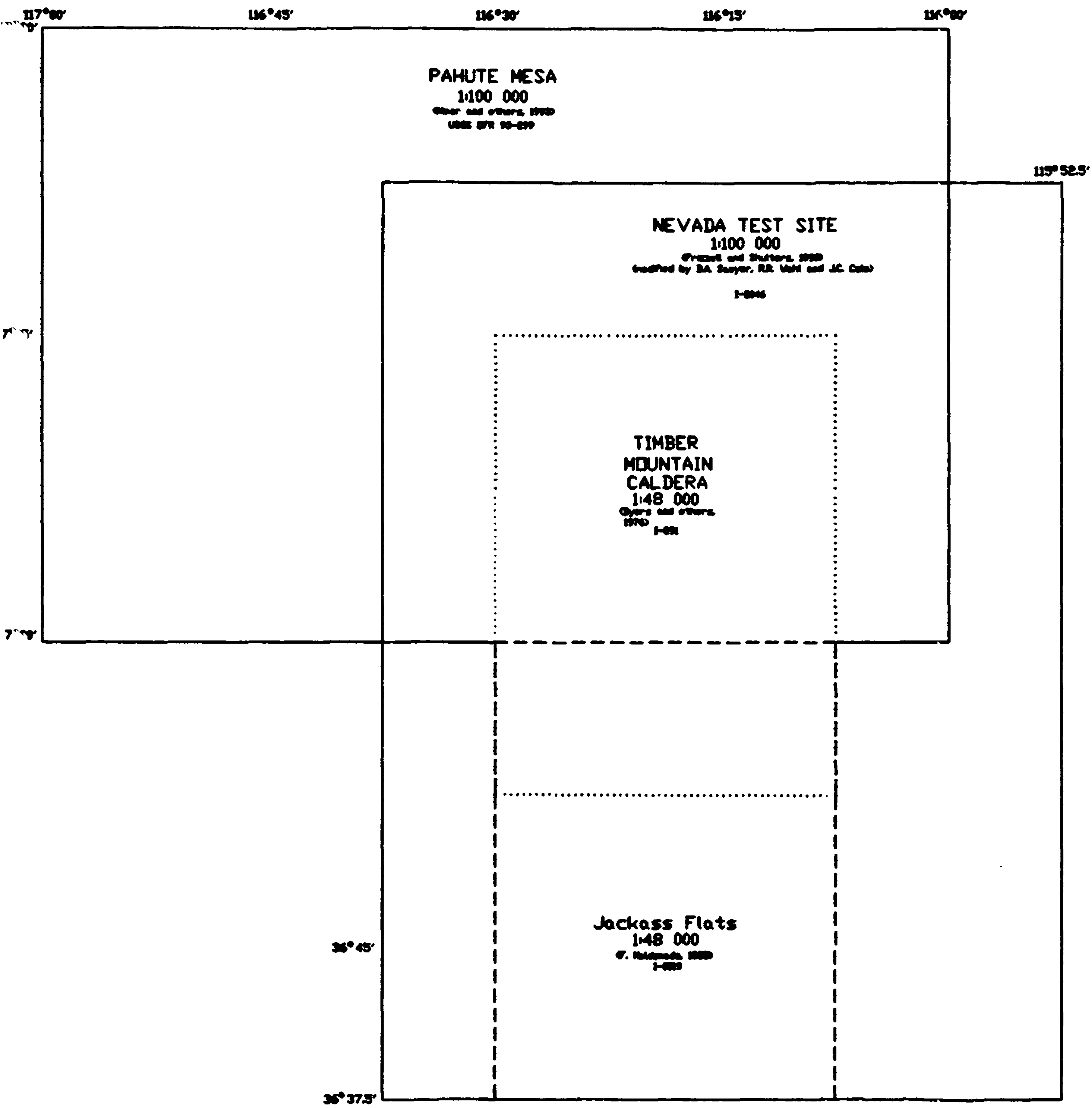
