Cenozoic Volcanism and Sedimentation, Silver Peak Region, Western Nevada and Adjacent California

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ABSTRACT

Cenozoic deposits of the Silver Peak region, western Nevada, and adjacent California consist principally of continental sedimentary and pyroclastic rocks of the Esmeralda Formation and lavas and tuffs of the Silver Peak volcanic center.

The sedimentary rocks comprise several thick sequences of tuffaceous volcanic sandstone and siltstone and interbedded air-fall tuff. These rocks were deposited in basins that coincide in a general way with the present valleys. Thick wedges of conglomerate and sandstone occur along the basin margins and reflect source areas.

Most of the sedimentary rocks were deposited under fluctuating fluviatile and lacustrine conditions, but paludal conditions prevailed locally. Abrupt facies changes and numerous local unconformities indicate that deposition was not uniform within a given basin.

The sedimentary rocks range in age from late Miocene to late Pliocene. The oldest reliably dated rocks in the Esmeralda Formation are 13.1 m.y.

by K-Ar (Barstovian), and all sedimentary strata are younger than an ash-flow sheet dated at 21.5 m.y. by K-Ar. An air-fall tuff in the upper part of the section has a K-Ar age of 4.3 m.y.

Rocks of the Silver Peak volcanic center, 4.8 to 6.1 m.y. by K-Ar, crop out principally in the central part of the Silver Peak Range. Along the margins of the range, they overlie and interfinger with the various sedimentary sequences. The volcanic rocks are mostly rhyolite and trachyandesite tuffs and flows with subordinate basalts and andesites.

Basin and Range faulting began in late early to middle Miocene time and has continued intermittently to the present, but present topography was largely established by late Pliocene time.

CONTENTS

INTRODUCTION

Regional Geologic Significance

The geologic evolution of the Basin and Range province in the central part of western Nevada is recorded principally in the Tertiary volcanic deposits. One of the best-exposed areas in which to study the volcanic-tectonic history of western Nevada is the Silver Peak region. Here, Tertiary volcanism is recorded not only by lava flows and tuffs, but by thick sequences of tuffaceous sedimentary rocks that underlie the major valleys. The Tertiary stratigraphy reflects the volcanic history and tectonic evolution of the region, and the sequence of events can be determined precisely by K-Ar dates.

Two principal periods of volcanism are represented in the Silver Peak region: one in early Miocene time, probably before the initial phase of Basin and Range faulting, the other in late Miocene to late Pliocene time. Evidence of the earlier volcanic activity is mostly indirect, for the thick and widespread ash-flow sheets of Oligocene and early Miocene age that occur throughout east-central Nevada and west-central Utah are largely missing in the Silver Peak region. However, thick sequences of Miocene and Pliocene volcanogenic sedimentary rocks crop out in the region. The only older Tertiary volcanic unit exposed in the area is an early Miocene ash-flow tuff that crops out locally at the north end of the Silver Peak Range. However, the abundance of volcanic detritus in the Miocene and Pliocene sedimentary rocks indicates that the older volcanic units must have been much more extensive at an earlier time.

Many thin beds of air-fall tuff crop out in the sedimentary sequences. Unlike the sedimentary rocks composed chiefly of dacitic detritus, the tuffs are rhyolitic. Some of these may have been locally derived, but others, especially the fine-grained vitric tuffs, the so-called silver-ash beds, were probably erupted from vents to the west or northwest.

Pliocene volcanic rocks of the region were erupted chiefly from the Silver Peak volcanic center located in the central part of the Silver Peak Range, one of a series of late Tertiary volcanic centers in south-central and southwestern Nevada. The Silver Peak center, with a middle to late Pliocene age, 4.8 to 6.1 m.y., is the youngest known center. Rocks of the volcanic center overlie and interfinger with the sedimentary rocks.

Tertiary deposits in the Silver Peak region, therefore, record at least two periods of volcanic activity. The region lies near the western margin of the Oligocene and Miocene ignimbrite province of central Nevada and these rocks are only sparsely represented. Most of the volcanic activity is younger and is probably more closely related to late Tertiary events that took place to the west and northwest.

Previous Work

The first significant study of the Silver Peak region was undertaken in 1899 by H. W. Turner (1900a, 1900b, 1902, 1909), who mapped the Silver Peak quadrangle and described the Cenozoic sedimentary and volcanic rocks. Stirton (1936) described the vertebrate fauna of the Esmeralda Formation and Knowlton (1900), Berry (1927), and Axelrod (1940) have described the flora. More recent investigations include reconnaissance mapping of the Hawthorne and Tonopah quadrangles to the north (Ferguson and Muller, 1949), the Coaldale quadrangle (Ferguson and others, 1953), and Esmeralda County (Albers and Stewart, 1965).

STRATIGRAPHY

General Statement

The Silver Peak region of western Nevada and adjacent California, which includes Big Smoky Valley, the type locality of the Esmeralda Formation, comprises approximately 1400 square miles and includes the Silver Peak Range, the Palmetto Mountains, and the Weepah Hills (Fig. 1). The Silver Peak Range, the dominant topographic feature of the region, is bounded on the east by Clayton and Big Smoky valleys and on the west by Fish Lake Valley. Northward, the range terminates abruptly at Coaldale; to the southeast, it merges with the Palmetto Mountains (Pl. 1).

The Cenozoic succession in the Silver Peak region consists of a thick accumulation of fluviatile and lacustrine sedimentary rocks and interlayered ash-flow tuffs, air-fall tuffs, and lava flows. The sedimentary deposits underlie the valleys and foothills of the region and crop out in the central part of the Silver Peak Range. Turner (1900a, p. 168) proposed the name Esmeralda Formation for these rocks

Figure 1. Index map showing location of the Silver Peak region of western Nevada and adjacent California.

and described a representative section in the southern part of Big Smoky Valley. As defined by Turner (1900b, p. 200–202), the Esmeralda Formation consists of approximately 15,000 feet of lacustrine shales, marls, and sandstones, with local breccia and conglomerate, that were deposited in a broad basin formerly occupied by Lake Esmeralda. This basin, which occupied the present site of Clayton, southern Big Smoky, and Fish Lake valleys, was supposedly bounded by the Montezuma Mountains on the east, the White-Inyo Mountains on the west, and the Palmetto Mountains on the south, with the northern limit unknown. Most of the volcanic rocks in the area were excluded from the formation, and it was assigned a Neocene (Miocene and probable Pliocene) age on the basis of fossil plant, fish, and molluscan remains (Turner, 1900b, p. 204).

Restudy of the type area has shown that the Esmeralda Formation of Turner was deposited in several local intermontane basins, not unlike those now found in the Basin and Range province. The sequences deposited in these basins appear generally similar but differ greatly in detail. Lateral and vertical facies changes are abrupt, and angular unconformities between units are common. The distribution, thickness variations, and facies patterns of the rocks suggest that the larger basins coincided approximately with the topographic depressions that exist today. In some places, however, the original basins have been uplifted hundreds of feet after they were filled with sediment. Most of the sedimentary rocks were deposited in fluviatile and lacustrine environments and are sparsely fossiliferous. As a result, the age of many sequences is imperfectly known, and correlation of sequences is based chiefly on radiometric ages obtained on interlayered tuffs. Radiometric and paleontologic ages agree closely and indicate a late Miocene to late Pliocene age for these rocks.

A Pliocene volcanic center is located in the central part of the Silver Peak Range (Stewart and Albers, 1962, p. 68; Robinson, 1967, p. 59). Rocks of this center are predominantly rhyolite and trachyandesite flows and tuffs with subordinate basalt and andesite flows and breccias. These rocks, which are middle to late Pliocene in age, 4.8 to 6.1 m.y. by K-Ar, interfinger with the upper part of the Esmeralda Formation along the flanks of the range.

Although it is possible to subdivide the Cenozoic succession of the Silver Peak region into numerous local formations, such an approach is considered impractical and confusing to an understanding of the regional geology. The definition of stratigraphic units on a rigorous lithologic basis would necessitate employing a large number of formational names, each useful in only one or two localities. The name Esmeralda Formation is used herein as originally defined by Turner (1900a, 1900b), and restricted to rocks at or near its type locality. Defined in this way, the Esmeralda Formation comprises a number of predominantly sedimentary sequences, which were deposited in the same environment and have the same genesis, and which crop out in Clayton Valley, Fish Lake Valley, and the southern part of Big Smoky Valley. Volcanic rocks of the Silver Peak center are excluded from the formation because of their different lithology and origin. They are distinct lithologic units that interfinger with the upper part of the sedimentary sequence.

The representative section of the Esmeralda Formation described by Turner (1900b, p. 200–202) is not a continuous superposed sequence, but represents two sequences of approximately equivalent age, which were probably deposited on opposite sides of the same basin. The upper part of Turner's section (southern part of Big Smoky Valley) is the most complete section of the Esmeralda Formation in the region, but it is different from nearby sections of the Esmeralda.

In the following discussion, the Cenozoic succession in the southern part of Big Smoky Valley, Clayton Valley, Fish Lake Valley, and the Silver Peak Range, is described (Pl. 1). Each of the valleys is thought to represent an individual late Tertiary basin, within which sedimentary rocks accumulated. The sequence in the Silver Peak Range indicates a complex history of subsidence and uplift, accompanied by folding and faulting and by extensive volcanic activity. Age designations follow Evernden and others (1964, p. 167), and a portion of their correlation and time placement diagram (Evernden and others, 1964, p. 167) is reproduced in Figure 2.

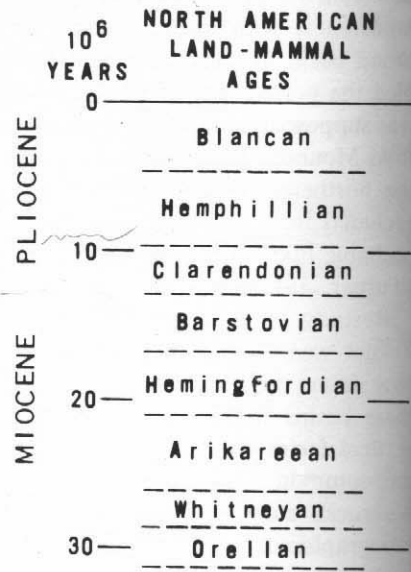

Figure 2. Radiometric age and North American land-mammal age. Modified from Evernden and others (1964, p. 167, Fig. 1).

Big Smoky Valley

Big Smoky Valley, the type locality of the Esmeralda Formation, is a desert basin underlain by the Esmeralda Formation and floored with Quaternary alluvium. The Esmeralda Formation crops out principally in three areas along the valley margins: the Alum area on the east, and the Coaldale and Vanderbilt areas on the west (Pl. 1). Turner (1900b, p. 200–202) measured a combined thickness of nearly 15,000 feet of strata in the Coaldale and Alum areas, but the sequences in these two areas are contemporaneous, as will be shown, and probably represent different facies within the basin. Approximately 9000 feet of sediments are present.

Alum area. The Alum sequence crops out over a 40-square-mile area on the east side of the valley. We measured more than 9000 feet of strata in this section, but the formation thins abruptly eastward and pinches out against the pre-Tertiary basement rock. Several other small outcrops occur farther east in the Weepah Hills.

Neither the base nor the top of the formation is exposed in the Alum area. The sequence, which dips about 30° to the south, is divided into seven units (A to G in ascending order). The lower six units are conformable (Fig. 3).

UNIT A

At the base of the sequence is a 540-foot-thick unit of pebble conglomerate composed of Paleozoic clasts with interbedded sandstones, siltstones, and limestones, and intercalated lenses of breccia made up of Paleozoic fragments.

