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SOME PETROLOGIC AND ALTERATION ASPECTS OF THE ALUM CREEK AREA, SAN JUAN VOLCANIC FIELD, COLORADO

by

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INTRODUCTION

The area of Figure 1 was mapped during the summers of 1964 and 1965. Since then the writer has continued to work within this area that has now been defined to lie within the west central resurgent portion of the Platoro caldera (Lipman and Steven, 1970). The extremely altered rocks located near Alum Creek provide the fundamental basis or foundation for the detailed explanation of the geology including both petrology and alteration.

GEOLOGIC SETTING

TIME-SEQUENCE OF IGNEOUS ROCKS

The igneous rock units in the Alum Creek area consist of extrusive, intrusive and hypabyssal rocks that are spatially associated with the Platoro caldera (fig. 1). The extrusive units consist of the Lower and Upper lavas within the Platoro caldera and vent-dome complexes. The Lower lavas are a complex series of andesite flow breccias, massive andesite flows and tuffaceous andesites that are unconformably overlain by Upper lavas of quartz latite which flowed from local volcanic vents. The unconformity is occasionally marked by well-charred log fragments with preserved woody texture. The vent-dome complexes, which are viscous protrusions of lava that were unconformably deposited upon the altered Upper and Lower lavas, are well-exposed around Lookout Mountain. These vent-dome complexes represent the final phase of volcanic activity.

The intrusive rock units consist of the equigranular augite quartz monzonite Alamosa River stock and the Alum Creek porphyry, which is an augite biotite quartz monzonite porphyry. The Alamosa River stock intrudes the Lower lavas and the Alum Creek porphyry intrudes the Alamosa River stock. No contacts were observed between the Upper lavas or the intrusions.

The hypabyssal rocks consist of sanidine quartz latite and quartz latite dikes. The sanidine quartz latite dikes are well-distributed throughout the area. Many of the quartz latite dikes probably represent chilled facies of the intrusive rocks.

STRUCTURE

The two most prominent faults are the east-west trending Red Mountain fault and the northwest trending South Mountain fault. The structure of the area is characterized by weaknesses along east-west, northwest, and northeast trends (fig. 1). The Red Mountain and South Mountain faults are the major zones of weakness that have permitted (1) local resurgent igneous activity and (2) a complex network of channels for solfataric and hydrothermal solutions.

The faulting is both pre- and post-alteration. The Red Mountain fault has a trend of east-west ± 20 degrees, dips 80 south to 80 north, has an intense fracture zone some 200 feet wide, and breccia zones 1-3 feet wide. Within the mapped area the Red Mountain fault is a high-angle normal fault with a left lateral map separation. The Red Mountain fault cuts the northwest trending South Mountain fault, which is a high-angle normal fault with a right lateral map separation. The Red Mountain and South Mountain faults have many associated subsidiary faults.

PETROLOGY

LOWER LAVAS

The field relations indicate that the Lower lavas are a heterogeneous group of andesite flow breccias, massive andesite flows and tuffaceous andesites. These multiple discontinuous flow units are thin (10 in.) to very thick (greater than 30 ft.). Within some of the thicker units the slower cooling has allowed a weakly porphyritic crystalline phase to develop in the central portion of the more massive flows. These phases resemble the chilled or fine-grained facies of the Alamosa River stock.

The characteristic texture displayed by the Lower lavas is holocrystalline, weakly porphyritic, very fine-grained to aphanitic, pilotaxitic, and weakly glomeroporphyritic. Lithic and crystal fragments attest to the flow breccia nature of this unit. The small plagioclase phenocrysts have a size range of 0.5-1.8 mm and a composition range of An_{36}-An_{48}. Augite is the characteristic mafic mineral and is commonly partially resorbed with clusters of fine-grained magnetite around irregular borders. Biotite generally is not