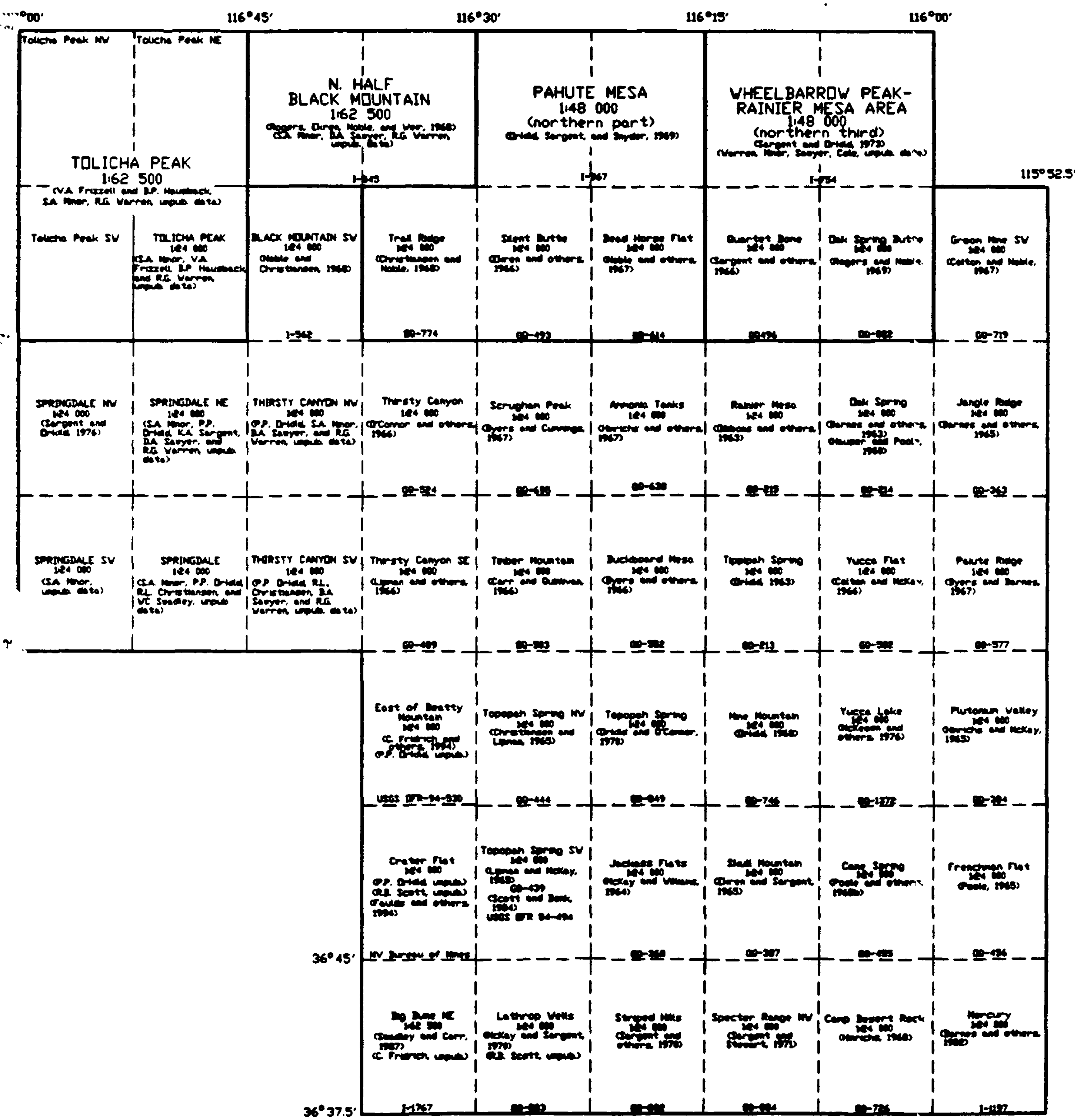


