Uppermost Oligocene and Lowermost Miocene Ash-Flow Tuffs of Western Nevada

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CONTENTS

ILLUSTRATIONS

TABLES

UPPERMOST OLIGOCENE AND LOWERMOST MIOCENE ASH-FLOW TUFFS OF WESTERN NEVADA

By Paul T. Robinson and John H. Stewart

ABSTRACT

A series of uppermost Oligocene and lowermost Miocene ash-flow tuffs informally named the Candelaria Hills sequence crops out in and around the Candelaria mining district of western Nevada. These tuffs form part of a broad belt of Oligocene and lower Miocene ash-flow tuffs extending across eastern California, central Nevada, and western Utah. The Candelaria Hills sequence presently occurs over an estimated 3,200 km^2 and has a volume of approximately 368 km^3. Eleven major ash-flow sheets are recognized in the sequence, three of which, the Metallic City, Belleville, and Candelaria Junction Tuffs, are voluminous and widespread. Minor basalt flows are interlayered with the tuffs in the Candelaria mining district, and a widespread andesitic lahar occurs in the upper part of the sequence. The tuffs were deposited during an approximately 2 m.y. interval between about 25.5 and 23.5 m.y. B.P. On the basis of phenocryst mineralogy, the sequence ranges from rhyolitic to andesitic in composition. Thickness variations and facies relations suggest that the tuffs were erupted from vents within the Candelaria Hills, and a major fault-bounded trough in this area is tentatively interpreted to be the result of cauldron subsidence. The wide distribution of the Candelaria Hills sequence suggests that the ash flows spread over relatively even topography and that their emplacement predated the initial phase of basin-and-range faulting in this area.

INTRODUCTION

A sequence of uppermost Oligocene and lowermost Miocene ash-flow tuffs, referred to informally as the Candelaria Hills sequence, crops out over a large area of northern Esmeralda and southern Mineral Counties, Nev. The sequence consists of a distinctive succession of silicic tuffs, which are lithologically distinct from, and younger than, upper Oligocene tuffs of the Yerington district in northern Mineral County and in Lyon County, Nev. (Proffett and Proffett, 1976; Ekren and others, 1980). The rocks described here are part of a widespread province of Oligocene and lower Miocene ash-flow tuffs extending across eastern California, central Nevada, and western Utah (fig. 1).

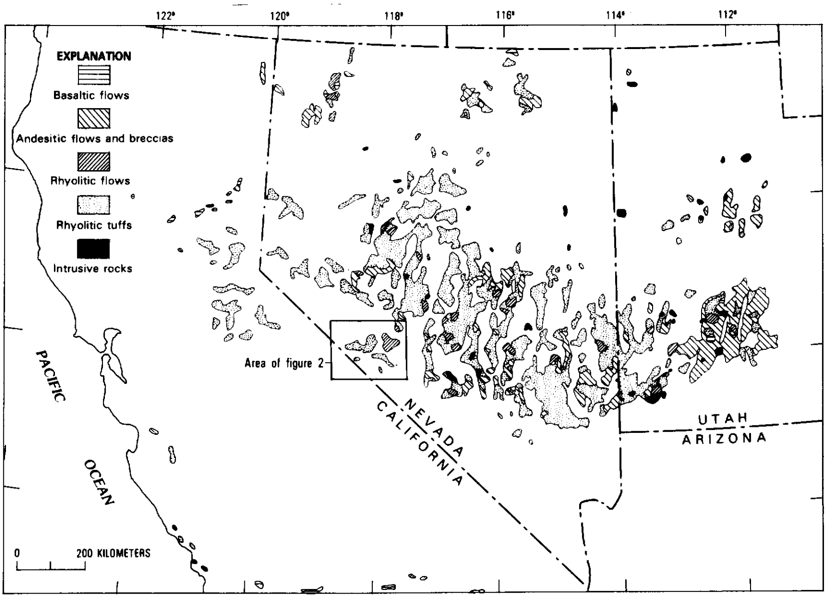

FIGURE 1.—Generalized map showing distribution of Cenozoic igneous rocks ranging in age from 34 to 17 m.y. in Nevada, Utah, and parts of adjacent states (after Stewart and others, 1977).

The Candelaria Hills sequence has been recognized as far north as the Excelsior Mountains and Garfield Hills in Mineral County and as far south as the central Silver Peak Range and west flank of the White Mountains (Krauskopf, 1971). On the east the tuffs extend to the edge of Big Smoky Valley and on the west to Huntoon Valley, north of the White Mountains (fig. 2). The existing outcrops, coupled with inferred subsurface sections beneath intermontane valleys, suggest an areal extent for this sequence in excess of 3,000 km^2. Because of this wide areal extent, previous studies have dealt with local sections in specific areas or quadrangles (for example: Page, 1959; Ross, 1961; Robinson and others, 1968; Crowder and others, 1972; Robinson and Crowder, 1973; Stewart and others, 1975; Robinson and others, 1976; Stewart, 1979, 1981a, 1981b; Garside, 1979; Speed and Cogbill, 1979b; Stewart and others, 1981).

In this paper we discuss the Candelaria Hills sequence in a regional context and compare stratigraphic sections from the entire outcrop area. We also present detailed lithologic and petrographic data which have been used for correlation of individual ash-flow sheets. From thickness variations and facies changes in the sequence we draw inferences regarding both the source of the ash flows and the nature of the surface over which they flowed.

Because the Candelaria Hills sequence is a widespread and readily recognizable unit, it is of considerable tectonic and paleogeographic importance in determining the time of initial extension that formed the present-day basins and ranges. Speed and Cogbill (1979c) suggested that extensional faulting occurred in this

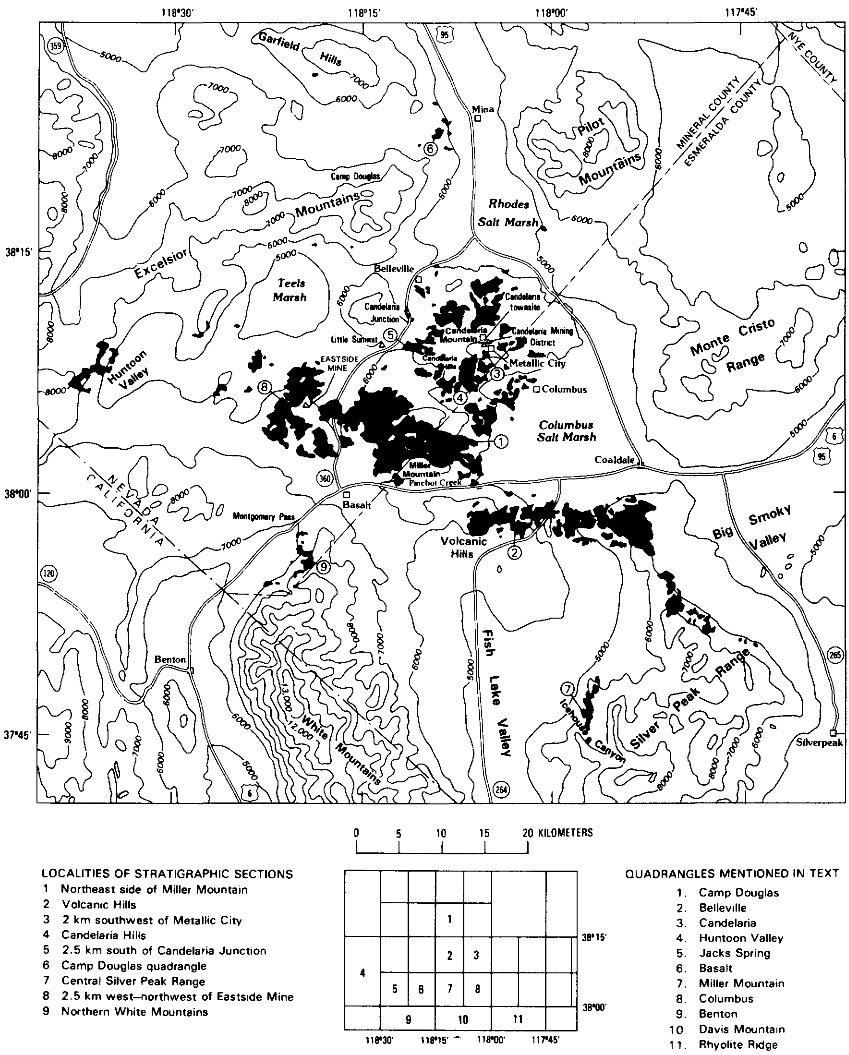

FIGURE 2.—Index map of southwestern Nevada and eastern California, showing distribution of Candelaria Hills sequence. Numbers 1–9 for localities of stratigraphic sections refer to figures 3–11. Base from U.S. Geological Survey 1:250,000-scale maps of Walker Lake, Tonopah, Mariposa, and Goldfield 1° by 2° quadrangles.

TABLE 1.—*Correlation of stratigraphic units in the Candelaria Hills sequence used in this report with those defined by previous workers*

This report	Speed and Cogbill (1979b)	Stewart (1979)	Page (1959)
Tuff of Candelaria	10	-	-
Candelaria Junction Tuff	Candelaria Junction Tuff	Tt-5	Tv 17, 18, 19
Andesite breccia of Little Summit with associated tuff and sedimentary rocks	8	Tt-3, 3b	-
Belleville Tuff	Belleville Tuff	Tt-3a	Tv 13, 14, 15, 16
Tuff of Eastside Mine	6	Tuff of Eastside Mine	-
Metallic City Tuff	Metallic City Tuff	Tt-2d	Tv 12
Tuff of Candelaria Mountain	4	Tt-2c	Tv 7, 11
Tuff of Volcanic Hills	3	Tt-2b	Tv 5, 6, 9
Tuff of Pinchot Creek	2	Tt-2b	Tv 2, 3, 4
Tuff of Miller Mountain	1	Tt-2a	Tv 1
Tuff of Columbus	-	Tt-1	-

part of southwestern Nevada in latest Oligocene time, contemporaneous in part with emplacement of the ash flows. Others (McKee, 1971; McKee and Noble, 1974; and Stewart, 1978) have indicated that regional extension in the Basin and Range province occurred only during the past 17 m.y.

STRATIGRAPHY

The uppermost Oligocene and lowermost Miocene tuffs crop out over a large area in Esmeralda and Mineral Counties, extending from Huntoon Valley on the west to Big Smoky Valley on the east and from the central Silver Peak Range on the south to the Garfield Hills on the north (fig. 2). The thickest and most complete sections occur in the Candelaria mining district in Mineral County, where Page (1959) first studied the sequence. He subdivided this Tertiary section into 19 units, 17 of which are pyroclastic in origin. A recent reinvestigation of this area by Speed and Cogbill (1979b) led to the recognition of 10 major pyroclastic units, most of which are separated by angular or erosional unconformities. Each of these is characterized by a distinctive lithology and phenocryst mineralogy, making identification of individual units relatively easy. Units 5, 7, and 9 in the sequence are especially voluminous and widespread, and these were given formational status by Speed and Cogbill (1979b), named respectively, the Metallic City, Belleville, and Candelaria Junction Tuffs.

In the present study we use the basic subdivision proposed by Speed and Cogbill (1979b) but recognize one additional unit not present in the Candelaria Hills. These 11 units can be widely recognized in the area on the basis of their phenocryst mineralogy, even where unconformities are absent. Rather than attempt to reconcile the different numbering systems used by previous workers we adopt the names Metallic City Tuff, Belleville Tuff, and Candelaria Junction Tuff as defined by Speed and Cogbill (1979b) and use informal names for the remaining units (table 1). Table 2 summarizes the stratigraphy and lithology of the Candelaria Hills sequence, whereas tables 3 to 12 give the modal variations of individual ash-flow sheets. The average modal composition of each unit is given in table 13, and table 14 summarizes the available K-Ar age data.

Few place names occur in the sparsely populated area where the Candelaria Hills sequence crops out, and we had difficulty in finding names that could appropriately be applied to many of the units described here. The word "Candelaria" thus occurs as part of several of the unit names (Candelaria Hills, Candelaria Junction,

TABLE 2.—*Stratigraphy, thickness, and lithology of Candelaria Hills sequence, western Nevada*
[Pl:S:Q, ratio of plagioclase (Pl), sanidine (S), and quartz (Q). <, less than]

Unit	Maximum thickness (m)	Stratigraphy and lithology
Tuff of Candelaria -------------	75	Gray medium- to coarse-grained weakly to densely welded biotite-rich tuff. Basal 2 to 3 m is white to brownish-gray weakly welded tuff grading upward into dark-gray vitrophyre with well-developed eutaxitic texture. Vitrophyre passes upward into gray crystallized moderately to weakly welded tuff. Pumice fragments 20 percent, angular to elongate, 2 to 15 mm. Obsidian flakes and black shards visible in groundmass. Rock fragments as much as to 30 percent, < 1 cm, subrounded to subangular, consist of tuff, scoria, and andesite. Crystals 15 to 20 percent, 1 to 3 mm, Pl:S:Q = 8:1:1, biotite 4 to 5 percent. Unit occurs only in vicinity of Candelaria (townsite), where it conformably overlies the Candelaria Junction Tuff (Speed and Cogbill, 1979b). Readily distinguished from underlying Candelaria Junction Tuff by abundance of biotite and lithic fragments and by predominance of plagioclase.
Candelaria Junction Tuff -------	105	Prominent gray to brownish- or reddish-gray cliff-forming ash-flow sheet. Two cooling units present in Candelaria Hills, lower one 20 to 25 m and upper one 80 to 90 m thick. Only one cooling unit recognized in most other sections. Tuff is coarse grained, moderately to densely welded, and crystal rich and has well-developed eutaxitic texture. Ash-flow sheet usually has basal zone of weakly welded glassy tuff grading upward into

dark-gray vitrophyre as much as 20 m thick. Upper part consists of 20 to 30 m of pink to reddish-brown moderately welded crystallized tuff locally overlain by 20 to 25 m of gray glassy tuff. In some sections the tuff is completely crystallized and is columnar jointed. Pumice fragments 10 to 20 percent, angular to elongate, mostly <1 cm, pink to black. Rock fragments 1 to 2 percent, subrounded, 1 to 2 mm, chiefly sedimentary. Crystals 15 to 20 percent, 1 to 5 mm, Pl:S:Q = 3:2:4, traces of biotite and green hornblende. Quartz crystals large and vermicular. Tuff locally overlies the Belleville Tuff with erosional unconformity; elsewhere the two are separated by the andesite breccia of Little Summit and associated tuffs and tuffaceous sediments. Readily distinguished from other units by abundance of large quartz and feldspar crystals.

