Tertiary Volcanic Stratigraphy in the Powderhorn—Black Canyon Region, Gunnison and Montrose Counties, Colorado

GEOLOGICAL SURVEY BULLETIN 1251-C

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By J. C. OLSON, D. C. HEDLUND, *and* W. R. HANSEN

CONTRIBUTIONS TO GENERAL GEOLOGY

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Nomenclature, lithology, and stratigraphic relations of a sequence of ash-flow tuffs, flows, and breccia

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TERTIARY VOLCANIC STRATIGRAPHY IN THE POWDERHORN–BLACK CANYON REGION, GUNNISON AND MONTROSE COUNTIES, COLORADO

By J. C. Olson, D. C. Hedlund, and W. R. Hansen

ABSTRACT

Volcanic flows, breccia, conglomerate, and tuff were deposited during several episodes of volcanic activity in Tertiary time in the Powderhorn–Black Canyon region of southwestern Colorado. Lava flows, breccia, and conglomerate predominate in the older part of the Tertiary volcanic section, whereas ash-flow tuffs predominate in the younger part.

The oldest Tertiary volcanic rocks in the region are the Lake Fork Formation and the West Elk Breccia, which consist of volcanic breccia and conglomerate, tuff, and flows of andesite and rhyodacite. These formations, and the San Juan Formation in nearby areas, were deposited during the same general volcanic episode and once formed a great composite mass of intermediate flows and breccias probably several thousand feet thick. Similar rocks previously mapped by others as Conejos Quartz Latite also underlie the ash-flow sequence on upper Cebolla Creek and are included with the older Tertiary volcanic rocks.

Thick and extensive ash-flow tuffs were erupted explosively after an erosional interval during which the Lake Fork and West Elk volcanic piles were extensively eroded and locally removed. The ash-flow tuff sequence is divided into five formations in the Powderhorn–Black Canyon region; from oldest to youngest, these are here named the Blue Mesa, Dillon Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs. The tuffs are mostly of quartz latitic composition and are both crystal poor and crystal rich. At least two of the formations, and possibly all five, consist of two or more separate ash flows. The succession of ash-flow tuffs varies in thickness but has a maximum exposed thickness of about 1,450 feet on the sides of Cebolla Canyon in the southern part of the area and generally is thinner toward the north. The northward thinning is accompanied by a diminution in the degree of welding.

The Blue Mesa Tuff, the oldest of the ash-flow formations, filled only the lowest parts of the irregular preexisting surface. Succeeding units partly or completely overlapped each other. The ash-flow tuffs in many areas are welded, but nonwelded varieties are also widespread. The Fish Canyon Tuff, the most distinctive and widespread ash flow in the region, is characterized by abundant crystal fragments that typically constitute 25–45 percent of the rock. It ranges in thickness from 300 to 1,280 feet. Biotite from the Fish Canyon Tuff has a

potassium-argon age of 27 million years ±10 percent, which indicates a late Oligocene age.

After deposition of the ash-flow tuffs, dark flows of the Hinsdale Formation ranging from latite to basalt in composition were erupted upon an erosional surface of low relief. The Hinsdale, the youngest volcanic formation in the region, originally covered a wide area but subsequently was extensively eroded. The preserved remnants range from 150 to 600 feet in thickness.

Gravels indicative of erosional episodes occur at the base of, and intercalated in, the Lake Fork Formation and West Elk Breccia, and at the base of the Blue Mesa, Dillon Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs and the Hinsdale Formation.

INTRODUCTION

Lava flows, volcanic breccia, volcanic conglomerate, and ash-flow tuff were deposited during several episodes of volcanic activity in Tertiary time in the region around Powderhorn and northwest along the Black Canyon in Gunnison and Montrose Counties, Colo. (fig. 1). These volcanic rocks extended over wide areas, and remnants of them are preserved on ridges and mesas separated by deep canyons cut into the underlying Precambrian rocks (pl. 1). The older flows and breccias were derived from several volcanic centers in the San Juan and West Elk Mountains. The ash-flow tuffs forming the younger part of the volcanic section apparently were derived from sources to the south

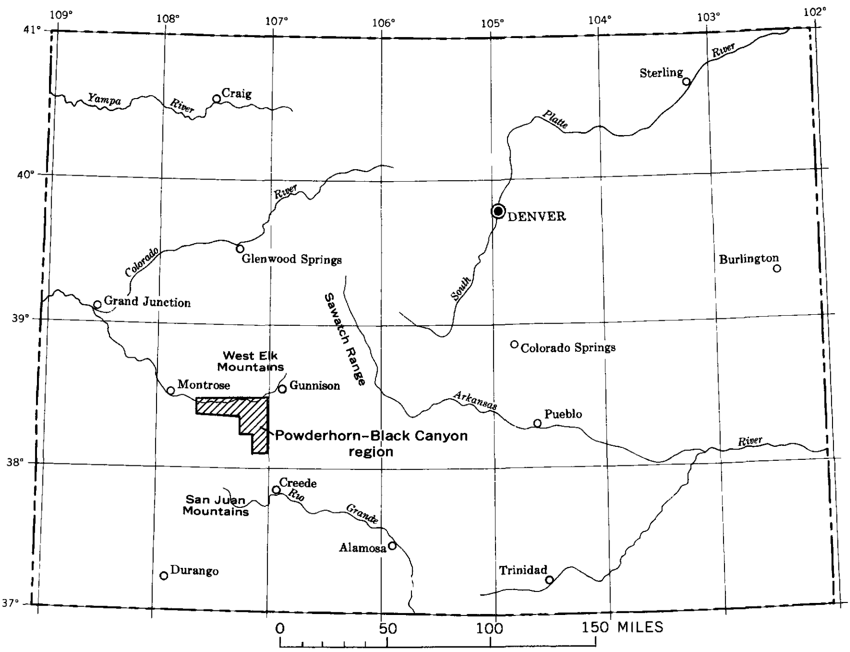

FIGURE 1.—Index map of Colorado.

or southwest where several cauldron subsidence structures are known to occur, as near Lake City and Creede (Luedke and Burbank, 1963, p. C40–C41; Steven and Ratté, 1964, p. D56), and possibly from sources to the north in the West Elk Mountains.

The volcanic rocks of the Powderhorn region were studied by Olson and Hedlund as part of the mapping and detailed study of thorium deposits during 1956–64. (See also Olson and Wallace, 1956.) The geology of five 7½-minute quadrangles (Cebolla, Iola, Gateview, Powderhorn, and Rudolph Hill, pl. 1) was mapped, and the thorium and niobium deposits and related alkalic igneous rocks, all older than the Tertiary volcanic rocks discussed in this report, were studied in detail (Hedlund and Olson, 1961). The volcanic rocks of the Black Canyon area were studied by Hansen as part of an areal mapping project of seven 7½-minute quadrangles along the Black Canyon, three of which (Cimarron, Curecanti Needle, and Sapinero) are shown on plate 1. This work is still in progress, although some features of it have been published (Hansen, 1964, 1965).

The Powderhorn–Black Canyon region is near the north edge of the San Juan Mountains volcanic field in a structurally high area known as the Gunnison uplift (Kelley, 1955). The Gunnison uplift includes that part of the region shown on plate 1 northeast of the Cimarron fault. This block probably rose several thousand feet in Laramide time, as the fault displaced the Mancos Shale but did not appreciably affect the Tertiary volcanics. On top of the Gunnison uplift block, the restored erosion surface upon which the Tertiary volcanic rocks were deposited slopes down to the north from near the Cimarron fault toward and beneath the West Elk Mountains. The part of the area north of the Gunnison River (pl. 1) is on the south flank of the West Elk Mountains, which is an area of predominantly volcanic rocks closely related to those of the San Juan volcanic field.

The stratigraphic terminology used by Larsen and Cross (1956) in their reconnaissance studies of volcanic rocks of the San Juan region has been shown to be inadequate for application to more detailed mapping. Steven and Ratté (1964, p. D56) were unable to accommodate the terminology of the Potosi Volcanic Series of Larsen and Cross to their revised volcanic sequence and, thus, did not use the terms. Also, they did not use the terms Alboroto and Piedra Rhyolites within their local sequence in the Creede area, because these terms included units that were widely scattered. In the western San Juan Mountains, Luedke and Burbank (1963) redefined the Potosi Volcanic Series as the Potosi Volcanic Group, and it is questionable without further regional studies whether any of the rocks of the Powderhorn–Black Canyon region correlate with the Potosi Volcanic Group as redefined. For these reasons, we do not apply the older terms here, and we present in this report the volcanic stratigraphy of the Powderhorn–Black Canyon region as an aid in geologic mapping and in making correlations with other nearby regions.

