Stratigraphy, Preliminary Petrology, and some Structural Features of Tertiary Volcanic Rocks in the Gabbs Valley and Gillis Ranges, Mineral County, Nevada

GEOLOGICAL SURVEY BULLETIN 1464

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By E. B. EKREN, F. M. BYERS, JR., R. F. HARDYMAN,
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Stratigraphy and petrologic features of voluminous ash-flow tuffs that were deposited in the Walker Lane and were then subjected to severe en echelon, right-lateral strike-slip faulting

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By E. B. EKREN, F. M. BYERS, JR., R. F. HARDYMAN, R. F. MARVIN, and M. L. SILBERMAN

ABSTRACT

A composite thickness of more than 2,000 m of Tertiary (22 m.y. to 27 m.y.) subalkaline, genetically related, ash-flow tuffs and intercalated lava flows of intermediate composition is exposed in the Gabbs Valley and Gillis Ranges in west-central Nevada. The two oldest ash-flow units can be traced for distances of more than 150 km. Six regionally extensive tuff sheets, locally separated by lava flows, are recognized: the Mickey Pass and Singatse Tuffs (names defined by Proffett and Proffett, 1976 and adopted in this report; included here together with the Petrified Spring Tuff in the Benton Spring Group, a new name), the herein-named Blue Sphinx Tuff, the herein-named Nugent and Poinsettia Tuff Members of the Hu-pwi Rhyodacite, and the tuff of Copper Mountain. In contrast to most tuff sheets that grade upward from silicic to intermediate composition, several of these units in western Nevada grade upward from bases of intermediate composition to silicic tops. One unit displays a remarkable change upward from rhyodacite at the base through quartz latite to rhyolite at the top.

The tuff sheets show northwesterly elongated distribution patterns that reflect a pretuff topographic trough. This trough coincides with the present-day Walker Lane and probably reflects the Walker Lane as a distinct rift zone prior to ash-flow tuff eruptions. In early Miocene time (at least 23 m.y. ago), after many of the tuff sheets were erupted, the region was subjected to conjugate strike-slip faulting along northwest- and northeast-trending faults. Most of the movement was right-lateral along a series of en echelon faults with northwest trends. This faulting continued into Quaternary time as indicated by fault scarps and shutter ridges in alluvium.

The eruption of tuff and lava in volumes comparable to that in the Gabbs Valley and Gillis Ranges normally gives rise to a large cauldron complex, but no such complex appears possible within this area. The possibility exists that, instead of a fault-bounded cauldron complex, the massive extrusions formed a southeasterly elongated depression or depressions whose axes were more or less coincident with the pretuff topographic trough. The fact that many tuffs contain intensely resorbed phenocrysts of quartz, plagioclase, and, in some units, alkali feldspar suggests that the magma was erupted from levels that were undersaturated with respect to water. Such undersaturation could indicate eruption from great depths. This possibility is suggested also by the unique zonation of the tuffs—from bases of intermediate composition to silicic tops. Perhaps these depths were too great to allow the development of normally zoned magma chambers and well-defined cauldrons.

INTRODUCTION

The geology of the Gabbs Valley and Gillis Ranges, Mineral County, Nev., is being studied as part of the U.S. Geological Survey's Earthquake Hazards Reduction Program. Previous geologic work (see next section) and the high seismicity of the area (Ryall and others, 1966; Gumper and Scholz, 1971; Slemmons, 1967) indicated that the area might be suitable for an earthquake control experiment. To provide the geologic and tectonic information deemed necessary for confirmation of suitability, detailed geologic mapping was started in the late spring of 1973.

One of the first objectives of the mapping program was to acquire a working knowledge of the stratigraphy of the voluminous Tertiary volcanic rocks exposed in the ranges. This report is a product of that phase of the work.

PREVIOUS WORK

The Gabbs Valley and Gillis Ranges and a large area surrounding these ranges in Mineral and Nye Counties, Nev., are the sites of pioneering studies by H. G. Ferguson and S. W. Muller that began in 1922 and continued intermittently through 1949. The most significant results of these investigations are in Muller and Ferguson (1939) and Ferguson and Muller (1949); these investigations, along with those of Silberling and Roberts (1962), and Nielsen (1965), concentrated almost exclusively on stratigraphy and structure of Mesozoic sedimentary rocks and batholithic rocks. Very little attention was paid to the extensive and thick Tertiary volcanic and sedimentary sequences until 1956, when D. C. Ross of the U.S. Geological Survey began investigating the geology of Mineral County as part of a cooperative program between the Nevada Bureau of Mines and the U.S. Geological Survey. The work of Ross, who was later accompanied by F. J. Kleinhampl of the USGS, was of necessity reconnaissance in nature; they grouped the volcanic rocks into four broad categories (Ross, 1961).

In the late 1960's, Kleinhampl, M. L. Silberman, and R. Kopf reconnoitered the Gabbs Valley and Gillis Ranges and other parts of Mineral County in greater detail as part of the Nevada State geologic map project (Stewart and Carlson, 1974). This work led to a better understanding of the ages of the major Tertiary lithologic units.

Recently Proffett and Proffett (1976) described and named various ash-flow tuffs in the Yerington district of the Singatse Range northwest of the Gabbs Valley and Gillis Ranges. The first draft of our manuscript was completed prior to learning that the Yerington report was being prepared. We subsequently revised our manuscript to avoid, as much as possible, duplicating the names and excellent descriptions of Proffett and Proffett (1976); we have adopted the nomenclature of two of their formally named ash-flow tuff formations, the Mickey Pass and Singatse Tuffs.

These tuffs and others named and described herein occur also in the Wassuk Range, where they have been briefly described but not formally named by Bingler (1973).

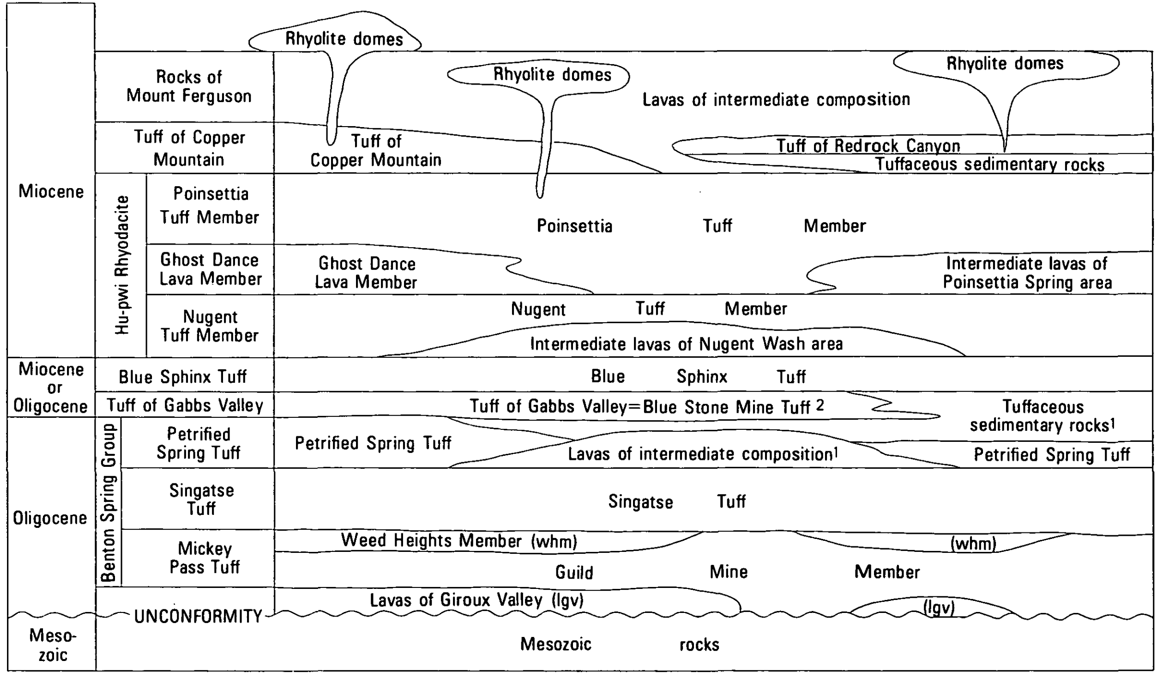
GEOLOGIC SETTING

The Gabbs Valley and Gillis Ranges lie within the Walker Lane as originally defined by Locke, Billingsley, and Mayo (1940). The two ranges, which contain Tertiary volcanic rocks more than 2,000 m thick (table 1 and fig. 1), are cut by five well-exposed northwest-trending right-lateral strike-slip faults having a combined displacement of at least 32 km (fig. 2). The fault that bounds the eastern flank of the Wassuk Range (fig. 3) probably is an oblique-slip fault that may provide an additional 5–10 km of right-lateral displacement. In addition to the regional strike-slip faults, virtually thousands of moderate-angle (30°–60°) normal and oblique-slip faults occur that, in general, strike parallel to the strike-slip faults and greatly extend the Tertiary strata. Detachment and bedding-plane faults occur at several stratigraphic horizons within the Tertiary section where there is marked contrast in lithologic competency. These are low-angle faults (0°–30°) that, in general, displace younger strata over older. They probably resulted from the same stresses that produced the strike-slip faults (Hardyman and others, 1975). In the Gabbs Valley and Gillis Ranges a major detachment fault separates the bulk of the Tertiary volcanic section from the underlying Mesozoic "basement." This "uncoupling" of Tertiary strata from the basement rocks was first noted by F. J. Kleinhampl, R. Kopf, and M. L. Silberman during mapping for the Nevada State geologic map (Stewart and Carlson, 1974).

The Mesozoic basement rocks in this region include thick Triassic and Jurassic marine sedimentary and volcanic rocks that were thrust faulted and tightly folded during the Jurassic Period (Ferguson and Muller, 1949). These rocks are extensively intruded by Mesozoic batholithic rocks that range in composition from diorite to granite. The batholithic rocks are spatially and temporally part of the Sierra Nevada. We have obtained dates of 158 ± 4 m.y. on biotite and 155 ± 7 m.y. on hornblende from granodiorite at Copper Mountain (fig. 2). These dates indicate a late Middle or early Late Jurassic age. According to the chronology scheme of Lanphere and Reed (1973), the granodiorite was intruded during "epoch B" of Mesozoic-Cenozoic plutonism (158–132 m.y. ago), and between the Yosemite and the Inyo Mountains intrusive epochs of Evernden and Kistler (1970).

TABLE 1.—*Principal Tertiary volcanic units in the Gabbs Valley and Gillis Ranges, Mineral County, Nev.*

Age	K-Ar age (m.y.)	Rock unit		Thickness (meters)	Tentative classification	Distinctive lithologic features of tuffs
Miocene	15–23.5	Rocks of Mount Ferguson Lavas of intermediate composition Tuff of Redrock Canyon Tuffaceous sedimentary rock and debris		0–900	Principally rhyodacite and quartz latite	Includes tuff of Redrock Canyon that is a lithologic repeat of the Blue Sphinx Tuff
		Tuff of Copper Mountain		0–100	Quartz latite and rhyolite	Abundant moderately embayed and resorbed quartz; abundant accessory sphene
	22–23	Hu-pwi Rhyodacite	Poinsettia Tuff Member	0–500	Rhyodacite	Vitric to weakly devitrified, moderately welded, rich in biotite and pyroxene
	23		Ghost Dance Lava Member/ Intermediate lavas of Poinsettia Spring area	0–100	Rhyodacite	
			Nugent Tuff Member	0–500	Rhyodacite	Extremely rich in biotite and pyroxene; plagioclase phenocrysts as large as 8 mm
		Intermediate lavas of Nugent Wash area		0–80	Rhyodacite	
		Blue Sphinx Tuff		0–300	Quartz latite	Extremely embayed and resorbed quartz phenocrysts
Oligocene or Miocene	25–26	Tuff of Gabbs Valley—equivalent to Blue Stone Mine Tuff of Proffett and Proffett (1976)		0–80	Rhyolite	Two cooling units of crystal-poor tuff; not genetically related to other units in table
		Sedimentary rocks		0–30		
		Intermediate lavas between the Blue Sphinx and Singatse Tuffs		0–200	Rhyodacite and quartz latite	
Oligocene	24–28	Benton Spring Gr.	Petrified Spring Tuff Singatse Tuff Mickey Pass Tuff Weed Heights Member Guild Mine Member	0–75 100–300 0–70 70–300	Rhyodacite, quartz latite, and rhyolite	Three (locally four) very similar cooling units, each of which grades upward from rhyodacite bases to quartz latite or rhyolite tops
	26–27	Lavas of Giroux Valley		0–30	Rhyodacite and quartz latite	



[1]Lavas of intermediate composition and tuffaceous sedimentary rocks intertongue with but are not part of Petrified Spring Tuff.
[2]Of Proffett and Proffett (1976)

FIGURE 1.—Schematic diagram showing relationships of principal volcanic units in the Gabbs Valley and Gillis Ranges.

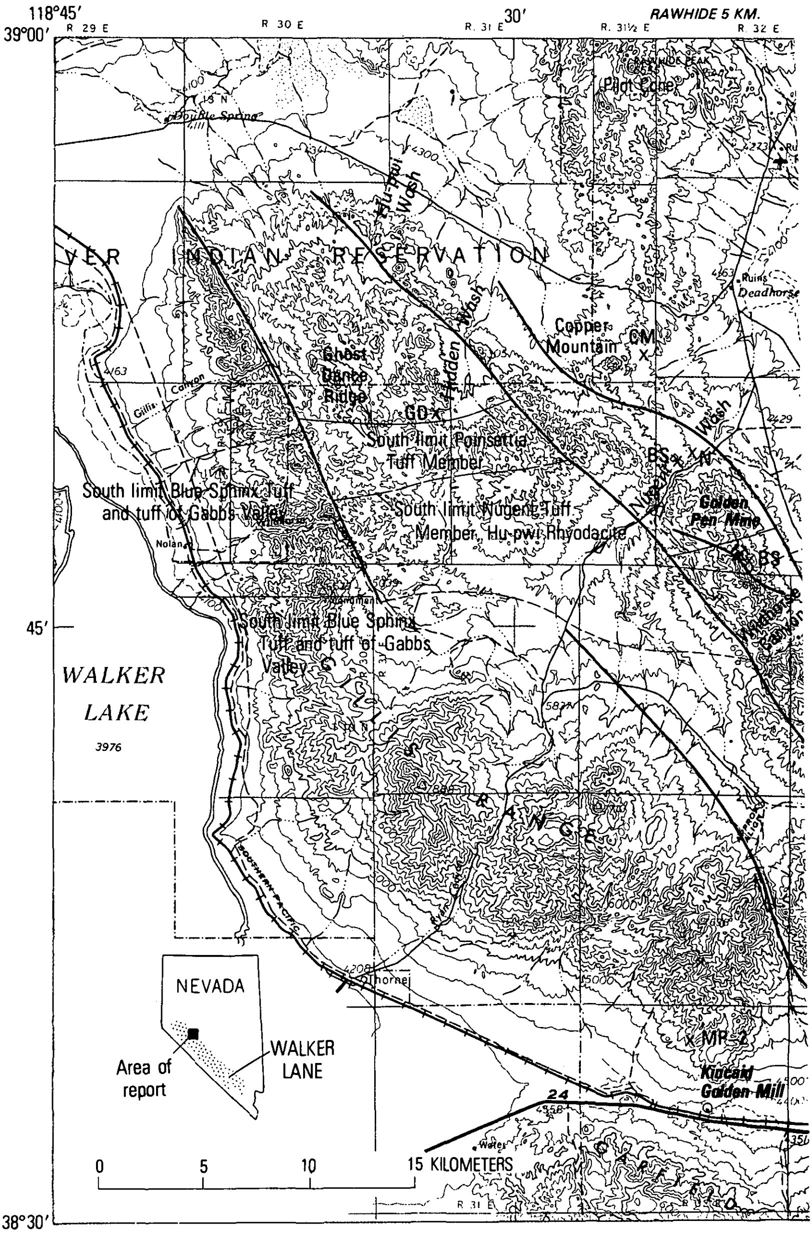
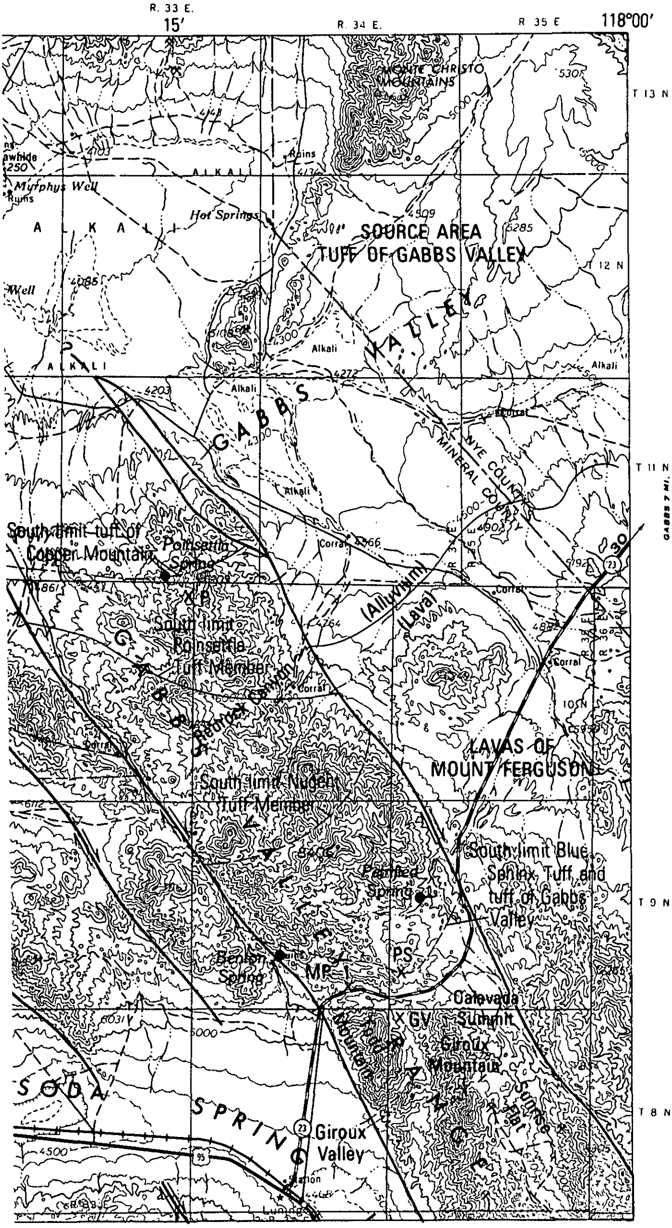


FIGURE 2.—Map showing type and reference localities of volcanic units described in this report. Heavy lines, strike-slip faults; arrows show direction of relative movement. Dashed where uncertain; queried where unknown. Also shown are southern limits of preserved outcrops of younger tuff units. The displacement indicated by right-lateral shift of Mesozoic rocks along the fault that passes west of Benton Spring is almost exactly equal to the shift of the Blue Sphinx Tuff—about 9 km. MP-1, -2, reference localities of Guild Mine Member of Mickey Pass Tuff; GV, out-



crops of lavas of Giroux Valley; PS, type locality of Petrified Spring Tuff; BS, type and reference localities of Blue Sphinx Tuff; P, type locality of Poinsettia Tuff Member of Hu-pwi Rhyodacite; N, type locality of Nugent Tuff Member of Hu-pwi Rhyodacite; GD, type locality of Ghost Dance Lava Member of Hu-pwi Rhyodacite; CM, outcrops of tuff of Copper Mountain. Base from AMS 1:250,000 Walker Lake, Nev., Calif., 1957 (revised 1969).