Andesite breccia of Little Summit with associated tuff and sedimentary rocks

Upper andesite tuff -------- 15

Light-gray to brownish-gray glassy unwelded poorly consolidated ash-flow tuff of andesitic composition. Pumice fragments 5 to 20 percent, angular to slightly flattened, most <5 mm, some as much as 3 cm. Rock fragments 1 to 7 percent, subrounded, most <1 mm, chiefly andesite with some siltstone and welded tuff. Sparse dark-brown fragments of glass, <2 mm, with perlitic cracks. Crystals sparse, 1 to 4 percent, <1 mm, chiefly plagioclase with traces of quartz and biotite. Tuff is separated from the lower andesite tuff unit by 20 to 25 m of very coarse-grained andesite breccia, and locally by 5-6 m of bedded and crossbedded tuffaceous sandstone and granule conglomerate.

TABLE 2.—*Stratigraphy, thickness, and lithology of Candelaria Hills sequence, western Nevada*—Continued.

Unit	Maximum thickness (m)	Stratigraphy and lithology
Andesite breccia of Little Summit ------------	20	Light-brownish-gray very coarse grained poorly sorted poorly bedded andesite lahar. Clasts as much as 2 m across, angular, chiefly hypersthene andesite with minor welded tuff. Matrix is sandy. Unit commonly fills channels in underlying tuff.
Lower andesite tuff --------	25	Light-gray coarse-grained pumice-rich glassy unwelded tuff. Pumice fragments 60 to 70 percent, 2 mm to 20 cm, size and abundance decrease upward. Rock fragments 5 to 10 percent, <1 cm in lower part, <2 mm in upper part, mostly andesite with minor siltstone. Crystals 10 to 15 percent, 1 to 2 mm, plagioclase and minor hypersthene. Unit rests unconformably on the Belleville Tuff, often with a thin layer of cobble to boulder conglomerate between them. Overlain conformably(?) by the andesite breccia of Little Summit. Easily distinguished from the upper andesite tuff unit by abundance of large pumice and from the underlying Belleville Tuff by gray color and unwelded character.
Belleville Tuff ----------------	80	Varicolored coarse-grained strongly welded widespread ash-flow sheet with good eutaxitic texture. Basal 1 to 2 m consists of gray weakly welded vitric tuff which grades upward into dark-gray vitrophyre. This is overlain by variable thicknesses

of bright-red, orange, or white crystallized tuff. Two cooling units present locally, each with typical layered structure. Pumice fragments 20 to 35 percent, highly flattened, as much as 10 cm long. Rock fragments 5 to 10 percent near the base, 1 to 2 percent in upper parts, subrounded, <10 mm, composed of hypersthene andesite. Crystals 7 to 20 percent, 1 to 3 mm, chiefly plagioclase with minor pyroxene and traces of quartz, sanidine, and biotite. Tuff fills channels cut into or through the underlying tuff of Eastside Mine, so thickness highly variable. Thin layer of cobble conglomerate often present at base. Distinguished from the overlying lower andesite tuff unit by bright colors and intense welding. Distinguished from all older units by plagioclase-pyroxene mineral assemblage.

Tuff of Eastside Mine -----------	130	White coarse-grained pumice-rich weakly welded tuff. Often weathers into small pinnacles. Lower few meters may be moderately welded and upper part of unit consists of strongly indurated reddish-brown tuff. Pumice fragments highly variable but usually abundant, 2 to 20 percent, white, angular, as much as 4 cm but averaging 1 cm. Rock fragments conspicuous, 2 to 10 percent, black, subrounded, 2 mm to 10 cm, andesite and shale. Crystals 5 to 25 percent, <2 mm, Pl:S:Q = 3:1:3, biotite and iron oxides <1 percent each. Unit rests unconformably on the Metallic City Tuff and is locally separated from it by 0.5 to 1 m of bedded and cross-bedded tuffaceous siltstone. Differs from the Belleville Tuff in color, poorly welded character, and quartz-rich mineral assemblage. Distinguished from the Metallic City Tuff by unwelded character, lower crystal content, and low biotite content.

TABLE 2.—*Stratigraphy, thickness, and lithology of Candelaria Hills sequence, western Nevada*—Continued.

Unit	Maximum thickness (m)	Stratigraphy and lithology
Metallic City Tuff --------------	70	Widespread medium-grained moderately to densely welded crystal-rich ash-flow sheet with pronounced vertical zonation. Basal 5 to 10 m is weakly to moderately welded usually glassy tuff grading upward into dark-gray vitrophyre, 3 to 7 m thick, often with platy jointing. Upper part of unit consists of moderately welded well-indurated crystallized tuff. Tuff is gray where glassy; salmon, brownish gray, or reddish gray where crystallized. Pumice fragments sparse, 5 to 10 percent, <2 cm, strongly flattened. Rock fragments small and sparse, 1 to 3 percent, <5 mm, chiefly andesite with some shale. Crystals 20 to 25 percent, <4 mm, Pl:S:Q = 6:1:2, biotite 2 to 5 percent, traces of hornblende and iron oxides. Unit is locally separated from the underlying tuff of Candelaria Mountain by 5 to 6 m of crossbedded tuff and lapilli tuff. Distinguished from other units by densely welded relatively fine-grained nature and high crystal content. In Candelaria mining district unit includes an olivine basalt flow (unit Tv 10 of Page, 1959).
Tuff of Candelaria Mountain -----	80	White to yellowish- or brownish-gray coarse- to very coarse grained unwelded to very weakly welded friable ash-flow tuff with abundant white pumice fragments. Crops out only in the Candelaria Hills and Candelaria mining district. Pumice 15 to

		30 percent, 2 to 20 cm, angular and equidimensional, coarse lumps concentrated in lenses and layers. Rock fragments 1 to 6 percent, 1 mm to 2 cm, angular, andesite and tuff. Obsidian chips 2 to 5 percent, 1 to 5 mm, angular, black. Crystals 5 to 7 percent, 0.5 to 2 mm, subhedral, Pl:S:Q = 12:1:2, bioite 1 to 20 percent, traces of iron oxides, allanite, and zircon. Unit separated from the underlying tuff of Volcanic Hills by thin layer of Paleozoic-pebble conglomerate and from the overlying Metallic City Tuff by 2 to 3 m of red tuffaceous siltstone. Distinguished from other units by abundance of pumice and rock fragments and low crystal content.
Tuff of Volcanic Hills ----------	40	White to grayish-brown pumiceous strongly to weakly welded moderately indurated ash-flow sheet. Unit locally zoned with basal poorly welded zone, 2 to 3 m thick, a dark-gray vitrophyre with eutaxitic texture, 3 to 4 m thick, and a moderately to weakly welded crystallized upper part as much as 25 m thick. Elsewhere entire unit consists of brownish-gray unwelded glassy tuff. Pumice fragments 10 to 15 percent, 1 mm to 2 cm, partly flattened. Rock fragments small and sparse, 0.5 to 2.5 percent, 0.5 to 5 mm, subrounded, volcanic. Crystals 10 to 20 percent, 0.5 to 3 mm, subhedral, quartz commonly vermicular, Pl:S:Q = 2:2:1, traces of biotite, iron oxides, allanite, and zircon. Unit separated from the underlying and overlying units by erosional unconformities. Locally overlain by thin layer of Paleozoic-pebble conglomerate, or by 6 to 7 m of reworked tuff. Separated from the underlying tuff of Pinchot Creek by 2 to 3 m of gray bedded tuff. Distinguished from other units by relatively high content of pumice and crystals and by low content of rock fragments.

TABLE 2.—*Stratigraphy, thickness, and lithology of Candelaria Hills sequence, western Nevada*—Continued.

Unit	Maximum thickness (m)	Stratigraphy and lithology
Tuff of Pinchot Creek -----------	35	White to yellowish-gray fine-grained unwelded to weakly welded glassy tuff. Two cooling units in Candelaria mining district; one elsewhere. Pumice fragments 2 to 5 percent, <5 mm, concentrated in lower part of unit, slightly flattened. Rock fragments sparse, usually <1 percent, locally as much as 3.5 percent in upper 5 m of unit, 1 to 5 mm, subrounded, volcanic. Crystals 8 to 15 percent, most abundant in upper part, 0.5 to 3 mm, subhedral to broken, Pl:S:Q = 6:1:3 but mineral proportions quite variable, traces of biotite, iron oxides, and allanite. In Candelaria mining district unit is separated from the underlying tuff of Miller Mountain by thin layer of gravel and from the overlying tuff of Volcanic Hills by red-weathering zone. Distinguished from other units by fine-grained character and low percentages of crystals and rock fragments.
Tuff of Miller Mountain ---------	60	Light gray to grayish-brown fine-grained crystal-rich weakly to densely welded tuff characterized by abundant biotite. In type area on Miller Mountain tuff is zoned with basal layer of moderately welded glassy tuff grading upward into dark-gray vitrophyre. Upper part consists of gray to yellowish-gray or reddish-brown moderately to weakly welded crystallized tuff.

		Elsewhere tuff is moderately to weakly welded glassy tuff. No pumice fragments. Rock fragments <1 percent, locally more abundant at base of unit where tuff rests on Paleozoic basement rocks, 1 to 2 mm, subrounded, chiefly siltstone. Crystals 5 to 25 percent, most abundant in densely welded zones, 0.5 to 1.5 mm, subhedral, quartz crystals highly vermicular, Pl:S:Q = 12:1:2, biotite 2 to 5 percent, traces of hornblende, iron oxides, and zircon. At most localities unit rests unconformably on Paleozoic basement, elsewhere it is separated from basement rocks by the tuff of Columbus. Unit locally separated from the overlying tuff of Pinchot Creek by thin gravel layer. Readily distinguished from other units by fine-grained character and abundance of biotite.
Tuff of Columbus ----------------	50	Gray and yellowish-gray to reddish-brown fine- to medium-grained densely welded tuff, characterized by abundant Paleozoic rock fragments. Outcrops are thin and discontinuous, most common in Columbus quadrangle. Gray basal vitrophyre grades upward into reddish-gray crystallized zone. Pumice fragments 1 to 5 percent, most abundant in basal part of unit, 5 mm to 2 cm, flattened. Rock fragments 3 to 10 percent in lower few meters, sparse in upper parts of unit, 2 mm to 2 cm, angular, chiefly siltstone and chert of Paleozoic age. Crystals average <10 percent, 0.5 to 2 mm, subhedral, Pl:S:Q = 4:3:2, traces of biotite, iron oxides, and zircon. Unit rests unconformably on Paleozoic sedimentary rocks and is overlain by the tuff of Miller Mountain. Distinguished from overlying tuffs by color, abundance of rock fragments, and crystal assemblage.

Candelaria Mountain, Candelaria). Such a redundancy is awkward, but unavoidable. In addition, several tuffs are named for geographic features that occur several kilometers from outcrops of the named tuff.

The names used in this report apply to mineralogically distinct tuffs, which in some cases are composed of a single cooling unit and in other cases of two or three cooling units of similar mineralogy. Sedimentary units and tuffs of local or unknown distribution are not named.

TUFF OF COLUMBUS

The tuff of Columbus is a relatively thin discontinuous ash-flow sheet resting unconformably on pre-Tertiary basement rocks and overlain by the tuff of Miller Mountain. It crops out chiefly in the hills along the northwestern margin of Columbus Salt Marsh (unit Tt–1 of Stewart, 1979), generally between Miller Mountain and the Candelaria Hills. Small outcrops of a tuff considered to be correlative occur in the Jacks Spring and Basalt quadrangles to the west (Stewart, 1981a, b) and in the Volcanic Hills to the south (see fig. 4). The unit is informally named for a relatively large exposure about 7.2 km west-southwest of Columbus, in the Columbus quadrangle. This tuff does not crop out in the Candelaria mining district and was not described by Page (1959) or Speed and Cogbill (1979b).

Near Miller Mountain, the tuff of Columbus is a single cooling unit of gray to reddish-brown densely welded tuff with a basal vitrophyre and an upper devitrified and crystallized zone (fig. 3). In the Volcanic Hills (fig. 4), the tuff is weakly welded and the basal vitrophyre is absent. Thicknesses are highly variable but are generally less than 50 m. The tuff is easily distinguished from the overlying unit by the common presence of lithic fragments and the general absence of biotite (table 13). Sparse flattened pumice fragments as much as 2 cm long are scattered in the tuff, imparting a crude eutaxitic texture.

Rock fragments constitute 3 to 10 modal percent, decreasing in abundance upward in the unit. These are chiefly pieces of black chert as much as 2 cm across, but smaller fragments of siltstone and altered volcanic material are also present. The sedimentary fragments are most abundant in the lower part of the unit, suggesting that they were picked up from the underlying surface during flow. Some of the volcanic fragments contain olivine pseudomorphs and are presumably altered basalt.

Phenocrysts make up 7 to 9 percent and consist dominantly of plagioclase, sanidine, and quartz in the approximate proportions of 4:3:2 (table 3). Plagioclase crystals are generally 0.5 to 1.5 mm

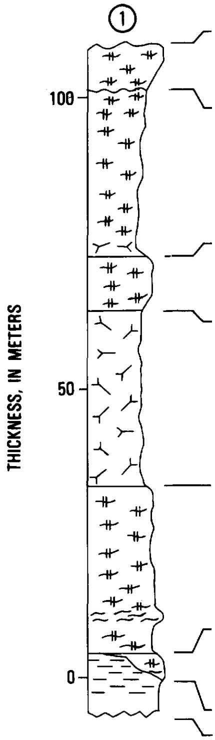

FIGURE 3.—Stratigraphic section of Candelaria Hills sequence on northeast side of Miller Mountain, Columbus quadrangle, Nevada. Number 1 at top of column indicates location in figure 2.

long, with a few glomerophyric clots as much as 3 mm across. Individual crystals are subhedral to subrounded, commonly broken, and rarely corroded or resorbed. Most plagioclase crystals are strongly zoned from andesine to oligoclase. Sanidine forms subhedral laths or prisms from about 0.5 to 2 mm long, some of which are zoned. Some sanidine laths enclose small crystals of plagioclase. Quartz forms rounded, corroded, or vermicular crystals from about 0.5 to 1.5 mm across. Trace amounts of biotite, iron oxides, and zircon are also present.

Sparse xenocrysts are also scattered in the tuff. The largest of these, as much as 1 mm across, appear to be subhedral olivine grains pseudomorphed by iron oxides and smectite. Smaller grains are angular fragments of the same material, presumably formed by breakup of the larger fragments.

The groundmass consists largely of shards and glass dust surrounding the flattened pumice fragments. Most shards are less than 0.5 mm long and none exceed 2 mm. Where fresh, the glass is pale brown to colorless. Devitrified shards consist of microcrystalline mixtures of cristobalite and alkali feldspar, commonly with axiolitic textures. The grain size of the devitrified groundmass increases somewhat in the upper parts of the unit, and tridymite crystals form small irregular patches in the crystallized zones.