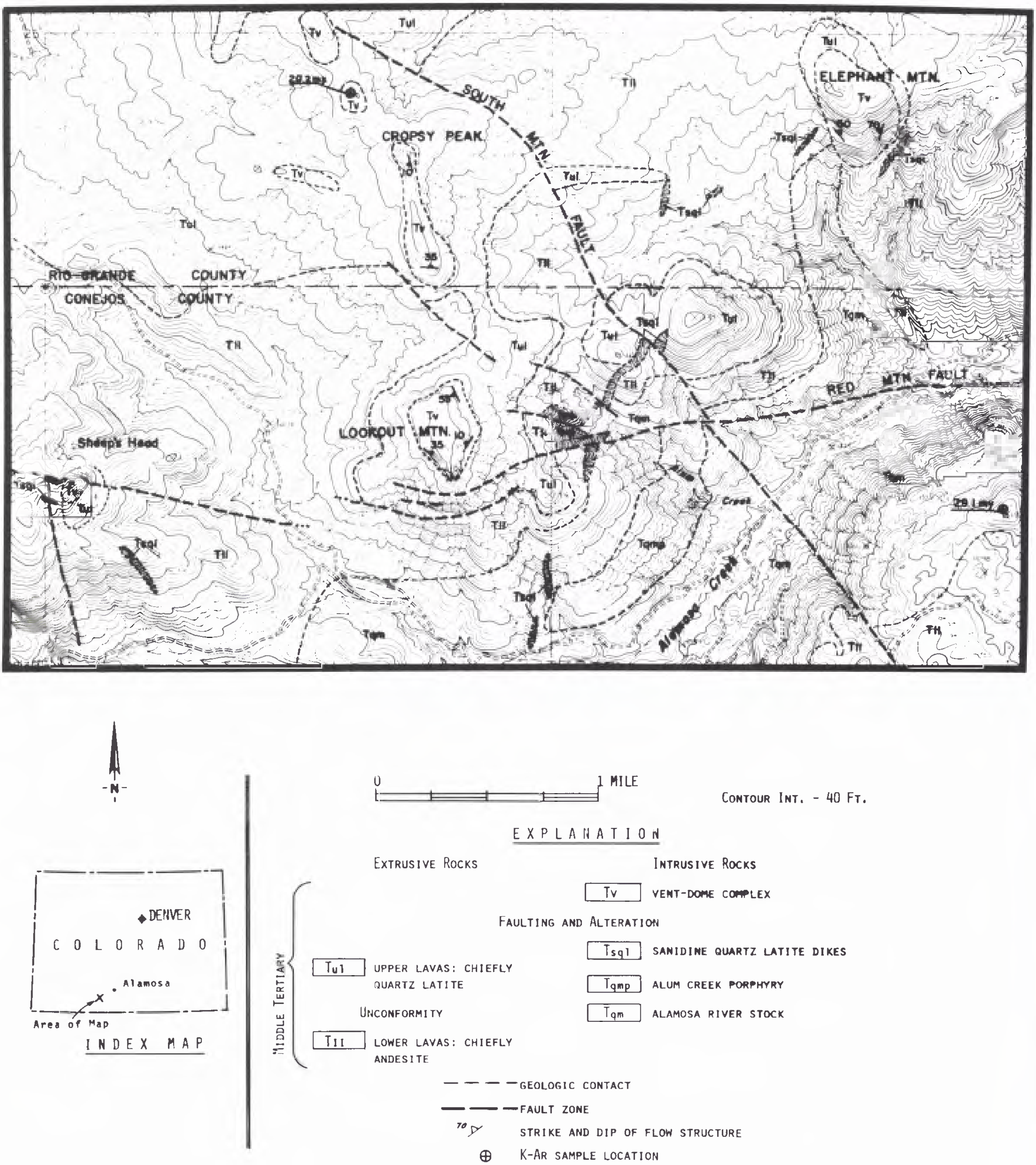

FIGURE 1.

Geologic map of the Alum Creek area, Colorado.

present. Accessory minerals include 1-2 percent magnetite and traces of apatite. The groundmass consists of very fine-grained intergrowths of plagioclase laths and aphanitic crystalline material. Sodium cobaltinitrate staining tests indicate approximately 20-25 percent of the total feldspar content is a potash feldspar. Minor to trace amounts of quartz occur in the groundmass.

The modal composition of 23 thin sections of the Lower lavas is as follows: phenocrysts—30%: plagioclase—25%, augite—5%, biotite—trace; groundmass—70%: plagioclase—50%, K-feldspar—13%, quartz—5%, and magnetite—2%.

The Lower lavas maintain a uniformly aphanitic to weakly porphyritic texture throughout the various stages of increasing intensity of alteration which include prophylitization, argillization, silicification, and alunitizaton. Magnetite is present in the unaltered rock, while 2-3 percent pyrite occurs in the altered rock. The Lower lavas are particularly susceptible to selective alteration.