PRE-TERTIARY ROCKS

Rocks exposed beneath the Tertiary volcanic rocks are of Precambrian and Mesozoic age (pl. 1). In much of the area, particularly on the Gunnison uplift, the volcanic rocks are underlain by Precambrian granite, gneiss, quartz-biotite schist, amphibolite, and felsite. In parts of the area, however, the Wanakah, Junction Creek, and Morrison Formations of Jurassic age and the Dakota Sandstone and Mancos Shale of Cretaceous age were not removed in the prevolcanism erosion and are preserved beneath the volcanic rocks. Locally, the basal parts of the ash flows that rest on Precambrian and Mesozoic rocks contain fragments of those rocks.

OLDER VOLCANIC ROCKS OF TERTIARY AGE

The oldest Tertiary volcanic rocks in the district are the Lake Fork Formation, which crops out along the Lake Fork of the Gunnison River and on Blue Creek south of the Cimarron fault (pl. 1), and the West Elk Breccia (Emmons and others, 1894, p. 5), which crops out near the Gunnison River. These formations consist of volcanic breccia and conglomerate, tuff, and flows of andesite and hornblende rhyodacite. These older volcanic rocks once covered extensive parts of the Lake Fork area, the Gunnison uplift, and the West Elk Mountains. They probably were derived from several centers in the San Juan and West Elk Mountains.

The Lake Fork Formation was called the Lake Fork Quartz Latite by Larsen and Cross (1956, p. 64). The name is changed in this report to the Lake Fork Formation because the formation contains a heterogeneous assemblage of units rather than quartz latite only. The Lake Fork ranges in thickness from 0 to at least 1,600 feet in the Gateview quadrangle (pl. 1). It thickens to about 4,000 feet 5 miles south of the Gateview quadrangle near the head of Trout Creek, where several small intrusive stocks are thought to mark a center of volcanic cones from which much of the material was ejected (Larsen and Cross, 1956, p. 64–67). The northward movement of at least the lower flows and breccias of the Lake Fork was blocked by the Cimarron faultline scarp.

The West Elk Breccia ranges in thickness from 0 to about 1,100 feet near the northwest corner of the Cebolla quadrangle and thickens greatly farther northward. Southward thinning of the West Elk

Breccia on the Gunnison uplift can be attributed to erosion and probably also to the height of the uplift, which imposed a barrier against some of the lower units of the West Elk that were deposited farther north.

The Lake Fork Formation and West Elk Breccia, which are considered as parts of a composite unit of older volcanic rocks, consist of three major groups of rocks:

1. Gravel and andesitic flows in the lower part of the Lake Fork.
2. Great masses of volcanic breccia and pyroclastic rocks that constitute the middle part of the Lake Fork Formation to the south and a major part of the West Elk Breccia in the northern part of the area near the Gunnison River.
3. Thick flows and autobreccias of rhyodacitic lava that make up the upper part of the Lake Fork Formation and at least part of the West Elk Breccia north of the area shown on plate 1.

The lower 600 feet or more of the Lake Fork Formation consists of gravel or volcanic conglomerate, tuff, and andesitic flows and breccias. Gravel or conglomerate, exposed at the base of the formation, contains boulders chiefly of Precambrian granite and metamorphic rocks and Mesozoic quartzitic sandstone. The tuffaceous gravels in the lower part of the Lake Fork Formation locally contain a few boulders of magnetite-rich rock that is similar to a distinctive rock found at Iron Hill. The presence of these magnetite-rich boulders in the gravels in Lake Fork Canyon just south of the Cimarron fault provides evidence that a valley existed along the Cimarron fault in Lake Fork time and that the boulders were transported from the Iron Hill complex northwestward down this valley.

The oldest andesite flow is a dense black rock characterized by labradorite and sparse pale-green clinopyroxene phenocrysts in a microcrystalline trachytic groundmass of andesine and sanidine microlites, interstitial ferric oxides, and pale-green clinopyroxene. The overlying andesite and rhyodacite flows, locally autobrecciated, are mostly gray and range in texture from aphanitic to porphyritic. They consist generally of phenocrysts of andesine, clinopyroxene, and red-brown oxidized hornblende (oxyhornblende) in a trachytic groundmass of andesine and sanidine microlites and abundant iron oxides.

Eruption of the early andesitic lavas from volcanic cones in the Lake Fork area was closely followed by erosion interspersed with minor volcanic eruptions. Volcanic breccias and conglomerates composing the middle part of the Lake Fork and West Elk mass were widely deposited by volcanic mud flows, or lahars, and were interbedded locally with tuffs and thin rhyodacite flows. This assemblage has a maximum thickness of about 700 feet along the Lake Fork, about 500 feet along

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the Gunnison River between Iola and Sapinero, and about 800 feet just north of the Black Canyon. It is much thicker in the West Elk Mountains. Except for small isolated remnants, these older volcanic rocks have been largely removed by erosion from the Gunnison uplift.

The breccias in both the Lake Fork and the West Elk units show large-scale stratification (fig. 2) due to the alternation of very coarse, blocky, and fine-grained breccia beds. The fragments are poorly sorted and angular, and some are as much as 6 feet across. Some of the lower volcanic breccia beds along the Gunnison River were deposited in channels cut into the underlying Mesozoic sedimentary rocks, and angular blocks of sedimentary rocks locally occur within the basal part of the volcanic breccia. The dip of stratification varies widely; along the Black Canyon, southward dips predominate, but in the cliffs north of the Gunnison River east of the Black Canyon the dips are commonly 10°–20° N.

Volcanic fragments in the breccia are commonly gray to purplish-gray rhyodacite consisting of tabular andesine-labradorite, oxyhornblende, and pyroxene phenocrysts in a microcrystalline groundmass containing plagioclase and potassic feldspar microlites and opaque minerals. The rhyodacite fragments are set in a coarse-grained matrix consisting of comminuted rhyodacite-andesite fragments, fragmented plagioclase crystals, and ferric oxides.

FIGURE 2.—West Elk Breccia resting on Mesozoic sedimentary rocks and overlain by Blue Mesa Tuff (dark band), Dillon Mesa, Sapinero quadrangle. Breccia is about 600 feet thick. Note crude layering, dipping to right in left side of exposure.

The large volume of laharic breccia in the West Elk Mountains indicates that the breccias were largely locally derived. The northward dips of the coarse foreset beds in parts of the Gunnison River area, however, suggest a possible source for some of the material to the south, or else lodgement on north-facing slopes. Emmons, Cross, and Eldridge (1894, p. 5) inferred that the breccias were probably deposited as a series of mudflows and suggested that crater lakes in volcanic vents may have been breached and released water that drained down the sides of the vents and transported the volcanic debris downslope.

Throughout most of the Black Canyon area, coarse gravel or loosely cemented conglomerate occurs at the base of the West Elk Breccia. This conglomerate is similar to that at the base of the Lake Fork Formation and consists mostly of well-rounded but poorly sorted andesitic cobbles and boulders in a tuffaceous matrix; it also contains scattered cobbles of Precambrian granite and gneiss and Mesozoic sedimentary rock, particularly quartzite. Good exposures of conglomerate can be seen in roadcuts along the north side of the Black Canyon on the slopes of Black Mesa. Gravels at the base of the West Elk Breccia are 200–240 feet thick on Black and Poverty Mesas. Near the Gunnison River, tuff and tuffaceous conglomerates overlie the volcanic breccias. They are locally well bedded, show small-scale crossbedding, and probably represent airfall tuffs reworked by stream action that locally incorporated rounded cobbles and pebbles of Mesozoic quartzite and Precambrian granite and schist. Some tuff beds contain crystals of biotite, sodic andesine, quartz, and hornblende and relatively fresh white pumice fragments, which are flattened parallel to the bedding. On Black Mesa, the West Elk Breccia also contains ash-flow tuff that is locally densely welded. The tuff beds and tuffaceous conglomerates within the laharic breccia section indicate that short intervals of explosive volcanic activity alternated with periods of dominantly mudflow deposition.

Rhyodacitic lava was erupted in the Lake Fork area after deposition of the fragmental volcanic rocks. Hornblende rhyodacite flows and autobreccias, composing the upper part of the Lake Fork Formation, accumulated to a maximum thickness of about 900 feet along the Lake Fork just south of the Cimarron fault. Thinner autobreccias accumulated as far west as Blue Creek. The porphyritic hornblende rhyodacite is pink to purplish or greenish gray and commonly trachytic and contains lineated oxyhornblende, andesine (An_{28-47}), pyroxene, and quartz phenocrysts. The groundmass consists of plagioclase and sanidine microlites and disseminated iron oxides. The rhyodacite contains phenocrysts of andesine (An_{32-39}), biotite, and oxyhornblende set in a microcrystalline groundmass of quartz, plagioclase, and sanidine.

Rocks similar to the Lake Fork assemblage have been mapped in the Rock Creek drainage basin in the southeast corner of the Rudolph Hill quadrangle (pl. 1). The lower few hundred feet of these rocks is made of rhyolitic tuff-breccia and is overlain by massive flows and breccias of pyroxene rhyodacite and andesite. These thick flows and breccias suggest the presence here of a volcanic center generally similar to that of the Lake Fork Formation. These rocks in the Rock Creek area were called Conejos Quartz Latite by Larsen and Cross (1956, pl. 1); this name would indicate an age different from that of the Lake Fork Formation and West Elk Breccia. No evidence was seen, however, in the present study to support a marked difference in age, and on the map (pl. 1) these rocks are simply included in the composite Lake Fork and West Elk mass as "older volcanic rocks."