SOURCES OF COMPILED GEOLOGIC DATA FOR THE NEVADA TEST SITE AREA



SOURCES OF ORIGINAL GEOLOGIC DATA FOR THE NEVADA TEST SITE AREA

Contact

Fault--Dotted where concealed, including faults in subsurface of Yucca Flat inferred from gravity data; ball and bar on apparent downthrown side; arrow shows direction and amount of dip. Red faults on Pahute Mesa and in Yucca Flat have been reactivated by underground nuclear detonations; such faults in Yucca Flat displaced surficial materials only after reactivation

Strike-slip faults

Thrust fault--Dotted where concealed; sawteeth on upper plate

Low-angle fault--Dotted where concealed; semi circles on upper plate (typically brecciated). Dip generally less than 30°. Formed as landslide glide surface or as normal fault that was rotated to low angle

Landslide slip surface--Hachures on slide block

Fold axes--Trace of axial surface; plunge direction shown where known

Anticline

Syncline

Overturned syncline

Monocline

Strike and dip of beds--Dip rounded to nearest 5° where greater than 10°

Inclined

Vertical

Overturned

Horizontal

Strike and dip of volcanic compaction and flow foliations--Dip rounded to nearest 5° where greater than 10°

Inclined

Vertical

Horizontal

Caldera boundaries

Structural margin--Dashed where approximately located

Topographic wall--Hachures toward caldera basin

Inferred margin--Nature of margin uncertain

APPENDIX A
README.FIRST

THE NTS 1:100,000 GEOLOGIC DATABASE

U.S. Geological Survey Open-File Report 95-0567

BASIC INFORMATION

Rev. 2.0 (07/21/95)

The NTS geologic database was developed in the Geographic Resource Analysis Support System (GRASS), a public-domain, Geographic Information System (GIS). The current release of GRASS and all pertinent documentation are available on Internet from:

moon.cecer.army.mil [129.229.20.254]

under the directory /grass.

The geologic data associated with this database are distributed in four formats:
(1) GRASS ASCII
(2) DLG-3 (optional)
(3) ARC/INFO ASCII-generate files, and
(4) ARC/INFO export files.

Location of the Data

All the data are found in directories under the directory NTS/Rev2. Please see the file NTS/Rev2/text/INDEX for a complete listing of the files included with this release. Please read the file:

NTS/Rev2/text/README.DOC

for more complete information about this database and instructions about using these data with ARC/INFO.

UNCOMPRESSING THE TAR FILE

The data file was compressed with the GNU utility gzip. If you this utility, it is available from any of the GNU source sites. This software is available for UNIX systems, PCs running DOS, and an executable version for DEC VMS systems. A "tar" utility is also available for all three systems. The command sequences shown below are in UNIX "C" shell (csh). The sequences are the same for other operating systems, but the form of the commands are different. To uncompress the data enter:

UNIX% gunzip nts.tar

To access the data, enter:

UNIX% tar vxf nts.tar

The data should now be available under the directories listed in README.DOC mentioned above.

Inquiries about the geologic interpretation should be directed to David Sawyer, James Cole, or Scott Minor. Technical inquiries concerning the data structures and the data file can be addressed to Ron Wahl or, for ARC/INFO users, Randell Laczniak.

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APPENDIX B
README.DOC

THE NTS 1:100,000 GEOLOGIC DATABASE

U.S. Geological Survey Open-File Report 95-0567

ON-LINE USER INSTRUCTIONS

Rev. 2.0 (07/21/95)

Introduction

The NTS geologic database was developed in the Geographic Resource Analysis Support System (GRASS), a public-domain, Geographic Information System (GIS). The current release of GRASS and all pertinent documentation are available on Internet from:

moon.cecer.army.mil [129.229.20.254]

under the directory /grass/grass4.1.