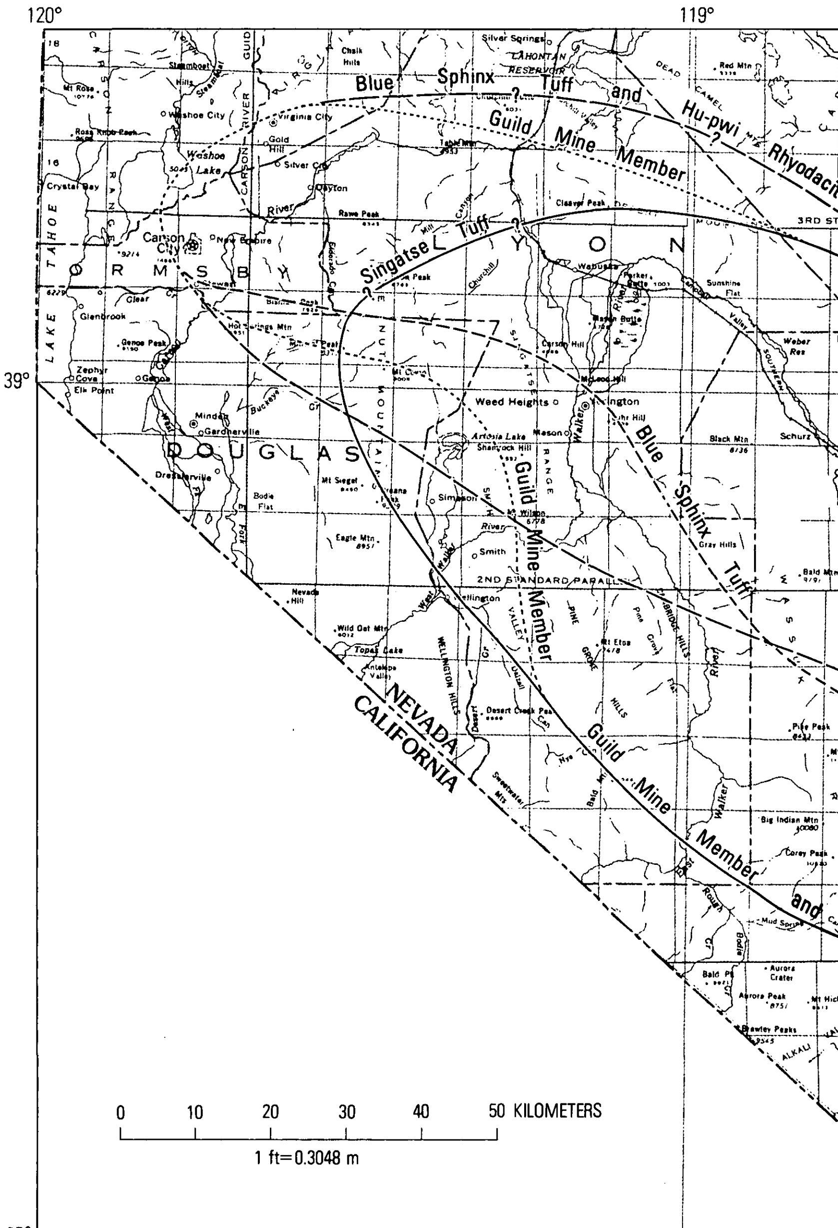
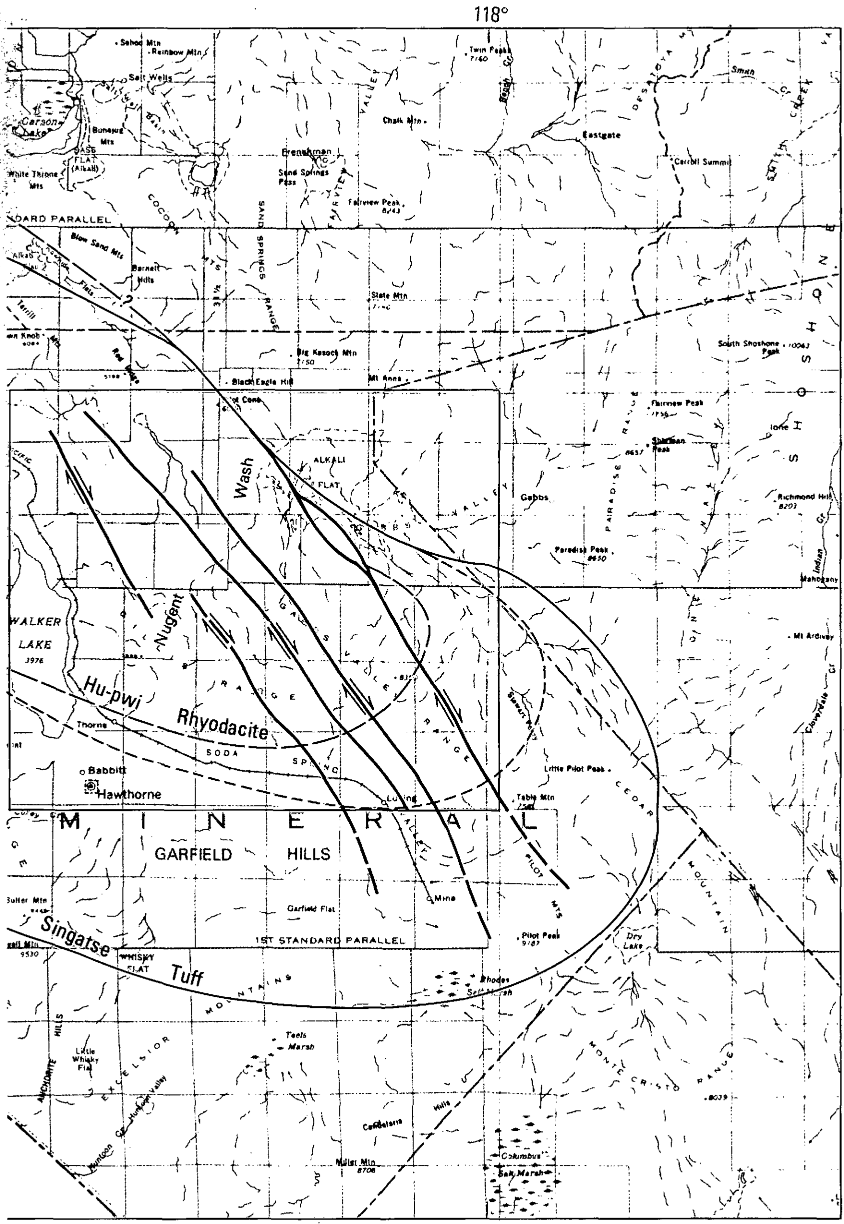


FIGURE 3.—Map showing inferred original distributions of Singatse Tuff and Guild Mine Member of Mickey Pass Tuff. Also shown are reconstructed distributions of Blue Sphinx Tuff and Hu-pwi Rhyodacite. The boundaries are queried where data are poor, and the boundaries of Blue Sphinx and Hu-pwi are projected considerable distances southwestward from preserved outcrops. (Compare with fig. 2.) We believe that the patterns shown here for the tuff sheets represent the maximum



distributions reasonable. Also shown are strike-slip faults (heavy lines, dashed where inferred); arrows show direction of movement. Map is based on our own observations, those of Proffett and Proffett (1976), Bingler (1978), unpublished data supplied by E. C. Bingler, H. F. Bonham, Jr., and R. C. Speed (oral and written communs., 1975, 1976), and Gilbert and Reynolds (1973). Area of figure 2 shown by rectangle. Base from U.S. Geological Survey 1:1,000,000 Nevada (1965).

The Mesozoic basement rocks had been deeply eroded and the paleotopography in the area of study was subdued when the first ash-flow tuffs of Oligocene age swept over the terrane. The distribution of these tuffs (fig. 3), however, indicates control by a regionally extensive northwest-trending topographic trough. We infer that this trough reflects the Walker Lane (fig. 2) as a distinct rift zone before the advent of ash-flow tuff eruptions. That faulting or rifting continued during the period of ash-flow tuff eruptions is indicated by the Poinsettia Tuff Member of the Hu-pwi Rhyodacite in the Gabbs Valley Range. The tuff was deposited there, mostly in a fault-controlled structural and topographic trough. The fault that bounds this tuff on its southwest side is definitely pre-Poinsettia in age and it trends N. 65° W., an orientation that is parallel to the axes of distribution of all the tuffs (fig. 3). This fault is older than about 23 m.y. and the pre-Poinsettia movements could have been, in part, strike-slip. Occurrences of landslipped debris beneath the tuff of Redrock Canyon in a zone 14 km long betweeen the two easternmost faults (figs. 2 and 3) suggest that strike-slip faulting did, indeed, commence at least 23 m.y. ago. That this faulting did not start much earlier is indicated by all the displacements along the faults shown in figure 2. As nearly as can be estimated, the displacements are the same in Tertiary strata as in the basement rocks. Shutter ridges and fault scarps in alluvium indicate that strike-slip faulting continued into Quaternary time.

STRATIGRAPHY AND GEOCHRONOLOGY

LAVAS OF GIROUX VALLEY

The oldest Tertiary volcanic rocks in the Gabbs Valley and Gillis Ranges comprise lava flows, flow breccias, and tuff breccias, all of intermediate composition. These rocks are rarely more than 30 m thick and they are exposed discontinuously. They are informally called the lavas of Giroux Valley after andesitic and latitic lava flows near the head of Giroux Valley at Calavada Summit (fig. 2). In the vicinity of Calavada Summit, these lavas underlie the Mickey Pass Tuff but are in low-angle detachment–fault or bedding plane–fault contact with the overlying younger tuff. In the southern Gillis Range, rocks included with the lavas of Giroux Valley are more silicic than those in the Gabbs Valley Range and comprise conspicuously porphyritic quartz latite and rhyodacite.[1] The lavas of Giroux Valley have not been recognized north of about lat 38°37′. It is problematical whether the absence of these lavas to the north and over broad areas in the south is due to nondeposition, erosion prior to ash-flow tuff eruption, or omission by low-angle detachment faulting. We consider that the

[1]Names are tentative and are based on phenocryst mineralogy—no chemical analyses are available.

first possibility is the most likely and that the lavas were never contiguous over great distances.

The lavas of Giroux Valley consist of two or more lava flows (or flow-breccia sequences) in nearly all exposures, and in the southern Gillis Range they include a thin stratum of biotite-rich tuff breccia that yields a K-Ar age of 26.7 ± 0.9 m.y. (table 2). The andesitic and calc-alkaline latitic lavas and flow breccias in the Gabbs Valley Range are typically stony (devitrified), somber gray on fresh surfaces, and weather dark brownish gray and dark purplish gray. The quartz latite and rhyodacite lavas of the Gillis Range, however, are entirely glassy in some exposures, whereas in others they are completely devitrified except for thin glassy (vitrophyric) zones near the base and top. Phenocrysts are mostly small, rarely exceeding 3 mm, and, in general, they compose less than 30 percent of the volume of the rock (fig. 4).

BENTON SPRING GROUP

The Benton Spring Group is here named after Benton Spring (figs. 2 and 5) in T. 9 N., R. 34 E., the type locality, and comprises in ascending order the Mickey Pass, Singatse, and Petrified Spring Tuffs. The Petrified Spring Tuff is not present at Benton Spring, but all three formations are well exposed in fault blocks east of the spring and within 2 km northwest of Calavada Summit, on Nevada State Highway 23 (fig. 2); Calavada Summit, in T. 9 N., R. 35 E., is here designated a reference locality for the Benton Spring Group. The group name is proposed because the three formations appear to be closely associated in time, in petrography, in distribution, and, perhaps, in source. The close time association between the three units is inferred from K-Ar age data and from general petrologic similarities. No significant stratigraphic units occur between the tuffs other than bedded tuff or thin (0–30 m), local nonwelded tuffs of similar petrographic character. There is little indication of significant erosion between the three tuff formations in the Gabbs Valley and Gillis Ranges, but the abundance of petrified fragments of large trees between the Singatse and Mickey Pass Tuffs, together with the occurrence of lignite beds and various tuffaceous sedimentary rocks in the Singatse Range (Proffett and Proffett, 1976), indicates that at least several thousand years elapsed between the eruption of the two units.

Of the three tuff formations assigned to the Benton Spring Group in the Gabbs Valley Range, the two youngest—the Petrified Spring and Singatse Tuffs—are multiple-flow simple cooling units; the Mickey Pass Tuff at the base consists of two cooling units. The oldest of these, the Guild Mine Member, is a compound cooling unit. With

TABLE 2.—*Analytical data for age determinations of Tertiary volcanic rocks, Gabbs Valley and Gillis Ranges, Mineral County, Nev.*

[Potassium argon analyses by standard isotope dilution procedures (Dalrymple and Lanphere, 1969). Mass analyses were done by a Neir-type 60° sector 6-inch mass spectrometer operated in the static mode. Analysts: R. F. Marvin, M. L. Silberman, and H. H. Mehnert. Potassium analysis by flame photometer, using a lithium metaborate fusion technique (Ingamells, 1970). Analysts: Violet M. Merritt, Lois B. Schlocker. Plus-minus(±)represents analytical uncertainty only at one standard deviation. USGS-D³Denver, Colo.; USGS-M³Menlo Park, Calif. Radiogenic argon indicated by asterisk(*)]

Sample No.	Lithologic unit	Mineral dated	K_2O	$*Ar^{40}$ (10^{110}/moles/gram)	$*Ar^{40}/Ar^{40}$	Age (m.y.)	Laboratory	Sample location
D2402GL	Black aphyric latite dike	Glass	2.17 2.13	0.1847	0.72	5.8±0.2	USGS-D	About 1.6 km south of Nugent Wash, Gabbs Valley Range, 38°45′ N., 118°22.5′ W.
D2468B	Rhyolite vent breccia	Biotite	8.535 (avg)	2.291	0.84	18.1±0.6	USGS-D	Northern Garfield Hills, due north of Mable Mountain, 38°30.4′ N., 118°17.8′ W.
D2408B	Rhyolite dike	Biotite	6.12 6.06	1.739	0.55	19.2±0.7	USGS-D	Gabbs Valley Range, 6.4 km east of Wild Horse Canyon, 38°45′ N., 118°18′ W.
	Rocks of Mount Ferguson:							
2384-1P	Andesite or latite lava	Plagioclase	0.770 0.765 0.767	0.2441	0.77	21.4±0.6	USGS-M	Nugent Wash, northern Gabbs Valley Range, 38°50′ N., 118°23′ W.
2384-1H	.... do	Hornblende	0.580 0.583	0.1945	0.60	22.5±0.6	USGS-M	Do.
D2470B	Quartz latite lava	Biotite	8.17 (avg)	2.522	0.80	20.8±0.7	USGS-D	Southeast flank Mount Ferguson, Gabbs Valley Range, 38°38.7′ N., 118°07.7′ W.
2605-5	Andesite or latite lava	Plagioclase	0.225	0.0450	0.40	15.0±0.5	USGS-M	South flank Mount Ferguson, Gabbs Valley Range.
D2536B	Tuff of Redrock Canyon	Biotite	8.48	2.962	0.28	23.5±0.6	USGS-D	Gabbs Valley Range, about 1.6 km SSW. of Petrified Spring, 38°38′ N., 118°07′ W.

D2395B	Hu-pwi Rhyodacite: Poinsettia Tuff Member, cooling unit 2	Biotite	8.40 8.33	2.886	0.72	23.2±0.8	USGS-D	Gabbs Valley Range, 6.4 km east of Wildhorse Canyon, 38°45′ N., 118°18′ W.
2306-7B	do	Biotite	8.41 8.36	2.811	0.64	22.6±0.6	USGS-M	Do.
2306-7P	do	Plagioclase	0.823 0.825	0.2635	0.72	21.5±0.6	USGS-M	Do.
D2543B	Ghost Dance Lava Member	Biotite	8.70 (avg)	3.014	0.68	23.3±0.6	USGS-D	Hidden Wash, Gillis Range, 38°53.3′ N., 118°32.7′ W.
D2572B	Nugent Tuff Member	Biotite	7.41 (avg)	2.508	0.64	22.8±0.5	USGS-D	East flank, Gillis Range, 38°45′ N., 118°30′ W.
MLS-73-9	Tuff of Gabbs Valley	Sanidine	7.91 7.92	2.941	0.61	25.0±1.0	USGS-M	Head of Gillis Canyon, north of Gentry mine, 38°51.8′ N., 118°37.9′ W.
MLS-73-10	do	Sanidine	10.26 10.27	3.981	0.82	26.1±0.8	USGS-M	Northern Gillis Range, 38°49.9′ N., 118°18′ W.

