GEOLOGY OF THE EAST SIDE OF THE GUFFEY VOLCANIC CENTER, PARK COUNTY, COLORADO

A Thesis

Presented to

the Faculty of the Department of Geology

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Master of Science

by

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ABSTRACT

The Thirtynine Mile volcanic field of Tertiary age is located in central Colorado on a high plateau between South Park on the north and the Wet Mountain Valley on the south. The Guffey volcanic center consists of a cauldron, numerous domes and flows, and the remnant flanks of a large composite volcano.

The Guffey cauldron formed early in the volcanic history by subsidence of a 4 by 8 mile east-northeast trending elliptical block. Numerous domes and flows of andesitic to rhyolitic composition were emplaced within and marginal to the cauldron during and after subsidence. Alignment of 5 domes and the existence of a scarp on the prevolcanic surface indicates the presence of a high-angle tangential fault leading outward from the southeast corner of the cauldron.

Eruption of fragmental andesite from numerous, small, randomly scattered vents and lateral distribution by mudflows built a chaotically stratified breccia sheet which covered at least 600 square miles to an average depth of 500 feet. These breccias which constitute the lower member of the lower andesite are interbedded with the domes and flows of the Guffey center and probably filled the cauldron.

Stratigraphic relationships are very complex due to overlapping eruptions from adjacent vents and the interbedding of breccias unrelated to the Guffey center.

Following emplacement of the breccia sheet, a large composite volcano was built over the Guffey center by eruption of andesitic flows and flow breccias of the upper member of the lower andesite. The remnant flanks of this volcano still exist on Thirtynine Mile, Saddle, Castle, McIntyre and Witcher Mountains. The last major event at the Guffey center was the emplacement of a large dome of andesite at Cover Mountain in the eroded southeast flank of the Guffey volcano.

INTRODUCTION

Purpose

The purpose of this study was to map the Tertiary volcanic rocks of the eastern portion of the Guffey volcanic center and to interpret the geologic history of the area. Of particular importance was evaluation of a major composite volcano whose existence was postulated by previous investigators of the Thirtynine Mile volcanic field (Epis and Chapin, 1968, p. 79). A second objective was to correlate rock units described by Whitman Cross in the Pikes Peak Folio of 1894 with similar units described by Chapin and Epis (1964) and Buchanan (1967).

Location and Accessibility

The study area includes 52 square miles in southeastern Park County (T. 14 and 15 S., R. 72 and 73 W.) near the center of the Thirtynine Mile volcanic field. This volcanic field covers about 1,500 square miles in the area south of South Park and east of the Mosquito Range in central Colorado. The field extends from about

$38^{\circ}30'$ to 39° north latitude and from $105^{\circ}10'$ to 106° west longitude. The town of Guffey, Colorado lies about 1 mile west of the thesis area. Other communities nearby include Cripple Creek, Canon City, Salida, and Hartsel (fig. 1, p. 7). Park County road 102 runs through the center of the area connecting to the east with roads from Cripple Creek and Florissant, and to the west with Park County road 59 which connects Guffey with Elevenmile Canyon Reservoir. Numerous other ranch roads provide easy access to the entire area.

Physiographic Setting

The main body of the Thirtynine Mile volcanic field extends northward from the Arkansas Gorge to South Park and westward from Pikes Peak to the Mosquito Range. Abundant outliers suggest that the field was considerably more extensive prior to late Tertiary erosion. The volcanic pile forms a high plateau at elevations of 8, 500 to 9, 500 feet resulting in a cool, dry climate with only about 14 inches of rain per year. The present drainage is largely southward into the Arkansas River; streams are small but ample for cattle raising which is the principal land use. Grass-covered slopes and sparse soil development predominate on southern slopes; thick spruce and pine forests interspersed with stands of aspen cover the northern slopes.

Previous Investigations

Geologic exploration of the Thirtynine Mile volcanic field was begun with the Hayden Survey in 1873. In the Hayden Survey report (Hayden, 1874) the important features of South Park, the Park Range, and the upper Arkansas Valley were described with some references to the volcanic rocks bounding the southern edge of South Park. Endlich (1878) who contributed to the Hayden Survey also published a review of the erupted rocks of Colorado which includes many references to the rocks of the Thirtynine Mile volcanic field.

The first significant mapping of the field was done by Whitman Cross (1894) in the Pikes Peak Folio. Cross' description of the volcanic rocks and his reconnaissance map were of great value during the present study. The author feels compelled to include a word of praise for the remarkable detail and accuracy of Cross' map and petrographic descriptions.

No published accounts of the Thirtynine Mile volcanic field appeared for the next 40 years. In 1935, the Geologic Map of Colorado, compiled by Burbank, Lovering, Goddard, and Eckel, showed the outline of the field but the volcanic rocks were left undivided. Beginning in about 1933, South Park was extensively studied by J. H. Johnson (1935-1937a, 1937b) and by a group at Northwestern University under the direction of J. T. Stark. Memoir 33 of the Geological Society of America (Stark and others, 1949) includes considerable discussion of the volcanic rocks at the southern end of South Park; the thick sequence of andesitic rocks exposed along the south flank of Thirtynine Mile Mountain was termed the Thirtynine Mile volcanic series from which the field later derived its name. Lovering and Goddard (1950) have an excellent discussion of the regional geologic setting of the field and make numerous references to its volcanic rocks. Also included in their report (op. cit., p. 289) is a brief discussion by E. B. Eckel of the Guffey mining district.

Discovery of commercial uranium deposits on Tallahassee Creek in 1954 brought active interest in the area. A reconnaissance map of the Tallahassee Creek district was produced by B. A. MacPhearson (1956) for the Atomic Energy Commission. F. S. Jensen (1957) published a brief geologic summary and discussed the potential of further uranium deposits. The name "Thirtynine Mile volcanic field" was first used in this paper. Chapin and Epis (1964) published a preliminary report on the stratigraphy and structure of the Thirtynine Mile field based on several years of study and a compilation of existing data. The report includes a stratigraphic column showing the lithology, thickness, and relative ages of the major volcanic units. Chapin and Epis proposed that a caldera in the vicinity of Guffey marks the major volcanic center of the field. In recent years several geologic theses have been completed in the Thirtynine Mile field. De Voto (1961, 1964) has studied the stratigraphy and structure of the Tertiary volcanic rocks northwest of the present study area in southwestern South Park. Chapin (1965) studied the volcanic rocks in the southern part of the field, (including the Tallahassee Creek area) and worked out the volcanic stratigraphy. Buchanan (1967) mapped the geology of the western half of the Guffey volcanic center and DuHamel (1968) mapped the Thirtyone Mile volcanic center which lies immediately south of the Guffey center. The northern end of the Thirtyone Mile cauldron overlaps the Guffey cauldron west of the present study area. Epis and Chapin (1968) have compiled a second progress report based on their continued work and the investigations of graduate students working under them. The present study is one such investigation.

Methods of Investigation

Surface geology was mapped directly on a 1:31, 680 (2 inches = 1 mile) mylar topographic base map. The map was prepared by joining portions of the Cover Mountain, Guffey, and Florissant 15-minute quadrangles (U.S. Geological Survey). Aerial photographs were used as guides to the location and configuration of geological features.

Forty-five thin sections were analyzed petrographically. The rocks were classified according to Williams, Turner and Gilbert (1954) using visual estimates of their modal mineralogy. The anorthite content of 124 grains of plagioclase was determined by the Fouqué method.

Acknowledgments

Financial assistance from the Society of the Sigma Xi during the field study is gratefully acknowledged. To Professor Charles E. Chapin, I owe special thanks for the original suggestion and for his constant advice and assistance both in the field and in the office. Completion of this thesis is due in large measure to his help and encouragement. Special thanks are given to Messrs. Robert Weber and Max Willard of the New Mexico Bureau of Mines and Mineral Resources for their helpful suggestions during the laboratory investigations. I extend a special thanks to Mr. Willard whose constant criticism was of great value.

Appreciation is extended to Dr. Morgan Berthrong who graciously permitted the author to use his cabin facilities near Current Creek and to the residents of the Guffey area and particularly to Mr. and Mrs. Ownby for their consideration and helpful cooperation during the field study.