The geologic data associated with this database are distributed in four formats:
(1) GRASS ASCII
(2) DLG-3 (optional)
(3) ARC/INFO ASCII-generate files, and
(4) ARC/INFO export files.

UNCOMPRESSING THE TAR FILE

The data file was compressed with the GNU utility gzip. If you this utility, it is available from any of the GNU source sites. This software is available for UNIX systems, PCs running DOS, and an executable version for DEC VMS systems. A "tar" utility is also available for all three systems. The command sequences shown below are in UNIX "C" shell (csh). The sequences are the same for other operating systems, but the form of the commands are different. To uncompress the data enter:

UNIX% gunzip nts.tar

To access the data, enter:

UNIX% tar vxf nts.tar

The data should now be available under the directories mentioned above.

Location of the Data

All the data are found in directories under the directory NTS/Rev2. Please see the file NTS/Rev2/text/INDEX for a complete listing of the files included with this release.

Polygon and Line Data

The GRASS ASCII polygon and line files are in the directory NTS/Rev2/dig_ascii. The DLG-3 data files are located in the directory NTS/Rev2/dlg. The ARC/INFO ASCII-generate files are located in the directory NTS/Rev2/arc/generate. The ARC/INFO export files are located in the directory NTS/Rev2/arc/export. The ARC export files are partially compressed only for more portability.

Map Feature Attribute Codes

Attribute codes, which are keyed numerically to tagged map features, are located in both ARC/INFO and GRASS ASCII attribute files. GRASS attribute code definition tables for the polygon (geol.poly), fault (geol.flts), and caldera (geol.calds) data layers are located in files of the same names in the directories NTS/Rev2/dig_cats and NTS/Rev2/plot. ASCII versions of the corresponding GRASS label location files are found in the directory NTS/Rev2/dig_att. Geologic attitude data (geol.atts - strike and dip data) are found in the directory NTS/Rev2/site_lists.

ARC/INFO ASCII attribute files are in the directory NTS/Rev2/arc/generate with the extension ".txt".

DLG-3 (optional) format does not yet have codes to deal with geologic data. Use the GRASS attribute files listed above for these data.

A file called catcolrs.txt shows the relationship between the GRASS numeric category codes, map unit symbols, the index number for a corresponding color in the ARC/INFO shadeset file alc1.shd and the CMY color values for each map unit is found in the directory NTS/Rev2/text.

A copy of the file README.1ST will also be found in the directory NTS/Rev2/text.

ARC/INFO

Detailed procedures for converting the ARC/INFO ASCII-generate files and for importing the ARC/INFO export files into ARC/INFO coverages and the use of an included shadeset are found in the instructions below. Also included is an AML (ARC Macro Language routine) for generating a basic plot of the geologic map from the ARC coverages. An ARC shadeset (alc1.shd) used in the plotting routine is provided in export format in the directory NTS/Rev2/arc/export. The correlation of map units is contained in the file geoltr.cchart which is located in all data directories except NTS/Rev2/dlg. The description of map units and other informative text are located in both ASCII (mapunits.asc) and Postscript (mapunits.pst) files in the directory NTS/Rev2/text.

Translations of the codes for line map elements are listed below under headings indicating the GRASS files the codes are located in.

NTS/Rev2/dig_cats/geol.flts

und=displacement unspecified
Lbb=normal fault; down-to-left (with respect to origin of digital fault line) apparent offset
Rbb=normal fault; down-to-right apparent offset
Lst=thrust fault; upper plate on left side
Rst=thrust fault; upper plate on right side
Lhr=landslide slip surface; slide block on left side
Rhr=landslide slip surface; slide block on right side
Lbx=low-angle (< 30 deg. dip) fault; upper plate on left side
Rbx=low-angle fault; upper plate on right side
Rss=strike-slip fault; right-lateral sense of movement
Lss=strike-slip fault; left-lateral sense of movement
Lro=oblique-slip fault; down-to-left / right-lateral sense of movement
Llo=oblique-slip fault; down-to-left / left-lateral sense of movement
Rro=oblique-slip fault; down-to-right / right-lateral sense of movement
Rlo=oblique-slip fault; down-to-right / left-lateral sense of movement