TABLE 2.—*Analytical data for age determinations of Tertiary volcanic rocks, Gabbs Valley and Gillis Ranges, Mineral County, Nev.*—Continued

Sample No.	Lithologic unit	Mineral dated	K_2O	$*Ar^{40}$ (10^{-10}/moles/gram)	$*Ar^{40}/Ar^{40}$	Age (m.y.)	Laboratory	Sample location
	Mickey Pass Tuff:							
3289-10S	Guild Mine Member	Sanidine	10.63 10.63	4.363	0.87	27.6±0.8	USGS-M	Wild Horse Canyon, Gillis Range, 3.35 km south of bend in canyon, 38°46.7′ N., 118°26.0′ W.
3289-10P	.... do	Plagioclase	1.08 1.06	0.3878	0.82	24.4±0.7	USGS-M	Do.
D2337B	.... do	Biotite	8.05 7.98	3.244	0.81	27.2±0.9	USGS-D	Southeast flank of Gillis Range, 38°36′ N., 118°22′ W.
D2337S	.... do	Sanidine	10.46 10.37	4.337	0.85	28.0±0.6	USGS-D	Do.
D2374B	.... do	Biotite	8.03 8.00	3.133	0.78	26.3±0.9	USGS-D	Reference locality about 2.5 km west of Calavada Summit in Gabbs Valley Range, north side of U.S. Highway 23; 38°35.7′ N., 118°08′ W.
D2469B	Lavas of Giroux Valley	Biotite	8.05 (avg)	3.191	0.80	26.7±0.9	USGS-D	South end of Gillis Range, 38°34.7′ N., 118°25′ W.
D2469S	.... do	Sanidine	5.53	2.112	0.52	25.7±0.6	USGS-D	Do.

the possible exception of the Singatse Tuff, each cooling unit in the group is characterized by a similar petrochemical zonation from rhyodacite or quartz latite in its lower parts to quartz latite or rhyolite in its upper parts. Biotite, pyroxene, and (or) hornblende are abundant in all three units. In general, quartz increases in size and abundance upward in each unit, and ferromagnesian minerals decrease by the elimination of pyroxene and most hornblende.

MICKEY PASS TUFF

The Mickey Pass Tuff was named by Proffett and Proffett (1976) for exposures just northeast of Mickey Pass (name of Proffett and Proffett), its type locality (sec. 13, T. 13 N., R. 24 E.), in the Singatse Range. At the type locality, two cooling units compose the formation, and these were named the Guild Mine and Weed Heights Members by Proffett and Proffett (1976). These three formal rock-stratigraphic names are herein adopted. The two members are respectively named after the Guild placer mines in sec. 18, T. 13 N., R. 25 E. and after Weed Heights, located about 4 km east of Mickey Pass in sec. 17, T. 13 N., R. 25 E. These two localities are the type localities for the two members. The Guild Mine Member is as much as 550 m thick in the Singatse Range; the Weed Heights Member, in contrast, is only 60–120 m thick.

GUILD MINE MEMBER

The Guild Mine Member is present throughout the Gabbs Valley and Gillis Ranges and ranges in thickness from less than 60 m to as much as 300 m. According to Proffett and Proffett (1976) the member occupies a deep southeast-trending paleovalley in the Singatse Range (fig. 3), where it may be as much as 900 m thick. We have tentatively identified the Guild Mine Member as far to the east as the northern Cedar Range (fig. 3, Cedar Mountain). The rock there is about 70 m thick and consists entirely of rhyodacite. (See following paragraph.) It contains considerably more lithic fragments than in the Gabbs Valley and Gillis Ranges, not unusual for a distal part of an ash-flow sheet. The member occurs as erosional remnants under much younger lavas of intermediate composition in the northern Garfield Hills, and, according to R. C. Speed (written commun., 1976), remnants occur as far south as the eastern Excelsior Mountains (fig. 3). Thin sections supplied by Speed and modally analyzed by F. M. Byers indicate that both the Guild Mine Member and Singatse Tuff are probably present there. According to M. W. Reynolds (oral commun., 1976), the member is present in the Pine Grove Hills (fig. 3); the remnants preserved there are thin and were deeply eroded prior to the onset of intermediate lava volcanism. Reynolds reported that although there is no indication that the Guild Mine is lapping onto higher

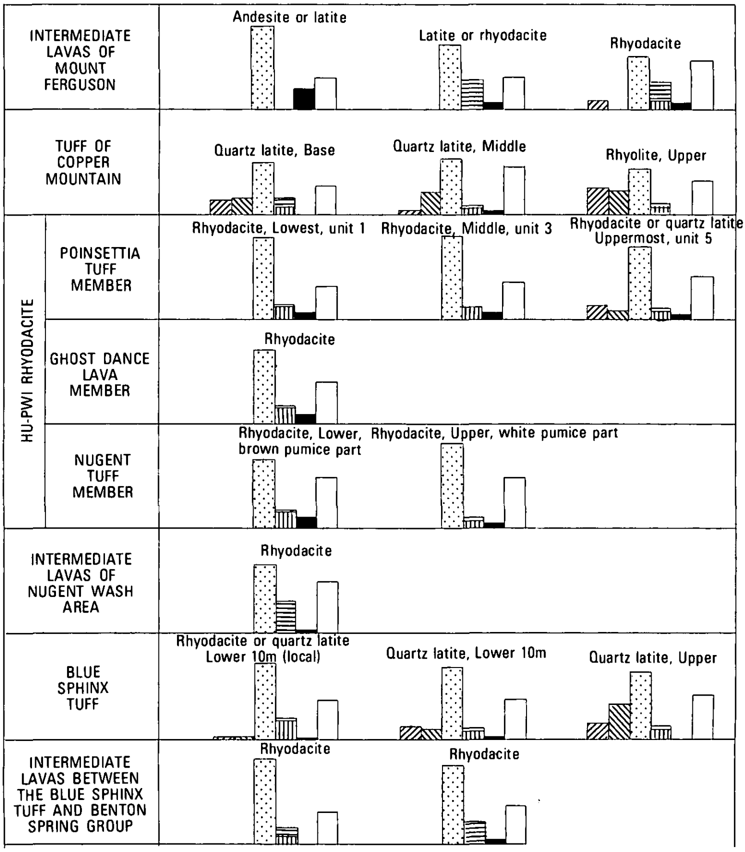
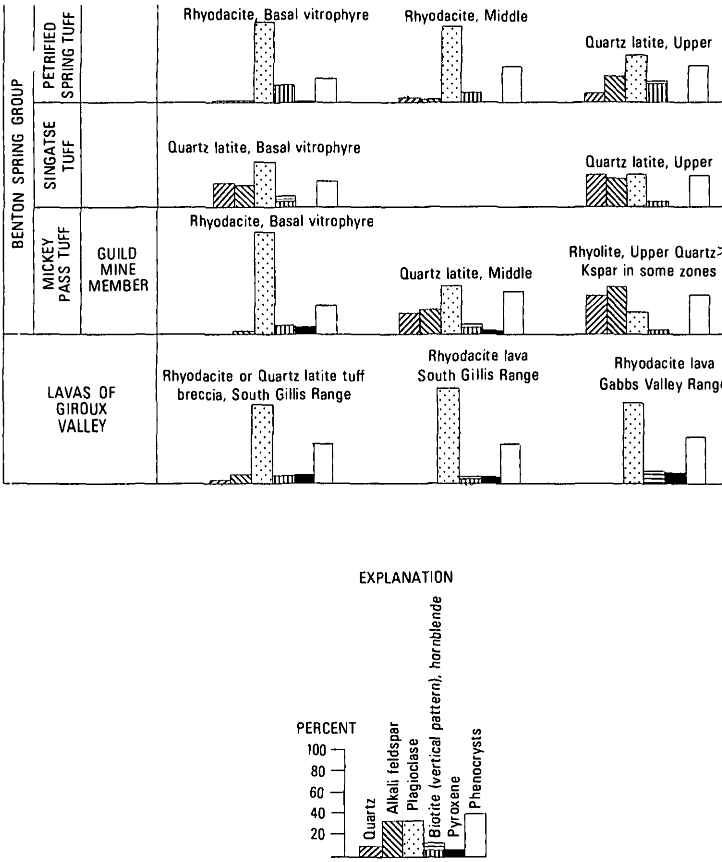


FIGURE 4.—Volume of phenocrysts and abundance of six crystal compon-
County,

topography to the southwest, the overall thinness suggests that the preserved outcrops are close to the distal end of the sheet. The member is absent in the northeastern part of the area shown in figure 2.

The Guild Mine Member of the Mickey Pass Tuff is a compound cooling unit (Smith, 1960), displaying alternating zones of dense and moderate welding. Pumice clasts, ranging in length from about 1 cm to as much as 25 cm, are abundant throughout the cooling unit. Where the tuff is densely welded, however, the pumice fragments are commonly extensively flattened. They more closely resemble flow laminae and lenticules in a rhyolite lava. The member has a persistent black basal vitrophyre that ranges in thickness from about 1 m to as much as 5 m. This vitrophyre generally is rhyodacite, but where the entire cooling unit is thin the rhyodacite may be missing and the



ents of principal volcanic rocks of Gabbs Valley and Gillis Ranges, Mineral
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basal vitrophyre is rhyolite. Lithic fragments, principally of lava of intermediate composition, are numerous in the basal 30 m of the unit; but, except for pumice, fragments of all kinds are exceedingly rare above this basal zone. The paucity of lithic fragments and the presence of extremely flattened pumice are useful criteria for distinguishing the Guild Mine Member from the Singatse Tuff.

Both members of the Mickey Pass Tuff show gradations upward from bases rich in plagioclase and ferromagnesian minerals to tops poor in ferromagnesian minerals and rich in alkali feldspar and quartz. Such changes in composition are much more extreme in the Guild Mine Member than in the Weed Heights Member. The basal part of the Guild Mine is rhyodacite and the upper part is alkali rhyolite (table 3, figs. 4 and 6) according to the classification scheme of Young. E. J. Young (Segerstrom and Young, 1972) has found a

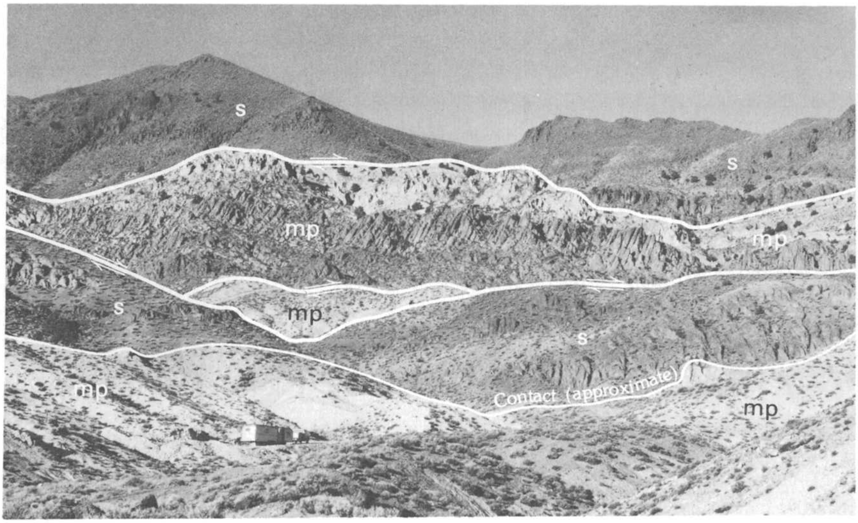

FIGURE 5.—View eastward of faulted outcrops of lower two formations of Benton Spring Group at Benton Spring, which is located in small gulley just beyond trailer and pickup truck. mp, Mickey Pass Tuff; s, Singatse Tuff. Zone in photograph lies just east of a major strike-slip fault (see fig. 2), and faults in photograph (heavy lines) strike parallel to main fault. They are interpreted as oblique-slip faults (arrows, direction of movement).

felsic-mafic ratio $(SiO_2+K_2O+Na_2O)/(FeO+Fe_2O_3+MgO+CaO)$ to be very useful in classifying igneous (and possibly metamorphic) rocks. Using data by Nockolds (1954) on average chemical compositions of igneous rocks, felsic-mafic ratios are distributed as follows:

Rock type	Felsic-mafic ratio
Extreme alkali granite	>50
Alkali granite (alkali rhyolite)	25 -50
Granite (rhyolite)	15 -25
Quartz monzonite (quartz latite)	10 -15
Granodiorite (rhyodacite)	7 -10
Quartz diorite (quartz andesite)	5 - 7
Monzonite (latite)	3 - 5
Diorite (andesite)	2.1- 3
Gabbro (basalt)	1.4- 2.1
Ultramafics	< 1.4

Note: This chart reflects minor changes made by E. J. Young in 1976 (written commun.).

In the Singatse Range and at Calavada Summit in the Gabbs Valley Range (fig. 6) the lower rhyodacite part is about 100 m thick and the upper rhyolite is 200–400 m thick. The sharp change in phenocryst content (fig. 6) probably coincides with a contact between ash flows, but no cooling break is indicated.

The ferromagnesian minerals constitute as much as 30 percent of the volume of the total phenocrysts in the rhyodacite but only about 4 percent in the rhyolite. In the rhyodacite, biotite and pyroxene vary in proportions from about 2:1 to 1:2. Clinopyroxene and orthopyroxene occur in subequal amounts. Hornblende occurs in only trace amounts in most thin sections of rhyodacite but some thin sections contain as much as 1.5 percent; this contrasts with the Singatse Tuff, which is rich in hornblende. Biotite is the sole fresh ferromagnesian mineral in the rhyolite but a few ubiquitous pseudomorphs probably are after pyroxene.

The rhyodacite zone generally lacks quartz and contains sparse alkali feldspar. Both minerals are consistently present in the gradational zone between the basal rhyodacite and the rhyolite, and these minerals increase in abundance and size upward. Most quartz phenocrysts are less than 3 mm but grains as large as 4 mm are not uncommon in the upper part. Quartz is moderately embayed and resorbed. As will become evident later, the size and the degree of embayment and resorption of quartz grains are critical features that aid in distinguishing among several cooling units.

Two reference localities are designated herein for the Guild Mine Member of the Mickey Pass Tuff. The first locality is 1.6 km north of Todd Mountain, just north of Nevada State Highway 23, on the southwestern flank of the Gabbs Valley Range (fig. 2, MP–1). The second locality is a northeast-trending fault block in the southern Gillis Range about 3.2 km northwest of the Kincaid gold mill and about 3.2 km due north of U.S. Highway 95 (fig. 2, MP–2). Two reference localities are designated because the tuff displays extremely contrasting megascopic and mineralogic features in the two areas. At the Todd Mountain locality (fig. 7), the Guild Mine Member is about 300 m thick and includes a lower rhyodacite zone that is nearly 100 m thick. Except for the basal vitrophyre, the cooling unit is incipiently hydrothermally altered and displays numerous bleached (tan and yellow) zones along near-vertical joints. The bleached zones in the lower part of the tuff range in width from a few centimeters to several meters and they thicken upward so that most of the upper part is bleached (fig. 7). The rock between the bleached zones is rusty-brown and this color too is secondary. It is due principally to the oxidation of ferromagnesian minerals by hydrothermal solutions and subordinately to the oxidation of finely disseminated hydrothermally introduced pyrite. The color and overall appearance of the tuff at this reference locality are fairly typical of the unit throughout the Gabbs Valley and Gillis Ranges, although in places the rock is altered throughout and is pastel shades of yellow, pink, and green.

At the second reference locality, in contrast, the tuff is fresh, thin (about 60 m thick), and, in most places, lacks the rhyodacite zone. The

TABLE 3.—*Chemical analyses and norms (in weight percent) of Mickey Pass, Singatse, and Copper Mountain Tuffs from Singatse Range and Gabbs Valley Ranges*

[For approximate modal analyses of zones sampled for chemical analyses see graphs (figs. 4, 6, 8, and 9); Leaders (---) indicate no data]

Field No. Sample[1]	675 A	270 B	295 C	661 D	300 E	277 F	S29A G	787A H
				Chemical composition				
SiO_2	66.34	74.96	77.75	69.43	71.55	76.04	68.75	74.45
Al_2O_3	16.68	13.78	12.41	16.79	15.53	12.88	15.77	13.63
Fe_2O_3	2.37	1.56	1.20	1.51	2.06	1.13	2.84 }	1.89
FeO	1.21	0.14	---	0.68	0.16	0.16	0.22 }	
MgO	1.15	0.33	0.10	0.66	0.29	0.09	1.09	0.30
CaO	3.14	1.19	0.77	2.58	1.82	1.16	2.57	1.30
Na_2O	4.10	2.94	3.16	4.25	3.18	3.70	3.71	3.27
K_2O	4.12	4.73	4.39	3.45	4.89	4.53	4.28	4.85
TiO_2	0.60	0.25	0.15	0.51	0.42	0.21	0.47	0.28
P_2O_5	0.16	---	---	0.10	---	---	0.12	---
MnO	0.07	0.12	0.06	0.04	0.06	0.05	0.16	0.02
ZrO_2	0.02	0.01	0.01	0.01	0.01	0.01	---	---
S	0.03	0.01	0.01	---	0.01	0.04	0.01	---
Total	99.99	100.02	100.01	100.01	100.00	100.00	100.00	99.99

Normative composition								
Q	18.716	36.745	40.812	25.307	29.974	34.670	23.976	32.216
C	0.153	1.673	1.071	1.621	1.688	0	0.637	0.631
Z	0.031	0.016	0.016	0.015	0.015	0.015	0	0
OR	24.324	27.953	25.926	20.364	28.906	26.749	25.306	28.688
AB	34.743	24.844	26.700	35.930	26.935	31.346	31.416	27.682
AN	14.510	5.880	3.806	12.152	9.031	5.154	11.970	6.450
WO	0	0	0	0	0	0.200	0	0
EN	2.863	0.812	0.242	1.635	0.735	0.233	2.711	0.757
MT	2.302	0.082	0	0.829	0	0	0	0
HM	0.784	1.498	1.199	0.936	2.064	1.134	2.838	3.037
IL	1.131	0.475	0.113	0.974	0.450	0.342	0.797	0.538
TN	0	0	0	0	0	0.068	0	0
RU	0	0	0.092	0	0.180	0	0.048	0
AP	0.389	0	0	0.243	0	0	0.289	0
PR	0.058	0.020	0.020	0	0.019	0.078	0.019	0
Total	100.002	99.999	99.998	100.006	99.998	99.990	100.006	100.000
Differentiation index	77.783	89.541	93.438	81.601	85.816	92.765	80.697	88.587

[1]Samples A through G are from Singatse Range, analyses by Anaconda Copper Company (Proffett and Proffett, 1976); A, D, and G are standard chemical analyses; B, C, E, F are by X-ray fluorescence except MgO and Na_2O by flame photometry, MnO by calorimetric method, FeO and S by wet chemical methods. Sample H from northern Gabbs Valley Range; values for SiO_2, Al_2O_3, TiO_2, total Fe as FeO, and MnO by X-ray fluorescence; analyst, J. S. Wahlberg. MgO, CaO, Na_2O, K_2O by atomic absorption; analyst, Wayne Mountjoy. All analyses recalculated to 100 percent minus H_2O and CO_2. Samples B, C, E, F, and G are slightly altered based on CO_2 contents of 0.38-0.56 percent. For raw chemical data see Proffett and Proffett (1976).