ALAMOSA RIVER STOCK

The intrusive contacts have associated xenoliths and roof pendants of Lower lavas. The small inclusions rapidly disappear 5-10 feet from the sharp contact. The 100-foot-wide border zone is generally covered by alluvium but indicates a chilled facies of the intrusive stock and no discernible metamorphism of the adjacent volcanic rock. These diagnostic features indicate that the Alamosa River stock is an epizonal pluton. The field evidence indicates that the stock is post-Lower lavas. K-Ar dating gives an age of 29.1 million years (Lipman and others, 1970). The present level of erosion and outcrop distribution illustrates that the Alamosa River stock does not intrude the Upper lavas of quartz latite composition.

The characteristic texture of this stock is holocrystalline, hypidiomorphic-granular, fine-grained to medium-grained with the outer chilled margins having an inequigranular-seriate texture. Poikilitic textures exist with biotite in plagioclase, plagioclase in biotite, and plagioclase in orthoclase. Both normal and weakly discernible oscillatory zoning exist in the plagioclase crystals. Microscopic-sized subgraphic textures frequently occur with the Alamosa River stock and are interpreted to be the result of late magmatic separation and simultaneous crystallization of quartz and potash feldspar. The grain size of the feldspars ranges from 0.1-5 mm, ferromagnesians from 0.1-2.5 mm, and quartz from 0.1-0.5 mm. The andesine plagioclase crystals are euhedral to subhedral, while the orthoclase crystals are anhedral. The mafic minerals, biotite and augite, are partially resorbed with associated clusters of magnetite-ilmenite. The quartz content is seldom recognized in the field due to the marginal content and the small size of the interstitial grains.

A typical composition based on modal compositions of 28 thin sections from this equigranular stock is as follows: plagioclase—38%, orthoclase—36%, quartz—14%, augite—6%, biotite—3%, hypersthene—trace, apatite—trace, and magnetite—3%. The Alamosa River stock is a biotite augite quartz monzonite.

Upon alteration the equigranular monzonite retains its original texture with argillized plagioclase and bleached ferro-magnesian crystals megascopically evident. The Alamosa River stock is generally propylitized with definite areas of selective alteration throughout the northern portion of the stock. However, in the vicinity of Alum Creek, the Alamosa River stock is pervasively altered.

ALUM CREEK PORPHRY

The small Alum Creek stock is a complex quartz monzonite porphyry with related fine-grained and chilled phases. The zone of contact is steep, indicates no contact metamorphism, and exhibits foliation and lineation of the plagioclase phenocrysts only within a few feet of the contact. Small inclusions of the older equigranular stock occur near the contact zone, while small wisps or shoots of porphyry extend outward discontinuously into the older stock. Near the contact a coarser-grained facies of the porphyry predominates, but the phaneritic groundmass gradually becomes fine-grained to microphaneritic toward the core. These phases of the complex Alum Creek porphyry are interrelated, intermingled and generally intensely altered.

The characteristic texture of this small stock is holocrystalline, porphyritic-microphaneritic. The subhedral to euhedral phenocrysts of plagioclase, augite, and biotite range in size from 1-3 mm. The groundmass consists of discrete, identifiable randomly distributed anhedral crystals of quartz and orthoclase which range in size from 0.04-0.25 mm. The texture may also be piokilitic with biotite in plagioclase or plagioclase in biotite and indicates a simultaneous crystallization sequence. The oligoclase-andesine plagioclase phenocrysts exhibit normal and oscillatory zoning (Vance, 1962). The original euhedral-subhedral crystal borders of the phenocrysts have been modified by partial resorption which is developed to a greater degree in augite and biotite than in plagioclase. Within the ferromagnesians the resorption is frequently accompanied by clusters of minute magnetite-ilmentite grains around the border. The quartz and orthoclase content is seldom recognized in the field as these grains occur only in the microphaneritic groundmass. The texture of the groundmass exhibits differences caused by chilling associated with the border zones.

A typical sample of the Alum Creek porphyry based on the modal composition of 31 thin sections is as follows: phenocrysts—40%: plagioclase—30%, biotite—6%, augite—4%, hypersthene—trace; groundmass—60%: orthoclase—32%, quartz—25%, apatite—trace, and magnetite—3%. The rock is an augite biotite quartz monzonite porphyry.

