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STRATIGRAPHIC RELATIONS BETWEEN BONANZA CENTER AND ADJACENT PARTS OF THE SAN JUAN VOLCANIC FIELD, SOUTH-CENTRAL COLORADO

by

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INTRODUCTION

Stratigraphic relations of units derived from the Bonanza volcanic center in the northeastern part of the San Juan volcanic field and units from sources in the central and western parts of the field are well exposed in the Trickle Mountain and Lake Mountain NE quadrangles, 8-16 miles northwest of Saguache, Colorado (figs. 1 and 2), where Saguache Creek and its tributaries East Pass, Sheep, Jacks, Cross, Middle and Ford Creeks have cut numerous valleys into the Cenozoic volcanic rocks. These exposures show that many of the rocks from the Bonanza center are generally equivalent in age to the early intermediate rocks in the rest of the San Juan volcanic field, and are older

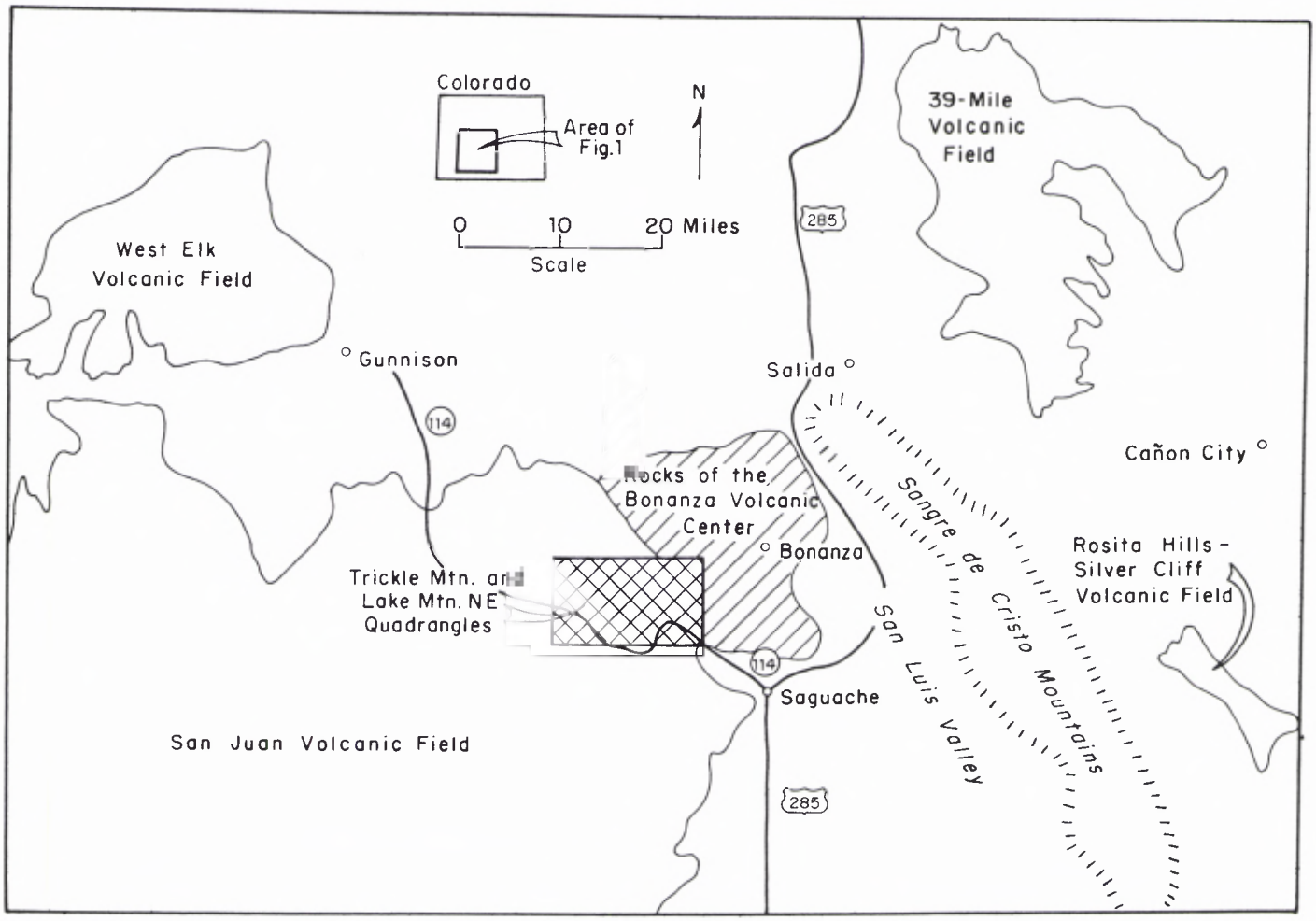

FIGURE 1.