NTS/Rev2/plot/geol.flts

solid=extends to surface
dotted=concealed
black=fault movement attributed only to natural (geologic) causes
red=latest fault movement(s) induced by nuclear detonation(s)

NTS/Rev2/dig_cats/geol.calds

und=caldera structural margin
hrl=caldera topographic wall; basin to left (with respect to line origin)
hrr=caldera topographic wall; basin to right

NTS/Rev2/plot/geol.calds

solid=caldera wall or structural margin well constrained
dashed=caldera margin approximately located or inferred

NTS/Rev2/site_lists/geol.atts

Structural attitude data are listed in tabular form in the file geol.atts located in the directory NTS/Rev2/site_lists. Each entry has the form:

<x coord.>| <y coord.>| <strike_azimuth> <dip> <attitude identifier>.

The strike azimuth is measured clockwise with respect to north, with the dip direction always 90 degrees clockwise relative to the azimuth (i.e., right hand rule). Attitude identifiers are defined as follows:

BED=inclined bedding
BDV=vertical bedding
BDH=horizontal bedding
OTB=overturned bedding
FOL=inclined foliation
FLV=vertical foliation
FLH=horizontal foliation
FLT=fault plane

CREATE ARC/INFO COVERAGES, ARC/INFO ASCII Files

The following procedure can be used to convert the ARC/INFO ASCII-generate files supplied herein to ARC/INFO coverages using standard ARC/INFO commands. The procedure assumes a UNIX platform but similar utilities are available for most other platforms running ARC/INFO. The procedure creates four coverages containing: (1) map unit polygon features, (2) fault line features, (3) caldera line features, and (4) structural attitude point features. Associated feature attributes are stored internally within each coverage. The procedure is by no means the only nor necessarily the most efficient method, but serves as an example of how one may utilize the digital data to generate coverages of basic geologic features when ARC/INFO is the GIS of choice. In reviewing the following procedure, note that the upper case syntax starting each command line designates the system or subsystem prompt (UNIX, ARC, INFO, etc.).

(1) Create a space on which to generate the ARC/INFO geologic feature coverages:

```
UNIX% mkdir wd
UNIX% cd wd
```

Action creates a directory named wd for the work space.

(2) Access ASCII-generate and ASCII-attribute files:

```
UNIX% cp <original_location>/NTS/Rev2/arc/generate/* .
```

Action copies required ASCII-generate files (geol_poly.pol, geol_flts.lin, geol_calds.lin, and geol_atts.lab) and ASCII-attribute files (geol_poly.txt, geol_flts.txt, geol_calds.txt, and geol_atts.txt) to the working directory.

(3) Enter ARC/INFO to create coverages of geologic features from the ASCII generate and ASCII attribute files.

```
UNIX% arc
ARC: precision double double
```

Action puts user in double precision mode of ARC/INFO. It should be noted that the PC ARC/INFO platform does not support double precision accuracy.

(4) Create a polygon coverage of map-unit features:

a) Generate a labeled polygon coverage of map units:

```
ARC: generate geol_poly
GENERATE: input geol_poly.pol
GENERATE: lines
GENERATE: input geol_poly.lab
GENERATE: points
GENERATE: quit
ARC: build geol_poly lines
ARC: build geol_poly poly
```

Action creates a polygon coverage of map units with label points named geol_poly. (Note that the given coverage name should not be changed until after the completion of the procedure.)

b) Add attribute items to the polygon coverage:

```
ARC: additem geol_poly.pat geol_poly.pat SYMBOL 3 3 i
ARC: additem geol_poly.pat geol_poly.pat MUNIT_NAME 10 10 c
```