The Alum Creek porphyry ultimately alters to a distinctly porphyritic rock consisting of phenocrysts of light brown bleached biotite and sericitized plagioclase in a groundmass of interstitial quartz and sericite with disseminated pyrite. The rock is commonly highly fractured and veined by an intricate network of quartz stringers with associated pyrite and molybdenite.

UPPER LAVAS

The Upper lavas lie unconformably over the Lower lavas. The Upper lavas are a biotite quartz latite with a gray aphanitic groundmass and exhibit moderate flow structure. The thickness of the Upper lavas varies as its base rests upon a surface of erosion and its top is an erosional surface.

The characteristic texture of the Upper lavas is holocrystalline, porphyritic-aphanitic to porphyritic, very fine-grained, and poikilitic. The phenocrysts consist principally of plagioclase, sanidine and biotite with lesser amounts of quartz, hornblende and augite. No hypersthene was detected in these flows. The oligoclase and particularly the sanidine phenocrysts are well-zoned with both normal and oscillatory zoning present. The phenocrysts of feldspar and ferromagnesians are commonly partially resorbed with the sanidine crystals showing the least amount of resorption. The phenocrysts range in size from 0.8-5 mm, while the groundmass crystals are aphanitic to 0.2 mm in size. Flow structure is generally pronounced as indicated by oriented feldspar phenocrysts and flow banding in the groundmass. The groundmass consists of intergrowths of feldspar laths, interstitial quartz, and aphanitic crystalline material.

Based on the modal analysis of 25 thin sections, an average composition is as follows: phenocrysts—28%: plagioclase—15%, sanidine—5%, quartz—3%, biotite—4%, hornblende—1%, augite—<1%; groundmass—72%; plagioclase—22%, K-feldspar—40%, quartz—9%, and magnetite—1%. The rock is a quartz latite with biotite as the characteristic mafic mineral.

The porphyritic-aphanitic texture of the Upper lavas is preserved throughout propylitic and argillic alteration but is essentially obliterated by the alunite-silica alteration.

QUARTZ LATITE AND SANIDINE QUARTZ LATITE DIKES

Dikes are ubiquitous within the Alum Creek area and have local concentrations near the border zones of the intrusions and around the vent sources of the local Upper lavas of quartz latite composition. The radial and concentric pattern of dikes around Sheep's Head, and to a lesser extent Elephant Mountain, attest to the volcanic activity around the vents and the associated structural doming. The dike rocks are of two major types, quartz latite and sanidine quartz latite. These dikes are separated into mappable units by the presence of 1 in. x 2 in. sanidine phenocrysts characteristic of the sanidine quartz latite dikes. A major sanidine quartz latite dike crops out periodically along a northeast trend, while others emanate from the vents. These large sanidine crystals occur only within the central portion of these prominent hypabyssal units which have a wide chilled zone that megascopically resembles the quartz latite dikes. The emplacement of the dike units occurred throughout post-Lower lava time in conjunction with the resurgent intrusive activity. The major dike activity is probably post-Upper lava in age as dikes cut the Upper lavas. Most of the dikes in the Alum Creek area were emplaced in cracks or zones of weakness and are believed to be genetically related to the magmatic activity which formed the extrusive Upper lavas and the intrusive porphyry.

The characteristic texture is holocrystalline, porphyritic-aphanitic to porphyritic-microphaneritic. Piokilitic textures are evident with biotite in plagioclase and plagioclase in biotite and indicate simultaneous and overlapping crystallization of the constituents. The phenocrysts range in size from 1-5 mm and are principally oligoclase-andesine plagioclase, sanidine, biotite, with minor occurrences of quartz and hornblende. The feldspar phenocrysts, and particularly the sanidine crystals, exhibit both oscillatory and normal zoning with the outer more alkalic zone more susceptible to alteration. The biotite and quartz phenocrysts are generally partially resorbed. The groundmass consists of intergrowths of quartz and orthoclase.

The modal composition of 16 thin sections from the dike units gives an average composition for the quartz latite dike units as follows: phenocrysts—33%: plagioclase—27%, biotite—5%, and hornblende—1%; groundmass—67%: plagioclase—14%, orthoclase—33%, quartz—18%; and magnetite—2%. An average composition for the sanidine quartz latite dikes is as follows: phenocrysts—39%: sanidine—3%, quartz—2%, plagioclase—28%, biotite—5%, and hornblende—1%; groundmass—61%: plagioclase—10%, orthoclase—30%, quartz—20%; and magnetite—1%.