Location of the Trickle Mountain and Lake Mountain NE quadrangles in the San Juan volcanic field, Colorado.

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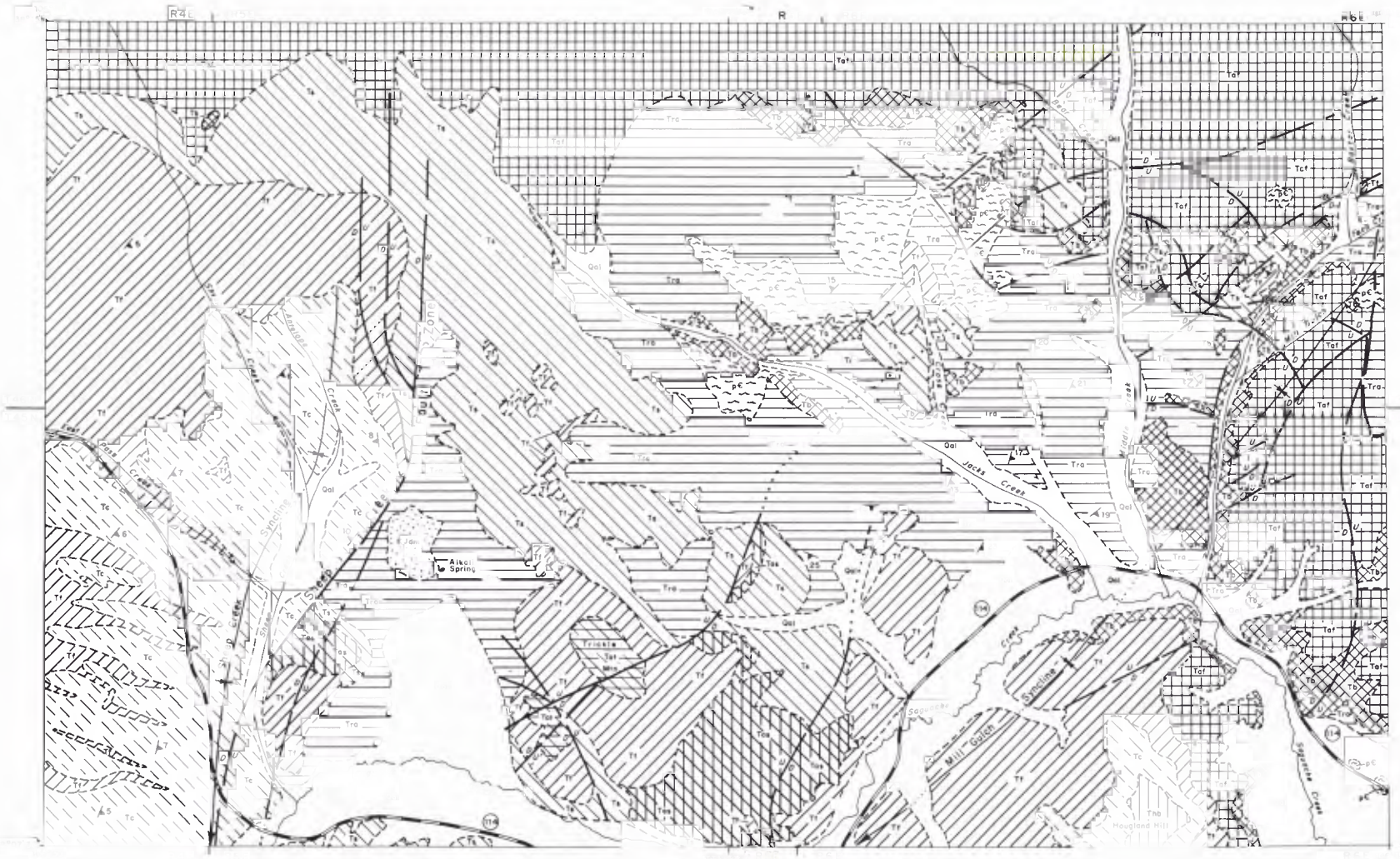

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than most of the ash-flow tuffs derived from caldera source areas in the central and western parts of the field.