Action creates two attribute items, SYMBOL and MUNIT_NAME. SYMBOL can be used to select colors directly from the shadeset, alc1.shd, which can be generated by importing an ARC/INFO export file (see HELP under "Creating ARC/INFO Coverages from ARC Export Files).

c) Move attribute values into map-unit coverage. (Note that INFO is case sensitive in regards to file and attribute item names, and that the error "NO MATCH IN RELATED DATAFILE 1 FOR RECORD 1," which is caused by the outside polygon, is acceptable when executing the INFO commands MOVE and CALC.):

```
ARC: info
ENTER USER NAME >arc
ENTER COMMAND >define GEO_LAB.DAT
ITEM NAME >GEO_LAB-ID,4,5,B
ITEM NAME >SYM_NUM,3,3,I
ITEM NAME >GEOL_POLY-ID,4,5,B
ITEM NAME >SYM_ALA,3,3,I
ITEM NAME >GEO_SYM,7,7,C
ITEM NAME > [enter a carriage return]
ENTER COMMAND >add from ../geol_poly.txt
ENTER COMMAND >sel GEO_LAB.DAT
```

ENTER COMMAND >sel GEOL_POLY.PAT
ENTER COMMAND >relate GEO_LAB.DAT by GEOL_POLY-ID with link
ENTER COMMAND >calc SYMBOL = $1SYM_ALA
ENTER COMMAND >move $1GEO_SYM to MUNIT_NAME
ENTER COMMAND >q stop

Action invokes INFO subsystem to move attribute values from ASCII-attribute file (geol_poly.txt) into the polygon attribute table (GEOL_POLY.PAT) of the map-unit coverage using a temporary INFO file named GEO_LAB.DAT. The values for MUNIT_NAME identify each map-unit polygon by common map unit notation. The values for SYMBOL can be used to shade polygons during plotting. The user is returned to the ARC prompt.

d) Remove temporary INFO file from directory:

ARC: kill geo_lab info

Action removes temporary INFO file created by the procedure.

(5) Create a line coverage of fault features:

a) Generate a coverage of fault traces:

ARC: generate geol_flts
GENERATE: input geol_flts.lin
GENERATE: lines
GENERATE: quit
ARC: build geol_flts lines

Action generates a line coverage of faults named geol_flts. (Note that the given coverage name should not be changed until after the completion of the procedure.)

b) Add attribute items to line coverage:

ARC: additem geol_flts.aat geol_flts.aat SYMBOL 3 3 i
ARC: additem geol_flts.aat geol_flts.aat FLT_TYPE 10 10 c

Action creates two attribute items, SYMBOL and FLT_TYPE.

c) Move attribute values into fault-trace coverage. (Note that INFO is case sensitive in regards to file and attribute item names.):

```
ARC: info
ENTER USER NAME >arc
ENTER COMMAND >define FLTS_LAB.DAT
ITEM NAME >FLTS_LAB-ID,4,5,B
ITEM NAME >SYM_NUM,3,3,I
ITEM NAME >GEOL_FLTS-ID,4,5,B
ITEM NAME >FLT_SYM,10,10,C
ITEM NAME > [enter a carriage return]
ENTER COMMAND >add from ../geol_flts.txt
ENTER COMMAND >sel FLTS_LAB.DAT
ENTER COMMAND >sel GEOL_FLTS.AAT
ENTER COMMAND >relate FLTS_LAB.DAT by GEOL_FLTS-ID with link
ENTER COMMAND >calc SYMBOL = $1SYM_NUM
ENTER COMMAND >move $1FLT_SYM to FLT_TYPE
ENTER COMMAND >q stop
```

Action invokes INFO subsystem and moves attribute values from ASCII attribute file (geol_flts.txt) into the arc attribute table (GEOL_FLTS.AAT) of the fault-trace coverage using a temporary INFO file named FLT_LAB.DAT. The value for FLT_TYPE identifies the fault type associated with each line segment and later can be used for assigning line symbology. The user is returned to ARC prompt.

d) Remove temporary INFO file from directory:

```
ARC: kill flts_lab info
```

Action removes temporary INFO file created by the procedure.