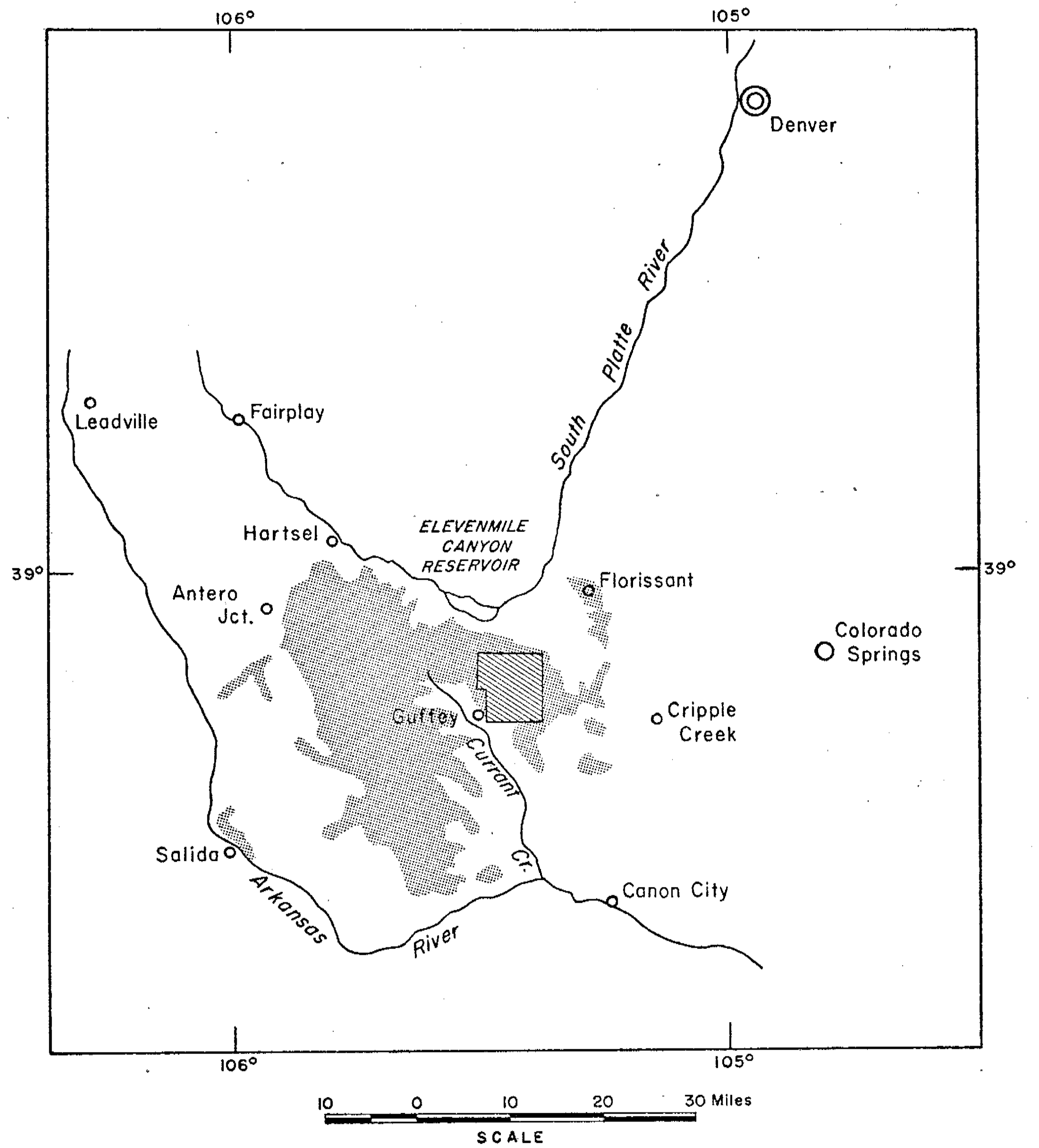
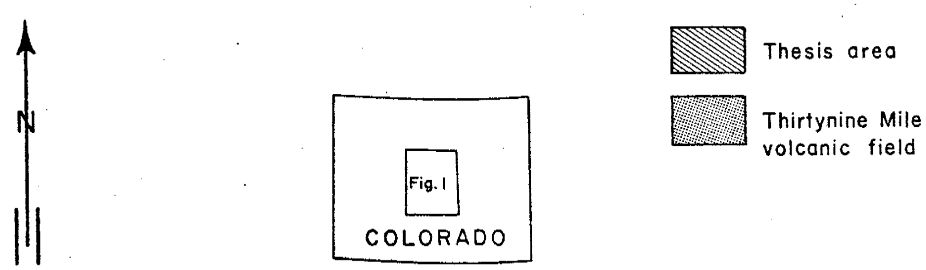


Figure 1

LOCATION OF THIRTYNINE MILE VOLCANIC FIELD, CENTRAL, COLORADO



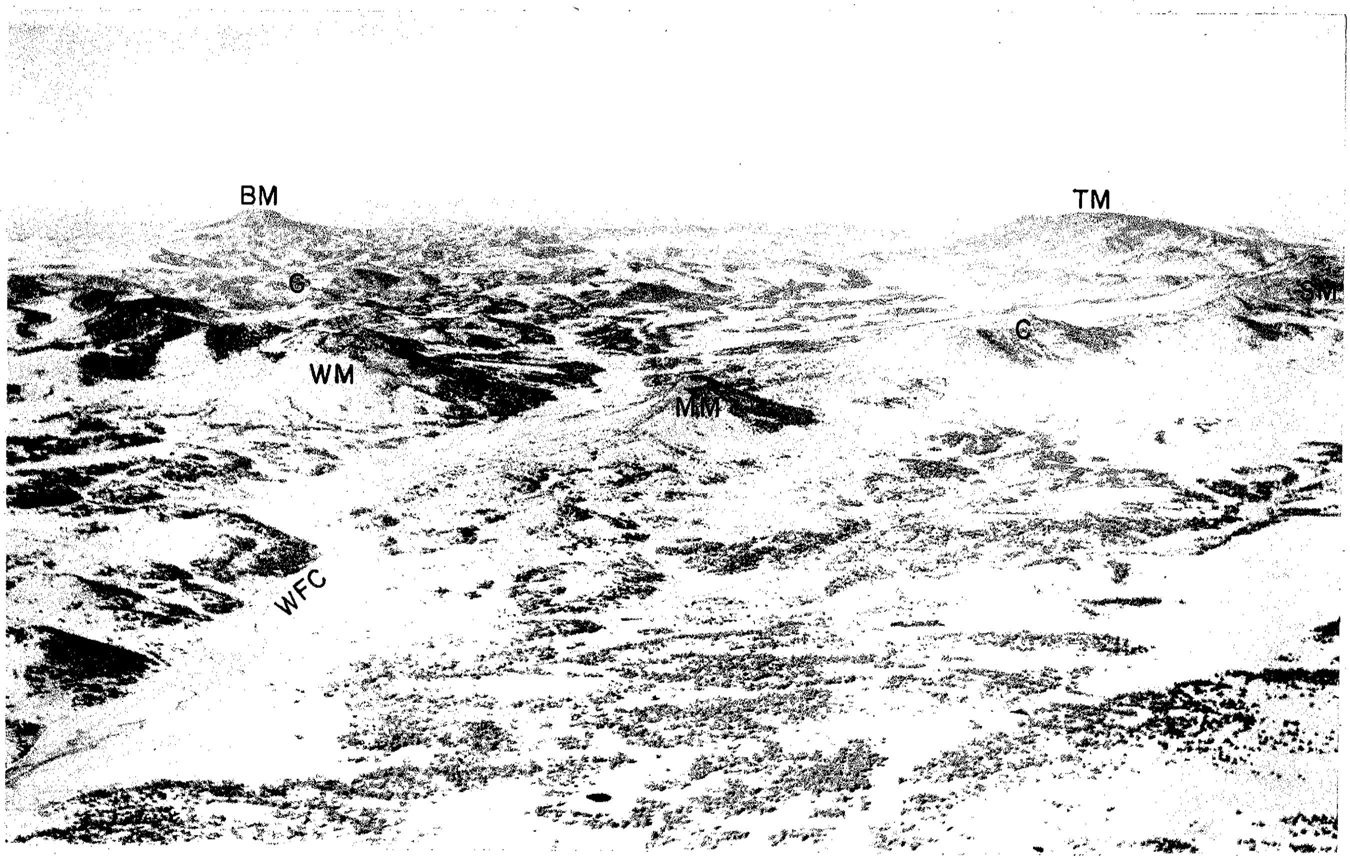


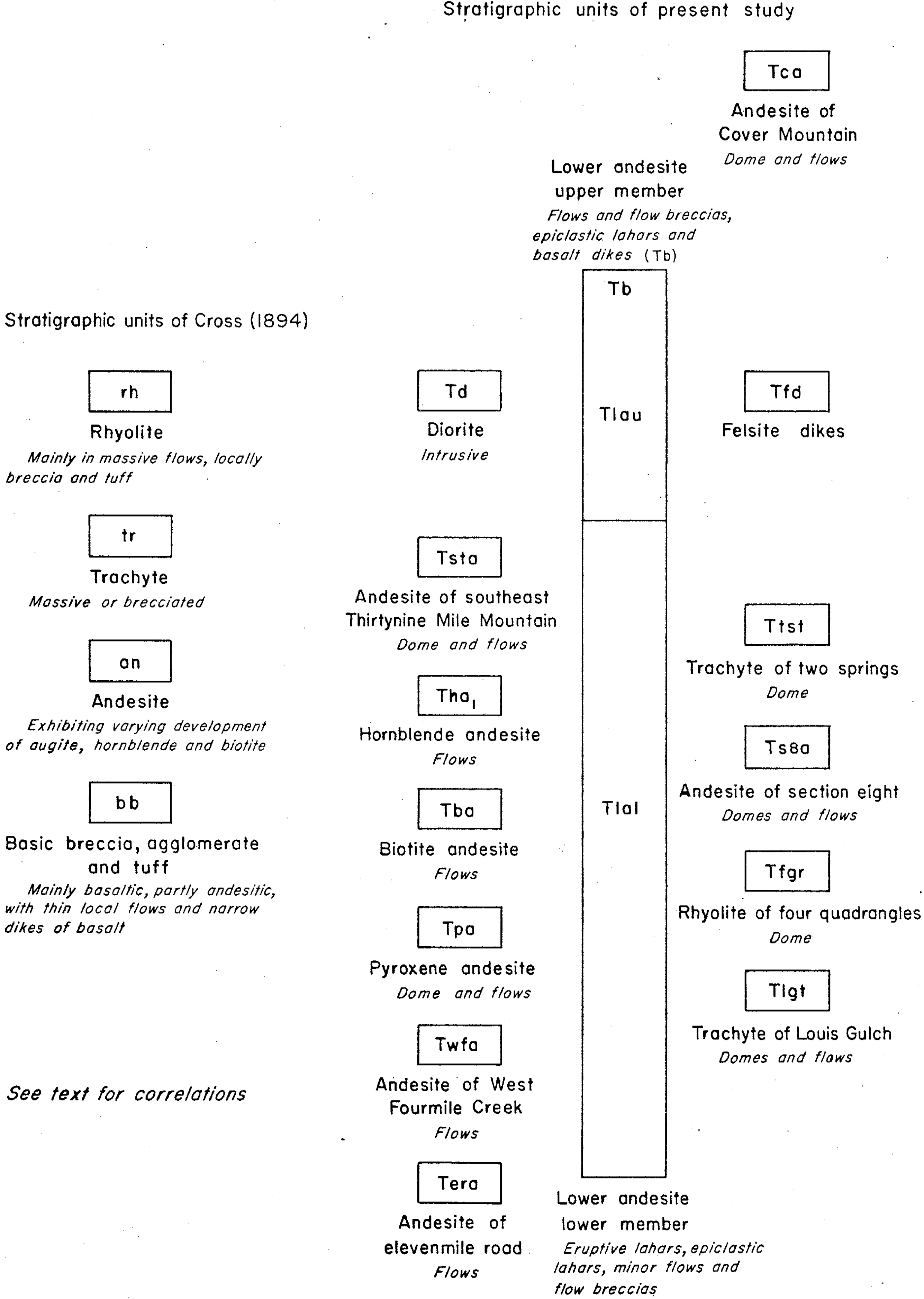
Figure 2. Oblique aerial view of the Guffey center looking west-northwest along upper West Fourmile Creek (WFC). Outward-dipping lava flows of the lower andesite (u.m.) underlie Black Mountain (BM), Thirtynine Mile Mountain (TM), Saddle Mountain (SM), The Castle (C), McIntyre Mountain (MM), Witcher Mountain (WM), and Cover Mountain (CM) and mark the remnant flanks of the Guffey composite volcano. The town of Guffey (G) lies in the southeastern part of the Guffey cauldron. Distance between Black Mountain and The Castle is 16 miles; distance between Cover Mountain and Thirtynine Mile Mountain is 10 miles. (Photograph courtesy of Rudy C. Epis).