PREVIOUS WORK

The San Juan volcanic field has been studied by many geologists in the past 100 years. Much of the earlier work was summarized by Larsen and Cross (1956), who included the volcanic rocks in and adjacent to the southern and western parts of the area described here in the Conejos Quartz Latite, Treasure Mountain Rhyolite, Sheep Mountain Quartz Latite, Alboroto Rhyolite, and Piedra Rhyolite of the Potosi Volcanic Series (fig. 3).

Later work in the western San Juan Mountains by Luedke and Burbank (1963) led to redefinition of the Potosi Volcanic Series to Potosi Volcanic Group, and to include a specific assemblage of ash-flow units there.

Steven and Ratté (1965, p. 13) abandoned use of the Potosi in the Creede area in the central part of the San Juan volcanic field. Olson, Hedlund, and Hansen (1968) re-studied ash-flow tuffs in the Powderhorn-Gunnison River region where they defined the Blue Mesa, Dillon Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs. These units were formerly mapped by Larsen and Cross as the Alboroto and Piedra Rhyolites. Olson, Hedlund, and Hansen (1968) retained the name Conejos Quartz Latite where previously used and included it, together with the Lake Fork Formation and the West Elk Breccia, as part of an assemblage of "older volcanic rocks of Tertiary age" (fig. 3).

Recently, Lipman, Steven, and Mehnert (1970) interpreted the volcanic history of the San Juan field on the basis of potassium-argon dating. They presented a major three-fold petrologic subdivision of the volcanic rocks: early intermediate lavas and breccias (generally 35-30 m.y. old), followed closely in time by more silicic ash-flow tuffs and related lavas (30-26.5 m.y.), and ending with a bimodal association of basalt and rhyolite (23.5-5 m.y.). They used the term Conejos Formation for the early intermediate rocks in the central and eastern parts of the San Juan volcanic field, and on the basis of radiometric ages, suggested that the Bonanza volcanic pile was correlative (fig. 3).

The volcanic rocks of the Bonanza center were first described by Patton (1916), and were treated in more detail in a comprehensive report by Burbank (1932). A summary of local stratigraphic terminology as proposed by Burbank is shown in figure 3.

Recent graduate thesis research by students from the Colorado School of Mines (Mayhew, 1969, Bruns, 1971, Perry, 1971, and Marrs, in progress), has expanded the knowledge of the Bonanza pile outward from the central mineralized area studied by Patton and Burbank. Burbank (1932) considered the Hayden Peak Latite to be younger than the Rawley Andesite, but additional work by Mayhew (1969) indicates that in large part the two units intertongue. Patton (1916) originally named the Bonanza Latite, and this usage was followed by Burbank (1932). Mayhew (1969) identified the Bonanza Latite as an ash-flow tuff and emphasized its stratigraphic and structural importance. The ash-flow sheet has since been traced from the northeastern and central parts of the Bonanza volcanic pile southwestward into the Trickle Mountain and Lake Mountain NE quadrangles by work of Marrs and Bruns, and students of the Geology Summer Field

MODIFIED AFTER LARSEN AND CROSS (1956)	OLSON, HEDLUND, AND HANSEN (1968)	MODIFIED AFTER LIPMAN, STEVEN, AND MEHNERT (1970)	THIS REPORT	BURBANK (1932)
Hinsdale Formation Basalt and Rhyolite	Hinsdale Formation	Hinsdale Formation Basalt (4.7-23.4 m.y.) and Rhyolite (4.8-22.4 m.y.)	Hinsdale Formation	
		ASH-FLOW TUFFS AND RELATED ROCKS		
Piedra Rhyolite	Carpenter Ridge Tuff	Carpenter Ridge Tuff-Bachelor Mtn. Rhyolite	Carpenter Ridge Tuff	
Alboroto Rhyolite Sheep Mtn. Quartz Latite	Fish Canyon Tuff	Fish Canyon Tuff-La Garita Qtz. Latite (27.8 m.y.)	Fish Canyon Tuff Andesite of Saguache Creek Water-laid and air-fall tuffs of Saguache Creek	Porphyry Peak Rhyolite Brewer Creek Latite
Treasure Mtn. Rhyolite	Sapinero Mesa Tuff		Sapinero Mesa Tuff	Squirrel Gulch Latite
	Dillon Mesa Tuff	Tuff of Masonic Park (28.2 m.y.)	Andesite of Ford Creek	
	Blue Mesa Tuff	Treasure Mtn. Rhyolite (29.8 m.y.)	Bonanza Tuff	Bonanza Latite
		EARLY INTERMEDIATE LAVAS AND BRECCIAS		
Conejos Quartz Latite Bonanza volcanic pile	*"OLDER VOLCANICS"* Conejos Quartz Latite, Lake Fork Formation, and West Elk Breccia	Conejos Formation (31.1-34.7 m.y.), Lake Fork Formation, West Elk Breccia and San Juan Fm. (Included Bonanza volcanic pile)	Rawley Andesite	Hayden Peak Latite and Rawley Andesite

FIGURE 3.