Breccias and tuffs of the San Juan Formation, similar to those in the Lake Fork and West Elk units, cover many square miles southwest of the Powderhorn-Black Canyon area. According to Larsen and Cross (1956, p. 64, 69), the San Juan Formation is slightly younger than the Lake Fork Formation but is correlative with the West Elk Breccia. There is little doubt, however, that all three formations formed during the same general volcanic episode and once formed a great composite mass of intermediate flows and breccias. These three formations and the Conejos Quartz Latite are considered to be of Oligocene or older age.

ASH-FLOW FORMATIONS

Explosive eruption of a thick and extensive succession of ash-flow tuffs took place after an erosional interval during which the Lake Fork and West Elk flows and breccias were extensively eroded and locally completely removed. The landscape before the oldest ash flow was deposited was characterized by a surface of low to moderate relief into which canyons had been cut to depths of several hundred feet. An erosional depression and south-facing escarpment were present along the Cimarron fault. A late Oligocene age for these eruptions is indicated by potassium-argon age determinations on a sample of biotite from the Fish Canyon Tuff.

The ash-flow tuffs were included in the Alboroto Rhyolite and Piedra Rhyolite of the Potosi Volcanic Series by Larsen and Cross (1956). More detailed mapping in the western and central San Juan Mountains by Luedke and Burbank (1963) and Steven and Ratté (1964) indicated the advisability of assigning separate formational names to mappable ash-flow units and not using the names Alboroto and Piedra. Luedke and Burbank have restricted the name Potosi to a specific assemblage of ash-flow units derived from sources in the western San Juans. Approximate correlations of the terminology in this report with that of Larsen and Cross are shown in the following table.

	Larsen and Cross (1956)	This report
	Hinsdale Formation	Hinsdale Formation
Potosi Volcanic Series	Piedra Rhyolite	Carpenter Ridge Tuff
Potosi Volcanic Series	Alboroto Rhyolite: Upper member	Fish Canyon Tuff
Potosi Volcanic Series	Alboroto Rhyolite: Lower member	Sapinero Mesa Tuff Dillon Mesa Tuff Blue Mesa Tuff
Potosi Volcanic Series	Conejos Quartz Latite	Conejos Quartz Latite, Lake Fork Formation, and West Elk Breccia
	Lake Fork Quartz Latite and West Elk Breccia	

The ash-flow tuff sequence (pl. 1) is divided into five formations in the Powderhorn–Black Canyon region. From oldest to youngest, these are here named the Blue Mesa, Dillon Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs. Each formation in turn can be subdivided according to degree of welding or of devitrification and by other characteristics. At least two of the formations, and possibly all five, consist of two or more separate ash flows.

Columnar sections on plate 1 illustrate variations in thickness and lithology throughout the region. The succession of ash-flow tuffs has a maximum exposed thickness of about 1,450 feet on the sides of Cebolla Canyon in the Rudolph Hill quadrangle in the southern part of the area and generally becomes thinner toward the north. The northward thinning is accompanied by a diminution in the degree of welding.

In typical vertical section, the ash-flow units grade upward from a discontinuous nonwelded base through a black or dark-brown vitrophyric zone, then a densely welded to partly welded devitrified zone, to a poorly welded to nonwelded top. Within the mapped area, soft nonwelded tuff constitutes the base of the ash flows only locally. More commonly, the base is a conspicuous black vitrophyre consisting of densely welded smoky-brown shards, numerous crystal fragments, and dusty inclusions of magnetite. Typically, the vitrophyre grades upward through a zone containing progressively more abundant brown spherulites that coalesce upward to form a completely devitrified rock containing phenocryst fragments set in a matrix of very fine grained alpha cristobalite and sanidine. In places, the vitrophyre is absent, and densely welded tuff is devitrified down to the base. Nonwelded to weakly welded tuffs occur at the top of some ash-flow units, but in most places they were eroded before the succeeding ash flow erupted.

The tuffs are mostly of quartz latitic composition, in contrast to the rhyodacitic-to-andesitic composition of the older volcanic units of Tertiary age (fig. 3; table 1). The glass in some of the vitric tuff has a refractive index of 1.49–1.50, which, according to the curves plotted by George (1924), corresponds to that of rhyolitic glass. The phenocrysts are commonly plagioclase and sanidine and rarely tridymite, cristobalite or quartz; biotite is common in most of the tuffs.

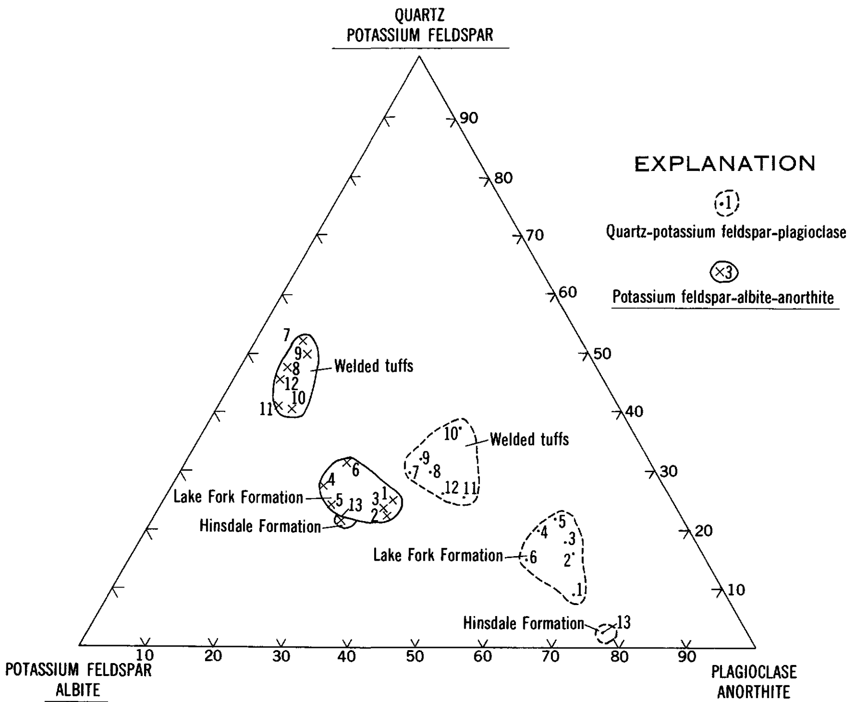

FIGURE 3.—Triangular diagram showing variations of normative feldspars and quartz of volcanic rocks from the Powderhorn–Black Canyon region, Colorado. Numbers refer to rock analyses in table 1.

TABLE 1.—*Chemical analyses, norms, and modes of Tertiary volcanic rocks*

[Analyses by rapid method by Lowell Artis, I. H. Barlow, S. D. Botts, Gillison Chloe, P. L. D. Elmore, M. D. Mack, E. L. Munson, K. Smith, and H. H. Thomas, 1957, 1958, 1964; n.d., not determined; Tr, trace]

	1	2	3	4	5	6	7	8	9	10	11	12	13
Rock type	Trachy-andesite	Hornblende-Pyroxene rhyodacite	Pyroxene rhyodacite	Hornblende rhyodacite	Hornblende rhyodacite	Hornblende-pyroxene rhyodacite	Quartz latite	Quartz latite	Quartz latite	Quartz latite	Quartz latite	Quartz latite	Pyrox-ene trachy-andesite
Field No	G710	G726	G3510	G3483	G815	G3380a	BC5781	G3328	BC6225	G2383	G2384	G3474	G3540
Lab. No	152860	152862	152859	152863	152864	152865	162581	152867	162587	150043	152868	152866	152861
Sp gr (powder)	2.70	2.70	2.64	2.69	2.54	2.58	n.d.	2.46	n.d.	n.d.	2.54	2.48	2.76
Analyses													
SiO_2	56.0	57.4	57.1	64.2	61.8	59.7	71.1	72.3	70.6	70.0	70.6	71.4	53.6
Al_2O_3	19.0	15.8	15.6	16.6	17.9	17.0	13.6	14.5	14.2	15.1	16.1	15.0	15.4
Fe_2O_3	3.0	3.4	5.2	4.3	4.7	5.1	1.3	1.6	1.3	1.1	1.7	1.4	3.8
FeO	3.0	5.0	3.1	.17	.26	1.2	.24	.08	.24	.45	.16	.23	5.2
MgO	1.5	3.5	3.3	1.0	.31	1.2	.20	.28	.22	.40	.26	.26	5.9
CaO	7.0	6.1	6.1	4.3	4.1	3.9	1.0	1.2	1.2	1.2	1.4	1.2	6.7
Na_2O	3.7	3.2	3.2	4.3	4.1	3.9	3.2	3.5	3.1	3.2	4.2	4.0	3.8
K_2O	3.2	2.4	2.5	3.4	2.8	3.9	5.8	5.2	5.3	3.8	4.9	5.4	2.4
TiO_2	1.0	.99	.95	.51	.60	1.1	.23	.27	.26	.26	.30	.23	1.6
P_2O_5	.55	.39	.38	.32	.35	.56	.03	.08	.07	.01	.08	.08	.54
MnO	.12	.20	.14	.12	.08	.08	.08	.04	.07	.07	.08	.08	.14
H_2O	1.7	1.0	2.2	.44	2.9	2.3	.60	.84	3.39	3.3	.78	.45	.46
CO_2	.38	.31	.06	.62	.07	.08	.05	.23	.05	.05	.06	.16	.07
Total	100.15	99.69	99.83	100.28	99.97	100.02	97.43	100.12	100.00	98.94	100.62	99.89	99.61