TUFF OF MILLER MOUNTAIN

The tuff of Miller Mountain is a prominent ledge-forming ash-flow sheet that crops out extensively in the Candelaria Hills and Miller Mountain area (unit 1 of Speed and Cogbill, 1979b; unit Tt–2a of Stewart, 1979). It is a single cooling unit of light- to yellowish-gray or grayish-brown fine-grained moderately compacted crystal-rich tuff averaging about 40 m thick. Locally, it conformably(?) overlies the tuff of Columbus; elsewhere it rests unconformably on Paleozoic basement rocks or is separated from the basement by thin lenses of conglomerate. At most localities it is separated from the overlying tuff of Pinchot Creek by a 1- to 2-m-thick layer of gravel composed of basement clasts. The unit is informally named for exposures on the northeast side of Miller Mountain in the Columbus quadrangle (fig. 3).

In the type locality this tuff has a moderately welded basal zone 1 to 5 m thick, grading upward into a 2- to 3-m-thick dark-gray vitrophyre. This, in turn, is overlain by 25 to 35 m of moderately to weakly welded gray to yellowish-gray or reddish-brown crystallized tuff. In some sections the upper part of the unit consists of poorly indurated white tuff that weathers to low rounded hills.

There are no pumice fragments in this tuff, and rock fragments are sparse. The latter are mostly small rounded pieces of silicic volcanic material as much as 0.2 mm across. A few fragments of chert, siltstone, and limestone occur in the basal part of the unit where it overlies pre-Tertiary rocks.

Crystals make up about 5 to 25 percent by volume and are chiefly plagioclase and biotite, with minor quartz, sanidine, and opaque minerals (table 4). Crystals are most abundant in the densely welded sections on Miller Mountain and least abundant in the unwelded distal parts of the unit. Most specimens also contain 1 to 2 percent of fresh or altered hornblende. The plagioclase occurs as euhedral to subhedral prisms, generally 1 to 1.5 mm long, or as smaller angular crystal fragments. Most of the plagioclase crystals are highly zoned, ranging from sodic andesine to oligoclase, and many contain small glassy inclusions in concentric zones parallel to the crystal faces. Sanidine crystals average about 0.5 mm in length and are generally subhedral prisms. Quartz forms rounded and

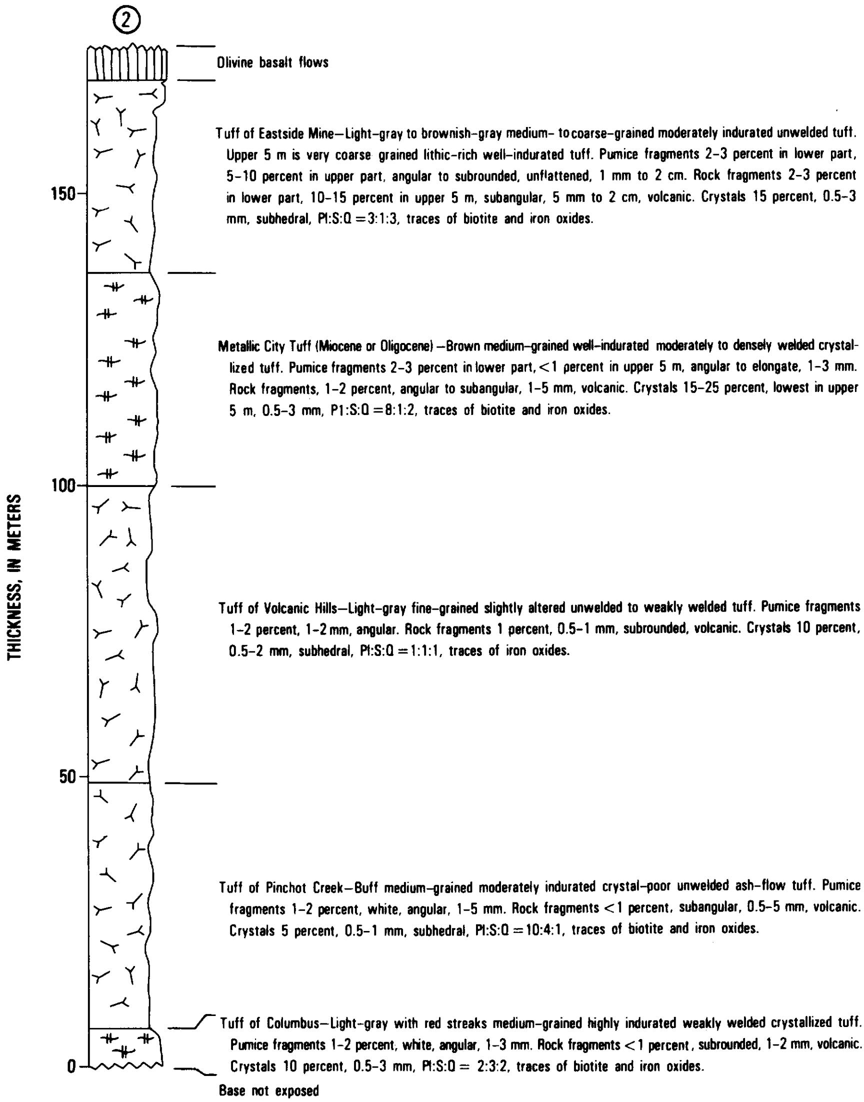

FIGURE 4.—Stratigraphic section of Candelaria Hills sequence in Volcanic Hills, northern Davis Mountain quadrangle, Nevada. Number 2 at top of column indicates location in figure 2.

highly corroded crystals, as much as 1.5 mm across, with a wormy or vermicular habit. Biotite flakes are euhedral to subhedral, are as much as 1.5 mm across, and have a dark-brown to yellowish- or reddish-brown pleochroic scheme. Hornblende crystals are subhedral prisms generally between 0.5 and 1.5 mm long. Fresh crystals occur only in a few outcrops; elsewhere the grains are replaced by yellowish-brown birefringent smectite. Opaque minerals are slightly rounded octahedra of magnetite, generally less than 0.2 mm across. Trace amounts of apatite, zircon, and allanite are also present in most specimens.

The groundmass consists of moderately to intensely deformed glass shards and dust. In the basal vitrophyre the shards are fresh and colorless; in the devitrified zones they are replaced by microcrystalline mixtures of cristobalite and alkali feldspar. In zones of incipient devitrification the interstitial dust is crystallized, whereas the shards are still glassy.

TUFF OF PINCHOT CREEK

The tuff of Pinchot Creek (unit 2 of Speed and Cogbill, 1979b; part of unit Tt–2b of Stewart, 1979) is a white to yellowish-gray fine-grained unwelded to weakly welded moderately indurated ash-flow tuff that crops out chiefly in the Candelaria Hills and the Miller Mountain area. This unit is thickest and best developed in the Candelaria mining district, where it comprises two distinct cooling units with a combined thickness of about 35 m (Speed and Cogbill, 1979b). In this area, it is separated from the underlying tuff of Miller Mountain by a thin gravel layer and has a red-weathering zone at the top; elsewhere these discontinuities are absent, but the unit can be distinguished from the underlying and overlying tuffs on the basis of lithology and phenocryst mineralogy

TABLE 3.—*Modal analyses of the tuff of Columbus*
[tr, trace]

	1	2	3	4	5
Groundmass	89.0	89.0	83.5	92.4	88.4
Plagioclase	4.2	5.0	4.5	2.2*	4.0
Sanidine	2.3	1.6	6.0	3.1	3.3
Quartz	1.8	3.0	3.0	1.8	2.4
Biotite	.1	-	.3	.2	.1
Opaques	tr	.4	.2	.1	.2
Zircon	tr	tr	-	tr	tr
Rock fragments	2.6	1.0	2.5	.2	1.6

1. Basal vitrophyre, Miller Mountain section, Columbus quadrangle.
2. Devitrified welded tuff, Miller Mountain section, Columbus quadrangle.
3. Devitrified welded tuff, Columbus quadrangle.
4. Devitrified welded tuff, Volcanic Hills, Davis Mountain quadrangle.
5. Average modal composition of the tuff of Columbus.

*Altered grains identified as plagioclase (table 13). The tuff is informally named for exposures in the vicinity of Pinchot Creek along the south margin of Miller Mountain (figs. 2, 4).

In the Candelaria mining district the lower cooling unit is 20 to 25 m thick and consists of weakly welded moderately compacted glassy tuff with 2 to 5 percent of small rounded pumice fragments. It is separated from the upper cooling unit by 1 to 7 m of well-bedded sandstone and conglomerate containing clasts of tuff as much as 30 cm across and a few small fragments of pre-Tertiary rocks (Speed and Cogbill, 1979b). The upper cooling unit, which is as much as 10 m thick, consists of light-gray unwelded tuff with 2 to 3 percent of pumice and sparse rock fragments. A somewhat higher crystal content and the presence of megascopic biotite distinguish the upper cooling unit from the lower one. In other sections, such as those in the Miller Mountain area, the bedded tuffs are absent and only one cooling unit can be recognized. On the basis of its mineralogy, this cooling unit appears to be equivalent to the lower one in the Candelaria mining district.

Phenocrysts average about 10 modal percent and consist chiefly of plagioclase and quartz, with lesser amounts of sanidine, biotite, and iron oxides (table 5). Plagioclase grains are subhedral to anhedral commonly broken prisms averaging less than 0.5 mm across. Most are moderately zoned oligoclase, but some grains have cores of sodic andesine. Sanidine occurs as weakly zoned subhedral crystals as much as 1.5 mm across, some of which have colorless volcanic glass adhering to their rims. Quartz forms rounded corroded commonly vermicular bipyramids from 0.5 to 1.5 mm across. Small flakes of biotite are always present but never exceed 1 modal percent. Magnetite occurs in subhedral to irregular crystals as much as 0.3 mm across, and trace amounts of zircon and reddish-brown allanite are also present.

In most specimens the groundmass is glassy and consists of small pumice and rock fragments surrounded by glass shards and dust. Most of the pumice fragments are equidimensional or slightly flattened and range from 0.5 to 3 mm across. These consist of gray glass with tubular vesicles, some of which are lined with minute grains of iron oxide. Sparse undeformed fragments of brown pumice enclosing crystals of biotite and plagioclase are interpreted as fragments of older pyroclastic material. The rare lithic fragments are as much as 5 mm across and consist of fine-grained andesite. Glass shards are small, angular, and uniform in size, averaging about 0.25 mm long. These consist of fresh colorless glass but the interstitial glass dust is usually devitrified to a mixture of cristobalite and alkali feldspar.

TUFF OF VOLCANIC HILLS

The tuff of Volcanic Hills (unit 3 of Speed and Cogbill, 1979b; part of unit Tt–2b of Stewart, 1979) is a widespread ash-flow sheet that crops out extensively in the Candelaria and Miller Mountain areas, extending from the Columbus quadrangle on the east to the Basalt quadrangle (Stewart, 1981a) on the west. It consists of a single cooling unit as much as 40 m thick composed of grayish-brown weakly to strongly welded well-indurated tuff characterized by abundant small pumice fragments. In the Candelaria Hills the tuff is bounded above and below by erosional unconformities. A red-weathering zone typically occurs at the top of the underlying tuff of Pinchot Creek, and a thin bed of Paleozoic-pebble con-

TABLE 4.—*Modal analyses of the tuff of Miller Mountain*
[tr, trace]

	1	2	3	4	5	6
Groundmass	72.2	80.6	74.8	79.4	78.0	77.0
Plagioclase	15.9	10.0	13.2	12.6	11.0	12.5
Sanidine	1.0	1.1	.8	1.3	1.0	1.0
Quartz	2.1	1.0	4.4	1.3	1.9	2.2
Biotite	5.4	3.9	4.4	3.3	4.1	4.2
Hornblende	-	-	-	-	2.4	.4
Altered hornblende?	2.2	2.2	1.2	tr	-	1.0
Opaques	.6	.7	.6	-	-	.4
Allanite	tr	-	-	-	-	-
Zircon	tr	tr	tr	tr	tr	tr
Apatite	tr	-	-	tr	-	tr
Rock fragments	.6	.5	.6	2.1	1.6	1.3

1. Basal vitrophyre, Miller Mountain section, Columbus quadrangle.
2. Devitrified welded tuff, upper part of unit, Miller Mountain section, Columbus quadrangle.
3. Basal vitrophyre, Columbus quadrangle.
4. Glassy welded tuff, Candelaria Hills, Columbus quadrangle.
5. Glassy welded tuff, Candelaria Hills, Candelaria quadrangle.
6. Average modal composition of the tuff of Miller Mountain.

TABLE 5.—*Modal analyses of the tuff of Pinchot Creek*
[tr, trace]

	1	2	3	4	5
Groundmass -----	88.5	91.0	86.4	90.0	89.0
Plagioclase ----	4.7	6.0	7.6	5.1	5.9
Sanidine -------	1.2	.7	1.2	1.4	1.1
Quartz ---------	4.3	1.0	3.1	2.1	2.6
Biotite --------	.7	.3	1.0	1.0	.8
Opaques --------	-	-	.2	tr	tr
Allanite -------	-	tr	tr	tr	tr
Zircon ---------	tr	tr	-	tr	tr
Rock fragments -	.6	1.0	.5	.4	.6

1. Basal vitrophyre, Candelaria Hills, Columbus quadrangle.
2. Glassy moderately welded tuff, Candelaria Hills, Candelaria quadrangle.
3. Glassy unwelded tuff, Candelaria Hills, Candelaria quadrangle.
4. Glassy moderately welded tuff, Miller Mountain section, Columbus quadrangle.
5. Average modal composition of the tuff of Pinchot Creek.

glomerate separates the tuff of Volcanic Hills from the overlying tuff of Candelaria Mountain. To the west, in the Basalt quadrangle, the unit is about 35 m thick and consists of gray to brownish-gray unwelded glassy tuff. There, it overlies several meters of fine-grained well-sorted vitric tuff and is overlain by 6 to 7 m of gray cross-bedded tuff and lapilli tuff. The unit is informally named for exposures in the Volcanic Hills in the northern part of the Davis Mountain quadrangle (figs. 2, 4).