Sample descriptions:

A. Basal vitrophyre of Guild Mine Member, Mickey Pass Tuff.
B. Guild Mine Member 167 m above base.
C. Guild Mine Member, near top.
D. Basal vitrophyre of Weed Heights Member, Mickey Pass Tuff.
E. Weed Heights Member, near base.
F. Weed Heights Member, near top.
G. Singatse Tuff, near middle.
H. Tuff of Copper Mountain, near top.

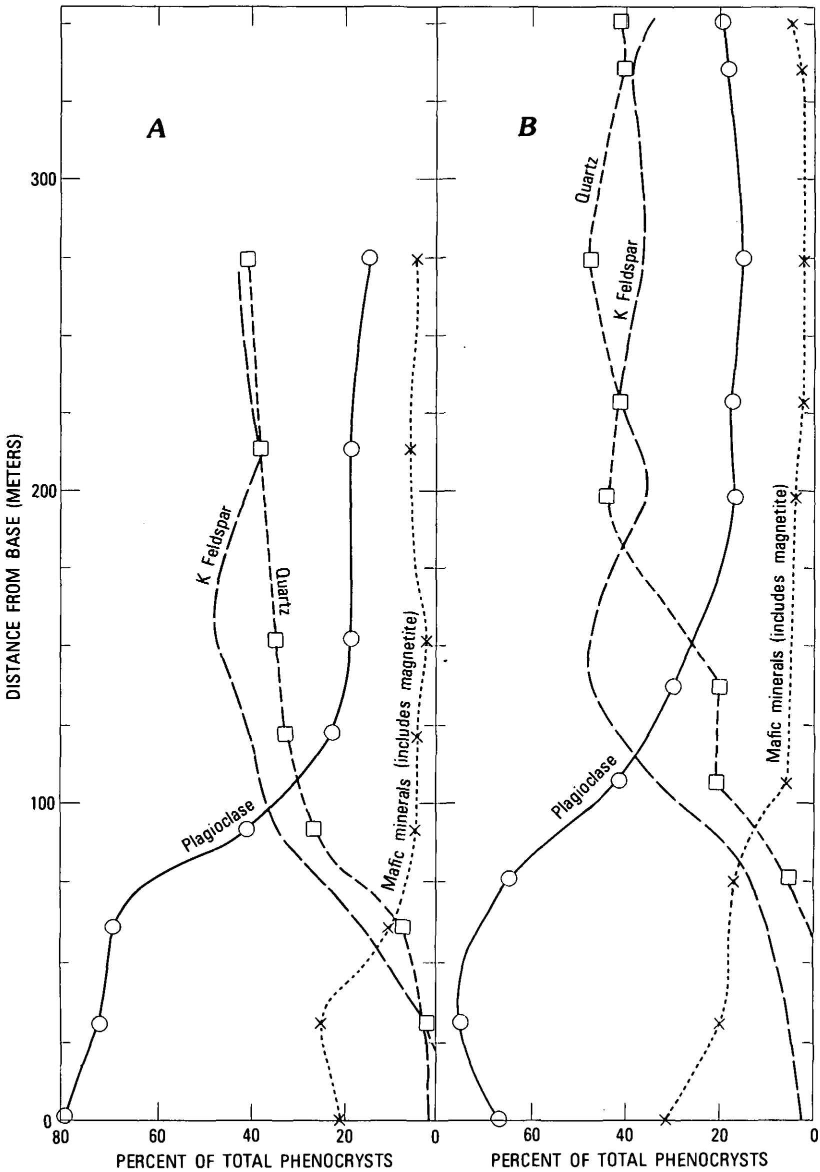

FIGURE 6.—Phenocryst variations from base to top of Guild Mine Member of Mickey Pass Tuff. *A*, at reference locality and vicinity in the Gabbs Valley Range (composite section at and in vicinity of reference locality north of Todd Mountain). *B*, at type locality of the member in the Singatse Range (continuous section). Symbols on graphs are approximate stratigraphic positions of 1,000-point modal analyses of single thin sections.

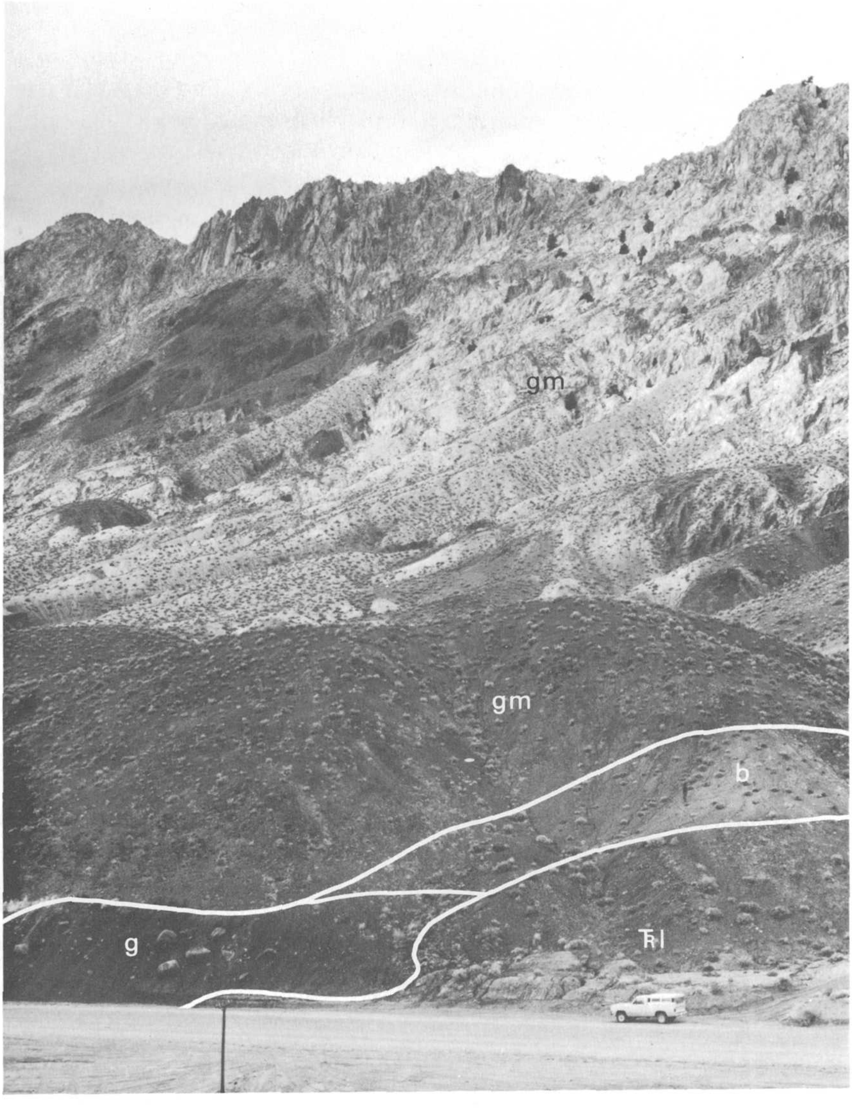

FIGURE 7.—View to northwest of the Guild Mine Member of the Mickey Pass Tuff at the reference locality of the member just north of Todd Mountain (see fig. 2). Here the member (gm) is separated by detachment-fault zones (enclosed by black lines) from the underlying Triassic Luning Formation (ŦRl). Vehicle gives scale. Zone b, fault breccia that includes fragments of quartz-rich densely welded tuff that is not part of the Guild Mine Member; zone g, scattered granite boulders set in slickensided clay gouge that was probably formed in part from residual regolith. Lack of sorting in this clay zone and ubiquitous slickensides attest fault movement. The basal vitrophyre of the Guild Mine Member here is badly broken and forms the slope. Farther to the west, however, the vitrophyre is intact and forms a cliff that is separated from the underlying Mesozoic batholithic rocks by a zone of gouge and breccia about 2 m thick. The breccia includes sheared wedges of densely welded tuff lacking quartz. Guild Mine Member here dips gently away from, and to the right of, the observer.

rock is light to medium reddish gray on fresh fracture and weathers brown and brownish gray. A minor detachment or bedding-plane fault occurs at the base of the tuff in this locality, and both the partially welded base and overlying vitrophyre are cut out locally along the fault zone. In these places the foliation in the tuff dips very steeply into the gently dipping fault zone.

In both reference localities the Guild Mine Member rests alternately on either Mesozoic rocks or the lavas of Giroux Valley and is overlain by the Singatse Tuff.

According to Proffett and Proffett (1976, p. 16) the Guild Mine Member is magnetically normal.

WEED HEIGHTS MEMBER

The Weed Heights Member (Proffett and Proffett, 1976) of the Mickey Pass Tuff is a simple cooling unit 60–120 m thick. It persists as a continuous, albeit much faulted, stratum throughout the northern Gillis and Wassuk Ranges where it underlies the Singatse Tuff and overlies the Guild Mine Member, but it is extremely discontinuous in the Gabbs Valley Range, having been recognized with certainty only in the vicinity of Calavada Summit.

Although the Weed Heights Member is preserved in various fault blocks in the northern Gillis Range, nowhere is a complete and unaltered section available. Thin sections from scattered outcrops, however, indicate that the member displays virtually the same mineralogic variations in the Gillis Range as it does in the Singatse Range (fig. 8). The member is buff to lavender to reddish brown and is characterized by abundant white pumice fragments (Proffett and Proffett, 1976). It is mostly weakly welded and the top 70 m is virtually nonwelded. The Weed Heights grades upward from quartz latite at the base to alkali rhyolite near the top (table 3). It displays a gradual upward increase in volume of quartz and alkali feldspar and a corresponding decrease in plagioclase (fig. 8). The percentage of ferromagnesian minerals fluctuates considerably from base to top. These minerals are biotite, sparse hornblende, and pseudomorphs of iron oxide and chlorite(?) that appear to be entirely after pyroxene. The fresh biotite and altered pyroxene occur in subequal amounts. In general, the phenocrysts are small. Most quartz and alkali feldspar crystals are 2 mm long, or less, and plagioclase crystals are rarely more than 3 mm long. Most of the small quartz grains, however, are moderately embayed and resorbed, and some hand specimens contain a few grains that are so riddled with holes that they qualify for the classification "worm eaten" in the vernacular of fieldnote descriptions.

In the southern Gabbs Valley Range, specifically at Calavada Sum-

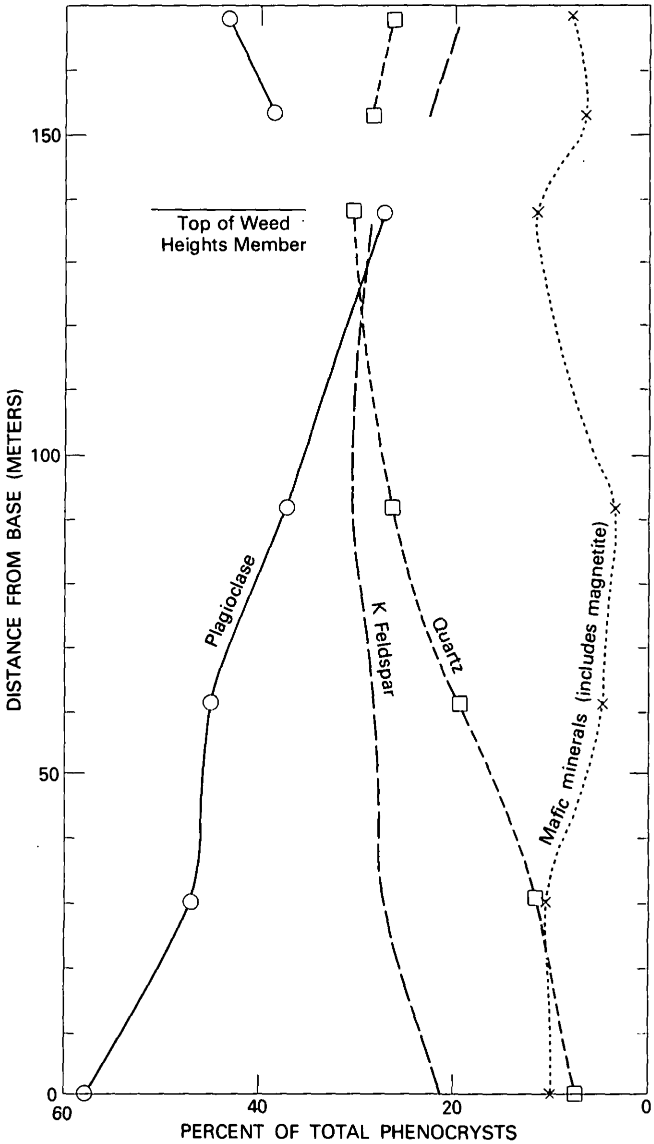

FIGURE 8.—Phenocryst variations in the Weed Heights Member of the Mickey Pass Tuff at the type locality of both in the Singatse Range (continuous section). Symbols mark locations of 1,000-point modal analyses of single thin sections. Upper 30 m has been determined to be a separate partially welded cooling unit (J. M. Proffett, oral commun., 1976).

mit, a zone of alternating densely and partially welded tuff occurs above the Guild Mine Member of the Mickey Pass Tuff and below the Singatse Tuff that we tentatively had considered to be part of the

Singatse Tuff. This tentative conclusion was based on the lack of precise evidence of complete cooling breaks within the zone and between the zone and unequivocal Singatse Tuff. Now, on the basis of mineralogic evidence, we conclude that the lowest 20–30 m, consisting of densely welded tuff grading upwards to partially welded tuff, is the Weed Heights Member and therefore the cooling break with the overlying tuff has to be complete. The mineralogic evidence consists of virtually identical percentages and ratios of phenocrysts with the Weed Heights at the type locality, identical sizes of various phenocrysts, and the occurrence of a few grains of "worm-eaten" quartz having not only the same size but the same degree of embayment as the quartz grains in the tuff at the type locality. This tuff is fresh and, in contrast to the rock at the type locality, contains unaltered pyroxene consisting of subequal hypersthene and clinopyroxene.

The basal vitrophyre of the Weed Heights is as much as 3 m thick, but it is discontinuous. It forms the lowest of three conspicuous ribs between the Guild Mine Member and the Singatse Tuff at Calavada Summit. Two samples from the discontinuous vitrophyre at Calavada Summit indicate that the Weed Heights Member is magnetically normal (G. D. Bath, written commun., 1975).

SINGATSE TUFF

The Singatse Tuff adopted in this report was named by Proffett and Proffett (1976) for exposures on Singatse Peak in the Singatse Range west of Yerington, where the Singatse is a multiple-flow simple cooling unit 240–410 m thick. They designated exposures in sec. 13, T. 13 N., R. 24 E. as the type area. It is brown to red brown, moderately to densely welded and crystal rich, containing abundant plagioclase, quartz, sanidine, biotite, and hornblende phenocrysts (Proffett and Proffett, 1976). It is quartz latite in composition from base to top in the Singatse Range and displays only slight variations in phenocryst mineralogy. Unlike the Mickey Pass Tuff, the Singatse Tuff is characterized throughout by abundant lithic fragments. These fragments, however, are much more numerous in some flows within the cooling unit than in others. The fragments compose as much as 10 percent of the rock and they range in length from less than 1 cm to more than 10 cm. The fragments are principally lavas of intermediate composition but they include Mesozoic granitic rocks, and variegated carbonate and clastic rocks.

Unaltered Singatse Tuff in the Gabbs Valley and Gillis Ranges is a mirror image in outcrop of the Singatse at the type locality and is nearly a mirror image in mineralogic profile (fig. 9). However, if the assumption is valid that the middle rhyodacitic rib-forming zone (see section, Ash-flow tuffs between the Mickey Pass and Singatse Tuffs) is genetically part of the Singatse at Calavada Summit, then the Singatse there differs significantly from the rocks exposed in the Yerington district. Like the members of the Mickey Pass, the formation displays a gradation upward from rhyodacite at the base to quartz latite at the top. The change from rhyodacite to quartz latite, however, is abrupt and, as discussed previously, coincides closely with a partial or complete cooling break.

In the Gabbs Valley and Gillis Ranges, the Singatse Tuff commonly has a black basal vitrophyre 1–4 m thick. The vitrophyre grades upward to densely welded light-red or reddish-gray devitrified tuff, which weathers pale brown and brownish gray. Pumice clasts are abundant throughout the cooling unit and are conspicuous in both altered and unaltered rock. The top 100 m is characteristically rich in flattened white pumice fragments about the size of silver dollars. Where the Singatse Tuff is altered, it is typically purple or purplish gray, weathering to dark purple and dark purplish gray.