Upon alteration the dike units retain their characteristic porphyritic-aphanitic texture. The intensity of alteration within the dike units is not consistent and indicates some dikes are intra-alteration. The sanidine quartz latite dikes generally have less pyrite than the quartz latite dikes. The quartz latite dikes are often more altered than the country rock.

VENT-DOME COMPLEXES

The locality of the vent-dome complexes initially served as centers for local eruption of the Upper lavas, later as sources of solfataric alteration, and, finally, as centers for the viscous protrusions of quartz latite to rhyolite.

The vent-dome complexes are symmetrically located with respect to the local vents and the surrounding alteration haloes. Morphologically they are circular to ellipitical in plan and mushroomed or bulbous in cross section with quaquaversal dips and contorted fan-like flow structures. The vent-dome complexes consist of three units based on lithology and texture. These distinctions are caused by differences in emplacement, cooling, and welding processes. Good outcrops of all three units generally exist somewhere at each vent-dome complex, and the spatial relationships of the three units are always the same. The lower friable agglomeratic tuff to tuffaceous agglomerate is conspicuous in all vent-domes. Toward the contact of an overlying vitrophyre unit the frequency of the vitrophyre blocks increase. The middle unit consists of a black vitrophyre which varies in thickness from 3-40 feet. Eutaxitic structures exist, and the vitrophyre is intermixed and intercalated with an upper unit of quartz latite. This upper unit of quartz latite occupies the core of all domes except Elephant Mountain, which is filled with white rhyolite containing no ferromagnesian constituents. Within the four principal volcanic domes the prominent flow structures are vertical to S-shaped in cross section and arcuate in plan with quaquaversal dips. K-Ar dating gives an age of 20.2 million years (Lipman and others, 1970).

Distinct textural differences associated with the groundmass exists within the three mappable units of the vent-dome complexes. The characteristic texture of the lower unit is hypocrystalline, porphyritic-aphanitic. The texture of the middle unit is hypocrystalline, vitrophyric. The texture of the upper unit is holocrystalline, porphyritic-aphanitic. Axiolitic structures exist in all three units. The phenocrysts within the three units are similar in size and are principally oligoclase, sanidine, quartz, and biotite with trace amounts of hornblende and augite. The ferromagnesians have a smaller grain size than the essential minerals and are weakly resorbed. The plagioclase and sanidine phenocrysts exhibit strong oscillatory and normal zoning. The groundmass consists of intergrowths of quartz, potash feldspar, and glass with the percentage of the constituents depending upon the dominant texture of the unit. The textures within the groundmass exhibit distinct megascopic and microscopic flow structure.

The modal composition of 15 thin sections from the different units of the vent-dome complexes has an average composition as follows: phenocrysts—28%: plagioclase—16%, sanidine—6%, quartz—2%, biotite—3%, hornblende—1%; groundmass—72%: glass—30%, quartz—15%, potash feldspar—26%; and magnetite—1%.

There has been no solfataric or hydrothermal alteration of the vent-dome complexes. A type of post-emplacement alteration caused by the latent heat of crystallization has produced partial fusion and recrystallization of the plagioclase crystals. Hematite coloration occurs within the flow structures of the groundmass and as rims around the magnetite and ferromagnesian grains. Partial oxidation of the iron-bearing minerals is believed to have occurred both during the emplacement and as a post-crystallization phenomenon.

PETROGENESIS

FELDSPAR RELATIONS

The composition of the plagioclase within the different rock units was determined on a universal stage utilizing the methods described by Slemmons (1962) and the curves for volcanic plagioclase. Only unaltered crystals were utilized as secondary calcite within the plagioclase was found to significantly lower the anorthite content. Primary plagioclase crystals occur in all rock units. The results of the determinations from unaltered crystals are tabulated here by anorthite content:

ROCK FORMATION	CRYSTALS MEASURED	RANGE OF AN	AVG. AN	
Vent-dome complexes	9	17.4-27.3	22.5	youngest
Sanidine quartz latite dikes	6	26.8-28.7	27.5	
Quartz latite dikes	6	32.7-37.1	34.7	
Upper Lavas	9	19.8-26.7	23.9	
Alum Creek porphyry	9	26.8-32.2	29.2	
Alamosa River stock	9	31.9-41.6	35.9	
Lower Lavas	9	35.7-48.3	41.6	oldest

With the exception of the dike activity that has occurred intermittently throughout post-Lower lava time, the major rock units show a systematic decrease in the plagioclase from An_{42} to An_{22}. This relationship corresponds with the relative ages of the rock units as determined in the field and is believed to represent the sequence of crystallization of the plagioclase feldspars.