The most complete section occurs in the Candelaria area (fig. 5). Here, the tuff is about 30 m thick and consists of moderately to densely welded pumiceous tuff that crops out in resistant ledges. A basal zone of poorly welded material, 2 to 3 m thick, grades upward into a dark-gray vitrophyre of variable thickness, which in turn is overlain by as much as 25 m of white to grayish-brown well-indurated stony tuff (Speed and Cogbill, 1979b). Flattened pumice fragments as much as 2 cm long constitute from 10 to 15 modal percent and impart a strong eutaxitic texture to the rock. Sparse

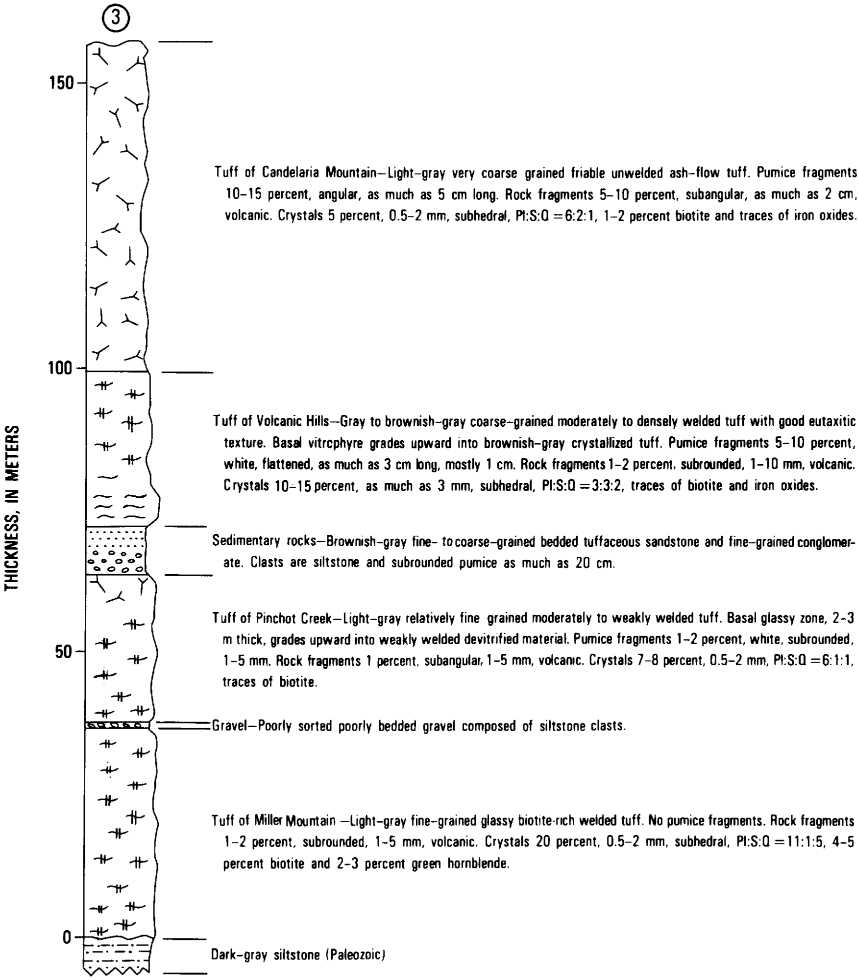

FIGURE 5.—Stratigraphic section of Candelaria Hills sequence 2 km southwest of Metallic City, Candelaria quadrangle, Nevada. Number 3 at top of column indicates location in figure 2.

rock fragments occur as small subrounded granules scattered in the tuff.

Crystals constitute from 10 to 20 percent of the tuff and are most abundant in the basal densely welded zones (table 6). Plagioclase, sanidine, and quartz are the common phenocrysts, and they occur in the approximate proportions 2:2:1. Plagioclase crystals are subhedral prisms 0.5 to 3 mm long, many of which are rounded and corroded. Most of the crystals exhibit strong normal zoning in the sodic andesine-oligoclase range. Sanidine crystals form slightly zoned subhedral or broken prisms as much as 2 mm long, but these are rarely corroded. A few crystals enclose small plagioclase laths, and some have marginal granophyric overgrowths. Quartz occurs as rounded and highly corroded bipyramids as much as 2 mm across. Small flakes of brown biotite, as much as 0.5 mm across, are present in all specimens but never exceed 1 modal percent. Magnetite forms euhedral to irregular crystals, about 0.2 mm across, that are widely dispersed. Trace amounts of zircon, apatite, and allanite are also present.

Pumice fragments consist of gray to light-brown glass containing phenocrysts of feldspar and quartz. In most of the tuff the fragments are strongly deformed and as much as 2 cm long. In unwelded portions they are equidimensional and angular and average about 5 mm across. Crystallized fragments consist of microcrystalline cristobalite and alkali feldspar, often with a core of coarser grained quartz or tridymite. Rock fragments are chiefly small rounded pieces of altered volcanic rock less than 0.5 mm across, but sparse fragments of Paleozoic siltstone as much as 5 mm across are also present.

The groundmass consists of glass shards and minor dust surrounding the crystals and pumice fragments. Most shards are strongly deformed and range from 0.25 to 0.5 mm long. In the vitrophyric zones they consist of colorless glass surrounded by devitrified interstitial material. In crystallized rocks the groundmass is a mixture of cristobalite and alkali feldspar with relict shard textures.

TUFF OF CANDELARIA MOUNTAIN

The tuff of Candelaria Mountain (unit 4 of Speed and Cogbill, 1979b; unit Tt–2c of Stewart, 1979) is a distinctive pumice-rich ash-flow sheet that crops out only in the Candelaria mining district and in the Candelaria Hills along the north edge of the Miller Mountain and Columbus quadrangles (fig. 6). It is informally named for exposures on the Candelaria Mountain in the southwest corner of the Candelaria quadrangle.

This unit is separated from the underlying tuff of Volcanic Hills and the overlying Metallic City Tuff by erosional unconformities. A thin layer of Paleozoic-pebble conglomerate occurs locally below the unit, and 2 to 3 m of red tuffaceous sediment occurs above it. In the Candelaria mining district the unit is as much as 80 m thick; to the south in the Candelaria Hills only about 15 m is exposed in an incomplete section. Elsewhere in the region the ash-flow sheet is missing and this stratigraphic interval is occupied by

TABLE 6.—*Modal analyses of the tuff of Volcanic Hills*
[tr, trace]

	1	2	3	4	5	6	7	8	9	10
Groundmass -----	81.3	87.9	79.9	89.6	87.9	90.2	88.0	88.4	82.4	86.6
Plagioclase ----	6.5	4.3	7.0	3.0	5.0	3.3	4.3	4.7	5.4	4.8
Sanidine -------	6.1	3.9	7.0	3.1	3.7	3.0	2.2	2.5	7.8	3.9
Quartz ---------	4.6	1.8	4.4	2.9	1.5	2.1	3.3	1.0	3.3	2.7
Biotite --------	.1	tr	.3	.8	.2	.3	.9	.5	.4	.4
Opaques --------	.4	.2	.3	.2	.5	.3	tr	.4	.2	.3
Allanite -------	tr	.1	-	tr	-	.1	tr	tr	tr	tr
Zircon ---------	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Apatite --------	-	-	tr	tr	-	tr	tr	tr	tr	tr
Rock fragments -	1.0	1.5	1.0	.4	.4	.7	1.3	2.5	.5	1.1
Other ----------	-	.3	.1	-	.8	-	-	tr	-	.2

1. Basal vitrophyre Candelaria Hills, Candelaria quadrangle.
2. Devitrified welded tuff, upper part of unit in Candelaria Hills; Candelaria quadrangle.
3. Devitrified moderately welded tuff, Columbus quadrangle.
4. Altered weakly welded tuff, Volcanic Hills, Davis Mountain quadrangle.
5. Devitrified weakly welded tuff, Candelaria Hills, Belleville quadrangle.
6. Glassy unwelded tuff at base of unit, Basalt quadrangle.
7. Glassy unwelded tuff at middle of unit, Basalt quadrangle.
8. Glassy unwelded tuff at top of unit, Basalt quadrangle.
9. Devitrified weakly welded tuff, Columbus quadrangle.
10. Average modal composition of the tuff of Volcanic Hills.

as much as 7 m of well-bedded and crossbedded tuffaceous sediment.

The tuff of Candelaria Mountain consists of white to yellowish- or brownish-gray coarse-grained weakly welded tuff characterized by abundant pumice and rock fragments and small chips of black obsidian. White pumice composes 15 to 30 percent of the rock and occurs chiefly as small fragments less than 2 cm across, although pumice lumps as coarse as 20 cm are locally abundant, typically being concentrated in lenses or layers. Rock fragments are also conspicuous, composing 1 to 6 modal percent. These are angular fragments as much as 2 cm across composed of dark-gray andesite and brown welded tuff. Small angular chips and flakes of black obsidian as much as 5 mm across are scattered in the rock. Only one cooling unit can be recognized in this tuff, but the presence of an interbedded olivine basalt flow in the Candelaria mining district (Speed and Cogbill, 1979b) and the uneven distribution of coarse pumice suggest the presence of multiple flow units.

Plagioclase and biotite are the most abundant crystals, and they are accompanied by small amounts of quartz and sanidine (table 7). The plagioclase forms subhedral prisms from 0.5 to 1 mm long, some of which are broken, rounded, or slightly corroded. Most of the plagioclase crystals are highly zoned oligoclase, although some have cores of sodic andesine. Sanidine occurs as subhedral laths as much as 2 mm long, and quartz forms small rounded crystals less than 1 mm across. Biotite flakes are pale yellow to reddish brown and range from 0.5 to 1 mm across. Trace amounts of magnetite, allanite, and zircon are present in most specimens.

The groundmass consists of glass shards with small amounts of interstitial dust and minute crystal fragments. The shards are undeformed to slightly flattened and average about 0.4 mm long. Most consist of colorless glass, but some have pale-brown cores and colorless rims, suggesting some bleaching. The unit is everywhere glassy with only minor devitrification of the interstitial material.

METALLIC CITY TUFF

The Metallic City Tuff (unit Tt–2d of Stewart, 1979b) is a voluminous, widespread ash-flow sheet that is present in nearly every section of the Candelaria Hills sequence. The thickest and most complete sections occur in the Candelaria Hills (figs. 6, 7), but the unit extends from the Garfield Hills on the north (fig. 8) to the central Silver Peak Range on the south (fig. 9) and from Huntoon Valley quadrangle on the west to Big Smoky Valley on the east. It

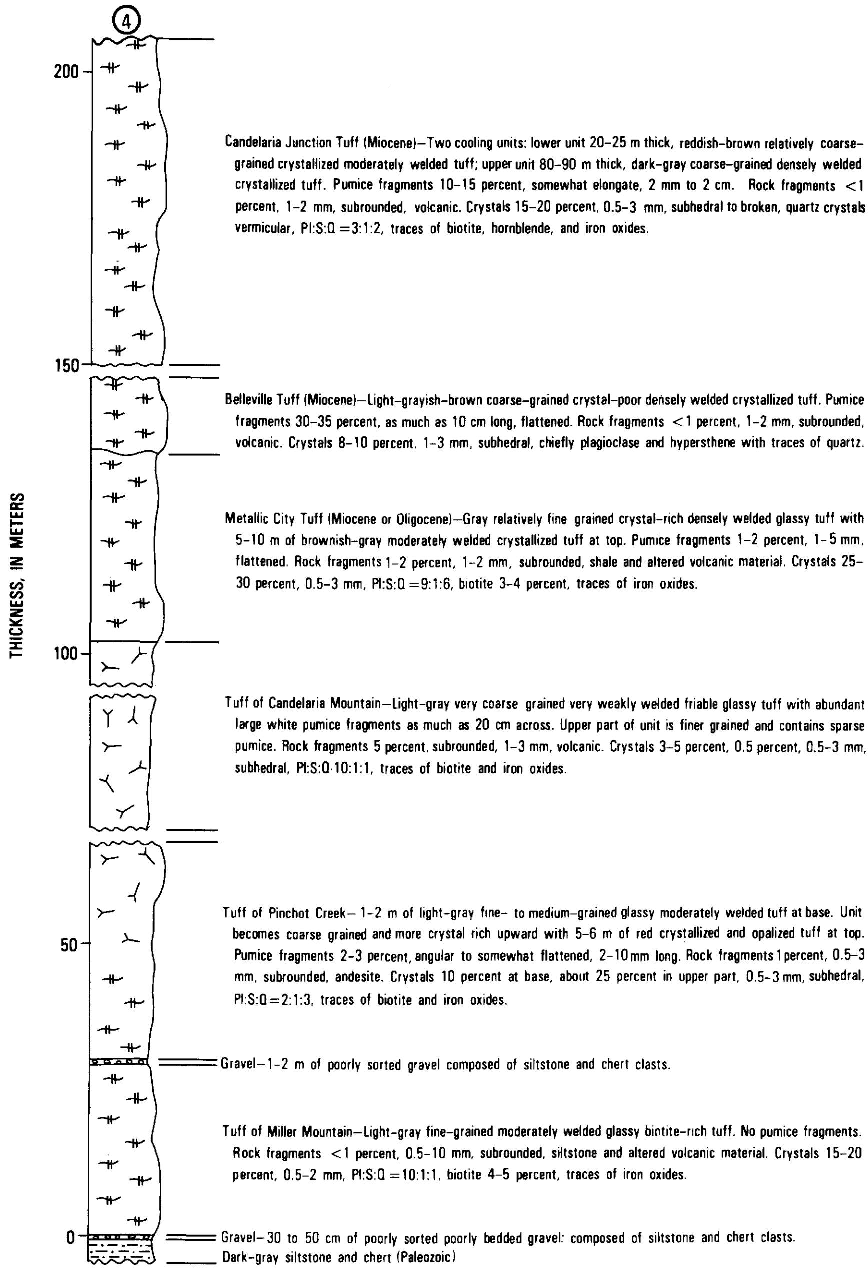

FIGURE 6.—Composite stratigraphic section of Candelaria Hills, Columbus quadrangle, Nevada. Number 4 at top of column indicates location in figure 2.

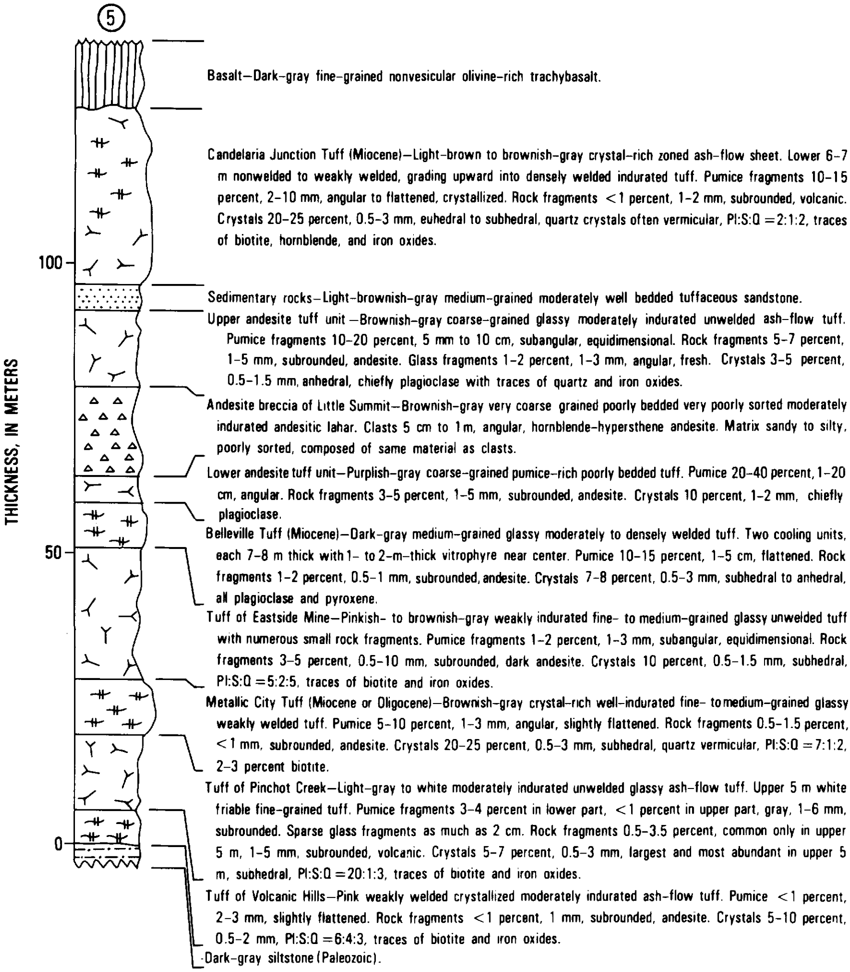

FIGURE 7.—Stratigraphic section of Candelaria Hills sequence about 2.5 km south of Candelaria Junction, Belleville quadrangle, Nevada. Number 5 at top of column indicates location in figure 2.

has been formally named by Speed and Cogbill (1979b) for exposures located 2.5 km southwest (S. 64° W.) of Metallic City, Nevada, in the southeast-facing cliff of hill 6010 in the Candelaria quadrangle. At most localities it is separated from the underlying tuff of Candelaria Mountain by 5 to 6 m of crossbedded tuff and lapilli tuff and from the overlying tuff of Eastside Mine by a thin bed of red tuffaceous siltstone. In the Candelaria mining district and the Camp Douglas quadrangle the upper contact is an angular unconformity, but this discordance is not observed elsewhere.