Summary and Correlation of Stratigraphic Terminology of the San Juan volcanic field and the Bonanza center. Established correlations are shown by horizonal dotted lines.

Course (1965-71) of the Colorado School of Mines under the direction of R. C. Epis and R. J. Weimer.

The area south and southwest of the Trickle Mountain and Lake Mountain NE quadrangles has been mapped by T. A. Steven of the U. S. Geological Survey, who extended his studies to Houghland Hill in the Lake Mountain NE quadrangle to establish a stratigraphic tie of his units with those derived from the Bonanza center.

STRATIGRAPHY OF THE TRICKLE MOUNTAIN AND LAKE MOUNTAIN NE QUADRANGLES

All major units discussed in this report that have been named by previous workers have been used in the form already established, except that Bonanza Tuff is proposed instead of Bonanza Latite, so as to describe the unit more clearly and to bring the terminology into conformity with that used for most other major ash-flow tuff units in the San Juan volcanic field. Informal designations have been used for all units not previously named formally.

PRE-VOLCANIC ROCKS

Pre-volcanic rocks crop out in several erosional windows where streams have cut through the volcanic rocks to expose some of the higher parts of the pre-volcanic topography. The older rocks consist largely of Precambrian crystalline rocks, but sedimentary rocks of the Morrison Formation and Dakota Sandstone are exposed in one window. Precambrian rocks are mainly medium- to coarse-grained quartz-biotite-microcline schist and gneiss with smaller quantities of fine- to medium-grained granite and granitic pegmatite. The largest and most numerous outcrops of Precambrian rocks are in the northwestern part of the Lake Mountain NE quadrangle between Jacks Creek and Middle Creek. Smaller outcrops are scattered about elsewhere, as for example, the three exposures along Colorado State Highway 114 near the southeastern corner of the Lake Mountain NE quadrangle. The Morrison Formation and Dakota Sandstone are exposed near the center of the Trickle Mountain quadrangle, immediately northwest of Alkali Spring. Here the Morrison is in depositional contact with the Precambrian and consists of about 30-50 feet of red, green, and tan mudstones, siltstones, and shales. The Morrison is overlain by about 50-70 feet of fine- to medium-grained, ferruginous orthoquartzite of the Dakota Sandstone. Conglomerate layers with pebbles of chert and quartzite up to one-half inch in diameter are found in the lower part of the Dakota.

In the area described, the pre-volcanic (pre-Early Oligocene) topography must have had moderate relief inasmuch as the present maximum difference in elevation on the top of the underlying Precambrian rocks is 1,370 feet. Some of this difference can be accounted for by post-volcanic faulting, but a topographically high area of pre-volcanic rocks trending northeastward between Jacks Creek and Middle Creek, and measuring about 2 by 4 miles, does appear to have existed. Whether this high area resulted from pre-volcanic structural disruption cannot be determined locally because of the extensive cover of Tertiary volcanic rocks.

TERTIARY VOLCANIC ROCKS

CONEJOS FORMATION

The Conejos Formation, as used by Larsen and Cross (1956, pl. 1) and more recently in extensive reconnaissance and detailed studies in the San Juan Mountains by T. A. Steven and P. W. Lipman of the U. S. Geological Survey (oral communication, 1971), is an accumulation of lavas and breccias, largely of intermediate composition, that was erupted from a number of local volcanoes throughout the eastern and central parts of the San Juan volcanic field. Considering the broad and rather loose definition of the Conejos that has grown by usage, the more general term "early intermediate rocks" used by Lipman, Steven, and Mehnert (1970) is perhaps preferrable. Equivalent rocks in local areas such as the western San Juan Mountains and around Bonanza, have been subdivided into smaller mappable units, many of which warrant formational rank.

Each of the early intermediate (Conejos Formation) centers had its own local volcanic history, and commonly it is difficult to establish specific equivalencies between local units derived from nearby centers. It is especially difficult to do so between units from distant centers. Broad equivalencies have been indicated by potassium-argon dating (Lipman, Steven, and Mehnert, 1970), and by marginal intertonguing of locally derived rocks from adjacent centers. Most of the early intermediate rocks (Conejos Formation) appear to have been erupted between 35 and 30 m.y. ago.

