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PRELIMINARY SURVEY OF TUFF DISTRIBUTION IN ESMERALDA, NYE, AND LINCOLN COUNTIES, NEVADA

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ABSTRACT

This report inventories the surface distribution of silicic tuffs in Nye, Esmeralda, and Lincoln Counties, NV, based on a review of available literature. The inventory was taken to provide a data base in evaluating tuff sites for the disposal of high-level nuclear waste. Silicic ash-flow tuffs that are about 11 to 34 million years (my) old are widespread in these counties. These rocks are locally deformed by right-lateral movement along Walker Lane and the Las Vegas Shear Zone, and left-lateral movement along a zone from near the Nevada Test Site (NTS) to the Utah border, and are commonly offset by steeply dipping normal faults. The normal faults that bound horsts, grabens, and tilted-fault blocks of the Basin-and-Range Province began to form 30 my ago; some are still active.

Tuff distribution is discussed on a regional basis. Tuff thicknesses and alterations, structural complexity, and proximity to recent faulting, recent volcanism, and mineral resources are discussed for each area. Although the literature on which it is based is often incomplete and sketchy, this report is intended to serve as a basis for future, more detailed work that includes initial field inspection, detailed field and laboratory studies, and extrapolations to the subsurface.

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A Glossary of Abbreviations and Technical Terms*

AIR-FALL TUFF. See ash-fall tuff

ALBITIZATION. An alteration process whereby albite is formed in the host rock

ALLOCHTHONOUS SHEET. Upper plate of overthrust fault

ALLUVIAL FAN. A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream

ALLUVIUM. A general term for all detrital deposits resulting from the operations of modern rivers

ALTERATION OF TUFF. In this report, all changes in the chemical or mineralogic composition of tuff after its deposition

ALUNITIZATION. An alteration process whereby alunite is formed in the host rock

ANDESITE. A volcanic rock composed essentially of andesine and one or more mafic components

ANTICLINE. A fold that is convex upward or had such an attitude at some stage of development

ANTITHETIC FAULT. A minor normal fault that is of the opposite orientation of displacement to the major fault with which it is associated

ARGILLIC ALTERATION. An alteration process whereby clay minerals are formed in the host rock

ASH-FALL TUFF. The volcanic rock resulting from the deposition of airborne volcanic ash

ASH-FLOW TUFF. The volcanic rock resulting from the deposition of an avalanche of a highly heated mixture of volcanic gases and ash

BASALT. A volcanic rock composed primarily of calcic plagioclase and pyroxene, with or without olivine

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*Definitions are derived mainly from the American Geological Institute Directory of Geological Terms

BASEMENT. A rock complex, generally of igneous and metamorphic rocks, overlain unconformably by sedimentary strata

BASIN-AND-RANGE PROVINCE. A geologic and physiographic province of the western US characterized by an abundance of high-angle normal faults that have formed block-faulted mountain ranges separated by alluvium-filled basins

BEDDED TUFF. See ash-fall tuff

BEDDING. Planes dividing sedimentary layers of the same or different lithology

BLOCK FAULTING. Type of faulting that produces fault-block mountains (masses of rock bounded by faults)

BRECCIA. Fragmental rock whose components are angular

CALDERA. A large basin-shaped volcanic depression, more or less circular in form, the diameter of which is many times greater than that of the included volcanic vent or vents

CAMBRIAN. The oldest of the Periods of the Paleozoic Era

CAULDRON. A structure resulting from the lowering along a steep ring fracture of a more-or-less cylindrical block into a magma chamber

CENOZOIC. The latest of the four eras into which geologic times (as recorded by the stratified rocks of the earth's crust) are divided; it extends from the close of the Mesozoic Era to and including the present

CONGLOMERATE. A cemented clastic rock containing rounded fragments corresponding in size to gravel or pebbles

CRETACEOUS. The third and latest of the Periods included in the Mesozoic Era

DACITE. A volcanic rock composed essentially of andesine and oligoclase, quartz, pyroxene, or hornblende (or both) with minor biotite and sanidine

DIATOMACEOUS EARTH. A friable earthy deposit composed of nearly pure silica and consisting essentially of the remains of microscopic plants called diatoms

DIKE. A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks

DIP. The angle at which a stratum or any other planar feature is inclined from the horizontal

en echelon. A geometric configuration consisting of parallel but noncontiguous elements

EOCENE. The second epoch of the Tertiary Period

EPICENTER. The point on the earth's surface directly above the focus of an earthquake

EXTENSION. A stress field in the earth's crust resulting from tensional opposition of forces

EXTRUSION. The emission of magmatic material at the earth's surface

FAULT. A fracture along which there has been displacement of the sides relative to one another parallel to the fracture

FAULT BLOCK. A mass bounded on at least two opposite sides by faults

FAULT SCARP. The cliff formed by a fault

FOLD. A bend in strata or other layers

GNEISS. A coarse-grained rock in which bands rich in granular minerals alternate with bands in which schistose minerals predominate

GRABEN. A block, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side

GRANITE. A plutonic rock consisting essentially of alkali feldspar and quartz

GRAVITY SLIDE. A downslope-shearing movement of part of the earth's crust on the flank of an uplifted area

HIGH-ANGLE FAULT. A fault with a dip >45°

HOLOCENE. The most recent epoch of geologic time spanning the time between the last ice age (Wisconsin in North America) and the present

HOMOCLINE. Inclined beds of the same dip

HORST. A block of the earth's crust, generally long compared to its width, that has been uplifted along faults relative to the rocks on either side

HYDROTHERMAL ALTERATION. Those phase changes in rocks brought about by the addition or removal of materials by hydrothermal fluids

IGNEOUS ROCKS. Those rocks formed by the solidification of hot mobile material called magma

IGNIMBRITE. The deposit of a fiery cloud or pyroclastic flow, extensive and generally thick

INTERCALATED. Occurring between beds; interbedded

INTERMEDIATE ROCKS. Igneous rocks containing between 52% and 66% SiO_2

INTRUSION. A body of igneous rock that invades older rock

JURASSIC. The middle of the three periods comprising the Mesozoic Era

LATITE. A volcanic rock composed essentially of potash feldspar and plagioclase either as normative or modal minerals, augite, or hornblende with minor biotite and opaque oxides

LEFT-LATERAL FAULT. A strike-slip fault with left-lateral displacement

LIMESTONE. A bedded sedimentary rock consisting chiefly of calcium carbonate

LINEAMENT. Straight or gently curved, lengthy features on the earth's surface, commonly expressed topographically

LITHOLOGY. The physical character of a rock

LOW-ANGLE FAULT. A fault dipping <45°

MAFIC. Pertaining to or composed dominantly of the iron-magnesian rock-forming silicates

MAGNITUDE OF EARTHQUAKE. A quantity characteristic of the total energy released by an earthquake and measured on the Richter scale; contrasts with "intensity," which describes its effects at a particular place

MESOZOIC. One of the eras of geologic time, following the Paleozoic and succeeded by the Cenozoic Era; comprises the Triassic, Jurassic, and Cretaceous Periods

METASEDIMENTS. Metamorphosed sedimentary rocks

MIOCENE. The fourth of the five epochs into which the Tertiary Period is divided

MOAT. The circular depression of a resurgent caldera located between the resurgent dome and outer caldera rim

m.y. Million years

m.y.BP. Million years before present

NORMAL FAULT. A fault at which the hanging wall has been depressed relative to the footwall

OLIGOCENE. The third of the epochs into which the Tertiary Period is divided

OROFLEX. Any structural element with arcuate trend that results from tectonic bending

OROGENY. The process of forming mountains, particularly by folding and thrusting

PALEOCENE. Oldest of the six epochs of the Cenozoic

PALEOZOIC. An era of geologic time between the Precambrian and Mesozoic and comprising the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods

PHENOCRYST. One of the relatively large and conspicuous crystals of the earliest generation in a porphyritic igneous rock

PLACER DEPOSIT. A surficial mineral deposit formed by mechanical concentration of mineral particles from weathered debris

PLEISTOCENE. The earliest of the two epochs comprising the Quaternary Period

PLIOCENE. The last of the five epochs of the Tertiary Period

PLUG. A monolithic mass of solidified igneous rock, probably the inside of an ancient volcano

PLUTON. A body of rock formed beneath the surface of the earth by consolidation from magma

ppm. Parts per million

PRECAMBRIAN. The era of geologic time before the Paleozoic, also all rocks formed before the Cambrian

PROPYLITIC ALTERATION. The process of forming one or more of the minerals in the assemblage (calcite, chlorite, epidote) by deuteric or hydrothermal alteration

PYROCLASTIC. A general term applied to detrital volcanic materials that have been aerially ejected from a volcanic vent

QUARTZ LATITE. A volcanic rock in which the principal minerals are quartz, sanidine, biotite, sodic plagioclase, and hornblende

QUATERNARY. The younger of the two geologic periods or systems in the Cenozoic Era

RADIOMETRIC AGE. The age of a rock measured by any one of several methods based on nuclear decay of natural radioactive elements

RECENT. Holocene

RECENT FAULTING. In this report, any tectonic activity during the Quaternary Period

RECENT SEISMICITY. In this report, any seismic activity during the Quaternary Period

RECENT VOLCANISM. In this report, any volcanic activity during the Quaternary Period

RESURGENT CALDERA. A caldera at which there has been an elevation or doming of a central elliptical area after caldera formation

RHYODACITE. The fine-grained volcanic equivalent of granodiorite

RHYOLITE. The fine-grained volcanic equivalent of granite

RIGHT-LATERAL FAULT. A strike-slip fault at which there has been right-lateral movement

RING FRACTURES. Elliptical fractures that accompany the development of a caldera

SANDSTONE. A compacted detrital sediment composed of sand-sized grains, mostly quartz

SCHIST. A medium- or coarse-grained metamorphic rock with subparralled orientation of its minerals

SEDIMENTARY ROCK. Rocks formed by the accumulation of sediment

SEISMIC ACTIVITY. Earthquakes

SERICITIZATION. An alteration process whereby sericite is formed in the host rock

SHALE. A fine-grained laminated sedimentary rock in which the constituent particles include abundant clay minerals, a large proportion of the constituent grains must be "clay-sized," i.e. ≤ 2 m in diameter

SHEAR ZONE. A zone in which shearing has taken place so that the rock is crushed and brecciated

SILICIC. Containing abundant silica (SiO_2), either bound and/or as free SiO_2

SILICIFICATION. The introduction of, or replacement by, silica

SILL. An intrusive body of igneous rock of uniform thickness and relatively thin compared to its lateral extent, that has been emplaced parallel to the bedding of the intruded rock

SILTSTONE. A sedimentary rock composed of silt-sized detritus

STOCK. A body of plutonic rock that covers <104 km^2 of outcrop

STRATA. Layers of sedimentary rock

STRATIGRAPHY. The branch of geology that treats the formation, composition, sequence, and correlation of stratified rocks

STRATOVOLCANO. A volcanic cone built of alternating layers of lava and pyroclastic materials

STRIAE. Minute grooves in rocks

STRIKE. The bearing or trend of the outcrop of an inclined bed or structure on a level surface

STRIKE-SLIP FAULT. A fault at which displacement has been parallel to the fault strike

SYNCLINE. A fold in rocks in which the strata dip inward from both sides toward the axis

SYNTHETIC FAULT. Subsidiary faults parallel in orientation and sense of displacement to the master fault

TEAR FAULT. Strike-slip fault that trends transverse to the strike of the deformed rocks

TECTONIC. Pertaining to the rock structure and external forms resulting from the deformation of the earth's crust

TERTIARY. The older of the two geologic periods comprising the Cenozoic Era

THRUST FAULT. A reverse fault with a low angle of inclination

TRIANGULAR FACETS. Truncated spur ends with broad base and apex pointing upward on a mountain range, usually associated with normal faults

TRACHYANDESITE. An extrusive rock containing sodic plagioclase and a considerable amount of alkali feldspar

TRACHYTE. An extrusive rock composed essentially of alkali feldspar and minor biotite, hornblende, or pyroxene

TRANSCURRENT. Strike-slip

TRIASSIC. The earliest of the three periods of the Mesozoic

TUFF. A rock formed of compacted volcanic fragments. In this report, ash-flow, ash-fall, air-fall, bedded tuffs, and interbedded tuff and sedimentary rock are discussed

UNCONFORMABLE. Resting on a surface representing a time of erosion or non-deposition

VENT. The location of eruption of a volcano

VITROPHYRE. Porphyritic volcanic glass generally occurring as a distinct zone at the base of a welded ash flow tuff

VOLCANIC ROCK. The class of igneous rocks poured out of or ejected at or near the earth's surface

VOLCANO-TECTONIC DEPRESSION. A large-scale depression that is controlled by both volcanic and tectonic processes

WELDED. Consolidated by latent heat in particles of rock of volcanic origin

WRENCH FAULT. A nearly vertical strike-slip fault

ZEOLITIZATION. Introduction of or replacement by zeolite minerals

PRELIMINARY SURVEY OF TUFF DISTRIBUTION IN
ESMERALDA, NYE, AND LINCOLN COUNTIES, NEVADA

I. INTRODUCTION

Tuffs appear to possess many properties that make them attractive host rocks for high-level nuclear-waste repositories.[1] Silicic tuffs are widespread in the Basin-and-Range Province, and it is the objective of the present study to summarize* the general geology and surface distribution of tuff in most of Esmeralda, Lincoln, and Nye counties of Southern Nevada. Discussion of the general geology of the area includes a brief review of Cenozoic volcanism in Nevada and the tectonic setting. The main portion of this report is an inventory of tuff localities and a discussion of their surface distribution. It is organized regionally by dividing the study area into four zones: Southern Nye County, Esmeralda County, Northern Nye County, and Lincoln County. A detailed inventory of tuff localities is made by further subdividing these counties into several areas, largely by groupings of mountain ranges and low hills with similar structural styles, overlap of lithologic units, geographic proximity, or some combination of these factors. Details of the reasoning for these subdivisions are given at the beginning of the discussion of each area. In each area, tuff distribution and occurrence are discussed in terms of thickness and alteration of tuff; structural complexity; and proximity of tuff to recent faulting, recent volcanism, and resource areas.

Although this report is based exclusively on a study of the published literature (which is often incomplete and sketchy), it should be a useful guide for future, more detailed work. The next stage in this program

*Based solely on a detailed survey of available literature should include an initial field inspection of some of the areas identified as a basis for narrowing the number of study areas for more detailed field and laboratory work. In particular, emphasis must be given to extrapolation of surface geology to the subsurface in each area.

All maps are grouped together behind the text of this report as Figures 1 to 12 for easy reference. The first three maps, of a general nature, are followed by alternate index maps and tuff distribution maps of the three counties studied. These maps are referred to throughout the text, as applicable.

II. TECTONIC SETTING OF SOUTHERN NEVADA

Southern Nevada, specifically Nye, Esmeralda, and Lincoln Counties covered in this report, lies within the southern portion of the Basin-and-Range physiographic province of the western US. This region is generally characterized by an abundance of high-angle normal faults that have generated discrete block-faulted mountain ranges separated by broad, alluvium-filled basins. Several general aspects of the tectonic setting of southern Nevada are briefly discussed here in order to place the region within a generalized geologic framework and because they may influence potential selection of study areas. These include (1) three distinct periods of regional-thrust faulting that may strongly affect the geology underlying specific deposits of tuff, though all thrusts described here are pre-Cenozoic and inactive at present; (2) widespread "Basin-and-Range" normal faulting that occurs mostly along steep, block-bounding faults, locally affects the distribution and occurrence of tuffs described here, and is in some places presently ongoing; and (3) present-day regional tectonics that provide some clue to patterns of any present and future seismicity. Features that immediately affect specific tuff occurrences are reviewed in the detailed discussions of specific areas.

Thrust Faults

Different portions of Esmeralda, Nye, and Lincoln Counties have experienced one or more periods of regional-thrust faulting during which rocks have been generally displaced eastward along nearly horizontal or gently-dipping fault surfaces. Major faulting generally decreases in age from west to east across the area described. Horizontal movement of material above individual thrust surfaces ranges up to at least 40 km, as in case of the "CP Thrust" on and near the Nevada Test Site.[2] Total lateral telescoping across multiple thrusts of a single region may exceed 100 km, as in the case of the Antler Orogen in Nye and Esmeralda Counties.[3]

Major-thrust faulting in southern Nevada first occurred ~360 my ago during the Antler orogeny. The eastern limit of thrusting of this age roughly coincides with the Roberts Mountains thrust, and extends along a line from north-central Nye County to southeastern Esmeralda County. Eastward-directed faulting occurred ~250 to 180 my ago west of a line through northeastern and southeastern Nye County and southwestern Lincoln County. Thrusting activity at this time also extended westward beyond the eastern limit of earlier thrusting. Major-thrust faults near the Nevada Test Site (NTS) are largely of this age, with up to 40 km of displacement along individual thrusts.[2,4] A third period of thrusting occurred 90 to 75 my ago, affecting most of Lincoln County and southeasternmost Nye County. This faulting was part of the Sevier orogeny and resulted in a regional telescoping of some 32 to 95 km.[5,6] Thrust activity at this time apparently did not significantly overlap the earlier thrusting farther west.

Thus, the thrust faults shown in Figures 5, 7, 9, and 11 fall into three distinct belts: (1) an eastern belt dating from 90 to 75 my ago; (2) a central belt dating from 205 to 180 my ago; and (3) a western belt, dating ~360 my ago, part of which underwent later faulting 205 to 180 my ago. At present, none of the mapped thrusts are believed to be active.

Basin-and-Range Faulting

The thrust faulting described above is restricted to distinct belts, but the Basin-and-Range province as a whole is characterized by a period of widespread faulting during the Cenozoic, as shown in Figure 2. The initiation time of this faulting varies locally and is 30 my ago or more in some areas.[7 8] Major normal faulting over the bulk of the province, however, is thought to have begun between 13 and 18 myBP.[4 9] Basin-and-Range faulting is predominately high-angle "normal" faulting, though there are indications of significant lateral or strike-slip movement in some cases.[10] As Basin-and-Range faulting was, in many cases, coeval with extrusion of tuff units described here, and in some cases markedly affected their local thicknesses and distribution,[11] the nature of Basin-and-Range faulting is critical to discussions of specific areas.

In some areas, especially along the southwest margin of the Basin-and-Range, significant strike-slip faulting appears to have occurred during the time of major Basin-and-Range faulting. For example, Longwell[12] has estimated that ~65 km of right-lateral offset occurred across the Las Vegas Shear Zone between 17 and 11 myBP, but there is little activity at present. Major right-lateral slip displacements have also been described in areas along the Southern California-Nevada border.[13]

Present-Day Tectonics

Basin-and-Range faulting is apparently still ongoing in some areas of Nevada (Figure 3), as in Dixie Valley,[10] the Nevada Seismic Zone,[14] and along a general east-west trend extending from near NTS into Utah[15 16] as well as at isolated localities throughout the region.* Available information concerning present-day tectonics in specific areas is discussed in the catalog (or inventory) of specific localities of this report. In

*Note that apparent seismic events resulting from underground testing on the Nevada Test Site have not been filtered out of Figure 3.

general. however, most recent faulting in the Nevada Seismic Zone is predominantly normal, although there is also some strike-slip movement.[14 15] Along the less well-defined trend extending from near NTS into Utah, there is apparently ongoing left-lateral strike-slip movement,[15] that may be related to regional bending or flexure across the Las Vegas Shear Zone and vicinity.[4] Much of the available information concerning "recent," (i.e., alluvium-cutting, normal, and strike-slip) faults is summarized in the figures showing tuff distribution in specific areas (Figures 5, 7, 9, and 11).

General Remarks

The physical distribution and local setting of tuffs are generally of two types. In localities well away from their source areas, tuffs may be emplaced as discrete sheets, and local stratigraphic complexity is minimal. Approximate limits to many of the widespread sheets are indicated in Figures 5, 7, 9, and 11. Regional correlations for this type of occurrence are most affected by generalized Basin-and-Range and regional present-day tectonics.[17]

The thickest sections of tuff, however, generally occur in the immediate vicinity of the source area--generally a caldera or resurgent caldera complex. Many of the known caldera complexes in Southern Nevada are shown in Figures 5, 7, 9, and 11. These complexes vary greatly in complexity, history, and information that is available concerning them.[11 18] Smith and Bailey[19] discuss the complex, yet predictable, patterns of behavior of resurgent calderas.

The present level of understanding of the Timber Mountain-Oasis Valley caldera complex, the best-described complex in Southern Nevada, has recently been summarized.[11 20 21] Activity in the complex covered a timespan of 6.5 my (from 16 to 9.5 myBP), and the complex served as the source of nine major ash-flow sheets, in addition to numerous rhyolitic tuffs and lava flows. Related basaltic volcanism occurred in the immediate vicinity before, during, and after the major caldera activity. Figures contained in the cited references indicate that the extent of localized faulting, related generally to both activity within the caldera complex and to regional behavior, is considerable. Only further research will reveal whether similar levels of both complexity and order may pertain to caldera complexes other than Timber Mountain.

III. TUFF DISTRIBUTION

Tuff is the most commonly exposed rock of Tertiary age in Esmeralda, Lincoln, and Nye Counties. Exposures of tuff are generally located at the high elevations and foothills of the numerous mountain ranges. Presumably, tuff is also extensive beneath alluvium-covered valleys that separate ranges. The distribution of tuff exposures in the three counties was inventoried and outcrops were transferred to topographic base maps at 1:500,000 scale. Ash-flow tuff, air-fall tuff, and interbedded tuff and sedimentary rocks were included in the category of "tuff." Faults and folds that affect Tertiary rocks are also shown on the same base map. In addition, major pre-Tertiary structures located near exposures of tuff were mapped. Calderas and probable calderas are also shown.

Available information and the scale of maps used in the tuff inventory varied widely throughout the three counties. Geologic maps at 1:250,000 scale of Lincoln, Esmeralda, and Southern Nye Counties and at 1:200,000 scale of Northern Nye Counties furnished much of the information. The geologic maps of Lincoln,[22] Esmeralda,[23] and Southern Nye Counties[24] are parts of Nevada Bureau of Mines and Geology Bulletins that show the geology of these three areas. The geologic map of Northern Nye County[25] is a preliminary reconnaissance map not accompanied by an explanatory text. All available maps showing more detail, mostly at scales of 1:125,000, 1:62,500, 1:48,000, and 1:24,000 of smaller areas, were used for additional information. Data on the subsurface distribution of tuff were not collected.

A list of all sources of information used to compile the inventory begins each discussion of designated areas.

IV. SOUTHERN NYE COUNTY

To facilitate discussion of tuff distribution and other geological characteristics relevant to this report, Southern Nye County is divided into seven areas: Stonewall Mountain-Tolicha Peak and vicinity, Kawich Range-Reveille Range, Belted Range-Halfpint Range, Cactus Range-Trappman Hills-Mellan Hills, caldera complex region of central Southern Nye County, Mount Helen, and Bullfrog Hills-Grapevine Mountains (Figure 5).

Stonewall Mountain-Tolicha Peak and Vicinity

These areas are grouped because of geographic proximity. See Figure 4 for location. Principal references: 24, 26, and 27.

Distribution

Surface exposure of tuff is ~147 mi^2 (Figure 5). Total distribution, including subsurface, is probably much greater than the outcrop area because tuff at many localities dips beneath and is overlapped by alluvial deposits. Tuff occurs at the highest elevations of Stonewall Mountain and on a south-southeast-trending plateau extending from Stonewall Mountain southeast to Tolicha Peak and Pahute Mesa. Tuffs at Stonewall Mountain have been intruded by quartz-latite plugs. Two blocks of Precambrian rocks crop out at the north end of Stonewall Mountain.[24] Rhyolite and basalt also crop out in the area. The following tuff units are present (oldest to youngest): Paintbrush Tuff (Tp), Air-fall Tuff (informal map unit-Tt), Uncorrelated Welded Ash Flows (informal map unit-Tw), Thirsty Canyon Tuff (Ttc). The Uncorrelated Welded Ash Flows (Tw) are found only in a roughly circular outcrop pattern at Stonewall Mountain. This geometry may have resulted from eruption of the unit into a volcano-tectonic depression.[24] The tuffs range in age from 13.2 to 7.5 my.

Thickness of Tuff

Composite Thickness -- The thickness of pre-Paintbrush tuffs in the area is unknown. The scarcity of data on thicknesses of several units in the area makes giving a composite thickness impossible.

Thickness of Tuff Units (in ft) --

1. Paintbrush Tuff (Tp) - 0 to 2300

2. Air-fall Tuff (Tt) - No data

3. Uncorrelated Welded Ash Flows (Tw) - No data

4. Thirsty Canyon Tuff (Tc) - 0 to 600

Structure

The area is located in the Walker Lane, a probable right-lateral shear zone that is perhaps an extension of the Las Vegas Shear Zone.[28] The Walker Lane is ~50-km wide, a northwest-trending zone of probable deep-seated strike-slip faulting.[11]

Stonewall Mountain consists of north-striking, steeply-dipping welded tuff intruded by quartz latite, bounded on the east by rhyolite flows and plugs and on the north by Precambrian rocks. The northern boundary of Stonewall Mountain is a steeply northward-dipping normal fault that places Precambrian rocks against alluvium.[24] The plateau extending southeast from Stonewall Mountain on the north toward Tolicha Peak on the south is underlain by flat-lying to gently east-dipping tuff. Several normal faults located on the western side of this plateau are the only mapped faults on the plateau. The Tolicha Peak area is underlain by steeply-dipping Welded Tuff (Tw) strata surrounded by gently-dipping Thirsty Canyon Tuff (Ttc). Post-Welded Tuff (Tw) to pre-Thirsty Canyon (Ttc) deformation is indicated by these structural relations.

Alteration of Tuff

No alteration is mentioned in the literature.

Proximity of Tuff to

Recent Faulting and Seismicity -- The normal fault bounding the northern side of Stonewall Mountain has been recently (?) active with the northern side downthrown, as evidenced by the displacement of alluvium.[24] According to the preliminary map of epicenter locations in Nevada (Figure 3) five or six earthquakes have been recorded in the area with magnitudes from ~3 to 6. [illegible], the earthquakes have centered near Stonewall Mountain and Tolicha Peak.

Recent Volcanism -- One exposure of Quaternary basalt crops out above valley alluvium at the southern end of the plateau extending southeast from Stonewall Mountain toward Tolicha Peak.[24] The thick stratigraphic section of mostly flat-lying tuffs between Stonewall Mountain and Tolicha Peak is cut by only a few faults. This area may be suitable for further examination. However, it is postulated that much of the area surrounding Stonewall Mountain has a high mineral-resource potential.[29]

Kawich Range-Reveille Range

These areas are grouped because of geographic proximity and overlap of rock units. See Figure 4 for location. Principal references: 24, 26, and 30.

Distribution

Surface exposure of tuff is ~186 mi^2 (Figure 5). Tuff is found at the highest elevations of both ranges in north-northwest-trending exposures. Tuff crops out with quartz-latitic, basaltic, dacitic, and rhyodacitic flows and plugs, tuffaceous sedimentary rocks, and, in the Quartzite Mountain area, with Precambrian metasediments. The following units are present (oldest to youngest): Monotony Tuff (Tm), Shingle Pass Tuff (Tsp), Tuff of White Blotch Spring (Twb), Fraction Tuff (Tf), Grouse

Canyon Member of the Belted Range Tuff (Tbr), and Rainier Mesa Member of the Timber Mountain Tuff (Ttm). These rocks were deposited 26.1 to 11.3 my ago. No range-bounding fault has been mapped on the east side of the Reveille Range; therefore, it appears that the gently east-dipping tuffs of the Reveille Range extensively underlie alluvium in Railroad Valley.

Thickness of Tuff

Composite Thickness -- A maximum composite thickness of 11 600 ft.

Thickness of Tuff Units (in ft) --

1. Monotony Tuff (Tm) - 0 to 2300; average thickness is 1000
2. Shingle Pass Tuff (Tsp) - 0 to 1000
3. Tuff of White Blotch Spring (Twb) - 0 to 3000; average thickness 800
4. Fraction Tuff (Tf) - 0 to 7200; 7200 at Trailer Pass in the Cathedral Ridge Caldera
5. Grouse Canyon Member of the Belted Range Tuff (Tbr) - In the Silent Canyon Caldera, drill holes have penetrated 5000 ft of Belted Range Tuff. This unit is probably <1000 ft thick elsewhere
6. Rainier Mesa Member of the Timber Mountain Tuff (Ttm) - 0 to 600

Structure

The Reveille Range in Southern Nye County is a fault-block range bounded on the west side by a normal fault with the west side down. Tuffs in the range dip ~20° eastward. No range-bounding fault has been mapped on the east side.

The Kawich Range can be divided into southern, central, and northern structural segments. The southern segment consists of Precambrian rocks and unconformably overlying Tertiary rocks cut by numerous northeast- and northwest-trending normal faults. The range is bounded on the west by a major normal fault (minimum stratigraphic throw is 4000 ft) that bifurcates to the south into many normal faults around Saucer Mesa.[26]

The central segment consists of a structural depression named the Cathedral Ridge Caldera[26] that is underlain by more than 7000 ft of Fraction Tuff, whose extrusion initiated the caldera formation. The Fraction Tuff is cut by numerous northwest- and northeast-trending normal faults. The caldera is bounded on the south by two normal faults with combined throws exceeding 7000 ft.[26] The northern boundary of the caldera is marked by collapse rubble near Cedar Pass; the eastern and western boundaries are covered by basin fill.

The northern segment of the Kawich Range is a horst block averaging 4 mi in width. Stratigraphic throws on the west- and east-bounding normal faults are 3000 and 1500 ft, respectively.[24] Northwest- to west-trending normal faults are common in the southern part of the northern segment of the Kawich Range. The west boundary fault coincides with part of the Cathedral Ridge Caldera fault system. The northern segment of the Kawich Range is underlain mostly by the Tuff of White Blotch Spring, which strikes northwest with variable gentle to steep dips. A large rhyolite intrusion probably underlies most of this part of the range at shallow depth.[26] The northern part of the northern segment is postulated to be part of a large caldera.[30]

Alteration of Tuff

In the Kawich Range, the Monotony Tuff is hydrothermally altered and weakly mineralized with gold and silver; plagioclase phenocrysts are albitized, and mafic minerals are replaced by chlorite, calcite, and iron oxides. The two exposures of Shingle Pass Tuff in the Kawich Range are intensely hydrothermally altered. The lower part of the Fraction Tuff is intensely altered and mineralized in local fractured areas.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary map of epicenter locations in Nevada (Figure 3), 9 or 10 earthquakes have been recorded in the area with magnitudes from ~3 to 5. Seismic activity has been concentrated somewhat (four or five quakes) in the northern Kawich

Range. Other earthquakes occurred in the Reveille Range, Cactus Flat, and Reveille Valley. One normal fault has displaced Quaternary alluvium to the west of Quartzite Mountain in the southern Kawich Range.[24]

Recent Volcanism -- Basalt that has been designated both Quaternary[24] and Tertiary-Quaternary[26] occurs in Reveille Valley, southern Railroad Valley, along the western side of Kawich Valley in the southern portion of the northern segment of the Kawich Range, and in the extreme northwest portion of the Kawich Range. The youngest basalt erupted along the flanks of the Reveille Range and flowed onto the valley fill of Reveille Valley.[26] This flow has not been dated.

Resource Areas -- No active mines or oil fields are located on the area. The Silverbow mining district (located in T1N and T1S, R49E) was mined mostly for gold and silver from 1904 to 1940. Gold and silver were mined in the early 1900s from the Eden District on the eastern flank of the Kawich Range in T1N, R50E. The Golden Arrow District, located T1N and T2N, R48E, produced gold and silver up to about 1950. The Gold Reed District on the eastern side of the Kawich Range produced gold and silver. The area is within the Nellis Air Force Bombing and Gunnery Range; mining is prohibited in this military reservation.

Areas Identified for Further Examination

The Southern Reveille Range is an eastward-tilted fault block underlain by a gently dipping thick section of tuff (<20°) and cut by normal faults ~5 mi apart. These features may make this area potentially attractive for further examination. However, Quaternary volcanism has occurred in the Reveille Range. The extreme northern part of the Kawich Range, (but south of latitude 38°) is underlain by a thick tuff section that shows evidence of mapped fault deformation only near the southern end. These features may make this an attractive area for further examination. Location of the vent areas and documentation of the ages of Quaternary basalts in the area are not known.

Belted Range-Halfpint Range

These areas are grouped together because of geographic proximity and overlap of rock units. See Figure 4 for location. Principal references: 24, 26, 27, 30, 31, 32, and 33.

Distribution

Surface exposure of tuff is ~248 m^2 (Figure 5). Tuff is distributed throughout the Belted Range and at the highest elevations of the Halfpint Range. The tuff crops out with scattered masses of dacitic and rhyodacitic composition, larger exposures of rhyolite flows and intrusions, tuffaceous sedimentary rocks (all Tertiary), scattered masses of Mesozoic intrusive rocks, and Paleozoic sedimentary rocks that crop out mostly on the northwestern and southeastern flanks of the Belted Range and the western flank of the Halfpint Range.

The following units are present (oldest to youngest): Monotony Tuff (Tm), Tuff of Antelope Springs (Twa), Shingle Pass Tuff (Tsp), Tuff of White Blotch Spring (Twb), Zeolitized Bedded Tuff (informal map unit-Tts), Tuff and Tuffaceous Sedimentary Rocks (informal map unit-Tts), Fraction Tuff (Tf), Tuff of Tolicha Peak (Tt), Tub Spring Member of the Belted Range Tuff (Tbr), Grouse Canyon Member of the Belted Range Tuff (Tbr), Ash Fall and Reworked Bedded Tuff (informal map unit-Tbr), Indian Trail Formation (Ti), Paintbrush Tuff (Tp), Rainer Mesa Member of the Timber Mountain Tuff (Ttm), and Ammonia Tanks Member of the Timber Mountain Tuff (Ttm). These units range in age from 26.1 (Monotony Tuff) to 10.8 my (Timber Mountain Tuff). Tuff appears to underlie alluvium to the east of the Belted Range at shallow depths since the gently east-dipping tufts of the Belted Range are apparently not cut by a range-bounding fault on the east side of the range.

Thickness of Tuff

Composite Thickness -- A maximum composite thickness of tuffs in the area is 13 750 ft.

Thickness of Tuff Units (in ft) --

1. Monotony Tuff (Tm) - 0 to 2300; average thickness is 1000
2. Tuff of Antelope Springs (Twa) - 0 to 600
3. Shingle Pass Tuff (Tsp) - 0 to 1000; average thickness is 700
4. Tuff of White Blotch Spring (Twb) - 0 to 3000; average thickness is 800
5. Zeolitized Bedded Tuffs (Tts) - 60 to 100
6. Tuff and Tuffaceous Sedimentary Rocks (Tts) - 0 to 2000
7. Fraction Tuff (Tf) - <1000
8. Tuff of Tolicha Peak (Tt) - 0 to 400
9. Belted Range Tuff (Tbr)
   Grouse Canyon Member - <700
   Tub Spring Member - <300
10. Ash fall and Reworked Bedded Tuff (Tbr) - No data
11. Indian Trail Formation (Ti) - 0 to 1900; average thickness is 1000
12. Paintbrush Tuffs (Tp) - <500
13. Timber Mountain Tuff (Tm) - 0 to 950

Structure

The Belted Range is a north-trending, east-dipping tilted-fault block bounded on the west by a normal fault that dropped the western side down more than 2000 ft.[24] Range-bounding faults on the eastern side have not been mapped. In the northern part of the range, Paleozoic rocks have been severely disrupted by folding, thrusts, normal faults, and gravity sliding. Paleozoic and Tertiary strata in the northern part of the range have been cut by numerous pre-Belted Range Tuff normal faults that displace the rocks up to 2000 ft.[24] Tertiary strata in the northern part of the Belted Range dip 20° to 60° to the east. These faults trend east, northeast, north, and northwest. Tertiary strata in the central and southern part of the range have been tilted only 5° to 10° east and have been cut by several north-trending faults with a few tens of feet of displacement.[26] These faults are post-Timber Mountain Tuff in age.