STRATIGRAPHY AND PETROLOGY

Precambrian

The Precambrian rocks in the study area consist of plutonic granite, quartz monzonite and gneisses of both metaigneous and metasedimentary origin. North of Cobb Creek, in the northeast corner of the study area, the Precambrian rocks vary from granite to quartz monzonite (Wobus, written communication, 1968). This unit has been informally named the quartz monzonite of Elevenmile Canyon by Wobus; farther north it has been dated at 1.45$\pm$b.y. by the Rb/Sr method and is hence equivalent in age to the Silver Plume granite of the central Front Range (Wobus, 1969). Numerous small pegmatites consisting of microcline, quartz and muscovite occur within the unit. In a few places the rock appears to have a weak northeast-trending foliation.

The Precambrian rocks along Daggett Creek in the southeast corner of the study area and along High Creek southeast of Cover Mountain are Cripple Creek granite which has been dated at its type locality by the Rb/Sr method at 1.43$\pm$b.y. (Hutchinson, 1967). This date is within the analytical error of the date for the Silver Plume granite and therefore is considered a "Silver Plume age" pluton.



STRATIGRAPHIC RELATIONSHIPS ON THE EAST SIDE OF THE GUFFEY VOLCANIC CENTER

Figure 3

Petrographically, this rock has a granitic texture and consists of about 60 percent orthoclase in which Carlsbad twinning is common, 25 percent quartz and 15 percent biotite.

The Precambrian rocks which crop out south and southwest of Cover Mountain and along Louis Gulch are older than "Silver Plume age". They are probably metasedimentary in origin and consist dominantly of sillimanitic gneisses which have been intruded, generally conformably, by lenses of granitic gneiss (locally augen gneiss) and pegmatites (Wobus, written communication, 1968). The granitic gneiss is probably correlative with augen gneisses of "Boulder Creek age" which have an age of 1.70$\pm$b.y. (Hutchinson, 1967).

The Precambrian terrane generally stands higher topographically than the surrounding volcanics and vegetation is more abundant. Only a cursory examination was included in the present investigation; the reader is referred to papers by Wobus (1968) and Hutchinson (1967) for further information.

Tertiary

Introduction

The volcanic stratigraphy of the present investigation appears in figure 3 (p. 10) along with the volcanic units described by Whitman

Cross in the western part of the Pikes Peak Folio (1894). In this figure no time correlation should be made between the two sets of stratigraphic units based on their relative vertical positions. The basic breccia, agglomerate and tuff described by Cross has been informally termed the lower andesite (Chapin and Epis, 1964, p. 147) and has been divided into an upper and lower member by the present author.* The basalt dikes described in this study as part of the lower andesite (u.m.) are similarly described by Cross as part of the basic breccia. Cross' massive andesite correlates with all of the andesitic units described below except the lower andesite. The felsite dikes, except those containing sanidine (p. 46) which Cross did not discuss, also correlate with this massive andesite. The trachyte rocks described by Cross correlate with the two trachyte units described below; the rhyolite units also have direct correlation. Further comparisons of the 2 sets of stratigraphy are made in the following lithologic descriptions.

The volcanic domes discussed in the following unit descriptions were identified by: (1) their steeply-inclined flow planes whose strike lines appear to wrap around the topographic centers of the domes; (2) their limited areal extent but appreciable thickness (240 to 1,100

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*Because of the awkwardness of this temporary nomenclature, the lower member of the lower andesite will be referred to throughout the text as lower andesite (l.m.). Similarly the upper member of the lower andesite will be referred to as lower andesite (u.m.).

feet); and (3) their intermediate to silicic composition which is suggestive of high viscosity. An alternate explanation is that of erosional remnants of once extensive flows whose vents are located outside the area studied. The evidence cited above argues against this interpretation as does the regional geology developed by other workers.

The volcanic rocks were classified according to Williams, Turner and Gilbert (1954). Except for the pyroxene andesite (p. 23) all the andesitic rocks contain plagioclase as their principal phenocryst. The average anorthite content of these phenocrysts in all but the biotite andesite (p. 24) is An50 to An65. Williams, Turner, and Gilbert (1954, p. 94) state that "...the porphyritic plagioclase in most andesites is labradorite more calcic than An55."

Andesite of Elevenmile Road

Several grayish purple pyroxene andesite flows cover about 2 square miles south of West Fourmile Creek in the west part of the study area (pl. 1, sec.36, T. 14 S., R. 73 W.; sec. 31, T. 14 S., R. 72 W., and Sec. 6, T. 15 S., R. 72 W.). This unit is overlain by the andesite of West Fourmile Creek; the base of the unit is not exposed but indirect evidence suggests that it is the oldest volcanic unit of Tertiary age in the study area and hence lies on the prevolcanic basement. The rocks locally show poorly developed flow structure and most of the outcrops display a slight to moderate brecciation especially near the bottom of the unit. The flows thicken to about 500 feet toward a probable source west of the study area. The lower andesite (l. m.) contains near its base a thin discontinuous group of andesitic to basaltic flows which are usually brecciated. The andesite of elevenmile road is very similar in lithology and mineralogy to these flows and may be genetically related. However, the lower andesite (l. m.) flows are never so thick nor extensive as the andesite of elevenmile road. These flows are present in the lower andesite (l. m.) along its contact with the andesite of elevenmile road and make that contact difficult to establish. That the andesite of elevenmile road is older than lower andesite (l. m.) is evidenced by the fact that the less resistant lower andesite (l. m.) is receding eastward by erosion off the andesite of elevenmile road with no relief along the contact. If the more resistant flows of the andesite of elevenmile road were lying on the lower andesite (l. m.), a sharp break in slope would be expected at the contact.

Petrographically, these andesites consist mainly of phenocrysts of plagioclase and clinopyroxene in a holocrystalline felted groundmass of plagioclase laths, magnetite grains and microlites of plagioclase. The plagioclase phenocrysts have an average composition of about An58 and are highly altered to clay which imparts a dull cream color to these grains in hand specimen. The clinopyroxene phenocrysts (probably pigeonite as the 2V is about 40 degrees) are up to 5 millimeters in length and commonly contain inclusions of secondary magnetite. A few relict grains of hornblende occur as phenocrysts and are almost completely oxidized to magnetite. Propylitization in the form of a greenish clay pervades the groundmass. In the brecciated areas, iron bearing minerals in some fragments have been highly altered to hematite, whereas, in other fragments oxidation is less pronounced thus lending a mottled aspect to the rock.

Andesite of West Fourmile Creek

A series of purplish to greenish gray hornblende andesite flows cover about two square miles near the head of West Fourmile Creek and south to the Louis Gulch area. This unit consists of flows which thicken to about 300 feet toward a possible source west of the study area. Flow structure defined by planar alignment of phenocrysts and by sub-parallel sheeting is well-developed at some localities. This group of flows is interbedded with the lower andesite (l.m.) and overlies the andesite of elevenmile road. Cross (1894), described a thick massive andesite flow at the head of West Fourmile Creek which he subdivided mineralogically into: 1) an older augite andesite which is correlative with the andesite of elevenmile road, and 2) a hornblende mica andesite which is correlative with the andesite of West Fourmile Creek and also correlative with the hornblende andesite (Buchanan, 1967), the andesite of section eight and the andesite of Cover Mountain.