As shown in figures 4 and 9, there is little mineralogic and, presumably, little chemical variation from base to top in the Singatse Tuff proper. Analyzed chemically, a sample from the middle of the Singatse at Yerington falls well within the quartz latite rock type of E. J. Young's classification (Segerstrom and Young, 1972). The most distinctive mineralogic feature is the occurrence of hornblende, which in many thin sections from the lower one-third of the unit is as abundant as biotite. There is less hornblende upwards, however, as a result of both alteration and gradual reduction in volume. Pyroxene occurs in a few thin sections near the base.

The Singatse Tuff together with the Guild Mine Member of the Mickey Pass Tuff comprise the most widespread ash-flow tuffs in the area under investigation. The Singatse occurs throughout the Gabbs Valley and Gillis Ranges, the northern Wassuk Range (E. C. Bingler, oral commun., 1975), the northeastern Excelsior Mountains, and, according to Proffett and Proffett (1976), as far west as the Pine Nut Mountains (fig. 3). To the southeast it is present in the northern part of Cedar Mountain (fig. 3) where it is estimated to be at least 60 m thick; and, according to R. C. Speed (written commun., 1976), it is as much as 100 m thick in the Pilot Mountains where it has been dated at 27 m.y.

Samples of Singatse Tuff from the type locality (Proffett and Proffett, 1976), the northern Wassuk Range, the northern Gillis Range, and Calavada Summit (including the rhyodacite and blob zone; see section, Ash-flow tuffs between the Mickey Pass and Singatse Tuffs), are magnetically normal (G. D. Bath, written commun., 1976).

PETRIFIED SPRING TUFF

The Petrified Spring Tuff is here named after Petrified Spring in the southern Gabbs Valley Range. The formation is not exposed in the immediate vicinity of the spring, but is locally exposed in several northwest-striking fault blocks in the southwest quarter of T. 9 N., R. 35 E. (fig. 2). The base and top of the Petrified Spring occur in only one locality, designated herein as the type locality. This exposure (fig. 2, PS) is in the NW¼ sec. 31, T. 9 N., R. 35 E., and is 4 km south of Petrified Spring.

At the type locality the Petrified Spring Tuff is underlain by two local thin and discontinuous nonwelded ash-flow cooling units, each about 15 m thick, and a discontinuous well-bedded air-fall tuff as much as 10 m thick. The nonwelded ash-flow tuff is mostly white and rich in lithic fragments of intermediate flow rock and rhyolite. Locally, the Petrified Spring rests directly on the Singatse Tuff. At the type locality the Petrified Spring Tuff is directly overlain by the Blue Sphinx Tuff, but 2 km to the north it is overlain unconformably by the much younger lavas of Mount Ferguson. At the base of the lava it is evident that much bedding-plane or detachment-fault movement has taken place, but we infer that most of the omission of strata is due to prelava erosion.

The Petrified Spring Tuff is about 75 m thick and consists of a basal vitric partially welded dark-gray zone as much as 5 m thick that is rich in white pumice clasts as long as 0.5 m. The dark-gray vitric tuff grades upward into a thick (as much as 15 m) medium-gray to black soft vitrophyre that contains black vitrophyric pumice as long as 0.5 m. The vitrophyre grades upward into moderately welded pinkish-gray partly devitrified tuff that weathers pinkish brown and yellowish brown. Lithic fragments of intermediate lava are conspicuous and abundant throughout the formation. The Petrified Spring is the most mafic of the three formations included in the Benton Spring Group, but it displays the same vertical variation in mineralogy as the underlying formations. Near the base the Petrified Spring is rhyodacite, and it is virtually lacking in quartz and alkali feldspar phenocrysts. Near the top, however, the rock is quartz latite; quartz crystals as much as 5 mm long compose 10 percent of the total phenocrysts. Volume of alkali feldspar phenocrysts increases upward to as much as 23 percent of total phenocrysts; these crystals may be as large as 4.5 mm. Plagioclase phenocrysts are as large as 6 mm and many of these are extremely poikilitic and charged with glass. The large feldspar phenocrysts are characteristic of this unit.

The Petrified Spring Tuff is sporadically preserved beneath the Blue Sphinx Tuff in the Gabbs Valley Range north of Benton Spring and locally preserved in the southern part of the northern Gillis

Range. Its absence in places appears to be due to both omission by very low angle faulting and by pre–Blue Sphinx Tuff erosion. The unit is magnetically reversed (G. D. Bath, written commun., 1976).

AGE OF THE BENTON SPRING GROUP

Potassium-argon ages for the Guild Mine Member of the Mickey Pass Tuff range from 26.3 m.y. (excluding the low 24.4-m.y. date on plagioclase) to 28.0 m.y. (table 2), and agree very well with ages for the Guild Mine Member from the Singatse Range listed by Proffett and Proffett (1976). An age of 26.7 m.y. also was obtained from lava of Giroux Valley beneath the Guild Mine Member, and two dates (25.0 m.y. and 26.1 m.y.) were obtained from tuff of Gabbs Valley that lies stratigraphically above the Benton Spring Group. These dates suggest that all the tuffs in the Benton Spring Group could have been erupted within a period of 1 m.y. or less.

ASH-FLOW TUFFS BETWEEN THE MICKEY PASS AND SINGATSE TUFFS

Studies by John Proffett (oral commun., 1976) that postdate the descriptions given in Proffett and Proffett (1976) indicate that a partially welded quartz latite or rhyolite tuff at the top of the Weed Heights Member in the Yerington district, formerly considered to be part of the poorly welded top of the Weed Heights, constitutes a separate and distinct cooling unit. Modes of two thin sections from this cooling unit are plotted on figure 8. A single thin section from the vicinity of Calavada Summit suggests that this unnamed unit occurs there also, but, if so, it is extremely local.

In addition to this unit, however, another higher cooling unit occurs at Calavada Summit that is widespread in the Gabbs Valley Range. This higher cooling unit is rhyodacite at the base and vitrophyric (fig. 9). The vitrophyric zone forms the middle rib of the three ribs previously mentioned. This zone grades upward to slope forming weakly welded light-gray tuff and thence upward to moderately welded light-brown tuff containing large (as much as 30 cm long) pumice fragments, some of which are black glass, others gray and devitrified. The large-pumice or "blob" zone forms the third and highest rib (fig. 9). It is composed of quartz latite or silicic rhyodacite and contains as much as 13 percent quartz and 22 percent sanidine. In contrast, the lower rhyodacite is without quartz and contains only 5–10 percent sanidine. The blob zone is separated from the Singatse Tuff proper by a zone of weakly welded tuff 10–20 m thick. The pumice lapilli in this zone are only slightly flattened and a partial or complete cooling break is indicated. Whatever the actual nature of the break, it seems reasonable to assume that very little time elapsed

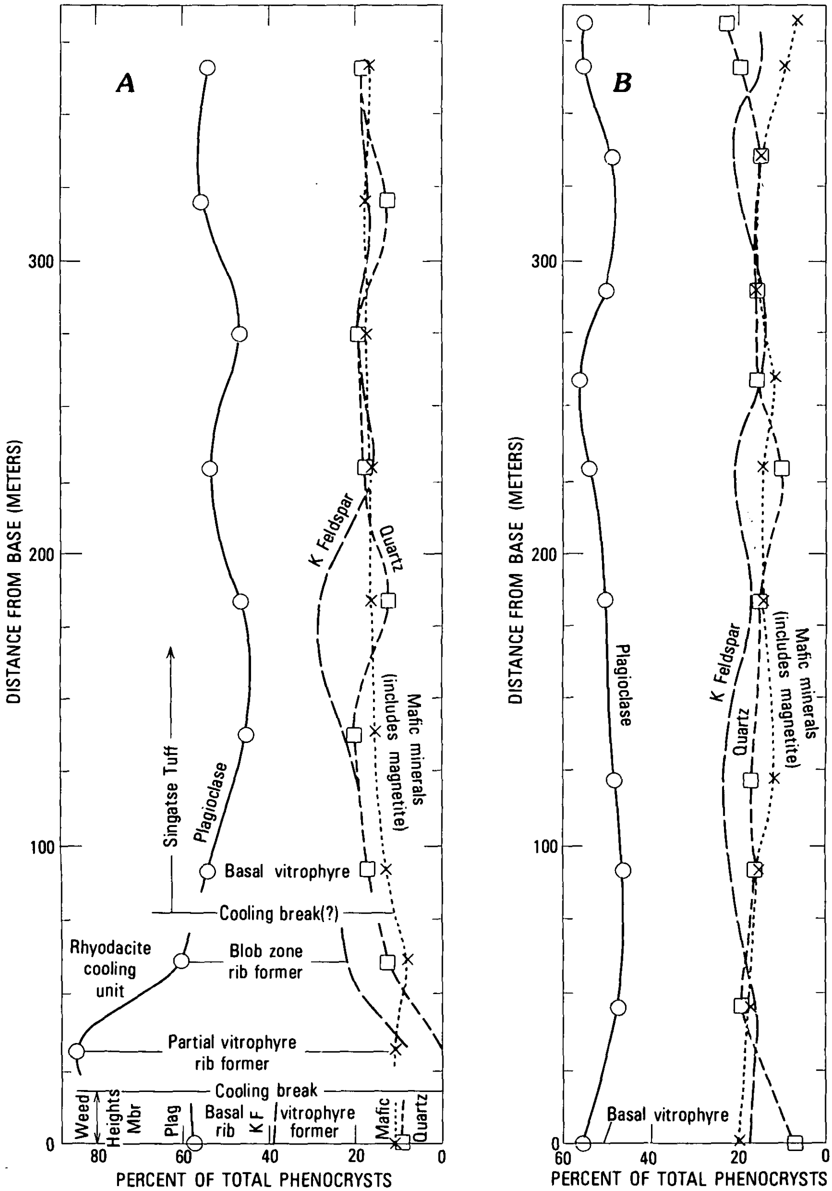

FIGURE 9.—Phenocryst variations of *A*, Singatse Tuff at Calavada Summit in the Gabbs Valley Range (composite section), compared with *B*, Singatse Tuff at the type locality, Singatse Range (continuous section). Also shown are phenocryst plots of three rib-forming zones between the Guild Mine Member and the Singatse Tuff at Calavada Summit. The lowest rib and overlying partially welded tuff (not sampled) are correlated with the Weed Heights Member of the Mickey Pass Tuff. The upper two ribs are regarded as parts of a single rhyodacite compound cooling unit. The cooling break between this unit and the Singatse Tuff proper may not be complete. The rhyodacite unit is not present in the Singatse Range.

between the eruption of the blob zone and the main ash-flows of the Singatse Tuff, and that the zone is genetically related to the Singatse.

LOCAL UNITS BETWEEN THE BLUE SPHINX TUFF AND THE BENTON SPRING GROUP

Following the eruption of the uppermost tuff of the Benton Spring Group, local units and thin tuffs originating outside the area were emplaced. Sequences of intermediate lavas, tuffaceous sedimentary rocks, and ash-flow tuffs at least 50 m thick, and locally more than 200 m thick, form a composite section between the Benton Spring Group and the overlying Blue Sphinx Tuff in the Gabbs Valley and Gillis Ranges near and to the north of Nugent Wash. The units are discontinuous, due to omission by both erosion and faulting. For example, in a single fault slice north of Nugent Wash as many as four thin (less than 30 m thick) cooling units of welded tuff are present between the Blue Sphinx Tuff and the Benton Spring Group. In adjacent fault slices, several or all units may be absent.

INTERMEDIATE LAVAS

Lavas beneath the Blue Sphinx Tuff and above the Benton Spring Group range in composition from rhyodacite to quartz latite (fig. 4). They commonly are lavender or blue gray. The lavender color indicates incipient hydrothermal (propylitic) alteration. Sparse fresh rocks are medium to dark gray. Most lavas in this sequence are conspicuously porphyritic, containing euhedral plagioclase as much as 1 cm long. Some lavas contain a few phenocrysts of quartz.

The lavas in at least one locality in the central part of the Gabbs Valley Range may be as much as 400 m thick. In most places, however, they comprise a stratum less than 30 m thick, and in several areas, as previously mentioned, they are absent.

SEDIMENTARY ROCKS

Sedimentary rocks consisting mostly of even-bedded lacustrine siltstones are present locally between the Blue Sphinx Tuff and the intermediate lavas just described. Thin-bedded air-fall tuffs, in some places pisolitic, occur locally within the sedimentary rocks. These beds were deposited in one or more shallow lakes and at one time possibly were continuous over a broad region northwest of Nugent Wash. The rocks probably reflect regional subsidence related to extrusion of the Benton Spring Group. They commonly are extensively altered; only locally is it possible to determine that the ash-fall beds originally were rich in biotite. No exposures of the sedimentary rocks are known to be more than about 30 m thick.

Southeast of Nugent Wash the lacustrine sedimentary rocks intertongue with fluvial sandstone, coarse gravel, and biotite-rich air-fall tuff. The entire sequence is mostly less than 20 m thick and it pinches out 2–3 km south of the latitude of Poinsettia Spring (fig. 2). Most clasts in all these rocks include fragments of intermediate lava but locally they include fragments of Singatse Tuff and boulders of pre-Tertiary quartzite.

ASH-FLOW TUFFS

As many as four ash-flow cooling units are present northwest of Nugent Wash. From base to top these units include a biotite-rich ash-flow tuff of quartz latite composition, a rhyolite ash-flow tuff, a biotite-rich quartz latite ash-flow tuff that is modally similar to the basal unit, and a second rhyolite ash-flow tuff that contains conspicuous shards. The biotite tuffs appear to thin northward; in contrast, the rhyolite tuffs thicken northward. The older biotite tuff is lithologically similar to the Petrified Spring Tuff and possibly correlates with that unit.

The two rhyolite tuffs are part of the "tuff of Gabbs Valley," a sequence of ash-flow tuffs (Ekren and Byers, 1976) best exposed on the north and east sides of Gabbs Valley (fig. 2). These two thin cooling units are inferred to have been extruded onto the Gillis Range and northern Gabbs Valley Range when the Gabbs Valley volcanic center lay far northwest of its present position. The two tuffs are very similar modally and megascopically. They are crystal poor, containing fewer than 10 percent phenocrysts, principally alkali feldspar. Quartz occurs as rare tiny grains less than 2 mm long. Ferromagnesian minerals, principally biotite, are sparse; they are rarely intact because of the extensive and pervasive alteration of the tuffs. The older rhyolite tuff contains conspicuous, well-flattened pumice fragments as much as 15 cm long. The younger unit is only partially welded, in contrast to the older; shards in the younger unit are visible with the hand lens.

Both tuffs are reddish brown where fresh, but throughout the area the reddish-brown color is rare because of intense alteration. In most places the tuffs are bleached white, light gray, or pastel shades of green or pink. They both contain numerous fragments of crystal-poor rhyolite lava and tuff and moderately crystal-rich fragments of intermediate lava.

The tuff of Gabbs Valley occurs in the Yerington district in the Singatse Range where it has been named the Blue Stone Mine Tuff (Proffett and Proffett, 1976). We prefer to continue to use the informal "tuff of Gabbs Valley" for the sequence because the ash flows originated there (Ekren and Byers, 1976) and there they are best developed. Furthermore, detailed stratigraphic studies in the region of Gabbs Valley will undoubtedly define very complex stratigraphic relationships of this important ash-flow field, and the strata may warrant member-, formation-, and even group-rank names. The adoption of a formal name for exposures of poorly welded ash flows far removed from the source area predictably will prove cumbersome.

BLUE SPHINX TUFF

The Blue Sphinx Tuff is here named for the Blue Sphinx, a natural monolith of Blue Sphinx Tuff located on the eastern flank of the Gabbs Valley Range just south of the Golden Pen gold mine in sec. 33, T. 11 N., R. 32 E. (fig. 2), its type locality. The monolith is aptly named because it is blue to lavender and closely resembles an Egyptian sphinx (fig. 10). The type locality of the Blue Sphinx Tuff includes the monolith. Because the base of the tuff is poorly exposed in this vicinity, an excellent exposure just north of Nugent Wash in sec. 18, T. 11 N., R. 32 E. (fig. 2) is designated here as a reference locality. At the reference locality, the Blue Sphinx Tuff rests on thin-bedded tuffaceous and lacustrine sedimentary rocks, but at the type locality these underlying rocks are exposed only in fault slivers south of the monolith. The Blue Sphinx Tuff in other localities, however, rests on thin biotite-rich air-fall tuff, the tuff of Gabbs Valley, the Petrified Spring Tuff, or directly on the intermediate lavas previously described. At the type locality, the Blue Sphinx Tuff is part of a fault block dropped down on the east side of the range by a northwest-striking fault (fig. 2).

At the type locality, hornblende-rich intermediate lavas of Nugent Wash overlie the Blue Sphinx Tuff. At the reference locality, in contrast, the Blue Sphinx is overlain by the Nugent Tuff Member of the Hu-pwi Rhyodacite, and only thin rubble of intermediate lavas separate the two tuff sequences.