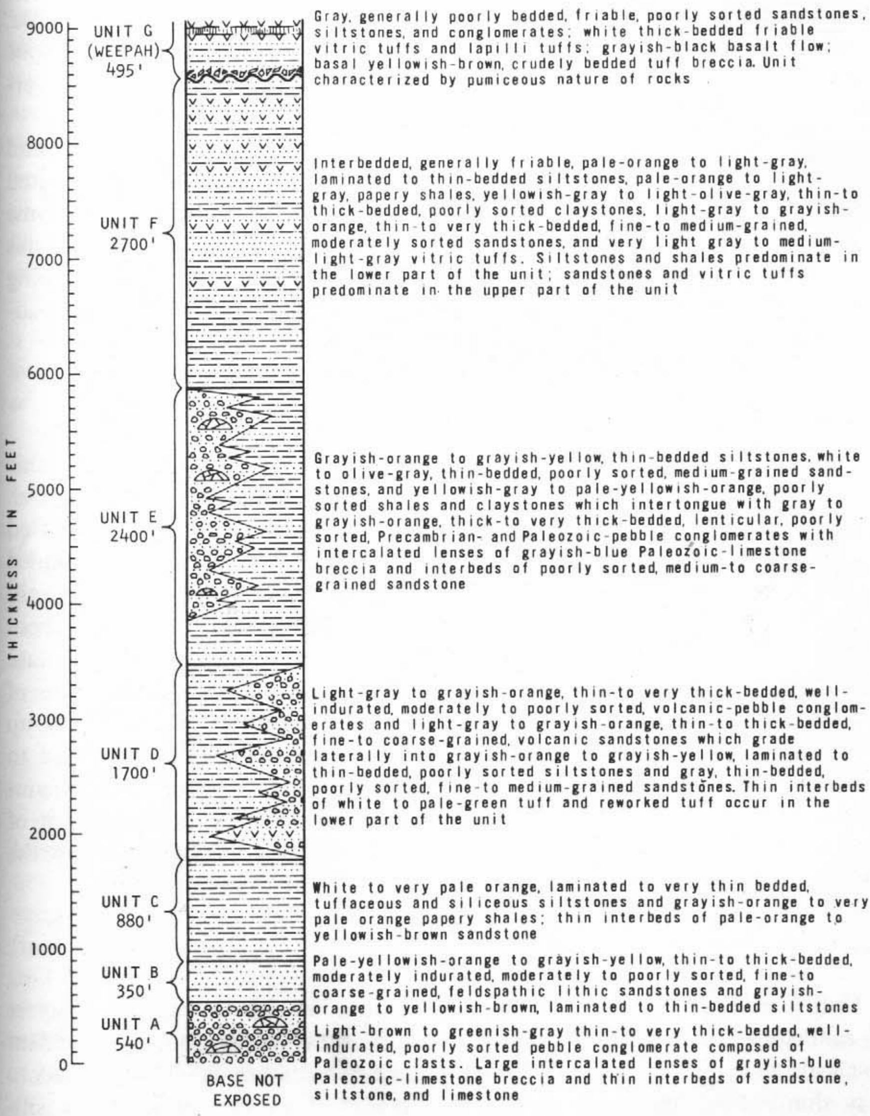

Figure 3. Composite measured section of the Esmeralda Formation in the Alum area, Big Smoky Valley.

The conglomerates are light brown to dark greenish-gray rocks composed of pebbles of chert, limestone, shale, and quartzite that are set in a sandy to silty matrix of the same composition. The pebbles range from 2 mm to 50 mm in diameter and have an average diameter of 10 mm. Scour-and-fill channels and crossbedding occur locally, but are not common.

Interbeds of feldspathic, lithic sandstone and siltstone and fresh-water limestone make up about 10 percent of the unit. The sandstones are fine- to medium-grained and consist of subangular grains of feldspar (chiefly orthoclase), quartz, and rock fragments (quartzite, chert, shale, and limestone). Rock fragments and feldspar make up 65 to 85 percent of typical samples; quartz rarely exceeds 5 percent. The grains are set in a silty to argillaceous iron-stained matrix. Authigenic K-feldspar is commonly present as overgrowths on orthoclase grains.

Lenses of grayish-blue limestone breccia, as much as 1500 feet long and 150 feet thick, occur at several horizons in unit A. They consist of brecciated masses of Lower Cambrian limestone with minor amounts of shale at some places. Similar breccias occur throughout the Alum sequence. The breccias are restricted to the eastern margin of the basin near areas of outcropping Cambrian strata and are presumed to have formed by landsliding from adjoining steep slopes.

UNIT B

The conglomerates of unit A grade upward into a sequence of feldspathic lithic sandstones and siltstones characterized by abundant vitric material. Most of the rocks are yellowish-orange, thin- to thick-bedded, poorly sorted sandstones. They consist principally of sand-size, subangular to subrounded rock fragments, feldspar, and quartz in a matrix of zeolitized vitric or argillaceous material. Pre-Tertiary sedimentary rock fragments make up about 50 percent of typical samples; the remaining percentage consists of orthoclase and a few percent each of plagioclase and quartz. Authigenic overgrowths of K-feldspar on orthoclase are common, and vitric material, which makes up as much as 25 percent of some samples, is either devitrified or altered to analcime and montmorillonite. Grayish-orange, slightly sandy, tuffaceous siltstones are interbedded with the sandstones and form about 30 percent of unit B. Thin-bedded granule conglomerates and gray cherts make up the remainder of this unit.

UNIT C

Unit C consists of about 880 feet of siltstone and shale with a few layers of sandstone. In contrast to units A and B, these rocks contain abundant epiclastic volcanic detritus. The siltstones and shales are finely laminated to very thin-bedded and weather into shaly pieces. They are tuffaceous or siliceous and range in color from white to very pale orange. Interbedded sandstones are pale orange to yellowish brown, thin-bedded, fine- to medium-grained and poorly sorted. Volcanic rock fragments, feldspar (orthoclase, andesine, and rare sanidine), and small amounts of quartz, biotite, and hornblende make up the bulk of these rocks. The matrix consists of vitric material altered to clinoptilolite, opal, or montmorillonite, or all three.

UNIT D

Unit D is a wedge-shaped body of interbedded conglomerate, sandstone, siltstone, and tuff. Approximately 1700 feet of strata are exposed in the measured section, but the unit thins abruptly to the east. Conglomerates and sandstones make up most of the western portion of the unit, whereas siltstones and fine-grained sandstones predominate in the eastern portion. The rocks are characterized by a high percentage of pyroclastic and epiclastic volcanic detritus; interbeds of tuff occur in the lower part of the western portion. Sedimentary features, except for scour-and-fill channels, are rare.

The conglomerates and sandstones are poorly sorted, thin- to very thick-bedded, and consist of rock fragments, quartz, feldspar, and pyroxene with small amounts of hornblende and biotite. Sanidine is the principal feldspar, although plagioclase (andesine and oligoclase) predominate in some samples; a small amount of orthoclase occurs in the eastern samples. The matrix consists chiefly of vitric material altered to clinoptilolite, opal, or montmorillonite, or all three.

Thin-bedded sandy siltstones make up the bulk of the eastern portion of unit D. They are poorly sorted and consist of Precambrian and Paleozoic rock fragments, quartz, and feldspar in an argillaceous or tuffaceous matrix.

White to very pale green tuffs are common in the lower part of the unit. They grade laterally and vertically into reworked tuffs and tuffaceous sandstones. They are fine- to medium-grained and consist of rock fragments and crystals of quartz, sanidine, and oligoclase in a matrix of vitric material. Fresh glass (R. I. $= 1.496 \pm 0.002$) occurs in a few samples, but most vitric material has been altered to mixtures of clinoptilolite, opal, and montmorillonite.

UNIT E

A 2400-foot-thick sequence of siltstone, shale, and sandstone with intertongues of conglomerate and breccia makes up unit E. The conglomerates and breccias form a wedge that westwardly intertongues with the finer grained sediments and eastwardly pinches out against the pre-Tertiary basement. The fine-grained rocks are rich in volcanic detritus, whereas the conglomerates and breccias consist principally of locally derived Precambrian and Paleozoic detritus.

The sandstones and siltstones are white to grayish-yellow, thin-bedded, and poorly sorted. They consist of quartz, feldspar, and rock fragments in a calcareous, argillaceous, or tuffaceous matrix. Quartz and feldspar (mostly sanidine) make up from 40 to 50 percent of most samples; quartz is the more plentiful mineral. Lithic fragments are abundant; they consist of Precambrian and Paleozoic sedimentary rock in the east and volcanic material in the west.

Shales and claystones of unit E are yellow-gray, poorly sorted rocks of uniform composition. Most samples contain from 5 to 10 percent of silt-size grains of quartz, feldspar, and rock fragments. A few thin layers of silty limestone are interbedded with these rocks. The limestones are generally fossiliferous, and contain casts of pelecypods, gastropods, and ostracods.

The conglomerates consist predominantly of subangular pebbles of Precambrian and Paleozoic dolomite, chert, limestone, shale, and quartzite in a sandy matrix. Pebbles of granite and diorite are present in a few samples. Lenses of breccia, similar to those in unit A, occur at several horizons in the conglomerates.

UNIT F

Unit F is a sequence of interbedded siltstone, sandstone, shale, claystone, and tuff, approximately 2700 feet thick. Siltstones and shales predominate in the lower part of the unit, and sandstones and tuffs dominate the upper part.

The siltstones and shales are generally thin-bedded, varicolored, and friable, and weather to smooth convex slopes with a popcorn-like surface. Most of these rocks are tuffaceous and some contain carbonaceous material. They consist almost entirely of pyroclastic and epiclastic volcanic detritus. Silt- and sand-size grains of quartz, feldspar, and volcanic rock fragments are set in a matrix composed principally of montmorillonite.

The sandstones are fine- to medium-grained, poorly sorted, and rich in pyroclastic material. They vary in color from light gray to grayish-orange and consist of quartz and feldspar crystals in a matrix of altered vitric material. Plagioclase (andesine and oligoclase) is the principal feldspar, but sanidine predominates in some samples. In most samples, the vitric material is fresh; in others, it has been replaced by clinoptilolite, opal, and montmorillonite.

Light-gray vitric tuffs are interbedded with the sandstones; at least 12 layers of tuff, from 1 to 8 feet thick, occur in the upper half of the unit. These tuffs are very friable and consist chiefly of glass shards (R. I. $= 1.495$ to 1.498 ± 0.002); crystals of quartz, plagioclase, sanidine, and biotite are usually present but never exceed 5 per cent by volume. These rocks are similar to the gray vitric tuffs that occur in Pliocene sequences throughout western and eastern Nevada (Van Houten, 1956, p. 2814).

UNIT G

Unit G unconformably overlies unit F and consists of about 500 feet of tuff, tuffaceous sandstone, siltstone, and minor conglomerate capped by a basalt flow (Pl. 2, fig. 1). A tuff-breccia marks the basal unconformity, which truncates rocks of unit F at angles of 5° to 15°. The rocks consist chiefly of epiclastic and pyroclastic volcanic materials, and the unit is characterized by abundant pumice lapilli tuffs.

