TABLE 1. Chemical analyses and norms of dark-colored lavas from east-central Lander County.

Map No. (fig. 7)	1	2	4	3	8	5	7	6	Average 2–8	Nockolds' (1954) average dacite and dacite-obsidian	Chayes' (1969) average andesite of U.S.	Taylor's (1969, p. 60) high-K andesite
Field No.	13125–69J	15978–12	14652–1	14650–1	15891–2	15891–3	15891–15	15888–8				
Location	Toiyabe Range	Simpson Park Mountains						Toiyabe Range				
Chemical Analyses (weight percent)												
SiO_2	68.5	64.4	63.0	61.9	61.7	61.2	60.4	60.0	61.8	63.58	59.78	60.8
Al_2O_3	13.2	16.2	18.4	17.0	17.3	17.2	17.2	17.2	17.2	16.67	17.19	16.8
Fe_2O_3	4.6	2.9	2.7	3.1	4.2	4.9	1.6	2.2	3.1	2.24	2.45	5.13
FeO	.84	1.2	1.1	2.2	.68	.68	4.6	3.4	2.0	3.0	3.65	
MgO	.57	1.6	.93	2.1	.98	1.3	2.5	3.0	1.7	2.12	3.17	2.15
CaO	2.3	3.5	4.7	4.3	4.6	4.5	5.8	6.0	4.7	5.53	6.06	5.60
Na_2O	2.5	3.2	3.0	3.4	3.3	3.5	2.7	2.8	3.1	3.98	3.96	4.10
K_2O	4.6	3.6	3.9	3.3	3.1	3.0	2.4	2.3	3.1	1.40	1.67	3.25
H_2O-	.56	1.2	.52	.46	1.4	1.4	.21	.34	.79	--	.87	--
H_2O+	1.0	.60	.68	.54	1.1	.80	1.0	1.1	.83	.56		--
TiO_2	.88	.17	.77	.86	1.0	.93	1.2	1.0	.85	.64	.85	.77
P_2O_5	.26	.04	.27	.32	.32	.39	.29	.31	.27	.56	.23	--
MnO	.04	.02	.06	.15	.04	.05	.06	.08	.07	.11	--	--
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	--	--	--
C.I.P.W. norms												
Q	31.43	22.62	20.00	18.04	20.36	18.99	17.86	17.25				
OR	27.22	21.56	23.03	19.57	18.37	17.75	14.18	13.62				
AB	21.18	27.45	25.37	28.87	27.99	29.65	22.85	23.75				
AN	9.53	17.14	21.35	19.12	20.59	19.61	26.69	27.62				
WO	--	--	--	--	--	--	--	--				
EN	1.42	4.04	2.32	5.25	2.45	3.24	6.33	7.49				
FS	--	--	--	.34	--	--	5.2	2.93				
IL	1.67	.33	1.46	1.64	1.53	1.55	2.2	1.9				
MT	.29	3.49	1.51	4.51	--	--	2.32	3.20				
HM	4.41	.54	1.66	--	4.21	4.91	--	--				
AP	.62	.10	.64	.76	.7	.93	.69	.74				
C	.62	.85	1.41	.86	.99	1.02	.38	.01				

from: NBMG Bull 88

Table 2. Chemical analyses and norms of densely welded Caetano Tuff.

Map No. (fig. 11)	1	2	3
Field No.	6517-2J	10427-5	BM-1
Location	Carico Lake Valley	N. Fish Creek Mountains	E. edge of Battle Mountain
	Chemical analyses		
SiO_2	71.2	70.7	70.3
Al_2O_3	14.6	14.2	14.4
Fe_2O_3	1.7	1.4	1.1
FeO	.34	.56	.90
MgO	.32	.59	.64
CaO	1.7	1.8	1.5
Na_2O	3.3	4.2	3.8
K_2O	4.8	4.3	4.7
H_2O-	.22	.82	.22
H_2O+	1.4	.88	2.0
TiO_2	.25	.34	.31
P_2O_5	.06	.06	.05
MnO	.02	.04	.06
CO_2	<.05	<.05	<.05
	C.I.P.W. norms		
Q	29.71	25.57	26.03
OR	28.39	25.44	27.78
AB	27.95	35.58	32.16
AN	8.05	7.20	7.12
WO	--	.56	---
EN	.80	1.47	1.59
FS	---	---	.34
IL	.48	.65	.59
MT	.44	.95	1.56
AP	.14	.14	.12
C	1.03	--	.45

Mountains. A few isolated outcrops occur about 5 miles from the southern edge of these mountains in the northern Augusta Mountains and northern part of Antelope Valley. Because the ash flows are confined to the Fish Creek Mountains, their source is considered to be within the boundary of that range; its thickness and distribution patterns support this conclusion. Tectonic features suggestive of caldera structure that formed on eruption of the ash flow are present within this body of tuff.