The Blue Sphinx Tuff is a multiple-flow simple cooling unit of quartz latite. Typically, it is blue or lavender, a result of mild hydrothermal alteration. In the rare exposures where the tuff is fresh, it is pink or pinkish gray on fresh fracture and weathers pale brown and medium brown. In the southern Gabbs Valley Range, the Blue Sphinx contains few lithic fragments. In the northern Gabbs Valley Range, however, for example at the type locality, the tuff contains abundant lithic fragments. Fragments consist principally of two types: (1) lavender and purple intermediate lava—mostly nearly aphyric but some with conspicuous large plagioclase phenocrysts and (2) dark-brownish-green-weathering, greenish-gray on fresh fracture, highly altered tuff(?) containing sparse quartz phenocrysts. Type 2 rocks have been almost entirely replaced by calcite, chlorite, and

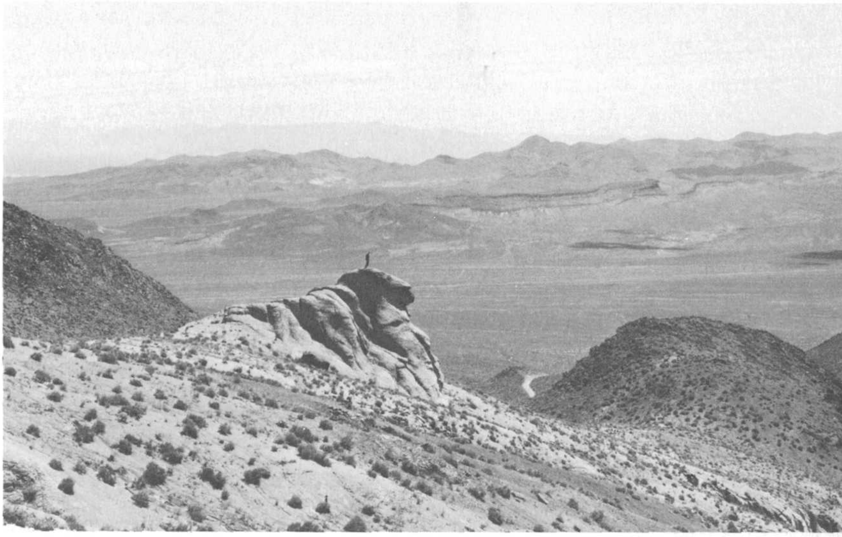

FIGURE 10.—View looking northeastward at Blue Sphinx monolith—the type locality of the Blue Sphinx Tuff. Dark outcrops to right of monolith are hornblende lava that overlies the Blue Sphinx Tuff; dark outcrops to left are Nugent Tuff Member of Hu-pwi Rhyodacite, which overlies the hornblende lava. Layered strata in background are cooling units of the Poinsettia Tuff Member, which rests on intermediate lavas of the Poinsettia Spring area. A major northwest-trending strike-slip fault (see fig. 2) separates the strata in foreground from those in the background.

epidote. At the reference locality, the type locality, and Calavada Summit, the Blue Sphinx Tuff is 30–90 m thick, but it possibly is as much as 300 m thick in the northern Gillis Range.

The Blue Sphinx Tuff contains about 35 percent phenocrysts. It shows a slight tendency to become more silicic upwards. At Calavada Summit, one of the few localities where the tuff is not altered, it contains about 13 percent quartz from base to top but, in contrast, alkali feldspar increases upward from about 20 percent at the base to as much as 34 percent near the top. Ferromagnesian minerals, consisting of subequal hornblende and biotite, constitute 8–14 percent of the total phenocrysts. Clinopyroxene occurs locally. The ferromagnesian minerals show little variation in volume from base to top.

The most distinguishing characteristic of the Blue Sphinx is its quartz phenocrysts (fig. 11). These are so intensely resorbed that many grains are sieves. They range in length from about 2 mm to as much as 6 mm, and although they constitute only about 5–15 percent of the phenocrysts (fig. 4), they nevertheless serve to distinguish the Blue Sphinx from all other major welded tuff units in the region. It is worthy of mention that a stratigraphically higher tuff (informally called tuff of Redrock Canyon, see later pages) contains quartz

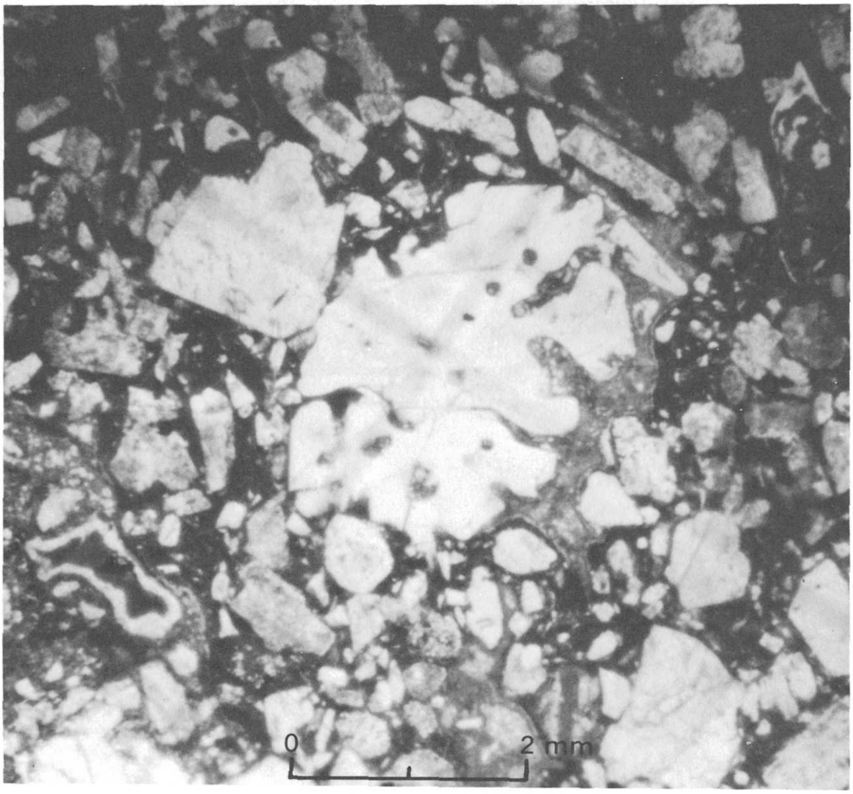

FIGURE 11.—Photomicrograph of thin section of Blue Sphinx Tuff showing intensely resorbed quartz phenocryst. Most phenocrysts in this view are plagioclase crystals that are partly replaced by calcite and clay. A cavity lined with secondary quartz and filled with birefringent clay lies at lower left. Plane polarized light.

phenocrysts as large and as resorbed as those in the Blue Sphinx but the tuff of Redrock Canyon is restricted to the eastern part of the Gabbs Valley Range and contains so many granite lithic fragments there that it is easily distinguished from the areally extensive Blue Sphinx. The overall composition of the Blue Sphinx and the presenceof resorbed quartz suggest that the formation is transitional in composition as well as in time between the Benton Spring Group and the Hu-pwi Rhyodacite.

The Blue Sphinx Tuff is a major mappable unit throughout the Gabbs Valley and Gillis Ranges. It is thick and crops out over broad areas in the northern Wassuk Range (E. C. Bingler, oral commun., 1975). It does not occur in the Singatse Range, but Proffett and Proffett (1976, p. 23) reported an ash-flow tuff with "sieve-textured resorbed quartz" about 7.25 miles S. 71° E. of Yerington that is in the same stratigraphic position as the Blue Sphinx. The Blue Sphinx has not been observed at Cedar Mountain and vicinity (fig. 3). The formation is younger than the tuffs of Gabbs Valley, which are dated at about 25 m.y. (table 2), and it is older than the Hu-pwi Rhyodacite, which has been dated at 22–23 m.y.

INTERMEDIATE LAVAS OF NUGENT WASH AREA

Dark-gray lavas of intermediate composition overlie the Blue Sphinx Tuff near Blue Sphinx monolith and over broad areas northwest and southeast of Nugent Wash. The most widespread lava is hornblende latite or rhyodacite. The lava is 30–50 m thick, dark gray on fresh fracture, weathering to dark greenish brown and black. It contains about 10 percent by volume of conspicuous phenocrysts of hornblende as much as 6 mm long and inconspicuous plagioclase that rarely exceeds 3 mm in length.

In several localities south of Nugent Wash, the hornblende lava is overlain by dense andesitic lava as much as 30 m thick that is moderately altered in all exposures. This lava closely resembles basalt in outcrop. It is dark gray to black where relatively fresh and dark purple where altered. It grades upward without a visible cooling break from massive-weathering andesitic phenocryst-poor rock containing sparse small phenocrysts of pyroxene and plagioclase into rhyodacitic flow breccia containing abundant large (as much as 8 mm) phenocrysts of plagioclase, pyroxene, and hornblende, and biotite as large as 5 mm. The phenocryst-rich breccia, in turn, is overlain by the pumice-rich Nugent Tuff Member of the Hu-pwi Rhyodacite.

HU-PWI RHYODACITE

The herein named Hu-pwi Rhyodacite consists of a sequence of rhyodacite tuff and lava that is rich in ferromagnesian minerals and nearly lacking in quartz, and totals at least 1,000 m in thickness. The formation is named after exposures in the vicinity of Hu-pwi Wash, the type locality (T. 12 N., R. 30 E.), which drains the northeastern flank of the northern Gillis Range (fig. 2). The Hu-pwi Rhyodacite consists of three formal members and one informal member—in ascending order the Nugent Tuff Member, Ghost Dance Lava Member, intermediate lavas of the Poinsettia Spring area that probably are coeval with the Ghost Dance, and Poinsettia Tuff Member. The Hu-pwi Rhyodacite is the equivalent of the tuff and breccia of Gallagher Pass of Proffett and Proffett (1976).

The three formal members are exposed in fault blocks between Nugent Wash and Hu-pwi Wash (fig. 2), and they occur together only in the type locality of the Ghost Dance Lava Member.

NUGENT TUFF MEMBER

The oldest member of the Hu-pwi Rhyodacite is the Nugent Tuff Member, here named after exposures in and near Nugent Wash in the northern Gabbs Valley Range. The type locality is designated as Nugent Wash in T. 11 N., R. 32 E., about 1 km east of R. 31 E. (fig. 2). In this vicinity the Nugent Tuff Member rests on thin-bedded red-brown ferruginous tuffaceous sandstone 1-5 m thick or on rubble of lavas of intermediate composition less than a few meters thick, which in turn rests on the Blue Sphinx Tuff. Southeast of Nugent Wash the member overlies either the Blue Sphinx Tuff or the intermediate lavas of the Nugent Wash area. The member is overlain in the Gillis Range by the Ghost Dance Lava Member, but in the Gabbs Valley Range it is overlain by a variety of strata including intermediate lavas of the Poinsettia Spring area, Poinsettia Tuff Member, tuff of Redrock Canyon, and local unsorted landslipped debris.

The Nugent Tuff Member is a compound cooling unit that displays little variation in phenocryst mineralogy from base to top; however, it displays marked megascopic variation. In the northeastern Gillis Range it is 300 m thick, but it thins drastically to 70 m thick in the vicinity of Ghost Dance Ridge (fig. 2), where it is entirely vitrophyre. There the tuff contains small pumice and abundant (as much as 40 percent) cognate fragments of the same mineralogy as the enclosing matrix. These fragments are somewhat compressed, are black in color, and in places are as much as 0.3 m long. A few cognate fragments are distinctively flow banded. The abundance of these fragments imparts a tuff-breccia appearance to the rock. The thinness and glassy nature together with the tuff-breccia character suggest that the tuff in this locality may be near the distal end of the unit. This conclusion is supported by absence of the tuff in the northern Wassuk Range (E. C. Bingler, oral commun., 1975). In the northeastern part of the Gillis Range and throughout the Gabbs Valley Range the tuff averages at least 300 m thick and is densely welded and devitrified throughout except for a local thin basal vitrophyre. Throughout this area it is a compound cooling unit consisting of many ash flows. In the basal two-thirds it is characterized by brown pumice fragments that contrast markedly with the gray matrix. Pumice fragments rarely exceed 3 cm in length, and some zones in the basal two-thirds are nearly devoid of pumice fragments. The top third consists of ash-flow tuffs that contain gray pumice fragments, which are lighter in color than the matrix, and less common brown pumice fragments. The gray pumice fragments are as much as 20 cm long. The contact between the upper ash-flow tuffs containing large gray pumice fragments and the lower ash-flow tuffs containing brown pumice fragments is marked by a zone of distinctively bedded welded air-fall tuff as much as 1.5 m thick and by numerous lava fragments of intermediate composition that occur in the basal 10 m of the upper tuff. A complete cooling break may not be indicated, however, because the pumice clasts above, below, and within the bedded sequence are well flattened, and the tuff is completely devitrified.

Unaltered devitrified Nugent Tuff Member is typically medium gray on fresh fracture, weathering pale brown and brown. Where moderately altered, the tuff is dark gray, weathering to dark brownish or dark purplish gray.

The Nugent Tuff Member commonly consists of as much as 50 percent phenocrysts (fig. 4) and, of these, 15–30 percent are ferromagnesian crystals—principally biotite and clinopyroxene in approximately equal proportions. Hornblende and orthopyroxene rarely exceed a few grains per thin section. The ferromagnesian crystals are large; biotite occurs in books as large as 4 mm; pyroxenes and hornblendes are as long as 5 mm. Plagioclase phenocrysts vary considerably in size; some ash flows of the Nugent contain plagioclase that rarely exceeds 4 mm, but other flows contain plagioclase that are mostly 5–8 mm long. Most large plagioclase phenocrysts are poikilitic and, surprisingly for a densely welded tuff, are little shattered and broken. Few of the more than 50 thin sections counted contain quartz or alkali feldspar. Some thin sections, however, contain as many as three grains of quartz and seven grains of alkali feldspar. The Nugent Tuff Member is magnetically reversed (G. D. Bath, written commun., 1976).

GHOST DANCE LAVA MEMBER

The Ghost Dance Lava Member is here named after Ghost Dance Ridge in the Gillis Range (fig. 2), but the type locality is in Hidden Wash in T. 11 N., R. 30 E., about 3.2 km east of the ridge. There the member overlies the Nugent Tuff Member and underlies the Poinsettia Tuff Member. The contacts between the members, however, are low-angle detachment faults.

The rhyodacitic lava of the Ghost Dance Lava Member is virtually identical in phenocryst mineralogy to the rhyodacitic tuff in the underlying Nugent Tuff Member and overlying Poinsettia Tuff Member; thus the contrasting rock types merely reflect changing physical conditions in the magma chamber. The basal part of the Ghost Dance Lava Member is a flow breccia of variable thickness, generally about 10 m. This zone consists of dark-brown to black glassy rhyodacite fragments, commonly flow banded, that range in length from about 1 cm to blocks as large as 1 m. These fragments are set in a brownish-gray glassy lava matrix that composes approximately 60 percent of the rock. The brownish-gray flow breccia grades upward into black glassy flow breccia and thence upward into devitrified gray flow-banded lava displaying ramp structures and flow folds. Layers in the flow-banded rock are alternately phenocryst-rich and phenocryst-poor, and the phenocrysts in the layers range markedly in length from only a few millimeters in some layers to more than 5 mm in others.

The maximum known thickness of the Ghost Dance Lava Member in the northern Gillis Range is about 100 m; it ranges from a feather edge to as much as 30 m thick in the northern Wassuk Range, according to E. C. Bingler (oral commun., 1975). Bingler also reported that in the Wassuk Range it is difficult to demonstrate a cooling break between the lava and the overlying Poinsettia Tuff Member. He believed that the lava and tuff sequences there constitute a single compound cooling unit.

The Ghost Dance Lava Member is confined to the northern Gillis and Wassuk Ranges and this distribution (keeping in mind a probable right-lateral slip of 5–10 km between the two ranges) probably corresponds very closely to the original distribution. The Ghost Dance Lava Member probably was fed simultaneously from several vents that were located in an area that lies between the northern parts of the two ranges.

INTERMEDIATE LAVAS OF POINSETTIA SPRING AREA

An apparently very local pile of lava of intermediate composition, at least 400 m thick, is exposed near Poinsettia Spring (fig. 2). The base of the pile is not exposed but we infer that the lavas overlie the Nugent Tuff Member of the Hu-pwi Rhyodacite. The lava sequence is overlain by the Poinsettia Tuff Member. These relations indicate that the sequence probably is the time equivalent of the Ghost Dance Lava Member but the lavas are not included in that member because they constitute such lithologically diverse flows.

Near Poinsettia Spring the rocks are propylitically altered and a northwest-trending fracture there is veined with cinnabar. The lava exposed at the cinnabar mine near the spring is conspicuously porphyritic, containing large hornblende prisms as much as 1.5 cm long, biotite books as much as 4 mm long, and plagioclase as much as 1 cm long. This rock contains a grain or two of quartz per hand specimen and probably is quartz latite in composition. Most of the lava in the pile, however, is femic rhyodacite, containing generally small phenocrysts. These include prisms of hornblende, clinopyroxene, and orthopyroxene that rarely exceed 3 mm long and plagioclase that also rarely exceeds 3 mm long. Some flows contain only pyroxene phenocrysts. The lavas of Poinsettia Spring, although in general finer grained and richer in pyroxene than the formal members of the Hu-pwi Rhyodacite, are similar to the enclosing tuffs and, like the Ghost

Dance Lava Member, represent a relatively quiescent stage in the eruptive cycle of the underlying magma chamber.

Bedding-plane or detachment faults are important structural features near Poinsettia Spring and eastward toward Gabbs Valley (fig. 2), and these were avenues for hydrothermal solutions. In several localities the lavas adjacent to the faults are intensely altered.

POINSETTIA TUFF MEMBER

The Poinsettia Tuff Member is here named for exposures in T. 10 N., R. 33 E., the type locality, about 2 km south-southeast of Poinsettia Spring (fig. 2, P). The tuff overlies alternately the Nugent Tuff Member or the intermediate lavas of the Poinsettia Spring area. Near the type locality the tuff is overlain by lavas of Mount Ferguson. Although the upper contact of the Poinsettia Tuff Member is a fault contact in this vicinity, the uppermost cooling unit of the Poinsettia displays a partially welded top, which indicates that very little of the cooling unit has been removed by faulting or prelava erosion. To the northwest, however, between Poinsettia Spring and Copper Mountain, the Poinsettia is conformably overlain by the tuff of Copper Mountain. The omission of this member at Poinsettia Spring therefore suggests that considerable erosion did occur prior to the extrusion of the oldest lava of Mount Ferguson.

In the vicinity of the type locality it is apparent that the Poinsettia Tuff Member was largely confined to a structural and topographic trough. The tuff is bounded on the southwest side by an old fault scarp formed of Nugent Tuff Member and older tuffs and lavas. This fault zone is 10 m or so wide and the intensity of shearing suggests that it may be a strike-slip fault, or at least that it had some component of strike-slip motion. The fault strikes about N. 65° W., an orientation that is parallel to the axes of distribution of all the tuff sheets exclusive of the tuff of Copper Mountain. On the northeast side the tuff laps up against the lavas of the Poinsettia Spring area. The zone of onlap is linear and can be traced for a distance of about 9 km trending about N. 70° W. This relationship suggests that this tuff boundary is controlled also by a fault, but that this fault zone was buried by the onlapping tuff sheet.