(6) Create a line coverage of caldera features: Follow same procedure as used for creating fault line coverage, substituting all references to "flts" and "flt" in file names with "calds" and "cald", respectively.

(7) Create a point coverage of attitudes:

a) Generate a coverage of attitudes:

```
ARC: generate geol_atts
GENERATE: input geol_atts.lab
GENERATE: points
GENERATE: quit
ARC: build geol_atts point
```

Action generates a point coverage of attitudes named geol_atts. (Note that the given coverage name should not be changed until after the completion of the procedure.)

b) Add attribute items to point coverage:

ARC: additem geol_atts.pat geol_atts.pat STRIKE 3 3 i
ARC: additem geol_atts.pat geol_atts.pat DIP 3 3 i
ARC: additem geol_atts.pat geol_atts.pat TYPE 10 10 c

Action creates three attribute items, STRIKE, DIP, and TYPE.

c) Move attribute values into attitude coverage (note that INFO is case sensitive in regards to file and attribute item names):

```
ARC: info
ENTER USER NAME >arc
ENTER COMMAND >define GEO_ATTS.DAT
ITEM NAME >GEOL_ATTS-ID,4,5,B
ITEM NAME >ST,3,3,I
ITEM NAME >DP,3,3,I
ITEM NAME >TP,10,10,C
ITEM NAME > [enter a carriage return]
ENTER COMMAND >add from ../geol_atts.txt
ENTER COMMAND >sel GEOL_ATTS.PAT
ENTER COMMAND >relate GEO_ATTS.DAT by GEOL_ATTS-ID with link
ENTER COMMAND >calc STRIKE = $1ST
ENTER COMMAND >calc DIP = $1DP
ENTER COMMAND >move $1TP to TYPE
ENTER COMMAND >q stop
```

Action invokes INFO subsystem and moves attribute values from ASCII attribute file (geol_atts.txt) into the point attribute table (GEOL_ATTS.PAT) of the attitude point coverage using a temporary INFO file named GEO_ATTS.DAT. The value for TYPE identifies the attitude type associated with each point and later can be used for assigning the appropriate point symbology. The user is returned to the ARC prompt.

d) Remove temporary INFO file from directory:

ARC: kill geo_atts info
Action removes temporary INFO file created by the procedure.

8) Rename coverages to any user desired name:

ARC: rename geol_poly <user_desired_name>
ARC: rename geol_flts <user_desired_name>
ARC: rename geol_calds <user_desired_name>
ARC: rename geol_atts <user_desired_name>

Creating ARC/INFO Coverages from ARC Export Files

The following procedure can be used to convert the ARC/INFO (version 7.0.2 and later) export files supplied herein to ARC/INFO coverages using the ARC/INFO import command. The procedure provided assumes a UNIX platform but similar utilities are available for other platforms running ARC/INFO. The procedure creates four ARC/INFO coverages containing: (1) map unit polygon features, (2) fault line features, (3) caldera line features, and (4) structural attitude point features; and a shadeset of suggested colors for plotting the geologic map. Attributes for geologic features are stored internally within each ARC/INFO coverage. In reviewing the following procedure, note that the upper case syntax starting each command line designates the system or subsystem prompt (UNIX, ARC, INFO, etc.).

(1) Create a space on which to generate the ARC/INFO geologic feature coverages:

UNIX% mkdir wd
UNIX% cd wd

Action creates a directory named wd for the work space.

(2) ACCESS ARC/INFO export files:

UNIX% cp <original_location>/NTS/Rev2/arc/export/* .