Light gray, poorly sorted sandstones and siltstones make up the bulk of

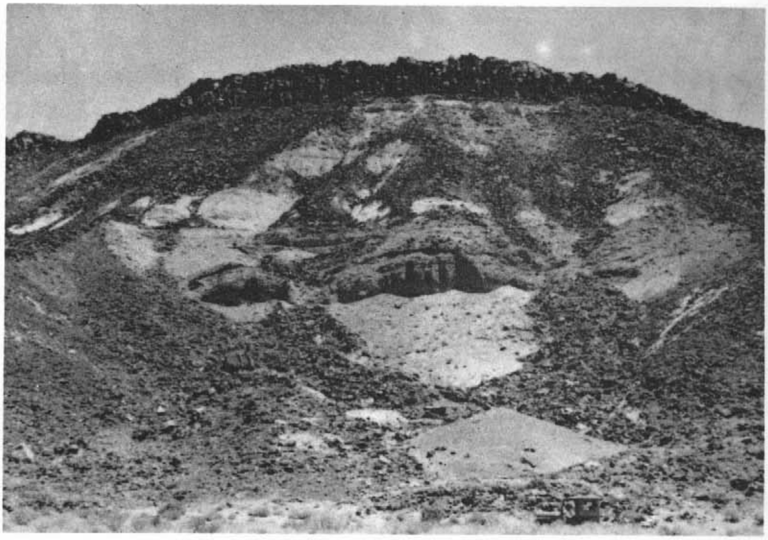

Figure 1. Unit G of the Esmeralda Formation in the Alum area of Big Smoky Valley. Tuff directly below basalt has a K-Ar age of 6.9 m.y.

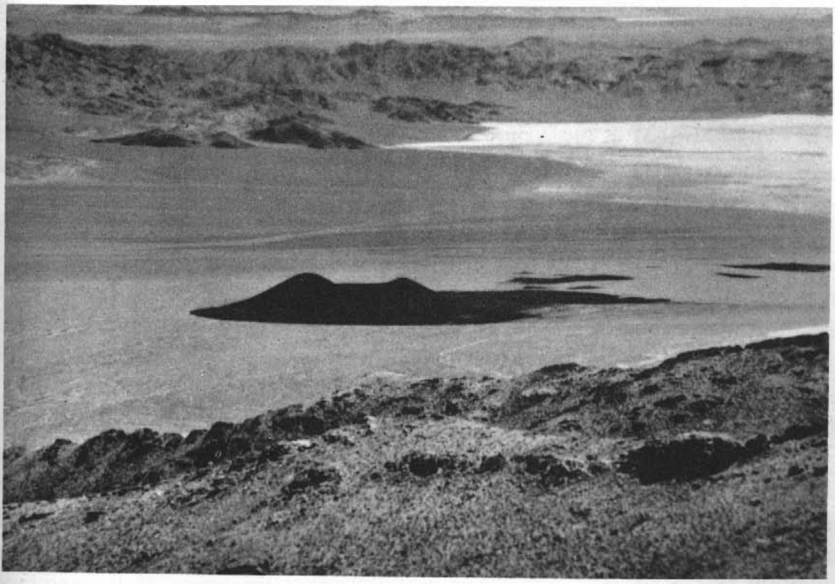

Figure 2. Recent basaltic cinder cone and flow in the northwest part of Clayton Valley.

CENOZOIC ROCKS OF BIG SMOKY AND CLAYTON VALLEYS the unit. These rocks typically are poorly bedded, friable, and often pumiceous. Lenticular masses of conglomerate mark old channels in the fine-grained rocks. Volcanic rock fragments, feldspar (sanidine and andesine), and quartz make up from 60 to 90 percent of most samples; unaltered vitric material and biotite make up the remaining percentages.

Rhyolitic vitric and lapilli tuffs make up about 30 percent of the unit. The vitric tuffs, confined to the lower part of the unit, are similar to those of unit F. The lapilli tuffs are white, thick-bedded, and poorly sorted; some are reworked and exhibit small-scale planar cross-bedding. Crystals, set in a matrix of fresh vitric material (R. I. $= 1.494 \pm 0.002$), make up 5 to 25 percent of these rocks.

The sequence is capped by a 5- to 30-foot-thick layer of porphyritic olivine basalt which is locally overlain by a layer of massive, coarse-grained, white pumice lapilli tuff containing many tear-shaped spheroids of obsidian.

AGE OF THE ALUM SEQUENCE

Fossils of fresh-water mollusks, ostracods, and fish, and some leaf imprints occur in this sequence. Of these, the mollusks are most reliable indicators of age; their value is limited, however, because of the long time range of most species.

A molluscan assemblage collected from the lower part of unit E contains several species (*Vorticifex tryoni, Lanx* cf. *L. undulatus, Pisidium* n.sp.) and is assigned a Miocene (Barstovian) age (Firby, 1963, oral commun.). Approximately 4500 feet of strata underlie this assemblage, and are tentatively assigned a Barstovian and possibly Hemingfordian age.

The upper part of the Alum sequence is assigned a middle Pliocene age, based on a K-Ar date of 6.9 m.y. (Hemphillian) that was obtained from a biotite tuff in unit G (Table 1, no. 13). The 4000 feet of strata between the dated horizons in units E and G are assigned to the Clarendonian, chiefly on the basis of a molluscan assemblage (*Vorticifex* sp., *Sphaerium* sp.) in unit F (Firby, 1963, oral commun.).

Coaldale area. The Coaldale sequence consists predominantly of tuffaceous and volcanic sandstone, siltstone, and shale. It rests unconformably on an older tuff sequence and is locally overlain by a thin veneer of alluvium. The rocks form a north-dipping, homoclinal sequence which extends northward beyond the Silver Peak region toward the Monte Cristo Range. More than 3000 feet of strata are present, but the exact thickness of the sequence cannot be determined, because the rocks are folded and faulted near the base. In this area, the sequence can be divided into a lower part of predominantly fine-grained rocks, a middle part of alternating fine-grained and relatively coarse-grained rocks, and an upper part of indurated volcanic breccia (Fig. 4).

Light gray, siliceous or tuffaceous shales and siltstones make up the bulk of the lower part of the sequence; the remainder consists of lignitic shales, coals, tuffaceous sandstones, granule conglomerates, fossiliferous limestones, and vitric tuffs. All rock types are thin- to very thin-bedded and moderately indurated. Sedimentary structures, except for poorly developed ripple marks, are rare. Volcanic and pyroclastic detritus predominate in the clastic rocks, but minor amounts of older rock fragments are also present. In a few samples, vitric material is altered to analcime.

Four coal-bearing units, from 20 to 40 feet thick, occur near the base of the sequence. The rocks exhibit all gradations from lignitic shale to bituminous coal. The presence here of bituminous coals in contrast to lignitic coals at a few other localities in the Esmeralda Formation is probably due to the

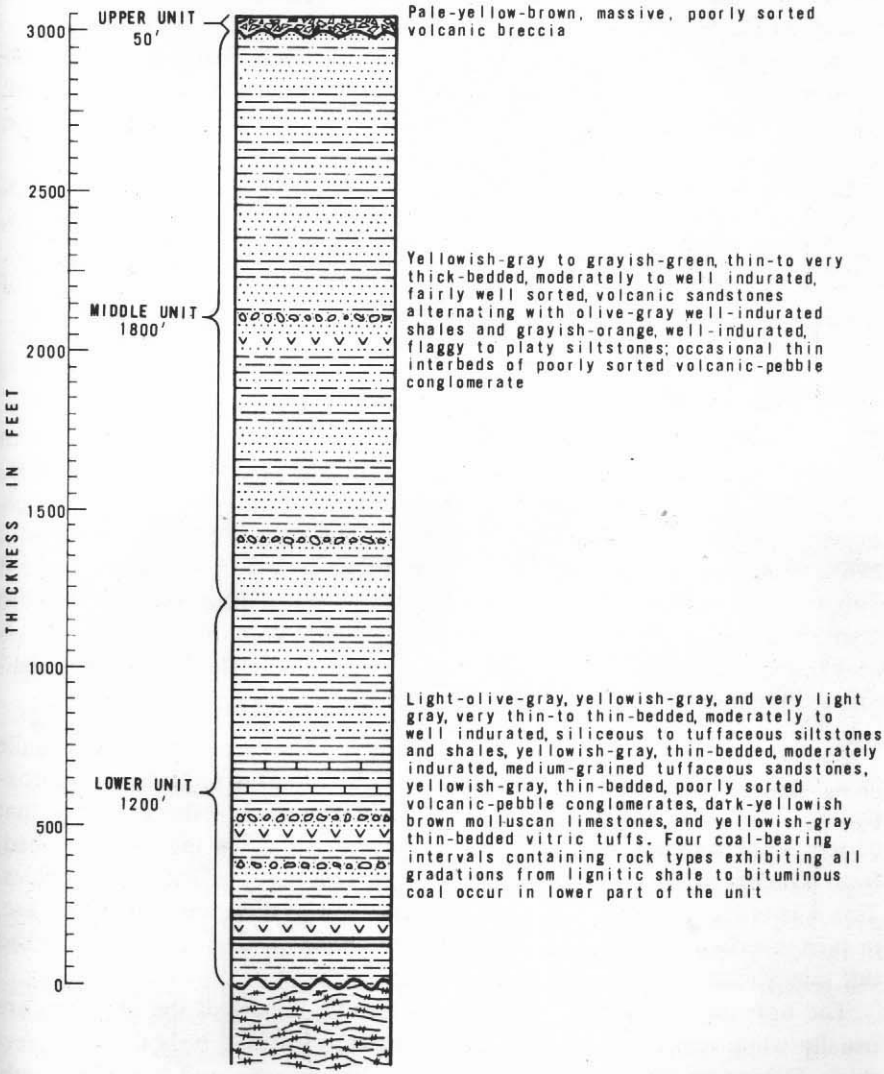

Figure 4. Measured section of the Esmeralda Formation in the Coaldale area, Big Smoky Valley.

intrusion of small plugs of rhyolite into the coal-bearing horizons (Ferguson and others, 1953).

The middle part of the sequence consists mostly of beds of gray-green, very fine- to medium-grained sandstone that alternate with layers of light gray shale and grayish-orange siltstone. The sandstones vary from thin- to very thick-bedded, and the latter are the more prevalent. They are moderately indurated, fairly well sorted, and consist principally of volcanic detritus and pyroclastic material. Sanidine, plagioclase (oligoclase and andesine), quartz, volcanic rock fragments and vitric material are the chief constituents of most samples; biotite, pyroxene, hornblende and Paleozoic rock fragments are usually present in minor amounts.

The shales are well indurated and vary from slightly carbonaceous to calcareous or tuffaceous. Most siltstones are flaggy or platy, well indurated, fairly well sorted, and tuffaceous. Well preserved fish remains, *Leuciscus,* are occasionally found in the shales and siltstones.

The sequence is capped by a 10- to 50-foot layer of volcanic breccia, which disconformably overlies the older rocks. The breccia is yellow-brown, poorly bedded and consists of angular to subrounded fragments of andesite, up to 2 feet in diameter. The fragments are embedded in a sandy matrix of comminuted andesite and some sedimentary rock fragments.

AGE OF THE COALDALE SEQUENCE

The lower part of the sequence is assigned a late Miocene (late Barstovian and early Clarendonian) age on the basis of plant remains (Axelrod, 1940), molluscan fossils (*Viviparus* sp., *Sphaerium* sp., *Pisidium* sp., *Lanx* sp.) collected from limestones above the coal-bearing intervals (Firby, oral commun., 1963), and a K-Ar date of 12.7 m.y. on biotite in a tuff that is interbedded with the coals (Table 1, no. 11). Mollusks collected from limestones more than 3500 feet above the base of the sequence and identified by Firby (*Valvata truckeensis, Perrinella cordillerana, Sphaerium* sp., *Vorticifex* sp.) indicate a Clarendonian age for the upper part of the sequence.