The Fish Creek Mountains Tuff is a composite ash-flow sheet (terminology of Smith, 1960) consisting of at least two ash flows separated by a complete cooling break, and many other ash flows separated by partial cooling breaks. All cooling breaks, partial or complete, can be traced for distances varying from a few hundred feet to several miles, but they ultimately disappear laterally and the units merge. The complete cooling break is between a lower unit characterized by the occurrence of abundant but variable lithic fragments and an upper unit characterized by absence of these fragments. Around the margins of the Fish Creek Mountains where the ash-flow sheet thins, a pronounced horizontal layering is developed. The layers of identical densely welded tuff are defined by horizontal joints or partings caused by partial cooling breaks. The welded tuff in this area is cut by vertical columnar joints that pass through all units and across the horizontal joints, suggesting that the entire ash-flow sheet cooled at the same time. Radiometric ages and remanent magnetization directions determined at different places within the ash flow support the conclusion that cooling was nearly simultaneous throughout the tuff body (McKee, 1970). In the south-central Fish Creek Mountains, where the welded tuff is thickest (3,000 feet or more), horizontal layering of the ash flow has not developed. Here it is a massive uniform rock, cut in places by columnar joints and characterized by large zones of alteration and what seem to be numerous faults. This core area of altered and structurally chaotic rock contrasts strongly with the layered marginal portions of the ash flow.

Petrology and chemistry. The Fish Creek Mountains Tuff is pink to light-gray, crystal-rich rock that is generally structureless and rarely shows eutaxitic features except in thin section or on wetted polished surfaces. Most of it is densely welded. It contains 30 to 50 percent phenocrysts of smoky quartz and sanidine in a groundmass of devitrified glass. Lithic fragments occur in places and one cooling unit is characterized by local accumulations of volcanic rock fragments which make up as much as 25 percent of the rock at its nonwelded base. This unit becomes progressively more welded upward; near the top, where most densely welded, it contains only a scattering of lithic fragments.

Chemical analyses show that the tuff is a rhyolite, about 74 percent SiO_2, 13 percent Al_2O_3, 1 percent total iron, 0.14 percent MgO, 0.75 percent CaO, and 8.5 percent total alkalies (McKee, 1970). The composition is very close to the average calc-alkali rhyolite of Nockolds (1954), compared in table 4 with an average of two chemical analyses taken from McKee (1970, table 3).

Age. The Fish Creek Mountains Tuff is considered to be early Miocene on the basis of radiometric ages (McKee, 1970). Three K-Ar and two fission-track dates determined on mineral separates from specimens collected at different places within the Fish Creek Mountains give an average age of 24.3±0.7 m.y., which is considered Miocene (Harland and others, 1964).

Bates Mountain Tuff

The Bates Mountain Tuff (Stewart and McKee, 1968a; McKee, 1968d) is the most widespread Tertiary formation in Lander County (fig. 15). Here this ash-flow sheet crops out in a belt extending northwestward from the Toquima

TABLE 4. Average of two analyses of Fish Creek Mountains Tuff. (Tuff compared with the average calc-alkali rhyolite and rhyolite obsidian of Nockolds (1954))

	Average of two analyses of Fish Creek Mountains Tuff (McKee, 1970)	Average calc-alkali rhyolite and rhyolite obsidian of Nockolds (1954)
SiO_2	74.6	73.66
Al_2O_3	12.9	13.45
Fe_2O_3	.97	1.25
FeO	.22	.75
MgO	.13	.32
CaO	.73	1.13
Na_2O	3.8	2.99
K_2O	5.2	5.35
H_2O+	.53	.78
H_2O-	.56	--
TiO_2	.16	.22

units a very small amount of biotite. A detailed petrographic description of the cooling units is given by Sargent and McKee (1969). One of the upper units is distinctive by the presence of ubiquitous gas cavities. This unit, informally called the "swiss cheese" unit, is the most widespread ash flow and the most easily recognized in Lander County and elsewhere.