The Halfpint Range consists of a series of en echelon northwest-trending tilted-fault blocks, grabens, and horsts.[31] The dominant structures mapped in this range are north-northwesterly-trending normal faults with both eastern and western sides down. Displacements are unknown but appear to be small as most of these faults do not juxtapose different rock units. Faults are numerous; the faults in the Halfpint Range are continuous with the faults in the southeastern Belted Range that are of post-Timber Mountain Tuff in age.[24]

Alteration of Tuff

The Monotony Tuff has been intensely hydrothermally altered and mineralized in the Belted Range. The Shingle Pass Tuff in the Belted Range is slightly to intensely hydrothermally altered. Zeolitized bedded tuff has been hydrothermally altered in the Belted Range. The tuff of Tolicha Peak has been locally zeolitized and silicified. The Tub Spring Member of the Belted Range Tuff has been zeolitized at the base and the top.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary map of epicenter locations in Nevada (Figure 3), more than 100 earthquakes of magnitudes from ~3 to 6 have been recorded in the Halfpint Range, extreme Southern Belted Range, and Yucca Flat. The Yucca Fault, located in Yucca Flat, offsets alluvium and tuff as much as 1200 ft;[24] some of the movement along the fault may relate to testing at NTS.[34] Prominent fault scarps are evidence of recent activity.[31]

Recent Volcanism -- One outcrop of Quaternary basalt occurs at the extreme northern end of the Belted Range.

Resource Areas -- No active mines or oil fields exist here. The Oak Spring Mining District south of Oak Spring Butte consists of tungsten and molybdenum prospects that produce minor amounts of ore. Minor deposits of gold, silver, and sulfide minerals also occur in this district. The area is within the Nellis Air Force Bombing and Gunnery Range where mining is prohibited.

Areas Identified for Further Examination

The presence of only a few local clusters of mapped normal faults, gently-dipping strata (<20°) and a thick stratigraphic section of tuff in the Central and Southern Belted Range may make this area attractive for further examination. However, offset of Quaternary alluvium along the western range-bounding fault of the Belted Range indicates recent tectonism.

Cactus Range-Trappman Hills-Mellan Hills Region

These ranges are grouped together because of geographic proximity, overlap of rock units, and similar structural styles. See Figure 4 for location. Principal references: 24, 26. and 27.

Distribution

About 117 mi^2 of tuff are exposed at the surface (Figure 5). Tuff is distributed at the highest altitudes of all three ranges adjacent to outcrop of Tertiary rhyolite, dacite, and rhyodacite flows and intrusive masses, Tertiary sedimentary rocks, rare Mesozoic intrusive rocks, and, in the Trappman Hills, Precambrian gneiss and schist.

The following units are present (oldest to youngest): Monotony Tuff (Tm), Tuff of Antelope Springs (Twa), Tuff of White Blotch Spring (Twb), Tuff of Wilson's Camp (Tw), Zeolitized Bedded Tuff (informal map unit--Tts), Tuff and Tuffaceous Sedimentary Rock (informal map unit--Tts), Fraction Tuff (Tf), Grouse Canyon Member of Belted Range Tuff (Tbr), Trail Ridge, Spearhead, and Rocket Wash Members of the Thirsty Canyon Tuff (Ttc). Tuffs range in age from 27 to 7 my.

Thickness of Tuff

Composite Thickness -- Ekren[26] suggests a composite thickness of 20 000 ft for Tertiary volcanic rocks of the northern part of Southern Nye County. Most of this thickness consists of ash-flow tuffs. A maximum composite thickness is 21 200 ft.

Thickness of Tuff Units (in ft) --

1. Monotony Tuff (Tm) - Average thickness 1000
2. Tuff of Antelope Springs (Twa) - Composite thickness 5000
3. Tuff of White Blotch Spring (Twb) - Composite thickness >3000
4. Tuff of Wilson's Camp (Tw) - Thickness from 100 to 600
5. Zeolitized Bedded Tuff (Tts) - 100 to 200
6. Tuff and Tuffaceous Sedimentary Rocks (Tts) - 0 to 2000
7. Fraction Tuff (Tf) - <1000
8. Grouse Canyon Member of the Belted Range Tuff (Tbr) - No data
9. Spearhead, Trail Ridge, and Rocket Wash Members of the Thirsty Canyon Tuff (Ttc) - 600

Structure

The Cactus Range-Trappman Hills-Mellan Hills area lies within Walker Lane, a zone of probable strike-slip faulting related to the Las Vegas Shear Zone.[28]

The Cactus Range is a complex northwest-trending horst bounded by an elliptical ring of faults.[24] The principal faults within the horst also trend northwest, although east and northeast trends also exist. Locally the fault pattern is randomly oriented. The fault density is much greater than that shown in Figure 5, as only faults that juxtapose rocks of contrasting lithology are shown. The structure of the range resulted from superposition of volcano-tectonic structures on Basin-and-Range and wrench-fault structures.[26] Major structural events are

1. Collapse after Antelope Springs extrusion

2. Collapse after White Blotch Spring extrusion

3. Prolonged intrusive activity with subsequent elevation of the range

4. Wrench and Basin-and-Range deformation

The two cauldron collapses used the same ring-fracture system.[26]

The Mellan Hills consist of a series of northwest-trending lava ridges separated by valleys of bedded tuff.[26] Northwest- and northeast-trending faults are the main structures. Northwest-trending, low-angle (25° to 35°) normal faults have their eastern sides downthrown. Gravity-sliding is the postulated origin of these features.[26]

Northeast-trending faults are strike-slip with both left and right slip. Fraction tuff and vounger strata dip 20° to 30° east, but underlying strata dip 70° west. Post-White Blotch Spring to pre-Fraction Tuff deformation (18 to 14 my ago) is indicated by these relations.

The Trappman Hills area is a northwest-trending horst bounded on north, east, and west by high-angle normal faults. Tertiary rocks may directly overlie the Precambrian crystalline basement as no Paleozoic rocks are seen in the area.[26] Northwest- and northeast-trending faults are the main structures. All faults are high-angle, normal faults.

Alteration of Tuff

The Monotony Tuff, Antelope Springs Tuff, White Blotch Spring Tuff, Zeolitized Tuff, and tuff of Wilson's Camp have been intensely hydrothermally altered at many localities. No unaltered exposures of Monotony Tuff are known in the Cactus Range. Most of the tuff of Antelope Springs has been hydrothermally altered; silicic and argillic alteration are dominant. The tuff of White Blotch Spring is highly faulted and intensely altered. Tuff of Wilson's Camp is intensely zeolitized and, near Mellan, has been intensely silicified by hydrothermal solutions.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary map of epicenter locations in Nevada (Figure 3), about four earthquakes of magnitudes ~3 to 4 have been recorded.

Recent Volcanism -- Quaternary volcanic rocks do not crop out in the area.

Resource Areas -- No active mines or oil fields are present. The Antelope Hills Mining District, located in the Southern Cactus Range and Northern Trappman Hills, produced small amounts of silver, gold, and sulfides before mining ended in the 1940s. Limited mining in Precambrian rocks of the Trappman Hills produced silver, galena, and gold in the early 1900s. This area is within the Nellis Air Force Bombing and Gunnery Range where mining is prohibited.

Areas Identified for Further Examination

Because of the presence of numerous faults and steeply-dipping tuffs (>30°), no localities were identified for further examination.

Caldera Complex Region of Central Southern Nye County

This area is grouped because of geographic proximity, similar structural styles, overlap of lithologic units, and similar volcanic features. See Figure 4 for location. Principal references: 11, 20, 21, 24, 26, and 27.

Distribution

Surface exposures of tuffs in this area cover ~723 mi^2 (Figure 5). This area is more extensively covered by tuff than any other of similar size in Nevada. Outcrops of tuff occur at the highest elevations and also cover broad dissected plateaus. Tuff outcrops occur adjacent to scattered outcrops of Tertiary dacite, rhyolite, rhyodacite, trachyte, and basalt flows and plugs, Mesozoic intrusive rocks, Paleozoic sedimentary rocks, and Precambrian rocks. The following tuff units are present (oldest to youngest): Redrock Valley Tuff (Trv), Crater Flat Tuff (Tp-Ttm), tuffs of Sleeping Butte (Tw), Tub Spring and Grouse Canyon Members of the Belted Range Tuff (Tbr), Indian Trail Formation (Ti), Stockade Wash Tuff (Tbr), Wahmonie Formation and Salyer Formation (Tp), Topopah Spring, Pah Canyon, Yucca Mountain, Tiva Canyon, and tuff of Pinyon Pass Members of the Paintbrush Tuff (Tp), Rainier Mesa and Ammonia Tanks Members of the Timber Mountain Tuff (Ttm), Trail Ridge, Spearhead, Rocket Wash, and Gold Flat Members of the Thirsty Canyon Tuff (Ttc). The major volcanic centers (and associated tuffs given in parentheses) are: Sleeping Butte Caldera (Redrock Valley Tuff, Crater Flat Tuff, and tuff of Sleeping Butte), Silent Canyon Caldera (Belted Range Tuff and Stockade Wash Tuff), Wahmonie-Salyer volcanic center (Wahmonie and Salyer Formations), Oasis Valley Caldera (Paintbrush Tuff). Claim Canyon Caldera (Paintbrush Tuff), Timber Mountain Caldera (Timber Mountain Tuff), and Black Mountain Caldera (Thirsty Canyon Tuff). The range in age of the tuffs in the area is 15.7 to 7.5 my.

Thickness of Tuff

Composite Thickness -- The composite tuff thickness in the area varies greatly in relation to distance from calderas. A maximum composite thickness for the entire tuff stratigraphic section is 22 230 ft.

Thickness of Tuff Units (in ft) --

1. Redrock Valley Tuff (Trv) - 0 to 1370; (mostly 100 to 700); thickest just west of Rainier Mesa
2. Crater Flat Tuff (Tp) - 0 to 760; at most localities this unit is <620. Thickest at the southern end of Crater Flat
3. Tuffs of Sleeping Butte (Tw) - 0 to 1000; thickest at Sleeping Butte
4. Belted Range Tuff (Tbr) - 0 to >6000; thickest in the Silent Canyon Caldera under Pahute Mesa
5. Indian Trail Formation (Ti) - 0 to 1900; average is 1000; thickest at the northern end of Yucca Flat
6. Stockage Wash Tuff (Tbr) - 0 to 400; thickest along the west side of Rainier Mesa and in the low hills north of Frenchman Flat

7. Salyer Formation (Tp) - 0 to 3000; thickest in the area east of Jackass Flats

8. *Wahmonie Formation (Tp) - 0 to 3500; thickest east of Jackass* Flats.

9. Paintbrush Tuff (Tp) - Attains a maximum thickness of 6500+ in the Claim Canyon Cauldron and 1400 on the cauldron rim.

10. Timber Mountain Tuff (Ttm) - 0 to 4600; the Rainier Mesa Member is more than 1600 on the west wall of the Timber Mountain Caldera--elsewhere it is <500; the Ammonia Tanks Member is >3000 beneath Timber Mountain resurgent dome and >1500 at Oasis Mountain; elsewhere <500.

11. Thirsty Canyon Tuff (Ttc) - 0 to 500; thickest at Black Mountain.

Structure

The caldera complex region of Southern Nye County lies within Walker Lane,[28] a zone of deep-seated strike-slip faulting related to the Las Vegas Shear Zone.[12] Walker Lane is a major structural discontinuity that separates north-trending ranges and basins to the northeast from variably trending basins and ranges to the southwest. The great intensity of late Tertiary volcanism in this region may have resulted from the intersection of the Walker Lane structural zone with the range-bounding faults of the Kawich and Belted Ranges.[11]

The major structures observed in the area are basin-range faults, structures related to caldera formation (ring fractures, normal faults related to doming, etc), strike-slip faults, and folds, thrust faults, and gravity-slide structures affecting only pre-Tertiary rocks. Many caldera-related structures are buried beneath younger volcanic and alluvial deposits; only the most recent calderas (Black Mountain and Timber Mountain) and remnants of older features are exposed. Calderas and caldera remnants are surrounded by a dissected block-faulted volcanic plateau underlain by flat-lying or gently-dipping extrusives. This plateau is preserved at Pahute Mesa, Rainier Mesa, Shoshone Mountain, and Yucca Mountain. Basin-range faulting has produced parallel, mostly east-dipping, tilted-fault blocks bounded by normal faults with west sides typically downthrown. This faulting has been most intense along a south-southwest trend from the Southern Kawich Range across Pahute Mesa and Yucca Mountain and along a south-southwest trend from the Southern Belted Range across Shoshone Mountain.[11]

The post-Fraction Tuff (16 my) events are

1. Extrusion of Redrock Valley Tuff, tuff of Sleeping Butte, and Crater Flat Tuff and subsequent caldera collapse at Sleeping Butte Caldera

2. Extrusion of the Belted Range Tuff and caldera collapse at Silent Canyon Caldera

3. Extrusion of the Stockade Wash Tuff and caldera collapse at Silent Canyon Caldera

4. Eruption of the Wahmonie-Salyer volcanic center and deposition of the Wahmonie and Salyer Formations

5. Extrusion of the Paintbrush Tuff and subsequent subsidence and resurgence at Claim Canyon Caldera and Oasis Valley Caldera

6. Doming of the area around Timber Mountain

7. Extrusion of Timber Mountain Tuff and subsequent subsidence and resurgence at Timber Mountain Caldera

8. Extrusion of the Thirsty Canyon Tuff and caldera collapse at Black Mountain

9. Caldera fill deposition and episodic basaltic volcanism.

Basin-and-Range faulting preceded, was concomitant with, and postdated these events.[11]

Alteration of Tuff

The Bullfrog Member of the Crater Flat Tuff has been extensively zeolitized and sericitized at many localities. The tuffs of Sleeping Butte have been mildly silicified. Locally, the Stockade Wash Tuff has been zeolitized. Various horizons of the Indian Trail Formation and the Belted Range Tuff have been moderately to intensely zeolitized. Aspects of tuff alteration in the area have not generally been well described in the literature.

Proximity of Tuff to

Recent Faulting and Seismicity -- The largest concentration of recorded earthquake epicenters in Nevada is located within the caldera complex region of Southern Nye County (Figure 3). The several hundred that have been recorded have ranged in magnitude from ~3 to 6(?). The largest concentration of activity has been between Black Mountain and Buckboard Mesa on Pahute Mesa. Most other seismic activity has occurred in a roughly semicircular tract around the northern, eastern and southern margins of the caldera complex. (Some of the recorded earthquakes may have resulted from nuclear testing at NTS.)

A major north-trending fault in Yucca Flat has displaced Quaternary alluvium and tuff as much as 1200 ft with the east-side downthrown.[24] Many north-trending basin-range faults displace the Thirsty Canyon sequence and are therefore younger than 7.5 my. Nuclear detonations have produced strike-slip movement along north-trending faults on Pahute Mesa.[4]

Recent Volcanism -- Quaternary basaltic volcanism has occurred at several localities in Crater Flat and in the northeastern part of the Timber Mountain Caldera moat at Buckboard Mesa.

Resource Areas -- No active mines or oil or gas wells exist. The Mine Mountain District in Paleozoic rocks at the southwest margin of Yucca Flat (T11S, R52E), was explored for silver, lead, and mercury in the 1920s. The area is within NTS and the Nellis Air Force Bombing and Gunnery Range where mining is prohibited.

Areas Identified for Further Examination

The area adjacent to Black Mountain on the south and east is a volcanic plateau underlain by a thick sequence of essentially flat-lying tuffs with intercalated lavas and sediments. This area lies west of the zone of numerous faults that trends south-southwest across Pahute Mesa. All these features make this area attractive for further study.

The eastern part of the Pahute Mesa, encompassing the eastern third of the Silent Canyon Caldera and the region to the west of Kawich Canyon, is underlain by a thick sequence of volcanics with gentle dips. This region lies to the east of the zone of numerous faults on Pahute Mesa. The volcanic sequence is 14 000 ft thick in the Silent Canyon Caldera. This area may be attractive for further study.

The Rainier Mesa area may also be attractive for further study since it is composed of a thick section of gently dipping volcanics that are cut by only a few mapped faults.

The eastern slope of Yucca Mountain, north of Busted Butte, south of the Claim Canyon Caldera, and west of Jackass Flat, is underlain by a thick sequence of gently east-dipping volcanics. This area lies to the east of numerous north-trending faults on Yucca Mountain and may warrant further investigation.

Mount Helen Area

The Mount Helen Caldera and associated structures distinguish this area. To some extent, lithologies also differ from those of the surrounding region. See Figure 4 for location. Principal references: 24, 26, 27, and 35.

Distribution

The surface areal distribution of tuffs is ~35 mi^2 (Figure 5). The total area underlain by tuff, including subsurface, is much larger than areal exposure.[26] Alluvium and basalt flows cover a large portion of the tuffs in the southern part of the Mount Helen Caldera, which is a topographic low. Tuffs in the northern part around Mount Helen crop out with Miocene intrusive quartz latites and rhyodacites, and basalt flows, andesitic basalt flows, and rhyolite flows of both Miocene and Pliocene age. Rare Paleozoic and Precambrian rocks are exposed to the west and northeast of the Mount Helen Caldera.

The following tuff units are present (oldest to youngest): Tuff of Antelope Springs (Twa), Tuff and Tuffaceous Sedimentary Rocks (informal map unit--Tts), Uncorrelated Welded Ash Flows (informal map unit--Tw), Belted Range Tuff (Tbr), Paintbrush Tuff (Tp), Rainier Mesa Member of Timber Mountain Tuff (Ttm), and all members of the Thirsty Canyon Tuff (Ttc). Tuffs range in age from 27.7 to 6.2 my.

Thickness of Tuff

Composite Thickness -- The composite thickness of tuff in the area surrounding Mount Helen varies. It may be as much as, but probably does not exceed, 20 000 ft.[26]

Thickness of Tuff Units (in ft) --

1. Tuff of Antelope Springs (Twa) - 0 to 5000; probably <4000 but >1500 at Mount Helen
2. Tuff of Tolicha Peak (Tw/Tts) - 0 to 400; ~400 at Mount Helen
3. Belted Range Tuff (Tbr) - 0 to 1000
4. Paintbrush Tuff (Tw/Tp) - 0 to 500
5. Rainier Mesa Member of Timber Mountain Tuff (Ttm) - 0 to 600
6. Thirsty Canyon Tuff (Ttc) - 0 to 500

Structure

Mount Helen is a volcanic pile that lies at the center of a structural dome in the center of a 9-mi-wide caldera. A 4-mi-wide inner caldera occurs between the lava pile and the outer caldera faults. Arcuate normal faults defining both the outer and inner calderas are observed only to the east, northeast, and west of Mount Helen. Caldera-bounding faults are numerous, and mostly synthetic, although several antithetic faults occur. The presence of numerous normal faults at the center of Mount Helen probably relates to tension that resulted from doming.[26]

The postulated events in the area are:

1. Extrusion of the welded ash-flow tuff shown as Tuff of Antelope Springs (Twa) on Figure 5 and subsequent collapse of outer caldera

2. Intrusion of quartz-latite central plug and extrusion of flows

3. Extrusion of the Tuff of Tolicha Peak and collapse of the inner caldera

4. Doming of Mount Helen[26]

Alteration of Tuff

The Tuff of Antelope Springs has been moderately to intensely altered by hydrothermal solutions at most localities. In the Mount Helen area the Tuff of Tolicha Peak is zeolitized and, locally, is intensely silicified.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary map of epicenter locations in Nevada (Figure 3), three . four earthquakes with magnitudes of ~3 to 4 have occurred. There is no evidence of recent fault activity.

Recent Volcanism -- Quaternary volcanic rocks do not occur in or near the area.

Resource Areas -- No active mines or oil or gas fields exist. The Wellington Mining District (located in T5S, R46E) has produced gold and silver, which occurs in quartz veins that occupy shear zones. This area is within the Nellis Air Force Bombing and Gunnery Range where mining is prohibited.

Areas Identified for Further Examination

At the southern end of the area, flat-lying or gently-dipping ash-flow tuff crops out at several localities. Outcrop geometries indicate that much of the alluvium is underlain by tuff at shallow depths.

The tuffs are not cut by many mapped faults. These observations suggest that this area should be examined in more detail.

Bullfrog Hills-Grapevine Mountains Area

These ranges are grouped together because of geographic proximity and overlap of lithologic units. See Figure 4 for location. Principal references: 11, 20, 21, 24, 27, and 36.

Distribution

The surface exposure of tuff is 54 mi^2 (Figure 5). Tuff crops out in the Bullfrog Hills, the low hills south of the Bullfrog Hills, and at the higher elevations of the Grapevine Mountains. Tuff outcrops occur adjacent to exposures of (1) Tertiary basalt and andesite flows, (2) Tertiary tuffaceous sedimentary rocks, (3) Dacite, rhyodacite, rhyolite, and quartz-latite flows and plugs, and (4) Precambrian and Paleozoic sedimentary and metasedimentary rocks. The following tuff units (oldest to youngest) are present: Uncorrelated Welded Ash Flows (informal map unit--Tw), Bullfrog Member of the Crater Flat Tuff (Tp-Ttm), Tiva Canyon Member of the Paintbrush Tuff (Tp), Rainier Mesa and Ammonia Tanks Members of the Timber Mountain Tuff (Ttm). The age of these units ranges from older than 14 to 11.1 my.

Thickness of Tuff

Composite Thickness -- The maximum composite thickness of tuff is 3830 ft.[11], whereas according to Cornwall and Kleinhampl[36] the composite thickness of tuff is 5000 ft.

Thickness of Tuff (in ft) --

1. Welded Tuff (Tw) - 0 to 1450
2. Bullfrog Member of Crater Flat Tuff (Tp-Ttm) - 0 to 930
3. Tiva Canyon Member of Paintbrush Tuff (Tp-Ttm) - 0 to 700

4. Rainier Mesa Member of Timber Mountain Tuff (Tp-Ttm) - 0 to 450

5. Ammonia Tanks Member of Timber Moutain Tuff (Tp-Ttm) - 0 to 300

Structure

The Grapevine Mountains are part of the Amargosa Range, an east-dipping tilted-fault block bounded on the west by a steep normal fault. The crest and eastern side of the range are mostly underlain by Tertiary volcanic rocks in variable but dominantly east- to southeast-dipping attitudes.[24] These rocks are cut by mostly north- and east-trending normal faults. Amounts of displacement along these faults are unknown.

The strata underlying the Bullfrog Hills and vicinity are cut by numerous Tertiary to recent normal faults of various attitudes; northerly, northeasterly, and easterly trends are predominant. The western sides of most faults have been downdropped. A total of 3500 ft of displacement has occurred along one such fault.[36] The origin of the deformation in the Bullfrog Hills is disputed in the literature. Cornwall and Kleinhampl[36] claim that most of the normal faults in the Bullfrog Hills resulted from cauldron formation related to extrusion of local tuffs. However, Christiansen and others[11] claim that the tuff in the area correlates with tuffs extruded from the Timber Mountain--Oasis Valley Caldera Complex; these authors suggest that faulting in the Bullfrog Hills relates to regional Basin-and-Range faulting.

The rocks of the Bullfrog Hills, mostly ash-fall and ash-flow tuffs, dip away from an intricately-faulted central dome of Paleozoic rocks that is surrounded by normal faults.[36] The Timber Mountain Tuff and older Tertiary rocks are steeply dipping and cut by many faults; however, all younger rocks are only slightly deformed; post-Timber Mountain Tuff deformation is indicated.

Alteration of Tuff

Tuff that crops out near many normal faults in the area has been moderately to intensely hydrothermally altered. Alteration of tuff and mineralization is mostly confined to steep normal faults near the rim of the postulated caldera and near the central domal uplift of basement rocks. However, alteration of tuff occurs at other localities of intense fracturing and faulting.

Proximity of Tuff to

Active Faulting and Seismicity -- The range-boundary fault on the west side of Bare Mountain, due south of Beatty, has displaced alluvial fans as much as 40 ft with the west side downthrown.[24]

According to the preliminary map of epicenter locations (Figure 3), 8 to 10 earthquakes of magnitudes ~3 to 5 have occurred.

Recent Volcanism -- One exposure of Quaternary basalt crops out in the northern part in Sarcobatus Flat.[24]

Resource Areas -- The Bullfrog Mining District, between Beatty and Rhyolite in the Southern Bullfrog Hills, has been the largest gold producer in Southern Nye County. Gold, silver, fluorite, bentonite, and quicksilver occur in veins along faults and fractures. The mineralization probably resulted from hydrothermal solutions related to local volcanic centers. Fluorspar and bentonite are being mined near Beatty and cinder-cone aggregate is being mined west of Lathrop Wells.[27]

Areas Identified for Further Examination

Tuffs exposed in the Grapevine Range have not been mapped in detail, and no synthesis of data exists. The tuff outcrops exposed at the northern terminus of the Grapevine Range should therefore be examined to determine their thickness and the structural complexity.

V. ESMERALDA COUNTY

To facilitate examination of the tuffs, Esmeralda County is divided into five areas (Figure 6). We have generally followed the subdivisions that group mountain ranges on the basis of overlap of rock units and geographic proximity.[23] Portions of the southeast and northeast corners of the county are discussed with the Nye County section to preserve continuity; no areas west of 118° longitude are discussed. The data for this section are chiefly derived from Nevada Bureau of Mines and Geology and USGS reports. Sources of information are listed in the introduction to each area.

Silver Peak Range and Palmetto Mountains

The Silver Peak Range and the Palmetto Mountains are grouped together based on overlap of rock units.[23] See Figure 6 for location. Principal references: 23, 27, 37, and 38.

Distribution

Surface exposure of tuffs is ~100 mi^2 (Figure 7). Tuff is distributed sporadically with largest concentrations in a pattern that encircles the Silver Peak Caldera in the Silver Peak Mountains and in an east-west elongated zone on the northern flank of the Palmetto Mountains. Tuffs crop out with Precambrian, Paleozoic, and Mesozoic sediments; Mesozoic and Tertiary intrusives; Tertiary sediments; and latite, trachyandesite, andesite, and basalt flows. Tuffs may extend beneath the alluvium north of the Palmetto Mountains. Tuff is not exposed at Magruder Mountain in the southern part of the area.

The following tuff units are present (oldest and youngest): Lower Nonwelded Ash Flow (informal map unit--Tafl), Lower Welded Ash Flow (informal map unit--Taw) 21.5 my, Welded Ash Flow (informal map unit--Tsa2) 12.7 my; Rhyolitic Air-Fall Tuff (informal map unit--Tafu) 6.0 my; and Upper Welded Ash Flow (informal map unit--Tawu) 6.1 my. Tuffs range in age from 21.5 to 6.0 my.

Thickness of Tuff

Composite Thickness -- The composite thickness of tuff in the Silver Peak-Palmetto Mountain area is not well documented. Thicknesses of some units are not described and others are variable. There is a general thickening of units away from the Silver Peak Caldera,[37] but no concrete information is given.

Thickness of Tuff Units (in ft) --

1. Lower Nonwelded Ash Flow (Tafl) - Information on thickness not available, although this unit is said to be absent in the central part of the Silver Peak Mountains

2. Lower Welded Ash Flow (Taw) - Same as 1 above

3. Welded Ash Flow (Tsa2) - No thickness described; it occurs as an interbed in a sedimentary sequence along the western flank of the Silver Peak Mountains

4. Rhyolitic Air-Fall Tuff (Tafu) - Thickness varies from a few tens of feet in the southern part of the area to 1200 to 1500 ft at Rhyolite Ridge in the north

5. Upper Welded Ash Flow (Tawu) - No information on thickness is available; however, its distribution is small

Structure

The Silver Peak and Palmetto Mountains lie in a zone of disrupted structure between the Furnace Creek Fault and the Las Vegas Shear Zone; both are zones of transcurrent right-lateral motion. The Silver Peak and Palmetto Ranges comprise the major part of an arcuate zone, convex to the south, described as the Silver Peak--Palmetto--Montezuma oroflex;[23] the structure of each range is described separately below. In addition, the Magruder Range (south of the oroflex) is described.

The Silver Peak Mountains have the shape of a parallelogram in outcrop pattern. The dominant structures affecting the pre-Tertiary rocks in the area are thrusts, gravity slides, folds, drag folds, and high-angle normal faults. The entire Tertiary sequency in the central portion of the range is cut by swarms of northeast-trending, high-angle normal faults that are downdropped predominantly to the northwest and, in places, crosscut, merge with, or are cut by less densely distributed north-trending normal faults. Rocks older than 5.9 my have been folded into a northeast-trending syncline. Dips of up to 70° have been observed.

The Silver Peak Caldera can be recognized by radial distribution and outward dip of volcanic rocks, general thinning of the volcanic rocks away from the center, and facies changes in the volcanic sequence. The activity in the caldera was from about 12.7 to 4.8(?) my ago. Tuff units Tsa2, Tafu, and Tawu were probably derived from this center.[37] Basaltic volcanism was the most recent.

For the most part, the strikes of pre-Tertiary sediments in the east-trending Palmetto Mountains conform to the trend of the range and are cut by thrust faults and high-angle normal faults. The generally east-trending normal fault marking the northern boundary of the Palmetto pluton conforms to the dominant trend of normal faults in Tertiary rocks. Some faults affecting Tertiary-rocks strike oblique to this trend. Most east-trending faults are downdropped on the north side, and most faults cutting the east-trending structures are downdropped on the west side.

Alteration of Tuff

Little information is available; however, the Upper Welded Ash-Flow (Tawu) and the Rhyolitic Air-Fall Tuff (Tafu) are said to be zeolitized and locally hydrothermally altered in the Silver Peak Caldera region.[37]

Proximity of Tuff to

Recent Faulting and Seismicity -- *A series of faults scarps in* Holocene alluvium just east of the White Mountains have been described. These are ~5 mi due west of the Silver Peak Mountains.

According to the preliminary map of epicenter locations in Nevada (Figure 3), more than 100 earthquakes have occurred, ranging in magnitude from ~3 to 6. Most of them have been centered near 118° W longitude and 38° N latitude, just northwest of the Silver Peak Range. Much of the rest of the recorded seismic activity occurred along the western margin of the area in and near the Nevada Seismic Zone.

Recent Volcanism -- A Quaternary basalt cone lies 1.5 mi north of Mineral Ridge in the Silver Peak Mountains. Robinson and others discussed basaltic volcanism along the Silver Peak Caldera rim.[39] These basalts have been dated at 4.8 my, but they may be Quaternary.[23] Sporadic Quaternary basalt occurs in the area.

Natural Resources -- One of the world's principal sources of lithium occurs east of Silver Peak in the Clayton Valley. Lithium salts are currently being mined from six mines at depths of 300 to 700 ft. Old mines and prospects occur sporadically over the entire Silver Peak, Magruder, Palmetto, and Sylvania Mountains. Ten areas of more concentrated mining activity have been defined as districts. The dominant focus of early mining and exploration was for deposits of gold, silver, copper, lead, and (to a lesser degree) tungsten and borax, occurring in a variety of rock types including volcanics as young as 5.9 my. Ore production was largest at the Silver Peak and Palmetto Districts, where recorded production was $16,312,849. Most production was completed by 1943. Since that time, however, the Sylvania District along the California border has become virtually the only talc producer in Nevada. Between 1941 and 1963, the district produced 186,136 short tons.

Bentonite, silver, and tungsten are currently being mined in the Silver Peak Range; silver and gold in the Palmetto Mountains; and lead-silver and gold placers just southwest of the Palmetto Mountains.[27]

Areas Identified for Further Examination

A section of tuff ~1000 ft thick to the west and east of Silver Peak Caldera occurs beneath basaltic cover that is cut by few mapped faults; this area may warrant further examination. The greatest thickness of tuff occurs at Rhyolite Ridge; this area may warrant field examination.

Slate Ridge and Gold Mountain Area

Slate Ridge and Gold Mountain are grouped for discussion based on overlap of rock units.[23] See Figure 6 for location. Principal references: 23 and 27.

Distribution

Surface outcrops of tuff cover ~110 mi^2 (Figure 7), mostly south and east of Gold Mountain. Discontinuous tuff outcrops surround the eastern half of Slate Ridge. Tuffs crop out near Precambrian and Cambrian sediments and Mesozoic granitic rocks.

Only two tuff units have been identified--the Timber Mountain Tuff (Ammonia Tanks Member) (Ttm), which has the considerably greater surface distribution, and the Thirsty Canyon Tuff (Ttc). The presence of several inselbergs of Timber Mountain Tuff southeast of Gold Mountain indicates that this unit may be extensively distributed in the subsurface. Tuffs range in age from 11.5 to 7.5 my.

Thickness of Tuff

The Timber Mountain Tuff makes up the largest portion of tuff thickness. Composite thickness of tuff varies, but is 1700 ft in some places.

1. Timber Mountain Tuff (Ttm) - Thickness 1350 ft
2. Thirsty Canyon Tuff (Ttc) - Composite thickness 300 ft

Structure

This area is structurally subdivided into two smaller areas. Slate Ridge and the area around Gold Mountain together lie in an arc that is convex to the south, concentric with the Silver Peak-Palmetto-Montezuma oroflex. The oroflex is cored by a series of Jurassic-Cretaceous plutonic rocks that have likely been affected by large amounts of right-lateral shear.

Slate Ridge trends east-west. The western half is dominated by the Sylvania pluton and the eastern half by Precambrian and Cambrian sediments flanked by air-fall and ash-flow tuff. Three high-angle, east-west-trending sections of major arcuate normal faults step down to the north, defining the geometry of the ridge to some extent. Offset is at least 4000 ft on the northern fault. Movement on the two other faults has both preceded and followed deposition of the ash flows. Several north-trending faults cut the tuffs; cross-cutting relations indicate that these faults predate the east-west-trending faults. Ash flows at the eastern end of Slate Ridge generally dip gently away from the core of the ridge. Some vertical uplift of the ridge since tuff deposition is suggested. A syncline is responsible for the elongated area of ash-flow southeast of Mount Dunfee.[23]

Gold Mountain is also part of the Sylvania pluton. Fingers of the pluton extend into Precambrian rocks. Flanking Gold Mountain on the east and south are large areas of Timber Mountain ash-flow tuff. To the south of Gold Mountain, these tuffs dip southwest. Three prominent east-trending faults branching off the eastern ones are downdropped to the northwest. The welded ash flows east of Gold Mountain strike northeast and dip northwest. They are cut by northeast-trending faults, downdropped to the southeast. This is the reverse of the sense of displacement in the tuff south of Gold Mountain.

Alteration of Tuff

No data are available.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary map of epicenter locations in Nevada (Figure 3), nine earthquakes have occurred at magnitudes from ~3 to 4. Two have occurred near Mount Dunfee, two near Gold Mountain, and the rest southwest and southeast of Gold Mountain. No faults that have displaced Quaternary rocks have been mapped in the area.