TABLE 1.—*Chemical analyses, norms, and modes of Tertiary volcanic rocks*—Continued

Rock type	1 Trachy-andesite	2 Hornblende-pyroxene rhyodacite	3 Pyroxene rhyodacite	4 Hornblende rhyodacite	5 Hornblende rhyodacite	6 Hornblende-pyroxene rhyodacite	7 Quartz latite	8 Quartz latite	9 Quartz latite	10 Quartz latite	11 Quartz latite	12 Quartz latite	13 Pyrox-ene trachy-andesite
Norms													
Q	7.5	11.9	13.6	18.0	19.3	13.0	28.1	27.7	29.7	33.7	24.5	25.3	1.6
or	18.9	14.2	14.8	20.1	16.5	23.0	34.3	30.8	31.3	22.4	28.9	31.9	14.1
ab	31.2	27.1	27.1	36.4	34.6	32.9	27.1	29.6	26.2	27.0	35.5	33.8	32.1
an	25.5	21.4	20.6	15.7	16.9	17.0	4.4	4.0	5.2	6.0	6.0	4.5	17.6
C	0.0	0.0	0.0	0.0	1.9	0.0	.4	1.6	1.5	3.5	1.6	.9	0.0
en	3.7	8.8	8.3	2.5	.8	3.0	.5	.7	.5	1.0	.6	0.6	14.7
hy	1.5	4.8	0.0	0.0	0.0	0.0	.5	0.0	.5	0.0	0.0	0.0	3.9
wo	1.6	1.9	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
mt	4.3	4.9	7.6	0.0	0.0	.7	.4	0.0	.2	1.6	0.0	0.0	5.5
il	1.9	1.9	.6	.9	.6	2.1	.4	0.5	0.5	.5	.6	.4	3.0
hm	0.0	0.0	0.0	4.3	4.7	0.0	1.0	1.6	1.1	.6	1.7	0.0	0.0
ap	1.2	.8	.3	.7	.8	1.2	.1	.2	.2	.02	.2	.2	1.2
tn	0.0	0.0	0.0	0.0	.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
cal	.9	.7	.2	1.4	.2	.2	.1	.5	1.1	0.0	.1	.4	.2
Total	98.2	98.4	96.0	100.0	97.0	93.1	97.3	97.2	98.0	96.3	99.7	98.0	98.9
Modes													
Groundmass:													
Vitric							81.1		83	82			
Devitrified							2.1	88	6	7	66	91	
Microcrystalline	78	73	99	88	82	71							90
Sanidine							6.4	8.8	3	2.9		2.5	
Plagioclase	21	17	1	7	15	18	8.8	2.2	6	6.1	28	5.5	3
Biotite	0.0	Tr.	0	0.0	0.0	0.0	1.1	.3	2	1	2.4	.3	0
Oxyhornblende	0.0	.3	0	3	2	1	Tr.	.1	Tr.	0.5	1.4	.3	4
Pyroxene	Tr.	7	Tr.	0.0	0.0	7	0.0	0.0	Tr.	Tr.	0.0	Tr.	Tr.
Iron oxides	.4	3	Tr.	1	1	2	Tr.	.4	Tr.	1	1.3	.2	3
Carbonate	.3	0.0	0	.4	0.0	Tr.	0.0	0.0	0	0.0	0.0	0.0	0
Sphene	0	0	0	0	0	0	0	0		0	0.1	0	0
Total	99.7	100.3	100	99.4	100.0	99.0	99.5	99.8	100	100.5	99.2	99.8	100

LOCATION AND DESCRIPTION OF SAMPLES

1. Trachyandesite, Lake Fork Formation: Center SE¼NE¼ sec. 32, T. 47 N., R. 3 W., Gateview quadrangle. Abundant labradorite phenocrysts are up to 8 mm in length, display normal zoning and have numerous resorption pits. Black aphanitic pilotaxitic groundmass contains andesine(?) microlites and interstitial augite and iron oxides.
2. Hornblende-pyroxene rhyodacite, Lake Fork Formation: NW¼NW¼NW¼ sec. 4, T. 46 N., R. 3 W., Gateview quadrangle. Black, fine grained, with abundant disseminated iron oxides. Andesine (An_{40-45}) and pyroxene phenocrysts are in a pilotaxitic groundmass consisting of andesine and sanidine microlites and interstitial iron oxides. The andesine phenocrysts display normal zoning and have numerous resorption pits.
3. Pyroxene rhyodacite, Lake Fork Formation: NW¼SE¼ sec. 11, T. 46 N., R. 3 W., Gateview quadrangle. Dark gray, microcrystalline. Sparse andesine (An_{36-40}) phenocrysts are set in a pilotaxitic to weakly trachytic groundmass consisting of andesine and sanidine microlites, interstitial iron oxides, and minute grains of pyroxene.
4. Hornblende rhyodacite, Lake Fork Formation: NE¼SW¼ sec. 11, T. 46 N., R. 3 W., Gateview quadrangle. Brownish-gray porphyritic with scattered phenocrysts of andesine (An_{35-40}) and oxyhornblende in a weakly trachytic groundmass consisting of calcic oligoclase (An_{25-28}) and sanidine microlites. The andesine phenocrysts display normal zoning and complex twinning. The oxyhornblende phenocrysts are commonly rimmed by ferric oxides.
5. Hornblende rhyodacite, Lake Fork Formation: NE¼SE¼SE¼ sec. 34, T. 47 N., R. 3 W., Gateview quadrangle. Purplish gray, porphyritic. Scattered phenocrysts of andesine (An_{43-47}) and oxyhornblende are set in a trachytic groundmass consisting of calcic oligoclase (An_{25}) and sanidine microlites with interstitial iron oxides. The andesine phenocrysts show normal zoning and complex twinning. The oxyhornblende phenocrysts are up to 7 mm in length and are commonly rimmed by ferric oxides.
6. Hornblende-pyroxene rhyodacite, Lake Fork Formation: SW¼SW¼SE¼ sec. 28, T. 47 N., R. 3 W., Gateview quadrangle. Dark gray, aphanitic with yellowish-brown alteration blebs after pyroxene and oxyhornblende. The texture is trachytic with microlites of calcic oligoclase (An_{25}) and sanidine and interstitial grains of pyroxene, iron oxides, and oxyhornblende. A few phenocrysts of andesine and pyroxene.
7. Vitrophyre of Blue Mesa Tuff: SW¼NW¼ sec. 8, T. 48 N., R. 4 W., Sapinero quadrangle. Black spherulitic vitroclastic vitrophyre, containing scattered phenocrysts and small cristobalite spherulites, traces of hematite, sphene, and apatite, and trichites in glass.
8. Devitrified welded tuff of Blue Mesa Tuff: NE¼SE¼ sec. 7, T. 47 N., R. 3 W., Gateview quadrangle. Cinnamon brown, aphanitic welded tuff consists chiefly of devitrified ash shards, pumice, and about 11 percent fragmented sanidine and sodic andesine (An_{30-32}) crystals.
9. Vitrophyre of Dillon Mesa Tuff: SE¼NW¼ sec. 17, T. 48 N., R. 4 W., Sapinero quadrangle. Dark brown vitroclastic vitrophyre containing tightly compressed shards, occasional flattened pumice fragments, scattered lithic inclusions, scattered phenocrysts, and a few trichites.
10. Vitrophyre of Sapinero Mesa Tuff: SE¼SE¼ sec. 10, T. 47 N., R. 3 W., Gateview quadrangle. Black vitric groundmass is composed of deformed, welded, glassy ash shards and compacted pumice fragments; the glass is of rhyolitic composition. Scattered, fragmented crystals of sodic andesine (An_{32}) up to 3 mm across.
11. Crystal-rich welded tuff of Fish Canyon Tuff: SE¼SE¼ sec. 10, T. 47 N., R. 3 W., Gateview quadrangle. Light brown, massive, crystal-rich welded tuff contains 32 percent crystal fragments disseminated in a cryptocrystalline groundmass consisting chiefly of sanidine and alpha cristobalite. Relict shard structures have commonly been destroyed by devitrification. Cyrstal fragments are chiefly sodic andesine (An_{35-37}) and biotite.
12. Devitrified welded tuff of Carpenter Ridge Tuff: NE¼SE¼ sec. 2, T. 46 N., R. 3 W., Gateview quadrangle. Cinnamon brown, aphanitic welded tuff consists chiefly of devitrified ash shards, pumice, and about 8 percent fragmented sanidine and sodic andesine to calcic oligoclase crystals.
13. Pyroxene trachyandesite, Hinsdale Formation: Round Mountain, SW¼SE¼SE¼ sec. 19, T. 47 N., R. 3 W., Gateview quadrangle. Dark groundmass has a trachytic to pilotaxitic texture with microlites of andesine (An_{30-35}) and sanidine and disseminated iron oxides. A few calcitic amygdule fillings, minute grains of pale green pyroxene and relatively abundant oxyhornblende are present.