Vanderbilt area. The Vanderbilt sequence crops out in a 5-square-mile area, east and southeast of Emigrant Pass (Pl. 1). This sequence is approximately 2600 feet thick and overlies an older tuff which is the same tuff that underlies the sedimentary rocks in the Coaldale area. At the base is a bed, from 6 inches to 2 feet thick, of conglomerate composed of Paleozoic pebbles. This is overlain by 300 to 350 feet of tuffaceous claystone and tuff, which are, in turn, overlain by more than 2200 feet of interbedded sandstone, reworked tuff, sandy siltstone, and silty claystone (Fig. 5).

The tuffs and tuffaceous claystones in the lower part of the sequence are usually white and typically form massive, poorly defined beds up to 10 feet thick. Gradations exist between the tuffs and claystones, and they differ only in the degree to which their vitric material has been altered. The claystones consist predominantly of glass shards altered to montmorillonite, whereas the tuffs consist principally of fresh glass. Crystals of sanidine, andesine, and quartz are present in both types.

Sandstones in the upper part of the sequence are gray to green, thin-bedded, and poorly sorted. They consist of varying proportions of quartz, sanidine, plagioclase and rock fragments (mostly volcanic) in a matrix of montmorillonite with minor amounts of clinoptilolite and celadonite. The interbedded tuffs have been reworked to varying degrees and form layers from 1 to 20

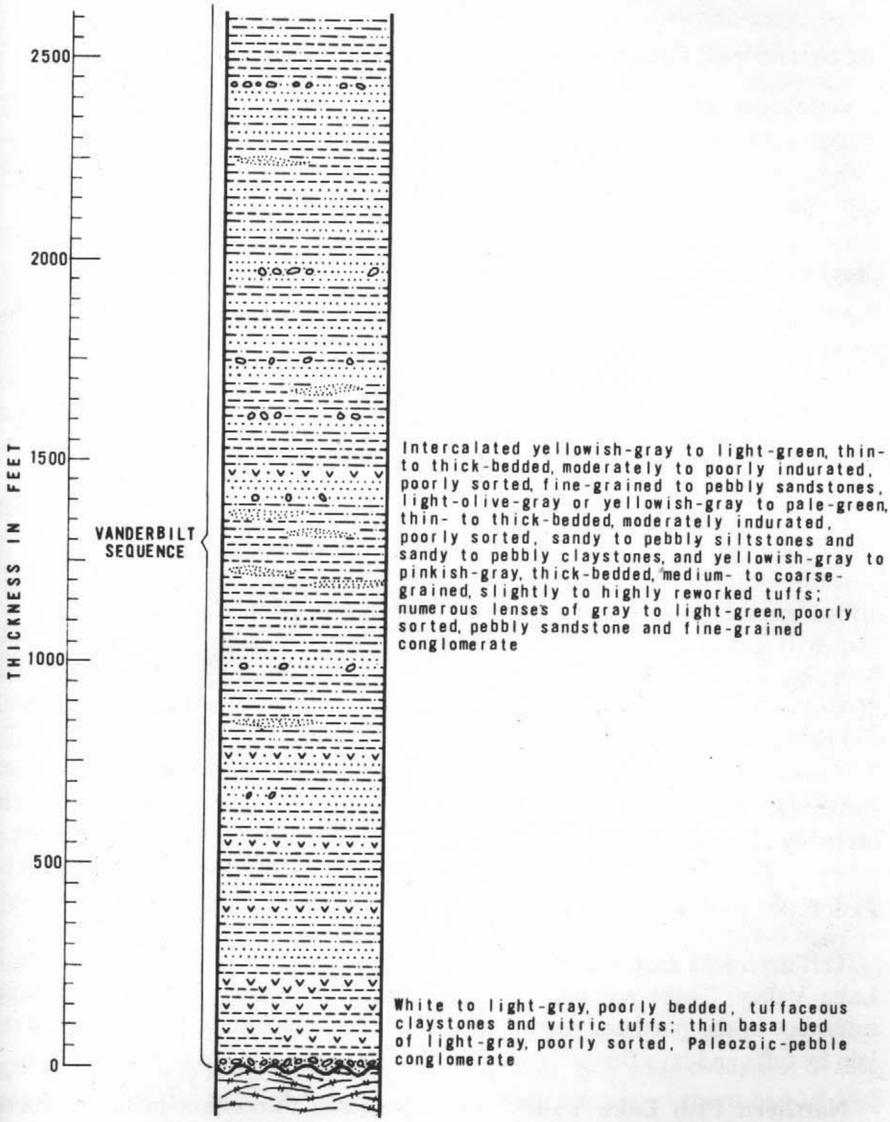

Figure 5. Measured section of the Esmeralda Formation in the Vanderbilt area, Big Smoky Valley.

feet thick. They are gray to pinkish-gray vitric tuffs which contain from 5 to 10 percent crystals — mostly sanidine, oligoclase, and quartz. Vitric material in most samples has been altered to montmorillonite, opal, and clinoptilolite.

Siltstones and claystones in the upper part of the sequence are thin- to thick-bedded and weather into smooth convex slopes. They vary from olive-gray to pale green and are typically poorly sorted. Silt-size grains of quartz and feldspar make up the bulk of the siltstones, and the claystones consist predominantly of montmorillonite.

AGE OF THE VANDERBILT SEQUENCE

Vertebrate remains collected from sandstone lenses in the middle of the sequence indicate a Miocene (Barstovian or Clarendonian) age (Webb, 1962, oral commun.). In addition to proboscidean remains, the following genera were identified: *Procamelus*(?), *Pliohippus*(?), and *Merycodus*.

Clayton Valley

Clayton Valley is a relatively small intermontane basin enclosed by the Silver Peak Range, the Palmetto Mountains, the Weepah Hills, and Clayton Ridge (Pl. 1). A playa occupies the northeast part of the basin; the remainder of the valley is floored with Holocene alluvium. Goat, Alcatraz, and Angel Islands, steep hills of faulted Paleozoic strata, project through the alluvial cover (Pl. 1).

Tertiary sedimentary and volcanic rocks, which crop out in the hills around the margin of the basin and in the narrow strip east of Angel Island, project beneath the central part of the valley. However, core samples from a well, drilled approximately 2⅓ miles south of the present playa, indicate more than 850 feet of Pleistocene and Holocene playa sediments beneath the valley floor, but show no trace of Tertiary rocks. Gravity profiles indicate that east of Goat Island, bedrock (rock with a density of 2.3 g cm^{-3}) is at least 1350 feet below the surface.

A small basaltic cinder cone and associated flow crop out in the northwest corner of the valley (Pl. 2, fig. 2). The cone is only slightly dissected and is probably Holocene in age.

Fish Lake Valley

Tertiary rocks crop out in the northern and extreme southern ends of Fish Lake Valley. These are mostly tuffaceous sedimentary rocks and reworked tuffs, but in the northern part of the valley the sedimentary sequence is overlain by tuffs and lava flows.

Northern Fish Lake Valley. The Esmeralda Formation in the northern part of Fish Lake Valley has long been famous for its well preserved and varied vertebrate fauna (Stirton, 1932, 1936). These rocks are predominantly tuffaceous sandstones and reworked tuffs with subordinate siltstones, pebble conglomerates, and cherts. The sequence dips generally to the east at angles from 15° to 30°, and has an exposed thickness of approximately 2000 feet.

The lower third of the section consists of poorly sorted brownish- to greenish-gray, crossbedded, tuffaceous sandstone composed of feldspar and volcanic rock fragments. This is overlain by approximately 300 feet of reworked sandy tuff, which is, in turn, overlain by approximately 800 feet of interbedded tuffaceous sandstone and siltstone, vitric tuff, volcanic pebble conglomerate, and minor chert. These rocks are thin- to medium-bedded, moderately indurated, and weather into small pinnacles. They are brownish-gray, poorly sorted rocks composed of volcanic detritus, chiefly feldspar and volcanic rock fragments in a tuffaceous matrix. Most sandstones and conglomerates exhibit small-scale cross-bedding, but other sedimentary structures are rare. Vitric material in these rocks has been mostly altered to montmorillonite and clinoptilolite.

The sedimentary sequence is unconformably(?) overlain by a rhyolitic ash-flow tuff from approximately 100 to 150 feet thick. This tuff also dips to the east and, along the eastern margin of the valley, is overlain by nearly 200 feet of interbedded sandstones, shales, vitric tuffs, and conglomerates. In the northwest corner of the valley, the sedimentary sequence is overlain by flows of rhyolite and basalt (Pl. 1).

AGE OF THE NORTHERN FISH LAKE VALLEY SEQUENCE

Mammalian fossils, especially *Nannippus tehonensis,* collected from rocks just above the middle of this sequence indicate a late Miocene (early Clarendonian) age (Evernden and others, 1964, p. 179). Tuffs associated with the fossil-bearing beds yield K-Ar ages of 11.1 and 11.4 m.y. (Table 1, nos. 9 and 10). Nearly 1200 feet of strata, probably Barstovian in age, underlie the early Clarendonian beds.

Southern end of Fish Lake Valley. The Esmeralda Formation occurs at the south end of Fish Lake Valley and in the low hills along the southwest side of the valley (Pl. 1). Here, the formation consists predominantly of volcanic tuffs, tuffaceous siltstones and sandstones, and coarse-pebble-to-boulder conglomerates. The thickness and facies pattern of these rocks indicate that the late Tertiary basin in the south end of Fish Lake Valley coincided with the present topographic depression. Sedimentary rocks in the hills which form the southwest edge of Fish Lake Valley and in Eureka Valley indicate that the basin extended into this area and that drainage flowed from Fish Lake Valley into Eureka Valley.

Two similar sections of tuffaceous, arkosic sandstone, siltstone, and conglomerate with interbeds of basalt and rhyolitic tuff were measured in this area: one, at the head of Willow Wash at the extreme southern end of Fish Lake Valley (Fig. 6); the other, at the mouth of Horse Thief Canyon on the east edge of Eureka Valley (Fig. 7). At both localities, a continuous section more than 1000 feet thick is present. Thinner basalt flows, basaltic agglomerates, rhyolitic tuffs, and various types of sedimentary rocks crop out in the hills north of Horse Thief Canyon and west of Fish Lake Valley.