Petrographically, these flows are hornblende andesites with minor pyroxene (augite?) and magnetite. Phenocrysts and glomerocrysts constitute approximately 60 percent by volume. The predominate phenocryst is plagioclase with strong normal-oscillatory zoning in which the composition ranges from An55 to An73 and averages An65. The plagioclase crystals are moderately altered to clays with minor sericitization. The hornblende is strongly oxidized as shown by the very low extinction angles and the semiopaque brownish to reddish color; some have undergone complete resorption to magnetite and hematite. The pyroxene is similarly oxidized with some of the grains altered to hornblende. Magnetite occurs as relatively large euhedral crystals, as very small granules in the groundmass and as an alteration product of the ferromagnesian minerals. The groundmass has a trachytic texture and consists of plagioclase laths of approximate composition An40 with abundant tiny magnetite granules and small pyroxene crystals. A faint chloritic substance veils the groundmass and a slightly iron-stained clay is also present.

Trachyte of Louis Gulch

A light gray to pink trachyte forms an east-west line of domes (pl. 1, cross section B-B') in the southern part of the study area. These domes and the younger trachyte of two springs are the trachyte rocks described by Whitman Cross in the Pikes Peak Folio of 1894. The easternmost occurrence of this unit is a large conspicuous dome south of Witcher Mountain (pl. 1, secs. 14 and 15, T. 15 S., R. 72 W.). Flow remnants from this dome occur south of High Creek and on Witcher Mountain; both of these remnants are being exhumed from beneath the upper member of the lower andesite. The remnant under Witcher Mountain may be the northern part of a large elliptical dome having a north-south major axis, or it may be a pile of domal flows which extend north from their source south of Witcher Mountain. That this body of the trachyte of Louis Gulch pre-dates the emplacement of the lower andesite (u.m.) and is within the time interval of the lower andesite (l.m.) is evidenced by the fact that it contributes considerable detritus to the lahars of the lower member southeast of the dome. Trachyte lithics are also found in an epiclastic phase of the upper member at 9,600 feet in the northeast corner of section 15, T. 15 S., R. 72 W.

A second dome lies in the northwest flank of Cover Mountain and has associated flows which extend northeastward and lie on Precambrian granite and on the lower andesite (l.m.). Flow remnants of the lower andesite (u.m.) are "plastered" around the north and west sides of this dome (pl. 1, cross section B-B') and the dome is overlain by flows from the later Cover Mountain dome; it may therefore be a structure of considerable size extending eastward beneath the andesite of Cover Mountain.

The westernmost occurrence of this unit is a dome in Louis Gulch which intrudes the Precambrian rocks and truncates the flows of the andesite of West Fourmile Creek (pl. 1, S/2 sec. 7, T. 14 S., R. 72 W.). This dome appears to intrude the lower andesite (l.m.) at about 9,200 feet at its northeastern corner (pl. 1, sec. 7, T. 14 S., R. 72 W.) and yet it contributes detritus to the lahars of the lower member at about 9,250 feet on the flank of Cover Mountain (pl. 1, SW/4 sec. 17, T. 14 S., R. 72 W.). This same dome probably contributed abundant material to laharic breccias of the lower andesite (l.m.) exposed about 7 miles southeast of Cover Mountain (Chapin, oral communication, 1967). The dome in Louis Gulch has several tongues of rather well-indurated, unstratified trachytic detritus of 2 to 4 inches average size set in minor amounts of matrix. These masses are probably talus accumulations which collected around the southern base of the dome during its extrusion and covered the Precambrian surface. Lithic fragments from this dome and from the dome south of Witcher Mountain have a semiequidimensial polyhydral shape usually bounded by six to nine sides. These "polyhedrons" apparently formed during autobrecciation of the extremely viscous magma.

The trachyte of Louis Gulch weathers to a rather subdued topography relatively free of trees and forms distinctive outcrops due to its very light color relative to the other rocks in the area. Flow planes are makred by alignment of phenocryst and by finely-spaced parallel joints or "sheeting".

Petrographically this unit has a holocrystalline trachytic groundmass consisting of some plagioclase laths but mostly of potassium feldspar. The potassium feldspar determination is based on: 1) refractive index of less than 1.537, 2) stubby crystal habit, and 3) strong potassium stain with sodium cobaltinitrite. The groundmass also contains abundant tiny dots of magnetite. Phenocrysts constitute about one third of the total rock and are composed of about two thirds plagioclase and one third biotite. The plagioclase phenocryst composition ranges from albite to andesine and averages An32. The dome south of Witcher Mountain and the dome in the flank of Cover Mountain contain about 10 percent phenocrysts of alkali feldspar in the form of tablets having no twinning, a 2V of about 25 degrees and indices of refraction (as determined with the sodium lamp of 1.526, 1.530 and 1.531 $\pm$ 0.001). The optical data suggests that this feldspar is a cryptoperthite within the sanidine-anothoclase-high albite series (Deer and others, 1965, p. 1-63). Biotite varies in degree of alteration from fresh to almost completely altered to hematite.

Rhyolite of Four Quadrangles

A brownish-red, flow-banded rhyolite lies on the north side of Louis Gulch along the west edge of the Florissant quadrangle. A black chill zone which occurs along its contact with the trachyte of Louis Gulch establishes it as the younger unit (pl. 1, W/4 sec. 18, T. 15 S., R. 72 W.). Another much smaller body of very similar rhyolite has intruded the lower andesite (l.m.) between Thirtynine Mile Mountain and Saddle Mountain (pl. 1, sec. 18, T. 14 S., R. 72 W.) and, although it may not be part of the same eruptive event, it is included within the rhyolite of four quadrangles because of lithologic similarity.

Petrographically, these rocks have a groundmass of partially devitrified brown glass and tiny grains of magnetite. The refractive index of the glass groundmass is about 1.513. Staining with sodium cobaltinitrite indicates a high potash content for the groundmass. The fine flow bands are filled with silica and constitute about 10 percent of the total volume. The phenocrysts in order of abundance are plagioclase, large sanidine tablets, fresh to moderately oxidized biotite, and a few grains of fresh green hornblende. The plagioclase crystals range in composition from An10 to An50 and average about An42.

Andesite of Section Eight

Two domes and associated flows of purplish gray andesite occur on opposite sides of Louis Gulch (pl. 1, secs. 8, 19, and 20, T. 15 S., R. 72 W.). The northern dome intruded the lower andesite (l.m.) and shed flows which overrode the lower andesite and the andesite of elevenmile road. These flows were later intruded by the trachyte of two springs. The smaller dome south of Louis Gulch intrudes the trachyte of Louis Gulch and is overlain by the lower andesite (u.m.). Flows from this dome lie directly on Precambrian rocks at elevations between 9,000 and 9,250 feet which suggests that the eruptions took place early in the depositional history of the lower andesite (l.m.) before these breccias were able to completely mantle the terrane. Good flow alignment of the phenocrysts is usually present along with a well-developed sheeting which in some localities is perpendicular to the flow direction. The unit is massive and commonly forms cliffs.

Petrographically, this rock is about 45 percent phenocrysts of plagioclase, oxyhornblende, biotite and a few small pyroxene and magnetite grains. The plagioclase grains commonly show normal-oscillatory zoning and have a composition ranging from An40 to An70 with an average value of An54. The hornblende and biotite grains are so highly oxidized to hematite and magnetite that they are often opaque. The groundmass consists of plagioclase laths and tiny grains of magnetite set in some interstitial glass or cryptocrystalline material. The entire rock is oxidized and propylitized.

Figure 4. Looking north at the trachyte of two springs dome. The light colored zone at the base of the dome is probably the result of hydrothermal alteration by influx of water from the lower andesite during intrusion.

Trachyte of Two Springs

A small dome of light gray trachyte (fig. 4, p. 22) intrudes the lower andesite (l.m.) and the andesite of section eight north of Cover Mountain (pl. 1, secs. 4, 8, and 9, T. 15 S., R. 72 W.). This body appears to be younger than the surrounding lower andesite (l.m.) as it does not seem to have contributed detritus to the epiclastic lahars of the lower andesite. The flow structure is everywhere well-developed by the orientation of phenocrysts and a finely spaced joint set. In the peripheral areas of the dome, the rock is lighter in color than toward the center suggesting that hydrothermal fluids altered the margins of the dome (fig. 4, p. 22).

Petrographically, this rock is very similar to the trachyte of Louis Gulch with the only significant difference being that the groundmass is somewhat coarser.

Pyroxene Andesite

A small exogenous dome of pyroxene andesite intrudes the andesite of elevenmile road just south of West Fourmile Creek (pl. 1, sec. 25, T. 14 S., R. 73 W.) forming a small but conspicuous topographic high. The dome has a well-developed, concentrically-diposed, inward-dipping flow structure. One small flow remnant lies northeast of the dome across West Fourmile Creek and dips 20 degrees away from its source. The rock has a purplish gray color which weathers to purplish brown. A well-developed sheeting lies in the flow plane.

Petrographically, this andesite has a very fine trachytic groundmass consisting of plagioclase laths whose composition is about An61, tiny magnetite crystals, and crystallites with some interstitial brown glass. The only phenocrysts are pyroxene (probably pigeonite as the 2V is about 40 degrees) and magnetite. The rock is only slightly oxidized and there is some minor propylitization. Silicification is abundant, both as irregular grains of quartz in the groundmass and as replacement of pyroxene.

Biotite Andesite

A reddish-gray biotite andesite lies on the andesite of West Fourmile Creek and the andesite of elevenmile road in the northwest part of the study area (pl. 1, sec. 25, T. 14 S., R. 73 W.). Maximum thickness of 200 feet is exposed within the study area but the unit thickens westward toward a possible source.