Chemical analyses of fine samples of Bates Mountain Tuff from densely welded, devitrified parts of three cooling units show these ash flows to be rhyolite (table 5) and all plot within the rhyolite field in the classification of O'Connor (1965) based on normative Or, Ab, and An (fig. 16).

Age. The Bates Mountain Tuff is of Miocene age (McKee and Stewart, 1971, p. B15). Ten radiometric ages have been determined on samples of Bates Mountain Tuff, seven from Lander County and three from localities to the east. These ages, K-Ar, one fission track, have been determined on the upper and lower cooling units; they represent complete geographic coverage of the formation. The upper cooling unit in Lander County, found only in the Toquima Range, is significantly younger than the others; its distribution suggests that it is an unrelated ash-flow sheet. In this report it is called Bates Mountain Tuff, because of general lithologic similarity. The radiometric ages are listed in table 6. The youngest unit (see above) is about 22.1 m.y. old, the oldest about 24.4 m.y., and the intermediate units slightly younger than 24.4 m.y. The radiometric ages of all the units except the upper one overlap within the analytical precision of individual age determinations. The average age of all units, except the upper one, is 23.7 m.y., early Miocene on the time scale of Harland and others (1964).

New Pass Tuff

The New Pass Tuff is a distinctive, moderately widespread ash-flow unit in west-central Lander County (fig. 17) named for exposures at New Pass, a canyon at the south end of the New Pass Range through which U. S. Highway 50 passes (McKee and Stewart, 1971). In the type area, it is more than 400 feet thick; it thins to less than 100 feet a few miles east of New Pass. The formation serves as a useful marker horizon in the southern New Pass Range, the northern Desatoya Mountains, and near Mount Airy of the central Shoshone Mountains, where in each case it is a distinctive unit in a series of lenticular ash-flow sheets otherwise difficult to correlate.

Petrology. The New Pass Tuff is a crystal-rich ash-flow sheet that is densely welded through most of its thickness. Nonwelded to partially welded tuff occurs locally at the base of the unit and east of New Pass, some tuffaceous rocks on top of the formation may include its nonwelded top.

A representative sample of typical densely welded tuff is a pink to gray rock containing 35 to 50 percent smoky quartz and sanidine phenocrysts in about equal amounts, together with a little plagioclase. Eutaxitic texture can rarely be seen except occasionally in thin section. No chemical analysis of this rock is available, but a general similarity in phenocryst mineralogy to other crystal-rich welded ash-flow tuffs in central Nevada (i.e., Fish Creek Mountains Tuff, Windous Butte Formation) suggests that it is a rhyolite.

Age. A potassium-argon date of 22.0±0.9 m.y. on sanidine from a sample collected at the east end of New Pass (McKee and Stewart, 1971) suggests a Miocene age (Harland and others, 1964).

Crystal-poor Rhyolite Ash-flow Tuff, Central Desatoya Mountains

The central part of the Desatoya Mountains in Lander County (fig. 18) is underlain by a thick but lenticular ash-flow tuff or series of similar tuffs that are very difficult to distinguish in the field. Most of this rock is a homogeneous body of densely welded tuff; there are nonwelded to weakly welded zones and vitrophyre pods within the body. The unit covers about 70 square miles in the range in southwestern Lander County and an additional 10 to 20 square miles in adjacent Churchill County. This tabular body of tuff is at least 2,000 feet thick in the east-central part of the range north of State Highway 2, thinning abruptly in all directions within a distance of 10 miles or less. This tuff unit is not found to the east in the Shoshone Mountains, to the north in the northern part of the Desatoya Mountains and New Pass Range, nor to the south in the southern Desatoya Mountains and Paradise Range. The distribution and shape of this tuff body strongly suggest a source within the central part of the Desatoya Mountains.