In the southern end of Fish Lake Valley, the Esmeralda is more than 2000 feet thick (Fig. 6). Toward the bordering mountains on the east, this sequence thins abruptly, accompanied by a change from siltstone to boulder conglomerate. The upper three-fifths of this section (upper unit, Fig. 6) consists largely of buff, friable arkosic sandstone and intertonguing conglomerate, which merge imperceptibly upward into Holocene alluvium on the valley floor. Coarse granitic detritus is distributed throughout this part of the section. Granitic

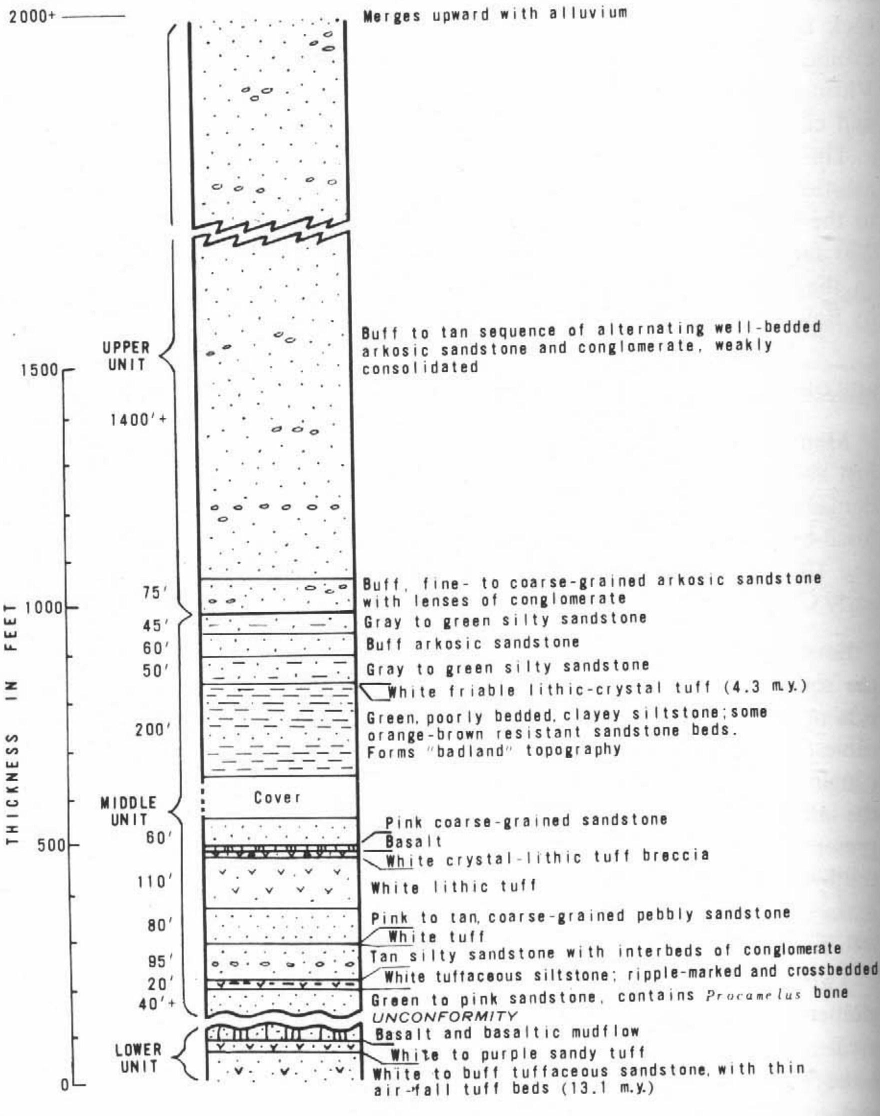

Figure 6. Measured section of the Esmeralda Formation at the southern end of Fish Lake Valley.

boulders or cobbles occur in conglomerate lenses; and orthoclase, quartz, and biotite grains occur in sandstone units. The middle part of the section, the middle unit (Fig. 6), consists mostly of pyroclastic rocks and green siltstones and is similar in appearance to the type Esmeralda Formation in Big Smoky Valley. The entire section dips westward, away from Sylvania Mountain, a granitic body which was the major source of detritus. In the axis of the valley, the arkosic, tuffaceous sequence unconformably overlies approximately 100 feet of steeply dipping, white to purple tuffaceous sandstone and basaltic agglomerate (lower unit Fig. 6 and Pl. 3, fig. 1).

The arkosic tuffaceous sequence is, for the most part, undisturbed, but one fault along the southwest side of the valley is so recent that its escarpment in these soft strata remains uneroded. The older Tertiary rocks at the base of the section strike at right angles to the overlying gently dipping strata and dip approximately 60° S. (Pl. 3, fig. 1).

Pliocene strata similar to the Pliocene portion of the Esmeralda Formation at the south end of Fish Lake Valley crop out at the mouth of Horse Thief Canyon on the northeast side of Eureka Valley (Fig. 7). The section here is approximately 1400 feet thick and dips from 40° to 60° SW toward Eureka Valley. These rocks are overlain unconformably by alluvial-fan deposits which are being eroded. The lower half of the section consists mostly of basaltic agglomerate and light-colored tuffs with some interbeds of tuffaceous sediment. A lenticular boulder fanglomerate, present locally at the base of the section, is overlain by a distinctive conglomerate, composed of well rounded Paleozoic pebbles in a red matrix. The upper half of the section is tuffaceous arkosic sandstone with a few ash interbeds. This part of the section is very similar to the upper part of the southern Fish Lake Valley sequence, and the granitic detritus in these rocks probably also came from Sylvania Mountain.

Scattered outcrops of Pliocene and possibly Miocene rocks occur north of Horse Thief Canyon along the northeast edge of Eureka Valley. Some of these rocks probably can be correlated with units in the measured section, but exact correlation is impossible because of the lenticular nature of the strata. The red, round-pebble conglomerate crops out at a number of localities, and various white tuffs and basalt units, which probably correspond to some of the units low in the Horse Thief Canyon section, are also present. Arkosic sediments are either very thin or missing within several miles north and south of Horse Thief Canyon.

AGE OF THE SEQUENCE IN THE SOUTHERN END OF FISH LAKE VALLEY

Tuff in the older, steeply dipping strata at the base of the Fish Lake Valley section (lower unit, Fig. 6), shown in Plate 3, figure 1, was dated by K-Ar at 13.1 m.y. (Table 1, no. 1), which is late Miocene (late Barstovian). Tuff at the top of the green siltstone unit about midway in the overlying strata, the middle unit (Fig. 6), yields a K-Ar age of 4.3 m.y. (Table 1, no. 2), which is Hemphillian.

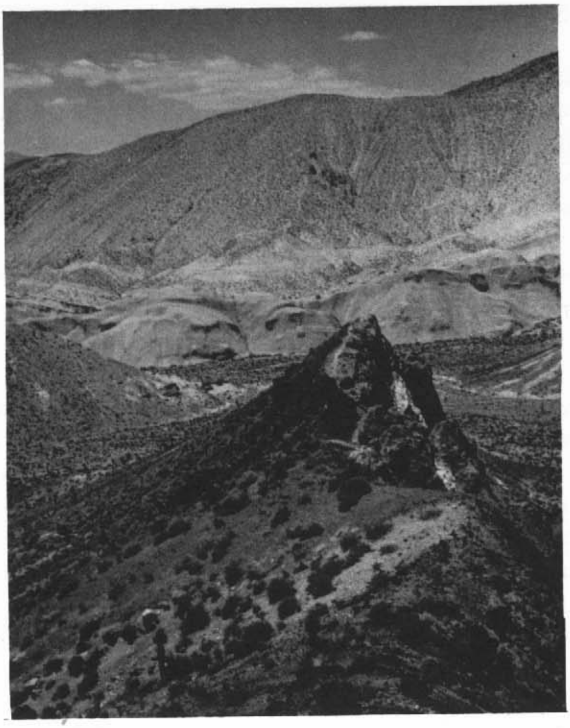

Figure 1. Esmeralda Formation in the south end of Fish Lake Valley. Steeply dipping strata in the foreground underlie unconformably the gently dipping strata in the background.

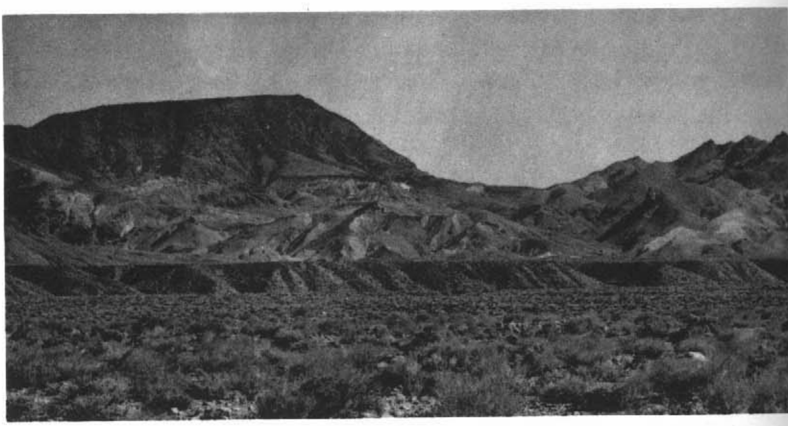

Figure 2. Fault scarp in Recent alluvium along the east side of Fish Lake Valley.

CENOZOIC ROCKS OF FISH LAKE VALLEY

ROBINSON AND OTHERS, PLATE 3
Geological Society of America Memoir 116

A camel bone, identified as *Procamelus* (proximal phalanx) by S. David Webb (oral commun., 1962) was found near the base of the middle sequence (Fig. 6) above the unconformity. It lies approximately 700 feet stratigraphically below the tuff that is 4.3 m.y. by K-Ar. This genus of camel has a range of late Miocene to middle Pliocene (Webb, 1965, p. 37, 45), and the bone found is probably slightly older than the age of the dated tuff.

Two K-Ar dates, nos. 3 and 4, Table 1, were obtained on rocks from the Esmeralda Formation of the Horse Thief Canyon area (Pl. 1): one, on a friable, white biotite-bearing tuff directly below the arkosic sandstone, the upper unit (Fig. 7), in Horse Thief Canyon; the other, on a rhyolitic tuff which crops out approximately 2½ miles north of Horse Thief Canyon. A similar sanidine-bearing rhyolitic tuff occurs in the measured section on

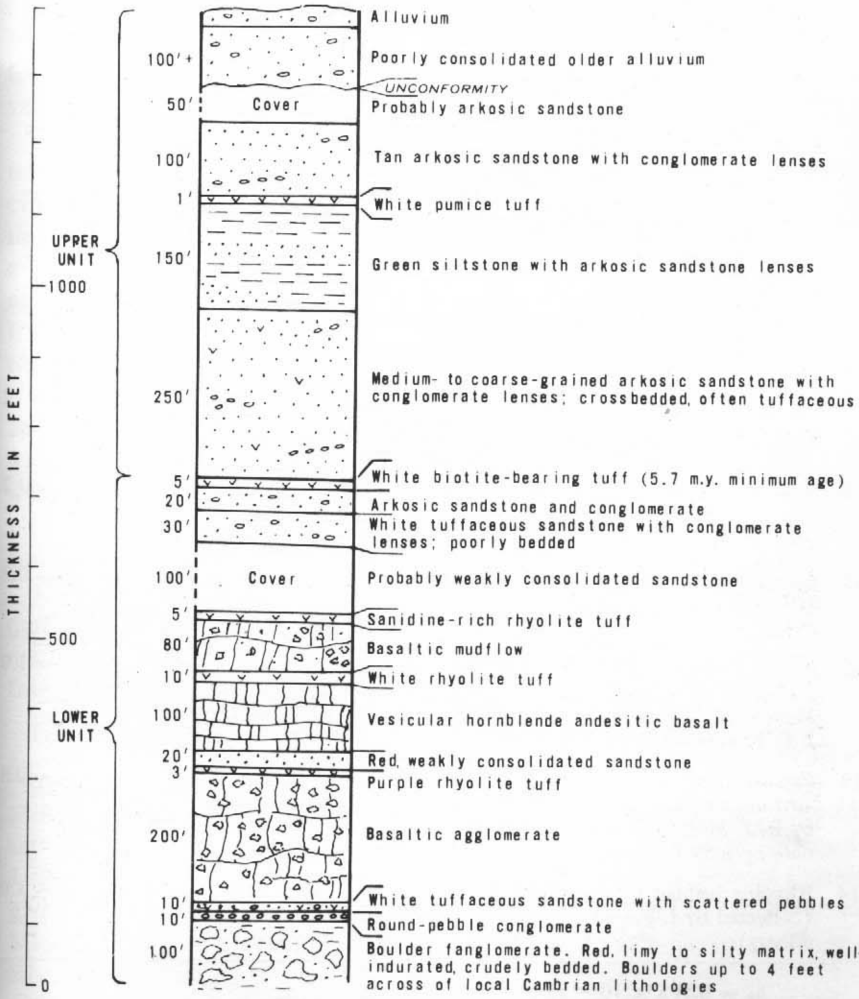

Figure 7. Measured section of the Esmeralda Formation at the mouth of Horse Thief Canyon, northeastern Eureka Valley.