The Metallic City Tuff ranges from about 20 to 70 m in thickness and comprises a single cooling unit of gray densely welded tuff that weathers to steep, cliff-forming outcrops. Pumice fragments are small and sparse, and the unit has only a weakly developed eutaxitic structure. Lithic fragments are also sparse, rarely exceeding 1 percent of the rock. Typical sections have a basal zone of weak to moderate welding which grades upward into a dark-gray vitrophyre from 3 to 7 m in thickness. This is followed by strongly to moderately welded tuff which commonly exhibits crude columnar jointing. In some sections the top of the unit exhibits platy jointing and weathers to thin slabs. In many outcrops, particularly those near the distal edges of the sheet, the entire unit is glassy and light gray; in others, the upper part of the tuff is stony and varicolored in shades of brown, red, and gray.

The Metallic City Tuff is everywhere characterized by having large and abundant phenocrysts (table 8). Plagioclase, sanidine, and quartz combined average 20 to 25 modal percent and occur in the approximate proportions of 6:1:2. Plagioclase crystals are euhedral to subhedral, occasionally corroded prisms as much as 2 mm long. Most are normally zoned, but the range of composition is difficult to determine because the cores of many crystals are replaced by brown smectite. Sanidine typically forms euhedral twinned prisms as much as to 1.5 mm long, all of which are fresh. Quartz

TABLE 7.—*Modal analyses of the tuff of Candelaria Mountain*
[tr, trace]

	1	2	3	4	5
Groundmass -----	89.5	88.4	94.3	89.3	90.5
Plagioclase ----	3.3	3.2	3.9	4.4	3.7
Sanidine -------	.1	.8	.2	.2	.3
Quartz ---------	.3	.4	.5	.8	.5
Biotite --------	1.2	1.2	.8	1.7	1.2
Opaques --------	-	.1	-	.1	tr
Allanite -------	-	-	tr	tr	tr
Zircon ---------	tr	-	-	tr	tr
Rock fragments -	5.6	5.9	.3	3.5	3.8

1. Glassy unwelded tuff, Candelaria Hills, Columbus quadrangle.

2. Glassy unwelded tuff, Candelaria mining district, Candelaria quadrangle.

3. Glassy unwelded tuff, Candelaria mining district, Belleville quadrangle.

4. Glassy unwelded tuff, Candelaria mining district, Belleville quadrangle.

5. Average modal composition of the tuff of Candelaria Mountain.

crystals are large subhedral bipyramids as much as 6 mm across, and they typically lack the corroded, vermicular habit that is characteristic of quartz in many of the other ash-flow sheets. Euhedral flakes of biotite as much as 1 mm across are scattered in the rock and are accompanied by small amounts of green hornblende. In most cases the hornblende has been replaced by brown smectite, but fresh grains are preserved in some devitrified specimens. The amphibole crystals are subhedral commonly broken prisms as much as 2 mm long. Magnetite occurs as small octahedra as much as 0.5 mm across, and zircon, apatite, and allanite are present in trace amounts.

Although the unit is everywhere characterized by having abundant crystals and a high proportion of plagioclase, the modal compositions are quite variable (table 8). In at least two sampled sections the basal zone contains fewer and smaller crystals than the upper part of the unit. This compositional variability suggests the presence of several flow units, but these have not been distinguished on the basis of other criteria.

In vitric specimens the groundmass consists of highly deformed colorless shards as much as 0.5 mm long and minor interstitial glass dust. Minute crystal fragments are also abundant in the spaces between shards. A few highly deformed pumice fragments as much as 2 cm long are present, but they never exceed 10 modal percent. Where the rock is devitrified, the groundmass is a microcrystalline mixture of cristobalite and alkali feldspar, often with well-developed axiolitic and spherulitic textures. The sparse rock fragments are from 3 to 5 mm across and consist of andesite and welded tuff.

TUFF OF EASTSIDE MINE

The tuff of Eastside Mine (unit 6 of Speed and Cogbill, 1979b) was named by Stewart (1981a) for a thick generally poorly welded ash-flow tuff characterized by large lithic fragments and abundant pumice. The tuff crops out over a large area, extending from the Columbus quadrangle on the east to the Jacks Spring quadrangle on the west (Stewart, 1979; 1981a, b). In the Candelaria mining district this unit overlies the Metallic City Tuff with an angular unconformity (Speed and Cogbill, 1979b); elsewhere the two units are structurally conformable but are separated by a thin layer of tuffaceous siltstone. The overlying Belleville Tuff fills deep channels incised into or completely through the tuff of Eastside Mine. The unit was informally named by Stewart (1979) for exposures about 2.5 km west-northwest of the Eastside Mine in the Basalt

TABLE 8.—*Modal analyses of the Metallic City Tuff*
[tr, trace]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Groundmass --------	81.9	73.2	77.6	63.5	69.8	67.5	78.5	74.4	74.1	78.1	69.6	65.9	73.6	59.6	72.0
Plagioclase -------	7.8	17.6	10.6	20.3	19.7	17.0	12.5	13.1	13.9	14.5	16.2	17.2	15.6	21.2	15.5
Sanidine ----------	3.5	2.3	2.0	.6	1.2	2.1	1.5	2.7	2.5	.7	6.1	1.8	1.6	2.8	2.2
Quartz ------------	2.8	.9	6.1	7.9	3.3	8.5	5.5	6.0	5.3	2.4	2.0	9.5	1.4	7.6	5.1
Biotite -----------	1.8	2.9	2.7	3.9	3.7	3.4	1.7	1.9	3.3	2.3	2.0	3.1	3.4	4.5	2.9
Hornblende---------	-	.4	-	-	-	-	-	.4	-	tr	-	-	-	-	.1
Altered horblende?-	-	-	-	.2	.1	.5	tr	-	.1	.2	.2	.3	2.0	3.4	.5
Opaques -----------	.2	.5	.5	.4	-	.7	-	.7	-	.4	.2	.9	.3	.2	.4
Allanite ----------	tr	tr	tr	tr	-	-	-	tr	-	tr	-	tr	tr	tr	tr
Zircon ------------	tr	tr	tr	tr	tr	.1	.1	tr	tr	tr	tr	tr	tr	tr	tr
Apatite -----------	tr	tr	tr	tr	-	-	-	.1	-	-	tr	tr	tr	tr	tr
Rock fragments ----	2.0	2.2	.5	3.2	2.2	.2	.4	.7	.8	1.4	.2	.9	2.1	.7	1.3

1. Glassy unwelded tuff, base of unit, Basalt quadrangle.
2. Glassy unwelded tuff, middle of unit, Basalt quadrangle.
3. Glassy unwelded tuff, top of unit, Basalt quadrangle.
4. Glassy welded tuff, Columbus quadrangle.
5. Glassy welded tuff, base of unit in Candelaria Hills, Columbus quadrangle.
6. Devitrified welded tuff, top of unit in Candelaria Hills, Columbus quadrangle.
7. Devitrified welded tuff, base of unit in Miller Mountain section, Columbus quadrangle.
8. Devitrified welded tuff, top of unit in Miller Mountain section, Columbus quadrangle.
9. Glassy unwelded tuff, base of unit, Belleville quadrangle.
10. Glassy moderately welded tuff, top of unit, Belleville quadrangle.
11. Devitrified weakly welded tuff, Columbus quadrangle.
12. Devitrified welded tuff, Columbus quadrangle.
13. Devitrified welded tuff, northern Fish Lake Valley, Davis Mountain quadrangle.
14. Altered welded tuff, Icehouse Canyon, Silver Peak Range, Rhyolite Ridge quadrangle.
15. Average modal composition of the Metallic City Tuff

quadrangle (Stewart, 1981a; fig. 10).

In most outcrops, the tuff of Eastside Mine is a single cooling unit of white weakly welded tuff that weathers to low rounded slopes or to small pinnacles. Locally, a glassy zone as much as 2 m thick occurs at the base of the unit, and in the Miller Mountain area the middle and upper parts of the unit are composed of reddish-brown moderately welded well-indurated tuff that weathers to a resistant ledge. The thickness of the unit varies considerably, but its maximum is about 130 m in the Candelaria mining district (Speed and Cogbill, 1979b). The thickness decreases gradually outward from this area, but most of the variation is due to local erosion before eruption of the overlying Belleville Tuff.

Angular pumice lumps are ubiquitous throughout the tuff but vary considerably in size and abundance. In the Miller Mountain section (fig. 3), the tuff is moderately welded and the pumice

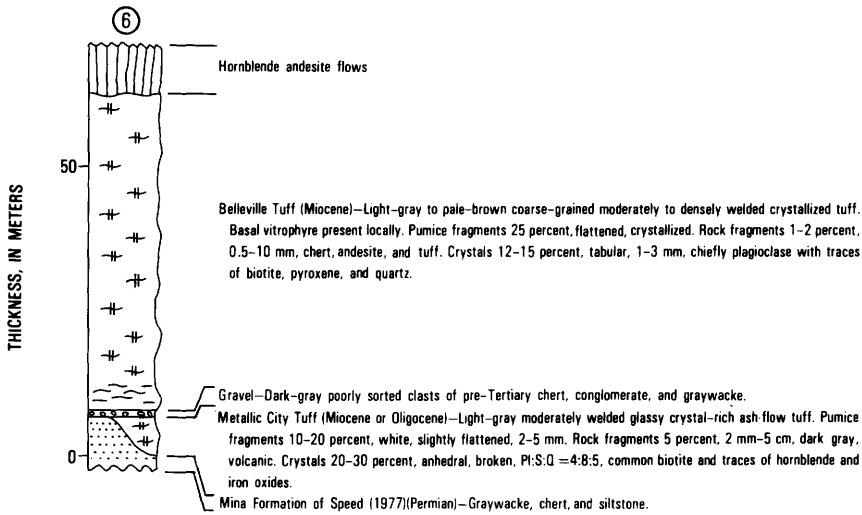

FIGURE 8.—Stratigraphic section of Candelaria Hills sequence in Camp Douglas quadrangle, Nevada (after Garside, 1979). Number 6 at top of column indicates location in figure 2.

fragments are flattened. In the Candelaria area they compose 10 to 15 modal percent and are as much as 4 cm in diameter, but in a good exposure along the highway about 6 km north of Basalt, pumice fragments compose only about 1 to 2 percent of the unit and average 5 mm in size. Farther west, near the west edge of the Basalt quadrangle, pumice composes 2 to 3 percent of the rock and measures as much as 2 cm across (fig. 10). Lithic fragments average from 2 to 10 percent, being most abundant in the lower parts of the unit. Individual fragments are subangular to subrounded and have a maximum diameter of about 8 cm; however, size and abundance vary markedly, generally decreasing westward away from the Candelaria mining district. The fragments are chiefly brown or black porphyritic andesite with minor amounts of Paleozoic siltstone and chert.

Phenocrysts compose 10 to 15 percent of typical specimens but exhibit considerable lateral and vertical variation in the unit (table 9). Plagioclase crystals average 0.5 mm across and are subhedral blocky prisms. Most are strongly zoned oligoclase, but some have corroded cores that may be slightly more calcic. Sanidine crystals are subhedral prisms, 0.5 to 1 mm long, many of which are broken. Quartz forms corroded and broken bipyramids from 0.5 to 1.5 mm across. Biotite and opaque grains are present in small quantities,

TABLE 9.—*Modal analyses of the tuff of the Eastside Mine*
[tr, trace]

	1	2	3	4	5	6	7
Groundmass -----	92.7	87.2	74.6	70.1	84.1	84.4	82.2
Plagioclase ----	3.8	6.0	9.9	7.8	5.8	4.6	6.3
Sanidine -------	.9	2.4	1.7	4.5	1.1	1.8	2.1
Quartz ---------	.8	2.4	4.5	11.8	4.6	5.0	4.9
Biotite --------	.6	.6	.4	.4	.5	.8	.5
Opaques --------	.1	.3	.1	.2	.4	.2	.2
Allanite -------	tr	-	tr	-	-	-	tr
Zircon ---------	tr	tr	-	tr	tr	-	tr
Apatite --------	tr	tr	-	-	-	-	tr
Rock fragments -	1.1	1.1	8.8	5.0	3.5	3.2	3.8

1. Glassy moderately welded tuff, base of unit, Basalt quadrangle.
2. Glassy unwelded tuff, top of unit, Basalt quadrangle.
3. Glassy weakly welded tuff, base of unit in Miller Mountain section, Columbus quadrangle.
4. Devitrified moderately welded tuff, top of unit in Miller Mountain section, Columbus quadrangle.
5. Devitrified unwelded tuff, Basalt quadrangle.
6. Glassy unwelded tuff, Candelaria mining district, Belleville quadrangle.
7. Average modal composition of the tuff of Eastside Mine.

and most specimens contain trace amounts of zircon and allanite.

The average grain size of the phenocrysts decreases away from the Candelaria mining district, and there is an indication of preferential loss of the large quartz and sanidine crystals in the distal parts of the ash-flow sheet. The vertical variations, particularly in phenocryst ratios, suggest the presence of multiple flow units.

The groundmass consists largely of undeformed glass shards surrounded by dust and sparse crystal fragments. The shards are well sorted and average about 0.5 mm in length. Fresh glass is very pale brown, whereas devitrified material is brown to golden brown and consists of microcrystalline cristobalite and alkali feldspar, often with axiolitic textures. Small amounts of tridymite occur in some devitrified pumice fragments.