Recent Volcanism -- Recent basalt flows overlie welded-ash flows in isolated areas north of Grapevine Canyon and are surrounded by alluvium in the canyon. Other basalts are sparsely scattered through the central and eastern portions. The precise age of the basalt is not known, but it is Pliocene or Pleistocene.[23]

Natural Resources -- Gold is being mined (as of 1976) at the western end of Slate Ridge.[27] Gold and silver were discovered in the 1860s at Hornsilver and Tokop Districts along Slate Ridge and east of Gold Mountain, respectively. Gold and then silver were discovered in the early 1900s at the Divide District on Gold Mountain. Production from the districts has been ~$1 million, mostly in gold and silver at Hornsilver; $4 thousand, mostly in gold at Tokop; and $3.5 million, mostly silver and some gold at the Divide District. The most active period of production was between 1905 and 1920.

Areas Identified for Further Examination

The thick section of Timber Mountain Tuff that is cut by only a few mapped faults east of Gold Mountain may warrant further examination. Reconnaissance field investigation is necessary to determine the structural relations more completely. The flat-lying tuffs northeast of Slate Ridge may warrant study even though outcrops are not extensive. Thickness of Thirsty Canyon Tuff is unknown.

Goldfield Hills-Montezuma Range-Clayton Ridge-Mount Jackson Ridge

Goldfield Hills, the Montezuma Range, Clayton Ridge, and Mount Jackson Ridge have been grouped together based on overlap of rock units;[23] see Figure 6 for location. Principal references: 23, 24, 27, and 40.

Distribution

The surface distribution of tuffs is ~130 mi^2 (Figure 7). Air-fall tuff is distributed at both the higher and lower elevations and covers a large portion of Montezuma Peak and Clayton Ridge and the expanse between ranges. Air-fall tuff also crops out in a circular pattern around Mount Jackson. The ash-flow tuffs are largely at low or moderate elevations. Tuffs overlie and are faulted against Precambrian and Cambrian sediments.

They are also intruded and interfingered locally with Tertiary andesite and rhyolite plugs and latite and dacite flows. Tuffs range in age from 25.6 to 7.5 my. Some of the tuffs are interlayered with sediments and flows as indicated below.

The tuff units are listed from oldest to youngest: the Vindicator Rhyolite (actually a welded ash flow--Tv), the Kendall Tuff and Interlayered Latite (Tk), Uncorrelated Welded Ash Flows (Nye County) (informal map unit--Tw), the Siebert Tuff (Ts) and stratigraphically continuous Air-Fall Tuff (informal map unit--Taf), the Fraction Breccia (Tf), the Spearhead and, possibly, Trail Ridge Members of the Thirsty Canyon Tuff (Ttc).

Thickness of Tuff

Composite thickness of tuff is not discussed, but locally at least 2200 ft is present; however, intercalated tuffaceous sediments and lava flows make up some of this thickness.

Thickness of Tuff Units (in ft) --

1. Vindicator Rhyolite (Tv) - No information available
2. Kendall Tuff and Interlayered Latite (Tk) - No information available
3. Uncorrelated Welded Ash Flows (Tw) - No information available
4. Siebert Tuff (Ts) - 500
5. Air Fall Tuff (Taf) - 1000
6. Fraction Tuff (Tf) - 745 near Tonopah
7. Thirsty Canyon Tuff (Ttc) - Composite maximum thickness is 80

Structure

The Montezuma Range, Clayton Ridge, Mount Jackson Ridge, and Goldfield Hills form the eastern limbs of the southward-convex Silver Peak-Palmetto-Montezuma oroflex.[23] All four ranges in this area conform to the same arcuate trend.

The Montezuma Range trends northeast. Deformed Precambrian and Cambrian sediments intruded by Mesozoic dikes and small plutons crop out in the northeast and southwest ends of the range. A large mass of air-fall tuff overlain in places by rhyolite or rhyodacite agglutinate dominates the central portion of the range. Dips of the tuff are on the order of 5° in various directions and some up to 20° on Montezuma Peak. The source area is thought to be a large rhyolitic volcano east of Montezuma Peak.[23]

Thrusts, folds, gravity slides, and high-angle normal faults have deformed the pre-Tertiary rocks. The air-fall tuff in the central part of the Montezuma Range rests unconformably on these older sediments. It and other young Tertiary units are relatively undisturbed. A few north-trending normal faults occur locally. Varying dips [illegible]brian and Precambrian sediments near a partially concealed small pluton in the north end of the range suggest that a major fault zone is obscured by overlying Tertiary tuffs in this area and by the possible presence of a large pluton at shallow depth underneath the entire north end of the Montezuma Range.[23]

Clayton Ridge is a north-northeast-trending fault block similar in structural style to Montezuma Range. Deformed Precambrian and Cambrian sediments crop out at the north and south ends of the range. A large zone of air-fall tuff that extends west from the Montezuma Range blankets the older sediments and dips at low angles. Two sets of numerous high-angle faults cut the tuff; one set trends north-northeast, the other trends east. Displacements appear small since contrasting lithologies are not juxtaposed. Some faults can be traced for as far as 3 mi. A range-bounding fault on the western side cuts the tuff in some places and seems to have had movement along it that both predates and postdates Tertiary volcanics. Small outcrops of Mesozoic to Tertiary quartz monzonite may indicate a larger pluton beneath the area.[23]

The western end of Mount Jackson Ridge is composed of mostly low-dipping Tertiary tuff and sediments intruded by rhyolite domes and covered by rhyolite and andesite flows. The central parts of Mount Jackson Ridge and Goldfield Hills are composed of Precambrian and Cambrian sediments deformed by thrust faults and northeast-trending normal faults. The northern section of the Goldfield Hills is a series of Tertiary lavas and ash flows and sparse exposures of an intrusive monzonite capped in places by a largely eroded Tertiary or Quaternary (?) basalt flow. Young north-trending Basin-and-Range faults cut the upper basalt. Collapsed structures of an east-west elongate caldera deform beds older than 21 my. Younger rocks, including the Thirsty Canyon Tuff, are mostly flat-lying. The following is an analysis of Tertiary deformation.[40]

1. Volcanic center extruded silicic tuffs and flows 30 to 31 my ago; ring fractures delineate caldera
2. An 8-my hiatus
3. Volcanism resumed 22 my ago with flows and tuffs covering the Oligocene section
4. A 2-my episode of faulting, hydrothermal alteration, and ore deposition overlapped 22-my-old volcanism; rejuvenation of ring fractures
5. Emplacement of a shallow pluton
6. Volcanism and Basin-and-Range faulting 18 to 6 my ago

Alteration of Tuff

All alteration of tuff is confined to units that predate deposition of the Meda rhyolite and dacite vitrophyre of Ransome (Taw) that are 21.1 my old. Thus, only the Vindicator Rhyolite Tuff (Tv) and the Kendall Tuff appear to have undergone alteration.

Proximity of Tuff to

Recent Faulting and Seismicity -- Several faults cut late Tertiary or early Quaternary basalts.

According to the preliminary map of earthquake epicenter locations in Nevada (Figure 3), five or six earthquakes of magnitude ~3 have occurred. Four or five occurred in and along the eastern margin of the Montezuma Range.

Recent Volcanism -- A large area of basalt overlies Thirsty Canyon Tuff (7.5 my) in the Goldfield Hills area. Basalts are up to 100 ft thick and widely distributed. Smaller outcrops of what are thought to be remnants of the same flow suggest a large late Tertiary or early Quaternary (?) volcanic event.[23]

Natural Resources -- Five major mining districts are located here: Cuprite, Diamondfield, Goldfield, Montezuma, and Silver Peak Marsh. Large portions of land in the Goldfield Hills and small portions of land in the Montezuma area are potential lode-mining claims. Gold-silver prospects near the southern end of the Montezuma Range were being mined in 1976.[27]

Cuprite district, along Mount Jackson Ridge, is noted largely for copper deposits; however, silver, gold, and lead also occur. No production is recorded.

The hydrothermally altered rock of the elliptical belt 5 mi northeast of Goldfield is known as the Diamondfield District. Production of free gold and silver is from silicified fault zones enveloped by hydrothermally altered andesite. The major production was in the early 1900s with minor production by lessees until World War II. Total recorded production is $52,305, but as much as $2 million has been suggested. Apparently there is no current mining.

About 75% of the mineral production of Esmeralda County came from a belt less than a mile long and a few hundred feet wide; this constitutes the main mining area of the Goldfield District. The principal producing units of gold and silver are the Milltown Andesite and the overlying dacite, both 21.5 my old and have undergone hydrothermal alteration. Ore is younger than alunitization and silicification. Total recorded production for Goldfield was $89,774,317, but as much as $100 million has been suggested. Related to the Goldfield ore deposits are deposits in rhyolitic rock in the Sandstorm area. Production was probably about $1.5 million. Most activity was between 1904 and 1915; however, some activity between 1935 and 1938 has been noted.

The Goldfield and Diamondfield ore deposits and other areas of ore production in the Goldfield Hills coincide with old collapsed structures related to the formation of the caldera 22 my ago. There is no active mining, but some gold has been produced locally; cinnabar prospecting continued into the 1960s.

The Montezuma District, which is about 6 mi west of Goldfield, was principally a silver-lead producer with most ore bodies in veins in limestone. Most of the ~$500,000 production occurred between 1900 and 1910. A mercury prospect occurs in the southern part of the district; no production is recorded.

One of the world's principal sources of lithium occurs in the Clayton Valley-Silver Peak Marsh Districts. Production of the metal from salt brines at depths of 300 to 700 ft has continued since 1965. Lithium concentrations are ~400 ppm. Other salts have been mined in the area for local use.

Areas Identified for Further Examination

Air-fall tuffs southwest of Montezuma Peak may warrant examination, although patented lode-mining claims and the age of basaltic flows should be carefully considered first. Thirsty Canyon Tuff at Mount Jackson may warrant examination for thickness and distribution under alluvium.

Monte Cristo Range-Cedar Mountains-Royston Hills

The grouping of the Monte Cristo Range and Cedar Mountains is based on overlap of rock units.[23] See Figure 6 for location. Principal references: 23, 27, and 40.

Distribution

Approximately 100 mi^2 of tuff outcrop at the surface (Figure 7). Welded ash-flow tuffs underlie most of the north-trending Cedar Mountains and northeast-trending Royston Hills where the tuffs crop out adjacent to Mesozoic stocks. Rhyolitic flow rocks that grade into welded ash-flow and sedimentary rocks containing tuff units occur throughout the Monte Cristo Range.

The tuff units are, from oldest to youngest: Nonwelded Ash Flows (informal map unit--Taf), Welded Ash Flows (informal map unit--Taw), Rhyolite Breccia (Tqb) [grades into Welded Ash Flows, shale, siltstone, sandstone, limestone, and tuff previously described as the Esmeralda Formation (Ts)]. Tuffs range in age from mid-Miocene to 10.7 my.

Thickness of Tuff

Composite Thickness -- The composite thickness of tuff may be as much as 3000 ft in the northern part of the Cedar Mountains. Some tuff units thicken to the north, suggesting a source area in this direction.[23]

Thickness of Tuff Units (in ft) --

1. Nonwelded Ash Flows (Taf) - No specific information is available

2. Rhyolitic to Quartz-Latitic Welded-Ash Flows (Taw) - Up to 3000 in the Crow Springs area of the Royston Hills.[23] The sequence thins to the south

3. Welded Ash Flows within Rhyolite Breccia (Tqb) - No thickness described for tuff; however, the total thickness of the rhyolite breccia host probably does not exceed 1000

Structure

The Monte Cristo Range and Royston Hills constitute most of an arcuate mountain system that is convex to the south, conforming to the form of the Silver Peak-Palmetto-Montezuma oroflex. The Cedar Mountains trend north and converge at their southern end with the arcuate system. Apparently, very little faulting affects Tertiary rocks in the Monte

Cristo Range; however, the precipitous eastern slope may be a fault scarp.[42] A series of north-northwest-trending faults juxtapose rocks of Triassic and Miocene age in the Royston Hills and Cedar Mountains. A western range-bounding fault occurs in the Cedar Mountains. Dips of tuffs are as high as 70° to the west in the Crows Springs area of the Royston Hills.[23] Much lower dips are observed to the east of these outcrops in the area east of a block of Triassic rocks. Field evidence supports westward tilting of one block of the Royston Hills several tens of degrees.[23]

The following is the probable series of orogenic events in the Tertiary:[42]

1. Intermittent volcanism followed a period of uplift and erosion in the early Tertiary, depositing Taw and Tab

2. Faulting and tilting preceded deposition and extrusion of sediments and tuffs (Ts) formerly referred to as part of the Esmeralda Formation

3. Faulting continued with discontinuous volcanic activity including rhyolite, andesite, and basalt extrusion at the end of the Pliocene or early Pleistocene

Unpublished field evidence suggests that the Monte Cristo Range and the Cedar Mountains are underlain by a large caldera complex.[43]

<u>Alteration of Tuff</u>

Little information is available. There has been local silicification of tuff associated with ore deposits in the Gilbert Mining District.

<u>Proximity of Tuff to</u>

<u>Recent Faulting and Seismicity</u> -- According to the preliminary map of earthquake epicenter locations in Nevada (Figure 3), four to five earthquakes have been recorded in the area with magnitudes of ~3 to 5. The Cedar Mountain Earthquake occurred December 10, 1932. Many earthquakes have been recorded in the southwestern part of the area in the Columbus Salt Marsh west of Coalfield with magnitudes from ~3 to 6.

Young fault scarps are present in alluvial gravels north of the Pilot Mountains.[42]

Recent Volcanism -- The youngest volcanic rocks in the area are thought to be late Pliocene or early Pleistocene.[23] No radiometric age determinations were obtained for these basalts.

Natural Resources -- There are four mining districts: Crow Spring (T5N, R39E); Gilbert (south of the town of Gilbert in the Monte Cristo Range); Columbus Marsh (southwest of the Monte Cristo Range); and Rock Hill (west of the Monte Cristo Range, along Highway 95). All mining areas have been idle since the 1940s. The principal minerals and ores mined or occurring in the areas are listed below:

Columbus Marsh: Some borax minerals and minor amounts of salt.

Crow Springs: Turquoise and minor diatomaceous earth, silver, lead, copper, and gold.

Gilbert: Gold and minor cerargyrite, ruby silver, argentite, and mercury.

Rock Hill: Placer deposits of scheelite and iron.

Areas Identified for Further Examination

Available, published geologic maps of the Monte Cristo Range and Cedar Mountains indicate that large areas of these two ranges are underlain by thick sections of essentially flat-lying tuffs that are cut by few faults. These areas may warrant field examination since there has been little geologic investigation of the ranges. Recent unpublished data regarding these ranges, however, suggest that there may be considerable structural complexity.[43]

Weepah Hills-Lone Mountain-Angel Island-Northwestern Part of Clayton Valley

These areas are grouped together by Albers and Stewart[23] based on radiometric age determinations and similarities in lithology. We have followed their grouping.

See Figure 6 for location. Principal reference: 23.

Distribution

Surface distribution of tuff in this area is very limited and only ~2 mi^2 is exposed (Figure 7). Tuff outcrops are confined to a narrow belt of ash flows at the northwestern tip of Lone Mountain and two small outcrops of air-fall tuff south and west of the Weepah Hills. Paymaster Ridge, the heart of Lone Mountain and the Weepah and General Thomas Hills is comprised of Precambrian, Paleozoic, and Mesozoic sediments and intrusives. Because of this, any subsurface tuff units are likely to occur beneath outcrops of the Tertiary Esmeralda Formation in the Big Smoky Valley and west and south of the Weepah Hills.

Only two tuff units are present in this area--the older welded-ash flows (Taw) and the interbedded-ash flows and air falls (Taf) within the Esmeralda Formation, which is dominantly sedimentary.

Thickness

Composite thickness of tuff in this area is difficult to determine. The interbeds of tuff within the Esmeralda Formation vary in thickness. The older welded ash flows (Taw) occur in far greater thicknesses. It appears that younger ash flows can be correlated across Big Smoky Valley with those of the same stratigraphic horizon in the Royston Hills and Cedar Mountains to the north and those of Rhyolite Ridge to the south. Thus, buried tuffs west of the Weepah Hills may be 2000 ft thick.

Structure

Lone Mountain, the Weepah and General Thomas Hills, and Paymaster Ridge are low-lying hills and north-trending ridges that are dominated by the Lone Mountain block on the north. All are part of an intricate mosaic of fault blocks controlled to a large extent by pre-Tertiary Structure. The Precambrian-to-early-Tertiary sediments and intrusives that make up the central portion of the mountain system contain thrusts and normal faults, folds, shears, and gravity slides. Tertiary rocks exposed in the

Weepah Hills have been folded into an open northwest-trending anticline-syncline pair with fold wavelengths of ~2 mi. Dips up to 40° have been observed. Apparently no faulting is present within this block of Tertiary outcrops. Holocene fault scarps that define the northwestern boundary of the entire mountain system indicate recent uplift.

Alteration of Tuff

Little tuff is present at the surface; however, alteration of tuff and interbedded rhyolite are described in the Alum Mining District. The character of older welded ash flows beneath the Esmeralda Formation and older alluvium is not known.

Proximity of Tuff to

Recent Faulting and Seismicity -- As indicated in the section concerning structure, faults cut Holocene alluvium along the northwestern boundary of the mountain system. According to the preliminary map of earthquake epicenter locations in Nevada (Figure 3), no earthquakes have been recorded.

Recent Volcanism -- Flows from a small basaltic cone south of the Weepah Hills at the northwest end of Clayton Valley appear to be younger than some of the Quaternary alluvium and are thought to be late Pleistocene or Holocene. Other basalt in the Weepah Hills area of postulated late Pliocene or Pleistocene age overlies the Esmeralda Formation.

Natural Resources -- All the mining areas have been grouped into two districts, Lone Mountain and Alum. The Lone Mountain District covers a large area including Lone Mountain, Paymaster Ridge, the General Thomas Hills, and the eastern part of the Weepah Hills near the Lone Mountain and Weepah plutons. Areas within this district have been worked for silver-bearing galena, gold, and free silver. The Gold Eagle Mine (south of Lone Mountain and west of Paymaster Canyon in the Weepah Hills) was worked in the 1960s for lead, zinc, copper, and silver, but fell inactive in 1967.

Mining in the Alum District (in the western part of the Weepah Hills) was largely for potassium, alum, kaolinite, and sulfur. No present activity in this district is described;[27] however, some attempt was made to develop what were tentatively identified as cinnabar deposits in 1967. Results of this work are not known. No active mining of deposits in either area is described in this literature. South of the area in Clayton Valley there is active mining of lithium from salt brines (see Clayton Ridge-Goldfield Hills-Montezuma Range-Mount Jackson Ridge section).

Areas Identified for Further Examination

Surface exposures of tuff are scarce in this area. Further study probably should focus on potential of older welded ash flows buried beneath exposures of the Tertiary Esmeralda Formation (in the Western Weepah Hills) and address the problems presented by Holocene-fault scarps and volcanic activity.

VI. NORTHERN NYE COUNTY

For the discussion of tuff distribution and other geologic characteristics relevant to this report, Northern Nye County is divided into four areas:

1. Paradise Range-Shoshone Mountains-Royston Hills-Toiyabe Range-San Antonio Mountains
2. Toquima Range
3. Monitor-Antelope-Hot Creek-Kawich-Reveille Ranges
4. Pancake Mountains-White Pine-Horse-Grant-Quinn Canyon-Golden Gate-Egan-South Egan, and Seaman Ranges (Figure 8).

These four areas were grouped on the Preliminary Geologic Map of Northern Nye County on the basis of overlap of lithologic units.[25] Structural styles of individual ranges in each group vary considerably. The data base of information concerning the geology of Northern Nye County is limited. Because no syntheses of the geology of Northern Nye County have been published, this part of the present report is based on review of the Preliminary Geologic Map of Northern Nye County,[25] several more detailed maps of smaller regions in the area, and published papers dealing with the geology of several areas. The data base used to compile information on each of the four areas is given at the beginning of the discussion of each area.

Paradise Range-Shoshone Mountains-Toiyabe Range-Royston Hills-San Antonio Mountains

These areas are discussed together because the same rock units overlap all the areas. See Figure 8 for location. Principal references: 25, 42, 44, 45, 46, 47, and 48. No detailed information is available concerning the geology of the Royston Hills.

Distribution

Surface outcrops of tuff cover ~586 mi^2 (Figure 9). Tuff is exposed

1. At high elevations of the northern end and eastern side of the Paradise Range and in the low hills at the southern end of the Paradise Range,
2. At high elevations of the Shoshone Mountains except along the central-western front,
3. At the crest, western slope, and southern terminus of the Toiyabe Range, and
4. In scattered tracts in the Royston Hills and San Antonio Mountains.

Tuff crops out adjacent to exposures of Tertiary basalt, andesite, quartz-latite flows and plugs, rhyolite flows, plugs and dikes, dacite flows, tuffaceous sedimentary rocks, granitic, rhyolitic and basaltic dikes and sills, Mesozoic plutonic rocks, and Paleozoic sedimentary rocks. Tuff exposures form the majority of the outcrops in the area.

The following tuff units are present (oldest to youngest): Lower Volcanic Sequence (Tvl) of the Paradise Range and Southern and Central Shoshone Mountains, including the Underdown Tuff of the Northern Shoshone Mountains; Tonopah Formation (Tto) exposed in the San Antonio Mountains; Middle Volcanic Sequence (Tvm) of the Paradise Range, including the Bonita Canyon Formation of the Northern Shoshone Mountains and the Esmeralda Formation of the Southern Shoshone Mountains, Toiyabe Range, and Royston Hills; Welded Ash-Flow Tuff (informal map unit--Twt), including Toiyabe Quartz Latite of the Toiyabe Range, Royston Hills, Shoshone Mountains, and Paradise Range; Fraction Tuff (Tf) of the Toiyabe Range and San Antonio Mountains; and Tuff and Tuffaceous Sediments (informal map unit--Tts) of the Royston Hills, Paradise Range, Toiyabe Range, and Shoshone Mountains, including the Siebert Tuff of the San Antonio Mountains. These lithologic units range in age from 26.1 to ~12 my.

Thickness of Tuff

Composite Thickness -- The maximum composite thickness of tuff in the Paradise Range exceeds 3600 ft. The composite thickness of the Tertiary section in the Central Shoshone Mountains is 9000 ft; tuff comprises >6800 ft of this section. The composite thickness of the Tertiary section in the Northern Shoshone Mountains is >5100 ft; tuff constitutes >4300 ft of this thickness. The composite thickness of the Tertiary section in the Toiyabe Range exceeds 4000 ft, 3700 ft of which is tuff. The maximum composite thickness of the Tertiary section in the Royston Hills exceeds 5200 ft; tuff comprises up to 4000 ft of this thickness. More than 5000 ft of Tertiary rocks are exposed in the San Antonio Mountains; ~3800 ft of this section is composed of tuff.

Thickness of Tuff Units (in ft) --

1. Lower Volcanic Sequence (Tvl): The Underdown Tuff of the Northern Shoshone Mountains ranges from 0 to 1000; the Lower Volcanic Sequence is ~2500 in the Shoshone Mountains, ranging up to 2200 in Paradise Range
2. Tonopah Formation (Tto): ~2500
3. Middle Volcanic Sequence (Tvm): The Bonita Canyon Formation attains a maximum thickness of 1600; the Esmeralda

Formation ranges up to 1000 in the Royston Hills, 2200 in the Toiyabe Range (1100 of which is tuff), and 4000 in the Southern and Central Shoshone Range; the Middle Volcanic Sequence in the Paradise Range exceeds 2000

4. Welded Ash-Flow Tuff (Twt): The Toiyabe Quartz Latite (ash-flow tuff) ranges up to 2000 in the Shoshone Mountains and up to 1500 in the Toiyabe Range; no data on thickness of this unit in the Royston Hills or Paradise Range are available

5. Fraction Tuff (Tf): This unit is 745 in the San Antonio Mountains; thickness of the Fraction Tuff in the Toiyabe Range is unknown

6. Tuff and Tuffaceous Sediments (Tts): Thickness of the Siebert Tuff in the Royston Hills, Toiyabe Range, Paradise Range, and Shoshone Mountains is unknown, but elsewhere this unit exceeds 600

Structure

The structural geology of individual ranges is discussed separately. The Paradise Range is a generally east-dipping tilted-fault block with three prominent range-bounded normal faults (with west sides downthrown) on the west side of the range. One local range-bounding fault on the east side of the range cuts Quaternary alluvium. Pre-Tertiary rocks, exposed in the central portion of the range, have been deformed by thrust faulting, folding, and normal faulting. Tertiary rocks, which are much less deformed than pre-Tertiary rocks, are cut by relatively few normal faults whose dominant trends are northerly and northeasterly. Tuffs unconformably overlie pre-Tertiary rocks and dip moderately to gently to the east in the eastern and northern parts of the range. Tuffs in the southernmost part of the range dip moderately to steeply in various directions.

The Shoshone Mountains, north of the latitude of Cripple Spring (T10N, R40E), comprise a horst with an intricate system of echelon, range-bounding normal faults on the east and west sides of the range. Displacement on the west range-bounding faults has been greater than on the east, as evidenced by the exposure of pre-Tertiary rocks along these faults. South of Cripple Spring, the range-bounding faults disappear and the range merges with the Toiyabe Range to the east. Pre-Tertiary rocks have been deformed by thrust faulting, folding, and normal faulting in variable trends. The dominant fault trends in normal faults cutting Tertiary rocks are north-northeasterly, northerly, and north-northwesterly. Reconnaissance field examination shows that the fault density is probably significantly greater in the Shoshone Range than appears on the map of Northern Nye County.[25] Tuffs unconformably overlie pre-Tertiary rocks and dip moderately to gently to the east or are flat-lying; locally, more variable bedding orientations are observed, especially south of the latitude of Cripping Spring.

The Toiyabe Range is a west-dipping tilted-fault block with a prominent range-bounding north-trending normal fault (and scarp) on the east side of the range, with the east side downthrown. Pre-Tertiary rocks along the eastern side of the range have been deformed by normal faults, thrust faults, strike-slip faults, and folds, all of variable trends. Tertiary rocks unconformably overlie pre-Tertiary strata and dip gently to the west. Dips in the Esmeralda Formation are steeper than those in the overlying Toiyabe Quartz Latite; post-Esmeralda to pre-Toiyabe Quartz-Latite tilting of the fault block is indicated. Very few faults are mapped in the Tertiary rocks of the Toiyabe Range; however, more detailed mapping will probably reveal more structural complexity. The dominant fault trends of the few post-Mesozoic normal faults mapped are northeasterly and east-northeasterly. An en echelon system of northeast-trending normal faults with northwest sides downthrown displaces Quaternary alluvium along the eastern side of the Reese River Valley that separates the Toiyabe Range from the Northern Shoshone Mountains. Tertiary rocks appear to underlie the Reese River Valley at shallow depths since west-dipping tuffs of the Toiyabe Range are not separated from the valley by a mapped range-bounding fault.

The Royston Hills area is a low range, exposed in a southeast-trending tract along the Esmeralda County line. The range curves to the southwest and west in Esmeralda County. This curvilinear trend of the range contrasts with the linear northerly trends of ranges in Northern Nye County, but conforms with the trends of the oroflex ranges of Esmeralda County. Presumably, the oroflexural bending resulted from the position of the ranges between two zones of transcurrent faults--the Furnace Creek fault and the Walker Lane.[23] No detailed geologic mapping of the Royston Hills has been conducted; information concerning the structure of the area is therefore limited. Tertiary rocks unconformably overlie the pre-Tertiary rocks (exposed in five separate blocks) and dip gently to steeply, mostly to the southwest. The most extensive tuff exposures (at the northwest end of the range) appear to be the most gently dipping tuffs. No faults have been mapped in the Tertiary rocks of the Royston Hills.

The San Antonio Mountains are a series of east-tilted fault blocks bounded on the west by steep, north-striking normal faults, down-thrown on the west. Pre-Tertiary rocks, exposed in three blocks, are highly folded and sheared with northwest-trending structural elements. Tertiary strata older than the Fraction Tuff are steeply dipping and have been cut by numerous variably-trending normal faults, especially near Tonopah. The Fraction Tuff and younger rocks are only gently dipping, but have been cut by numerous high-angle, north-trending normal faults with variable displacements.

Alteration of Tuff

Information concerning alteration of tuff in the area is very limited. The Lower Volcanic Sequence in the Shoshone Mountains and Paradise Range has undergone widespread intense propylitic alteration. The Underdown Tuff of the Northern Shoshone Mountains has been moderately hydrothermally altered locally. The Tonopah Formation in the San Antonio Mountains is extensively bleached and has weak-to-intense argillic and silicic alteration. Localized alteration in the Northern Shoshone Mountains has formed chlorite, sericite, calcite, quartz, stilbite, and clinoptilotite in the Bonita Canyon Formation.

Proximity of Tuff to

Recent Faulting and Seismicity -- High-angle normal faults displace Quaternary deposits: (1) along the western and eastern sides of the Central Lone Valley, (2) near Vates Canyon on the eastern side of the

Shoshone Mountains, (3) along the eastern side of the Reese River Valley, (4) at Indian Valley near Cripple Spring in the Shoshone Mountains, and (5) at many localities in the San Antonio Mountains. Quaternary movement along the eastern range-bounding fault of the Toiyabe Range is indicated by freshness of the fault scarp, triangular facets and the presence of well-preserved striae along the fault.[44]

According to the preliminary epicenter map of Nevada (Figure 3), >150 earthquakes of magnitudes 3 to 7+ have been recorded. Most of the earthquakes are concentrated west of the Toiyabe Range in and near the Nevada Seismic Zone, a north-trending sigmoidal belt of concentrated recent earthquake activity >200 mi along and 50 mi wide that includes the western edge of Northern Nye County. The area of most intense seismic activity is just west of the Paradise Range, where earthquakes with magnitudes of ~7 occurred.

Recent Volcanism -- Volcanic rocks designated as Pliocene-Pleistocene in age occur: (1) in the eastern half and northwest corner of the San Antonio Mountains, (2) in the Royston Hills area, (3) south of Dry Canyon and at Black Mountain in the southern and western parts of the Toiyabe Range, respectively, (4) in the Shoshone Mountains, and (5) in a linear north-south trend along the eastern side of the Paradise Range.[25]

Natural Resources -- As of 1976, tungsten was being mined in the Central Toiyabe Range and Western Paradise Range, gold in the Central and Western Shoshone Mountains and Northern Paradise Range, and magnesite just east of Gabbs.[27]

Gold, silver, antimony, pyrite, and galena prospects have been mined (mostly in the 1800s and early 1900s) at many localities in the Toiyabe Range. In the San Antonio Mountains, the Tonopah Mining District produced major amounts of gold and silver from veins along faults. The San Antonio District in the northern part of the San Antonio Mountains produced gold, silver, lead, and copper. A large molybdenum prospect exists near Liberty Springs (T5N, R42E) in the San Antonio Mountains. In the Shoshone Mountains, gold and silver were mined in the early 1900s from the Gold Park

District and the Ward Mine. Uranium and mercury prospects also occur in the Shoshone Mountains. The Royston Mining District in the Royston Hills produced small amounts of gold, silver, lead, and copper, and significant amounts of turquoise.

Areas Identified for Further Examination

While very few mapped faults cut Tertiary rocks in the Eastern Shoshone Mountains and the Western Toiyabe Range, the preliminary geologic map of Northern Nye County, Nevada[25] (the principal data base) probably does not accurately depict true fault density since mapping was reconnaissance in nature. The true nature of the structural relations of the area cannot be known without more detailed field mapping. The presence of numerous historical earthquake epicenters nearby may present a problem. The exact age of basalt designated as Pliocene-Pleistocene would be helpful to know since it crops out in the two regions.

The northwest terminus of the Royston Hills may warrant further examination since the tuff units are gently dipping and apparently undeformed by faulting. Field reconnaissance of the Royston Hills would generate much-needed information on thickness of tuff units and on structural relations. None of the information available on the Royston Hills is more recent than the 1967 preliminary geologic map.

Monitor-Antelope-Hot Creek-Kawich-Reveille Ranges

These ranges are grouped together on the basis of extensive overlap of rock units. The Park Range and Squaw Hills are included with the Hot Creek Range in this report. See Figure 8 for location. Principal references: 20, 21, 25, 27, 49, 50, 51, 52, 53, and 54.

Except for the reconnaissance geological map of Northern Nye County,[25] no geologic information is available for the Northern Kawich Range and Southern and Central Monitor Range (south of the latitude of White Rock Canyon).

Distribution

The areal extent of tuff exposure is ~984 mi^2 (Figure 9). Tuff crops out in the high elevations of the ranges and in a 30-mi-long exposure along a ridge in Stone Cabin Valley. Tuff exposures crop out adjacent to exposures of (1) Tertiary basalt, latite, andesite, and rhyolite flows; rhyodacite, rhyolite, and quartz-latite plugs and domes; rhyolitic to basaltic dikes and sills; and sedimentary rocks, (2) Cretaceous plutonic rocks, and (3) Paleozoic sedimentary rocks. These tuffs range in age from older than 32.6 to 17.8 my.

Thickness of Tuff

Composite Thickness -- The composite Tertiary section in the Park Range-Squaw Hills-Northern Hot Creek Range-Southern Antelope Range area exceeds 5000 ft with up to 4900 ft of tuff. The composite Tertiary section in the Central Hot Creek Range exceeds 14 800 ft with more than 10 000 ft of tuff. The composite Tertiary section in the Reveille Range is more that 5000 ft thick; tuff comprises more than 4000 ft of this thickness. The composite tuff stratigraphic section in the Monitor Range south of Tulle Creek exceeds 3000 ft; north of Tulle Creek the section exceeds 500 ft.