In the type locality of the Conejos Formation along the Conejos River in the southeastern San Juan Mountains, the formation is overlain by the La Jara Canyon Member of the Treasure Mountain Tuff (age 29.8 m.y. according to Lipman, Steven, and Mehnert, 1970). This relationship has been traced northward to within a few miles of the Rio Grande west of Del Norte, Colorado, where the Treasure Mountain overlies rocks along the south flanks of the Summer Coon, Twin Peaks, and Baughman Creek volcanoes within the Conejos Formation.

RAWLEY ANDESITE

The oldest volcanic rocks in the Trickle Mountain and Lake Mountain NE quadrangles are a heterogeneous assemblage of andesite flows, breccias, and agglomerates that underlie the distinctive Bonanza Tuff. These rocks probably are largely locally derived, but they correlate in a broad sense with the lithologically similar Rawley Andesite and Hayden Peak Latite which underlie the Bonanza Tuff near the center of the Bonanza pile. Marrs, (in progress; see also Knepper and Marrs, this quidebook), has traced the Rawley Andesite and overlying Bonanza Tuff into the eastern part of the Lake Mountain NE quadrangle. Lipman, Steven, and Mehnert (1970) report ages of 33.4 and 34.2 m.y. for the Rawley, which are within the range (35-30 m.y.) they suggest for the more general Conejos Formation.

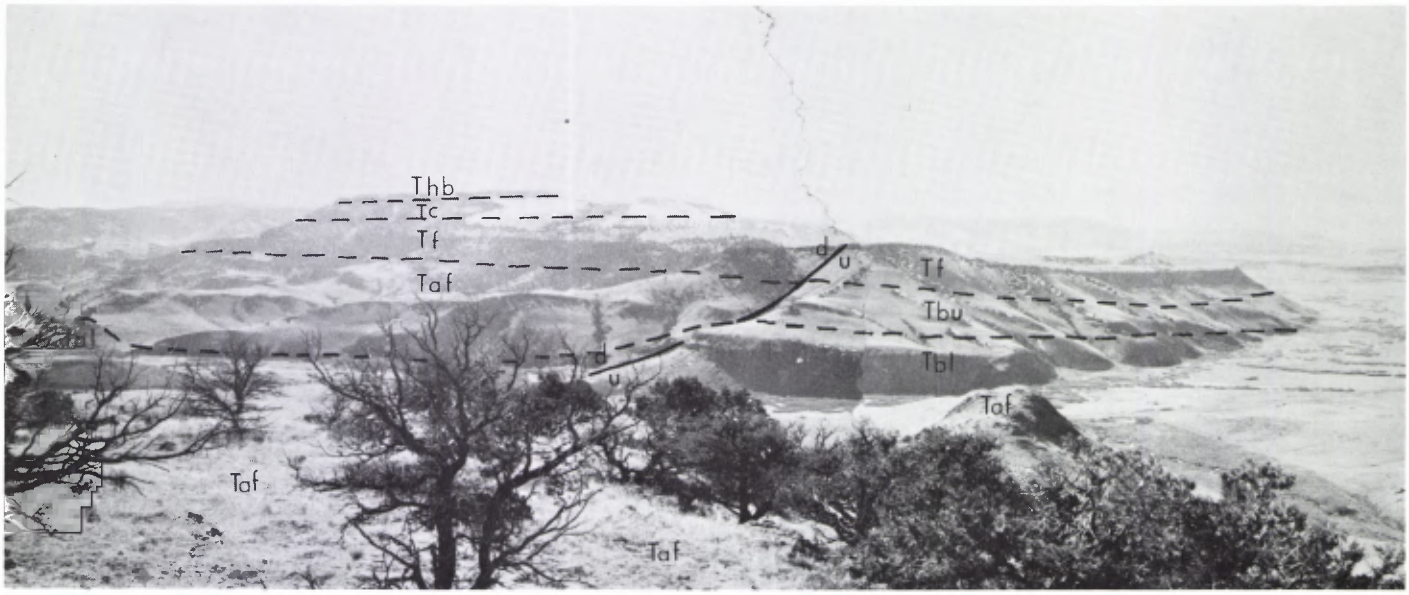

FIGURE 4.