Table 1. K-Ar dates from Tertiary units in the Silver Peak region, Nevada and adjacent California

Sample location Map No.	Unit name	Mineral	K_2O percent	Ar^{40} rad mole/gm^{-1}	$\frac{Ar^{40}\text{ rad}}{Ar^{40}\text{ total}}$	Apparent age (m.y.)
1	Esmeralda Formation air-fall tuff	Biotite	5.68 (3)	10.98×10^{-11}	17.7	13.1 ± 0.8
2	Esmeralda Formation air-fall tuff	Biotite	7.30 (2)	4.62×10^{-11}	28.0	4.3 ± 0.4
3	Esmeralda Formation air-fall tuff	Biotite	5.32 (2)	4.47×10^{-11}	25.8	5.7 ± 0.6
4	Rhyolite welded tuff	Sanidine	6.13 (2)	7.47×10^{-11}	80.6	8.2 ± 0.2
5	Trachyandesite welded tuff	Biotite	8.60 (2)	7.78×10^{-11}	40.6	6.1 ± 0.3
6	Rhyolite tuff	Biotite	8.48 (2)	7.58×10^{-11}	28.4	6.0 ± 0.5
7	Basalt	Whole rock	2.55 (2)	1.82×10^{-11}	8.3	4.8 ± 0.6
8	Trachyandesite flow (collected by J. P. Albers; K-Ar date by M. A. Lanphere)	Biotite	8.29 (2)	7.28×10^{-11}	50.0	5.9 ± 0.2
9	Esmeralda Formation (Evernden and others, 1964; UC KA 480)	Biotite	5.59		64.0	$11.1 \pm\sim 0.2$
10	Esmeralda Formation (Evernden and others, 1964; UC KA 499)	Biotite	7.37		69.0	$11.4 \pm\sim 0.2$
11	Esmeralda Formation (Evernden and James, 1964; UC KA 1268)	Biotite	8.25		69.0	$12.7 \pm\sim 0.2$
12	Rhyolite welded tuff (collected by R. J. Moiola; K-Ar date by J. F. Evernden)	Biotite				$21.5 \pm\sim 1.0$
13	Esmeralda Formation air-fall tuff (collected by R. J. Moiola; K-Ar date by J. F. Evernden)	Biotite				$6.9 \pm\sim 0.3$
14	Rhyolite welded tuff (collected by J. P. Albers)	Biotite	7.88 (2)	26.65×10^{-11}	62.8	$22.8 \pm\sim 1.0$

$\lambda_\varepsilon = 0.585 \times 10^{-10}\ yr^{-1}$

$\lambda\beta = 4.72 \times 10^{-10}\ yr^{-1}$

$K^{40}/K = 1.19 \times 10^{-4}$ atom percent top of the basaltic agglomerate, the lower unit (Fig. 7), and may correlate with the one that was dated. The rhyolitic tuff has an age of 8.2 m.y. (Table 1, no. 4), which is Pliocene (Hemphillian), and biotite from the friable tuff gave an age of 5.7 m.y. (Table 1, no. 3), also Pliocene. The second date, 5.7 m.y., is considered less reliable but is included as a minimum age.

Silver Peak Range

In the Silver Peak Range Tertiary rocks that are not considered part of the Esmeralda Formation are largely middle Pliocene lavas and tuffs, which were erupted from the Silver Peak volcanic center (Robinson, 1968, p. 59). These rocks crop out in the central part of the range; along the margins of the range, they interfinger with the sedimentary units described above. An older ash-flow sheet crops out over the northern part of the range in the Emigrant Pass area. This tuff is early Miocene in age and is overlain unconformably by the sedimentary rocks which underlie Big Smoky and Fish Lake valleys.

Emigrant Pass area. A thick rhyolite ash-flow sheet makes up the Tertiary sequence in the northern part of the Silver Peak Range. This tuff crops out over most of the northern part of the range and extends northward toward the Monte Cristo Range and westward to the Volcanic Hills (Pl. 1). It has a maximum thickness of approximately 1100 feet near Coaldale, but thins abruptly southward and is less than 200 feet thick south of Emigrant Pass. It rests unconformably on Paleozoic rocks and, along the margins of the range, is overlain unconformably by the Esmeralda Formation.

The ash-flow sheet constitutes a single cooling unit that comprises three zones: a lower zone of pink, unwelded vitric tuff; a middle zone of densely welded, dark-gray vitrophyre; and an upper crystallized zone of moderately welded, brownish-gray tuff characterized by abundant spherulites. The vitrophyre is best developed at the north end of the Silver Peak Range. South of Emigrant Pass, it is present only locally.

Crystals make up from 15 to 20 percent of the tuff and consist chiefly of quartz, sanidine, and calcic oligoclase; most specimens also contain small amounts of biotite, hornblende, and iron oxide, and from 5 to 10 percent rock fragments. The groundmass consists of devitrified glass, chiefly shards.

AGE OF THE ASH-FLOW TUFF

A K-Ar age of 21.5 m.y. (Table 1, no. 12) was obtained from biotite in a sample collected 180 feet above the base of the tuff. A sample collected by J. P. Albers, north of Highway 6 approximately 15 miles west of Coaldale, gives a date of 22.8 m.y. (Table 1, no. 14). This places the tuff in the early Miocene (late Arikareean), making it the oldest known Tertiary unit in the Silver Peak region.

Central part of the Silver Peak Range. Tertiary rocks in the central part of the Silver Peak Range crop out in a northwest-trending belt, from 12 to 15

Figure 1. Angular unconformity in the Esmeralda Formation on the east side of the Silver Peak Range. Volcanic siltstone and sandstone in foreground dip 55° to 60° E.

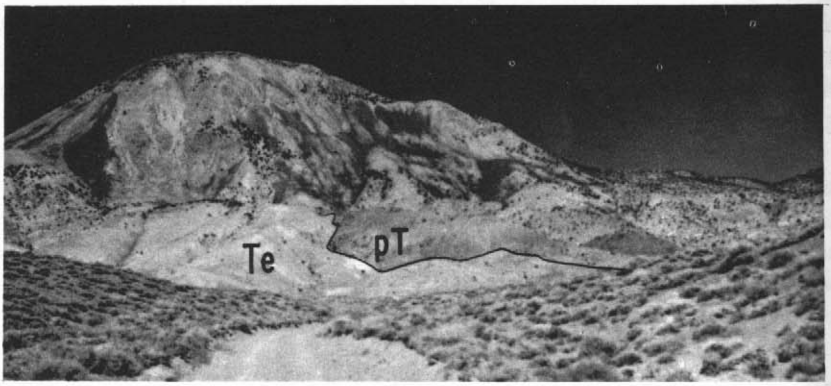

Figure 2. Red Mountain, a large rhyolite dome intruded into the Esmeralda Formation (Te), and pre-Tertiary rocks (pT).

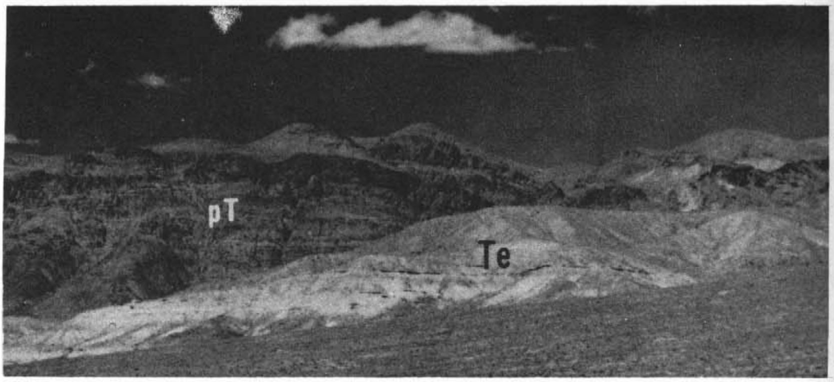

Figure 3. Strata of the Esmeralda Formation (Te) in the fault contact with pre-Tertiary rocks (pT) on west side of the Silver Peak Range.

CENOZOIC ROCKS OF THE SILVER PEAK RANGE

miles wide, that extends diagonally across the range (Pl. 1). This belt roughly parallels the pre-Tertiary rocks exposed on Mineral Ridge and in the southern part of the range. Most of the Cenozoic rocks are lavas and tuffs erupted from the Silver Peak volcanic center. On the flanks of the range, the volcanic rocks overlie and interfinger with the sedimentary strata which crop out in the valleys. Sedimentary rocks not only crop out along the margins of the range but also in places in the central part of the range. All of the rock units, both sedimentary and volcanic, are discontinuous and vary greatly in thickness.

A series of andesite flows and interlayered breccia, unit C (Fig. 8), crops out on the west side of the Silver Peak Range and on the north slope of the Palmetto Mountains. These andesites, which are the oldest rocks definitely associated with the Silver Peak center, have a maximum thickness of approximately 1250 feet in the Palmetto Mountains (Dover, 1962, unpub. MS thesis, Univ. of Washington, Seattle, Wash.), but are thinner at most localities. The flows are dark gray to greenish- or reddish-gray porphyritic andesites composed predominantly of andesine, hornblende, and biotite phenocrysts in a pilotaxitic to microfelsitic groundmass.

The interlayered breccias are greenish-gray, thick-bedded, poorly sorted rocks that are composed entirely of andesitic detritus. Most fragments range from 1 to 5 cm in diameter, but blocks up to a meter across are common. The breccias locally grade upward into greenish-gray, fine-grained sandstones of similar composition, unit D (Fig. 8).

At most localities, the andesite flows and breccias rest unconformably on pre-Tertiary rocks, but on the west flank of the Silver Peak Range, they are separated from the older rocks by lenses of conglomerate composed of Paleozoic clasts and, locally, by a series of ash-flow tuffs, units A and B (Fig. 8). The pebble conglomerates are gray to reddish- or greenish-gray, poorly bedded, weakly indurated rocks and are very similar to the conglomerates in Big Smoky Valley. The conglomerates on the west side of the range are only a few hundred feet thick, but similar rocks on the east side are nearly 5700 feet thick, unit A (Fig. 9), in the area between Nivloc and Silver Peak. In this area, the andesite flows and breccias are missing and the conglomerates locally grade upward into volcanic siltstones and sandstones, unit B (Fig. 9).

The andesite flows and breccias and the volcanic siltstones and sandstones, units C and D (Fig. 8) and unit B (Fig. 9) are overlain by a widespread unit of volcanic siltstone, sandstone, and granule conglomerate, unit F (Fig. 8) and unit C (Fig. 9). These rocks crop out on both flanks and, locally, over the central part of the range. On the west flank they are separated from the underlying andesitic sandstones by a thin ash-flow tuff, unit E (Fig. 8). Nearly 2000 feet of strata are exposed on the west flank, but the unit thins eastward and is less than 200 feet thick on top of the range near Red Mountain. It thickens again on the east flank to approximately 700 feet (Pl. 4, fig. 1). This unit overlies older sedimentary and volcanic rocks on the flanks of the range, but rests on pre-Tertiary rocks in the center of the range.