Thickness of Tuff Units (in ft) --

Park Range--Squaw Hills, Northern Hot Creek and Southern Antelope Ranges

1. Stone Cabin Formation (Twa) - 0 to 700
2. Cottonwood Canyon (Twa) - 0 to 180
3. Pritchard's Station (Twa) - 0 to 480
4. Windous Butte Formation (Twa) - 0 to 1800
5. Needles Range Formation (Twa) - 0 to 50
6. Crested Wheat Ridge (Twa) - 0 to 800
7. Pot Hole Valley (Twa) - 0 to 350

8. Orange Lichen Creek (Twa) - 0 to 200

9. Shingle Pass (Tsh) - 0 to 190

10. Bates Mountain (Twa) - 0 to 150

Central Hot Creek Range

1. Williams Ridge and Morey Peak (Twa) - 0 to 5000

2. Twin Peaks (Twa) - 0 to 3000

3. Hot Creek Canyon (Twa) - 0 to 3200

4. Monotony (Tm) - 0 to 2500

5. Orange Lichen Creek (Twa) - 0 to 1000

6. Kiln Canyon (Twa) - 0 to 1800

7. Shingle Pass (Tsh) - 0 to 600

8. Lunar Cuesta (Twa) - 0 to 300

9. Granite-Weathering (Twa) - 0 to 300

Northern Reveille Range

1. Williams Ridge and Morey Peak (Twa) - 0 to 500

2. Monotony (Tm) - Goblin Knobs: 0 to 5000
   Quartz Latitic Tuff: 0 to 1000

3. Bald Mountain (Twh) - 0 to 100

4. Arrowhead (Twh) - 0 to 370

5. Shingle Pass (Tsh) - 0 to 820

6. Northern Reveille Range (Twh) - 0 to 500

7. Reveille Range (Twh) - 0 to 500

8. Streuben Knob (Twh) - 0 to 400

9. Lunar Cuesta (Twh) - 0 to 400

10. Buckskin Point (Twh) - 0 to 100

11. Buckwheat Rim (Twh) - 0 to 300

12. Black Beauty Mesa (Twh) - 0 to 30

13. Granite-Weathering (Twh) - 0 to 100

Monitor Range (south of Tulle Creek)

1. Monitor Range (Twa) - Lower unit: 0 to >2000
   Upper unit: 0 to >1500

2. Welded Ash-Flow Tuffs (Th) - No data available

3. Fraction Tuff (Tf) - No data available

Monitor Range (north of Tulle Creek)

1. Windous Butte Formation (Twa) - 0 to 200

2. Northern Monitor Range (Twa) - No data available

3. Bates Mountain, Lunar Cuesta, Kiln Canyon, Orange Lichen Creek, Pot Hole Valley, and Crested Wheat Ridge (Twa) - No data available

Structure

The Monitor Range is a west-tilted fault block bounded on the east by prominent normal faults with eastern sides downthrown. North of the latitude of Fish Lake, the range is bounded by an en echelon northeast-trending system of normal faults. South of this latitude, a generally continuous north-trending range-bounding fault exists. Pre-Tertiary rocks, exposed mostly on the eastern side of the range next to Little Fish Lake Valley, are cut by numerous thrust and normal faults. Tertiary rocks unconformably overlie the more deformed pre-Tertiary rocks and dip gently to the west. More variable orientations (and steeper dips) occur at the southernmost end of the range. The parts of the range underlain by Tertiary rocks have been cut by very few faults. Faults cutting Tertiary rocks mostly trend northeasterly and east-northeasterly. Tuff exposures comprise the majority of Tertiary exposures. The Tulle Creek-Pritchard's Station lineament passes through Tulle Creek in an east-west direction. This structure, which has had significant left-lateral movement between 23 and 12 my before present, is the southern boundary of an Oligocene volcanic province dominated by intermediate lavas.[52]

The Kawich Range, a horst in Southern Nye County, is a west-tilted fault block in Northern Nye County. A continuous range-bounding normal fault exists on the eastern side of the range; one local normal fault occurs on the western flank of the range. Tertiary tuffs and dacites, which are the only rocks exposed in the range, dip gently to moderately (<25°) to the west-northwest, although local variations in bedding attitudes occur.

Although only one fault is shown to cut Tertiary rocks of the Northern Kawich Range (Figure 9), field reconnaissance indicates that the area may be significantly more complex. Information about the Northern Kawich Range is limited and comes mostly from the preliminary map of Northern Nye County; this remains the only map of the area.[25]

A 30-mi-long by 2-mi-wide, west-tilted fault block trends south-southwest down the valley of Willow Creek to the east of the Monitor Range. A series of range-bounding normal faults border the fault block on the east. Tuffs, the only rocks exposed, dip gently to the west and appear to underlie the valley of Willow Creek at shallow depths since no range-bounding fault has been mapped on the west side of the ridge. Several normal faults with variable orientations cut the tuffs of the fault block.

The Northern Reveille Range is an east-tilted fault block in Southern Nye County. In a general way, this range is a horst block in Northern Nye County. An intricate, en echelon system of range-bounding normal faults borders the range on the east and west sides. Two left-lateral strike-slip faults separate the Reveille Range from the Pancake Range to the north. Pre-Tertiary rocks, which have been intensely deformed by thrusts and normal faults, are exposed on the western flank of the range, indicating more displacement on the western range-bounding faults. Tertiary rocks (mostly tuff) dip generally to the east; however, many local complex bedding attitudes are present in fault-bounded blocks. The strata of the Northern Reveille Range have been cut by numerous normal faults (highly variable orientations), thrust faults (highly variable orientations), and strike-slip faults (mostly northwest-trending). Tertiary strata are cut by all the faults.

The Hot Creek Range can be divided into three structural subdivisions: southern, central, and northern. The Southern Hot Creek Range, south of the latitude of Water Canyon, is a west-tilted fault block bounded on the east by a discontinuous system of normal faults with eastern sides downthrown. Pre-Tertiary rocks, which are exposed along the eastern flank of the range, are cut by many normal and thrust faults. Tertiary rocks (mostly tuffs) unconformably overlie pre-Tertiary rocks and dip moderately to steeply (>25°) to the west, although local variations in attitudes are common. The numerous normal faults that cut Tertiary rocks generally trend northerly and northwesterly. One left-lateral strike-slip fault, the Dimick Fault, strikes northwesterly through the range.

The Central Hot Creek Range, adjacent to Morey Peak, consists of a roughly circular fault block of tuff exposures bounded by pre-Tertiary rocks on the south and north and alluvium on the east and west. This fault block is considered to be part of the Hot Creek Valley Caldera Complex, which formed after extrusion of the Windous Butte Formation.[50] The section of tuff is thick in the fault block and bedding dips in highly variable orientations at low angles. Few faults cut Tertiary rocks in this area; however, since this area has been mapped only in reconnaissance, greater structural complexity is probably present.

The Northern Hot Creek Range is a horst block bounded on the east and west by discontinuous sets of normal faults. Tertiary strata generally dip gently to moderately (<30°) to the east-southeast, although local bedding attitudes vary. Numerous northeast-trending normal faults cut the Tertiary strata. One normal fault bounds the southeastern part of the range and juxtaposes a thin band of pre-Tertiary rocks against the alluvium of Hot Creek Valley. The Tulle Creek-Pritchard's Station Lineament is a left-lateral strike-slip fault in the Monitor Range and Squaw Hills, and is a low-angle-thrust fault which cuts Tertiary strata in the Hot Creek Range.[55] [56] The Park Range and Squaw Hills areas are east-tilted fault blocks arranged en echelon to the east of the Hot Creek

Range. Range-bounding northeast-trending normal faults, with west sides downthrown, separate the Park Range from the Hot Creek Range and the Squaw Hills. Tertiary strata of the Park Range and Squaw Hills are cut by numerous normal faults. Bedding attitudes vary considerably; dips are generally less than 30°.

The Antelope Range, a northern extension of the Hot Creek Range, also appears as an east-tilted fault block, although geologic mapping in this area has only been of a reconnaissance nature. Tertiary strata dip moderately (<30°) to the east and are cut by few faults.

Alteration of Tuff

The only reference to alteration of tuffs of the Monitor Range in the literature is that they are highly altered. In the Northern Hot Creek Range, Southern Antelope Range, and the Park Range-Squaw Hills area the Stone Cabin Formation is silicified, most intensely near Red Wing Mountain. In the Southern Hot Creek Range, the following units may be altered:

1. Williams Ridge and Morey Peak (argillized, oxidized, and locally partially silicified)
2. Twin Peaks (bleached, argillized, and locally propylitized)
3. Hot Creek Canyon (bleached, argillized, and oxidized)
4. Orange Lichen Creek (bleached and oxidized)
5. Lunar Cuesta (near Red Rock Canyon)
6. Granite-Weathering Tuff

In the Northern Reveille Range, the following units may be altered:

1. Williams Ridge and Morey Peak (moderately to intensely in all exposures)
2. Arrowhead
3. Northern Reveille Range (zeolitized)

No information concerning tuff alteration in the Northern Kawich Range is available.

Proximity of Tuff to

Recent Faulting and Seismicity -- Faults displace Quaternary alluvium (1) along the eastern side of Monitor Valley, (2) at the southern end of the Valley of Willow Creek, east of the Southern Monitor Range, (3) along the northwestern margin of Little Fish Lake Valley, (4) north of the northern terminus of the Park Range, (5) in Hot Creek Valley directly east of Morey Peak in the Central Hot Creek Range, and (6) in Hot Creek Valley directly east of the Hot Creek Range at a latitude 8 mi north of Rawhide Mountain.

According to the preliminary epicenter location map of Nevada (Figure 3), ~30 earthquakes have been recorded in the area with magnitudes from ~3 to 5. Concentrated areas of earthquake activity occur (1) along the east side of the Monitor Range adjacent to Little Fish Lake Valley, (2) at the southern end of the Monitor Range, in Ralston Valley, and (3) near Warm Springs in the Hot Creek Range. Earthquakes have also been recorded sporadically in the Monitor, Hot Creek, and Northern Reveille Ranges.

Recent Volcanism -- Quaternary volcanic rocks are present along the eastern and western flanks and the northern terminus of the Reveille Range. Volcanic rocks designated as Pliocene or Pleistocene occur at the southern terminus of the Monitor Range and the northern terminus of the valley of Willow Creek in the Central Monitor Range, along the eastern flank of the Antelope Range and the western side of Little Smoky Valley east of the Antelope Range, along the western flank and the southern terminus of the Park Range, at the southern end of the Squaw Hills, and along the western flank of the Kawich Range.[25]

Resource Areas -- The Arrowhead Mining District in the Northern Reveille Range produced silver and lead before 1939. The Bellehelen Mining District in the Northern Kawich Range produced gold and silver before 1935. The Danville Mining District at the headwaters of Danville Creek in the Monitor Range produced silver in the late 1800s and in the

1900s before 1945. The Morey Mining District on the east flank of the Hot Creek Range just northeast of Morey Peak, produced gold, silver, and lead from the late 1800s to the 1940s. The Tybo Mining District on the east flank of the Hot Creek Range just south of Hot Creek produced gold, lead, and silver before 1937. There is no active mining or oil and gas production in this area (as of 1976).[27]

Areas Identified for Further Examination

Tuffs in the Northern Kawich Range dip at low angles and, based on the literature, are essentially undeformed by faulting. Field study is essential to determine the thickness of tuff and the details of structural geology in this area. The entire Monitor Range north of the latitude of Rock Spring Point may warrant further examination since the range is underlain by a gently-dipping section of tuff that is cut by only a few mapped faults. However, field study is essential to determine the thickness of tuff. The circular fault-bounded block located near Morey Peak in the Central Hot Creek Range is underlain by a thick section of tuff that dips at variable orientations and low angles and is cut by only a few mapped faults; this area may warrant further examination. The Antelope Range should be studied further since mapped faults are scarce and tuffs dip at low angles.

Toquima Range

This range is discussed separately from the adjacent ranges since several local tuffs are exposed only in the Toquima Range.[25] See Figure 8 for location. Principal references: 25, 27, 44, 57, 58, 59, 60, 61, 62, 63, and 64.

Distribution

The areal distribution of tuff surface outcrops is ~250 mi^2 (Figure 9). Tuff crops out in several small exposures at the southern terminus of the range, in a large circular tract centered at Bald Mountain in the central part of the range, and at the high elevations throughout the northern part of the range. *Tuff crops out adjacent to exposures of Tertiary basalt* and andesite flows; rhyolite plugs and domes; rhyolitic to basaltic dikes and sills, and conglomerate; Cretaceous plutonic rocks; and Paleozoic sedimentary rocks. The following tuff units are present (oldest to youngest): Crystal-rich welded (informal map unit--Twa); Middle Volcanic Sequence (Tvm), including the Hedwig Breccia Member, Round Rock Member, Diamond King Member, Bald Mountain Member, and Quartz-Latite Member of the Esmeralda Formation (the Toiyabe Quartz-Latite is correlative with the Quartz-Latite Member of the Esmeralda Formation); Moores Creek (Tmc) including the Northumberland and Welded (included Hoodoo Canyon[58 59] and Bottle Summit); Mount Jefferson (Tj); Meadow Creek (Tmd), and Fraction (Tf). These tuffs range in age from older than 32 to 17.5 my.

Thickness of Tuff

Composite Thickness -- Data on thickness of tuff units in the Toquima Range are sketchy; the determination of the composite thickness of tuff is therefore difficult. The composite thickness of tuff east of Round Mountain in the Toquima Range is >3500 ft.[44] A composite tuff thickness for a locality just north of Manhattan is >2000 ft.[60] The thickness of tuff in the Northumberland Caldera is >1000 ft.[58 59] The Mount Jefferson area is underlain by a very thick (?) pile of ash-flow sheets.[58]

Thickness of Tuff Units (in ft) --

1. Crystal-rich Welded (Twa) - No data available

2. Middle Volcanic Sequence (Tvm) -
   Esmeralda Formation: 0 to >2000
   Hedwig Breccia Member: 0 to <1000
   Round Rock Member: 0 to <800
   Diamond King Member: 0 to <800
   Bald Mountain Member: 0 to <500
   Quartz Latite Member: 0 to <700

3. Moores Creek (Tmc) - No data available
   Northumberland: 0 to >1000
   Welded (including Hoodoo Canyon): No data available
   Bottle Summit: 0 to <200

4. Mount Jefferson (Tj) - No data available

5. Meadow Creek (Tmd) - No data available

6. Fraction (Tf) - No data available

Structure

The Toquima Range is, in a general way, a west-tilted fault block bounded on the east by normal faults that occur as an en echelon northeast-trending system south of Mount Jefferson and that continues north of Mount Jefferson. Several anastomosing normal faults bounded the southwestern part of the range, juxtaposing pre-Tertiary rocks against the alluvium of Big Smoky Valley. Paleozoic rocks found at the southern terminus of the range, the eastern front of the northern part of the range, and in several tracts north of Bald Mountain, are highly deformed by thrust faulting, normal faulting, and folding. Tertiary rocks, which are less deformed, unconformably overlie the pre-Tertiary rocks and dip gently to moderately (<30°) in variable directions but mostly to the west and southwest. Numerous faults cut pre-Tertiary rocks, but only several mapped faults cut Tertiary rocks. Normal faults (the only type of fault that cuts Tertiary rocks) trend mostly northwesterly and northeasterly. It has been postulated that the thick (?) pile of ash-flow tuffs underlying Mount Jefferson resulted from infilling of a large caldera.[58] However, the caldera structures have never been observed. The Northumberland Caldera at Northumberland Canyon southwest of Wildcat Mountain is bounded by an elliptical system of normal faults that formed during cauldron collapse after eruption of the Northumberland Tuff (32 my).[59]

Alteration of Tuff

No data available.

Proximity of Tuff to

Recent Faulting and Seismicity -- Faults displace Quaternary alluvium in the Monitor Valley east of the latitudes of White Rock Mountain, Red Rock Canyon, and Northumberland Canyon.

According to the preliminary epicenter location map of the area (Figure 3) ~15 earthquakes have occurred in and near the Toquima Range with all but one centered in Big Smoky Valley and the adjacent mountains near the intersection of 117° W longitude and 39° N latitude.

Recent Volcanism -- Pliocene-Pleistocene basalt crop out at the southern terminus of the range and at the eastern flank of the range just south of Corcoran Canyon.[25]

Resource Area. As of 1976, gold was being mined at six localities in the Southern Toquima Range south of Mount Jefferson; silver in the South-Central Toquima Range; and barite in the North-Central Toquima Range.[27]

The Northumberland Mining District, located at the head of the canyon along the crest of the Toquima Range, has produced gold and silver. The Jefferson Canyon Mining District, 6 mi northeast of Round Mountain on the east slope of the Toquima Range, produced gold and silver in the late 1800s and early 1900s.

Areas Identified for Further Examination

Lack of geologic information on the Toquima Range makes assessment of the potential of this area difficult. However, parts of the Toquima Range are underlain by flat-lying to moderately dipping (<30°), thick sections of tuff that are cut by few mapped faults. Field work is essential to fill in large gaps in the knowledge of thickness of tuff units and detailed structural relations. The Mount Jefferson and Bald Mountain areas, specifically, may warrant examination because of lack or mapped faults and the probability of thick sections of tuff.[58]

Pancake-White Pine-Horse-Grant-Quinn Canyon-Golden Gate-Egan-South Egan-Seaman Ranges

These ranges are discussed together because of extensive overlap of rock units.[25] See Figure 8 for location. Principal References: 25, 27, 55 56, 65, 66, 67, 68, 69 and 70.

Distribution

The surface outcrops of tuff cover ~444 mi^2 (Figure 9). The greatest concentration of tuff exposures is in the Quinn Canyon and Pancake Ranges. Layercake stratigraphy of tuffs in mesas of the latter range is primarily responsible for the name "Pancake Range."[55 56] Tuffs crop out at some of the higher and lower elevations of both ranges. Rocks exposed in the Grant, Horse, and White Pine Ranges in Nye County are predominately pre-Tertiary. Outcrops of tuff within these three ranges are sporadic, with greatest concentrations along the eastern slope of the Grant Range and just north and south of the Horse Range. Portions of the Golden Gate, Seaman, and South Egan Ranges within Nye County contain outcrops of tuff, bu Egan Range is devoid of it.

The tuffs in this section of Northeastern Nye County crop out with Precambrian and Paleozoic sediments, Mesozoic sediments and intrusives, and Tertiary sedimentary and igneous flows and plugs. Underlying the tuffs are Oligocene latite and rhyolite flow rocks. Sedimentary and flow rocks are commonly interbedded with the tuffs.

Thickness of Tuff

The greatest thickness of tuff is concentrated in the southern half of the Pancake Range within and surrounding the subsidence structures of three calderas, where cumulative thicknesses may reach 8000 ft near the Lunar Crater Caldera,[68] and as much as 14 600 ft within the Williams Ridge Caldera.[67] The apparent maximum composite thickness of tuff in the area is 27 970 ft. There may be some duplication of units and the true thickness may be less. The ranges in thickness (ft), where available, are listed below for units that have been described. The following tuff units (oldest to youngest) are present.

Tuffaceous Sedimentary Rocks (Ts) - Thickness not described

Crystal-rich welded tuffs (thickness in ft)

Calloway Well Formation (Twa) - Thickness not described

Welded (Twa) - 0 to 700

Stone Cabin Formation (Twa) - 0 to 3300

Bedded and Lithic (Twa) - 0 to 800

Pritchard's Station (Twa) - 0 to 700

Nonwelded and Bedded (Twa) - 0 to 300

Cottonwood Canyon (Twa) - 0 to 250

Windous Butte Formation (Twa) - 0 to 100

Williams Ridge and Morey Peak (Twa) - 0 to 6500

Ash-Flow (Twa) - 0 to 900+

Black Rock Summit (Twa) - 0 to 1450+

Hornblende-Biotite (Twa) - 0 to 200

Big Round Valley (Twa) - 0 to 700

Chaos Creek (Twa) - 0 to 600(?)

Halligan Mesa (Twa) - 0 to 600

Palisade Mesa (Twa) - 0 to 400

Hot Creek Canyon (Twa) - 0 to 1500+

Quartz-Latitic Ash-Flows (Twa) - 1200 to 1500

Needles Range Formation (Twa) - 0 to 1000+

Tuff Between the Needles and Moores Station Buttes tuffs (Twa) - 0 to 900+

Moores Station Buttes (Twa) - 0 to 1000

Slanted Buttes (Twa) - 0 to 1000+

Monotony Valley (Tm) - 0 to 1000

Pott Hole Valley (Twa) - 0 to 110+

Orange Lichen Creek (Twa) 0 to 400+

Shingle Pass (Tsh) - 0 to 200

Lunar Cuesta (Tsh) - 0 to 400

Buckskin Point (Tsh) - 0 to 250

Buckwheat Rim (Tsh) - 0 to 500

Black Beauty Mesa (Tsh) - 0 to 60

Granite-Weathering tuff (White Blotch Springs?) (Tsh) - 0 to 250

Structure

The Pancake, Quinn Canyon, Grant, Horse, White Pine, Golden Gate, Seaman, Egan, and South Egan Ranges contain cores of Precambrian to Mesozoic sediments deformed by thrusting, gravity sliding, tear faulting, normal faulting, and complex folding. Tertiary rocks unconformably overlie the pre-Tertiary rocks. The structure of the Tertiary section of each range or group of ranges is described separately.

The Pancake Range -- Basin-and-Range normal faulting influences the central, northern, and (to a lesser extent) the southern part of the Pancake Range. The central portion of the range is a north-trending horst exposing a core of Paleozoic sediments flanked by Tertiary tuffs and flows that dip at low angles. This horst is superimposed on older structures related to the Williams Ridge Caldera of Oligocene(?) age. The range branches northward into several eastward-tilted, north-trending fault blocks with exposures of pre-Tertiary rocks confined to the western margins along the range-bounding faults of each block. Tertiary and Quaternary rocks predominate along, but are not confined to, the eastern margins of the fault blocks. The Lunar Lake and Pancake Range Calderas are the main structures in the southern part of the Pancake Range. Younger basin and range structures die out toward the south and appear to have little influence in this end of the range. Both the younger Lunar Lake Caldera and the Pancake Range Caldera are superimposed on the southern end of the Williams Ridge Caldera. The entire cauldron complex is bounded on the north by the east-trending Tulle Creek-Pritchard's Station lineament and on the south by the northwest-trending Reveille fault system. The formation of all three calderas and the extrusion of tuff from them took place between 34 and 17 my ago.[55] Most of the movement along basin and range faults in the area has occurred more recently than 17 my ago.[65]

Quinn Canyon Range -- Only the northern half of the Quinn Canyon Range lies within Nye County. The range comprises several structural blocks bounded in part by alluviated-intermontane basins and Basin-and-Range faults.[69] The western range-bounding fault juxtaposes both pre-Tertiary and Tertiary rocks against the alluvium of Railroad Valley.

Other high-angle faults juxtapose pre-Tertiary and Tertiary rocks. Large areas of tuff are apparently relatively undeformed by faulting. However, some low-angle, post-Oligocene normal faults and gravity slides locally disrupt the tuff, exposing the underlying pre-Tertiary section. In general, the attitude of the Tertiary rocks is characterized by gentle dips (<20°). Locally steep and vertical dips can likely be attributed to drag movement caused by nearby normal faults.

The existence of a caldera in this region is conjectural. Numerous volcanic plugs and flows that intrude and overlie some of the pyroclastic rocks indicate a discrete center of volcanism, the exact shape and extent of which is not well defined.[69] Evidently, zones of alteration and brecciation indicate loci of structural weakness that may define a volcanic center.

Grant, White Pine, and Horse Range -- The Grant, White Pine, and Horse Ranges comprise a system of north-trending, eastward-tilted fault blocks and smaller scale horsts and grabens of the same trend. North-, northeast-, and east-trending normal faults constitute the greatest number of faults affecting the Tertiary section. Gravity slides similar to those in the Quinn Canyon Range affect units in the Horse Range and, to a lesser degree, units in the Grant and White Pine Ranges with rocks of both the pre-Tertiary and Tertiary present in the allochthonous sheets. The history of events is described as (1) formation of gentle northeast-trending folds and high-angle faults from the Mesozoic to Eocene (200 to 40 my ago), (2) initiation of normal faulting with significant displacement (?) during the middle to late Eocene (50 to 45 my ago), (3) limited normal faulting of moderate displacment and maximum ignimbrite activity during the Oligocene (37 to 25 my), (4) slight increase in magnitude of normal faulting, slight arching of Horse Camp Basin along an east-northeastern-trending axis, and the last phase of ignimbrite activity during the early to middle Miocene [25 to 20 (?) my], (5) uplift of Grant and White Pine Range area, folding along north-trending axes; also low-angle faulting and gravity sliding during the early to late Pliocene [20 (?) to 10 my].[70] Basin-and-Range faulting likely continued through this period to the present.

The attitude of the tuffs in all ranges varies. For the most part, the bedding attitudes are steep and local structural geometries are complex because of the complex tectonic history.

Golden Gate Range -- The north-northeast-trending Golden Gate Range is an uplifted structural block cut by east-trending normal faults, some of which expose a core of pre-Tertiary rocks mantled by Tertiary volcanics. No information is available on the attitudes of the tuff.

Seaman, South Egan, and Egan Ranges -- Only small portions of the Seaman, South Egan, and Egan Ranges extend into Nye County. East-trending normal faults cut the northern tip of the northwest-trending Seaman Range, forming a graben that is perpendicular to the trend of other Basin-and-Range structures in the area. Most of the Tertiary rocks present in the northern part of the range lie in this graben. Pre-Tertiary rocks are exposed as flanks of the graben. Several other normal faults cutting the Tertiary section trend northwest and northeast. No information is available on the attitudes of tuffs in the area.

The western part of the South Egan Range is a fault block exposing pre-Tertiary rocks along its western margin. Range-bounding faults along its western edge appear to decrease in displacement and fan out to the south into a number of smaller faults in the Tertiary section. Similar to the Seaman Range, exposures of Tertiary rocks are mostly confined to a down-dropped block that is bounded on the south by a west-northwest-trending normal fault zone, and to the north and east by an arcuate northwest-to-north trending normal fault, convex to the east. A sequence of low-lying tuffs is exposed outside of this down-dropped block at the eastern margin of the county. There is no available description of tuff attitudes in these areas.

The Egan Range is a fault block whose western margin lies in Nye County. Outcrops within this part of the range are confined to rocks of pre-Tertiary age.

Alteration of Tuff

The tuff sequence in Northeastern Nye County has locally been silicified, zeolitized, bleached, argillized, propylitized, oxidized, and iron-stained. Hydrothermal activity has been responsible for much of the alteration. The only widespread alteration illuminated in the literature occurs in the Quinn Canyon Range where volcanic rocks have been silicified, propylitized, argillized, bleached, and mineralized. The following tuff units have been altered in the Pancake Range:

1. The oldest welded tuffs (silicified locally)
2. The bedded and lithic tuffs (bleached, silicified, zeolitized, and iron-stained)
3. Williams Ridge and Morey Peak (bleached, argillized, and oxidized south of Big Round Valley)
4. The ash-flow tuffs immediately below (?) the tuff of Williams Ridge and Morey Peak (locally zeolitized)
5. Chaos Creek (locally silicified and argillized)
6. Moores Station Buttes (locally zeolitized)

No specific information is available on alteration of tuffs in other ranges.

Proximity of Tuff to

Recent Faulting and Seismicity -- Faults displace Quaternary alluvium along the western sides of (1) the northern half of Pancake Range, (2) the entire Quinn Canyon, Grant, and White Pine Ranges, (3) the South Egan Range, and (4) the Egan Range.

According to the preliminary epicenter location map of Nevada (Figure 3), 30 to 35 earthquakes of magnitudes ~3 to 5 have occurred, about a third of which are centered in Little Smoky Valley near the intersection of 116°W longitude and 39°N latitude. Other smaller concentrations of earthquakes occur in the Lunar Crater area of the Pancake Range, in Railroad Valley west of the Quinn Canyon and Grant Ranges, and in the Horse Range near the Nye-White Pine County line.

Recent Volcanism -- A concentrated zone of recent volcanic activity is centered in the Lunar Lake Caldera where three episodes of basaltic volcanism have occurred,[68] creating the Lunar Lake volcanic field. Basalt of Pleistocene and probable Holocene age are present.[55 56] Sporadic outcrops of other Quaternary basalts are present within a radius of 8 mi around the Lunar Lake Caldera. Young basalts of either Pliocene or Pleistocene age also exist throughout the north end of the Pancake Range and sporadically along the eastern side of the Quinn Canyon, Grant, Horst, and White Pine Mountain system and within the Golden Gate and South Egan Ranges.

Resources Areas -- There is no active mining in this area as of 1976.[27] The Willow Creek Mining District in the Quinn Canyon Range produced gold, silver, lead, and manganese during the late 1800s and the first half of the 1900s. Fluorite deposits are scattered over a 15-mi^2 area within the range, some ore averaging as much as 90% CaF_2. Production of fluorite was modest through 1961; however, there are some commercial deposits.[69]

The Troy Mining District includes Troy and Irwin Canyons in the western side of the Grant Range. Minor amounts of copper, lead, gold, and silver had been produced through the 1940s.

The Currant Mining District is near the town of Currant, west of the Horse Range. Gold and silver deposits were worked from the early 1900s and continued intermittently through the 1930s.

Oil is produced from wells 1 mi northwest of Blue Eagle Springs in Railroad Valley west of the Grant Range.

Areas Identified for Further Examination

Some of the more flat-lying tuffs in the northern and northeastern parts of the Pancake Range may warrant further consideration; however, Pliocene and/or Pleistocene basalts exist. Many of the tuffs in the Quinn Canyon Range are flat-lying and are cut by few mapped faults. Field examination to determine tuff thicknesses is warranted. However, the western range-bounding fault of the Quinn Canyon Range has had recent movement along it. A large outcrop of relatively undeformed tuff at the northern end of the county in the White Pine Mountains may warrant field examination. Thickness and attitude of tuffs are unknown. The tuffs in the Golden Gate Range along the Nye-Lincoln county border appear undeformed and warrant further study. Outcrops of tuff in the Northern Golden Gate Range, Eastern Seaman Range, and Western South Egan Range appear relatively undeformed and flat-lying and, therefore, these areas warrant further study.

VII. LINCOLN COUNTY

Lincoln County is divided into four areas: (1) Snake-Wilson Creek-Fortification-Fairview-Bristol-Highland Ranges-Limestone and Pioche Hills-White Rock Mountains; (2) Quinn Canyon-Groom-Golden Gate-Seaman-Timpahute-South Pahroc-Hiko-East Pahranagat and Pahranagat Ranges-Jumbled Hills-Worthington Mountains-Irish Mountain, (3) North Pahroc-Schell Creek-Egan Ranges, and (4) Caldera Complex Region of East-Central Nevada. Nevada Bureau of Mines Bulletin 73[22] summarizes the geology and mineral resources of Lincoln County; however, the Tertiary volcanic rocks of the county are discussed cursorily. The geologic map of the county included in this bulletin and the geologic map of Lincoln County[71] delineate Tertiary tuffs by age. These two maps serve as the principal data base for the ensuing discussion of tuff in Lincoln County. More detailed maps are used where available.

Snake-Wilson Creek-Fortification-Fairview-Bristol-Highland Ranges-Limestone and Pioche Hills-White Rock Mountains

These mountain ranges are discussed together because of geographic proximity and similarities in structural styles. See Figure 10 for location. Principal references: 22, 27, 53, 62, 63, 72, and 73.

Distribution

The surface outcrops of tuff cover is ~435 mi^2 (Figure 11). Tuff crops out at the southern end of the Fortification Range; throughout the Wilson Creek Range, White Rock Mountains, and Mahogany Mountains; at the southeastern terminus of the Pioche Hills; between Ely Springs Range and the Highland Range; and throughout the Fairview Range. Tuff exposures occur at high elevations of the ranges adjacent to exposures of Tertiary sandstone, Tertiary basalt, basaltic andesite, quartz latite, rhyodacite, andesite, dacite, and rhyolite flows; Mesozoic and/or Tertiary intrusive stocks, plugs, dikes, and sills; and pre-Tertiary sedimentary rocks. The following tuff units (oldest to youngest) are present: Tuffaceous Sandstone (informal map unit-Ts2), oldest welded tuffs (informal map unit-Tt2) including the Needles Range Formation and perhaps the tuffs of the Seaman Range, and the middle ash-flow tuffs (informal map unit-Tt3) including discontinuous cooling units of the Shingle Pass Tuff and Isom Formation, the Leach Canyon Tuff, the Condor Canyon Formation (Bauers and Swett Tuff Members), the Harmony Hills, Racer Canyon, and Hiko Tuffs. These tuffs range in age from early Oligocene (Ts2) to late Oligocene [33 to 26 my (Tt2)] to Miocene [26 to 17 my (Tt3)].[71]

Thickness of Tuff

Composite Thickness -- The composite thickness of Tertiary tuffs and lavas in the Bristol and Ely Springs Ranges is ~6000 ft.[73] Cook gives a composite section of Tertiary volcanics that totals 3900 ft and averages 1500 ft.[53] Composite thickness figures for individual ranges are generally not available in the literature.

Thickness of Tuff Units (in ft)[53] --

1. Tuffaceous Sandstone (Ts2) - 0 to >200

2. Oldest Welded (Tt2) -
   Needles Range Formation: Average thickness in 21 Nevada sections is 617; this unit is 500+ in the Southern Wilson Creek Range, 700+ in the Southern Fairview Range, 800+ in the Northern Fortification Range, 596+ in the Northern Limestone Hills, 400+ in the Northern Wilson Creek Range, and 300+ in the Southern White Rock Mountains

   Seaman Range: No data available

3. Middle Ash-Flow (Tt3) -

Shingle Pass: 50 in the Southern Fairview Range; no other data available

Isom Formation: No data available

Leach Canyon: 755+ at the northwestern terminus of the Wilson Creek Range, 1000+ in the Northern Wilson Creek Range, 800+ in the Southern Wilson Creek Range north of Ursine, 250+ in the Southern Wilson Creek Range south of Ursine, 508 just north of Panaca; this unit is present in the area in the Highland Range, Wilson Creek Range, and White Rock Mountains

Condor Canyon Formation: 449 in the Northern Wilson Creek Range, 630 in the Southern Wilson Creek Range north of Ursine, 393 in the Southern Wilson Creek Range north of Ursine, 376 at Condor Canyon north of Panaca; both the Bauers and Swett Ignimbrite Members are present; this unit is only present in the Bristol Range, Wilson Creek Range, Highland Range, and Western White Rock Mountains

Harmony Hills: 88 (?) in the Southern Wilson Creek Range north of Ursine, 99+ in the Southern Wilson Creek Range south of Ursine, 168 at Condor Canyon north of Panaca; this unit is present in the only area south of the Latitude of Parsnip Peak in the Wilson Creek Range

Racer Canyon: 200+ northeast (?) Caliente

Hiko: 118+ at Condor Canyon north of Panaca; this unit is present only in the extreme southern part.

Structure

The Fortification Range is a horst block consisting of a series of narrow, elongated, east-tilted fault blocks separated by north-trending normal faults with western sides downthrown. Pre-Tertiary rocks are located on the western side of the range. Tertiary rocks, mostly Older Welded Tuffs, unconformably overlie pre-Tertiary rocks and dip gently to moderately (<30°) to the east. Normal faults trending north cut both pre-Tertiary and Tertiary rocks. Mapped faults are scarce.

The southern Snake Range and its southern extension, the Limestone Hills, are fault blocks that expose mostly pre-Tertiary rocks. A major range-bounding fault occurs on the eastern flank of the two ranges. Tertiary rocks found in five scattered small outcrops on the western side of the range are cut by northerly-trending normal faults with mostly western sides downthrown, and by several northwest-trending normal faults with northeast sides downthrown. Tertiary rocks dip gently to moderately (<30°) either to the west or east. Mapped faults are scarce.

Composition of the Wilson Creek Range and the White Rock Mountains is almost entirely volcanic. Northwest-trending normal faults with both northeast and southwest sides downthrown are the dominant structures of both ranges. Northerly- and northeasterly-trending normal faults also occur. Both Tertiary and pre-Tertiary rocks are cut by these faults. Numerous faults occur at the Parsnip Peak area, the Rosencrans Peak area, and around "peak 7358" between Camp Valley Wash and Burnt Canyon Creek. Elsewhere in the two ranges mapped faults are scarce. Tertiary tuffs, mostly Older Welded and Middle Ash-Flow Tuffs, underlie most of the two ranges, although rhyolites prevail at Mount Wilson and Parsnip Peak. These two areas are postulated to be major volcanic centers as indicated by flow directions, thickness relations, and ring-fracture systems (at Mount Wilson).[71] Tertiary rocks in the White Rock Mountains generally dip moderately (<30°) to the northeast. Tertiary rocks of the Wilson Creek Range have variable attitudes, but dip mostly to the southwest or northeast at gentle to moderate angles (<30°). Tuff exposures in the low hills west of Ursine to the southwest of the Southern Wilson Creek Range are within three local east-tilted fault blocks. The tuffs dip generally gently (<20°) to the east and appear to underlie Ursine Valley at shallow depths since they are not separated from the Valley by a mapped range-bounding fault. Few mapped faults cut Tertiary rocks at this locality.