Photograph looking southwest at Houghland Hill from above Ford Creek. Outcrops in the foreground (Taf) are part of the andesite of Ford Creek. The lower (Tbl) and upper (Tbu) cooling units of the Bonanza Tuff present in the area can be seen overlain in part by the andesite of Ford Creek (Taf) and the later Fish Canyon Tuff (Tf), Carpenter Ridge Tuff (Tc), and Hinsdale Basalt (Thb). The Bonanza Tuff has been displaced 60 to 80 feet by a fault and erosion has removed the andesite of Ford Creek from the upthrown side of the fault prior to deposition of the Fish Canyon Tuff.

BONANZA TUFF

The Bonanza Tuff is the most distinctive stratigraphic unit derived from the Bonanza center (Mayhew, 1969). The unit is a widespread ash-flow sheet that separates lithologically similar assemblages of intermediate volcanic rocks in the older Rawley Andesite and Hayden Peak Latite and the younger Squirrel Gulch and Brewer Creek Latites. As shown in figures 2 and 3, the Bonanza Tuff and associated intermediate volcanic formations derived from the Bonanza center are overlain by major ash-flow sheets (Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs), derived from caldera sources in the central and western parts of the San Juan volcanic field. These relations are clearly revealed in outcrops in the central and southern Lake Mountain NE quadrangle, particularly along the valley of Saguache Creek and the slopes of Houghland Hill (fig. 4).

The maximum thickness of the Bonanza Tuff in the Trickle Mountain and Lake Mountain NE quadrangles is about 450 feet, although it generally is thinner, and locally is absent where it wedges out against the higher parts of pre-existing topography. Locally the Bonanza Tuff consists of 2 cooling units. The lower unit forms prominent dark reddish brown outcrops. It is a moderately to densely welded rock that contains phenocrysts of sanidine, andesine, and biotite, as well as characteristic purplish-gray lithic lapilli. The upper unit is lighter in color, less welded, and generally does not form good outcrops. The upper unit also contains fewer andesine and biotite phenocrysts and lithic lapilli. A few miles northeast of the Lake Mountain NE quadrangle, along Findley Gulch, the Bonanza Tuff is considerably thicker and displays at least 5 separate cooling units. Good exposures of the Bonanza Tuff occur along Colorado State Highway 114 northeast of Houghland Hill.

Mapping is incomplete in and around the Bonanza volcanic field, and the source and lateral distribution of the Bonanza Tuff are unknown. The unit is suspected to have originated from the Bonanza volcanic center as suggested by Burbank (1932) and Mayhew (1969), and it may be equivalent to Ash-Flow 7 of the Thirtynine Mile volcanic field (Epis and Chapin, 1968) northeast of Salida, Colorado. These relationships are as yet unconfirmed and a more complete evaluation must wait further field and petrographic work.

ANDESITE OF FORD CREEK

A series of interbedded andesitic and latitic flows and flow breccias intervene between the Bonanza and Sapinero Mesa Tuffs in the northern and eastern parts of the area of figure 1. The flows are well exposed along the valleys of Ford Creek and Bear Creek, and the informal name is taken from the former locality. The rocks thicken to the northwest and northeast, and appear to have been derived from separate centers in these respective directions; the maximum thickness exposed in the Trickle Mountain and Lake Mountain NE quadrangles is about 1,100 feet. The andesites along Ford Creek may represent southwestern extensions of the Squirrel Gulch and Brewer Creek Latites which overlie the Bonanza Tuff near the center of the Bonanza pile (figs. 3 and 4).

On the southeast side of Houghland Hill just south of

the area of fig. 2, the andesite of Ford Creek intertongues with thick intermediate flows forming part of an assemblage that extends southward at the top of the section of early intermediate rocks to the vicinity of Carnero Creek, 12 miles north of Del Norte, Colorado. This assemblage overlies rocks from Conejos-age volcanoes at Tracey Creek, Beidel, Summer Coon, and Baughman Creek, and was mapped separately by Larsen and Cross (1956, pl. 1) as Sheep Mountain Quartz Latite. Regional studies by T. A. Steven and P. W. Lipman (oral commun., 1971) have cast doubt on the correlation of these flows with the type Sheep Mountain west of Wolf Creek Pass, but the problem of age still exists. For convenience, Steven and Lipman have included these thick flows in the early intermediate assemblage (Conejos Formation) in reconnaissance mapping of the Durango 1° x 2° quadrangle, but recognize that this assignment is arbitrary. Geologically, the flows are bracketed by dated rocks in the Conejos volcanoes at Beidel and Summer Coon (34-32 m.y.) and the Sapinero Mesa Tuff (older than 28 m.y.); (Lipman, Steven and Mehnert, 1970), and conceivably could be equivalent to some of the lavas intertongued elsewhere with the ash-flow sequence. Additional data, especially radiometric ages for the Bonanza Tuff, are badly needed before precise correlations can be made.