Petrology. The densely welded tuff is pink to gray, crystal-poor rock that contains less than 10 percent phenocrysts of sanidine and plagioclase. Quartz is uncommon, but occurs in a few specimens. In places the rock has a very distinctive eutaxitic texture and large fragments of pumice partially or completely compressed give the rock a woody appearance. In other localities the unit is glassy and only partially devitrified; the outcrops are deep red to black and contrast with the pink and gray color typical of outcrops where the glass is devitrified.

TABLE 5. Chemical analyses and norms of densely welded or vitrophyre portions of Bates Mountain Tuff.

Map No. (fig. 15)	1	2	3	4	5
Field No.	15592–1	CC–3A	15978–1	15891–5	15891–5A
Location	N. of Clipper Gap Canyon, Toquima Range	Clipper Gap Canyon, Toquima Range	Southern Simpson Park Mountains	Southern Simpson Park Mountains	Southern Simpson Park Mountains
Unit	Intermediate vitrophyre unit	Intermediate vitrophyre unit	Lowest(?) vitrophyre unit	Lowest(?) vitrophyre unit	Lowest(?) welded devitrified unit
			Chemical analyses		
SiO_2	71.00	73.6	74.0	73.4	73.8
Al_2O_3	12.90	12.90	13.0	12.7	13.0
Fe_2O_3	1.40	.85	.47	.56	1.6
FeO	.60	.32	.48	.40	.24
MgO	.23	.16	.10	.20	––
CaO	.50	.50	.72	.91	.26
Na_2O	2.90	3.0	3.0	3.4	4.2
K_2O	5.80	4.8	5.0	5.6	5.3
H_2O-	.53	.29	.16	.27	.30
H_2O+	3.5	2.8	2.5	2.2	.44
TiO_2	.16	.11	.08	.08	.13
P_2O_5	––	––	––	––	.05
MnO	.20	.06	.05	.06	.07
CO_2	$<.05$	$<.05$	$<.05$	$<.05$	$<.05$
			C. I. P. W. norms		
Q	30.65	36.73	35.67	30.32	28.85
OR	34.42	28.56	29.68	33.15	31.51
AB	24.64	25.56	25.50	28.82	35.76
AN	2.49	2.50	3.59	2.86	.97
WO	––	––	––	.53	––
EN	.58	.40	.25	.50	––
FS	––	––	.46	.25	––
IL	.31	.21	.15	.15	.25
MT	1.8	.92	.68	.81	.63
AP	––	––	––	.14	.12
C	.95	1.88	1.35	––	––

units decrease, the section thinning to about 200 feet in the Shoshone Range (Gilluly and Gates, 1965, p. 83).

Petrology and chemistry. The basaltic andesite ranges from reddish-gray, platy, flow-banded to massive, slightly vesicular lava typically gray to black. The olivine basalt is massive, somewhat vesicular, dark-gray rock superficially resembling the massive vesicular andesitic basalt. Phenocrysts of plagioclase and a few of pyroxene and olivine are visible with hand lens in most specimens. The microscope shows the rocks to have intergranular to intersertal texture.

Chemical analyses of the basaltic andesite and olivine basalt reveal that the two rock types are very different in bulk chemistry. The analyses shown in table 7 differ by more than 10 percent SiO_2, about 3.5 percent total iron, about 7 percent MgO, about 8.5 percent CaO, and 5 percent total alkalies. The olivine basalt compares closely with analyses of oceanic tholeiites by Engel and others (1965); the andesitic basalt is similar to the average andesite of the United States (Chayes, 1969). Because of the striking difference in chemistry and the affinities of rocks of both

TABLE 7. Chemical analyses of basaltic andesite and olivine basalt from northern Lander County.

Map No. (fig. 20)	1	2
Field No.	6238-2J	6238-1JB
Location	Sheep Creek Range	Sheep Creek Range
Unit	Olivine basalt	Basaltic andesite
SiO_2	48.2	59.1
Al_2O_3	16.6	17.3
Fe_2O_3	2.5	4.0
FeO	6.6	1.7
MgO	8.9	2.2
CaO	12.1	3.4
Na_2O	2.1	4.8
K_2O	.17	3.6
H_2O-	.30	1.0
H_2O+	.68	1.6
TiO_2	.86	.83
P_2O_5	.23	.43
MnO	.17	.12
CO_2	.14	.05
Total	100	100

Shoshone Mountains near State Highway 2. These bodies differ from those in the northernmost part of Lander County in that extrusive parts are mostly flow breccia and welded to nonwelded tuff. They produced a relatively small volume of lava flows. Concentric flow planes are weakly developed around the margins of these domes, and columnar joints are the main structural feature of the central part of such bodies.