Petrographically, this andesite has a trachytic groundmass of plagioclase laths, pinpoint crystals of magnetite, pyroxene grains, crystallites and interstitial brown glass. The phenocrysts are predominantly normal-oscillatory zoned plagioclases of about An45. Biotite is the most abundant mafic phenocryst with a few scattered grains of green hornblende. Sericitization of the plagioclase has occurred along cleavage fractures and the mafic phenocrysts show some hematization of their edges. The groundmass contains iron-stained clay which imparts a reddish brown color in reflected light.

Hornblende Andesite

Buchanan (1967, p. 37) has described hornblende andesite flows in the eastern part of his study area which cover about 2.5 square miles. These flows extend eastward along the western edge of the present study area covering about 1/2 square mile to a maximum thickness of 400 feet. A possible source west of the study area at Ankrums intrusion is suggested by Buchanan (1967, p. 38). A small dike of similar hornblende andesite cuts the andesite of elevenmile road and the andesite of West Fourmile Creek (pl. 1, Sec. 36, T. 14 S., R. 73 W.) thus suggesting this unit is younger. The map symbol Tha_1 used by Buchanan (1967) is carried in this study.

Petrographically, this rock consists of about 50 percent phenocrysts of plagioclase, fresh green hornblende, pyroxene, magnetite, and biotite set in a trachytic groundmass. The unit is characterized by its dark green color and its large, fresh hornblende phenocrysts which are commonly 1/2 inch or more in length. Glomerocrysts of hornblende are also common and are as much as two inches across.

Andesite of Southeast Thirtynine Mile Mountain

A partially exhumed dome of reddish brown biotite andesite crops out along the southeast flank of Thirtynine Mile Mountain (pl. 1, sec. 24, T. 14 S., R. 73 W.) where it was probably emplaced prior to the building of the Guffey volcano. Flows which spread eastward from the dome are exposed to a thickness of approximately 500 feet. The main joint set lies in the flow plane which is well-defined by the planar alignment of biotite plates.

Petrographically, the rock consists of phenocrysts of plagioclase (An50) and biotite in a trachytic groundmass of plagioclase laths and abundant tiny crystals of magnetite. The phenocrysts make up about 35 percent of the total rock. The biotite is almost completely oxidized to magnetite and specular hematite; a few of the plagioclase grains show sericitization. Minor propylitization pervades the whole rock.

Lower Andesite

The lower andesite (Chapin and Epis, 1964, p. 147) is the most voluminous and areally extensive formation in the Thirtynine Mile volcanic field, covering 600 square miles to an average thickness of 500 feet. This unit is the "basic breccia and agglomerate" mapped by Cross (1894, p. 3) in the western half of the Pikes Peak Sheet. The lower andesite has been divided into two parts which

Figure 5. Looking north at Castle Mountain, showing the subdued, rolling topography of the lower andesite (l. m.). The upper third of the mountain shows the lower andesite (u. m.) which consists of a well stratified series of flows and flow breccias capped by a 70 foot sequence of at least 7 epicalstic breccias. Note the Precambrian cliffs in the middle distance (right center), north of Cobb Creek.

are informally termed the lower and upper members and which correspond to the lower and upper halves respectively of what Stark and others (1949, p. 101) referred to as the Thirtynine Mile volcanic series. They have a total thickness of approximately 2,000 feet along the south flank of Thirtynine Mile Mountain. The lower member consists predominantly of erupted and epiclastic laharic breccias, and the upper member of flows and flow breccias (fig. 5, p. 27). The term laharic is used to modify all breccias which are fluidized at least in part by water.

Lower Member

This is the most extensive unit in the study area. It is made up of chaotically-stratified breccias which cover about 23 out of the 52 square miles mapped. These breccias appear to have been erupted predominantly as fragmental andesite from numerous, small, randomly-scattered vents and distributed laterally by mudflows. This process resulted in the construction of a sheet of coalescing breccia aprons which must have completely disrupted the surface drainage as the unit contains very few interbedded sands and gravels. These permeable fragmental deposits provided an extensive ground-water reservoir which may have contributed to the fluidization of fragmental andesite in the vents to form hot lahars. Considerable heat and the abundance of water to aid in deuteric alteration and

Figure 6. Looking northeast at McIntyre Mountain which is built almost entirely of the lower andesite (l. m.). A thin layer of the lower andesite (u. m.) is capped by a prominent flow of the andesite of Cover Mountain. A vent in the lower andesite (l. m.) has been exposed by the sharp gulley running down the left flank of the mountain.

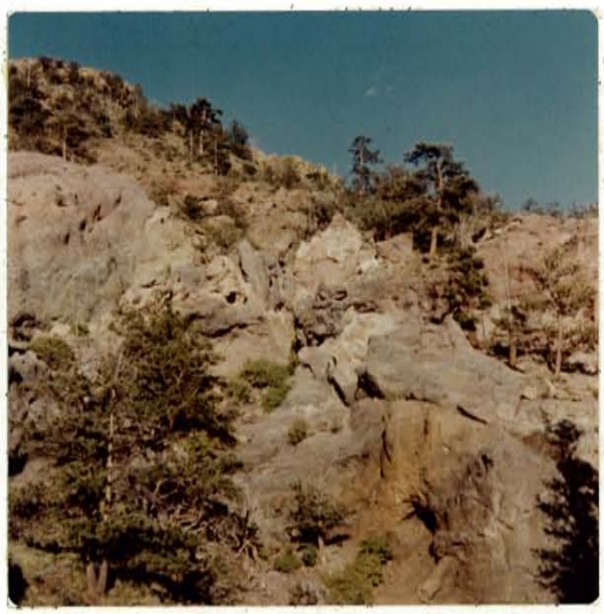


Figure 7. Looking into the breccia vent on McIntyre Mountain. The high degree of discoloration is apparently the result of hydrothermal alteration from gasses and fluids in the vent.

the precipitation of chemical cements may explain the highly indurated nature of most of the breccias. Products of violent pyroclastic eruptions such as agglomerates, bedded tuffs and cinder cones are notably scarce within the lower andesite (l.m.). This suggests that the brecciation was a relatively quiet process which dominated eruptive activity over a large area for a long time.

Two small vents have been recognized within the study area; many more are known to exist in other parts of the Thirtynine Mile volcanic field (Epis and Chapin, 1968, p. 65). These vents are identified by small, dissected breccia cones (pl. 1, E/4, SE/4 sec. 7, T. 15 S., R. 72 W. and SW/8 sec. 36, T. 14 S., R. 72 W. (fig. 6, p. 29)). Tuffaceous sediments are present within the vent craters and dip inward toward the throat. The breccias within the cones are sometimes highly discolored and altered, presumably by hydrothermal activity resulting from discharge of volatiles (fig. 7, p. 30). However, the amount of hydrothermal alteration is usually too meager to be of much help in locating vents. The cones consist entirely of breccias with outward-dipping breccias on the flanks intruded by breccias in the central conduit and by breccia dikes. Thus, the breccia cones tend to blend into the surrounding breccia sheet and are easily overlooked.

The most abundant breccia type is monolithic laharic breccia which makes up about 60 percent of the total unit (fig. 8, p. 32).

Figure 8. View of an erupted laharic breccia on the north flank of McIntyre Mountain. This breccia was probably erupted from a vent about 500 yards away. The grayish-blue to purple color typifies these breccias. The area photographed is about 6 feet wide.

The material was apparently brecciated in the vent and erupted as hot breccia flows. It is suggested that the upward moving magma was brecciated in passing through a thermal viscosity barrier and erupted from the vent as a thick slurry of andesitic clasts, fine attritional particles, steam, and water (fig. 9, p. 34). These breccias are about 80 percent subequant clasts of andesite containing irregular to oval microvesicles distributed evenly throughout the clasts. G. H. Curtis (1954, p. 165-171) has suggested that vesiculation may suddenly have increased the viscosity of the degassed magma and promoted brecciation. The highly irregular shape of the microvesicles suggests that vesiculation occurred during brecciation with the bubbles expanding first in one direction and then in another as surfaces formed in the fragmenting body. Preservation of the highly irregular vesicles indicates that laminar flowage had ceased, otherwise the delicate projections on the vesicles would have been sheared in the direction of flow. The matrix of these erupted breccias consists of finely comminuted rock fragments cemented with varying amounts of chemical cements such as silica, calcite, and authigenic clay. Hematization and chloritization are abundant alterations.

Epiclastic laharic breccias are common throughout the lower andesite (l. m.); thus, surface derived mud flows helped to laterally distribute the andesitic debris. Individual lahars are

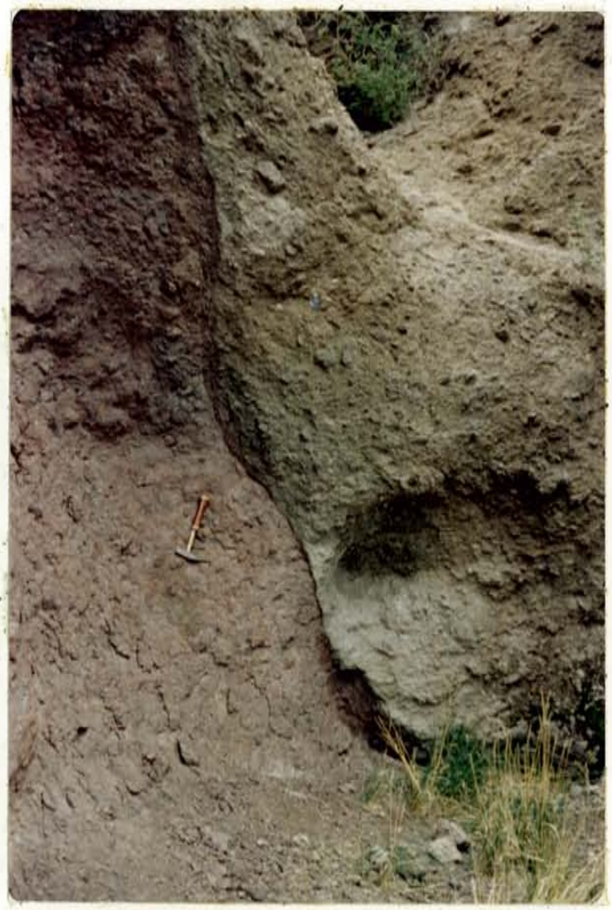


Figure 9. View of an intrusive contact in the vent on McIntyre Mountain. The wall of the throat is on the left with a light colored, eruptive breccia as the throat filling. No alteration or thermal effects are visible at the contact suggesting that the wall rock was probably not cold.