FERROMAGNESIAN RELATIONS

The characteristic ferromagnesian minerals include augite and biotite. Less than one percent of hypersthene occurs in the early rocks and minor amounts of hornblende occur in the late rocks. The Ca-Mg pyroxenes were investigated on the universal stage to determine the exact nature of the extinction angles. Within the pyroxenes of the Alamosa River stock seven determinants have an average value of $Z_{\wedge}C = 56°$ with a range of $Z_{\wedge}C$ of 47-61°. Four crystals showing both optic axes have an average 2V = 59° with a range of 57-61°. Within the pyroxenes of the Alum Creek porphyry six determinations have an average value of $Z_{\wedge}C = 48°$ with a range of $Z_{\wedge}C$ of 44-52°. The principal pyroxene in the intrusive rocks is augite. Hornblende is scarce in the rocks of the Alum Creek area.

In a magma under high partial pressure of water hornblende is a stable mineral phase; however, a rapid decrease in pressure will cause a shift in the mineral stability field and hornblende will invert to a pyroxene in conjunction with resorption of biotite (Turner and Verhoogen, 1960, p. 139). Within some of the small intrusive masses of the San Juan region, Larsen (1937, p. 893) states that most of the pyroxenes have developed from the resorption of hornblende. The presence of augite and resorbed biotite within the Alamosa River stock and the Alum Creek porphyry suggest that a rapid decrease in the partial pressure of water occurred during the emplacement of these stocks.

The biotite from unaltered post-Lower lava rock units was investigated by oil immersion media techniques to determine N_z in order that any significant trends in the iron content might be ascertained. The results of the determinations are tabulated below.

	N_z	FE/(FE + MG)
Vent-dome complexes	1.615 ± 0.003	.03
	1.630 ± 0.003	0.4
	1.650 ± 0.003	0.6
Upper Lavas	1.640 ± 0.003	0.5
	1.590 ± 0.003	0.2
Alum Creek porphyry	1.640 ± 0.003	0.5
	1.640 ± 0.003	0.5
Alamosa River stock	1.630 ± 0.003	0.4
	1.630 ± 0.003	0.4

The Fe/(Fe + Mg) values were determined from Wones and Eugster (1965), and a brief summary of their work follows. The composition of biotites lie in the ternary system annite [$KFe_3^{2+}AlSi_3O_{10}(OH)_2$], phlogopite [$KMg_3^{2+}AlSi_3O_{10}(OH)_2$], and "oxybiotite" [$KF_3^{3+}AlSi_3O_{12}(H_{-1})$]. Comparing phlogopite with annite, phlogopite has the lower N_z value and lower Fe/(Fe + Mg) ratio. Two biotite trends exist during the crystallization of a magma. Trend I: During the crystallization and cooling of a magma that becomes saturated in water with the fugacity of oxygen remaining constant or increasing slightly, there is a slight decrease or little change in the Fe/(Fe + Mg) ratio of the biotites, and the final products of crystallization include magnesium-rich biotite and magnetite. Trend II: During the crystallization of a magma that has low water content there is a noticeable increase in the Fe/(Fe + Mg) ratio of the biotites and the final products of crystallization include iron-rich biotite and very little magnetite.

The biotites from the rock units of the Alum Creek area indicate a generalized 50-50 relationship in the annite-phlogopite solid solution series with a slight increase in the Mg-rich biotites of the younger rock units. Magnetite occurs continuously throughout the volcanic sequence. This evidence indicates the biotites crystallized according to Trend I of Wones and Eugster (1965).

PETROGENETIC INTERPRETATION

The petrogenetic interpretation of the rocks in the Alum Creek area is based upon rock textures and both feldspar and ferromagnesian relations. The porphyritic, vitrophyric, aphanitic and phaneritic textures that exist in the rock units are related to differences in the cooling environment associated with the mode of emplacement. The porphyritic textures reflect intratelluric crystallization. The oscillatory and normal zoning in the plagioclase phenocrysts and the resorption of augite and biotite phenocrysts indicate changes in the stability relations of mineral phases during emplacement and crystallization.