Sapinero Mesa Tuff

The Sapinero Mesa Tuff (Olson, Hedlund and Hansen, 1968) is the oldest of the major ash-flow sheets derived from the central or western parts of the San Juan volcanic field that is present in the area of this report (fig. 3). It underlies most of the northwestern and central parts of the area, and in the northeastern part, it rests directly on the andesite of Ford Creek. The Sapinero Mesa Tuff consists of a single cooling unit with a thin, light gray, poorly welded base grading upward into a thick, cliff-forming, densely welded, reddish-brown devitrified interior, and finally into a thin, light-colored nonwelded upper zone. Locally, the densely welded zone develops lenticular vugs up to 4 inches in diameter that represent lithophysae and weathered-out devitrification spherulites.

The Sapinero Mesa is a crystal-poor quartz latite tuff with 5-10 per cent phenocrysts of andesine, sanidine, biotite, quartz and minor hornblende. Flattened pumice lapilli are common. It attains a maximum thickness of 200 feet in the area. Locally it is underlain by light-colored air-fall and water-laid tuffs and tuffaceous sedimentary rocks, but outcrops of these units are too thin and small to show in figure 2. The Sapinero Mesa Tuff extends more than 80 miles from its pinchout in the Houghland Hill area westward toward its probable source in the caldera areas in the western part of the San Juan volcanic field.

Water-laid and Air-fall Tuffs of Saguache Creek

The Sapinero Mesa Tuff is overlain by as much as 200 feet of light gray water-laid and air-fall tuffs. These are best exposed on both sides of Saguache Creek between Trickle Mountain and Houghland Hill. The tuffs are predominantly of air-fall origin, but there are many interbedded zones showing reworking, channeling and cross-stratification. Several of the reworked layers contain volcanic gravels mainly of andesitic composition.

Andesite of Saguache Creek

A local accumulation of gray andesitic lavas as much as 200 feet thick occurs between the Sapinero Mesa Tuff and the Fish Canyon Tuff just north of Saguache Creek along the south-central margin of the map area where they overlie the water-laid and air-fall tuffs described above. The andesitic lavas form prominent cliffs, and lithologically resemble the andesite of Ford Creek. This younger accumulation of andesite within the ash-flow sequence is similar to the intermediate lavas interbedded and associated with the major ash-flow sheets of the San Juan volcanic field as described by Lipman, Steven and Mehnert (1970).

Fish Canyon Tuff

The Fish Canyon Tuff is a distinctive ash-flow tuff that characteristically forms light salmon-colored vertical cliffs and rounded, pedestal and beehive forms on the mesas above these cliffs. Many of the surface characteristics result from weathering of a moderately welded crystal-rich tuff cut by crude columnar joints. Extensive outcrops are found along the western portion of the map area and on the slopes of Trickle Mountain and Houghland Hill (fig. 4). A local maximum thickness is about 550 feet.

The Fish Canyon is a crystal-rich quartz latite tuff, commonly containing more than 50 percent phenocrysts. The phenocrysts are mainly andesine, sanidine, and biotite, with lesser quartz and hornblende. Pumice lapilli are also common. Lipman, Steven and Mehnert (1970) indicate that it was erupted from the La Garita caldera, some 30-40 miles southwest of the area about 28 m.y. ago. The La Garita Quartz Latite represents the intercaldera equivalent (fig. 3). They estimate the area covered by the Fish Canyon Tuff to have been 15,000 sq. km. with a volume in excess of 3,000 cu. km.

Andesite of Trickle Mountain

Gray, vesicular, and platy andesite comprises the upper one-third of Trickle Mountain and rests on the Fish Canyon Tuff. The rock is similar to that of the andesite of Saguache Creek but of younger stratigraphic position. Its relation to the Carpenter Ridge Tuff is unknown. The andesite of Trickle Mountain is temporally coincident with the intermediate lavas associated with the major ash-flow sheets in the San Juan field.

Carpenter Ridge Tuff

The youngest of the San Juan ash-flow sheets present in the Trickle Mountain and Lake Mountain NE quadrangles is the Carpenter Ridge Tuff (Olson, Hedlund and Hansen, 1968). Lipman, Steven and Mehnert (1970) show that the tuff was erupted from the Bachelor caldera along the western side of the La Garita caldera, and that its intercaldera equivalent is the Bachelor Mountain Rhyolite.