Figure 10. Two epiclastic mudflow breccias within the lower andesite (u.m.) high on Castle Mountain. Note the sorting in the upper 1 foot of the flow which suggests that there was some settling after the unit came to rest or that water and finer material became concentrated in the upper portion of the flow before movement ceased.

generally 3 to 20 feet thick (fig. 10, p. 35) and can only be followed for short distances. A gross sorting is often present as a decrease in the frequency and size of the larger fragments from bottom to top. For example, the lighter colored lahar in Fig. 10, p. 35, shows some vertical gradation especially in the upper part. However, the complete lack of sorting or bedding on a small scale within the individual lahars proves without question that these bodies were emplaced en masse by turbid flow. These laharic breccias are heterolithic and contain several different types of clasts whose composition varys from trachyte to andesite. The matrix consists of finely comminuted rock fragments and clay; tuffaceous material is sometimes present. These mudflow breccias are better indurated than older fluviatile sediments. For example, joints within the mudflows cut across the clasts instead of jointing around them. Clay apparently serves as a very effective binding agent in the fine detrital matrix. Chemical cements are notably absent.

A few andesitic or basaltic flows which are partly to completely autobrecciated occur in the lower andesite (l. m.) especially near its base. These are similar to the flows and flow breccias of the lower andesite (u. m.) (p. 40). The autobrecciated portions of these flows consist of subequant clasts in a matrix which varies from fragmental to igneous as one approaches the massive center of the flow. The rock is indurated by agglutination and by chemical cements, usually

Figure 11. View of a partially autobrecciated basaltic andesite flow within the lower andesite (u.m.) on Castle Mountain. The massive core of this flow grades abruptly upward into the overlying breccia zone. A similar breccia zone is present below the field of view.

silica or calcite. Short, stubby, completely autobrecciated flows are common near vents. Complete autobrecciation of a flow seems to greatly inhibit its mobility.

The three major types of breccias in order of abundance are monolithic, erupted breccias; heterolithic, epiclastic breccias; and monolithic, autobrecciated lava flows. Many gradational types are present between the erupted and epiclastic lahars. A brief table of the petrologic characteristics of these breccias follows (table 1, p. 39).

Table 1. Some petrologic observations of breccia types in the lower andesite (l.m.)

Observations	Heterolithic, epiclastic laharic breccias	Monolithic, erupted laharic breccias	Autobrecciated lava flows
Estimated volume percent of the breccia sheet	30	60	10
Composition	variable, but average is andesitic	andesite	andesite
Fabric	subequant clasts in fragmental matrix	subequant clasts in fragmental matrix	subequant clasts in fragmental or igneous matrix
Lithification	predominantly clay	chemical cements: clay, calcite, silica and combinations thereof	agglutination chemical cements
Clast/matrix ratio	50/50 to 70/30 usually 50/50	60/40 to 85/15 usually 80/20	85/15
Microvesicles within clasts	irregular to spherical or absent	irregular rarely oval rarely absent	irregular
Alteration	hematization chloritization variable	(most altered) hematization chloritization	hematization chloritization (least altered)
Ratio of smallest/largest clasts	1/1,000	1/50	1/50

Upper Member

The upper member of the lower andesite is a well-stratified sequence of basaltic andesite flows and flow breccias with some laharic breccias and minor ash-fall tuffs. The unit comprises the upper parts of Thirtynine Mile Mountain, Saddle Mountain, Castle Mountain (fig. 5, p. 27) and Witcher Mountain. The unit also crops out high on McIntyre Mountain, in the west flank of Cover Mountain and along the ridge southeast of Cover Mountain. The basaltic andesite flows are almost always partly brecciated and consist of a lower autobrecciated zone which grades abruptly into a central massive zone which, in turn, grades abruptly into an upper autobrecciated zone (fig. 11, p. 37). Each of these three zones generally represent about one third of the total thickness of a particular flow; the flows vary from about 6 to 36 feet in thickness.

Contacts between zones may change elevation very rapidly as one moves laterally along the flow. The massive, central portions of the flows consist of black basaltic andesite whose most outstanding mineralogic feature is the abundance of pyroxene (pigeonite, 2V about 35 degrees) crystals up to 1/4 inch on a side. The other phenocrysts are plagioclase (An58) and magnetite. The rock in general is quite fresh with hematization being notably minor. The groundmass of plagioclase laths and magnetite grains shows moderate chloritization with many small grains of pyroxene

Figure 12. View of an 18-inch-thick red air-fall tuff beneath a partially autobrecciated flow on Castle Mountain. Note the undulating contact between the massive central zone of the flow and the underlying autobrecciated zone.

completely altered to a chloritic substance. In contrast, the brecciated tops and bottoms of the flows are highly altered by chloritization and hematization and contain considerable secondary silica or calcite which helps to cement the rock. The petrographic observations made in table 2 for autobrecciated flows in the lower member also apply to flow breccias in the upper member.

The upper member differs morphologically from the lower member in that it is well-stratified and forms prominant ledge and shelf topography (fig. 5, p. 27). There are, however, a few striking examples of laharic breccias high within the upper member. One of these is the uppermost knob on Castle Mountain, which is made up of at least seven separate epiclastic mud flows which average about 10 feet in thickness and carry fragments up to 3 feet in diameter. The observations for epiclastic breccias in table 2 apply to similar mud flows of the upper member.

A few basic air-fall tuffs occur within the upper member. These tuffs are about 18 inches thick and generally have a reddish coloration (fig. 12, p. 41). The rock consists of small (less than 2 mm.) angular fragments of several different andesites set in a fine matrix of plagioclase, pyroxene, and brown, partially devitrified glass. Secondary carbonate is a pervasive cement.

The contact between the upper and lower members is not everywhere sharply defined for there are places where the flows in the upper member are completely autobrecciated and thus have the morphology and appearance of the lower member. The contact was generally picked at the change in slope from rounded, featureless topography to steep, ledge-like topography of the well-stratified upper member.

Pyroxene Diorite

A small irregular plug of diorite intrudes the andesite of West Fourmile Creek and the hornblende andesite in the western part of the study area (pl. 1, S/2 sec. 36, T. 14 S., R. 73 W.). This small phaneritic mass may be one of the conduits which contributed to the building of the composite Guffey volcano. The mass has steep to nearly vertical flow structure and two well-developed vertical joint sets which trend N 30 E and N 55 W. The rock weathers from brownish gray to grayish white.

Petrographically, this intrusive is a fine to medium grained phanerite of euhedral to subhedral grains of plagioclase, augite, biotite and magnetite. The large biotite grains poikiliticaly include plagioclase, magnetite and augite. Late stage alkali metasomatism greatly affected the mineralogy of the rock and partially altered the plagioclase (average An48) to albite. The secondary albite is not twinned, forms anhedral to subhedral grains, and contains enough potassium to give a very slight stain with sodium cobaltinitrite.

Secondary apatite crystals have also grown in the plagioclase grains and now make up about 2 percent of the rock. The ferromagnesian minerals were extensively chloritized. Other very fine grained alteration products are present but could not be identified.

Basalt Dikes

The eastern side of the Guffey volcanic center is cut by more than 100 basaltic dikes. In many instances several closely spaced, parallel dikes appear as one on the map. The dikes intrude the lower andesite (u.m.) but do not cut the andesitic dome and flows of Cover Mountain in spite of their considerable areal extent; for this reason, the dikes are thought to have been emplaced during the building of the Guffey volcano and prior to emplacement of the dome of Cover Mountain. In the southern half of the study area the dikes trend generally east-west (p. 54), whereas, in the northern half they appear to have a radial disposition with the focus very near the diorite intrusive in the southern half of sec. 35, T. 12 S., R. 73 W. It may be that pressure from a magma chamber beneath this conduit produced radial fractures along which magma moved to produce the dikes. The dikes may represent feeders which contributed material to the composite Guffey volcano. The short lateral extent of the dikes suggests that the principal direction of movement of the basaltic magma was upward. The average thickness of the dikes is about 5 feet; columnar

Figure 13. View of a basalt dike cutting the lower andesite (l. m.) northeast of Castle Mountain. Note the very well developed columnar jointing normal to the cooling surfaces.

jointing perpendicular to the cooling surfaces (fig. 13, p. 45) is usually well-developed.

Petrographically, these dikes are olivine basalts. The phenocrysts are small and make up about 60 per cent of the rock. Of the phenocrysts, clinopyroxene (pigeonite ?) is the largest and most abundant (35%), plagioclase (An60) is the next most abundant (30%), olivine with some iddingsite (?) alteration makes up 25%, and fresh magnetite represents about 10%. The groundmass consists of fine laths of plagioclase and abundant tiny dots of magnetite. The whole rock is propylitized and there is some argillization as well. Unlike most of the other volcanic rocks studied, these dikes contain essentially no hematite or ferric iron stain.