The Fairview Range is composed largely of volcanic rocks except for isolated outcrops of highly deformed Paleozic rocks in the southern part of the range. The structure of the volcanic rocks is "fairly simple;"[22] however, only reconnaissance mapping has been done. Tertiary rocks generally dip moderately (<30°) to the east-southeast and southwest and are cut by mostly northwesterly- and northerly-trending faults. Mapped faults are scarce; however, only the faults that are conspicuous on aerial photographs have been mapped. Tuff exposures in a southwest-trending trace southwest of the range are located within six elongated northeast-tilted fault blocks. Tuffs in these fault blocks dip gently (generally <20°) to the northeast.

No Tertiary rocks occur in the Dutch John and Grassy Mountains horst block, Bristol Range, and most of the Highland Range. Only scattered outcrops of limited extent occur in the Highland Range. Tuff is exposed along the eastern flank of the Ely Springs Range, and east-tilted fault block bounded on the west by the Dry Lake fault system. Tuffs dip moderately (generally <30°) to the east.

The Eastern Pioche Hills are underlain extensively by tuff that dips moderately (generally <30°) to the east. Only one fault is shown on geologic maps; however, only reconnaissance mapping has been done.

Alteration of Tuff

The tuff in the extreme northern terminus of the Wilson Creek Range northwest of Rosencrans Peak has been moderately to intensely hydrothermally altered. The tuff in the southern end of the Wilson Creek Range and White Rock Mountains has also been moderately to intensely altered. No other data on tuff alteration are available.

Proximity of Tuff to

Recent Faulting and Seismicity -- North-trending faults cut Quaternary alluvium west of the Highland Range in Dry Lake Valley.

According to the earthquake epicenter map (Figure 3), there were two recorded earthquakes of magnitude ~4, one at the northern terminus of one of the Quaternary faults in Dry Lake Valley, and the other ~5 mi east in the Bristol Range.

Recent Volcanism -- The youngest volcanic rocks in the area are Miocene basalts.

Resource Areas -- Following are the mining districts:

1. Pioche (Ely District): Located in the Pioche Hills, this district produced $133 million, principally in zinc, lead, silver, and manganese from 1908 through 1958.

2. Bristol and Jackrabbit Districts: Located on the west side of the north end of the Bristol Range, they produced $16,256,000, principally in silver, copper, lead, zinc, and manganese from 1868 through 1958.

3. Highland District: Located in the Highland Range near its junction with the Bristol Range between 4 and 8 mi west of Pioche, this district produced ~$2 million in lead, silver, gold, copper, and manganese since 1875.

4. Comet District: Extending along the west side of the Highland Range adjoining the Highland District on the north and the Ely Springs District on the west, it produced $764,100 in silver, lead, zinc, manganese, tungsten, and gold from 1895 through 1952. As of 1976, lead-silver mining was active in this district.[27]

5. Eagle Valley, Gold Springs, and Stateline Districts: Extending in a north-trending line along the Nevada-Utah state line north of the Mt. Diablo base line, the three districts have produced ~$423,000 in gold, silver, and uranium within the Nevada portions of these districts from 1896 through the 1940s. Most of the areas apparently are inactive now, although the Stateline (?) District shipped ore in 1956 and later.[22]

6. Atlanta and Silver Peak (Silver Springs) Districts: Located at the northern end of the Wilson Creek Range, intermittent activity in the districts has produced ~$270,300 in silver, gold, and uranium from 1871 through 1956. As of 1976, gold and silver were being mined here.[27]

7. Fairview and Silverhorn Districts: Production from silver and lead deposits is unknown in these abandoned districts, which are in the southern Fairview Range.

Areas Identified for Further Examination

The Fortification Range may warrant further study since mapped faults are scarce and tuffs dip gently to moderately (generally <30°). More data are needed on thickness of tuffs in this area.

In the Wilson Creek Range, the area around Mount Wilson (specifically from Mount Wilson northeast across Camp Valley Wash to the White Rock Mountains) is underlain by Tertiary rocks that are virtually unaffected by mapped faults. Data on tuff bedding orientation in this area are meager. However, the relative lack of mapped faults and probable thick section of tuff near the Mount Wilson volcanic center may make this area suitable for further study.

The low hills west of Ursine in the Southern Wilson Creek Range may warrant further examination since there are few mapped faults and tuffs dip gently (generally <20°). More data are needed on the thickness of tuffs.

In the White Rock Mountains, the area around White Rock Peak is shown on geologic maps to contain few faults, and tuffs are shown to dip moderately (generally <30°) to the east. More data on thickness of tuff and structural relations are needed. This area warrants further study.

The Eastern Pioche Hills area is underlain by tuffs that dip moderately (generally <30°) to the east and are apparently cut by only one mapped normal fault. This area should be examined further to determine tuff thicknesses and the details of structural relations.

The Fairview Range should also be examined further to determine the details of the structural geology and thickness of tuffs.

Quinn Canyon-Groom-Golden Gate-Seaman-Timpahute-South Pahroc-Hiko-East Pahranagat-Pahranagat Ranges-Jumbled Hills-Worthington Mountains-Irish Mountain Area

These ranges are grouped together for collective discussion on the basis of overlap of rock units and geographical proximity. See Figure 10 for location. Principal references: 22, 27, 53, 62, 71, and 74.

Distribution

The areal distribution of tuff outcrops covers ~519 mi^2 (Figure 11). Tuff does not crop out extensively in the Sheep, Desert, East Desert, Pintwater, and Spotted Ranges, Buried Hills, and the Papoose Range, therefore, these areas are omitted from the ensuing discussion.

Tuffs crop out extensively in the Central and Southern Seaman Range, Southern Golden Gate Range, along the eastern flank of the Groom Range, throughout the Jumbled Hills, along the eastern side and southern terminus of the Pahranagat Range, throughout the South Pahroc and Quinn Canyon Ranges, and along the southern terminus of the Hiko Range. Tuff exposures at other localities are scattered and of limited extent.

Tuffs crop out adjacent to exposures of pre-Tertiary sedimentary rocks; Cretaceous and/or Tertiary (?) intrusive rocks, and Tertiary sandstones; conglomerates; and andesitic, dacitic, rhyolitic, and basaltic flow rocks. Tuffs comprise the overwhelming majority of Tertiary rock exposures present in this area.

The following tuff units (oldest to youngest) are present in the area: Oldest Welded Tuffs (informal map unit--Tt2) ranging in age from 33 to 20 my and including the Monotony Tuff in the southwestern part of the area and the Needles Range Formation and Tuff of the Seaman Range in the north and northeastern part of the area. In the Timpahute Range, it is inferred that both the Needles Range Formation and the Monotony Tuff occur along with middle ash-flow tuff (informal map unit-Tt3) ranging in age from 26 to 17 my, including the Tuffs of White Blotch Spring, Quinn Canyon Range, Shingle Pass Tuff, Hiko, Harmony Hills, Condor Canyon Formation, Leach Canyon Formation and Isom Formation, and youngest ash-flow and ash-flow tuffs (informal map unit-Tt4), ranging in age from 15 to 11 my and including the Kane Wash, Indian Trail Formation, Paintbrush, and Timber Mountain tuffs.

Thickness of Tuff

Composite Thickness -- Data on composite thickness of tuff in individual ranges are not readily available in the literature. Cook gives a composite Tertiary volcanic section of 3900 ft for an unknown location and further states that the thickness at any one locality rarely exceeds 3000 ft and averages 1500 ft.[53] The Tertiary volcanics in the Pahranagat Range area exceed 3000 ft.[75] The tuff sequence along the eastern Jumbled Hills is ~3000 ft thick.[74]

The Tertiary sequence in the Pahranagat Ranges exceeds 3000 ft. A composite thickness of Tertiary volcanics in western Lincoln County is estimated as 5000 ft.[22]

Thickness of Tuff Units (in ft)[51] --

1. Oldest Welded Tuff (Tt2) -

   Needles Range Formation: Average thickness measured in 21 sections in Nevada is 617; this unit is present only in the northeastern part

   Monotony: No data available

   Seaman Range: No data available

2. Middle Ash-Flow Tuff (Tt3) -

   White Blotch Springs: 0 to 250

   Quinn Canyon Range: 0 to 500

   Shingle Pass: 131 in the northern Pahranagat Range, 450 (?) in the northeastern Groom Range, 430+ along the the northern flank of the Timpahute Range, 75+ (?) in the southern Seaman Range, 20+ along the eastern flank of the Seaman Range

   Leach Canyon: 108 (?) in the southern Pahranagat Range, 300+ in the northern Pahranagat Range, 607 in the southern South Pahroc Range, 170+ in the northern South Pahroc Range, 401 (?) in the southern Seaman Range, 637 (?) along the northern flank of the Timpahute Range

   Condor Canyon Formation: 50+ in the southeastern Pahranagat Range, 496 in the southern South Pahroc

Range, 838 in the northern South Pahroc Range, 54+ in the southern Seaman Range

Harmony Hills: 140 (?) in the northeastern Groom Range, 152 along the eastern side of the Seaman Range, and 179 in the southern Pahranagat Range

Hiko: 277 in the southern Pahranagat Range, 1135 in the northern South Pahroc Range; this unit ranges from <200 to >1500

Isom Formation: No data available

3. Youngest Ash-Flow and Ash-Fall Tuffs (Tt4) -

Kane Wash Formation: 812+ in the southern Pahranagat Range, 375+ in the southern South Pahroc Range

Indian Trail Formation: No data available

Paintbrush: No data available

Timber Mountain: No data available

Structure

The Quinn Canyon Range is an uplifted, west-tilted fault block. Mapped faults are scarce in this range. Tertiary rocks dip gently (<20°) to steeply (>30°) at variable orientations.

The Golden Gate Range is a west-tilted fault block. Tertiary rocks unconformably overlie pre-Tertiary rocks on the western side and southern terminus of the range. Faults are numerous. Normal fault trends are dominantly northeasterly in the Tertiary rocks along the western side of the range and northerly and easterly in the southern part of the range. Tertiary rocks dip moderately to steeply (>30°) in variable directions.

The Timpahute Range is a northeasterly-trending range bounded on the northwest by a fault which shows both normal and strike-slip displacement.[70] Numerous faults cut Tertiary rocks. Easterly-trending structures are dominant in Tertiary rocks since the easterly-trending Timpahute lineament crosses the range.[76] Tertiary rocks are exposed mainly in numerous fault-bounded blocks. Tertiary rocks dip moderately to steeply (>30°) in many directions.

The Groom Range is an uplifted fault block bounded on the west by the Stumble Fault.[22] Tuff crop out at the northern terminus and northeastern flank of the range and at Bald Mountain. Tuffs at Bald Mountain fill a well-defined cauldron, dip steeply into the center of the cauldron, and are relatively unfaulted. Tuffs that crop out on the northeastern flank of the range are bounded by northeast-trending normal faults that define several southeast-dipping fault blocks. There are numerous faults in these blocks. The fault system on the east side of the Groom Range may have had a strong component of left-lateral displacement.[71]

The Jumbled Hills constitute a series of topographic highs between the Groom Range and Tikaboo Valley. Numerous northerly-trending normal faults cut the extensive tuff exposures in these hills. Tertiary rocks dip moderately to steeply (>30°) in variable directions.

The Pahranagat and East Pahranagat Ranges are north-northwesterly-trending ranges that define three structural blocks separated by two northwest-trending faults with southwest sides downthrown. Tuffs are exposed (1) in a narrow, elongated tract between the two ranges from Irish Mountain to Hancock Summit, (2) along the eastern side of the East Pahranagat Range, and (3) at the southern terminus of the Pahranagat Range. Numerous northwesterly-trending normal faults and northeasterly-trending normal and left-lateral strike-slip faults cut Tertiary and pre-Tertiary rocks. The strike-slip faults constitute the Pahranagat Shear System, which has been inactive since the late Miocene.[22]

The South Pahroc Range is composed mostly of tuff that is cut by numerous northerly- and easterly-trending normal faults. Tuffs dip mostly to the west at variable angles. The southern part of the South Pahroc Range is intricately cut by many northerly-trending normal faults and northeasterly-trending strike-slip and normal faults.

The Hiko Range is an east-tilted fault block bounded on the west by the Hiko Fault.[22] Tuffs are exposed in the central and southern parts of the range. Numerous faults cut Tertiary rocks. Northerly- and northeasterly-trending normal faults are dominant. Tertiary rocks attitudes are highly variable.

The Seaman Range is a northeast-trending range bounded on the east by the Pahroc Fault, a major normal fault with east side downthrown.[22] The Seaman Range volcanic center is a simple stratovolcano (not a source of widespread tuffs) located in the central part of the range.[77] Tuffs crop out in a circular pattern around the volcanic center and in an irregularly shaped tract at the southern terminus of the range. Tuffs exposed at the southern part of the range are cut by normal faults of variable attitudes. Tuffs exposed around the volcanic center are relatively unfaulted. Information on bedding orientation is unavailable.

Tuffs are exposed at the southeastern terminus of the Worthington Mountains. These rocks are intricately cut by numerous north-trending normal faults.

Alteration of Tuff

Tuffs near Bald Mountain in the Groom Range have been moderately to intensely hydrothermally altered. Tuffs in several tracts in the Quinn Canyon Range and at the northern terminus of the Groom Range and southwest terminus of the Timpahute Range have also been moderately to intensely hydrothermally altered. No further data on alteration of tuff is available.

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary epicenter map of the State of Nevada (Figure 3), more than 100 earthquakes of magnitudes ~3 to 5 have occurred. The largest concentrations of epicenters occur in the Groom Range, Buried Hills-Pintwater Range, Irish Mountain, and at the south end of the South Pahroc Range.

Faults offset Quaternary alluvium in Coal Valley east of the Golden Gate Range, Pahranagat Valley west of the Hiko Range, southern Tikaboo Valley east of the Desert Range, the southeastern end of Desert Valley and west of the Sheep Range, and along the eastern margin of the Sheep Range in Coyote Spring Valley. There is no obvious correlation between any of the faults offsetting Quaternary alluvium and historic epicenter concentrations.

Recent Volcanism -- The youngest volcanic rocks lie west of the Buried Hills in Nye Valley at the southwest corner of Lincoln County. These basalts are classified as Pliocene to Holocene.[71]

Resource Areas -- The following mining districts lie within the area:

Tempiute District: Located in the western part of the Timpahute Range near Coyote Peak, the district produced ~$14,700,000 primarily in tungsten and to a lesser extent silver, fluorspar, and zinc between 1869 and 1959. As of 1976, tungsten was being mined in this district.[27]

Groom District: Located near the southern end of the Groom Range (T.7S., R.55E.), the district produced more than $1 million in lead and silver between 1869 and 1956.

Don Dale District: The district is near the north end of the Groom Range north of Bald Mountain. Production is unknown. There apparently has been no activity on deposits of lead, silver, gold, and mercury since 1955.

Papoose District: On the east side of the Papoose Range, the district produced 1,157 oz of silver, 3 oz of gold, and 44 lb of lead. The productive periods of the district are not described in the literature.

Arrowhead (Southeastern) Mine: At the north end of the Pintwater Range near its junction with the Desert Range, the district contains deposits of copper, lead, and silver. Production is not known. In the North-Central South Pahroc Range perlite was being mined in 1976.[27]

Areas Identified for Further Examination

It is apparent from the preceding section on structural geology that most localities underlain by extensive tuff exposures in this area may not warrant further examination on the basis of numerous faults and complex, mostly moderate to steep, bedding orientation. Two areas, however, might warrant further examination: (1) the region around the Seaman Range volcanic center in the Seaman Range, and (2) the area underlain by tuff in the Quinn Canyon area of the Quinn Canyon Range. Both are underlain by tuff that has been cut by only a few mapped faults. Information on bedding orientaiton, structural relations, and tuff thickness is needed for both localities.

North Pahroc-Schell Creek-and Egan Ranges

These ranges were grouped together for discussion on the basis of geographic proximity and overlap of rock units. See Figure 10 for location. Principal references: 22, 27, 62, 71, and 78.

Distribution

The surface outcrops of tuff in this area cover ~183 mi^2 (Figure 11). Tuff crops out throughout the southern and central North Pahroc Range, in the low hills between the South Pahroc Range and Delamar Valley, in the east-central part of the Schell Creek Range, and at the southern terminus and eastern part of the Egan Range. Tuffs crop out adjacent to extensive exposures of pre-Tertiary sedimentary rocks (mostly in the Egan and Schell Creek Ranges); Tertiary andesite, rhyolite, and basalt flows; Tertiary limestone and sandstone; and Tertiary and/or Cretaceous intrusive rocks. The following tuff units (oldest to youngest) are present: Tuffaceous sandstone (informal map unit--Ts2), oldest welded tuffs (informal map unit--Tt2) ranging in age from 33 to 26 my including the Needles Range Formation and Tuff of the Seaman Range; middle ash-flow tuffs (informal map unit--Tt3) ranging in age from 26 to 17 my including the Shingle Pass, Leach Canyon, Condor Canyon Formation, Harmony Hills, and Hiko Tuffs; and youngest ash-flow and ash-flow tuffs (informal map unit--Tt4) ranging in age from 15 to 11 my including the Kane Wash Formation.

Thickness of Tuff

Composite Thickness -- The exposed Tertiary volcanic sequence in the North Pahroc Range is ~2000 ft thick and in the Southern Schell Creek Range is at least 1200 ft thick.[22]

Thickness of Tuff Units (in ft)[53] --

1. Tuffaceous Sandstone (Ts2) - 0 to 2000 in the Egan Range

2. Oldest Welded Tuffs (Tt2) -

   Needles Range Formation: 1330+ in the Schell Creek Range, 464 in the Egan Range, 1372 in the southern Egan Range, and 530 in the northern North Pahroc Range

   Seaman Range: No data available

3. Middle Ash-Flow Tuffs (Tt3) -

   Shingle Pass: 125 at Shingle Pass in the Egan Range, 122 in the southern Egan Range

   Leach Canyon: [illegible]24 in the North Pahroc Range

   Condor Canyon Formation: 291 in the southern North Pahroc Range, 45 in the central North Pahroc Range, 190 in the east-central Pahroc Range

   Harmony Hills: 101 in the southern North Pahroc Range, 293 in the central North Pahroc Range

   [illegible] in the southern North Pahroc Range

4. Youngest Ash-Flow and Ash-Fall Tuff (Tt4) -

   Kane Wash Formation: No data available

Structure

The Egan Range in Lincoln County consists of two structural blocks: the Egan Range block (north of Shingle Pass) and the southern Egan Range block (south of Shingle Pass). Both blocks are east-tilted fault blocks bounded on the west by the Egan fault, a normal fault with western side downthrown.[22] Tuffs unconformably overlie pre-Tertiary rocks along the eastern side of the Egan Range block and are cut by a relatively high number of mostly northeast-trending normal faults. A northerly-trending low-angle fault of probable gravity-slide origin separating tuffaceous sandstone from overlying Oldest Welded Tuffs (Tt2) is present in the Egan Range block.[71] Tertiary rocks dip mostly to the east at moderate-to-steep angles (generally >30°). The southern Egan Range block is underlain entirely by pre-Tertiary sedimentary rocks except at the southern terminus of the range. At this locality, the Oldest Welded Tuffs (Tt2) unconformably overlie pre-Tertiary rocks, dip mostly to the east at moderate angles (<30°), and are cut by several normal faults.

The Schell Creek Range is an east-tilted fault block bounded on the west by the Cave Valley Fault, a normal fault with the western side downthrown.[22] Tuffs are exposed in one section along the eastern side of the range just north of Sidehill Pass. The tuffs (Oldest-Welded Tuffs) unconformably overlie per-Tertiary rocks and dip to the east at moderate (<30°?) angles. This section of tuff is cut by few mapped faults.

The North Pahroc Range is an intricately-faulted structural block bounded on the west by the Pahroc Fault that is the eastern range-bounding fault of the Seaman Range.[22] Tertiary tuffs comprise most of its outcrops in the range. Numerous northerly-trending normal faults with mostly eastern sides downthrown cut the Tertiary rocks. Tuffs dip mostly to the west at moderate angles (<30°) in the southern part of the range. However, in the northern part of the range east of White River Fault the range becomes an east-tilted fault block with tuffs unconformably overlying pre-Tertiary rocks and dipping to the east at most low angles (<25°).[22]

Alteration of Tuff

No data are available

Proximity of Tuff to

Recent Faulting and Seismicity -- According to the preliminary epicenter loci map of the State of Nevada (Figure 3), 15 to 20 earthquakes of magnitudes from 3 to 5 have occurred. The largest concentrations of historic epicenters are in the White River Valley near 38° N latitude, 115° W longitude between the Seaman and the North Pahroc Ranges, and in a tract through the South and North Pahroc Ranges.

One east-trending fault cuts Quaternary alluvium in Dry Lake Valley north of the Timpahute lineament. There is no obvious correlation between historic epicenter concentrations and Quaternary faults in the White River Valley.

Recent Volcanism -- Apparently, there are no volcanic rocks younger than Miocene in age.

Resources Areas -- The only mining district in the area is the Patterson District. It is in the Southern Schell Creek Range near Patterson Pass in the northern part of the county and, although total production has not been recorded, more than $75,000 in tungsten, silver, zinc, copper, and gold were produced between 1880 (?) and 1952. This district is not currently active.[27]

Areas Identified for Further Examination

The section of tuff along the eastern flank of the Schell Creek Range just north of Sidehill Pass may warrant further study since few faults that cut the tuff have been mapped. More data on tuff thickness and bedding orientation are needed.

Caldera Complex Region of East-Central Nevada

The various mountain ranges in this area were grouped together for collective discussion, since volcano-tectonic structures dominate the structure of the area. Several mountain ranges with no volcano-tectonic features are included on the basis of geographic proximity. See Figure 10 for location. Principal references: 18, 22, 27, 53, and 71.

Distribution

The outcrop areas of tuff cover ~641 mi^2 (Figure 11). This area is the one most extensively covered by tuff in Lincoln County. Because the tuff does not extensively cover the Mormon and East Mormon Mountains, and Tule Springs Hills areas, these areas will be omitted from the ensuing discussion. Tuff is extensively exposed in the Clover Mountains, Burnt Springs Range, Delamar Mountains, Meadow Valley Mountains, and in the hills south of Goldsprings Wash. Tuffs crop out adjacent to exposures of Tertiary andesite, basalt, dacite, rhyolite, and rhyodacite flows, Tertiary sedimentary rocks, Tertiary intrusive rocks, and pre-Tertiary rocks. The following tuff units (oldest to youngest) are present: bedded (informal map unit--Ts3); bedded (with tuffaceous sandstone and siltstone) (informal map unit--Ts4); altered intermediate lavas and tuff undivided (informal map unit--Tat); Rhyolite Lava and tuff undivided (informal map unit--Trt); oldest welded tuffs (informal map unit--Tt2) ranging in age from 33 to 26 my and including the Needles Range Formation; middle ash-flow (informal map unit--Tt3) ranging in age from 26 to 17 my and including the Leach Canyon; Condor Canyon Formation, Harmony Hills, and Hiko Tuffs; and youngest ash-flow and air-fall tuff (informal map unit--Tt4) ranging in age from 15 to 11 my, including the Kane Wash and Ox Valley Tuffs.

Thickness of Tuff

Composite Thickness -- Very little data exist on the composite thickness of tuffs in the individual ranges in this area. Tuffs exposed in the Caliente Cauldron Complex and Kane Springs Wash volcanic center are described as being extraordinarily (?) thick.[71]

Thickness of Tuff Units (in ft) --

1. Bedded (Ts3) - 0 to 50

2. Bedded (with tuffaceous sandstone and siltstone) (Ts4) - 0 to 500+

3. Altered Intermediate Lavas and Tuffs Undivided (Tat) - No data available

4. Rhyolite Lava and Tuff Undivided (Trt) - No data available

5. Oldest Welded (Tt2) -

   Needles Range Formation: 500 *at Condor Canyon north of the area*

6. Middle Ash-Flow (Tt3) -

Leach Canyon: 778 in the Chief Range, 330+ just north of Caliente, 112 in the southern Delamar Mountains, 242 (?) in the southern Meadow Valley Mountains

Condor Canyon Formation: 58 in the southern Delamar Mountains, 186 (?) in the northwestern Delamar Mountains, 480 in the Chief Range, 460 in the northern Cedar Range

Harmony Hills: 228 in the southern Delamar Mountains, 470 in the northwestern Delamar Mountains, 177 in the Chief Range, 182 in the northern Cedar Range, and >330 at the head of Pennsylvania Canyon in the Clover Mountains

Hiko: 1255 in the northern Cedar Range, 213 in the southern Delamar Mountains, 300 in the central Meadow Valley Mountains, 406 in the southern Meadow Valley Mountains, and 1500 in the Caliente Caldron Complex in the Clover Mountains

7. Youngest Ash-Flow and Ash-Fall (Tt4) -

Kane Wash: 1195 in the southern Delamar Mountains, 660 along Meadow Valley Wash in the northeastern Delamar Mountains, 300 in the central Meadow Valley Mountains, 406 in the southern Meadow Valley Mountains

Ox Valley: 0 to 500+ in the extreme eastern part

Structure

The area designated as the cauldron complex region is influenced by structures related to the Caliente Caldron Complex, the Kane Springs Wash Volcanic Center, the Pahranagat Shear System, the Timpahute Lineament, and Basin-and-Range tectonics.

The Caliente Cauldron Complex, a volcano-tectonic depression 40 x 18 mi oblate east-west, is bounded on the north by the Timpahute Lineament and lies at the northeastern end of the left-lateral Pahranagat Shear Zone. The cauldron contains a central complex and a western resurgent lobe.[71] Northwest-trending normal and strike-slip faults dominate its internal structure and encircle the western lobe and the southern boundary of the central part of the complex, defining the margin of interior collapse. Tuffs extruded from the complex include the Hiko, Harmony Hill, Racer Canyon, and Ox Valley Tuffs.[79] These tuffs form the dominant outcrops in the western lobe of the cauldron and in a heart-shaped zone encircling the central part of the cauldron.

The southern part of the Caliente Cauldron Complex is defined by the Clover Mountains that are underlain mostly by tuffs and other volcanics from the cauldron with rare outcrops of pre-Tertiary rocks. Its arcuate geometry, convex to the south, probably resulted from the influence of structures in the southern part of the central Caliente Cauldron Complex described above.[71] North-trending basin-and-range normal faults, down-dropped to the west, and left-lateral strike-slip faults related to the Pahranagat Shear Zone cut Tertiary volcanics and pre-Tertiary rocks of the southern extension of the range into the Tule Desert.[71]

The morphology of the northeast-trending Delamar Mountains is controlled by the Menard Lake and Kane Springs Wash left-lateral strike-slip faults that are part of the Pahranagat Shear Zone and have the same trend as the mountains.[22] The Kane Springs Wash volcanic center[18] dominates the central part of the range. The location of this volcanic center, which extruded the Kane Wash Tuff, was probably controlled by a northeast-trending zone of structural weakness that later became the Pahranagat Shear Zone.[71] Aside from the arcuate-normal faults that define the oblate east-west central collapse structure of the caldera, most normal faults are arcuate, north-to-northwest-trending, convex to the northeast, and predominantly down-dropped to the southwest. Tuff outcrops dominate the central part of the range.

The Meadow Valley Mountains are a southeastward-tilted fault block bounded on the northwest by the left-lateral Kane Springs Wash Fault. Normal faults are predominantly north-trending with the west side down. Tuffs dominate the central part of the range.

The Burnt Springs Range is a north-trending fault block dominantly controlled by Basin-and-Range normal faults of the same trend that extensively deforms outcropping tuffs in the eastern part of the range.

The Chief and Black Canyon Ranges are north-northwest-trending and underlain by pre-Tertiary rocks that are separated by the left-lateral Burnt Springs Range Fault and a series of low-lying volcanics dominated by Basin-and-Range normal faults.

The region north of Blue Mountain in the Cedar Range is a series of low-lying volcanics and sediments. These rocks were deformed by north-trending Basin-and-Range normal and strike-slip faults, and east-northeast and east-southeast-trending right- and left-lateral strike-slip faults along the Timpahute lineament. The Timpahute was probably a deep-seated structure that controlled east-trending structures along a belt through the county.[71]

Alteration of Tuff

Tuffs in the following areas have been moderately to intensely hydrothermally altered: (1) around Little Mountain in the Cedar Range, (2) the southern Chief Range, (3) just north of Ella Mountain in the Clover Mountains, (4) the southern projection of Clover Mountains between Meadow Valley Wash and the Tule Desert, and (5) the area in the eastern and southeastern Clover Mountains underlain by the altered intermediate lavas and tuffs undivided (Tat).

Proximity of Tuff to

Recent Faulting and Seismicity -- Quaternary alluvium is offset along the western margin of the Burnt Springs Range in Dry Lake Valley, and alluvium (Holocene to Miocene) is offset along Kane Springs Wash northwest of the Meadow Valley Mountains.

According to the preliminary earthquake epicenter map of Nevada (Figure 3), between 80 and 100 earthquakes of magnitudes ~3 to 5 have occurred here. The largest concentration of historic epicenters lies in a circular area ~14 mi in diameter around the southern boundary of the Central Caliente Cauldron. Less distinct concentrations occur in the Delamar Mountains, at the south end of Kane Springs Wash, near Rainbow

Canyon at the southwestern edge of the Central Caliente Cauldron, and at the northeastern edge of the central cauldron.

Recent Volcanism -- No Quaternary volcanic rocks are known here. The most recent volcanism in this region probably occurred in the Miocene.[71]

Resource Areas -- The following are the mining districts in the area; as of 1976, there was no active mining.[27]

1. Delamar District - Located along the west slope of the Delamar Range about 30 mi southwest of Caliente, the district produced ~$14,983,700 in gold and silver since 1892. Principal production came before 1910; minor production has occurred since 1942.

2. Viola (Pittsburg, Cherokee) District - Located at the southern edge of the Clover Mountains, northwest of the Tule Desert, the district probably produced ~$40,000 in silver, copper, lead, zinc, and mercury. Earliest activity was in the 1880s; however, most production has come from fluorspar deposits since 1958.

3. Chief (Caliente) District - On the east slope of Chief Range (T3 S, R67 E), the district produced ~$88,000 in gold, silver, and lead between 1870 and 1953.

4. Pennsylvania District - Located near the head of Pennsylvania Canyon about 3 mi northeast of Elgin, the district probably produced ~$50,000 in copper, silver, and gold. The history of mining activity is unknown.

5. Little Mountain District - Located in the Cedar Range about 12 mi southeast of Panaca. No production history is available on its copper deposits.

6. Gourd Springs District - Located on the east flank of the East Mormon Mountains, the district produced $600 worth of manganese ore in 1929.

Areas Identified for Further Examination

The tuffs within the Delamar Mountains are largely flat-lying and, in some areas, are uncut by mapped faults. Within the Kane Springs Volcanic Center (in the Delamar Mountains), the tuffs also appear relatively undeformed and may be thick; therefore, the Delamar Range may warrant further investigation. Although the thickness and attitudes of tuffs in the Meadow Valley Mountains are not well known, some areas underlain by tuff outcrops are relatively unaffected by documented faulting. This area may, therefore, warrant further study. The western lobe of the Caliente Cauldron Complex may also warrant further study since the tuffs are cut by few mapped faults and are likely underlain by a thick section.

Note that before any further investigation of the areas listed above is undertaken, the problems of surface drainage into the Colorado River should be addressed.