Action copies the required ARC/INFO export files to the working directory. The export file are:

geol_atts.e00 (structural attitude features);
geol_calds.e00 (caldera line features);
geol_flts.e00 (fault line features);
geol_poly.e00 (map unit polgon features);
alc1.shd.e00 (shadeset of suggested colors for map units)

(3) Enter ARC/INFO to import coverages of geologic features and associated shadesets from the ARC/INFO export files:

```
UNIX% arc
ARC: import cover geol_atts.e00 geol_atts
ARC: import cover geol_calds.e00 geol_calds
ARC: import cover geol_flts.e00 geol_flts
ARC: import cover geol_poly.e00 geol_poly
ARC: import shadeset alc1.shd.e00 alc1.shd
```

Action creates ARC/INFO coverages and a shadeset for generating the geologic map. Feature attributes are contained internally within each coverages. The ARC/INFO coverages created are:

geol_atts (point coverage of structural attitude features);
geol_calds (line coverage of caldera features);
geol_flts (line coverage of fault features);
geol_poly (polygon coverage of map unit features);
alc1.shd (shadeset of suggested colors for map units).

An AML to Plot the Geologic Map

This AML can be used to create a plot of the geologic map. As written, the AML does not distinguish differing line or attitude types within a coverage. All line features are drawn as solid lines. All attitude features are drawn as solid circles with no strike or dip information displayed. Shading is done with the shadeset alc1.shd, which is povided as an ARC export file. The AML produces an ARC/INFO meta file of about 13 Mbytes, and if desired, an encapsulated postscript file of about 18 Mbytes.

```
/* start of AML
/*
&if [exists geo.gra] &then &s dele [delete geo.gra]
&if [exists geo.eps] &then &s dele [delete geo.eps]
arcplot
display 1040
geo.gra
pagesize 36 36
maplimits page
mapextent geol_poly
mapunits meters
mapscale 130000       /* Largest scale that fits on 36x36 inch paper
mapposition cen cen
weeddraw off
shadeset alc1.shd     /* Set shadeset for polygon shading
polygonshades geol_poly symbol
linesymbol 1
arcs geol_poly
linesymbol 2
arcs geol_flts        /* Faults - single width red line
linesymbol 3
arcs geol_calds       /* Calderas - single width green line
markerset water.mrk
markersymbol 108
markersize .08
points geol_atts      /* Attitudes - solid black circle
mapinfo
q
/* To obtain a PostScript file for plotting,
/* uncomment the following line to produce an EPS file (approx 18MB).
/* postscript geo.gra geo.eps 1.0
/*
/* end of AML
```

POINTS-OF-CONTACT

Inquiries about the geologic interpretation should be directed to David Sawyer, James Cole, or Scott Minor. Technical inquiries concerning the data structures and the data file can be addressed to Ron Wahl or, for ARC/INFO users, Randell Laczniak.

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One-paragraph description

OF 95-0567. NEVADA. Preliminary digital geologic map database of the Nevada Test Site area, Nevada, by David A. Sawyer, Ronald R. Wahl, James C. Cole, Scott A. Minor, Randell J. Laczniak, Richard G. Warren, Colin M. Engle, and Roberto G. Vega. Prepared in cooperation with the Department of Energy. The digital database includes a revised version of the S.A. Minor and others--Pahute Mesa 30' x 60' quadrangle (OF 93-29?), merged with a revised and updated version of the V.A. Frizzell, Jr. and J. Shulters--Geologic map of the Nevada Test Site (I-2046). The digital database is available, in GRASS ascii vector, DLG-3 (optional), and in Arc/Info ASCII (Generate) and export formats, from the USGS, Denver, on-line repository on Internet (via 'anonymous ftp') at greenwood.cr.usgs.gov [136.177.48.5], path (/pub/open-file-reports/ofr-95-0567). Lat 36°37'30" to 37°30', long 115°52'30" to 117°. Scale 1:100,000 (1 inch = about 1.6 miles). Paper copy consists of 61-page text including description of map units, source index maps, explanation of map units, and the text of the readme.doc and readme.first files, all of which are included within the on-line database release. It does not include a paper version of the map; however, an encapsulated postscript (.eps) plot file is available with the bundled files on the on-line repository.