In the rocks of the Alum Creek area from oldest to youngest there is a systematic change in plagioclase from An_{42} to An_{22}, while the biotite shows little or no change in the Fe/(Fe + Mg) ratio. With decreasing age there is a loss of hypersthene and a gradual loss of augite. Hornblende occurs only in the youngest rock units. Biotite occurs throughout the rock sequence increasing to a maximum content in the Alum Creek porphyry and then decreasing in percentage. The siliceous rhyolite core of the Elephant Mountain vent-dome complex contains only trace amounts of biotite and no other ferromagnesians. Hypersthene, augite, hornblende, and biotite crystals occur in this volcanic sequence and indicate the ferromagnesians form a discontinuous series. Magnetite has continuously crystallized throughout the rock sequence. The combined relations of plagioclase feldspar, augite and biotite ferromagnesians, and magnetite suggest that the rocks of the Alum Creek area crystallized according to Trend I (Bowen trend).

The spatial association of extrusive, hypabyssal, and epizonal plutonic rocks combined with the petrologic conclusions strongly suggest a genetic relationship, or consanguinity, among these rocks. The rocks of the Alum Creek area are believed to substantiate the concept of a volcanic association as defined by Kennedy (1938) and support the concept of the Bowen trend as restated by Osborn (1962).

ALTERATION

Both solfataric and hydrothermal alteration products are found within the Alum Creek area. The areas of intense alteration can be interpreted from knowledge gained in some areas of limited alteration.

As seen in the Alum Creek porphyry the changes caused by alteration are mineralogical, chemical, and in some cases textural. Upon initial examination of the altered rocks, it may erroneously appear that the alteration products bear no resemblance to the original rock. There is, however, a general persistence of the original texture of the rocks. Field observations indicate that the alteration has an intimate association with structural features. On the basis of the extensive fracturing that controlled the alteration patterns and zones, the rocks of the area were well-fractured before the solfataric and hydrothermal alteration activity commenced. Alteration is a multicomponent metamorphic reaction with the consequent development of alteration facies and alteration zones.

ALTERATION FACIES

The concept of hydrothermal alteration facies has been discussed by Burnham (1962) and Creasy (1959 and 1966) through the application of ACF and AFK diagrams and later treated by Lowell and Guilbert (1970). The propylitic facies is characterized by a prominence of lime-bearing minerals such as calcite, epidote, and chlorite. The argillic facies is characterized by the presence of clay minerals of the kaolin and montmorillonite groups in conjunction with strong leaching of CaO. The phyllic facies is characterized by a quartz-sericite assemblage. The potassic facies is characterized by newly formed phases of biotite and K-feldspar. This concept of hydrothermal alteration facies is utilized in the Alum Creek area to describe the different aspects of dominant alteration types. In the field the propylitic facies is readily recognized by the green color of the rocks; the argillic facies is recognized by the white chalky appearance of kaolinite which replaces all phenocrysts, and the phyllic facies is recognized by minute flakes of sericite, "bleached biotite," and associated quartz.

The concepts of solfataric alteration facies has been discussed by Mukaiyama (1959). Solfataric alteration is formed by gaseous sulfurous exhalations from volcanic vents and fissures. Sulfurous gases are of limited abundance in fumarolic activity. The solfataric alteration facies progress through saponitized, kaolinized, alunitized, opalized, pyritized, and sulfurized rock. The saponitized rock is formed by alkaline solutions, the kaolinized rock is formed by weakly acidic solutions, and the alunitized rock is formed by strongly acidic solutions.

ALTERATION ZONES

The pervasive areas of solfataric alteration are best developed around the volcanic vents such as Lookout Mountain. The most intense hydrothermal alteration is best developed in proximity to the Alum Creek porphyry. Zones of decreasing intensity of alteration extend outward from the Lookout Mountain volcanic vent and the Alum Creek porphyry.

Solfataric Alteration: Zones of propylitized rock, with some veinlets of amorphous silica, occur in an outer zone ranging from hundreds to several thousands of feet peripheral to the Lookout Mountain volcanic vent. Argillized rock occurs in an intermediate zone hundreds of feet away from this vent. Quartz-alunite rock occurs in an inner zone adjacent to the volcanic vent. The degree of silicification associated with both the Lower and Upper lavas becomes more intense as one approaches Lookout Mountain from any direction. This evidence indicates that the zones of solfataric alteration become more intense toward the volcanic vents.