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EXPLANATION

QUATERNARY — PLEISTOCENE

Qb Basalt

TERTIARY — PLIOCENE

Ttc 7.5 m.y. Thirsty Canyon Tuff

Ttm/Tp 10-12 m.y. Timber Mountain Tuff (Ttm) Paintbrush Tuff (Tp)–Tp–Ttm indicates both Paintbrush and Timber Mountain Tuffs and, in places, the Salyer and Wahmonie Formations and Crater Flat Tuff

TERTIARY — MIOCENE

Tw Uncorrelated Welded Ash-Flows; includes Tuff of Wilson's Camp and Tuffs of Sleeping Butte

Tt Designates Tuff of Tolicha Peak and 'Air-Fall Tuff'

Ti 13.5 -16 m.y. Indian Trail Formation

Tbr Belted Range Tuff includes in places, Stockade Wash Tuff and other local tuffs

Trv Redrock Valley Tuff

Tf 17.5 m.y. Fraction Tuff

Tts Tuff and Tuffaceous Sedimentary Rock; includes 'Zeolitized Bedded Tuff'

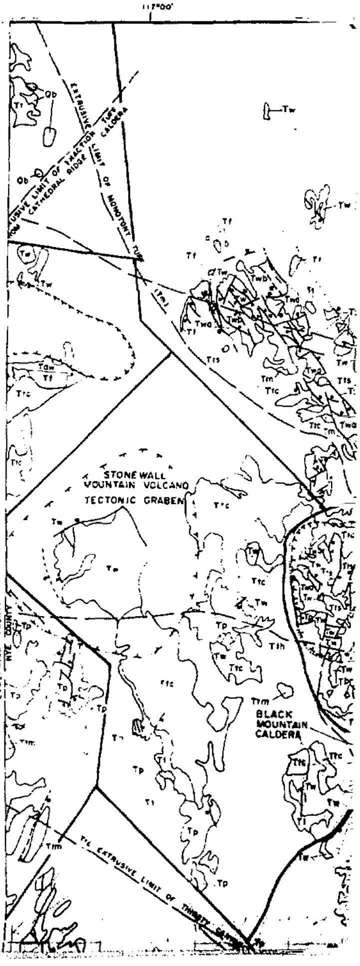
Twb 21.1-21.9 m.y. Tuff of White Blotch Spring

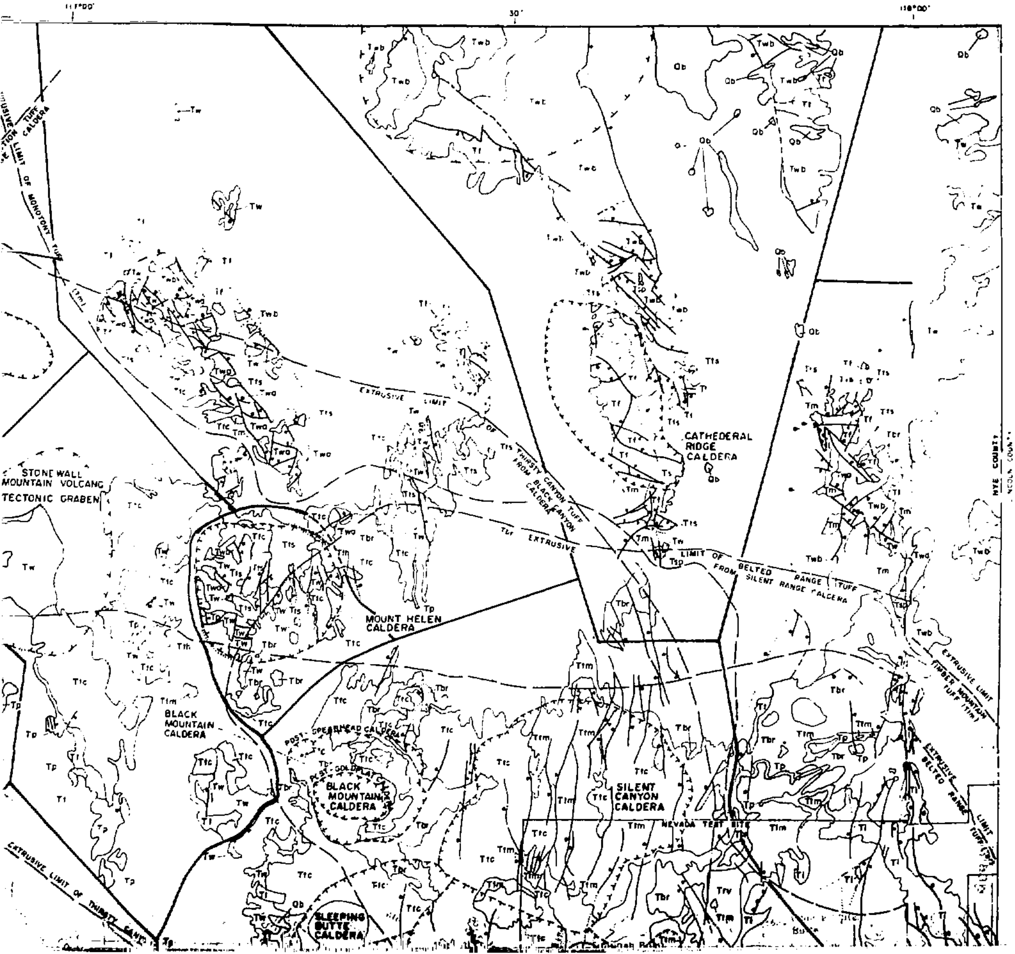
Tsp 23.8-25.4 m.y. Shingle Pass Tuff

Twa Tuff of Antelope Springs

TERTIARY — OLIGOCENE

Tm 26.5 m.y. Monotony Tuff




117°00'
30'
116°00'
STONEWALL MOUNTAIN VOLCANO TECTONIC GRABEN
BLACK MOUNTAIN CALDERA
MOUNT HELEN CALDERA
CATHEDERAL RIDGE CALDERA
POST-SPEARHEAD CALDERA
BLACK MOUNTAIN CALDERA
SILENT CANYON CALDERA
SLEEPING BUTTE CALDERA
NEVADA TEST SITE
EXTRUSIVE LIMIT OF TTS THIRSTY CANYON TUFF FROM BLACK CANYON CALDERA
TBR EXTRUSIVE LIMIT OF BELTED RANGE TUFF FROM SILENT RANGE CALDERA
EXTRUSIVE LIMIT TIMBER MOUNTAIN TUFF (TTM)
EXTRUSIVE LIMIT BELTED RANGE TUFF
EXTRUSIVE LIMIT OF THIRSTY CANYON
EXTRUSIVE LIMIT OF MONOTONY TUFF
NYE COUNTY
LINCOLN COUNTY

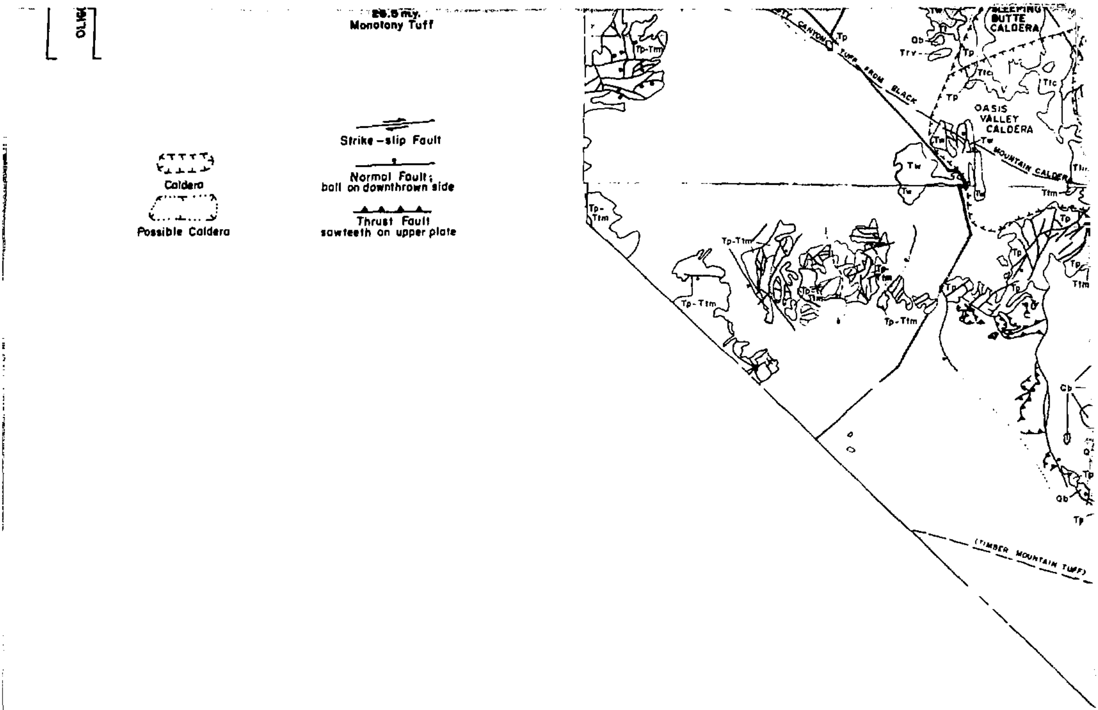


Fig. 5. ***TUFF DISTRIBUTION***

IN

SOUTHERN NYE COUNTY
NEVADA

SCALE 1:500,000

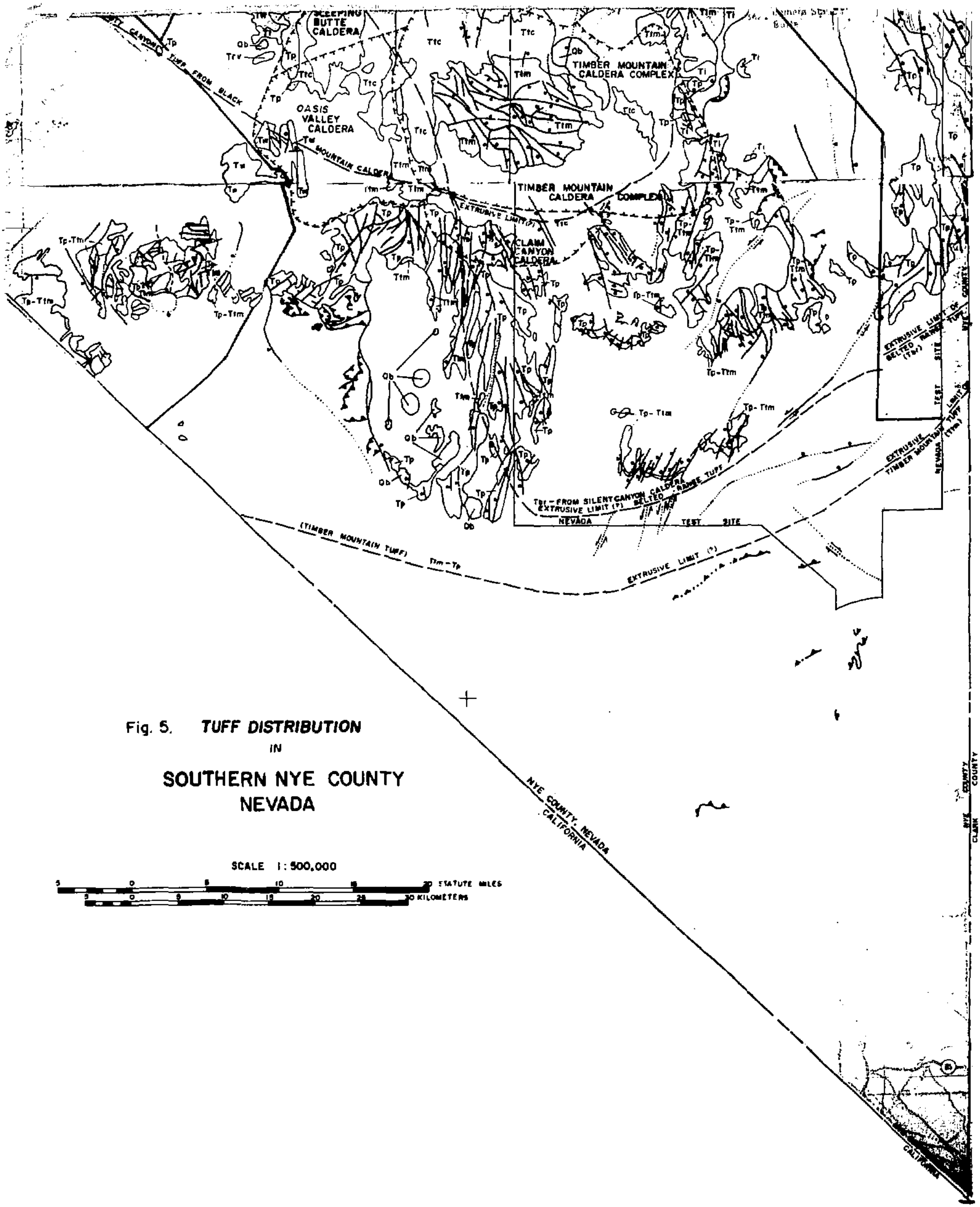


Fig. 5. ***TUFF DISTRIBUTION***

IN

SOUTHERN NYE COUNTY
NEVADA

SCALE 1 : 500,000

5 0 5 10 15 20 STATUTE MILES

5 0 5 10 15 20 25 30 KILOMETERS

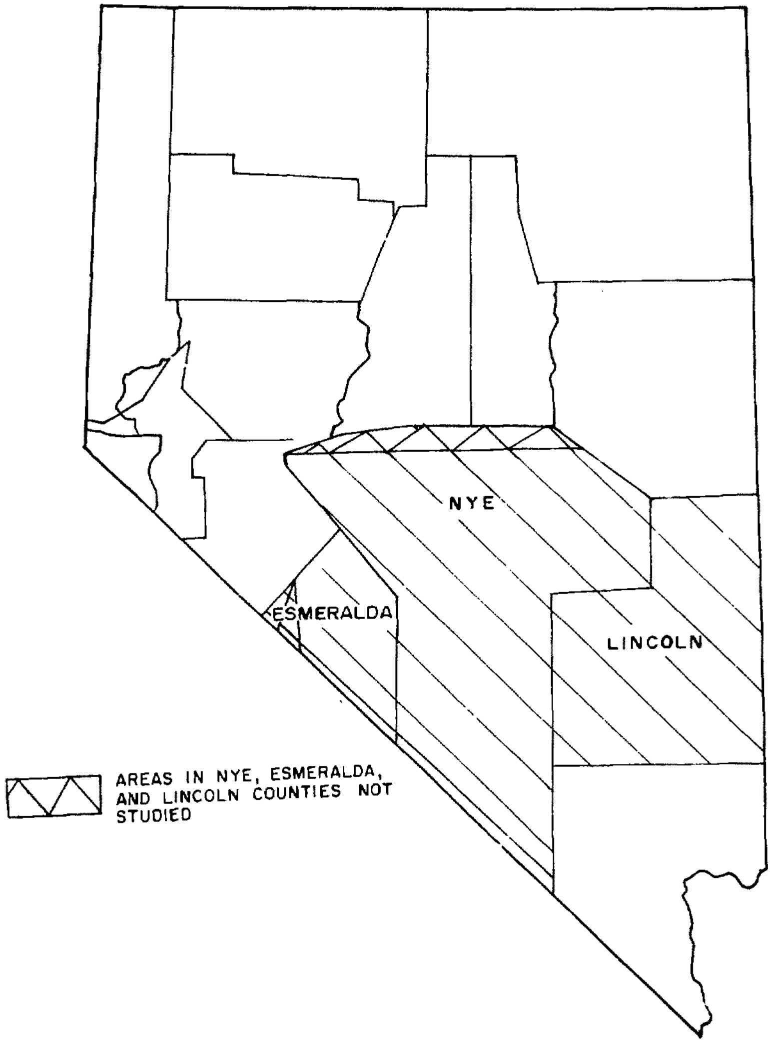


Figure 1. Index Map of Nevada Showing Counties Studied

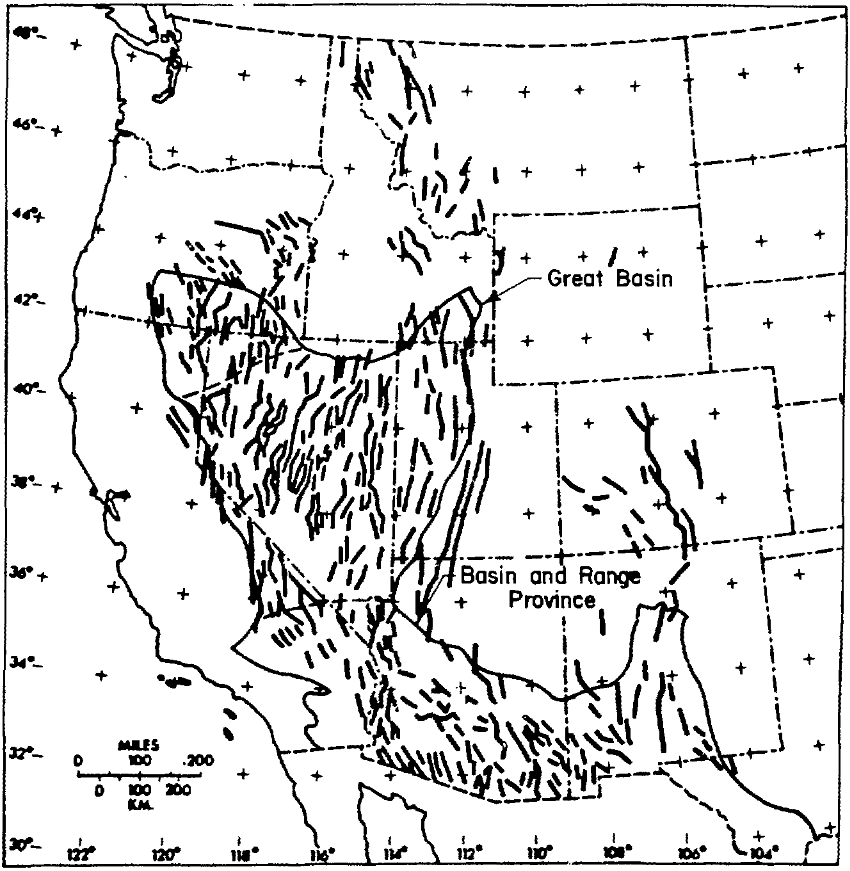
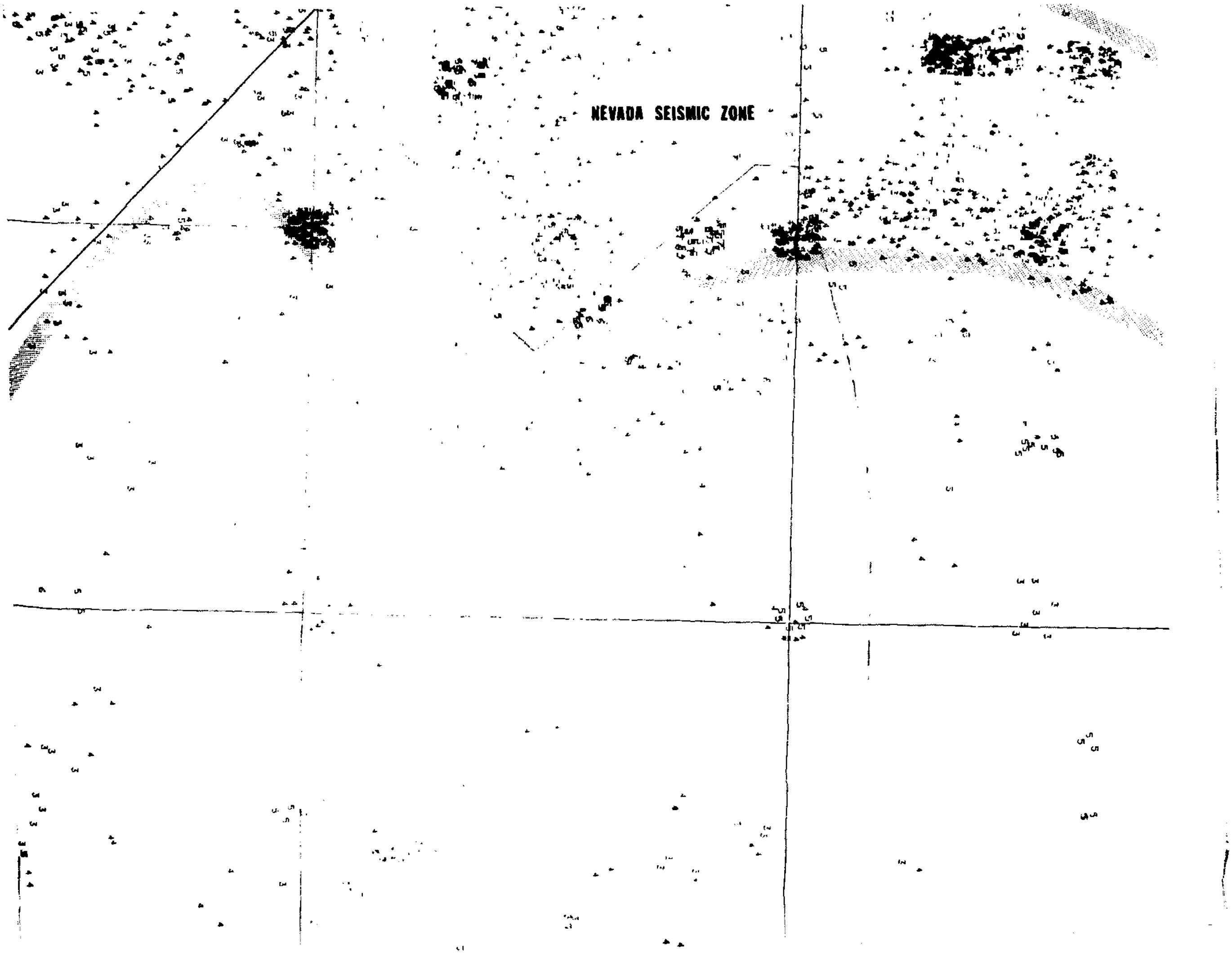
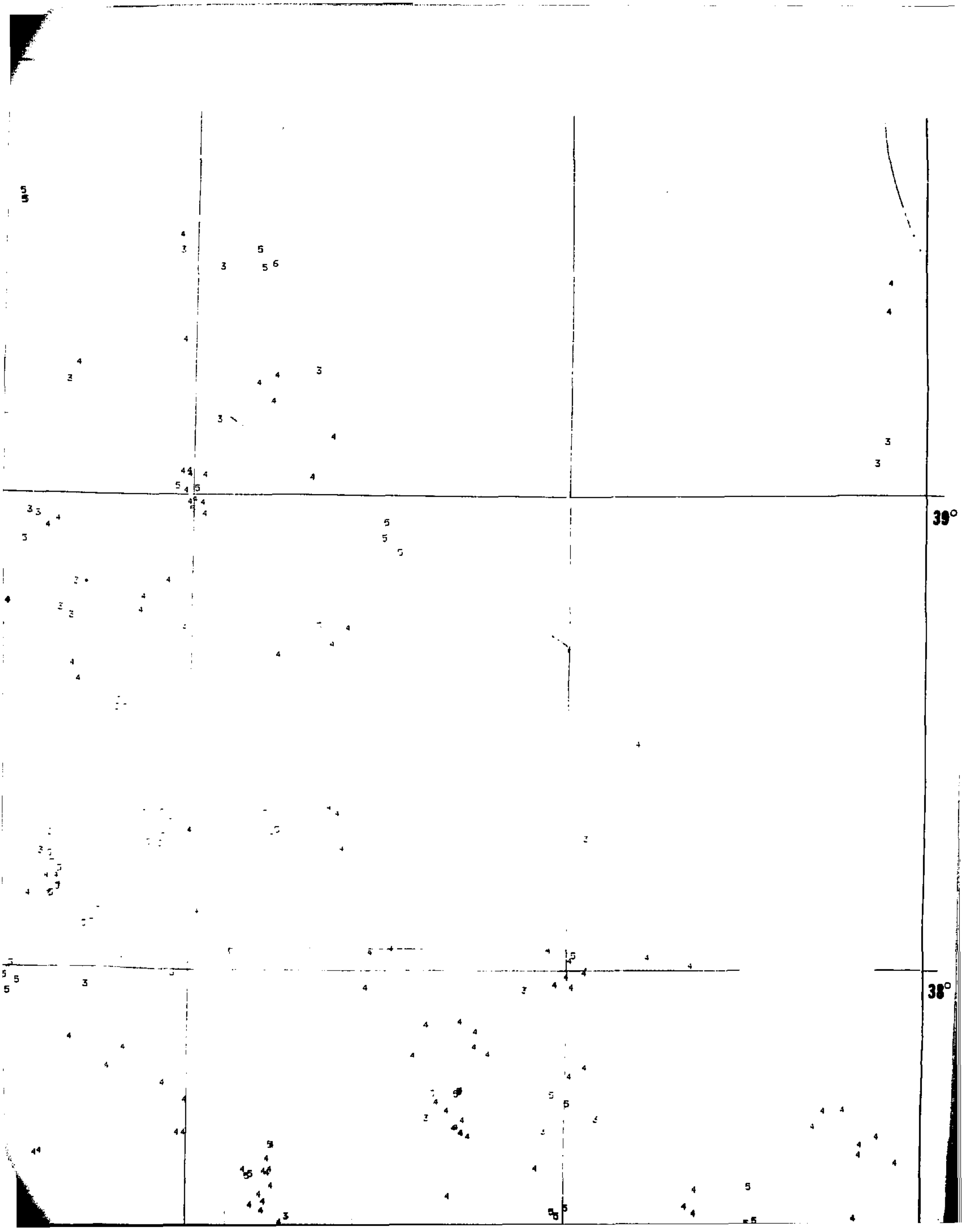
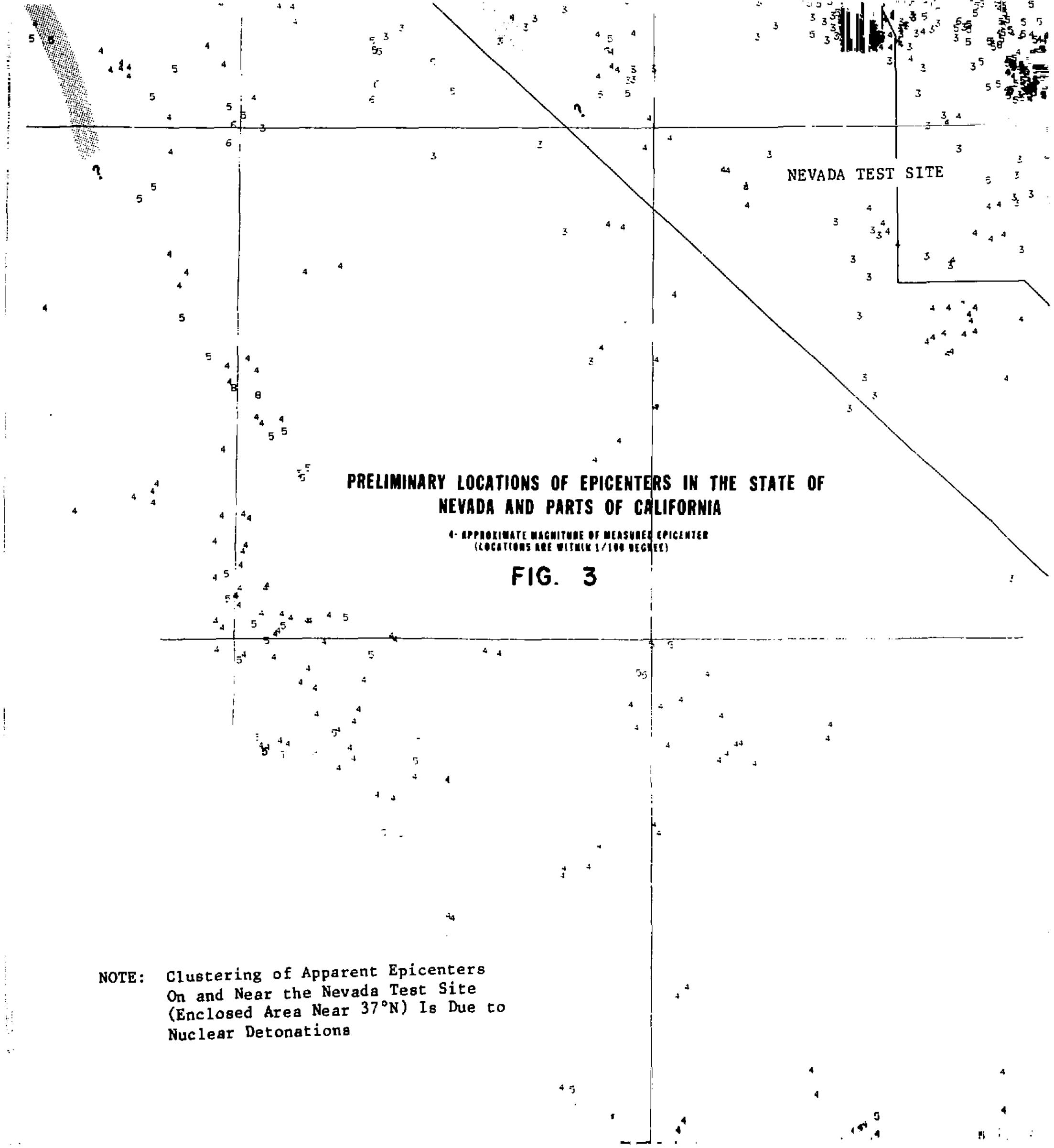


Figure 2. Predominantly Normal Faults of Late Cenozoic Age in the Western United States


NEVADA SEISMIC ZONE


39°
38°

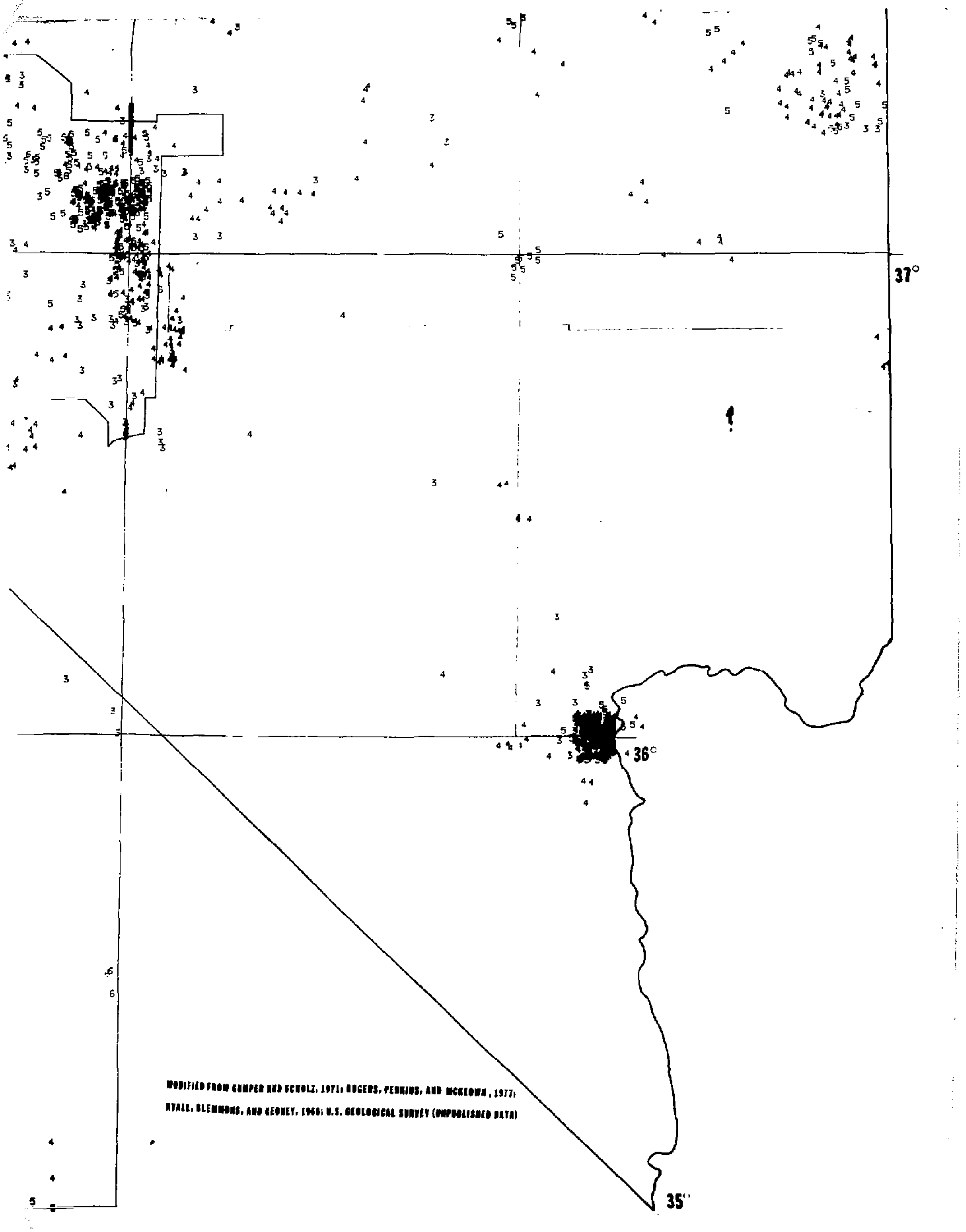


PRELIMINARY LOCATIONS OF EPICENTERS IN THE STATE OF NEVADA AND PARTS OF CALIFORNIA

4- APPROXIMATE MAGNITUDE OF MEASURED EPICENTER
(LOCATIONS ARE WITHIN 1/100 DEGREE)

FIG. 3

NOTE: Clustering of Apparent Epicenters On and Near the Nevada Test Site (Enclosed Area Near 37°N) Is Due to Nuclear Detonations


37°
36°
35°
MODIFIED FROM GUMPER AND SCHOLZ, 1971; ROGERS, PERKINS, AND MCKEOWN, 1977;
RYALL, SLEMMONS, AND GEDNEY, 1966; U.S. GEOLOGICAL SURVEY (UNPUBLISHED DATA)

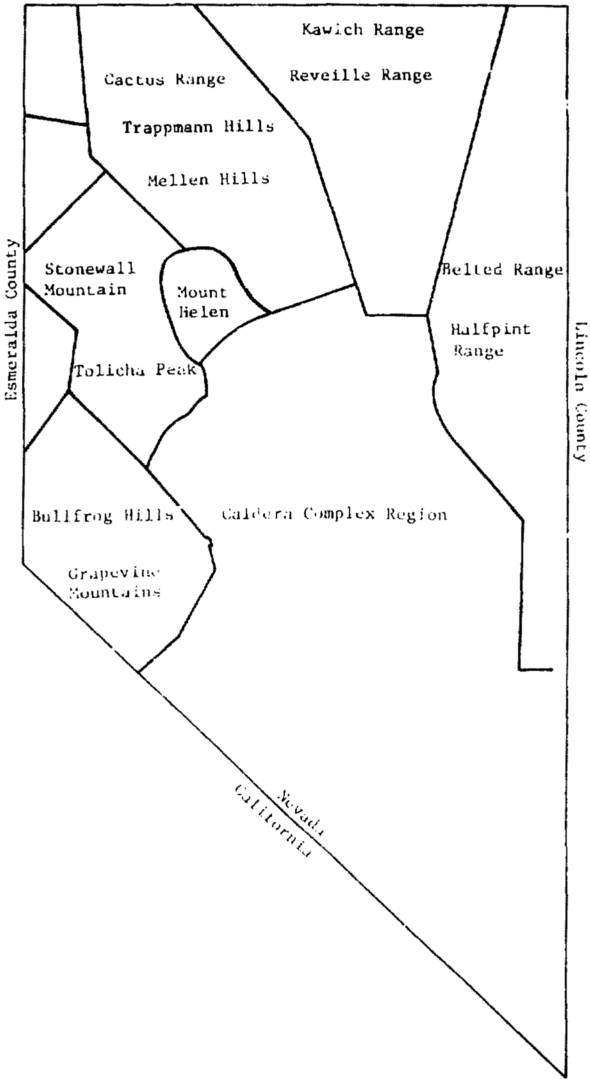


Figure 4. Index Map of Southern Nye County

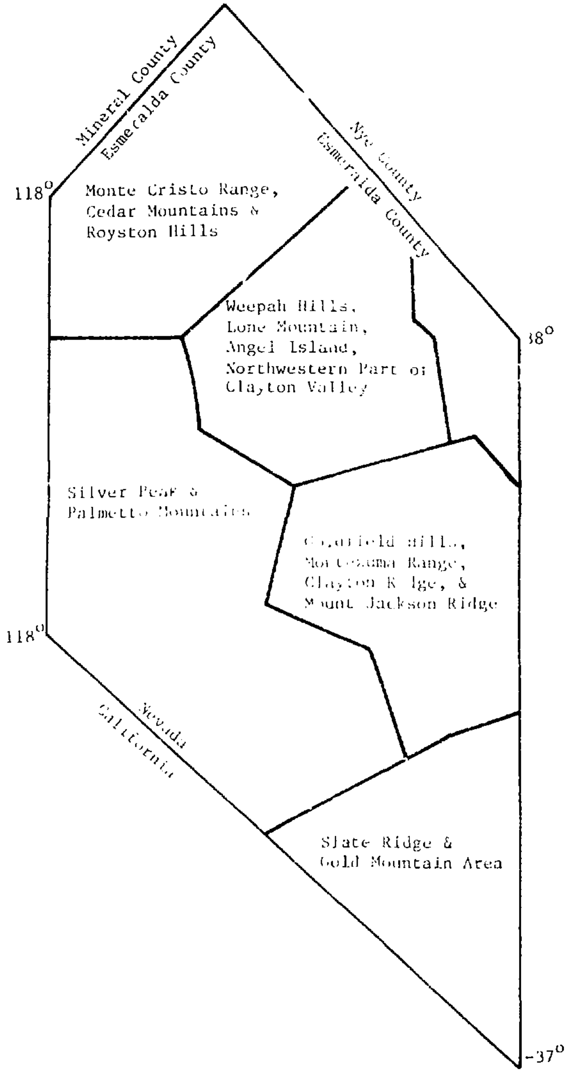
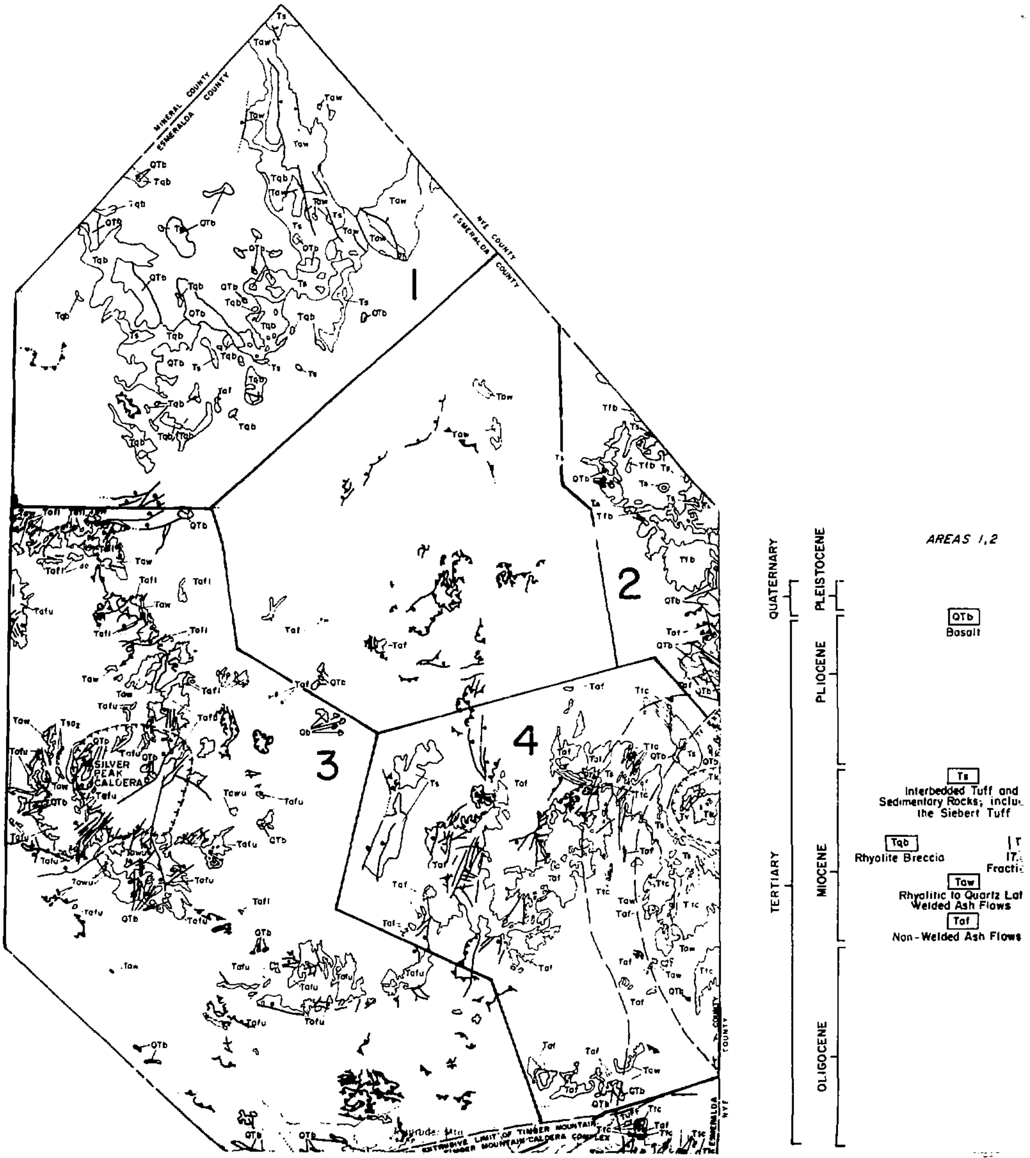
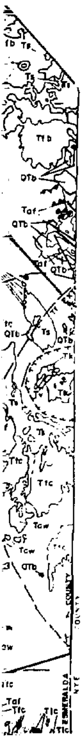