BELLEVILLE TUFF

The Belleville Tuff (unit Tt–3a of Stewart, 1979) consists of varicolored coarse-grained pumice-rich tuff with a distinctive phenocryst assemblage (table 13). It overlies the tuff of Eastside Mine with pronounced erosional unconformity, typically occurring in steep-sided channels cut into the underlying unit. In the Candelaria area it is as much as 80 m thick (Speed and Cogbill, 1979b), but the thickness decreases rapidly away from this location. In the Columbus and Miller Mountain quadrangles Bellville Tuff is as much as 30 m thick where it fills channels but more commonly it is 10 m or less in thickness (figs. 3, 6). In a few places erosion has completely removed the tuff of Eastside Mine and the Belleville Tuff rests directly on the underlying Metallic City Tuff (figs. 6, 8). The unit was formally named by Speed and Cogbill (1979b) for exposures located 2.3 km southeast (S. 20° E.) of Belleville on the east side of hill 5954 in the Belleville quadrangle.

In the Candelaria area Speed and Cogbill (1979b) recognized two cooling units, and three cooling units are locally present in the Miller Mountain quadrangle. Each cooling unit typically has a weakly welded basal zone grading upward into a dark-gray vitrophyre, with the vitrophyres being best developed and thickest where the tuff fills a channel. Above the vitrophyres the rock consists of densely to moderately welded brick-red to orange or white crystallized tuff, typically with large flattened pumice fragments that impart a well-developed eutaxitic texture to the rock. The pumice fragments are small and sparse in the lowest parts of the unit, becoming coarser grained and more abundant upward. Near the top of the unit, flattened pumice fragments may be as

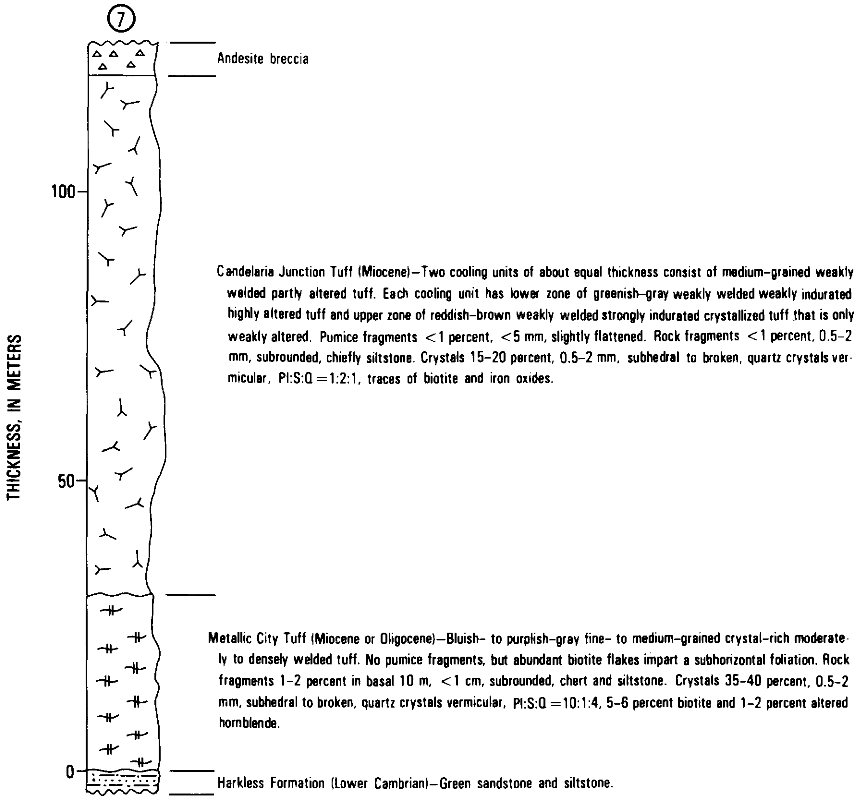

FIGURE 9.—Stratigraphic section of Candelaria Hills sequence in central Silver Peak Range, Rhyolite Ridge quadrangle, Nevada. Figure 7 at top of column indicates location in figure 2.

much as 10 cm long and may compose 30 to 35 percent of the rock (fig. 6). Lithic fragments as much as 1 cm in diameter are also common throughout the tuff. These are porphyritic andesite containing phenocrysts of plagioclase, hypersthene, and magnetite.

Farther west, in the Basalt quadrangle, the tuff averages 7 to 8 m in thickness and contains 20 to 30 percent pumice fragments, generally less than 5 cm long (fig. 10). Lithic fragments are also common here, but occur as small, rounded grains less than 5 mm across.

Mineralogically, the Belleville Tuff is distinct from other ash-flow sheets in the sequence, containing chiefly plagioclase and hypersthene (table 10). Quartz, sanidine, and biotite are locally present, but combined they compose less than 1 modal percent. The plagioclase forms subhedral, occasionally broken or corroded crystals as much as 3 mm long, which occur either singly or in glomerophyric clots with hypersthene and magnetite. Much of the plagioclase is strongly zoned, ranging from sodic labradorite to calcic oligoclase in composition. The hypersthene occurs in corroded and broken crystals, 0.5 to 1.5 mm across, many of which are partly to completely replaced by brown smectite. The few specimens that do not contain hypersthene crystals have hypersthene-bearing rock fragments. All of the hypersthene and at least some of the plagioclase crystals are probably xenocrystic, on the basis of their highly corroded habits and their occurrence in the lithic fragments.

The groundmass consists of densely welded shards and small flattened pumice fragments surrounded by glass dust. The shards are as much as 0.5 mm long and, where fresh, consist of pale-brown glass. Devitrified shards and pumice fragments consist of cristobalite and alkali feldspar. A few angular equidimensional pumice fragments were probably derived from older ash-flow tuffs.

ANDESITE BRECCIA OF LITTLE SUMMIT WITH ASSOCIATED TUFF AND SEDIMENTARY ROCKS

A laterally varying succession of tuff, ash-flow tuff, andesite breccia, and tuffaceous sedimentary rock occurs between the Belleville Tuff and the Candelaria Junction Tuff. The sequence crops out in an east-west belt extending from the Columbus quadrangle on the east to the Huntoon Valley on the west (Stewart, 1979; 1981a, b). It is thickest and best developed in the Candelaria Hills, where it forms a conspicuous part of the trough facies of Speed and Cogbill (1979b). At most localities it conformably overlies the Belleville Tuff and is separated from the overlying Candelaria Junction Tuff by an erosional unconformity. Locally, a thin layer of boulder to cobble conglomerate occurs along the lower contact (fig. 10). A volcanic breccia unit that forms part of the succession is informally named the andesite breccia of Little Summit after an inconspicuous pass in the Belleville quadrangle.

A typical section consists, from the base upward, of a gray poorly sorted poorly bedded unwelded andesite tuff, 15 to 25 m thick; the andesite breccia of Little Summit; and an unwelded to weakly welded ash-flow andesite tuff, generally less than 15 m thick (fig. 7). In some sections a variable thickness of bedded and cross-bedded sandstone and granule conglomerate separates the breccia from the upper tuff (fig. 10). The tuffs are lithologically and compositionally similar, the upper one being somewhat finer grained than the lower. The upper tuff is clearly an ash-flow deposit, but the lower one may have been somewhat reworked.

The upper andesite tuff is composed of light-gray to brownish-gray pumice-rich unwelded glassy material with abundant lithic fragments. In the Candelaria area pumice fragments compose 10 to 20 modal percent and are as much as 10 cm across (fig. 7), but they decrease in size and abundance outward from this area. For

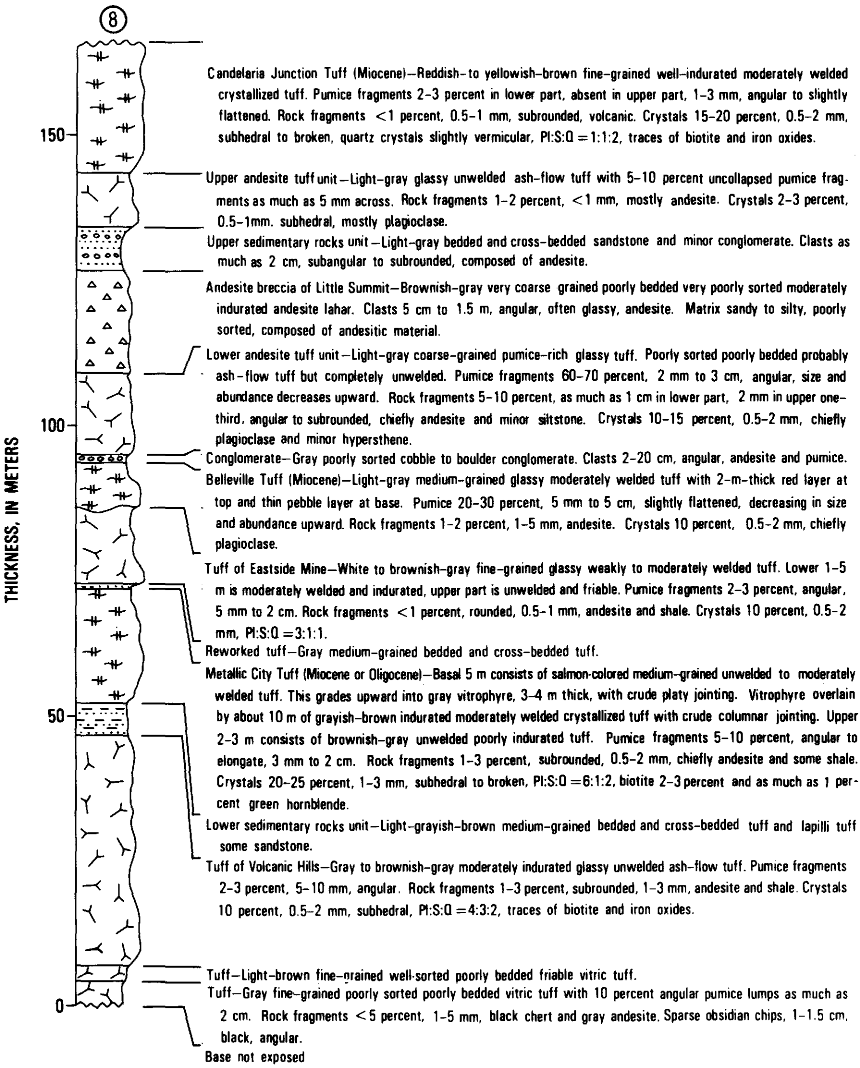

FIGURE 10.—Stratigraphic section of Candelaria Hills sequence 2.5 km west-northwest of Eastside Mine, Basalt quadrangle, Nevada. Number 8 at top of column indicates location in figure 2.

example, outcrops in the Basalt quadrangle to the west contain about 5 to 10 percent pumice with a maximum diameter of 5 mm (fig. 10). All of the pumice is fresh and is composed of brown highly vesicular glass with a tubular texture. Lithic fragments vary from 7 percent in the Candelaria mining district to 1 to 2 percent in the Basalt quadrangle. Most fragments are subangular to subrounded, range from 1 to 5 mm across, and consist chiefly of porphyritic andesite, locally accompanied by Paleozoic siltstone and shale.

Phenocrysts compose 1 to 4 modal percent and consist chiefly of plagioclase with very small quantities of quartz and biotite (table 11). A few specimens also contain partly altered grains of hypersthene, probably xenocrysts derived from the andesitic rock fragments. The plagioclase occurs as subhedral prisms, often broken and corroded, ranging from about 0.2 to 1 mm across. Most grains are strongly zoned and many have irregular corroded cores as calcic as andesine. Some of the more calcic plagioclase grains may also be xenocrysts.

The groundmass consists of small pumice lumps, glass fragments as much as 2 mm across, shards as much as 0.8 mm long, and interstitial glass dust. The shards, fragments, and pumice lumps are glassy, whereas the interstitial material is devitrified or altered to clay minerals. In most specimens the glass is pale to dark brown, but in others it is colorless probably due to bleaching.

The lower andesite tuff is compositionally similar to the upper one but is coarser grained and contains higher percentages of pumice and crystals (table 11). Lateral variations are less regular in this tuff than in the upper one. Both pumice and rock fragments are less abundant in outcrops in the Candelaria district than in areas farther west (figs. 7, 10). The size of the rock fragments increases to the west, but the pumice fragments become smaller.

The interlayered andesite breccia of Little Summit is a widespread unit that has been traced from the Columbus quadrangle as far west as Huntoon Valley. It often fills channels cut in the underlying tuff and usually grades upward into bedded tuffaceous sediments. The andesite breccia (lahar) is poorly sorted, poorly bedded, and consists of angular blocks of hypersthene andesite ranging from 1 cm to 2 m in diameter. The clasts are set in a sandy matrix of the same composition. Some fragments of the Belleville Tuff are locally present in the upper few meters of the unit.

The bedded and crossbedded tuffaceous sediments of the sequence are moderately to poorly sorted lithic sandstones and granule conglomerates composed largely of andesitic detritus. The sediments range from 5 to 50 m in thickness and average about 15

TABLE 10.—*Modal analyses of the Belleville Tuff*
[tr, trace]

	1	2	3	4	5	6	7	8	9	10	11
Groundmass ------	79.4	87.8	90.0	80.2	82.4	83.5	89.0	90.6	90.1	84.1	85.7
Plagioclase -----	15.7	8.8	6.4	11.4	8.5	10.4	9.2	7.6	6.9	9.1	9.4
Sanidine --------	-	-	tr	.2	.4	.6	-	-	-	-	.1
Quartz ----------	.1	-	.2	.2	2.2	.4	tr	.2	-	-	.3
Biotite ---------	-	-	.1	.3	.2	-	.1	.1	-	-	.1
Pyroxene --------	1.7	1.2	-	-	-	-	.2	.2	1.2	1.9	.6
Opaques ---------	1.1	.6	.8	.1	.2	.6	.2	.1	.5	.3	.4
Zircon ----------	-	-	-	-	-	-	-	-	-	tr	-
Apatite ---------	.3	-	tr	tr	tr	-	tr	-	tr	tr	tr
Rock fragments --	1.7	1.6	2.5	7.6	6.1	4.5	1.3	1.2	1.3	4.6	3.2
Other -----------	-	-	-	-	-	-	-	-	tr	-	-

1. Vitrophyre, base of unit, Miller Mountain section, Columbus quadrangle.
2. Devitrified moderately welded tuff, top of unit, Miller Mountain section, Columbus quadrangle.
3. Devitrified welded tuff, base of unit, Miller Mountain quadrangle.
4. Devitrified moderately welded tuff, top of unit, Miller Mountain quadrangle.
5. Devitrified moderately welded tuff, middle of unit, Miller Mountain quadrangle.
6. Devitrified moderately welded tuff, Columbus quadrangle.
7. Glassy welded tuff near base of unit, Basalt quadrangle.
8. Devitrified moderately welded tuff, top of unit, Basalt quadrangle.
9. Glassy welded tuff, base of unit, Belleville quadrangle.
10. Glassy welded tuff, middle of unit, Belleville quadrangle.
11. Average modal composition of the Belleville Tuff.

m. Where the sediments are thickest, the upper andesite tuff is absent.