The Poinsettia Tuff Member consists of five partially to densely welded multiple-flow simple cooling units. The four basal cooling units are of rhyodacite composition and the top cooling unit is of quartz latite composition. The basal cooling unit is as much as 200 m thick. The other units range in thickness from about 30 m to 150 m. All five units are largely devitrified but much of this devitrification probably is due to postcooling groundwater alteration because pumice fragments in all units are characteristically perlitic. The units dip 20°–70° to the northeast and are greatly extended by obscure moderate- to low-angle southwest- and west-dipping faults. Because of the obscure nature of the faults, the five cooling units appear, at first glance, to compose a single compound cooling unit several hundred meters thick.

The four rhyodacite cooling units are virtually identical, containing the same phenocryst abundance and assemblage. They are the same color—light gray or light reddish gray on fresh fracture, weathering to pale brownish gray and brown. The uppermost quartz latite cooling unit is reddish gray on fresh fracture and weathers medium brown or reddish brown. This unit contains both quartz and alkali feldspar (fig. 4) and is the only unit to do so. It also contains a grain or two of sphene per thin section.

AGE AND DISTRIBUTION OF HU-PWI RHYODACITE

All three formal members of the Hu-pwi Rhyodacite have been dated by K-Ar methods (table 2). Exclusive of a plagioclase date, these ages are in good agreement and indicate that the formation is 22.6–23.3 m.y. old.

The Nugent Tuff and Poinsettia Tuff Members resemble each other so closely that in isolated outcrops one cannot be certain which member is present. Because of this close similarity, the distribution of Hu-pwi Rhyodacite shown in figure 3 encompasses both members. The Nugent Tuff Member has been recognized with certainty only in the northern Gabbs Valley and Gillis Ranges, and, as previously mentioned, the local abrupt thinning of the member in the Gillis Range together with its absence in the northern Wassuk Range (E. C. Bingler, oral commun., 1975) suggest that the Nugent Member was much more restricted areally than the older tuff units and, perhaps, the younger Poinsettia Tuff Member as well. The possibility exists that the Nugent Member was confined entirely to a depression that formed in response to the extrusion of the older tuffs. According to J. M. Proffett (oral commun., 1975), however, the tuff and breccia of Gallagher Pass (in Proffett and Proffett, 1976) in the Singatse Range could correlate with either the Nugent Tuff Member or the Poinsettia Tuff Member. Therefore, the possibility cannot be ruled out that the Nugent Tuff Member is more widespread than we have suggested.

TUFF OF COPPER MOUNTAIN

The tuff of Copper Mountain is informally named for exposures about 0.8 km east of Copper Mountain (fig. 2, CM). The best exposure is the first prominent north-striking fault block east of Copper Mountain. This block is the most westerly of a series of repeated fault blocks that are controlled by west-dipping normal or oblique-slip faults that dip 15°–45° W. The tuff of Copper Mountain in each block dips 50°–80° E. In the first fault block the tuff is very steeply dipping above a fault that dips about 15° W. and that places the Copper Mountain on the underlying quartz and alkali feldspar cooling unit of the Poinsettia Tuff Member of the Hu-pwi Rhyodacite. The basal vitrophyre, although dipping on the average about 80° E., is so repetitiously repeated by faults, each fault having less than a meter or so of displacement, that it appears from a distance to be dipping very gently. The tuff of Copper Mountain in this locale is capped by a small outlier of lava of Mount Ferguson. This lava, however, is detached at the base and the former top of the tuff is missing either as a result of faulting or prelava erosion. Despite the complex faulting, the tuff of Copper Mountain retains a part of the nonwelded base beneath the steeply dipping vitrophyre.

The tuff of Copper Mountain is a simple cooling unit of quartz latite. In various fault blocks in the vicinity of Copper Mountain, 60 meters to as much as 100 m of tuff are preserved. The tuff is light gray on fresh fracture and weathers brownish gray and brown. It is characterized by a persistent black vitrophyre, about 3 m thick, at the base, which overlies nonwelded to partially welded light-gray tuff that is at least 6 m thick. The tuff above the vitrophyre is moderately to densely welded and devitrified. Pumice fragments are conspicuous from base to top.

The volume of phenocrysts ranges from about 28 to 44 percent. Quartz grains constitute from 3 to 25 percent of the total phenocrysts. They are as much as 5 mm long and are moderately resorbed and embayed. The tuff carries abundant accessory sphene. These grains are visible with a hand lens, and as many as 15 grains occur in a single thin section. The accessory mineral is less abundant in the middle part of the exposure than at the base and top. The abundance of sphene distinguishes the Copper Mountain from all other tuffs in the region; without this accessory it could easily be mistaken for the Singatse Tuff.

Like the Singatse Tuff, the ferromagnesian minerals in the tuff of Copper Mountain are principally biotite and hornblende but clinopyroxene is ubiquitous and as abundant as hornblende in some thin sections. The ferromagnesian minerals constitute from 11 percent to as much as 20 percent of the total phenocrysts.

In most exposures the tuff of Copper Mountain does not display a pronounced tendency to become more silicic upwards. In general, ferromagnesian minerals decline from base to uppermost exposures, but there is no corresponding increase of quartz and alkali feldspar. In the fault block near Copper Mountain, quartz actually diminishes in volume upwards from about 14 percent in the basal vitrophyre to about 3 percent in the topmost exposure. Alkali feldspar and plagioclase fluctuate in volume, showing no systematic variations. Three kilometers east of Copper Mountain, however, rock at the top of the exposure is rich in quartz and alkali feldspar, and we infer that the rock there includes ash-flow tuff that was removed by erosion or faulting in the fault blocks nearer Copper Mountain. Rock having this quartz- and alkali feldspar-rich mineralogy was sampled for chemical analysis in Gabbs Valley on the east flank of the northern Gabbs Valley Range (table 3, sample H). According to the classification of Young (see p. 18), the rock is rhyolite in composition.

The tuff of Copper Mountain is exposed discontinuously beneath the lavas of Mount Ferguson in several fault blocks starting from about the latitude of Poinsettia Spring to north and northeast of the ghost town of Rawhide (fig. 2). It is poorly exposed in the Pilot Cone–Rawhide area, but it is well exposed in the Monte Christo Mountains along the west flank of Gabbs Valley (fig. 2). In the exposures northeast of the Rawhide area and in the Monte Christo Mountains, the tuff of Copper Mountain rests directly on rhyolite tuffs of Gabbs Valley, which, in turn, rest directly on Mesozoic rocks. The absence of all other tuffs, which are thick and widespread in the Gabbs Valley and Gillis Ranges to the west, must be due to: (1) original deposition of those tuffs within a northwest-trending trough that lay southwest of the Monte Christo–Gabbs Valley area and (2) juxtaposition of two separate and distinct ash-flow fields by the right lateral strike-slip faults. The tuff of Copper Mountain, which overlaps both fields, must have been extruded after the northwest-trending trough was more or less filled, and, in addition, must have had a more northerly source than the other tuffs described in this report. According to E. C. Bingler (1978), the tuff of Copper Mountain probably correlates with his Santiago Canyon Tuff, which is thick and widespread in the Carson City–Silver City area.

There is no evidence of extensive erosion between the Poinsettia Member and the tuff of Copper Mountain. The two units are of similar age (about 23 m.y.) because intermediate lava that directly overlies the Copper Mountain has been dated at about 22 m.y. (table 2, samples 2384–1P and 2384–1H). The eruption of the tuff of Copper Mountain marked the end of main ash-flow tuff volcanism that persisted in the region for a period of 3–4 m.y.

ROCKS OF MOUNT FERGUSON

Although lava of intermediate composition makes up most strata exposed in and adjacent to Mount Ferguson (fig. 2), and is the sole lithology in many places, other rock types are locally important. These include the tuff of Redrock Canyon, a densely to partially welded ash-flow tuff that appears to be confined to the Gabbs Valley Range, and a thick sequence of tuffaceous sedimentary rocks including landslipped debris and rock that is principally lacustrine in origin. The lacustrine strata suggest subsidence possibly related to ash-flow eruptions. The landslipped debris, on the other hand, probably reflects early movements along the strike-slip faults.

TUFF OF REDROCK CANYON

The distinctive ash-flow tuff in the Mount Ferguson sequence is here called informally the tuff of Redrock Canyon. The tuff is a compound cooling unit that may be as much as 300 m thick. It is locally exposed from the vicinity of Petrified Spring northwestward nearly to the latitude of Poinsettia Spring (fig. 2). The tuff rests unconformably on a great variety of rocks. Near Petrified Spring it rests, in places, on Singatse Tuff and Blue Sphinx Tuff. One kilometer to the north it rests on coarse landslipped debris; 3 km farther north it rests on lavas of intermediate composition that intertongue with debris and are typical of the Mount Ferguson pile; near Redrock Canyon (fig. 2) tuff of Redrock Canyon rests on debris that includes fragments of Poinsettia Tuff Member.

The tuff of Redrock Canyon, although apparently of local extent, is nevertheless an interesting unit because it combines the characteristics of the Mickey Pass and Blue Sphinx Tuffs. The basal 50–70 m is densely to partially welded, dark-brown rhyodacite that is rich in lithic fragments and that contains as much as 25 percent ferromagnesian phenocrysts. These include 5–13 percent of clinopyroxene and orthopyroxene, a trace to 6 percent of biotite, and a trace to 6 percent of hornblende. The rhyodacite contains only a few grains of quartz and alkali feldspar per thin section, and the quartz is not noticeably embayed. The rhyodacite contains abundant plagioclase, consisting of about equal amounts of fresh euhedral crystals and extremely embayed and poikilitic crystals. These last are virtual sieves that are charged with glass. The initial flows of the rhyodacite were apparently very hot because a persistent homogeneous black vitrophyre occurs at the base, and in several places the underlying tuffaceous sedimentary rocks are baked to a depth of 1 m or more. A characteristic feature of the rhyodacite that proved to be a valuable criterion for identification in the field is the tendency of the pumice in the basal vitrophyre and the immediately overlying devitrified rock to weather to pits.

The rhyodacite grades upward to partially welded, brownish-gray quartz latite that also is rich in lithic fragments; however, in contrast to the rhyodacite, whose fragments are almost exclusively lava of intermediate composition, the fragments in the quartz latite include numerous clasts of Mesozoic granite, some of which are as much as 3 m long.

The quartz grains in the quartz latite are as large as 7 mm; the grains larger than about 2 mm (fig. 12) are as embayed and resorbed as those in the Blue Sphinx, but most grains smaller than about 2 mm show very little embayment. The quartz latite contains an occasional grain of sphene per thin section, but sphene is absent in the rhyodacite. This absence, together with a different assemblage of lithic fragments, suggests that the quartz latite and rhyodacite were erupted from different parts of the magma chamber as well as from different levels of the chamber.

Biotite from the tuff of Redrock Canyon yields an age of 23.5 ±0.6 m.y. (table 2).

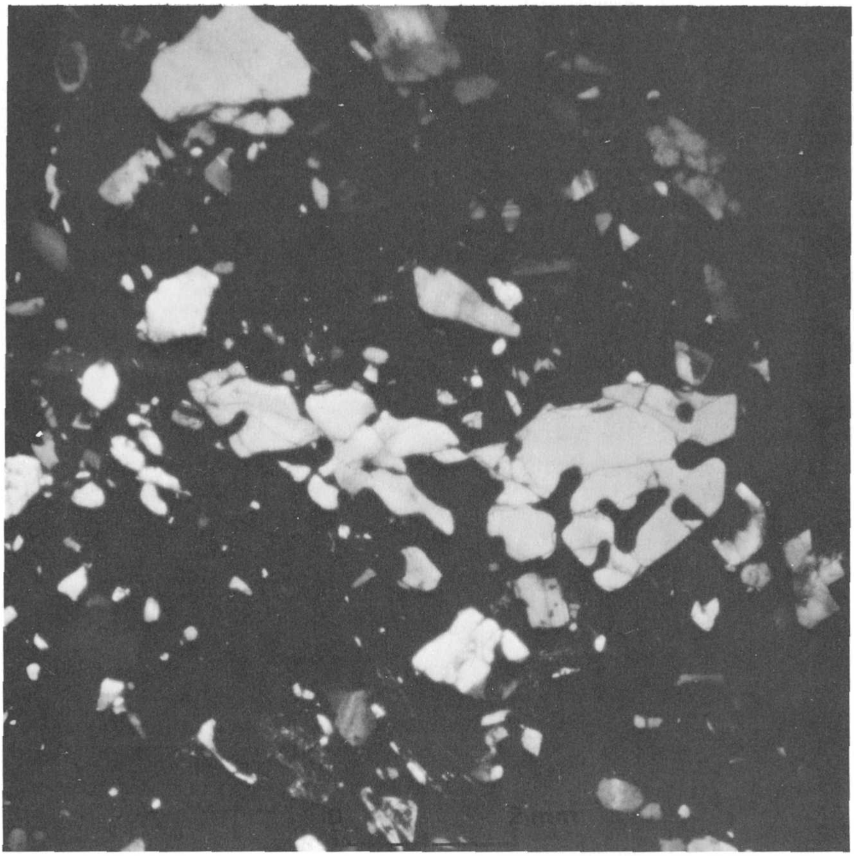

FIGURE 12.—Photomicrograph of tuff of Redrock Canyon showing shattered, intensely resorbed quartz phenocryst. The three parts of the grain are in optical continuity. Crossed nicols.

TUFFACEOUS SEDIMENTARY ROCKS AND LANDSLIPPED DEBRIS

Tuffaceous sedimentary rocks and landslipped debris intercalated with lavas of intermediate composition crop out locally beneath the tuff of Redrock Canyon. These rocks appear to be confined to the same general area as the tuff of Redrock Canyon. The landslipped debris, however, persists northward for several kilometers beyond the outcrops of sedimentary rocks and the tuff of Redrock Canyon. The debris is restricted to a zone between the two easternmost strike-slip faults, and we infer that it reflects early movements along these faults.

The sedimentary rocks are mostly thin bedded and include tuffaceous lacustrine siltstones, reworked air-fall tuff, and conglomerate. The beds average about 8 cm in thickness and are pastel shades of yellow, green, and gray. The bedded sequence exclusive of landslipped debris is as much as 200 m thick. The debris consists of well-cemented, unsorted boulders, cobbles, and pebbles of lava of intermediate composition and welded tuff, locally including the Poinsettia Tuff Member of the Hu-pwi Rhyodacite. Most fragments are angular to subangular and undoubtedly include landslide material. The debris is not continuous and varies considerably in thickness. In places, it is at least several tens of meters thick.

LAVAS OF INTERMEDIATE COMPOSITION

In the vicinity of Mount Ferguson, lavas that range in composition from trachyandesite or latite to quartz latite crop out beneath, within, and above the tuffs and sedimentary rocks previously described. These lavas, although similar to the localized piles (fig. 1) that we infer were fed from the same magma source as the ash-flow tuffs, are so regional in extent that, with the possible exception of the oldest flows that predate the tuff of Redrock Canyon, they cannot be genetically related to the ash-flow tuffs. The lavas were erupted more or less simultaneously over a large part of the Great Basin and adjacent parts of the Sierra Nevada. (See, for example, Proffett and Proffett, 1976; Anderson and Ekren, 1968; Gilbert and Reynolds, 1973.)

The lavas in detail show a considerable range in color, but they present an overall aspect of somber gray. Despite their hardness they tend to weather to rounded ridges and slopes. This is especially true of flow-brecciated rock. The latites that border on andesite in composition are the most competent rocks and have the greatest tendency to weather to steep slopes and cliffs. They are dark gray on fresh fracture and weather dark brownish gray and black. The rocks are porphyritic and the phenocrysts are set in a pilotaxitic groundmass. The principal ferromagnesian phenocrysts are clinopyroxene and orthopyroxene. The occurrence of both minerals is generally apparent in hand specimen because the clinopyroxene is green and the orthopyroxene is brown—commonly cinnamon brown. Phenocrysts of labradorite rarely exceed a few millimeters in length and these are mostly dark and indistinct in hand specimen. The latite lavas are not continuous over great distances and they are not confined to any particular horizon within the pile. They are estimated to compose less than 50 percent of the overall volume of the lava sequence.

Rocks considered to be rhyodacite and quartz latite (pending confirmation by chemical analyses) show all gradations from near latite on the one hand to near rhyolite on the other. All rocks are porphyritic and contain pilotaxitic groundmasses. Some flows contain quartz phenocrysts; none contain alkali feldspar phenocrysts. The dominant ferromagnesian mineral is hornblende, which may be as large as 2.5 cm by 4 mm in some flows. Nearly all rocks examined in thin section contain clinopyroxene and orthopyroxene. Pyroxene is nearly as abundant as hornblende in some flows; in others it constitutes only a tiny fraction of the ferromagnesian assemblage. Some rocks, which we consider to be quartz latite in composition, contain abundant biotite. Phenocryst bar graphs of several lavas are shown in figure 4.

Available data indicate a considerable range in age for the lavas of Mount Ferguson. A basal lava that rests on the tuff of Copper Mountain near the mouth of Nugent Wash in T. 11 N., R. 32 E., yielded an age of 22.5±0.6 m.y. on hornblende and 21.4±0.6 m.y. on plagioclase. A sample of one of the youngest flows on the eastern flank of Mount Ferguson yielded an age of 15.0±0.5 m.y. on plagioclase (table 2).

INTRUSIVE ROCKS

Intrusive dikes, plugs, and small stocks occur in several localities in the Gabbs Valley and Gillis Ranges. These rocks range in composition from basalt to rhyolite. Most of the larger masses are of intermediate composition; hornblende is the principal ferromagnesian mineral. Textures of the intermediate rocks vary considerably. Some rocks of rhyodacitic composition are conspicuously porphyritic with phenocrysts as long as 1 cm that are set in holocrystalline but very fine grained groundmasses. Other rocks of dioritic composition are equigranular but mostly fine grained.

A K-Ar age determination on an aphyric basaltic andesite or black latite that was intruded along one of the strike-slip faults in the Gabbs Valley Range yielded an age of 5.8±0.2 m.y. on whole rock. Biotite from a rhyolite dike in the Gabbs Valley Range and from rhyolite vent breccia in the Garfield Hills yielded ages of 19.2±0.7 m.y. and 18.1±0.6 m.y., respectively (table 2).