Figure 6. Index Map of Esmeralda County



MINERAL COUNTY
ESMERALDA COUNTY
NYE COUNTY
ESMERALDA COUNTY
1
2
3
4
SILVER PEAK CALDERA
EXTRUSIVE LIMIT OF TIMBER MOUNTAIN
TIMBER MOUNTAIN CALDERA COMPLEX
AREAS 1,2
QUATERNARY
TERTIARY
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
QTb
Basalt
Ts
Interbedded Tuff and Sedimentary Rocks; inclu
the Siebert Tuff
Tqb
Rhyolite Breccia
Taw
Rhyolitic to Quartz Lat
Welded Ash Flows
Taf
Non-Welded Ash Flows



EXPLANATION

		AREAS 1, 2	AREA 3	AREA 4	AREA 5
QUATERNARY	PLEISTOCENE		Qb Basalt		
QUATERNARY / TERTIARY	PLEISTOCENE / PLIOCENE	QTb Basalt	QTb Basalt	QTb Basalt	QTb Basalt
TERTIARY	PLIOCENE		Tafu 6.0 m.y. Rhyolitic Air-Fall Tuff; Tawu 6.1 m.y. Upper Welded Ash-Fall	Ttc 7.5 m.y. Thirsty Canyon Tuff	Ttc 7.5 m.y. Thirsty Canyon Tuff; Ttm Timber Mountain Tuff ('Tp – Ttm' designates both Paintbrush Tuff and Timber Mountain Tuff)
TERTIARY	MIOCENE	Ts Interbedded Tuff and Sedimentary Rocks; includes the Siebert Tuff; Tqb Rhyolite Breccia; Tfb 17.5 m.y. Fraction Breccia; Taw Rhyolitic to Quartz Latite Welded Ash Flows; Taf Non-Welded Ash Flows	Tsa_2 Welded Ash-Flow; Taw 21.5 m.y. Lower Welded Ash-Flow; Tafl Lower Non-Welded Ash-Flow	Ts Siebert Tuff; Taf Air-Fall Tuff; Taw Lower Welded Ash-Flow	Taf Air-Fall Tuff
TERTIARY	OLIGOCENE			Tk Kendall Tuff and Interlayered Latite; Tv Vindicator Rhyolite (tuff)	

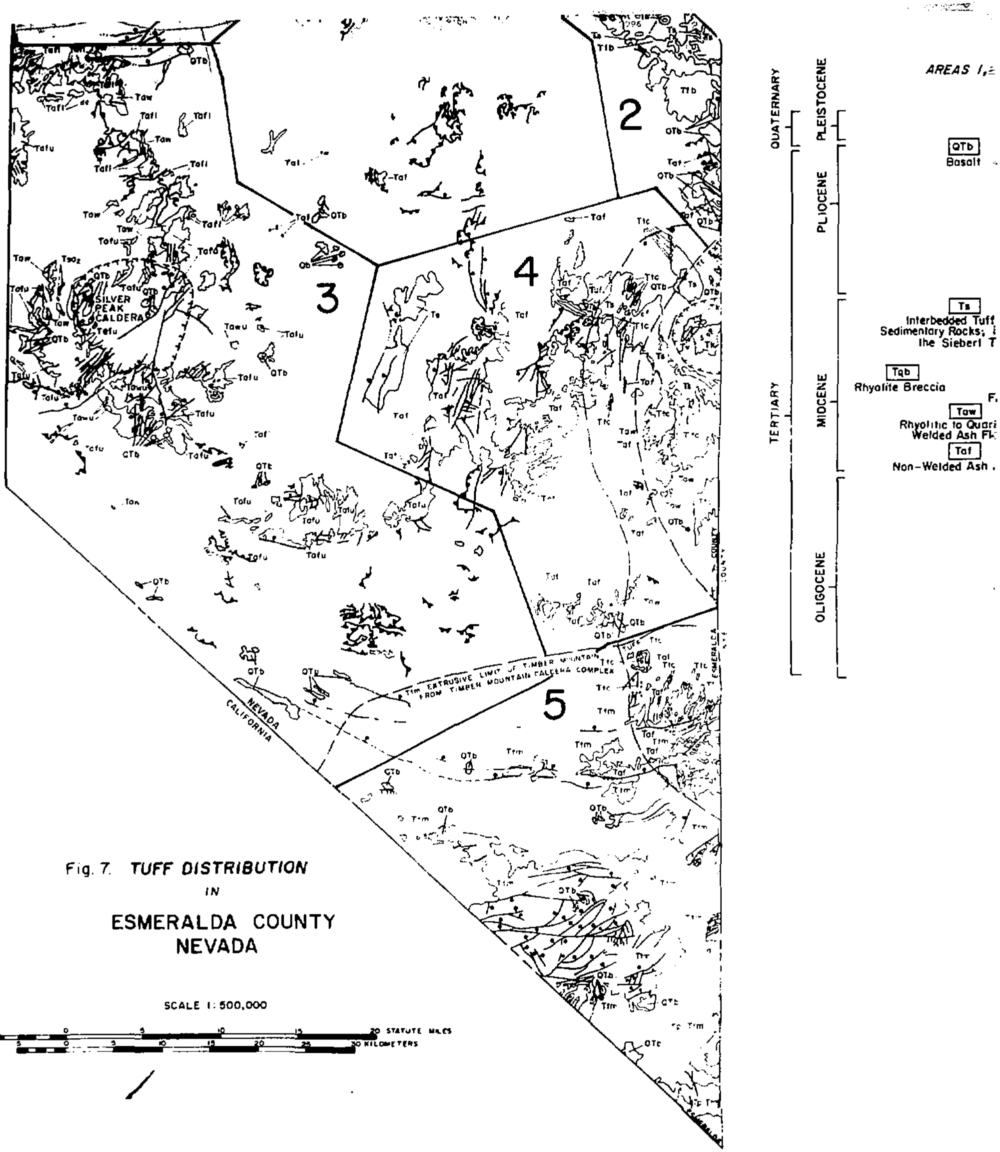
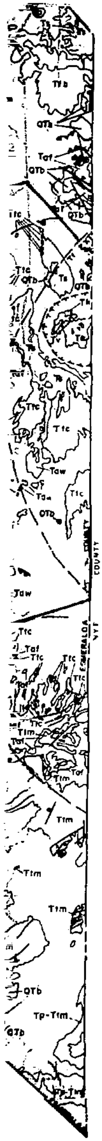


Fig. 7. *TUFF DISTRIBUTION*

IN

ESMERALDA COUNTY
NEVADA



EXPLANATION

QUATERNARY: PLEISTOCENE
TERTIARY: PLIOCENE, MIOCENE, OLIGOCENE

Period	Epoch	AREAS 1,2	AREA 3	AREA 4	AREA 5
QUATERNARY	PLEISTOCENE		Qb Basalt		
QUATERNARY / TERTIARY	PLEISTOCENE / PLIOCENE	QTb Basalt	QTb Basalt	QTb Basalt	QTb Basalt
TERTIARY	PLIOCENE		Tafu 6.0 m.y. Rhyolitic Air-Fall Tuff; Tawu 6.1 m.y. Upper Welded Ash-Fall	Ttc 7.5 m.y. Thirsty Canyon Tuff	Ttc 7.5 m.y. Thirsty Canyon Tuff; Ttm Timber Mountain Tuff 'Tp – Ttm' designates both Paintbrush Tuff and Timber Mountain Tuff
TERTIARY	MIOCENE	Ts Interbedded Tuff and Sedimentary Rocks; includes the Si.bert Tuff; Tqb Rhyolite Breccia; Tfb 17.5 m.y. Fraction Breccia; Taw Rhyolitic to Quartz Latitic Welded Ash Flows; Taf Non-Welded Ash Flows	Tsa$_2$ Welded Ash-Flow; Taw 21.5 m.y. Lower Welded Ash-Flow; Tafl Lower Non-Welded Ash-Flow	Ts Siebert Tuff; Taf Air-Fall Tuff; Taw Lower Welded Ash-Flow	Taf Air-Fall Tuff
TERTIARY	OLIGOCENE			Tk Kendall Tuff and Interlayered Latite; Tv Vindicator Rhyolite (tuff)	

Caldera

Possible Caldera

Normal Fault; ball on downthrown side

Thrust Fault sawteeth on upper plate

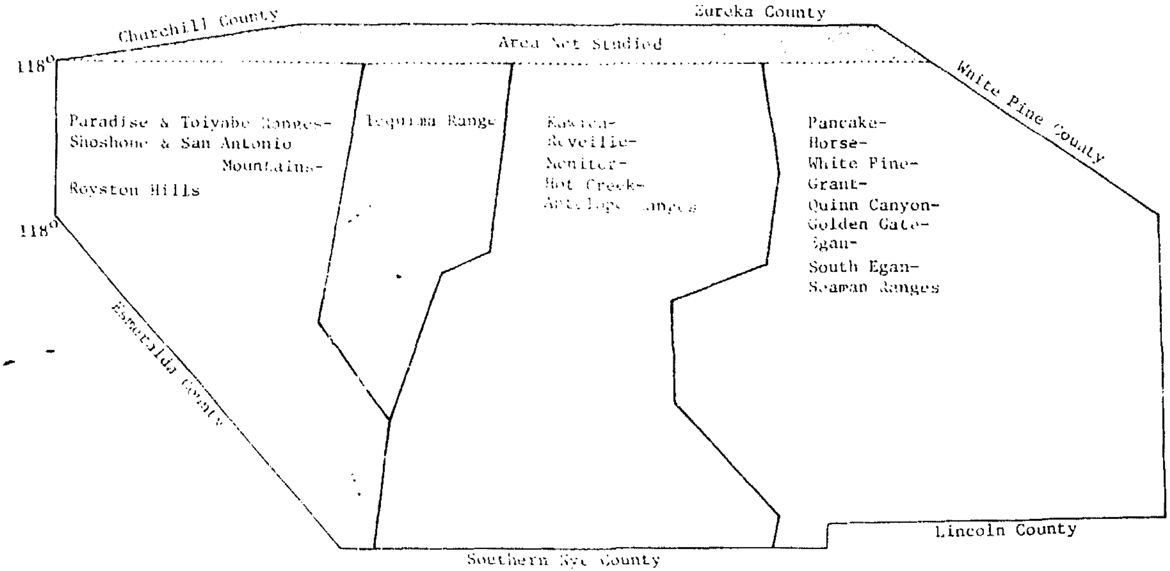
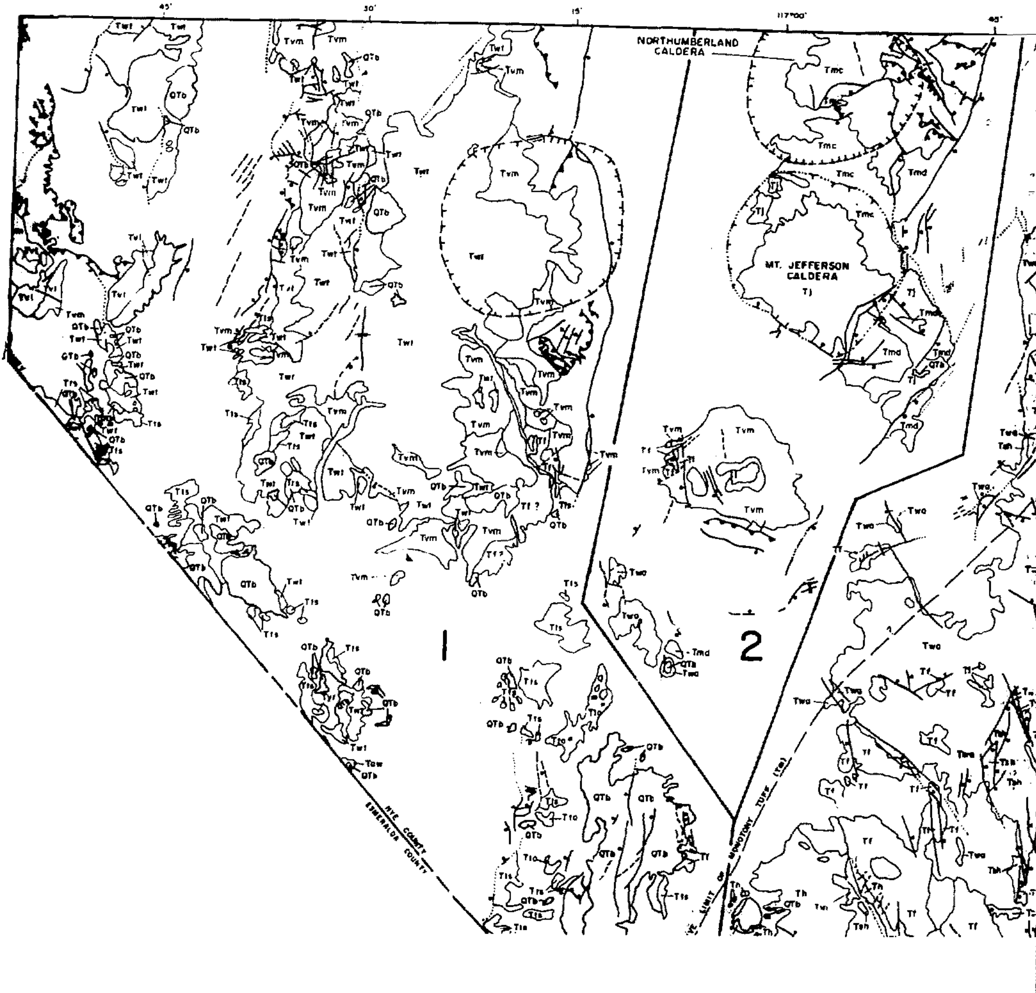
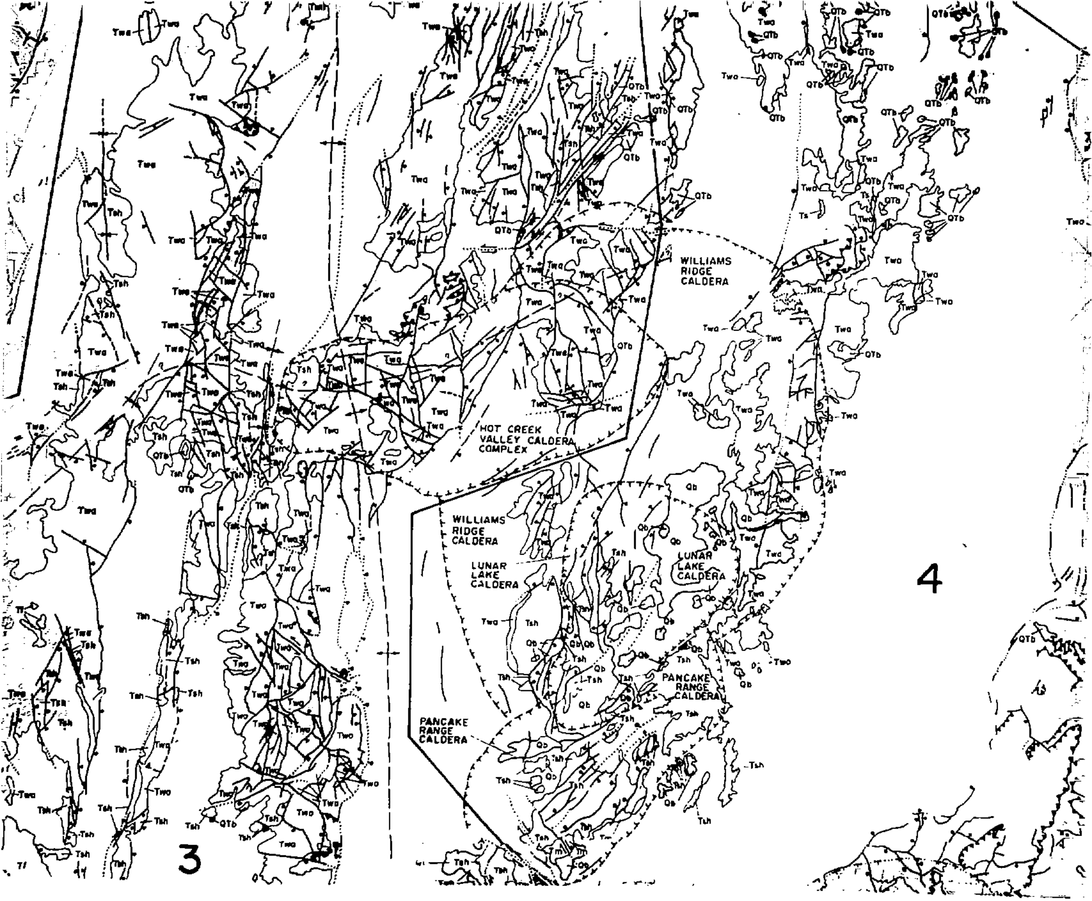
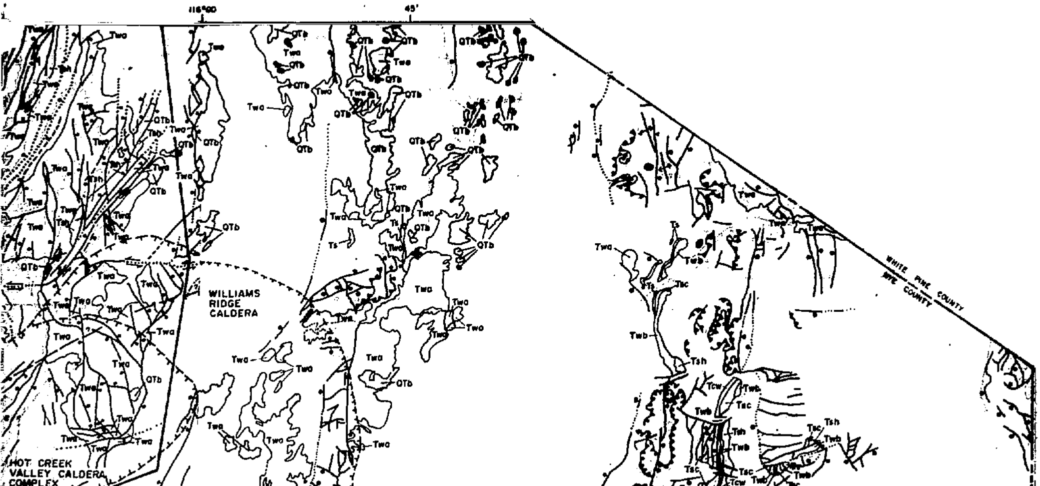


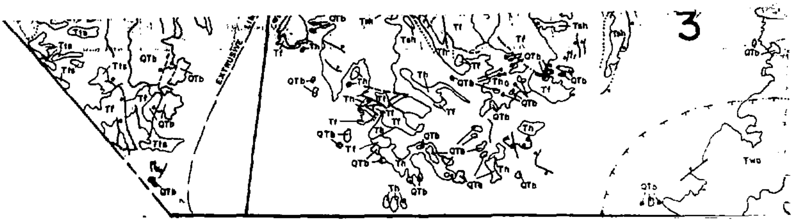
Figure 8. Index Map of Northern Nye County



45'
30'
15'
117°00'
45'
NORTHUMBERLAND CALDERA
MT. JEFFERSON CALDERA
1
2
NYE COUNTY
ESMERALDA COUNTY
LIMIT OF MONOTONY TUFF (Tm)

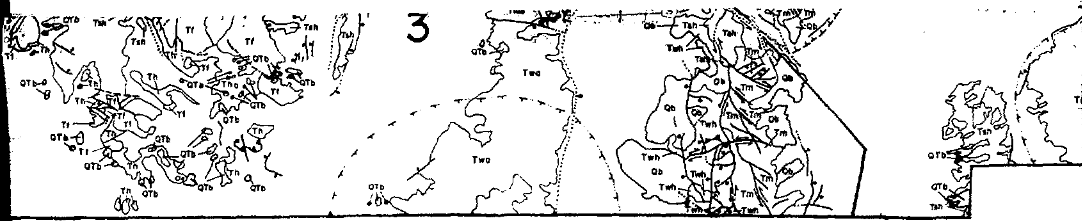

WILLIAMS RIDGE CALDERA
HOT CREEK VALLEY CALDERA COMPLEX
WILLIAMS RIDGE CALDERA
LUNAR LAKE CALDERA
LUNAR LAKE CALDERA
PANCAKE RANGE CALDERA
PANCAKE RANGE CALDERA
3
4


116°00
45'
WILLIAMS RIDGE CALDERA
HOT CREEK VALLEY CALDERA COMPLEX
LUNAR LAKE CALDERA
PANCAKE RANGE CALDERA
WHITE PINE COUNTY
NYE COUNTY
4



EXPLANATION

	AREA 1	AREA 2	AREA 3	AREA 4
QUATERNARY – PLEISTOCENE			Qb Basalt	Qb Basalt
TERTIARY – PLIOCENE	QTb Basalt	QTb Basalt	QTb Basalt	QTb Basalt
TERTIARY – MIOCENE	Tts Tuff and Tuffaceous Sediments			
	Tf 17.5 m.y. Fraction Tuff	Tf 17.5 m.y. Fraction Tuff	Tf 17.5 m.y. Fraction Tuff	Tf 17.5 m.y. Fraction Tuff
	Twt 21.5–23.1 m.y. Welded Ash-Flow Tuffs	Tmd Tuffs of Meadow Creek	Twh Tuffs	
		Tj 24.7–26.1 m.y. Tuffs of Mount Jefferson	Tsh 23.8–25.4 m.y. Shingle Pass Tuff	Tsh 23.8–25.4 m.y. Shingle Pass Tuff and other tuffs of Miocene age
TERTIARY – OLIGOCENE			Tm 26.5 m.y. Monotony Tuffs	Tm 26.5 m.y. Monotony Tuffs
		Tmc Tuffs of Moores Creek		
	Tvm Middle Volcanic Sequence	Tvm Middle Volcanic Sequence		
	Tto Tonopah Formation	Twa Crystal-rich Welded Tuffs; Th Welded Ash-Flow Tuffs	Twa Crystal-rich Welded Tuffs	Twa Crystal-rich Welded Tuffs including those listed below and other tuffs of Oligocene age
	Tvl Lower Volcanic Sequence			Tnr Needle Range Formation
				Twb Windous Butte Tuff
				Tsc Stone Cabin Tuff
				Tcw Calloway Well Formation
				Ts Tuffaceous Sedimentary Rocks



ION

AREA 3

Qb
Basalt

QTb
Basalt

Tf
17.5 m.y.
Fraction Tuff

Twh
Tuffs

Tsh
23.8–25.4 m.y.
Shingle Pass Tuff

Tm
26.5 m.y.
Monotony Tuffs

Th
ed Ash-
Tuffs

Twa
Crystal-rich
Welded Tuffs

AREA 4

Qb
Basalt

QTb
Basalt

Tf
17.5 m.y.
Fraction Tuff

Tsh
23.8–25.4 m.y.
Shingle Pass Tuff and
other tuffs of Miocene age

Tm
26.5 m.y.
Monotony Tuffs

Twa
Crystal-rich
Welded Tuffs including
those listed below and other
tuffs of Oligocene age

Tnr
Needle Range Formation

Twb
Windous Butte Tuff

Tsc
Stone Cabin Tuff

Tcw
Calloway Well Formation

Ts
Tuffaceous Sedimentary Rocks

Fig. 9. ***TUFF DISTRIBUTION***
IN

NORTHERN NYE COUNTY
NEVADA

SCALE 1 : 500,000

5 0 5 10 15 20 ST
5 0 5 10 15 20 25 30 KILOME

Caldera

Possible Caldera

Strike-slip Fault

Normal Fault;
ball on downthrown side

Thrust Fault
sawteeth on upper plate

Anticline

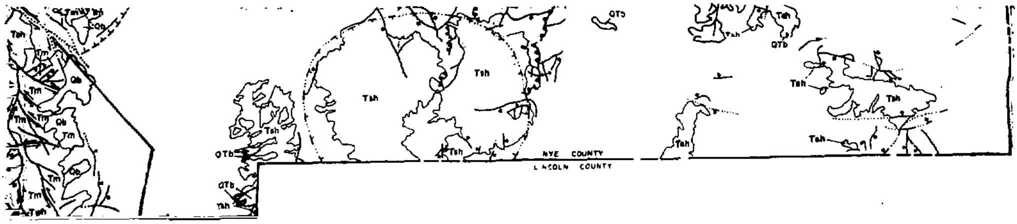


Fig. 9. ***TUFF DISTRIBUTION***
IN

NORTHERN NYE COUNTY
NEVADA

SCALE 1 : 500,000

0 5 10 15 20 STATUTE MILES

0 5 10 15 20 25 30 KILOMETERS

Caldera

Possible Caldera

Strike-slip Fault

Normal Fault; ball on downthrown side

Thrust Fault sawteeth on upper plate

Anticline

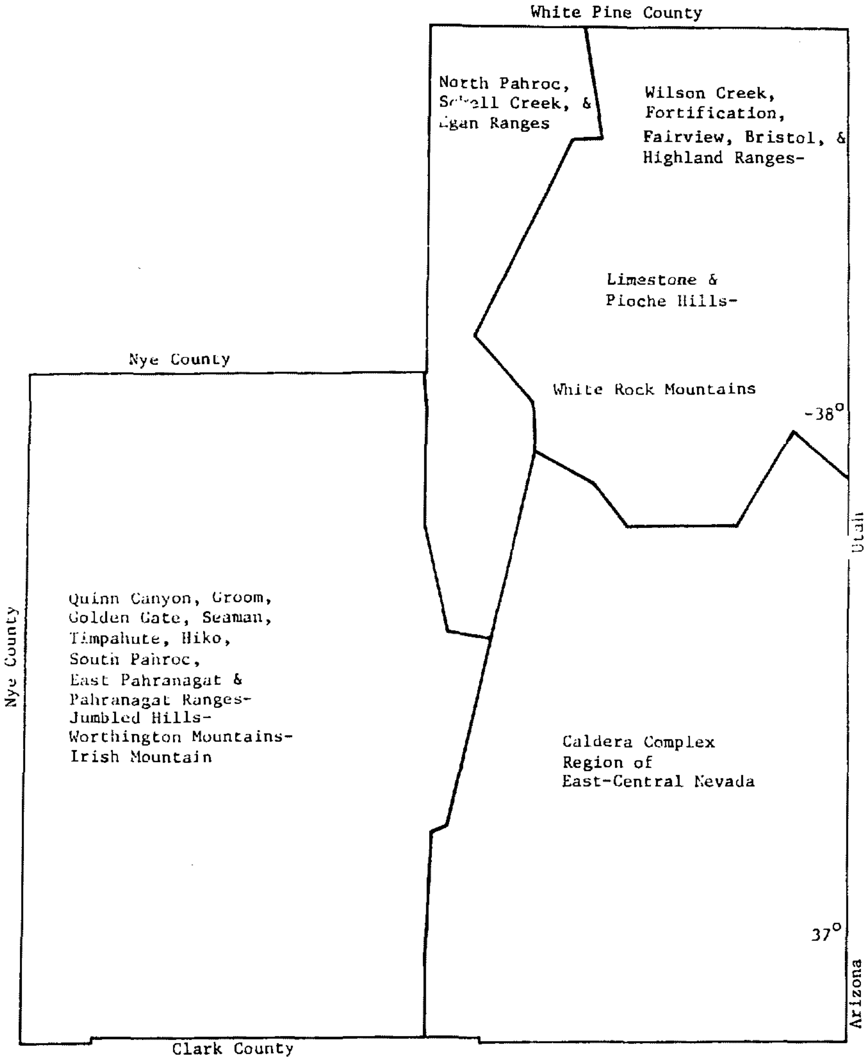


Figure 10. Index Map of Lincoln County

EXPLANATION

QUATERNARY — PLEISTOCENE
TERTIARY — PLIOCENE; MIOCENE

QTb
Basalt

Tt4
11–15 m.y.
Youngest Ash-Flow and Ash-Fall Tuffs; includes Timber Mountain Tuff, Ox Valley Tuff, Kane Wash Tuff

Trt
Rhyolite Lava and Tuff Undivided, includes Kane Wash Tuff and Ox Valley Tuff

Ts4
Bedded Tuff (with tuffaceous sandstone and siltstone)

Tt3
17–26 m.y.
Middle Ash-Flow Tuffs, includes Tuff of White Blotch Springs, Tuff of Quinn Canyon Range, Shingle Pass Tuff, Tuff of Bald Mountain, Hiko Tuff, Racer Canyon Tuff, Harmony Hills Tuffs, Condor Canyon Formation, Leach Canyon Formation, Isom Formation

Tat
Altered Lavas and Tuffs Undivided

Ts3
Bedded Tuff

Tt2
26–33 m.y.
Oldest Welded Tuffs; includes Monotony Tuff, Needles Range Formation, Tuff of Seaman Range

Ts2
Tuffaceous Sandstone

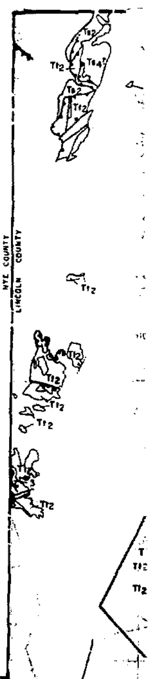
Caldera

Possible Caldera

Hydrothermally Altered Area

Normal Fault; ball on downthrown side

Low-angle Fault sawteeth on upper plate



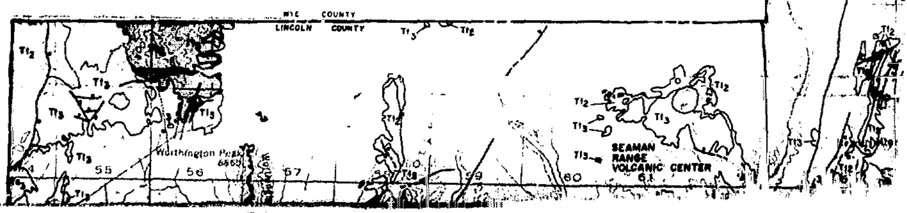
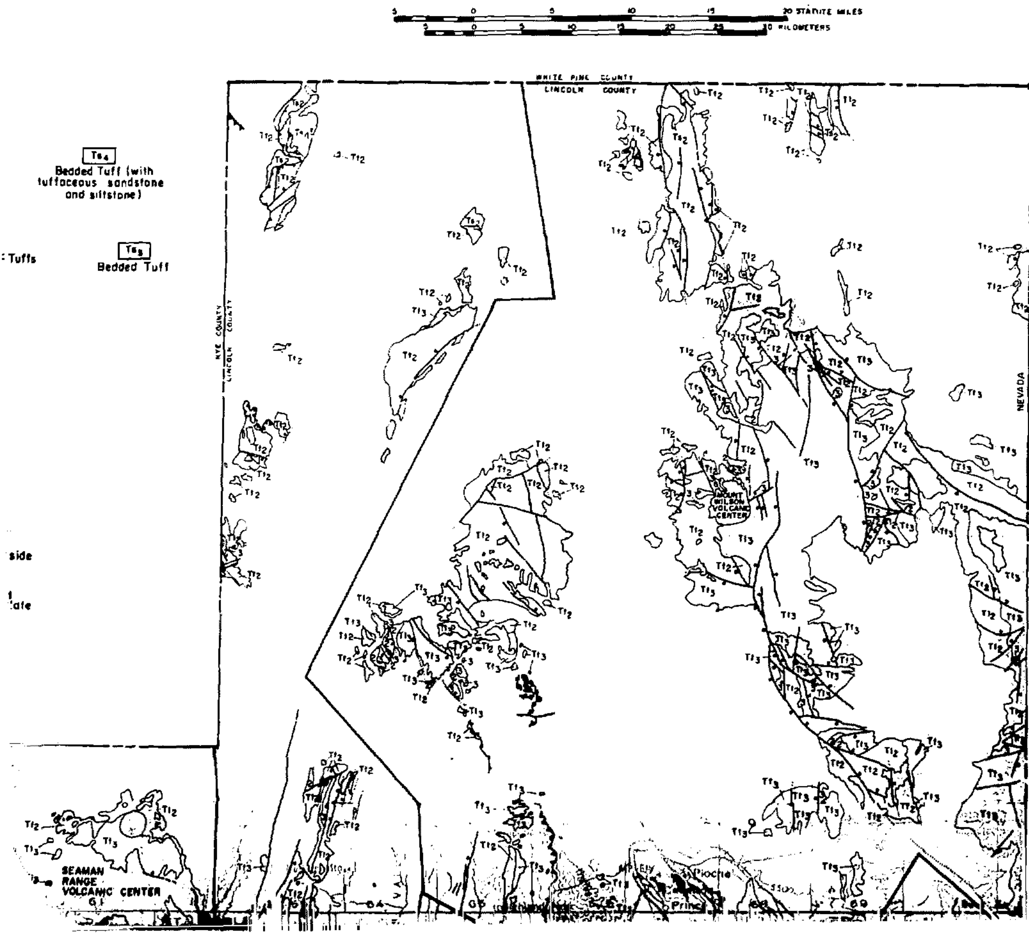