Sedimentary Rocks

Sedimentary rocks (fig. 22) are found at various horizons in the Tertiary column of Lander County. Most of these rocks are younger than the ash-flow tuffs; sedimentary rocks interbedded with or beneath the oldest of the volcanic units make up less than one-fourth. The various sedimentary rock units are difficult to distinguish in the field. Almost all are tuffaceous, ranging from ash-bearing siltstone, sandstone, and conglomerate to uncontaminated air-fall vitric tuffs. These sedimentary deposits accumulated under lacustrine conditions in local basins and are characterized by abrupt facies change. Correlation of individual units within a single basin is difficult; between basins, it is impossible. The sedimentary rocks have been subdivided stratigraphically and mapped in Lander County on the basis of position in relation to radiometrically dated volcanic units. The younger sedimentary rocks contain vertebrate remains that aid in placing the unit in its approximate position in the Tertiary time scale.

Mapping difficulties arise, however, where volcanic units tongue into a sedimentary sequence. Where the volcanic unit occurs, the sedimentary rocks are mapped as two units; where it is absent, the sedimentary rocks are mapped as one unit.

Age. At one locality in the Toiyabe Range about 20 miles north of Austin on the northeast side of the Fish Creek Mountains, tuffaceous sedimentary rocks underlie the oldest of the volcanic units. These are dacite-andesite flows similar to dated flows in the Simpson Park Mountains (see page 59); this similarity and their relation to ash-flow sheets of known age suggest an age of about 35 m.y. If this is true, these sedimentary rocks must be older than about 35 m.y., probably being early Oligocene or even late Eocene (Harland and others, 1964).

Similar sedimentary strata are found above the Caetano Tuff (age 32.5 m.y.) at several places in the Shoshone Range and above the dacite-andesite flows at localities in the central part of the Toiyabe Range. The sedimentary rocks in the Shoshone Range are overlain in a few places by a biotite-bearing ash-flow tuff about 30 m.y. old by the potassium-argon method. These sedimentary rocks are bracketed between 32.4 and about 30 m.y., thus being considered Oligocene (Harland and others, 1964).

In the area east of New Pass, tuffaceous sedimentary rocks and some nonwelded tuffs lie on top of the New Pass Tuff (age 22.0±0.9 m.y.) and are overlain by a welded tuff having a potassium-argon age of 23.6±0.9 m.y. This sequence of strata must be about 22 to 23 m.y. old, which suggests early Miocene (Harland and others, 1964).

The most widespread and voluminous Tertiary sedimentary rocks in Lander County, as in most of Nevada, are of late Miocene to middle Pliocene age. Strata within this age range include the Esmeralda Formation (upper Miocene to upper Pliocene) of the Silver Peak region, southwestern Nevada, the Truckee Formation (Pliocene) of western Nevada, and the Humboldt Formation (Miocene and Pliocene?) of northern Nevada. Strata in Lander County of this general age and lithology are mostly on the flanks of existing ranges or in valleys, especially the Reese River and Carico Lake Valleys north of Austin. A large area in the center of the Fish Creek Mountains is underlain by rocks of this type. The late Miocene and Pliocene strata contain a higher ratio of clastic to tuffaceous material than the older sedimentary strata. Typically, a section consists of greenish-gray clay and siltstone, buff sandstone and conglomerate and a few white ash beds. All the units are lenticular, although the ash beds tend to be thin (less than 5 feet) and more continuous than the other beds. Rocks of this type typically form badland topography. Vertebrate remains collected at a number of localities from rocks of this type include faunas of Barstovian, Clarendonian age (Macdonald and Pelletier, 1958; Gilluly and Gates, 1965) and Hemphillian age (C. A. Repenning, oral communication, 1970). Their approximate localities are shown on figure 22.

SUMMARY OF TERTIARY STRATIGRAPHY BY REGION (REGIONS ACCORDING TO SUBDIVISIONS UNDER *EXPLANATION* OF GEOLOGIC MAP)

Northern Area

The northern area includes that part of Lander County