PRELIMINARY PETROLOGY AND VOLCANO-TECTONIC ORIGIN OF THE THICK VOLCANIC SECTION

The marked petrographic similarity of ash-flow tuffs and intercalated lava flows of intermediate composition in the Gabbs Valley and Gillis Ranges suggests that many, if not most, volcanic units were derived from a common magma source. A single substratum or large magma chamber probably was the source of nearly all the rocks. If present, this chamber would be located somewhere between Yerington and the northern Gabbs Valley Range, because the strata are thickest in this region and the region encompasses the center of distribution of the various ash-flow sheets (fig. 3). Mapping of this area, however, by ourselves, John Proffett, E. C. Bingler, and H. F. Bonham, Jr., failed to disclose a cauldron complex or any structures that can logically be interpreted as cauldrons. All of the ranges in the area expose large outcrops of Mesozoic rocks and the basins that are sufficiently large to partly conceal a caldera—for example, Gabbs Valley and Walker Lake—either lie outside the tuff distribution area or they are bounded by such extensive outcrops of Mesozoic rocks that a concealed center within the valleys appears extremely unlikely.

Because of deep erosion that stripped the volcanic rocks from large parts of the ranges, it is difficult to calculate the volumes of the tuff sheets. Assuming average thicknesses of 100 m for the major ash-flow sheets whose distributions are plotted in figure 3, the Guild Mine Member of the Mickey Pass Tuff has a volume of 1,100 km^3; the Singatse has about the same; and the combined Hu-pwi Rhyodacite and the Blue Sphinx Tuff somewhat more. These calculations are rough, and for one reason or another these volumes may be excessive. Even allowing for errors, however, the volumes must be enormous, and had cauldrons formed they would be huge—either very deep or extremely broad and of such magnitude that if they were bounded by arcuate faults they should be easily discerned. We believe that instead of fault-bounded cauldrons, a broad saucer-shaped volcano-tectonic depression developed that was elongated in a northwest direction and centered on what is now the northern parts of the Gabbs Valley, Wassuk, and Gillis Ranges. Within this depression various broad "sags" or basins developed that were, in part, fault controlled. The main evidence for the broad depression is the presence of composite sections consisting of as much as 2,000 m of ash-flow tuff and 1,000 m or more of lava; the evidence for local basins is the presence of lake sediments at two horizons within the ash-flow tuff and lava sections. The depression and local basins must have developed concomitantly with the eruption of the volcanic rocks. The present-day outcrop pattern of the tuff units (fig. 2) suggests that the younger units were increasingly confined to the more central part of the sagging depression. The depression was subsequently segmented by northwest-trending strike-slip faults, and the segments were shifted in a right-lateral sense.

The apparent lack of a fault-bounded cauldron complex in the source area for tuffs and lavas whose combined volume exceeds many hundreds of cubic kilometers must be explained. We believe that the logical explanation for the lack of such a complex is that the rocks were erupted from depths that were too great to allow fault-bounded calderas to form. That this is not an unreasonable concept is shown by analogy with results of underground nuclear testing at the Nevada Test Site. Explosion of a nuclear device at any depth underground creates a cavity. Where the device is at shallow depth a subsidence crater forms at the surface above the underground cavity within a few minutes or a few hours after the explosion. Where the device is exploded at deeper levels no surface subsidence crater forms (Houser, 1970), but sags develop over some of the deep sites. The extrapolation of these observed facts to caldera mechanics has been suggested by various geologists who have worked at the Nevada Test Site, notably by K. A. Sargent (oral commun., 1977).

Three features are present in the tuffs of the Gabbs Valley and Gillis Ranges that we believe suggest eruption from a deeply buried source. One feature is the presence of strongly resorbed quartz and feldspar phenocrysts, another is the virtual lack of compositional zoning in the Hu-pwi Rhyodacite, and a third feature is the unusual reverse zoning exhibited by formations in the Benton Spring Group.

SIGNIFICANCE OF PHENOCRYST RESORPTION

The resorption of phenocrysts indicates that the magma was undersaturated with respect to water (Robertson and Wyllie, 1971; Steiner and others, 1975; Lipman, 1966; and Noble, 1970). The undersaturation, in turn, indicates that the magma chamber was positioned at a deep water-deficient level of the crust. Noble (1970) pointed out that resorption in intratelluric crystals takes place if pressure is reduced when magma is undersaturated with respect to water, but not when the magma is water saturated. He perhaps was the first to consider the possibility that ash-flow tuffs containing strongly resorbed phenocrysts may have been derived from great depths, and, thus, that their eruption may not be accompanied by caldera collapse.

The presence of resorbed phenocrysts alone, however, cannot be used as bona fide evidence of great depth of eruption because resorbed phenocrysts occur in rocks that were erupted from chambers at shallow depths. The tuffs from the Timber Mountain caldera, for example, that were erupted from the resurged caldera contain moderately resorbed quartz phenocrysts (Byers and others, 1976).

Some of the lavas that were erupted from the Platoro caldera (Lipman, 1975) have strongly resorbed quartz phenocrysts, as do some of the lavas that were erupted from cauldrons on the Mogollon Plateau (Rhodes, 1976). Some cauldron-forming tuffs with resorbed phenocrysts apparently were derived from magmas that began to crystallize at deep water-undersaturated levels and then moved upward to spend considerable time in shallow depth chambers. This has been carefully documented in the Superstition-Superior volcanic area of Arizona by Stuckless and O'Neill (1973): $^{87}Sr/^{86}Sr$ of the tuffs and the associated mafic and silicic lavas in the Superstition-Superior area indicate that the parent magma was derived below the base of the Precambrian granitic crust—probably at depths greater than 22 km—and they inferred that crystallization began at those depths. Their studies further showed, however, that two of the ash-flow tuffs and one lava are greatly enriched in ^{87}Sr and have largely reequilibrated under P-T (pressure-temperature) conditions of a shallow magma chamber. Presumably, the eruption of tuffs from this environment caused the development of Superstition-Superior cauldron complex (Sheridan and others, 1970; Peterson, 1968). Apparently, therefore, resorbed phenocrysts may or may not be indicative of deep (non-caldera forming) eruptions and the vital factor is whether or not the magma moved into a shallow-seated "halfway house" prior to tuff eruptions. We believe that in the area of the Gabbs Valley and Gillis Ranges the magma probably did not reside for any lengthy periods at shallow depth because of the zoning relationships.

SIGNIFICANCE OF A VIRTUAL LACK OF COMPOSITIONAL ZONING IN THE HU-PWI RHYODACITE AND REVERSE ZONING IN TUFFS OF THE BENTON SPRING GROUP

Compositional zoning of ash flows from shallow-seated chambers generally shows a simple upward succession from high-silica to low-silica rhyolite or from mafic-poor rhyolite to mafic-rich quartz latite (Byers and others, 1976; Lipman and others, 1966; Smith and Bailey, 1966). This vertical zoning in the ash flows is generally attributed to reflecting vertical compositional zoning caused by differentiation in the magma chamber—the first eruptions tapped the upper silica-rich levels of the chamber and subsequent eruptions tapped deeper, more mafic and less silicic levels.

The tuffs in the Gabbs Valley and Gillis Ranges do not show the compositional zoning characteristic of shallow-seated chambers. They either display no zoning (Hu-pwi Rhyodacite) or zoning that is the reverse of zoning characteristic of shallow chambers. The latter could be produced by a compositionally zoned chamber being tapped initially at a deep level and, as eruptions proceeded, at progressively higher levels; or by magma levels sinking to the level of the tap.

Although this theory is plausible, it seems unlikely that this mechanism could have occurred several times; further, it probably has little merit because of the likelihood that magma chambers are always tapped from the top or from the sides near the top. The top of the chamber at any depth is the part that is under the least confining pressure, and the immediately overlying rocks would certainly tend to be more fractured than the rocks on the flanks of the chamber. Different P-T conditions and chamber configurations in a deep chamber versus a shallow one must account for the differences in zoning.

Shallow-depth chambers are known to have domed overlying surface rocks prior to ash-flow eruptions (Christiansen and others, 1965; Smith and Bailey, 1968). Lipman (1966) suggested that resurgent doming would be geometrically improbable if the upper part of the magma chamber had the proportions of a thick cylinder. On the other hand, a magma chamber at great depth may have the shape of a thick cylinder; at least there would be less potential for a domical roof and less potential for a laccolithic shape because of greater confining pressures. Certainly, extensive vertical compositional zoning in a shallow chamber suggests that there may be an extensive floor.

Perhaps the deeper chambers are not extensively floored. Vertical zonation due to fractional crystallization would be disrupted by convection currents and new silicic melt flowing upward from the melting source. The rising melt probably would tend to occupy the central part of the chamber and press the early crystal fraction against the sides and top. In the case of the Hu-pwi Rhyodacite the eruptions in three broad stages (three members) were unable, until the very last gasp, to exhaust the copious rhyodacite magma concentrated at the top and sides of the chamber. In the case of the more voluminous Guild Mine Member the eruptions exhausted the rhyodacite melt and reached deeply into the siliceous rhyolite interior.

RELATIONSHIP OF VOLCANIC CENTER TO WALKER LANE

The Gabbs Valley Range–Gillis Range–Wassuk Range volcanic center is another volcanic source area that lies along Walker Lane. These volcanic centers to the southeast include Tonopah, Goldfield, Cactus Range, Stonewall Mountain, Mount Helen, Black Mountain, Silent Canyon, Timber Mountain–Oasis Valley, Calico Hills, and Wahmonie (Ekren and others, 1971; Christiansen and others, 1977). Centers occur on either side of the lane throughout the Great Basin but they occur in considerably greater numbers along the lane.

The Walker Lane throughout Nevada (fig. 2) is a broad zone 50–70 km wide that is marked by changes in range trends, structural and topographic discontinuities, several major right-lateral faults and oroclinal bends. Unlike the San Andreas fault zone, no single fault or closely alined fault zone can be mapped continuously throughout the lane (Christiansen and others, 1977). Conceivably, tensional fractures related to deep-seated right-lateral faulting tapped an already hot substratum under the thin crust of the Great Basin and could have localized the volcanic centers.

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REFERENCES CITED

Anderson, R. E., and Ekren, E. B., 1968, Widespread Miocene igneous rocks of intermediate composition, southern Nye County, Nevada, *in* E. B. Eckel, ed., Nevada Test Site: Geological Society of America Memoir 110, p. 57–63.

Bingler, E. C., 1973, Oligocene welded tuff sequence in the northern Wassuk Range, central-western Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 1, p. 12.

______1978, Abandonment of the Hartford Hill rhyolite tuff and new formation names for middle Tertiary ash-flow tuffs in the Carson City–Silver City area, Nevada: U.S. Geological Survey Bulletin 1457-D, 19 p.

Byers, F. M., Jr., Carr, W. J., Orkild, P. P., Quinlivan, W. D., and Sargent, K. A., 1976, Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley caldera complex, southern Nevada: U.S. Geological Survey Professional Paper 919, 70 p.

Christiansen, R. L., Lipman, P. W., Orkild, P. P., and Byers, F. M., Jr., 1965, Structure of the Timber Mountain caldera, southern Nevada, and its relation to basin-range structure, *in* Geological Survey Research 1965: U.S. Geological Survey Professional Paper 525-B, p. B43–B48.

Christiansen, R. L., Lipman, P. W., Carr, W. J., Byers, F. M., Jr., Orkild, P. P., and Sargent, K. A., 1977, Timber Mountain-Oasis Valley caldera complex of southern Nevada: Geological Society of America Bulletin, v. 88, no. 7, p. 943–959.

Dalrymple, G. B., and Lanphere, M. A., 1969, Potassium-argon dating—Principles, techniques, and applications to geochronology: San Francisco, W. H. Freeman and Co., 258 p.

Ekren, E. B., Anderson, R. E., Rogers, C. L., and Noble, D. C., 1971, Geology of northern Nellis Air Force Base Bombing and Gunnery Range, Nye County, Nevada: U.S. Geological Survey Professional Paper 651, 91 p.

Ekren, E. B., and Byers, F. M., Jr., 1976, Ash-flow fissure vent in west-central Nevada: Geology, v. 4, no. 4, p. 247-251.

Evernden, J. F., and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Ferguson, H. G., and Muller, S. W., 1949, Structural geology of the Hawthorne and Tonopah quadrangles, Nevada: U.S. Geological Survey Professional Paper 216, 55 p.

Gilbert, C. M., and Reynolds, M. W., 1973, Character and chronology of basin development, western margin of the Basin and Range province: Geological Society of America Bulletin, v. 84, p. 2489-2509.

Gumper, F., and Scholz, C., 1971, Microseimicity and tectonics of the Nevada seismic zone: Seismological Society of America Bulletin, v. 61, no. 5, p. 1413-1432.

Hardyman, R. F., Ekren, E. B., and Byers, F. M., Jr., 1975, Cenozoic strike-slip, normal, and detachment faults in northern part of Walker Lane, west-central Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 7, no. 7, p. 1100.

Houser, F. N., 1970, A summary of information and ideas regarding sinks and collapse, Nevada Test Site: Available from U.S. Dept. of Commerce, National Technical Information Service, Springfield, Va. 22161, as Report USGS-474-41, 129 p.

Ingamells, C. O., 1970, Lithium metaborate flux in silicate analysis [with French and German summaries]: Analytica Chimica Acta, v. 52, p. 323-334.

Lanphere, M. A., and Reed, B. L., 1973, Timing of Mesozoic and Cenozoic plutonic events in circum-Pacific North America: Geological Society of America Bulletin, v. 84, p. 3773-3782.

Lipman, P. W., 1966, Water pressures during differentiation and crystallization of some ash-flow magmas from southern Nevada: American Journal of Science, v. 264, no. 10, p. 810-826.

______1975, Evolution of the Platoro caldera complex and related volcanic rocks, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 852, 128 p.

Lipman, P. W., Christiansen, R. L., and O'Connor, J. T., 1966, A compositionally zoned ash-flow sheet in southern Nevada: U.S. Geological Survey Professional Paper 524-F, 47 p.

Locke, A., Billingsley, P., and Mayo, E. B., 1940, Sierra Nevada tectonic pattern: Geological Society of America Bulletin, v. 51, p. 513-539.

Muller, S. W., and Ferguson, H. G., 1939, Mesozoic stratigraphy of the Hawthorne and Tonopah quadrangles, Nevada: Geological Society of America Bulletin, v. 50, p. 1573-1624.

Neilsen, R. L., 1965, Right-lateral strike-slip faulting in the Walker Lane, west-central Nevada: Geological Society of America Bulletin, v. 76, p. 1301-1308.

Noble, D. C., 1970, Significance of phenocryst resorption for the intratelluric crystallization and eruptive history of silicic pyroclastic rocks [abs.]: Geological Society of America Abstracts with Programs, v. 2, no. 2, p. 125.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geological Society of America Bulletin, v. 65, no. 10, p. 1007-1032.

Peterson, D. W., 1968, Zoned ash-flow sheet in the region around Superior, Arizona, *in* Southern Arizona Guidebook 3—Geological Society of America Cordilleran Section, 64th Annual Meeting, Tucson, 1968: Arizona Geological Society, p. 215–222.
Proffett, J. M., Jr., and Proffett, B. H., 1976, Stratigraphy of the Tertiary ash-flow tuffs in the Yerington district, Nevada: Nevada Bureau of Mines and Geology Report 27, 28 p.
Rhodes, R. C., 1976, Petrologic framework of the Mogollon Plateau volcanic ring complex, New Mexico—Surface expression of a major batholith: New Mexico Geological Society Special Publication No. 5, p. 103–112.
Robertson, J. K., and Wyllie, P. J., 1971, Rock-water systems, with special reference to the water-deficient region: American Journal of Science, v. 271, p. 252–277.
Ross, D. C., 1961, Geology and mineral deposits of Mineral County, Nevada: Nevada Bureau of Mines Bulletin 58, 98 p.
Ryall, A., Slemmons, D. B., and Gedney, L. D., 1966, Seismicity, tectonism, and surface faulting in the western United States during historic time: Seismological Society of America Bulletin, v. 56, no. 5, p. 1105–1135.
Segerstrom, K., and Young, E. J., 1972, General geology of the Hahns Peak and Farwell Mountain quadrangles, Routt County, Colorado, *with a discussion of* Upper Triassic and pre-Morrison Jurassic rocks, by G. N. Pipiringos: U.S. Geological Survey Bulletin 1349, 63 p.
Sheridan, M. F., Stuckless, J. S., and Fodor, R. V., 1970, A Tertiary silicic cauldron complex at the northern margin of the Basin and Range province, central Arizona, U.S.A.: Bulletin of Volcanology, v. 34, no. 3, p. 649–662. [1971]
Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 58 p.
Slemmons, D. B., 1967, Pliocene and Quaternary crustal movements of the Basin and Range province, U.S.A., *in* Sea level changes and crustal movements of the Pacific—Eleventh Pacific Scientific Congress, Tokyo, 1966, Symposium 19: Osaka City University Journal of Geosciences, v. 10, p. 91–103.
Smith, R. L., 1960, Zones and zonal variations in welded ash flows: U.S. Geological Survey Professional Paper 354-F, p. 149–159. [1961]
Smith, R. L., and Bailey, R. A., 1966, The Bandelier tuff—A study of ash-flow eruption cycles from zonal magma chanbers: Bulletin of Volcanology, v. 29, p. 83–103.
______1968, Resurgent cauldrons, *in* R. R. Coats and others, eds., Studies in volcanology [Williams volume]: Geological Society of America Memoir 116, p. 613–662.
Steiner, J. C., Jahns, R. H., and Luth, W. C., 1975, Crystallization of alkali feldspar and quartz in the haplogranite system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O at 4 kb: Geological Society of America Bulletin, v. 86, p. 83–97.
Stewart, J. H., and Carlson, J. E., compilers, 1974, Preliminary geologic map of Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-609.
Stuckless, J. S., and O'Neill, J. R., 1973, Petrogenesis of the Superstition-Superior volcanic area as inferred from strontium- and oxygen-isotope studies: Geological Society of America Bulletin, v. 84, p. 1987–1997.

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