Felsite Dikes

Felsic dikes of variable composition cut the western half of the study area. The least felsic of the dikes are three light-green, hornblende-bearing dikes which trend in an east-west direction. One of these dikes is over a mile in length and about eight feet in width (pl. 1, sec. 7, T. 15 S., R. 72 W.); the two smaller dikes flank West Fourmile Creek in the center of the study area. The remainder of the dikes are light gray to white in color and contain biotite as their only ferromagnesian mineral. The three largest of these (one each in the flanks of Thirtynine Mile and Saddle Mountains and the third in secs. 7 and 8, T. 15 S., R. 72 W.), contain about 10 percent phenocrysts of sanidine; the rest of the dikes contain only plagioclase phenocrysts.

The felsic dikes generally have a well-developed flow structure striking along the dike trend and dipping sub-vertically; a joint set usually parallels the flow structure. Because several of the felsic dikes cut high into the lower andesite (u.m.), they are thought to have been placed within, or possibly later than, the eruptive interval of the upper member. All of the dikes may not be so young, but they have been grouped together on the basis of their similar lighologic character. The focus of the felsic dikes is not so well-defined as for the basic dikes, but appears to be in the same general vicinity, that is, the Gold Hill-Ankrums intrusion area (see plate 1, Buchanan, 1967) one to two miles north of Guffey. This area contains the most intense hydrothermal alteration and mineralization of the Guffey volcanic center as well as 3 of the 5 known diorite plugs. Thus, it appears that one of the principal holding chambers for the Guffey volcanism may have underlain the Gold Hill area.

Andesite of Cover Mountain

The last volcanic event of any significance in the study area was the eruption of a large mass of andesite at Cover Mountain and probably from at least one other source in the vicinity of Saddle

Figure 14. View on Witcher Mountain looking east northeast at the capping flow of the andesite of Cover Mountain. The flow is resting on the upper member of the lower andesite and dipping about 4.5 degrees away from its source at Cover Mountain. The highest point in the far distance is Pikes Peak about 22 miles away.

Mountain. Remnant flows from the Cover Mountain dome lie on the lower andesite (u.m.) and cap Witcher (fig. 14, p. 48) and McIntyre (fig. 5, p. 27) Mountains to thicknesses of 250 and 100 feet respectively. At the northern edge of the study area, Saddle Mountain, which consists largely of the lower andesite (u.m.), is capped by 500 feet of andesite which dips about five degrees to the northeast. The unit forms high, steep cliffs with extensive talus slopes made up of blocks as large as several feet on a side. The fact that the andesite of Cover Mountain lies on the lower andesite (u.m.) at all of its locations and that the basalt dikes of the lower andesite (u.m.) do not cut it establishes it as being younger than the lower andesite (u.m.).

Petrographically, the rock contains 60 percent phenocrysts of which plagioclase is the major constituent with green hornblende, biotite, pyroxene and magnetite present in lesser amounts. The plagioclase phenocrysts range in composition from An20 to An60 with an average of An51 and display normal-oscillatory zoning. The groundmass has a trachytic texture and consists of plagioclase laths, abundant dots of magnetite, euhedral grains of pyroxene, feldspar microlites of unknown composition and minor interstitial glass. Seritization is not uncommon along fractures in the plagioclase grains. The green hornblende and biotite are moderately to highly oxidized to hematite, whereas the pyroxene is only slightly altered. The magnetite grains usually show oxidation rims of hematite; they grade in size from 0.5 millimeters to tiny dots in the groundmass.

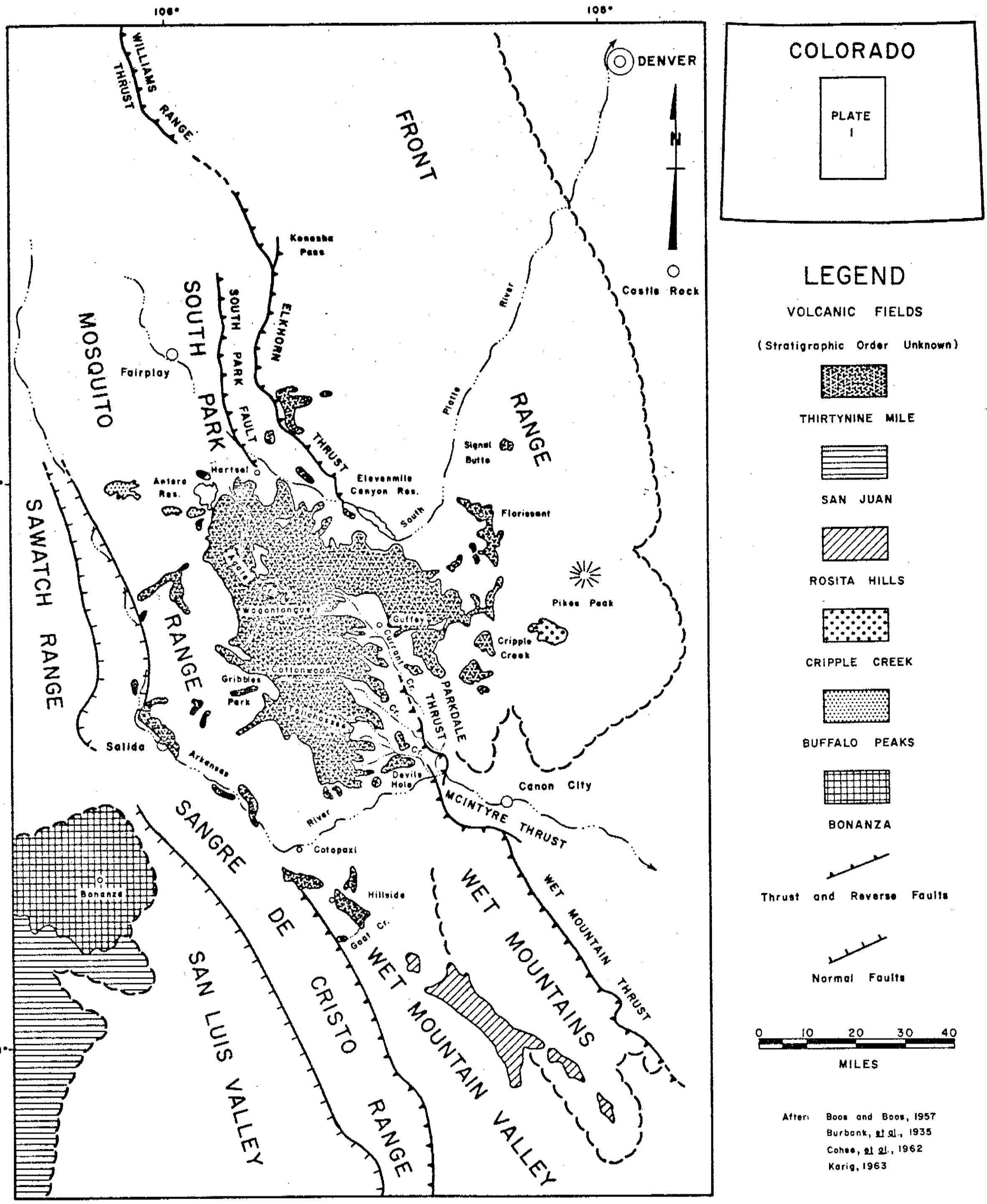
Quaternary Deposits

Quaternary alluvium is mapped in the major stream valleys where it has sufficient thickness and lateral extent. These fluvial sediments consist of unconsolidated silt, sand and gravel. The Quaternary deposits are of relatively small volume and terraces are generally absent. Small pediment surfaces thinly veneered by gravels have developed along the slopes of the higher mountains but they have not been mapped or studied in this project.

STRUCTURAL GEOLOGY

Regional Structure

The Thirtynine Mile volcanic field is located on a high plateau which separates South Park on the north from the Wet Mountain Valley on the south. It is situated within a regional belt of north-northwest trending intermontane basins extending from North Park



REGIONAL SETTING OF THE THIRTYNINE MILE VOLCANIC FIELD

to the Raton Basin. The east dipping Williams Range thrust, Elkhorn thrust, and South Park reverse fault bound the west side of the Front Range Highland and impinge on the north end of the volcanic field (Boos and Boos, 1957, p. 2639). The west dipping Parkdale, McIntyre and Wet Mountain thrusts bound the east side of the Wet Mountain Highland and impinge on the south end of the volcanic field (op. cit., Lovering and Goddard, 1950, p. 58, 59). A major fault zone parallels Currant Creek in the central portion of the field and probably connects these two major structural lineaments.

Local Structure

Faults within the Thirtynine Mile volcanic field have been categorized into three groups after those suggested by Buchanan (1967, p. 57). The first group consists of large north-northwest trending high angle faults such as those along Current Creek. They are unquestionably part of the system of Laramide faults described above (Epis and Chapin, 1968, p. 82). A second group of faults consists of those associated with volcanism and have varying attitudes. The present investigation has revealed three such faults, all high angle. Two occur on the east flank of Saddle Mountain (pl. 1, secs. 15 and 16, T. 14 S., R. 72 W.) and have offset the lower andesite (u.m.) about 400 feet with the north sides being down. The third fault (pl. 1, sec. 16, T. 15 S., R. 72 W.) places both members of the lower andesite in fault contact with the andesite of Cover Mountain. There may be more faults within the volcanic pile which have gone undetected for lack of recognizable offset or through burial by younger deposits. The third group of faults include the ring faults which follow the perimeter of the Thirty-one Mile Mountain cauldron and the Guffey cauldron (see pl. 1, Epis and Chapin, 1968).