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Gravel occurs at the base of the Blue Mesa, Dillon Mesa, Sapinero Mesa, and Fish Canyon Tuffs, and at the base of and within the Carpenter Ridge Tuff and the Hinsdale Formation. The gravel beds are commonly only a few feet thick, but in general they seem to thicken westward in the Black Canyon area.

The proportions of different rock types making up the boulders in the gravel vary from place to place. Common to all the gravel beds are well-rounded cobbles and boulders of quartzitic sandstone and conglomerate of the Morrison and Dakota Formations and locally derived granite, gneiss, and schist from the Precambrian. The proportion of Precambrian rock types to other boulders increases upward in the section. Gravel above the West Elk Breccia and Lake Fork Formation commonly contains numerous boulders and cobbles of rhyodacite and andesite, numerous porphyritic rocks of hypabyssal origin, and some quartzite, granite, and gneiss. The gravel locally contains boulders of coarse porphyritic gneissic granite that has carlsbad-twinned phenocrysts 1–2 inches long, unlike the granite mapped in most of the area. Also within the gravel at many stratigraphic levels is a coarse-grained pinkish-gray biotite quartz monzonite. These two rock types may have been derived from some distant source, possibly from the Sawatch Range east of the map area.

BLUE MESA TUFF

The Blue Mesa Tuff, the oldest of the ash-flow formations, is here named for typical exposures in the rim of Blue Mesa on the south side of Black Canyon above Blue Mesa Dam (loc. 4, pl. 1), which is designated the type locality. The Blue Mesa Tuff filled in the lowest parts of the preexisting irregular topographic surface but did not everywhere cover the highest surface. Much of the formation has been removed by erosion, but nearly continuous exposures form vertical cliffs (fig. 4) along the north side of the Black Canyon to the west end of Black Mesa, where the formation has an erosional limit. Its northern limit in Black and Soap Mesas has not been mapped, but it is several miles north of the Black Canyon. North and east from Blue Mesa Dam the Blue Mesa Tuff is well exposed in the rim of Dillon Mesa.

South of Blue Mesa Dam the Blue Mesa Tuff forms prominent cliffs from Fitzpatrick Mesa east to Sapinero Mesa. Indeed, all these mesas owe their prominence to the erosive resistance of the Blue Mesa Tuff. Small remnants cap ridge tops as far west as Poverty Mesa northwest of Cimarron and Storm King Mountain 10 miles south-southwest of Cimarron. Along the Black Canyon the Blue Mesa Tuff is thickest near the north rim of Blue Mesa and near the south and west rims of Soap

FIGURE 4.—Blue Mesa Tuff, forming cliffs along south side of Soap Mesa near Blue Mesa Dam, Curecanti Needle quadrangle. Cliffs of welded tuff are about 200 feet high. Inner gorge of Black Canyon, 900 feet deep but concealed from view, is directly behind trees in foreground.

Mesa, where it exceeds 240 feet in thickness. It thins and wedges out north and east on Dillon Mesa, southward on Pine Creek and Willow Creek Mesas, and eastward on Sapinero Mesa.

Good exposures of Blue Mesa Tuff are in the Dutch Gulch–Gateview area in the Gateview quadrangle, the west-central and northwestern parts of the Cebolla quadrangle, Huntsman Gulch in the Powderhorn quadrangle, an area near the confluence of Fish Canyon and Cebolla Creek in the Rudolph Hill quadrangle and another area near the center of that quadrangle. In the Iola quadrangle, possible correlatives of the Blue Mesa Tuff occur at least as far northeast as Sugar Creek and also in sec. 22 above Steuben Creek north of the Gunnison River. Correlations between these scattered localities are based on stratigraphic position and lithologic similarity and are not everywhere certain.

The greater part of the Blue Mesa Tuff consists of densely welded devitrified tuff, which commonly forms jointed vertical cliffs 50–200 feet high in the outer walls of the Black Canyon and its tributaries. The base of the densely welded zone is concealed by talus in most places, but wherever exposed in the Black Canyon area it consists of several inches to several feet of vitric nonwelded tuff overlain by 10–14 feet of black vitrophyre. In many places farther southeast, the base of the Blue Mesa Tuff is devitrified. A compound cooling history of the densely welded but devitrified zone is suggested by large flattened gas vesicles 40–100 feet below the top of the zone and by vague almost horizontal layering. The upper 40 feet of welded tuff is conspicuously layered (fig. 5) and lighter colored than that below; nevertheless, it is densely welded. This zone grades upward into porous nonwelded tuff in the upper several feet of the member.

The Blue Mesa Tuff contains about 10–15 percent phenocrysts, in the following proportions: Plagioclase (An_{23-25}), 5–11 percent; sanidine, 3–6 percent; biotite, from less than 1 to 2 percent; and rare oxyhornblende and pale-green clinopyroxene. Sphene, apatite, zircon, and opaque iron minerals are accessory in trace amounts. The rock also locally contains scattered inclusions of pumice, and lithic rock fragments of quartzite and quartz latite.

The Blue Mesa Tuff is generally pale reddish brown but is locally white to purplish white in the gas-phase crystallization zone in the upper part of the unit. The devitrified groundmass is a lithoidal microcrystalline mixture of alpha cristobalite, sanidine, and ferric oxides. Numerous hollow lithophysae are locally present.

FIGURE 5.—Devitrified Blue Mesa Tuff in cliffs along north side of Blue Mesa, Curecanti Needle quadrangle. Layered habit in upper part of cliff is characteristic. Light-colored nonwelded tuff at top.

Pumiceous nonwelded tuff consisting of shards, pumice, minor amounts of plagioclase, sanidine, biotite, and calcite, and locally a few sparse fragments of quartzite crops out under the devitrified welded tuff in various places in the region (for example, loc. 16, pl. 1). This tuff is commonly white but locally is light gray, owing to its content of disseminated black shards. The pumice fragments tend to be oriented with their long dimensions nearly horizontal in most outcrops.

In the sequence of tuff units below the younger Sapinero Mesa Tuff on upper Cebolla Creek and in the south-central part of the Rudolph Hill quadrangle, the lower devitrified welded tuff is tentatively correlated with the Blue Mesa Tuff because of similar lithology, although it is 3–5.5 miles from the two nearest areas correlated with Blue Mesa. In the area near the confluence of Fish and Cebolla Creeks, the light-gray crystal-poor Blue Mesa Tuff consists of resistant, cliff-forming welded tuff with black vitrophyre at the base in places. It is overlain in this area by an airfall(?) and water-laid tuff, which is about 200 feet thick. The tuff is bedded in part and generally fine grained, soft, and buff colored. This soft nonwelded tuff may or may not be a correlative of the Dillon Mesa Tuff.

DILLON MESA TUFF

Dillon Mesa Tuff is named in this report for the excellent exposures on Dillon Mesa, its type locality, in the northern part of the Sapinero and Cebolla quadrangles. Exposures of the formation are chiefly in those two quadrangles, where remnants are commonly intercalated between the Blue Mesa Tuff below and the Sapinero Mesa Tuff above. Tuffs that probably correlate with the Dillon Mesa Tuff occur also in the Gateview, Iola, Powderhorn, and Rudolph Hill quadrangles.

In many places the ash-flow tuff that makes up most of the Dillon Mesa Tuff is separated from tuffs below and above by gravel or conglomerate. On Dillon Mesa about 55 feet of gravel, mostly of West Elk provenance, overlies the Blue Mesa and forms the basal part of the Dillon Mesa Tuff.

The Dillon Mesa Tuff, including the gravel at its base, is generally less than 80 feet thick; but on Pine Creek Mesa, where possibly it contains more than one eruptive unit, it is as much as 180 feet thick.

In typical sections the Dillon Mesa Tuff consists of light-brown slightly porphyritic moderately welded tuff. Compressed shards commonly are discernible through a hand lens or even by the naked eye. Where densely welded, the rock is darker brown and stony to flinty in appearance and has a splintery subconchoidal fracture. In some places the lower 10–20 feet is dark-brown spherulitic vitrophyre; else-where the tuff is reddish brown and devitrified to its base. On the east side of Blue Mesa, for example, vitrophyre grades laterally into completely devitrified welded tuff within a few tens of yards. Nonwelded phases of the tuff are light yellowish brown, vitroclastic, and friable.