Fig. 11. ***TUFF DISTRIBUTION***

IN

LINCOLN COUNTY
NEVADA

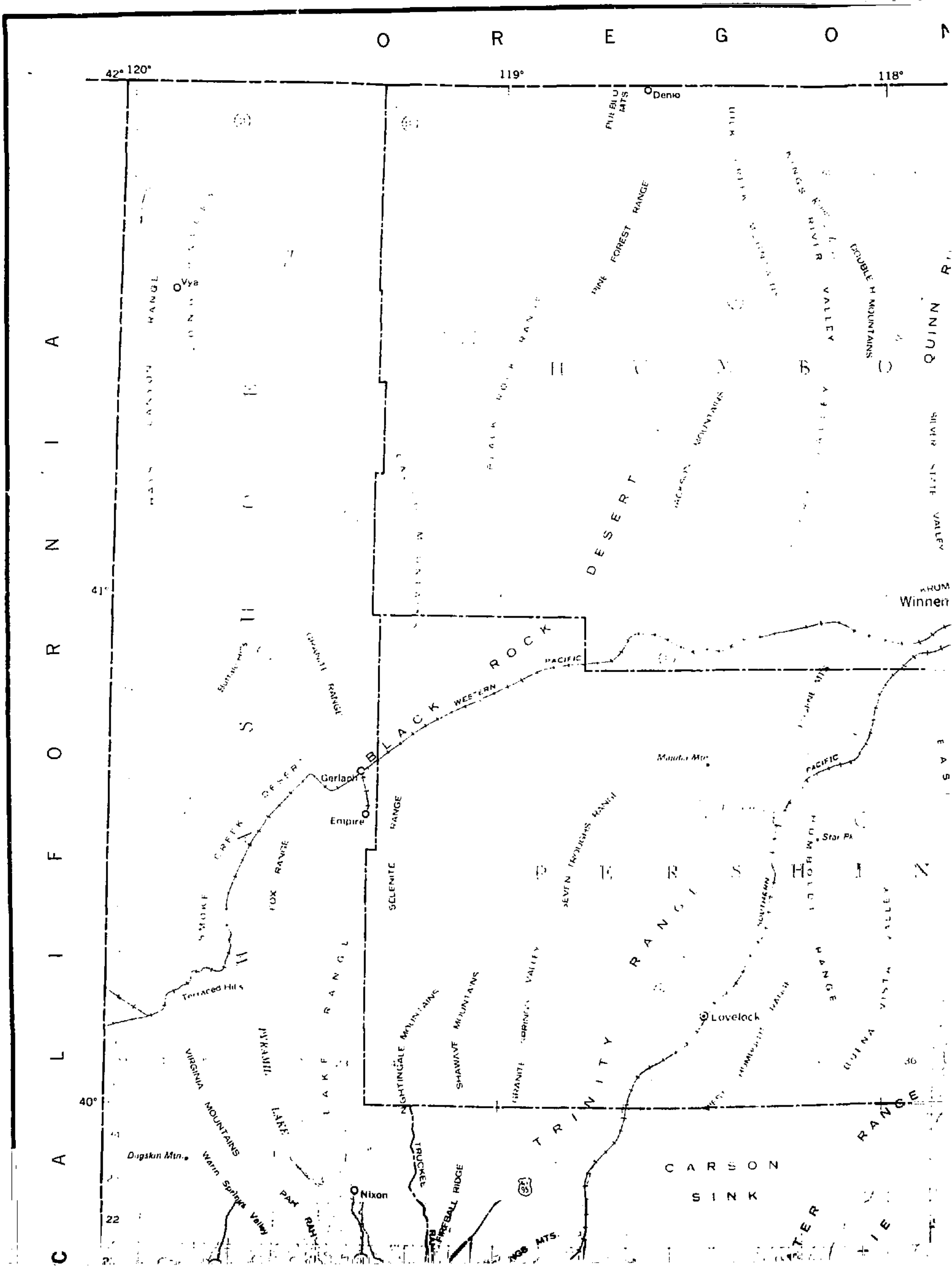
SCALE 1:500,000

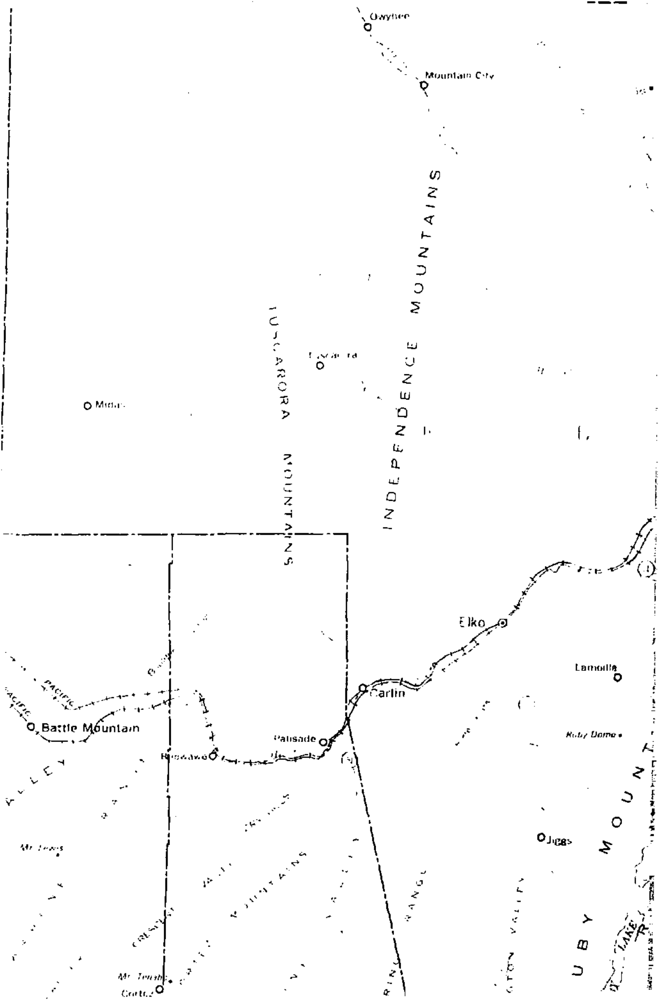


SEAMAN RANGE VOLCANIC CENTER
BALD MOUNTAIN CALDERA
NYE COUNTY
LINCOLN COUNTY
NEVADA TEST SITE
STRUCTURAL CHAOS
STRUCT-URAL CHAOS
LINCOLN COUNTY
CLARK COUNTY

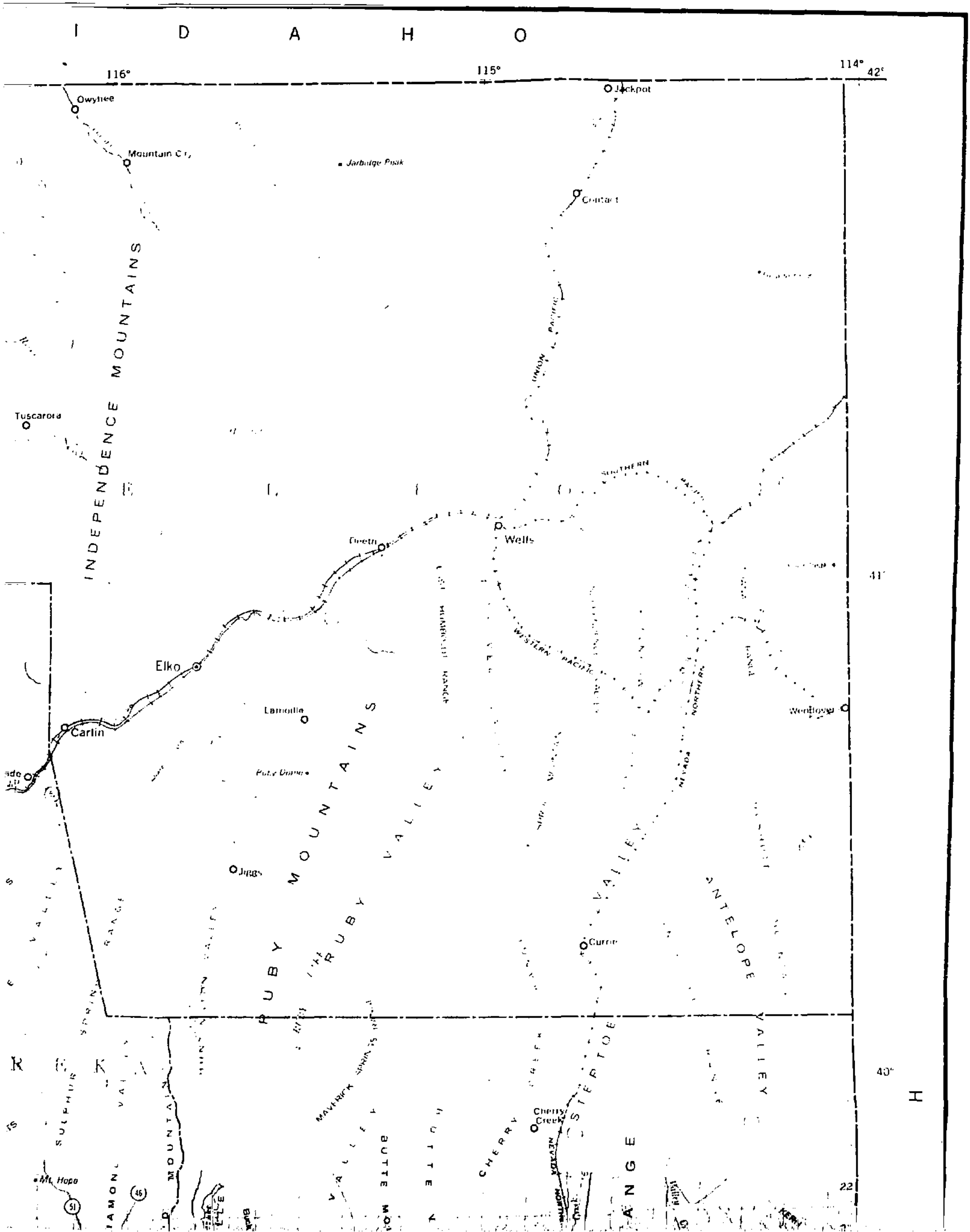

SEAMAN RANGE VOLCANIC CENTER
LOBE OF CALIENTE CAULDRON COMPLEX
CALIENTE CAULDRON COMPLEX
STRUCTURAL CHAOS
KANE SPRINGS WASH VOLCANIC CENTER
STRUCT-URAL CHAOS
LINCOLN COUNTY
CLARK COUNTY

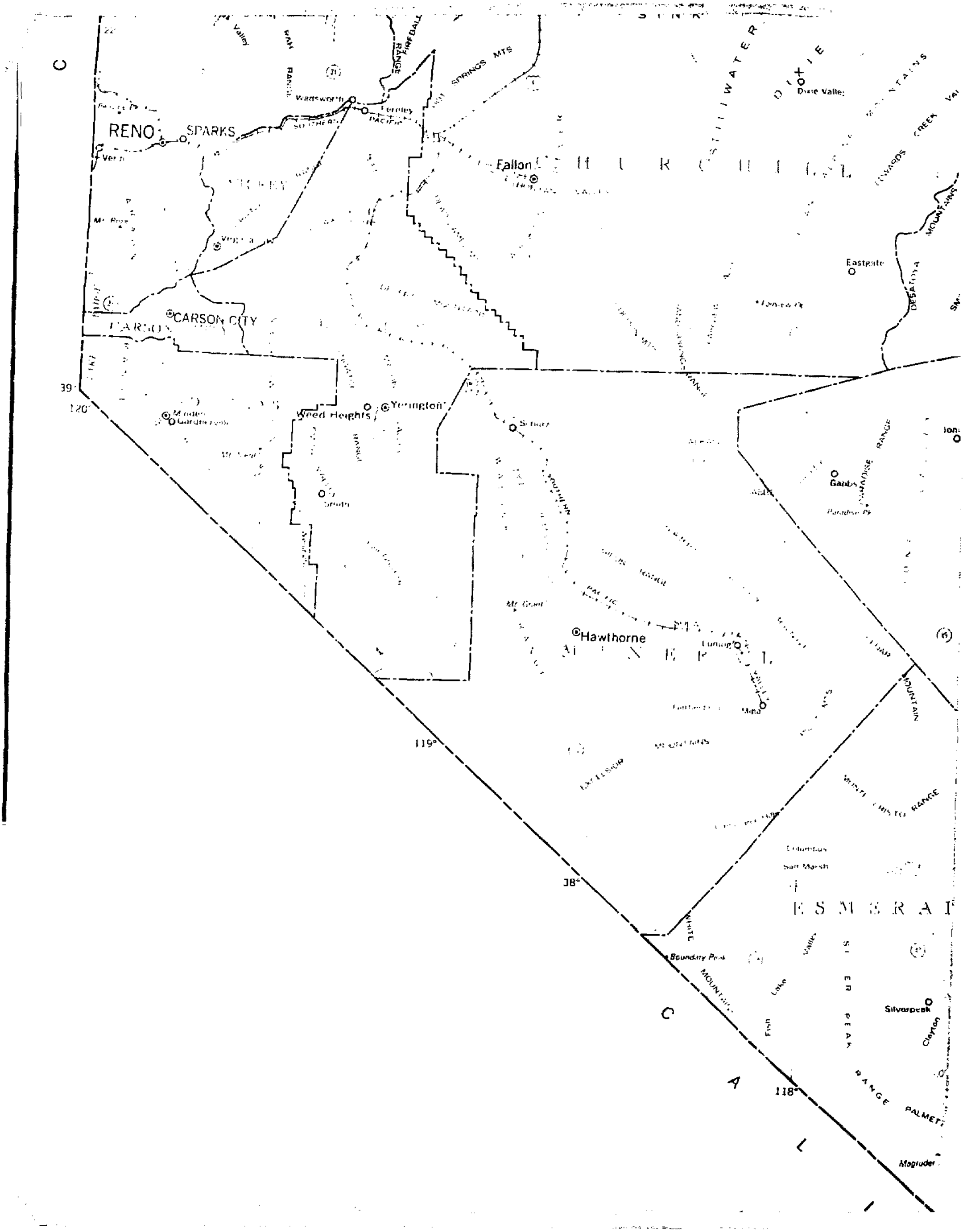
NEVADA BUREAU OF MINES AND GEOLOGY



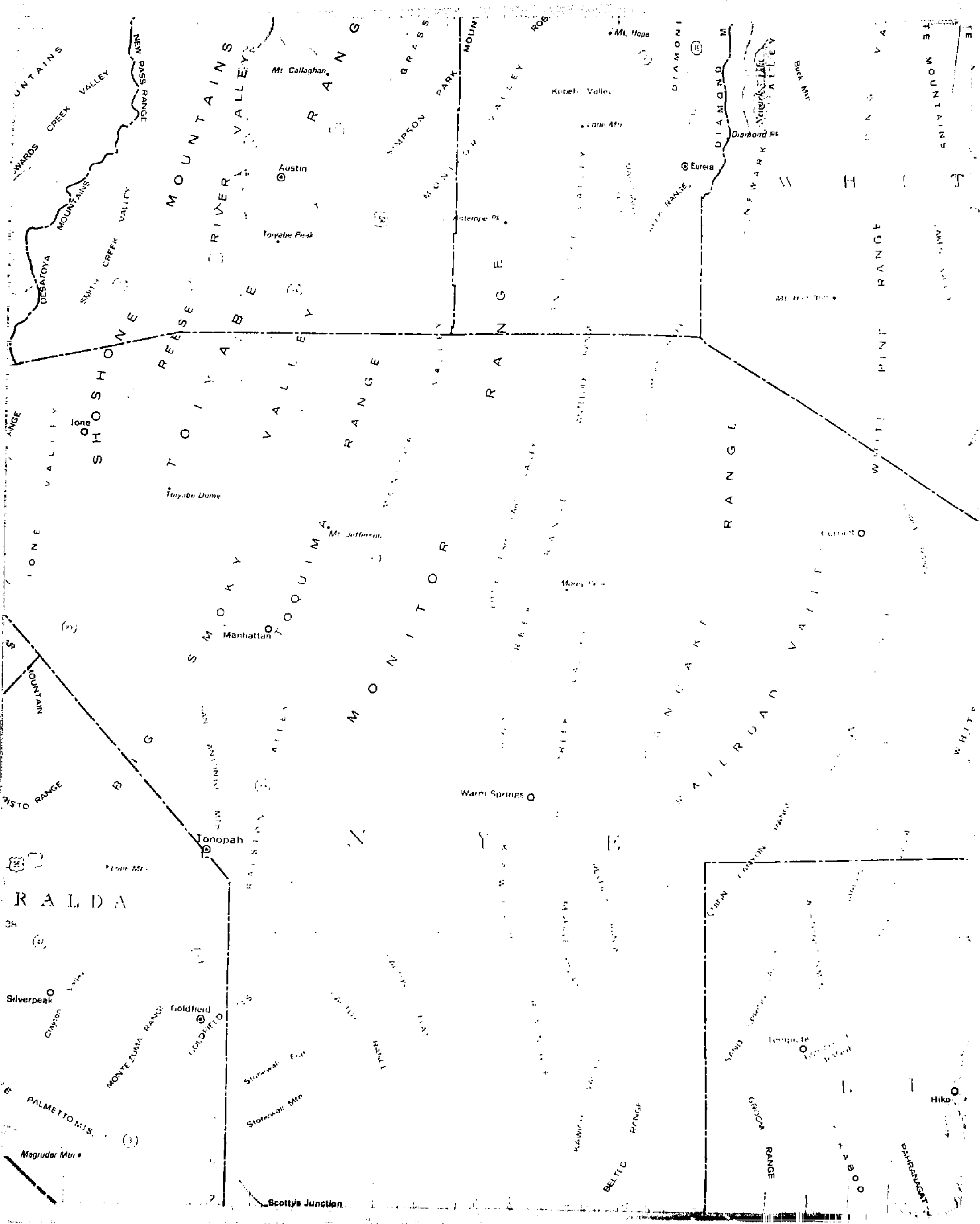

Owyhee
Mountain City
INDEPENDENCE MOUNTAINS
MOUNTAINS
Elko
Lamoille
Carlin
Battle Mountain
Palisade
Ruby Dome
Jiggs
PACIFIC
LAKE

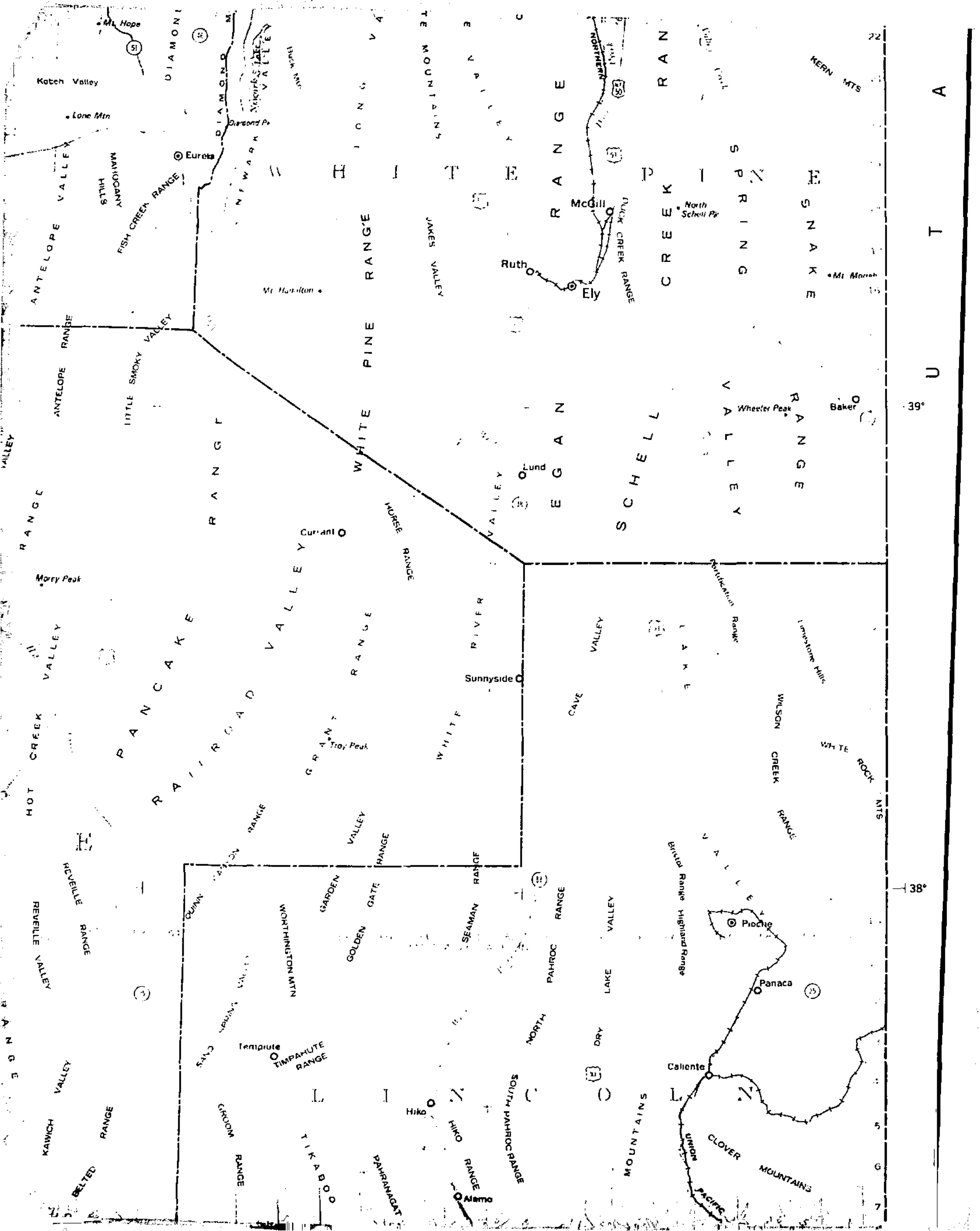
MAP 43 TOPOGRAPHIC MAP OF NEVADA



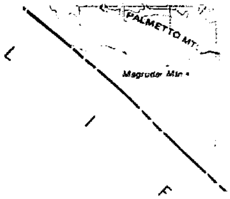


RENO
SPARKS
Wadsworth
Fernley
SOUTHERN PACIFIC
Fallon
CARSON CITY
Weed Heights
Yerington
Schurz
Hawthorne
Luning
Mina
Gabbs
Eastgate
Dixie Valley
Silverpeak
Clayton
Magruder
Boundary Peak
Columbus Salt Marsh
STILLWATER
HOT SPRINGS MTS
FIREBALL RANGE
DESATOYA MOUNTAINS
EDWARDS CREEK
PARADISE RANGE
Paradise Pk
MONTE CRISTO RANGE
SILVER PEAK RANGE
WHITE MOUNTAINS
Fish Lake Valley
PALMETTO
EXCELSIOR MOUNTAINS
Mt Grant
CHURCHILL
ESMERA
120°
119°
118°
39°
38°


NEW PASS RANGE
EDWARDS CREEK VALLEY
DESATOYA MOUNTAINS
SMITH CREEK VALLEY
SHOSHONE MOUNTAINS
REESE RIVER VALLEY
TOIYABE RANGE
Mt. Callaghan
Mt. Hope
Kobeh Valley
Lone Mtn
SIMPSON PARK
Austin
Eureka
Diamond Pk
DIAMOND MTS
NEWARK VALLEY
Buck Mtn
Antelope Pk
Toiyabe Peak
WHITE PINE RANGE
Ione
Toiyabe Dome
Mt. Jefferson
TOQUIMA RANGE
MONITOR RANGE
SMOKY
BIG
Manhattan
RAILROAD VALLEY
Warm Springs
Tonopah
Lone Mtn
RALDA
Silverpeak
Goldfield
GOLDFIELD
MONTEZUMA RANGE
PALMETTO MTS.
Stonewall Mtn
Magruder Mtn
Scottys Junction
RANGE
BELTED RANGE
GRANT RANGE
Hiko
PAHRANAGAT



Mt. Hope
Katch Valley
Lone Mtn
Eureka
Diamond Pk
ANTELOPE VALLEY
MAHOGANY HILLS
FISH CREEK RANGE
DIAMOND
NEWARK VALLEY
LONG VALLEY
MAVERICK VALLEY
W H I T E P I N E
McGill
Ruth
Ely
DUCK CREEK RANGE
North Schell Pk
SCHELL CREEK RANGE
SPRING VALLEY
SNAKE RANGE
KERN MTS
Mt. Moriah
Mt. Hamilton
WHITE PINE RANGE
JAKES VALLEY
EGAN RANGE
ANTELOPE RANGE
LITTLE SMOKY VALLEY
Wheeler Peak
Baker
39°
Lund
WHITE RIVER VALLEY
Currant
HORSE RANGE
Morey Peak
PANCAKE RANGE
RAILROAD VALLEY
GRANT RANGE
Troy Peak
Sunnyside
CAVE VALLEY
LAKE VALLEY
Limestone Hills
WILSON CREEK RANGE
WHITE ROCK MTS
HOT CREEK VALLEY
QUINN CANYON RANGE
GARDEN VALLEY
GOLDEN GATE RANGE
SEAMAN RANGE
WORTHINGTON MTN
NORTH PAHROC RANGE
DRY LAKE VALLEY
Bristol Range
Highland Range
Pioche
Panaca
38°
REVEILLE RANGE
REVEILLE VALLEY
SAND SPRING VALLEY
Tempiute
TIMPAHUTE RANGE
Hiko
HIKO RANGE
SOUTH PAHROC RANGE
L I N C O L N
Caliente
UNION PACIFIC
CLOVER MOUNTAINS
MOUNTAINS
KAWICH VALLEY
KAWICH RANGE
BELTED RANGE
GROOM RANGE
TIKABOO
PAHRANAGAT
Alamo
U T A H



NEVADA BUREAU OF MINES AND GEOLOGY
UNIVERSITY OF NEVADA, RENO

TOPOGRAPHIC MAP OF NEVADA

EDITION OF 1972

Scale 1:1,000,000
1 inch equals approximately 16 miles

10 0 10 20 30 40 50 Miles

10 0 10 20 30 40 50 Kilometers

Contour interval 1000 feet

Modified from U. S. Geological Survey 1:500,000 scale topographic map of Nevada, 1965. North American datum. Lambert conformal conic projection based on standard parallels 33° and 45°.

Modification and cartography by Susan [illegible] Nichols and [illegible] A. [illegible]

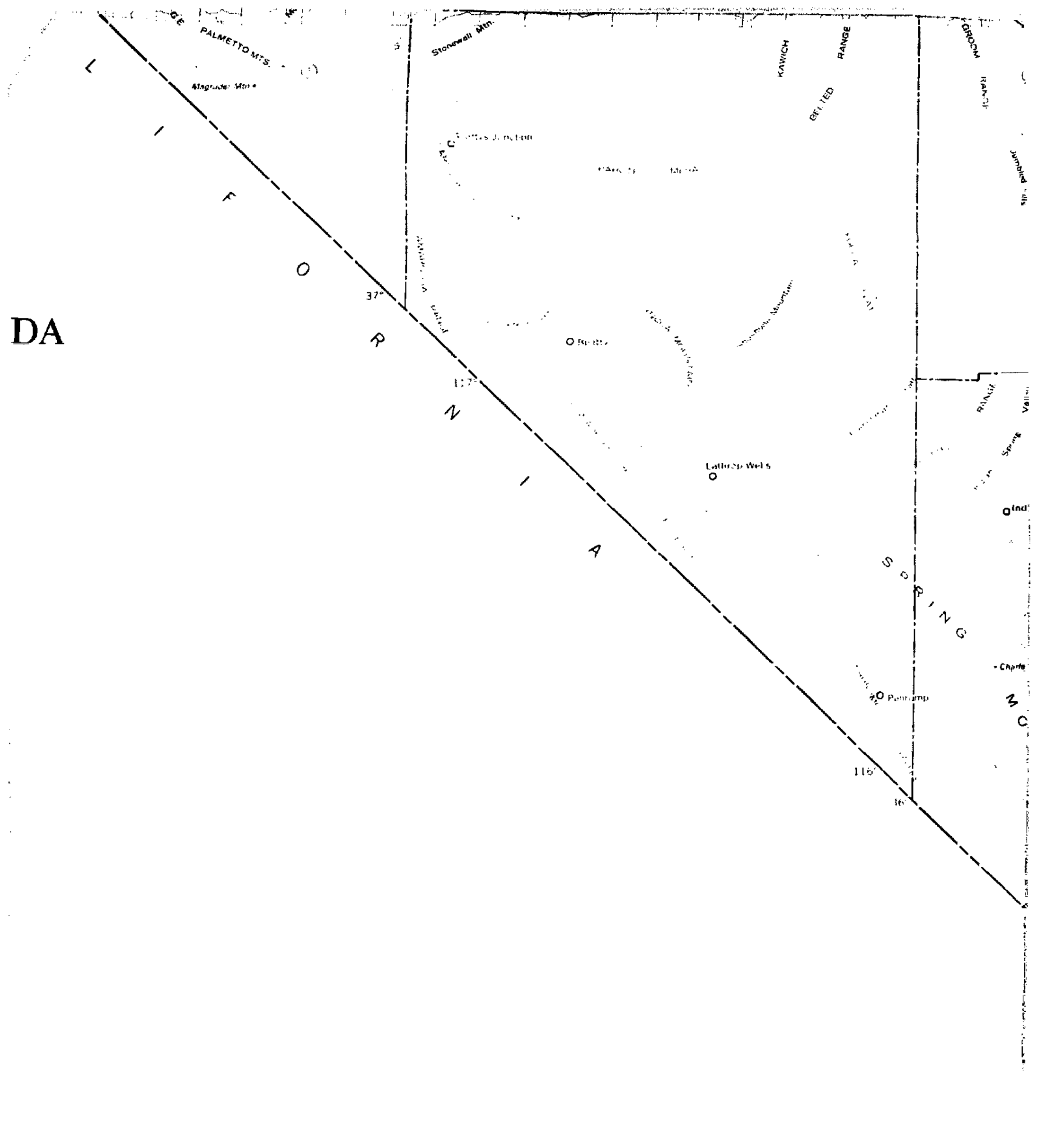
POPULATION KEY

RENO	over 25,000
SPARKS	10,000-25,000
Fallon	2,500-10,000
Lovelock	1,000-2,500
Fernley	less than 1,000

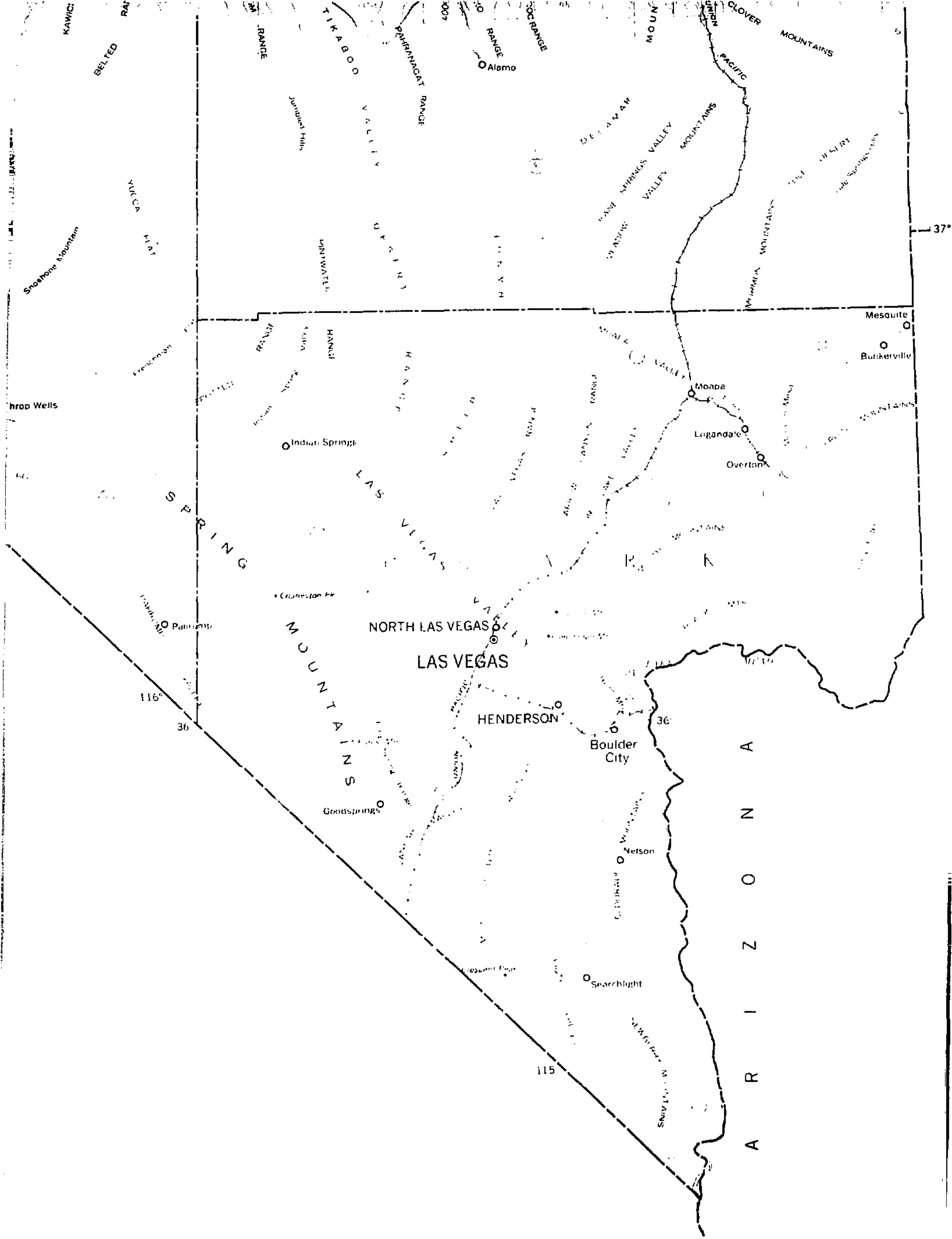
LEGEND

⊙ County seat
o Other [illegible]
Paved road
Unpaved road
Interstate highway
U. S. highway
State highway

FOR SALE BY NEVADA BUREAU OF MINES AND GEOLOGY,
UNIVERSITY OF NEVADA, RENO, NEV. 89507
PRICE ONE DOLLAR



PALMETTO MTS.
Magruder Mtn
Stonewall Mtn.
KAWICH
RANGE
BELTED
GROOM
L I F O R N I A
37°
DA
117°
Lathrop Wells
Pahrump
116°
36°
S P R I N G



BELTED
TIKABOO
PAHRANAGAT RANGE
Alamo
CLOVER MOUNTAINS
UNION PACIFIC
DELAMAR MOUNTAINS
YUCCA FLAT
Snoshone Mountain
37°
Mesquite
Bunkerville
Moapa
Logandale
Overton
Indian Springs
SPRING MOUNTAINS
LAS VEGAS VALLEY
NORTH LAS VEGAS
LAS VEGAS
HENDERSON
Boulder City
116°
36
36°
Goodsprings
Nelson
Searchlight
115
ARIZONA