CANDELARIA JUNCTION TUFF

The Candelaria Junction Tuff (unit Tt–5 of Stewart, 1979) is a densely welded ash-flow sheet that crops out over a large area in this part of western Nevada. Present-day outcrops extend from the Candelaria Hills on the north to the central Silver Peak Range on the south, and from Big Smoky Valley on the east to Huntoon Valley on the west. Earlier ash flows in the uppermost Oligocene and lowermost Miocene Candelaria Hills sequence apparently filled in topographic lows so that the Candelaria Junction Tuff could flow unobstructed for long distances. However, in the distal areas of emplacement this tuff overlaps older units and rests directly on pre-Tertiary basement rocks.

This unit rests with erosional unconformity on tuffs and sedimentary rocks associated with the andesite breccia of Little Summit and, within the Candelaria mining district, is conformably overlain by the tuff of Candelaria. In other areas, the tuff of Candelaria lowermost Miocene sequence. The Candelaria Junction Tuff has been formally named by Speed and Cogbill (1979b) for exposures located 2.15 km southwest (S. 15° W.) of Candelaria Junction in the north- trending canyon between hills 5992 and 6010 in the Belleville quadrangle.

The Candelaria Junction Tuff is a distinctive cliff-forming relatively crystal-rich ash-flow sheet, easily distinguished from other units in the sequence. It attains its maximum thickness of about 105 m in the Candelaria Hills and generally thins outward from this locality, so that in most outcrops it is from 20 to 50 m thick. In some sections two distinct ledges are visible, representing separate cooling units, although there are no discernible differences in lithology or mineralogy between the two (figs. 6, 9). Elsewhere, the unit consists of a single unbroken sequence.

In the type section the tuff shows well-developed compaction and welding zones (Speed and Cogbill, 1979b). A basal zone, ranging from 5 to 15 m thick, consists of grayish-brown weakly welded glassy tuff. This grades upward into a 10- to 20-m-thick dark-gray vitrophyre which in turn is overlain by about 20 to 30 m of moderately welded stony tuff grading upward into gray glassy unwelded tuff as thick as 25 m. In other areas, particularly near the distal edges of the ash-flow sheet where it laps onto pre-Tertiary highs, the zonation is much less pronounced. In these areas, the lower half of the unit commonly consists of white moderately compacted friable

tuff and the upper half of reddish-brown weakly welded but strongly indurated tuff.

Pumice fragments compose as much as 20 percent of this unit, being less abundant in the upper parts of the section and in the distal parts. These are small pink or black fragments less than 1 cm across, typically accompanied by chips of black glass. However, in some parts of the vitrophyre strongly flattened pumice fragments are as much as 2 cm in length. Rock fragments are sparse, except in the basal part of the unit where it rests directly on pre- Tertiary rocks. Most of the fragments are Paleozoic sedimentary rocks which were picked up from the underlying surface, but some volcanic rock fragments are also present.

The Candelaria Junction Tuff everywhere is moderately crystal rich, containing abundant large phenocrysts of plagioclase, sanidine, and quartz in an average ratio of about 3:2:4 (table 12). Plagioclase occurs as subhedral or broken crystals as much as 2 mm long. These are mostly zoned oligoclase, but a few highly resorbed grains are more calcic and may be xenocrysts. Sanidine crystals are square to prismatic, subhedral to euhedral, and range from 1 to 2 mm across. Large subhedral quartz bipyramids are characteristic of this unit and compose as much as 10 modal percent. Individual crystals are as much as 5 mm across and are moderately corroded. Both biotite and hornblende are present, but together they never exceed 1 modal percent. Biotite forms brown to yellowish-brown flakes as much as 1 mm across, and hornblende occurs as green pleochroic prisms less than 0.5 mm across. Opaque minerals are sparse but occur as relatively large subhedral crystals as much as 1 mm across.

Small pumice fragments, glass shards, and interstitial glass dust compose the groundmass. The shards are weakly to moderately deformed and range from 0.2 to 1 mm across. Fresh glass is pale brown, but many shards have bleached, colorless rims. Large glassy pumice fragments typically have a distinctive perlitic fracture pattern. In devitrified specimens the groundmass consists of microcrystalline cristobalite and alkali feldspar, usually with axiolitic textures.

TUFF OF CANDELARIA

The tuff of Candelaria is a weakly to densely welded lithic-rich ash-flow tuff that crops out only in one small area in the Candelaria mining district (unit 10 of Speed and Cogbill, 1979b). It is informally named for exposures about 2 km northwest of the Candelaria townsite, where it conformably overlies the Candelaria Junction

Tuff. It is the youngest of the uppermost Oligocene and lowermost Miocene tuffs and is overlain unconformably by Miocene andesite or Pliocene basalt (Speed and Cogbill, 1979b). This tuff was not studied petrographically by us, so the description given here is from Speed and Cogbill (1979b).

In its type locality the unit has a maximum thickness of about 75 m and displays well-developed zonation. The lower 2 to 3 m consists of white to brownish-gray weakly welded tuff that grades upward into a densely welded dark-gray vitrophyre with good eutaxitic texture. This is overlain by gray moderately to weakly welded stony tuff that extends to the top of the unit. The tuff of Candelaria is easily distinguished from the older units by its abundant pumice and lithic fragments (Speed and Cogbill, 1979b).

Pumice composes about 20 to 30 modal percent and occurs as angular lumps, generally less than 1 cm across, often accompanied by small obsidian chips. Lithic fragments consist of tuff, scoria, and porphyritic andesite and make up as much as 30 percent of the tuff. These are less than 1 cm across and are subrounded to subangular. Crystals make up 15 to 20 modal percent and consist chiefly of plagioclase, sanidine, and quartz in the ratio 8:1:1 (Speed and Cogbill, 1979b). Biotite is relatively abundant, composing 5 percent or more of the unit.

TABLE 11.—*Modal analyses of tuffs associated with the andesite breccia of Little Summit*
[tr, trace]

	1	2	3	4
Groundmass	85.2	81.2	89.6	97.7
Plagioclase	9.2	12.1	3.2	1.3
Sanidine	-	.4	-	-
Quartz	.4	1.0	.3	tr
Biotite	.1	.1	-	.2
Pyroxene	.5	-	-	-
Opaques	.4	.8	.1	tr
Allanite	-	-	tr	-
Zircon	-	tr	tr	-
Apatite	-	tr	tr	tr
Rock fragments	4.2	4.0	6.8	.8

1. Glassy tuff, lower andesite tuff unit, Belleville quadrangle.
2. Glassy tuff, lower andesite tuff unit, Basalt quadrangle.
3. Glassy moderately welded tuff, upper andesite tuff unit, Belleville quadrangle.
4. Glassy unwelded tuff, upper andesite tuff unit, Basalt quadrangle

The groundmass consists of small black shards in glassy specimens or microcrystalline mixtures of cristobalite and alkali feldspar in devitrified samples.

COMPOSITION

The Candelaria Hills sequence consists predominantly of silicic ash-flow tuffs and derivative tuffaceous sediments. Silicic lavas or domes are not present, but flows of basalt and andesite are intercalated with the ash-flow sheets in the Candelaria Hills (Page, 1959; Speed and Cogbill, 1979b), and the andesite breccia of Little Summit occurs in a large part of the region (Stewart, 1979; 1981a, b).

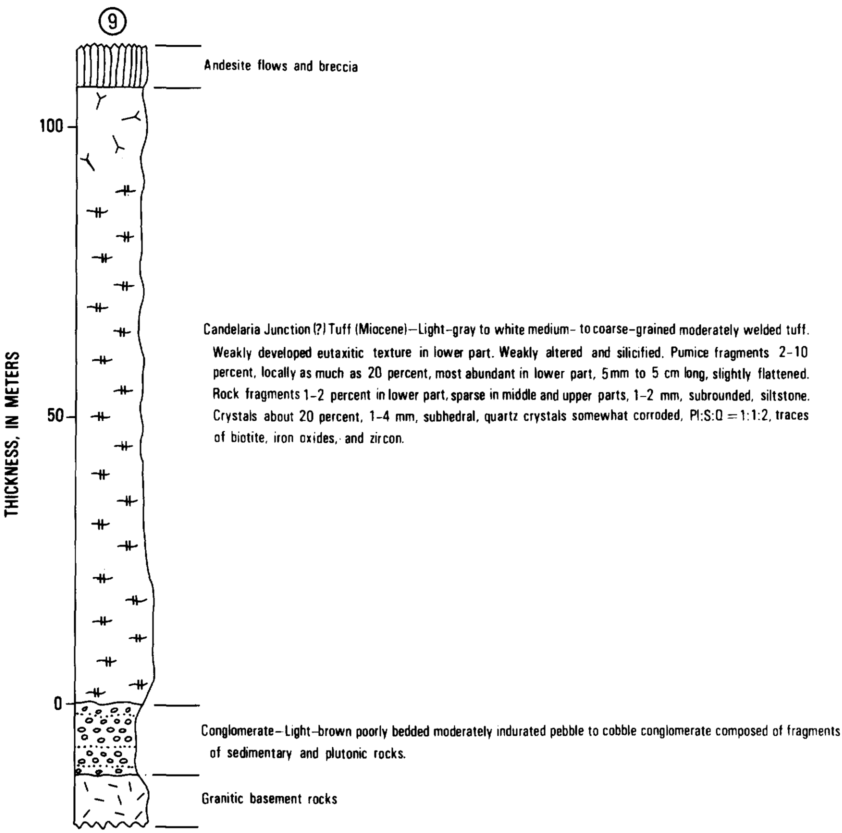

FIGURE 11.—Stratigraphic section of Candelaria Hills sequence in northern White Mountains, Benton quadrangle, Nevada. Number 9 at top of column indicates location in figure 2.

No chemical data are available for the tuffs, but their phenocryst mineralogies suggest that most are rhyolitic to quartz latitic in composition. All but the tuff of Candelaria Mountain, the Belleville Tuff, and the tuffs and sedimentary rocks associated with the andesite breccia of Little Summit contain significant quantities of phenocrystic quartz and most contain sanidine (table 13). Plagioclase in these units is dominantly oligoclase, and the groundmass minerals in devitrified specimens are cristobalite and alkali feldspar. Biotite is the common mafic mineral, but it is abundant only in the tuff of Miller Mountain, the Metallic City Tuff, and the tuff of Candelaria. In these units the biotite is usually accompanied by 1 to 2 percent of green hornblende, now largely altered.

The Belleville Tuff and overlying tuffs and tuffaceous sedimentary rocks associated with the andesite breccia of Little Summit are distinctly less siliceous than the remainder of the sequence. Plagioclase is the only common phenocryst in these tuffs, and it is generally andesine in composition. Quartz and sanidine are rare, but small amounts of hypersthene are typically present. However, because of their anhedral and corroded habits, the hypersthene grains are interpreted as xenocrysts derived from the breakup of numerous andesitic rock fragments. Even in these tuffs the devitrified groundmass minerals are cristobalite and alkali feldspar, suggesting an overall dacitic composition.

AGE

The available K-Ar dates for the uppermost Oligocene and lowermost Miocene tuffs range from 25.5 ± 1.0 to 22.0 ± 0.9 m.y. (table 14). The youngest date, which is from the Belleville Tuff, is probably slightly in error because this unit is overlain by the Candelaria Junction Tuff, which has five dates averaging 23.6 m.y. One date of 22.1 ± 1.0 m.y. from the Metallic City Tuff is also somewhat younger than the average (23.9 m.y.) for that unit. Excluding the dates from the Belleville Tuff the sequence spans approximately a 2-m.y. period from about 25.5 to 23.5 m.y. B.P. The common presence of erosional unconformities between units attests to episodic eruption of the tuffs during this period. Based on the amount of erosion the longest hiatus between eruptions was between the tuff of Eastside Mine and the Belleville Tuff. A major compositional change from rhyolite to dacite also occurs at this boundary.

REGIONAL RELATIONS

THICKNESS VARIATIONS AND FACIES CHANGES

Present-day outcrops of the uppermost Oligocene and lowermost Miocene tuffs extend from the Garfield Hills on the north to the central Silver Peak Range on the south and from Big Smoky Valley on the east to Huntoon Valley on the west (fig. 2). These outcrops, coupled with the inferred subsurface distribution, suggest that the tuffs presently occur over an area of about 3,200 km^2.

Despite the wide areal extent of this sequence, only three of the ash-flow sheets, the Metallic City, Belleville, and Candelaria Junction Tuffs, are voluminous and widespread. The earliest eruptions appear to have filled in topographic lows in the Candelaria area, allowing succeeding ash flows to travel greater distances. Hence, the five units older than the Metallic City Tuff are found chiefly in the Candelaria area, pinching out against the basement in their distal parts.

In all cases, the thickest and most complete sections of individual ash-flow units occur in the Candelaria mining district. Speed and Cogbill (1979b; 1979c) estimate a maximum thickness in excess of 1,300 m for the uppermost Oligocene and lowermost Miocene tuffs in this area. This great thickness is due to accumulation of the tuffs in the Candelaria trough, a feature that developed contemporaneously with emplacement of the ash flows (Speed and Cogbill, 1979c). In the surrounding region the sequence is much thinner, generally less than 300 m thick. Most individual ash-flow sheets thin gradually away from the Candelaria district, although local fluctuations occur where units are separated by erosional unconformities. The Belleville Tuff shows the most extreme thickness variations, typically filling deep channels cut into, or through, the underlying tuff of Eastside Mine. The regional thinning is such that the peripheral outcrops of the sequence consist of only the Metallic City, Belleville, and Candelaria Junction Tuffs (figs. 8, 9, 11). The overall sequence also thins away from the Candelaria Hills, being about 160 m thick in the Basalt quadrangle (fig. 10), about 150 m thick in the Volcanic Hills (fig. 4), about 120 m thick in the central Silver Peak Range (fig. 9), and about 60 m thick in the Garfield Hills (fig. 8).

Thinning of the individual ash-flow sheets away from the Candelaria Hills is accompanied by notable decreases in intensity of welding, grain size, and abundance of pumice and lithic fragments. Units that are densely welded in the Candelaria Hills are weakly to moderately welded elsewhere. Even the voluminous and widespread units such as the Metallic City, Belleville, and Candelaria

Junction Tuffs are weakly welded in their distal outcrops. Variations in size and abundance of pumice fragments have already been described for individual units. The most notable changes are in the pumice- rich units such as the tuff of Volcanic Hills, the tuff of Candelaria Mountain, the tuff of Eastside Mine, and the Belleville Tuff. In all of these units the outcrops in the Candelaria mining district contain the largest and most abundant pumice fragments. In more distal outcrops the fragments are smaller and less abundant, and these changes can be correlated with distance from the Candelaria area. Rock fragments show a similar pattern of variation, but their abundance reflects the nature of the underlying surface as well as the outcrop location. Where a given unit overlaps the underlying tuffs and rests directly on pre-Tertiary basement rocks, fragments of Paleozoic sedimentary rocks are usually abundant, regardless of distance from the Candelaria Hills. In these cases, however, the rock fragments are concentrated in the lower part of the ash-flow sheet and decrease rapidly in abundance upward. Despite these local variations, systematic variations in size and abundance of rock fragments are observed in some units, such as the tuff of Eastside Mine, which everywhere rest on older tuffs. In the heart of the Candelaria area lithic fragments compose as much as 10 percent of the tuff of Eastside mine (Speed and Cogbill, 1979b) and are as much as 8 cm across; near Candelaria Junction rock fragments compose 3 to 5 percent and are as large as 1 cm (fig. 7), whereas in the Basalt quadrangle farther west lithic fragments make up < 1 percent of the tuff and have a maximum diameter of about 1 mm (fig. 10).