Buchanan (1967) and DuHamel (1968) have mapped most of the Guffey cauldron using the ash flow -1 sheet as a structural datum plane. The Guffey cauldron measures about 4 miles north-south by 8 miles east-west. Previous workers (Chapin and Epis, 1964, fig. 2) have suggested that the eastern boundary of the cauldron lies along the western margin of the study area. The absence of observable stratigraphic offset has made it impossible to definitely locate the ring fault in this area. However, the accurate alignment of domes and flows extending from Louis Gulch to the head of West Fourmile Creek may mark a buried ring fracture zone. Epis and Chapin (1968, p. 79) have suggested that the Guffey cauldron might better be categorized as an erosion feature rather than a subsidence structure in the terminology of Williams (1941) as the amount of demonstrable subsidence is small. This may be especially appropriate in the description of the northern and eastern sides of the cauldron.

The east-west alignment of domes from Louis Gulch to south of Witcher Mountain (see pl. 1, cross section B-B') may be controlled by an east-west trending high-angle fault. Paralleling this line of domes is an abrupt break in slope on the buried prevolcanic erosion surface one half mile to the south which may represent a fault-line scarp. To the south, the Precambrian rocks are at an elevation of about 9, 500 to 9, 700 feet. The Precambrian rocks north of this line are at about 9, 150 to 8, 800 feet. This scarp forms the northern termination of a ridge of Precambrian rocks which extends southward for 7 miles (Chapin, oral communication, 1969). Six of the eight basalt dikes that occur in the vicinity of the possible fault also trend east-west. This dike alignment further indicates the existence of an east-west trending fracture zone within the Precambrian rocks in this area.

If a fault does exist as suggested, it would branch outward from the southern part of the east-west ring fault of the Guffey cauldron as mapped by Buchanan (1967) and DuHamel (1968). Such a fault suggests the possibility of a graben structure extending eastward from the cauldron, although there is apparently no evidence for the existence of a corresponding northern boundary fault. The common occurrence of such structures in other volcanic fields warrants the mention of a possible graben here. The Silverton, Lake City, and Creede cauldrons in the San Juan volcanic field are examples of cauldrons having faults which branch off from the ring faults that bound them (Luedke and Burbank, 1968, fig. 11; Steven and Ratte, 1960, figs. 8.1 and 8.2). In his discussion of the Santorin caldera, Williams (1941, p. 268) noted that the form of the depression was determined by a fracture pattern, partly regional and tectonic, and partly local and volcanic. He further noted that deep radial grabens formed from three of the four corners of the caldera probably as a result of intrusions along tectonic lines of weakness. The east-west orientation of the major axis of the Guffey cauldron further suggests the presence of an east-west trending line of weakness.

Chapin and Epis (1964, 1. 156) speculated on the possible existence of a volcanic belt trending northeast from the San Juan volcanic field across the southern end of the Front Range including the Silverton, Lake City, Bonanza, Guffey, and Cripple Creek volcanic centers. The proposed east-west trending structure at Guffey points towards the Cripple Creek center and adds some support to the proposed northeast trending Tertiary volcanic belt.

GEOLOGIC HISTORY

Prevolcanic History

The area now occupied by the Thirtynine Mile volcanic field was deeply eroded during and following Laramide orogenic movements with the result that many thousands of feet of Paleozoic and Mesozoic sediments were stripped away so that most of the field is underlain by Precambrian granite and high-grade metamorphic rocks (Epis and Chapin, 1968, p. 56). This prevolcanic surface has a low relief, locally as much as 800 feet, and dips gently to the south from elevations of about 9, 500 feet in northeastern South Park to about 8, 500 feet in the northern Wet Mountain Valley (op. cit., p. 56, 57). When Thirtynine Mile volcanism began in late Eocene time (op. cit., p. 51) it was over this surface of modest relief that the rocks were erupted.

In the present study area the prevolcanic surface consisted entirely of Precambrian rocks having moderate relief with the possible exception of a ridge in the southwest part of the study area which now stands 700 to 1, 000 feet above the surrounding surface. This unusually high relief may reflect an east-west trending high-angle fault (p. 54) related to volcanism and cauldron subsidence.

Volcanic History

Epis and Chapin (1968, p. 52) have published K-Ar age determinations for 4 of the most important stratigraphic units in the Thirtynine Mile volcanic field. These dates are, 40.0 $\pm$ 1.4 m.y. on ash flow 1, the oldest volcanic unit in the field; 34.8 $\pm$ 1.4 m.y. on ash flow 7, the youngest ash flow in the field; 34.1 $\pm$ 1.1 m.y. on the upper member of the lower andesite (p. 40); and 18.9 $\pm$ 1.2 m.y. on the upper andesite, the youngest volcanic unit in the field. Thus, volcanism began in latest Eocene time, was most active during Oligocene time and closed in Miocene time.

The earliest volcanic rocks deposited in the field were ash-flow tuffs from an unknown source, followed by silicic to intermediate tuffs, tuff breccias and andesitic domes and flows which were erupted at the Antelope Mountain and Thirtyone Mile Mountain centers southwest of Guffey (Epis and Chapin, 1968, p. 61). Central-type volcanism then shifted to the larger, cauldron-type center at Guffey where numerous domes and flows ranging in composition from rhyolite to andesite were emplaced within and peripheral to the cauldron. At the same time, fragmental andesite was erupted from numerous small vents scattered throughout the field and distributed laterally as mudflows. Aprons of andesitic debris built up around small breccia cones and coalesced to form the chaotically stratified breccia sheet of the lower andesite (l.m.). The mudflows lapped onto, were interbedded with, and largely buried the domes and domal flows of the Guffey center.

The oldest flow unit on the east side of the Guffey cauldron is the andesite of elevenmile road which lies at the base of the lower andesite (l. m.) and is very similar to it petrographically. The andesite of West Fourmile Creek (p. 15) then flowed onto the andesite of elevenmile road and was in turn overlain by laharic breccias of the lower andesite (l. m.). A small body of fine grained pyroxene andesite (p. 23) intruded the elevenmile road and West Fourmile andesites and was in turn overlain by a younger flow of biotite andesite on the north side of West Fourmile Creek (p. 15). The green hornblende andesite to be erupted around the head of West Fourmile Creek during the volcanic episode related to formation of the Guffey cauldron.

The domes and flows of the trachyte of Louis Gulch were probably emplaced early in the volcanic sequence as they lie on rocks of Precambrian age as well as on the andesite of West Fourmile Creek; they also contributed considerable material to epicalstic lahars of the lower andesite (l. m.). A large mass of rhyolite (p. 19) intruded the trachyte in and immediately north of Louis Gulch. A black chill zone within the rhyolite clearly establishes the sequence of intrusion. A similar but smaller body of rhyolite intruded the lower andesite (l. m.) 6 miles north of Louis Gulch between Thirty-nine Mile and Saddle Mountains. A dome of hornblende andesite intruded the lower andesite (l.m.) 1 mile northeast of Louis Gulch; flows of this andesite were in turn intruded by a body of trachyte similar to, but apparently younger, than the trachyte of Louis Gulch (p. 16).

After emplacement of the domes and domal flows of the Guffey Center and their burial by the breccia sheet, building of a large composite volcano began from one or more centrally located vents and from numerous basalt dikes (p. 44). The rocks of the volcanic superstructure form the lower andesite (u.m.). Thirtynine Mile, Saddle, Castle, McIntyre, Witcher and Black Mountains are erosional remnants which mark the flanks of the volcano (fig. 2). A whole-rock K-Ar age of 34.1 $\pm$ 1.1 m.y. was obtained from one of the flows near the top of Thirtynine Mile Mountain (Epis and Chapin, 1968, p. 65).

The Guffey volcano apparently suffered extensive erosion prior to emplacement of the andesitic dome of Cover Mountain. Flows from this dome issued onto a surface which truncated the southern flank of the volcano and exposed the lower andesite (l.m.) to the north of Cover Mountain and rocks of Precambrian age to the south of Cover Mountain.

CONCLUSIONS

The volcanic history of the Guffey center is complex with simultaneous and overlapping volcanic activity from numerous vents in the Guffey area as well as from unrelated vents in adjacent areas. Stratigraphic correlation is difficult and it is impossible to construct a stratigraphic column in which all rock units fit neatly one on top of the other.

Formation of the Guffey cauldron occurred early in the history of the center prior to and perhaps during the emplacement of the ring domes and flows. The eastern margin of the Guffey cauldron is approximately located by the arcuate alignment of domes and domal flows along the western margin of the study area. A probable east-west trending tangential fault leads outward from the southeastern corner of the Guffey cauldron as evidenced by the alignment of five domes and a steep north-facing scarp on the underlying Precambrian surface.

The chaotically stratified breccia sheet of the lower andesite (l. m.) was formed by eruption of fragmental andesite from numerous, widely scattered, small vents with lateral distribution of the debris principally by mudflows, both erupted (60 percent) and epicalstic (30 percent), with a few autobrecciated flows (10 percent). As this mantle of laharic breccias accumulated, it interfingered with the products of central-type volcanism of the Guffey center, overlapped them, and eventually buried most of the center. The Guffey cauldron is now being exhumed from within and beneath the breccia sheet.

The Guffey composite volcano was built late in the volcanic history with pyroxene diorite plugs and hundreds of basalt dikes providing feeders for the flows of the lower andesite (u. m.) which make up the superstructure of the volcano. The volcano was appreciably eroded prior to emplacement of the last domes and flows. More recent erosion has extensively disected the volcano revealing the underlying cauldron but leaving remnant flanks on Thirtynine Mile, Saddle, Castle, McIntyre and Witcher Mountains.

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