The Carpenter Ridge Tuff forms extensive grass-covered

dip slopes between Sheep Creek and the western edge of the map area. Canyons that cut these slopes are flanked by prominent cliffs formed by both the Carpenter Ridge and the Fish Canyon Tuffs; these are well displayed above Colorado State Highway 114 where it follows East Pass Creek. Other excellent outcrops of the Carpenter Ridge occur on the upper slopes of Houghland Hill where it attains a maximum thickness of about 400 feet (fig. 4).

The Carpenter Ridge Tuff generally consists of a compound cooling unit in which two densely welded zones are separated by a few feet of partially welded ash. The upper and lower densely welded zones consist of black vitrophyre which commonly contains reddish brown lithophysae and aphanitic spherulites that appear nearly identical to the densely welded, devitrified rocks in the Sapinero Mesa Tuff. The thin, light gray unwelded base of the ash-flow sheet is generally covered by talus from the overlying cliffs, but it is well exposed in the highway cuts along East Pass Creek.

The Carpenter Ridge Tuff is a crystal-poor quartz latite with 5-10 per cent phenocrysts. The phenocrysts are mainly andesine, sanidine, biotite, with lesser quartz, and hornblende. Flattened pumice lapilli are also common. The Sapinero Mesa and Carpenter Ridge Tuffs are closely similar in megascopic appearance, and the formations can easily be misidentified where the intervening, distinctive Fish Canyon Tuff is absent.

Hinsdale Formation (basalt)

Houghland Hill, in the southeastern part of the Lake Mountain NE quadrangle, is capped by about 120 feet of gray to black, vesicular basalt flows of the Hinsdale Formation (Larsen and Cross, 1956). Basalt and associated rhyolite of the Hinsdale Formation are the youngest volcanic rocks in most of the San Juan volcanic field and occur in numerous scattered and isolated outcrops. They have been shown to range in age from about 5 to 23.5 m.y. (fig. 3) by Lipman, Steven and Mehnert (1970).

Post-volcanic Deposits

The only post-volcanic units in the area include a variety of Holocene surficial deposits. These include modern stream gravels and sands, older stream terrace deposits, small alluvial fans and cones, and several small landslide blocks. They are not differentiated in the accompanying geologic map (fig. 2) and are shown collectively as Quaternary alluvium (Qal).

STRUCTURE OF THE TRICKLE MOUNTAIN AND LAKE MOUNTAIN NE QUADRANGLES

Because the main purpose of this report is a description of the stratigraphy, only a brief account of the structural geology of the quadrangles is included. The mid-Tertiary volcanic rocks have been involved in both folding and faulting. Examples of larger tectonic folds include the north-northeast-trending Sheep Creek syncline on the west and the Mill Gulch syncline on the east. Small compactional folds are common in all of the ash-flow sheets and clearly reflect topographic patterns underlying them. The most significant block-faulting is displayed along the Sheep Creek fault zone where several hundred feet of displacement can be observed. This fault zone is known to continue south of the Trickle Mountain quadrangle for more than 7 miles. A number of small northeast-trending faults in the Lake Mountain NE quadrangle may be related to a broad system of radial faults associated with the Bonanza volcanic center to the northeast (Bruns, 1971; Knepper and Marrs, this guidebook). All of the rocks in the area older than the Hinsdale basalt are involved in folding and faulting. This history probably reflects the regional period of Middle to Late Cenozoic block faulting and attendant erosion which affected large segments of south-central Colorado as outlined by Steven and Epis (1968).

SUMMARY

The Trickle Mountain and Lake Mountan NE quadrangles provide physical stratigraphic correlations between units derived from the Bonanza center and units that comprise the rest of the San Juan volcanic field. The Bonanza units are equivalent to the early intermediate rocks in the field (35-30 m.y. old), and underlie the great ash-flow sheets derived from caldera-source areas in the central and western parts of the field. The Bonanza Tuff intertongues with rocks believed to be equivalent to the upper part of the Conejos Formation as that unit has been mapped to the south. Basalt of the Hinsdale Formation caps both the units derived from the Bonanza center and the ash-flow tuffs from the west and southwest; this basalt probably was erupted some time during the Miocene or Pliocene as similar basalts have been dated as ranging between 23.5 and 5 m.y. in age. Post-Oliogocene folding and block faulting have deformed the volcanic and older rocks.

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