Within the Candelaria mining district, angular unconformities occur above and below the tuff of Eastside Mine, but these discontinuities are not observed elsewhere. They reflect faulting during deposition of the tuffs, leading to the formation of the Candelaria trough, a northeast-trending graben extending through the Candelaria Hills (Speed and Cogbill, 1979c). This trough is about 5 km wide, 15 km long, and 1.5 km deep. If it extends to the edge of Rhodes Salt Marsh, as suggested by the gravity data (Speed and Cogbill, 1979c), it could be as much as 20 km long. Based on gravity profiles the trough is filled with low-density, weakly compacted uppermost Oligocene and lowermost Miocene tuff that constitutes the trough facies of Speed and Cogbill (1979b). Within the trough, unconformities are less common and more subdued than in surrounding outcrops, and angular unconformities occur only along the trough margins. Decollement structures have been identified locally along the south margin of the trough (Speed and Cogbill, 1979c). In the uplift facies, sections are thinner and incomplete,

TABLE 12.—*Modal analyses of the Candelaria Junction Tuff*
[tr, trace]

	1	2	3	4	5	6	7	8	9	10	11	12
Groundmass -----	77.7	78.2	84.9	82.7	82.0	88.3	84.6	77.8	79.1	81.4	77.5	81.3
Plagioclase ----	6.5	4.6	4.9	7.4	8.0	3.3	4.5	7.1	5.2	6.2	5.0	5.7
Sanidine -------	6.8	5.8	4.6	4.2	2.1	2.4	2.7	4.5	5.5	5.8	4.2	4.4
Quartz ---------	8.7	10.5	4.5	4.7	7.1	5.7	5.9	9.9	10.1	6.1	7.3	7.3
Biotite --------	.2	.4	.5	.7	.4	.2	.1	.1	.1	.1	.6	.4
Hornblende -----	-	-	-	tr	-	tr	tr	-	-	-	tr	tr
Pyroxene -------	-	-	-	tr	-	-	-	-	-	-	-	-
Opaques --------	.1	.1	.1	.2	.1	.1	.2	tr	tr	.1	.2	.1
Allanite -------	-	-	-	tr	-	-	-	-	-	-	-	-
Zircon ---------	tr	-	-	.1	.1	tr	tr	tr	tr	tr	tr	tr
Apatite --------	tr	-	-	-	-	-	-	-	-	-	tr	-
Rock fragments -	-	.4	.2	-	.2	-	2.0	.6	-	.2	5.4	.8
Other ----------	-	tr	.3	-	-	-	-	-	-	.1	-	tr

1. Devitrified welded tuff, Miller Mountain quadrangle.
2. Devitrified moderately welded tuff, Basalt quadrangle.
3. Devitrified moderately welded tuff, Basalt quadrangle.
4. Vitrophyre at base of unit, northern Fish Lake Valley, Davis Mountain quadrangle.
5. Devitrified welded tuff, northern Fish Lake Valley, Davis Mountain quadrangle.
6. Devitrified welded tuff, basal cooling unit, Columbus quadrangle.
7. Devitrified welded tuff, upper cooling unit, Columbus quadrangle.
8. Devitrified welded tuff, Belleville quadrangle.
9. Altered moderately welded tuff, northern White Mountains, Benton quadrangle.
10. Altered moderately welded tuff, central Silver Peak Range, Rhyolite Ridge quadrangle.
11. Devitrified weakly welded tuff, northern Silver Peak Range, Rhyolite Ridge quadrangle.
12. Average modal composition of the Candelaria Junction Tuff.

consisting largely of densely welded and indurated tuff.

VOLUME

At present, the Candelaria Hills sequence crops out over an area of about 3,200 km^2. Because the outlying outcrops in the Garfield Hills, the Silver Peak Range, and Big Smoky and Huntoon Valleys represent the distal edges of the ash-flow sheets, the original distribution was probably not much greater than the present distribution. In the Candelaria mining district, outside the Candelaria trough, the thickness of the sequence is 200 to 300 m, and most of the units thin away from this area. Outside the Candelaria Hills area we estimate an average thickness of about 80 m for the sequence and therefore a volume of about 256 km^3. Assuming that the Candelaria trough is 5 km wide, 15 km long, and 1.5 km deep (Speed and Cogbill, 1979c), the volume of tuff that fills this feature is about 112 km^3 and the total volume of the Candelaria Hills sequence is about 368 km^3. Lithic fragments compose an average of about 5 percent of the sequence for a volume of about 18 km^3. Crystals average about 15 modal percent indicating a volume of about 55 km^3, leaving about 295 km^3 of glass.

The sequence consists of both welded and unwelded tuff in variable proportions. Densely welded specimens have an average specific gravity of about 2.30 while unwelded samples are 1.90 (Speed and Cogbill, 1979c). Porosities are highly variable, ranging from about 7 to 40 percent. Overall, we estimate that the uppermost Oligocene and lowermost Miocene tuffs consist of about 75 percent uncompacted material and 25 percent welded material, with an average density for the sequence of 2.0 g/cm^3. This is close to the average density of the sequence filling the Candelaria trough (Speed and Cogbill, 1979c). We estimate a volume correction of about 35 percent to account for the effects of vesiculation, based on a density of unvesiculated rhyolite of approximately 2.6. The application of this correction to the estimated volume of tuff leads to an estimated overall volume of erupted magma, including crystals, of about 247 km^3.

SOURCE

All of the available evidence suggests a source for the Candelaria Hills sequence within the Candelaria Hills. The thickest and best developed sections of tuff always occur in the Candelaria area, and individual ash-flow sheets all show decreases in thickness, grain size, and degree of welding away from this locality.

TABLE 13.—*Average modal analyses of uppermost Oligocene and lowermost Miocene ash-flow tuffs of western Nevada*

[No modal analyses are available for the tuff of Candelaria. tr, trace]

	1	2	3	4	5	6	7	8	9	10	11
Groundmass ----------	88.4	77.0	89.0	86.6	90.5	72.0	82.2	85.8	81.2	93.6	81.3
Plagioclase ---------	4.0	12.5	5.9	4.8	3.7	15.5	6.3	9.4	12.1	2.3	5.7
Sanidine ------------	3.3	1.0	1.1	3.9	.3	2.2	2.1	.1	.4	-	4.4
Quartz --------------	2.4	2.2	2.6	2.7	.5	5.1	4.9	.3	1.0	.2	7.3
Biotite -------------	.1	4.2	.8	.4	1.2	2.9	.5	.1	.1	.1	.4
Hornblende ----------	-	.4	-	-	-	.1	-	-	-	-	tr
Altered hornblende? -	-	1.0	-	.2	-	.5	-	-	-	-	tr
Pyroxene ------------	-	-	-	-	-	-	-	.6	.4	-	-
Opaques -------------	.2	.4	tr	.3	tr	.4	.2	.4	.8	tr	.1
Allanite ------------	-	-	tr	tr	tr	tr	tr	-	-	tr	-
Zircon --------------	tr	tr	tr	tr	tr	tr	tr	-	tr	tr	tr
Apatite -------------	-	tr	-	tr	-	tr	tr	tr	tr	-	-
Rock fragments ------	1.6	1.3	.6	1.1	3.8	1.3	3.8	3.3	4.0	3.8	.8

1. Tuff of Columbus
2. Tuff of Miller Mountain
3. Tuff of Pinchot Creek
4. Tuff of Volcanic Hills
5. Tuff of Candelaria Mountain
6. Metallic City Tuff
7. Tuff of Eastside Mine
8. Belleville Tuff
9. Lower andesite tuff
10. Upper andesite tuff
11. Candelaria Junction Tuff

TABLE 14.—*K-Ar ages of the Candelaria Hills sequence*
[Ages recalculated using new decay and abundance constants (Steiger and Jager, 1977; Dalrymple, 1979)]

Unit	Age ± 2σ (m.y.)	Mineral	Source
Candelaria Junction Tuff -------	22.8±0.4	Biotite	1
	22.8±0.6	Sanidine	2
	23.5±0.5	Sanidine	1
	23.5±1.3	Plagioclase	2
	25.3±0.9	Biotite	1
Belleville Tuff ----------------	22.0±0.9	Plagioclase	1
	22.6±0.7	Plagioclase	5
Tuff of Eastside Mine ----------	24.1±1.9	Basalt (whole rock)	1
Metallic City Tuff -------------	22.1±1.0	Biotite	3
	22.7±0.4	Sanidine	2
	23.4±0.6	Plagioclase	2
	23.4±1.0	Biotite	3
	23.4±1.0	Sanidine	4
	24.7±1.0	Biotite	2
	24.9±0.7	Biotite	5
	24.9±0.9	Biotite	1
	25.5±1.0	Plagioclase	5
Tuff of Volcanic Hills ---------	23.4±1.0	Sanidine	4
Tuff of Miller Mountain --------	25.4±0.8	Biotite	1

1. Marvin and others (1977)
2. Gilbert and others (1968)
3. Robinson and others (1968)
4. Silberman and others (1975)
5. Garside and Silberman (1978)

Eruption of nearly 250 km^3 of magma should produce cauldron collapse in the source area. Speed and Cogbill (1979b, c) found no clear evidence of a typical caldera in the Candelaria Hills, but they described a major fault-bounded trough that formed contemporaneously with emplacement of the ash-flow tuffs. They assumed that all of the ash flows originated from outside the Candelaria area and interpreted the fault trough as evidence of early basin-and-range faulting. However, the regional facies variations in the Candelaria Hills sequence indicate strongly that the tuffs were erupted from vents within the Candelaria Hills. This interpretation is strengthened by the fact that regional extensional faulting did not occur in western Nevada until about 17 m.y. B.P. (McKee and Noble, 1974; Stewart, 1978) and by the presence of basaltic and andesitic lava flows in the Candelaria Hills sequence indicating that local volcanism occurred here in latest Oligocene and earliest Miocene time.

Speed and Cogbill (1979c) argued that the trough is not a calderalike feature because there are no siliceous lava flows or domes in the area and the tuffs are not hydrothermally altered. They interpreted the extension in the Candelaria Hills to have resulted from a regional oblique slip system and related the basaltic volcanism to this fault regime. Silicic flows and domes, although common in calderas, do not occur in all of them, and hydrothermal alteration may affect only the deeper parts of the caldera fill. In the Candelaria trough the lower parts of the trough sequence are not exposed. Eruption of small quantities of basalt lava, such as that found in the Candelaria Hills, does not necessarily indicate the onset of block faulting. Such basaltic lava flows often occur in predominantly silicic volcanic centers. For example, in the nearby Silver Peak volcanic center, basalt flows were erupted from a ring fracture zone at a late stage and are interlayered with intracaldera sediments (Robinson, 1972).

Clearly the Candelaria trough is not a typical subcircular caldera and the estimated volume of the trough (112 km^3) is only about one-half that of the estimated volume of magma erupted. However, if the trough extends as far as Rhodes Salt Marsh, as suggested by the gravity data (Speed and Cogbill, 1979c), it may be much larger. The presence of numerous erosional unconformities in the sequence indicates that the tuffs were erupted episodically over about a 2-m.y. period. The volume of material erupted during emplacement of any one ash flow was significantly less than the overall volume. Under these circumstances subsidence may have occurred in small increments, leading to a relatively broad depression, rather than to a single sharply defined caldera. The stratigraphic relations indicate that the earliest ash flows filled a general depression in the Candelaria area and were overlapped by younger units.

Although thickness variations and facies relations preclude a source for the Candelaria Hills sequence to the north, west, or south of the Candelaria Hills, an eastern source cannot be completely excluded. There are no exposures of the tuffs east of the Candelaria Hills, but the sequence presumably extends beneath Columbus Salt Marsh. A buried source could possibly lie beneath Columbus Salt Marsh or possibly in the Monte Cristo Range farther east. In the latter area, Stewart (unpub. data, 1982) has found a volcanic center with possible cauldron collapse from which major ash-flow tuffs may have been erupted. These tuffs, however, are petrographically different, on the basis of preliminary work, from those of the Candelaria Hills sequence. Thus, it is unlikely that the tuffs of the Candelaria Hills sequence were derived from the volcanic center in the Monte Cristo Range, but this possibility cannot be definitely ruled out until the age of the tuff of Castle Peak has been determined. It is also possible that the Candelaria Hills sequence was derived from an older, buried center in the Monte Cristo Range, but there is no evidence to support such an interpretation.

In summary, we believe that the available evidence suggests the presence of an ancient volcanic center in the Candelaria Hills from which the uppermost Oligocene and lowermost Miocene tuffs were erupted. Speed and Cogbill (1979a, b, c) have clearly demonstrated that faulting and trough formation occurred contemporaneously with deposition of the ash-flow sheets, and we tentatively interpret the Candelaria trough as a collapse feature resulting from eruption of the pyroclastic rocks.

LATEST OLIGOCENE AND EARLIEST MIOCENE PALEOGEOGRAPHY

The Candelaria Hills sequence of uppermost Oligocene and lowermost Miocene ash-flow tuffs occurs over a broad area in western Nevada, providing a marker horizon that can be used to interpret the structure and paleotopography of the area. Although faulting and subsidence occurred contemporaneously with emplacement of the tuffs in the Candelaria Hills, there is no evidence of tectonic activity elsewhere in the region at this time. Outside the Candelaria area the ash-flow tuffs are all structurally conformable, being locally separated only by erosional unconformities. The wide distribution of the ash-flow sheets, particularly the upper units, indicates that they flowed over an area of relatively low relief. Small basement highs are indicated where older tuffs are overlapped by younger units, but since the entire sequence is generally less than 200 m thick, the topographic relief was probably small. Only the Metallic City, Belleville, and Candelaria Junction Tuffs occur at the periphery of the Candelaria Hills sequence. The absence of the other units around the periphery suggests that they were of relatively small volume and not widespread. Postdepositional uplift and erosion of these units before eruption of the more voluminous tuffs is unlikely because of the absence of angular unconformities in the sequence. We find no evidence to suggest that late Oligocene extensional faulting occurred in this region outside of the Candelaria Hills. Thus, we conclude that the ash flows were emplaced on a stable erosional surface with relief of a few hundred meters and that the major episode of extensional faulting did not occur until later.

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