The texture of the welded tuff, as seen in thin section, is foliated vitroclastic. The groundmass of the more vitric phase consists of clear tightly welded compressed shards, occasional dark-brown streaks of collapsed tubular pumice, and a few trichites. Scattered phenocrysts consist of a few percent of zoned plagioclase and sanidine in a ratio of about 2:1, scattered flakes of partly oxidized biotite, traces of hematite, apatite, and zircon, and very sparse oxyhornblende. The rock contains scattered small stony inclusions, most of them only a few millimeters across.

The groundmass in the devitrified zone consists chiefly of cristobalite and feldspar in fine radial aggregates; voids are partly filled with tridymite. Despite devitrification, the vitroclastic texture is well preserved.

The Dillon Mesa Tuff wedges out northward on Dillon Mesa, southeastward on Sapinero Mesa, southward on Pine Creek and Willow Creek Mesas, and westward on Blue Mesa. Near the distal wedgeout on Dillon Mesa the formation thins northward and becomes nonwelded as the nonwelded base and top thicken and converge northward at the expense of the welded core.

A probable correlative of the Dillon Mesa Tuff is a nonwelded tuff that underlies devitrified welded tuff of the Sapinero Mesa Tuff along the southeast side of Big Mesa; a similar tuff, consisting of discontinuous beds of nowwelded tuff and tuffaceous breccia, underlies the Fish Canyon Tuff in the north-central part of the Iola quadrangle and is also a probable correlative of the Dillon Mesa. These tuff units have a maximum thickness of 80 feet and pinch out southward. The white nonwelded tuff correlated with the Dillon Mesa in these two localities contains numerous angular, rather undeformed shards, coarse pumice fragments, about 5 percent crystal fragments which are chiefly zoned calcic oligoclase (An_{28-30}), and sparse biotite and iron oxides. The shards have a refractive index of 1.503 ± 0.004. The tuffaceous breccia, which is commonly above the nonwelded tuff in the north-central part of the Iola quadrangle, consists of diverse fragments of Precambrian rock and Mesozoic quartzite in a tuffaceous matrix.

In the Gateview area (sec. 14, pl. 1), about 40 feet of soft gray airfall tuff, bedded near its top, overlies the Blue Mesa Tuff and is correlated with the Dillon Mesa Tuff. In the southern part of the Rudolph Hill quadrangle (sec. 17, pl. 1), nonwelded, in part bedded, tuff about 200–250 feet thick can possibly be correlated with the Dillon Mesa Tuff because of similar stratigraphic position. This tentative correlation may not be valid, however, because the tuff is several miles southeast of the other exposures; in addition, this interval between the Blue Mesa and Sapinero Mesa Tuffs in the southern part of the Rudolph Hill quadrangle contains both welded and nonwelded tuff units and represents more than one eruption.

Locally, as just west of Powderhorn in the southeastern part of the Gateview quadrangle, breccia underlying the Sapinero Mesa Tuff is included in the Dillon Mesa Tuff. This breccia consists chiefly of fragments of lithic ash, crystals, and some Mesozoic quartzite fragments as much as 6 inches across. The matrix consists of fine- to medium-grained comminuted fragments of devitrified welded tuff, lithic ash, and some crystals of angular plagioclase and biotite. Weathered outcrops are commonly reddish brown and ferruginous and are vuggy where lithic ash and quartzite fragments have been eroded out. Local stratification in the tuff suggests it has been reworked by water.

SAPINERO MESA TUFF

A persistent, widespread welded tuff that overlies the Dillon Mesa and Blue Mesa Tuffs and older rocks throughout the study area is here named the Sapinero Mesa Tuff for its striking exposures on that mesa in the Sapinero, Cebolla, and Gateview quadrangles. In its type locality at Tenmile Springs in the southern part of the Cebolla quadrangle, the formation was deposited on an irregular surface of Precambrian rock, Dillon Mesa Tuff, and Blue Mesa Tuff and is 80–140 feet thick. In Lake Fork Canyon, near Gateview, the Sapinero Mesa Tuff is as much as 220 feet thick.

The black vitrophyre near the base of the Sapinero Mesa Tuff is underlain in many places by about 10 feet of basal gravel. The vitrophyre is commonly 10–50 feet thick but locally is as much as 100 feet thick along the north side of Dutch Gulch. The vitrophyre contains about 5–15 percent crystal fragments in a groundmass of welded vitric ash and pumice. The shards have a refractive index of 1.49–1.50, which corresponds to a silica content of about 72 percent, or a rhyolitic composition (George, 1924). The crystal fragments are chiefly zoned calcic oligoclase and sodic andesine (An_{28-35}), which display oscillatory-normal zoning; sanidine, biotite, resorbed quartz grains, sparse oxyhornblende and green clinopyroxene, and iron oxides each constitute less than 1 percent of the rock. Pumice fragments are abundant. Fragments of Precambrian rock and Mesozoic quartzite are present in very minor amounts. Hollow lithophysae and reddish-brown spherulites as much as 4 inches across are locally abundant, particularly in the upper parts of the vitrophyre where they commonly coalesce upward within a few feet into completely devitrified welded tuff.

The devitrified welded tuff unit, which makes up most of the formation and is commonly about 100 feet thick, contains the same amounts and kinds of crystal components as the vitric base, but its matrix has devitrified to a microcrystalline mixture of sanidine, alpha cristobalite, and ferric oxides. The devitrified welded tuff is commonly reddish brown and lithoidal, but in places it is light gray and contains many hollow lithophysae.

The hard, devitrified welded tuffs of the Sapinero Mesa Tuff that cap mesas in the Powderhorn district are commonly nearly flat. Exceptions are found in those that cap the mesas on the sides of Huntsman Gulch near Powderhorn, which dip southwest as much as 8°, and those north of the Gunnison River in the northwestern part of the Cebolla quadrangle, which dip southward as much as 5°. In the Black Canyon area, a synclinal structure formed by the ash-flow sequence coincides with the canyon axis (Hansen, 1965, fig. 23). Remnants of tuff sheets north of the river dip gently southward, and remnants south of the river dip northward. Total relief on this syncline exceeds 1,200 feet.

FISH CANYON TUFF

The crystal-rich Fish Canyon Tuff is the most distinctive and widespread ash-flow tuff in the region. The Fish Canyon Tuff is here named for the excellent exposures in Fish Canyon, its type locality (loc. 17, pl. 1), near the south edge of the Rudolph Hill quadrangle, where it is from 950 to 1,100 feet thick; the maximum observed thickness of the formation, about 1,280 feet, is about a mile north of Fish Canyon. This thickness diminishes to 450 feet in the Gateview and Iola quadrangles and to 300 feet in the Sapinero and Cebolla quadrangles. It diminishes to zero on Black Mesa and Blue Mesa in the Curecanti Needle quadrangle. In general, the thickness varies with the distance from the source, which was apparently to the south or southwest, and with the relief on the underlying surface of deposition.

The Fish Canyon consists largely of crystal-rich welded tuff that grades upward and laterally into nonwelded tuff. The tuff is commonly light gray, buff, or white and massive. It typically weathers to rounded, pedestal, and beehive forms. Much of the crystal-rich tuff has a foliation with flat to diverse gentle dips (figs. 6, 7). Commonly the rock is broken by conspicuous nearly vertical joints that strike north to northeast in most of the region.

The Fish Canyon Tuff is medium grained and contains 25–45 percent angular crystal fragments (fig. 8) in a microcrystalline groundmass. Eutaxitic textures are poorly developed, and shard relicts are commonly obscured by devitrification. About 70–90 percent of the crystals are oscillatory-normal-zoned sodic andesine and calcic oli-

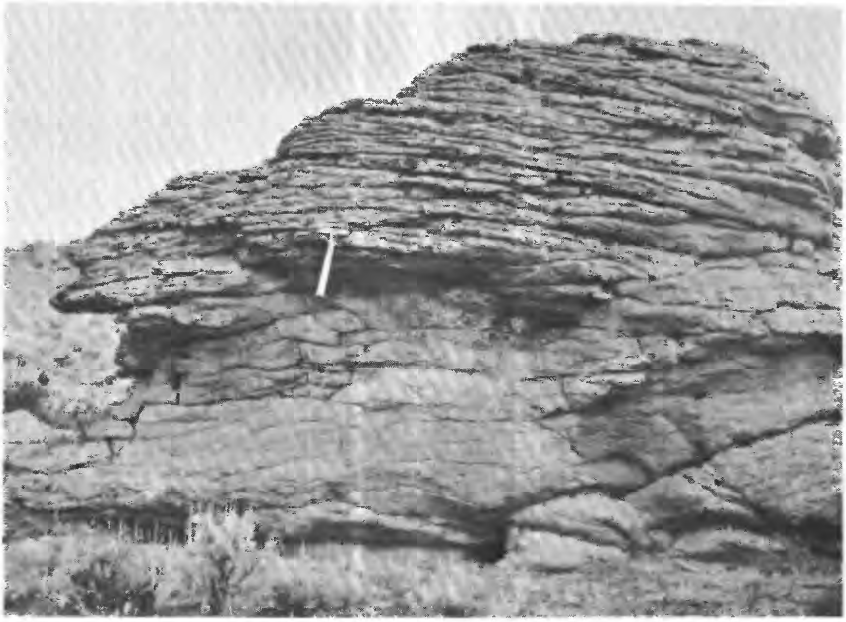

FIGURE 6.—Crystal-rich Fish Canyon Tuff between Willow and Sugar Creeks, Iola quadrangle, showing flat foliation and typical beehive weathering form.