These rocks, unit F (Fig. 8) and unit C (Fig. 9) are medium-bedded volcanic sandstones, and most of them are tan to light brown, though some are dark gray or green. Thin layers of black carbonaceous shale are interbedded with the sandstones, and dark gray carbonaceous siltstones occur locally near the base of the unit. Silicic rock fragments and feldspar make up the bulk of these rocks. The feldspar consists of variable proportions of calcic andesine and sanidine with minor amounts of oligoclase. Most samples also

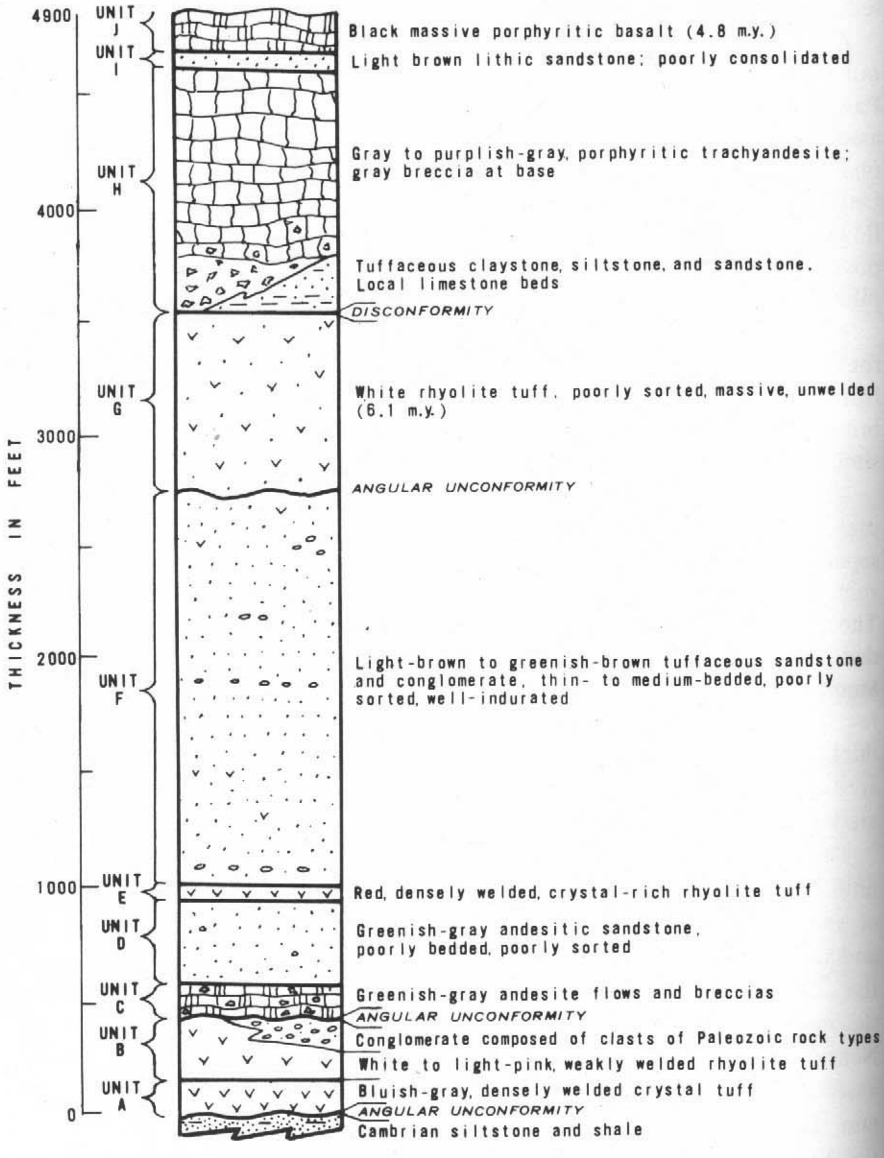

Figure 8. Measured section of Tertiary strata on the west flank of the Silver Peak Range east of Ice House Canyon.

contain from 2 to 3 percent of quartz and traces of biotite and iron oxide. Poorly sorted rocks contain from 10 to 20 percent of montmorillonite or kaolinite, or both. A few are rich in pyroclastic material, most of which is altered to heulandite and montmorillonite or celadonite. Calcite cement is widely distributed and makes up as much as 25 percent of some well sorted specimens.

Overlying the epiclastic rocks, described above, and encircling the volcanic

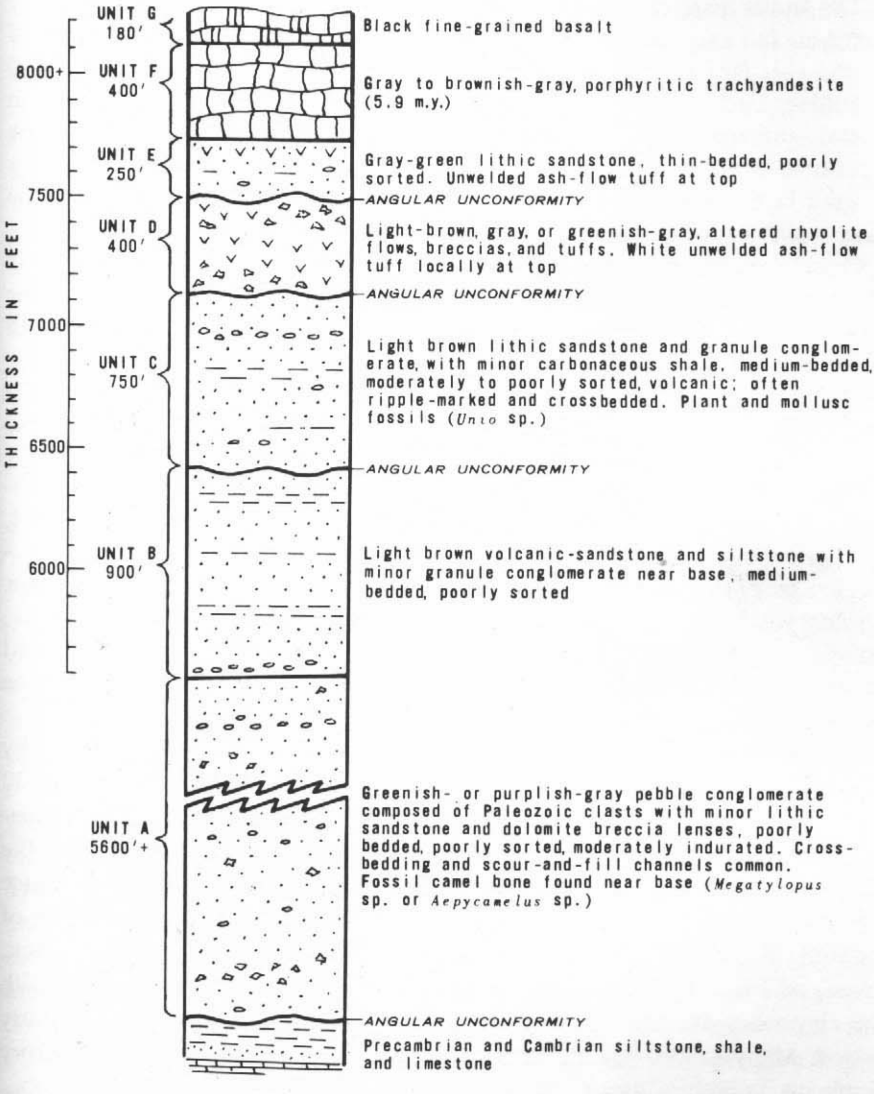

Figure 9. Composite section of Tertiary strata exposed on the east flank of the Silver Peak Range in the vicinity of Nivloc. All units are discontinuous and vary greatly in thickness.

center is a sequence of rhyolitic tuffs and breccias and associated flows and domes, unit G (Fig. 8) and unit D (Fig. 9). These rocks vary greatly in thickness and have a maximum of approximately 2000 feet. A sequence, unit D (Fig. 9) of light-brown to greenish-brown vitric tuffs, volcanic breccias, and flows crops out at the base of this unit on the east flank of the range. These rocks have been intruded by small andesite plugs and extensively altered and silicified. Most of them are aphanitic and may be andesites, dacites, or quartz latites; some that are rich in quartz are probably rhyolitic.

The upper part of this unit is a sequence of poorly bedded and poorly sorted air-fall and nonwelded ash-flow(?) tuffs. These are excellently exposed on the east face of Rhyolite Ridge, where they form layers from 80 to 600 feet thick. Each layer grades upward from coarse-grained lapilli tuff, rich in crystals and rock fragments near the base, to fine-grained vitric tuff near the top. Some layers exhibit crude bedding, but most layers are massive. The color of each layer varies from white to light brownish- or greenish-gray near the base to pink or red at the top.

Crystals make up from 5 to 25 percent of these tuffs and are set in a matrix of vitric material, chiefly shards. Sanidine and quartz make up the bulk of the crystals, but there are also lesser amounts of oligoclase, that is rimmed with sanidine, biotite, clinopyroxene, and iron oxide. The glass is altered to mixtures of heulandite and alkali feldspar. Rock fragments make up from 5 to 40 percent of typical specimens and are predominantly rhyolite, but include basalt, granite, schist, and siltstone.

Interlayered flows and domes are most common on the north and southeast sides of the volcanic center, west and south of Red Mountain (Pl. 4, fig. 2). These are rhyolites, mostly red or reddish-gray, holocrystalline, flow-banded rocks that are composed of microcrystalline quartz and alkali feldspar. Phenocrysts rarely exceed 5 percent by volume and consist of oligoclase, sanidine, quartz, and biotite. Lithophysae are abundant in some flows, and dark-gray, flow-banded perlites are associated locally with the crystalline rocks.

On the west flank of the range, the rhyolite tuffs are overlain locally by epiclastic volcanic sedimentary rocks, base of unit H (Fig. 8). Nearly 1000 feet of interbedded tuffaceous claystone, siltstone, sandstone, and minor limestone crop out in an elongate fault trough along the west side of Rhyolite Ridge. The claystones and siltstones that make up the bulk of the sequence are fine-grained, laminated, poorly sorted rocks composed predominantly of montmorillonite. Most of them are light gray, or brown, but some are black, green, or blue. Tuffaceous sandstones and reworked tuffs interlayered with the claystones are light gray or brown, fine- to medium-grained, and poorly sorted. Many sandstones are cross-bedded, and some show large, oscillatory ripple marks.

In the center of the range, the rhyolite tuffs and flows are overlain by a series of porphyritic trachyandesite flows, unit H (Fig. 8) and unit F (Fig. 9). The distribution and thickness variations of these flows suggest that they fill a subcircular caldera (Pl. 1) approximately 4.5 miles in diameter (Robinson, 1968, p. 59). The flows, which are restricted to the center of the range, generally dip inward and crop out at lower elevations within the depression than do the older rocks outside. The juxtaposition of trachyandesites and older rocks is most evident on the south and west sides of the caldera. Elsewhere, the rim is completely covered.

The trachyandesites are light gray, grayish-green, or dark red rocks that are characterized by large (from 1 to 3 cm) euhedral phenocrysts of calcic oligoclase and sanidine. Biotite and diopsidic augite are the dominant ferromagnesian minerals. Some samples also contain small amounts of hypersthene, hornblende, and, rarely, olivine.

Light gray laharic breccias occur locally at the base of the trachyandesite flows. These breccias are poorly bedded and poorly sorted and consist of angular blocks of trachyandesite up to 1 m in diameter.

In the central and southern parts of the range, the trachyandesite flows are overlain disconformably by a porphyritic basalt flow which, in turn, is overlain by trachyandesite welded tuffs. Where the flows are absent, the trachyandesite tuffs unconformably overlie the older rhyolite tuffs and flows. The welded tuffs are light brown to black, moderately to densely welded, eutaxitic rocks that are composed chiefly of glass shards and pumice lapilli. Crystals make up from 15 to 20 percent of typical samples and are principally andesine and biotite with small amounts of clinopyroxene, sanidine, magnetite, and, rarely, quartz.

Many other small flows and associated dikes and plugs of basalt crop out in the central part of the range, unit J (Fig. 8) and unit G (Fig. 9), where they disconformably overlie the trachyandesite tuffs and flows (Pl. 1). The basalts are black to dark gray, holocrystalline, and have porphyritic intergranular, intersertal, or pilotaxitic textures. The principal types are olivine-augite-hypersthene basalt, olivine-augite basalt, augite basalt, and hornblende-hypersthene andesitic basalt.

A 2200-foot-thick sequence of conglomerate, sandstone, claystone, and tuff crops out along the western margin of the range (Pl. 4, fig. 3). These rocks unconformably overlie the older rhyolite tuff just southwest of Emigrant Pass and trachyandesite flows southwest of Cave Spring. Elsewhere, they are in fault contact with pre-Tertiary and older Tertiary rocks (Pl. 1). The sequence has been faulted and folded and is overlain unconformably by poorly consolidated older alluvium along the edge of Fish Lake Valley. Tuffaceous sandstones and vitric tuffs make up nearly half of this sequence. They are light gray to light brown, medium-bedded, medium-grained rocks composed of andesine and silicic volcanic rock fragments in a matrix of vitric material. Most of the vitric material is altered to clinoptilolite, montmorillonite, and K-feldspar. Fresh glass (R. I. $= 1.495 - 1.497 \pm 0.002$) has been found in only three samples.

Greenish- to brownish-gray, poorly sorted conglomerates form the upper part of this sequence. They consist principally of locally derived rock fragments, and the composition of the clasts at any given locality is related to adjacent exposures of older rock.

The claystones of this sequence are massive, grayish-green rocks of uniform composition. Montmorillonite makes up from 95 to 98 percent of typical samples; the remainder consists of silt-size feldspar crystals and rock fragments. X-ray diffraction patterns of these rocks reveal mixtures of montmorillonite, authigenic K-feldspar, mica, clinoptilolite, searlesite, halite, calcite, and opal. Veinlets of gypsum and anhydrite cut the claystones, and "cottonball" aggregates of ulexite are common.

AGE OF THE SILVER PEAK SEQUENCE

Fossil camel bones collected near the base of the pebble conglomerate, unit A (Fig. 9), on the east side of the range are probably Miocene or Pliocene (Clarendonian or Hemphillian) in age, but may be as old as Barstovian (Webb, 1962, written commun.). The tuffs of Rhyolite Ridge have a K-Ar age of 6.0 ± 0.5 m.y. (Table 1, no. 6); the overlying porphyritic trachyandesite flows, 5.9 ± 0.2 m.y. (Table 1, no. 8); and the trachyandesite welded tuffs, 6.1 ± 0.3 m.y. (Table 1, no. 5). A basalt flow that overlies the trachyandesite welded tuffs is middle Pliocene based on a K-Ar date of 4.8 ± 0.6 m.y. (Table 1, no. 7). The sedimentary rocks on the west side of the range that contain basalt clasts (derived from this dated basalt) are assumed to be late Pliocene or early Pleistocene in age.

STRUCTURAL EVOLUTION OF THE SILVER PEAK REGION

The absence of pre-Miocene Tertiary strata suggests that the Silver Peak region was a highland throughout early Tertiary time. Drainage was probably westward, across the present site of the Sierra Nevada (Axelrod, 1950, p. 226). By Oligocene time, a structural basin had developed in the Death Valley region to the south in which the Oligocene Titus Canyon Formation of Stock and Bode (1935) was deposited. The complete lack of Oligocene strata in the Silver Peak region indicates that it was not a site of deposition during this epoch.

Block faulting in late early to middle Miocene time disrupted the external drainage and produced several partially closed basins that corresponded, approximately, to the present topographic lows. A maximum age for this faulting, about 22 m.y. by K-Ar (late Arikareean), is provided by the ash-flow tuff which is displaced by the faulting at the north end of the Silver Peak Range (Pl. 1, locality 12). The distribution of this tuff suggests that it was erupted onto a surface of low relief before the area was broken by the faulting that formed the basins into which the Esmeralda Formation was deposited. A minimum age for faulting and formation of basins is provided by the late Miocene and Pliocene sedimentary sequences deposited in the basins. Rapid erosion resulting from the first uplift is suggested by thick accumulations of pebble conglomerate composed of Paleozoic clasts along the basin margins, particularly along the eastern margin of the Silver Peak Range. Repeated uplift of the ranges is suggested by landslide breccias composed of basement rock intercalated with the conglomerates.

Tectonic stability prevailed during late Miocene and early Pliocene time, and thick finer grained sedimentary sequences accumulated in the basins. A second major episode of faulting, probably in late early to middle Pliocene time, deformed these sedimentary sequences, and a regional angular unconformity developed in Big Smoky, Fish Lake, and Clayton valleys. At approximately the same time, sediments were being deposited in what is now the central part of the Silver Peak Range. This deposition suggests a temporary connection between the basins in Clayton and Fish Lake valleys. The oldest date obtained from rocks above the unconformity, 6.9 m.y. (Table 1, no. 13), is from a tuff in the upper unit of the Alum sequence, about 500 feet stratigraphically above the unconformity. In the southern end of Fish Lake Valley, a tuff more than 800 feet stratigraphically above the unconformity has a K-Ar age of 4.3 m.y. (Table 1, no. 2).

Except for minor faulting, there has been only slight deformation of most of the basin deposits since middle Pliocene time. Rocks above the widespread unconformity are nearly flat lying, and the thickness variations and facies patterns of these rocks indicate that the late Tertiary basins coincided closely with the present valleys. This is particularly evident in the southern part of Fish Lake Valley, where middle and late(?) Pliocene rocks dip very gently toward the axis of the valley and merge imperceptibly upward into Pleistocene and Recent alluvium.

In contrast, parts of the Silver Peak Range have been uplifted at least 3000 feet since middle Pliocene time. Sedimentary rocks that were deposited in the transverse trough that connected Clayton and Fish Lake valleys now crop out at the top of the range at elevations between 7200 and 7600 feet. This uplift apparently occurred shortly after deposition of the middle(?) Pliocene sediments, and may have been related to volcanic activity at the Silver Peak volcanic center. Most of the uplift took place prior to extrusion of the porphyritic trachyandesite flows, because, in several places, these lavas flowed down the flanks of the range toward the adjacent valleys. These flows are Hemphillian in age (5.9 m.y. by K-Ar, Pl. 1, locality 8).

Although the present topography was largely established by late Pliocene time, faulting has continued to the present. The youngest volcanic and sedimentary rocks in the region have been cut by faults, and fault scarps are visible in the alluvium along the margins of most valleys in the region (Pl. 3, fig. 2).

SUMMARY

Tertiary deposits in the Silver Peak region consist of continental sedimentary rocks of the Esmeralda Formation and associated volcanic rocks of

Miocene and Pliocene age. The Esmeralda Formation was deposited in several basins that coincide in a general way with the present valleys. These late Tertiary basins are represented by outcrops in Big Smoky Valley (type section of the Esmeralda Formation), Clayton Valley, and Fish Lake Valley, and in the central part of the Silver Peak Range. Although the stratigraphic sequences in these basins differ greatly in detail, they have a general lithologic similarity and share a common origin.

The Esmeralda Formation ranges in age from late Miocene to late Pliocene. The oldest reliably dated rocks in the Esmeralda Formation, which occur at the base of the southern Fish Lake Valley sequence, have a K-Ar age of 13.1 m.y. (Pl. 1, locality 1) (Barstovian). Rocks of similar age occur in the northern part of the valley, where approximately 1200 feet of Barstovian(?) strata underlie rocks dated as early Clarendonian, 11.4 m.y. (Pl. 1, locality 10). In Big Smoky Valley (Alum section), nearly 4500 feet of strata underlie rocks assigned a Barstovian age on the basis of molluscan fossils. These strata are probably Barstovian or, possibly, Hemingfordian in age. Rocks from the section near Coaldale, which probably correlate with the lower part of the Alum section, are dated at 12.7 m.y. (Pl. 1, locality 11). A maximum age for these strata is provided by the age of the widespread ash-flow tuff that crops out in the northern part of the Silver Peak Range. This tuff which has a K-Ar age of about 22 m.y. (Pl. 1, localities 12 and 14), was extruded prior to the formation of the basins in which the sediments were deposited. All of the strata included in the Esmeralda Formation are younger than this tuff. The youngest date obtained for the Esmeralda Formation is from a tuff in the southern Fish Lake Valley sequence (Pl. 1, locality 2). This tuff, which has a K-Ar age of 4.3 m.y. is overlain by more than 1400 feet of tuffaceous arkosic sandstone, which grades upward into Recent alluvium on the valley floor. Some sedimentary strata on the west side of the Silver Peak Range are younger than a basalt flow dated at 4.8 m.y. (Pl. 1, locality 7).

Epiclastic and pyroclastic volcanic rocks make up most of the sedimentary units, although local differences in lithology reflect local source areas. Most of the epiclastic rocks are sandstones and siltstones composed predominantly of silicic volcanic rock fragments and some plagioclase. Tuffs and reworked tuffs are common throughout the sedimentary sequences. They are principally fine-grained vitric tuffs of rhyolitic composition. Some of these tuffs probably originated from the Silver Peak volcanic center, but many are older than this center and probably originated outside the region. The age of the center is approximately 6 m.y. by K-Ar.

Nonvolcanic detritus is abundant only in the lower part of the section and along the margins of the basins. Thick sequences of pebble conglomerate and breccia, composed of Paleozoic clasts, occur on the east flank of the Silver Peak Range and near the eastern margin of Big Smoky Valley. Granitic detritus is abundant only in the sequence at the south end of Fish Lake Valley, but some occurs in the sequence at Alum. In both areas, it is derived from nearby exposures of granitic rocks.

Most of the rocks of the Esmeralda Formation were deposited under alternating fluviatile and lacustrine conditions. The presence of coals at some localities in the lower part of the sequence indicates that local paludal conditions prevailed intermittently. The coarse-grained rocks are usually medium bedded and poorly sorted and contain sedimentary features, such as cross-bedding and scour-and-fill channels, which are indicative of deposition under fluviatile conditions. These rocks, particularly the pebble conglomerates, occur in wedge-shaped bodies that thicken toward the basin margins. The sandstones and conglomerates grade laterally and vertically into thin-bedded or laminated siltstones and shales. These rocks typically exhibit oscillation ripple marks, laminations, and slump bedding, which are indicative of lacustrine deposition. The absence of saline minerals in most of these rocks and the common occurrence of fish remains, ostracods, and mollusks indicate that the lake waters were not highly saline. Saline minerals, searlesite, ulexite, and halite, occur only in the youngest Pliocene sedimentary rocks on the west side of the Silver Peak Range. However, these minerals do not rigidly follow bedding and may be secondary.

From a study of the flora associated with the Coaldale sequence, Axelrod (1940) concluded that the basin was surrounded by an oak-juniper community and that rushes and ferns formed dense growths along the borders of the lake. The annual precipitation was probably between 12 and 15 inches, and temperature conditions might have been similar to those now found on the western slope of the southern Sierra Nevada.

Facies changes over short distances and numerous local unconformities indicate that deposition was not uniform within a given basin. Faulting repeatedly modified the basins and perhaps blocked out isolated areas within the larger structural units. In some areas, basins have been uplifted as much as 300 to 400 feet since deposition of the sedimentary sequences. The central part of the Silver Peak Range has been elevated at least 3000 feet above the adjacent valley floors.

Rocks of the Silver Peak volcanic center overlie and interfinger with the sedimentary sequences of the surrounding valleys. These volcanic rocks, which are middle to late Pliocene in age, 4.8 to 6.1 m.y. by K-Ar, are mostly tuffs and lava flows that crop out in the central part of the range. Lava flows are predominantly rhyolites and trachyandesites with subordinant andesites and basalts. The tuffs are rhyolitic and trachyandesitic in composition.

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