FIGURE 7.—Welded Fish Canyon Tuff exposed at northwest end of Sapinero Mesa, Sapinero quadrangle. Slabby habit at top of cliff, characteristic of this formation, seems to be controlled by compaction foliation and surficial exfoliation. Cliff is about 20 feet high.

goclase (An_{20-40}); the remainder are sanidine, biotite, quartz, oxyhornblende, and sparse pale-green clinopyroxene. Euhedral biotite plates as much as 4 mm across are distinctive and constitute 2–3 percent of the tuff. The biotite is iron rich and has a strong pleochroism from dark dusky brown to pale brown or colorless. Quartz is sporadic and uncommon, and most quartz grains are rounded owing to marginal resorption. Tridymite is present but rare. Sphene is more conspicuous as an accessory mineral in the Fish Canyon Tuff than in other ash flows in the region; apatite and magnetite are also common accessories. The pinkish-gray microcrystalline groundmass has an axiolitic to felted texture and consists chiefly of sanidine and alpha cristobalite. Devitrified pumice fragments, which have frayed terminations, occur in places.

Numerous black shards and some glassy pumice fragments are present in places near the base of the Fish Canyon Tuff. One sample of glass in this basal vitric phase has a refractive index of 1.500 ± 0.004.

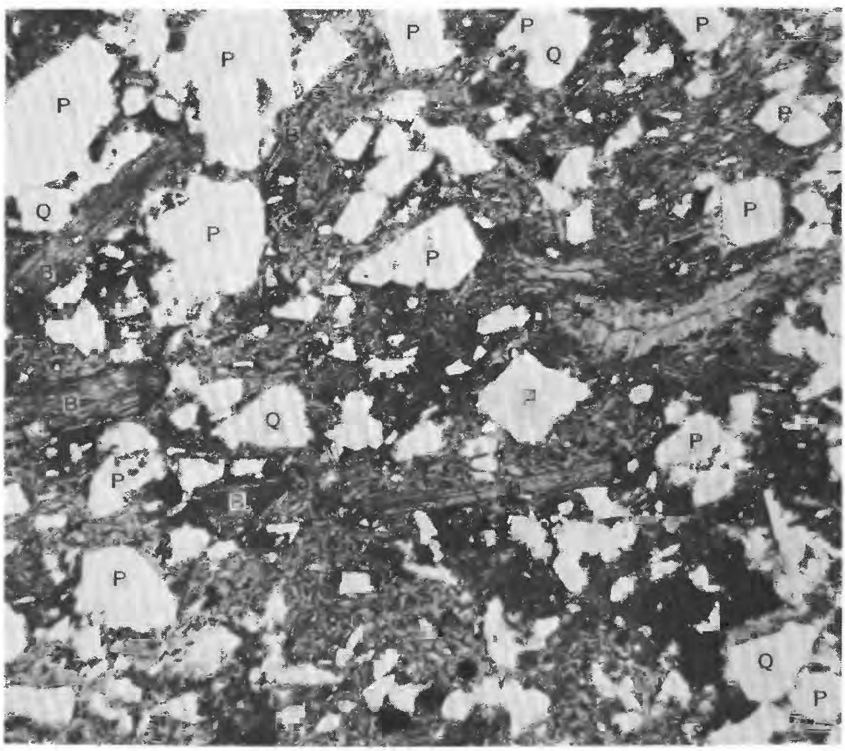

FIGURE 8.—Crystal-rich Fish Canyon Tuff, south end of Sapinero Mesa in central part of Gateview quadrangle. Fragmented sodic andesine-calcic oligoclase phenocrysts (P), minor quartz (Q), and accessory biotite (B) in matrix of welded devitrified ash and pumice; × 18.5, plane-polarized light.

The lower part of the formation is commonly well consolidated, massive, and strongly welded, and it locally contains numerous angular inclusions of Precambrian and Mesozoic rock fragments at the base.

Upward in the ash flow the tuff becomes less welded, the biotite crystals become smaller, and the less-welded tuff grades into nonwelded pumiceous tuff. This transition zone is locally characterized by concretions as much as 2½ feet across. From a thickness of more than 100 feet in the northeastern part of the Iola quadrangle, the upper, nonwelded part of the tuff pinches out to the southwest within a few miles.

The Fish Canyon Tuff is a very large ash-flow and airfall sheet that appears to have been deposited largely by eruptions from a southern source. It is probably composite, although lithologic breaks in it are difficult to recognize. There is a generally greater degree of welding toward the south and a higher proportion of nonwelded tuff toward the north and northeast. The Fish Canyon Tuff rests on the Sapinero Mesa Tuff or older Tertiary volcanics in some areas, but in others it was deposited on Precambrian rocks on a surface of considerable relief. The surface of the Fish Canyon Tuff before erosion was smooth and flat, but ridges of Precambrian rock projected above it in places. The Fish Canyon Tuff has been tentatively traced southward into the drainage basin of the upper Rio Grande (T. A. Steven and R. G. Luedke, written commun., 1965) and extends at least 15 miles eastward from the northeast corner of the Iola quadrangle beyond Cochetopa Creek.

Biotite from a sample of Fish Canyon Tuff collected by Hansen on Sapinero Mesa in the Sapinero quadrangle had a potassium-argon age of 27 million years±10 percent as determined by H. H. Thomas, R. F. Marvin, and Paul Elmore of the U.S. Geological Survey.

CARPENTER RIDGE TUFF

The Carpenter Ridge Tuff consists of at least two ash flows, some water-laid tuff, and tuffaceous gravel. It is preserved only locally in the mapped area, owing to erosion that has exposed the underlying Fish Canyon Tuff and older rocks. A vitrophyre occurs in many places near the base of the formation and locally overlies a basal nonwelded tuff and some gravel deposits. Most of the formation is devitrified welded tuff, but the upper part is typically a soft, easily eroded nonwelded tuff.

The Carpenter Ridge Tuff is here named for a ridge of the same name in the Cebolla quadrangle where the formation is well exposed. It is 240 feet thick in the type area on Carpenter Ridge (loc. 7, pl. 1), but 170–200 feet in the southern part of the region, 200–230 feet in the central part, 200–280 feet on Black Mesa north of the Black Canyon, and as much as 295 feet on Big Mesa in the northeastern part. In general, the proportion of the formation that is nonwelded increases toward the north.

White to light-buff nonwelded pumiceous tuff at the base of the Carpenter Ridge is locally as much as 230 feet thick. It is a weak, friable rock that overlies the soft nonwelded upper part of the Fish Canyon Tuff, so that the contact of these two tuffs is difficult to establish in many places. The tuff is generally poorly sorted, only locally stratified, and rarely crossbedded, and it contains no more than 25 percent phenocrysts. This basal part of the formation locally contains lenses of angular fragments of Precambrian rock and Mesozoic quartzitic sandstone. The nonwelded tuff largely represents an airfall tuff that was locally reworked by streams.

The Carpenter Ridge is composed of white lustrous pumice fragments, ash, and comminuted crystal fragments. Phenocryst fragments, which compose 5–10 percent of the tuff, consist chiefly of zoned angular sodic andesine and calcic oligoclase (An_{25-35}), sanidine, biotite, magnetite, oxyhornblende, and sparse pale-green clinopyroxene. Euhedral biotite plates are disseminated in the tuff and are similar in size and quantity to those in the Fish Canyon Tuff. The shards are angular and of rhyolitic composition. Coarse white pumice fragments are abundant and become larger, as much as 8 inches long, upward in the tuff; they are commonly compacted and alined with their long axes parallel to the bedding, imparting a compaction foliation to the tuff. Angular fragments of Precambrian schist and Mesozoic quartzite are locally abundant in the nonwelded tuff, particularly in the lower part; they may have been picked up by the ash flow or deposited by streams.

Black shards that are dispersed throughout the upper 15 feet of the basal nonwelded unit in some places increase in abundance upward to form a discontinuous vitrophyre (fig. 9) about 10 feet thick. The vitrophyre is overlain by devitrified welded tuff (fig. 10) 20–140 feet thick.

The devitrified welded tuff, which makes up most of the Carpenter Ridge Tuff, is a reddish-brown to light-gray lithoidal rock; hollow lithophysae are locally abundant in the upper part of the unit. The groundmass consists of welded ash and pumice that have crystallized to sanidine and alpha cristobalite. The texture is eutaxitic—flattened deformed shards are molded about crystal and lithic fragments.

Variations within the Carpenter Ridge Tuff indicate that it is composed of two or more ash flows. Vitrophyres or other distinctive zones appear locally at two or more horizons in a vertical section. On Round Mountain in the southwestern part of the Gateview quadrangle, for example, at least two cooling units, 140 and 50 feet thick, are present, and float fragments of partly vitric tuff suggest the possibility of more than two. Near Big Mesa in the Iola quadrangle, stratification in the upper part of a nonwelded tuff unit in the Carpenter Ridge indicates local airfall deposition or reworking by streams between ash flows.

In three areas on the mesa west of Willow Creek in the Iola quadrangle, tuffaceous breccia as much as 50 feet thick overlies the devitrified welded tuff. In mapping, this breccia was assigned to the upper part of the Carpenter Ridge Tuff. Angular boulders and cobbles of Mesozoic quartzite and diverse Precambrian rocks released by the weathering of the tuffaceous matrix cover the ground in many places.

Resistant and conspicuous columnar pipes that are interpreted as being fossil fumaroles locally characterize the soft nonwelded tuff in the lower part of the Carpenter Ridge Tuff. The pipes are best developed atop the hill just west of Kezar Basin, Cebolla quadrangle, where they form vertical and cylindrical pipes (fig. 11) as much as 6 feet high and 6–12 inches thick. The pipes contain more Precambrian schist fragments and also more coarsely crystalline calcite than the surrounding tuff. Both the schist fragments and the calcite become

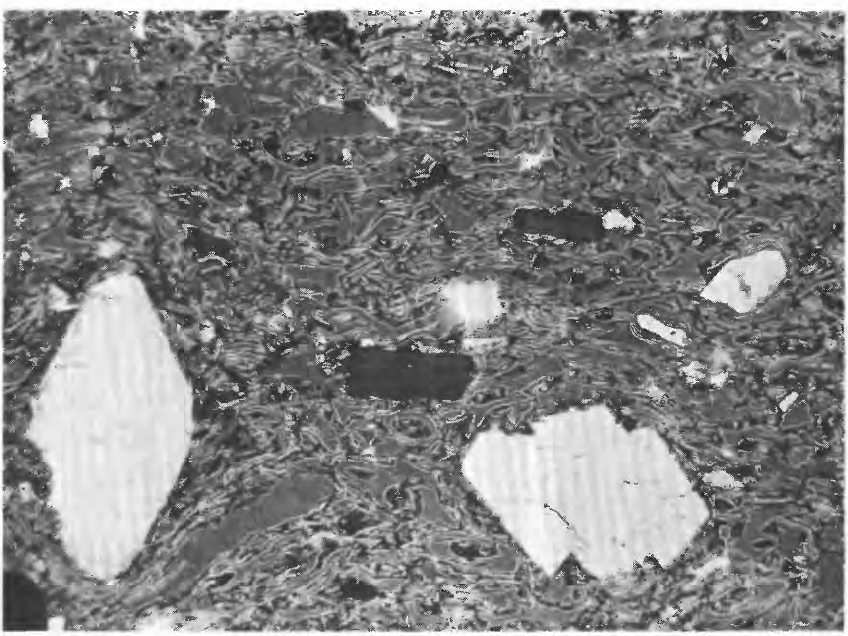

FIGURE 9.—Photomicrograph of vitrophyre of Carpenter Ridge Tuff, south-central part of Gateview quadrangle (outcrop shown in fig. 10). Partly fragmented calcic oligoclase phenocrysts and biotite in matrix of welded shards. × 22.5, plane-polarized light.

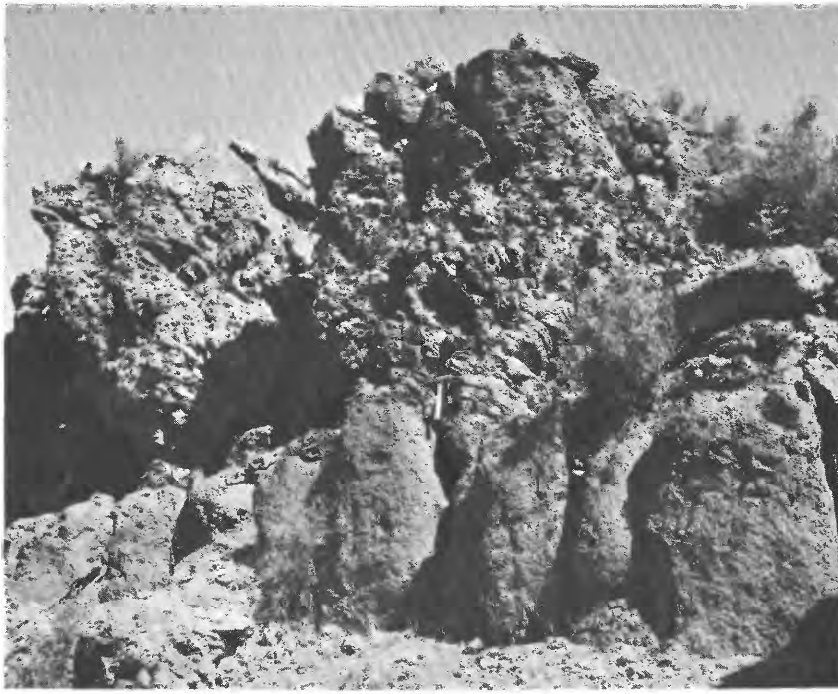

FIGURE 10.—Vitric and devitrified welded tuff near base of Carpenter Ridge Tuff, south-central part of Gateview quadrangle. Lower compact base, below hammer, is black vitric welded tuff containing scattered reddish-brown spherulites. Upper part is reddish-brown devitrified welded tuff containing abundant hollow lithophysae.

coarser toward the cores of the pipes. The marginal parts of the pipes consist of calcite-cemented tuff, and nearby joints within the non-welded tuff are filled with calcite.

HINSDALE FORMATION

Dark flows of the Hinsdale Formation, latitic to basaltic in composition, originally extended over much of the Powderhorn region. The flows were erupted upon a surface of low relief eroded across the volcanic and older rocks; the flows are commonly separated from the ash-flow tuffs and diverse older rocks by a layer of gravel generally less than 40 feet thick which is included in the Hinsdale Formation. The Hinsdale Formation is the youngest volcanic rock in the region and was considered to be Pliocene(?) in age by Larsen and Cross (1956, p. 92). An age of 12.5 million years was recently determined by the potassium-argon method for the Hinsdale Formation south of the area of this study (T. A. Steven, oral commun., 1965). Erosion has removed the Hinsdale Formation from much of the Powderhorn–

FIGURE 11.—Vertical calcite-rich pipes, interpreted to be fossil fumaroles, in soft, nonwelded tuff atop hill west of Kezar Basin, Cebolla quadrangle.

Black Canyon region except for isolated caps on the higher ridges and mesas (fig. 12). The Hinsdale ranges in thickness from about 150 feet on mesas near the Gunnison River to 600 feet on ridges east and west of Powderhorn Creek, in the southern part of the area and nearer the source.

The Hinsdale Formation contains flows ranging in composition from latite to basalt (Larsen and Cross, 1956, p. 208). The rock is commonly gray to dark bluish gray, aphanitic to porphyritic, and vesicular or scoriaceous, and it locally contains sparse calcite-filled amygdules. Flow structures are present, and in some localities the base is reddened and ropy. Typically, a few andesine (An_{38-43}) and pale-green clinopyroxene phenocrysts are set in a microcrystalline, trachytic groundmass consisting of andesine and sanidine microlites with interstitial magnetite and pale-green clinopyroxene. Specimens from the two small remnants of the Hinsdale Formation preserved on Pine Creek Mesa in the Sapinero quadrangle contain scattered phenocrysts of zoned plagioclase (about An_{60}), augite, and altered

FIGURE 12.—Flow of Hinsdale Formation (above) capping Fish Canyon Tuff (below), showing typical rounded form of some outcrops of Fish Canyon Tuff. South of Big Springs in south-central part of Iola quadrangle.

olivine in a subophitic matrix containing abundant microlites of plagioclase, abundant grains of orthopyroxene, and scattered irregular grains of magnetite.

In the southeastern part of the Cebolla quadrangle, the Hinsdale consists of two flows: a lower, nonporphyritic flow about 40 feet thick and an upper, porphyritic flow about 120 feet thick. The bases of the flows are commonly dense, gray, and platy, and the flow tops are commonly reddened, scoriaceous, and weathered to rubbly surfaces.

Gravel at the base of the flows of the Hinsdale Formation contains boulders of quartzitic sandstone and conglomerate and small amounts of granite, other Precambrian rocks, and Tertiary volcanic rocks. In places the gravel contains no boulders of Tertiary volcanic rocks; this absence suggests that some of the gravel was deposited on the welded tuffs from higher terranes of pre-Tertiary rocks nearby.

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