Hydrothermal Alteration: Propylitic, argillic, and phyllic hydrothermal alteration facies are areally distributed around the Alum Creek porphyry. The selective alteration near the Alum Creek porphyry is a hood or cap region of propylitic alteration with the more intense and pervasive argillic and phyllic alteration in the deeper exposed portions of the Alum Creek drainage.

Alteration Interpretation: The combined evidence from the volcanic vents and the Alum Creek porphyry indicates that there is a broad zonal pattern of alteration facies increasing in intensity toward the major local centers of solfataric and hydrothermal alteration. The principal centers or sources of solfataric alteration are the volcanic vents, and the principal center of hydrothermal alteration is the Alum Creek porphyry. Local zonal patterns of intense or selective alteration are associated with faults, dikes, and fissures. In the Alum Creek area the solfataric alteration is centered around volcanic vents that are 1,500 to 2,000 feet higher in elevation than the hydrothermal alteration around the Alum Creek porphyry. Spatial relationships of alteration in the Alum Creek area indicate a depth-zone transition of solfataric and hydrothermal environments associated with epithermal, xenothermal, and mesothermal conditions. A vertical transition between solfataric and hydrothermal alteration through a depth-zone concept is suggested within the Alum Creek area.

SUMMARY

TIME-SEQUENCE OF IGNEOUS ROCKS

The rock units in the Alum Creek area consist of extrusive, hypabyssal, and epizonal plutonic rocks that are spatially associated with the Platoro caldera in a region of mid-Tertiary volcanic activity in the San Juan Mountains of southwestern Colorado. From oldest to youngest, the major rock units include Lower lavas, Alamosa River stock, Alum Creek porphyry, Upper lavas, and vent-dome complexes. The Lower lavas are a complex group of andesite flow breccias, massive andesite flows, and tuffaceous andesite that are unconformably overlain by the Upper quartz latite lavas that erupted from local volcanic vents. The equigranular augite quartz monzonite Alamosa River stock intrudes the Lower lavas. The augite biotite quartz monzonite Alum Creek porphyry intrudes the Alamosa River stock. Both the equigranular and porphyritic stock lack planar flow structure or foliation, have narrow chilled border facies, contain small inclusions of the country rock, and show no discernible metamorphism of the adjacent rock. Both stocks are considered to be epizonal plutons. Quartz latite and sanidine quartz latite dike activity occurred intermittently throughout post-Lower lava time. The alteration activity is post-Upper lava in age. The vent-dome complexes are siliceous viscous magmatic protrusions that formed local volcanic domes upon the highly altered Upper and Lower lavas.

STRUCTURE

Faults, structural trends of the rock units, and joint sets were utilized for the local tectonic interpretation. The two most prominent faults are the east-west trending Red Mountain fault and the northwest trending South Mountain fault. The predominant trend of the dikes and the Alum Creek porphyry occur in a N30-50E zone. This northeast trending zone is believed to represent a zone of tensional weakness along which igneous activity occurred periodically.

PETROLOGY

From oldest to youngest the major rock units show a systematic change in the plagioclase content from An_{42} to An_{22}. With decreasing age there is a loss of hypersthene and a gradual loss of augite. Biotite occurs throughout the sequence increasing to a maximum content in the Alum Creek porphyry and then decreasing in percentage. The biotite shows little or no change in $Fe/(Fe + Mg)$ ratio. The siliceous rhyolite core of the Elephant Mountain volcanic dome contains only trace amounts of biotite. Magnetite has continuously crystallized throughout the sequence. The trends of the feldspar and ferromagnesian relations indicate a sequence of crystallization comparable to the middle-to-lower portion of Bowen's reaction series.

The spatial association of the rock units combined with the petrologic conclusions strongly suggest a consanguinity or genetic relationship among the rocks. Thus the Alum Creek area represents a volcanic association of extrusive, hypabyssal, and epizonal intrusive rocks.

ALTERATION

Surface coloration and altered rocks are areally extensive in the Alum Creek area. On the basis of the extensive fracturing that has controlled the selective alteration trends, it is apparent that the rocks of the area were well-fractured before the solfataric and hydrothermal alteration activity commenced. Local zonal patterns of selective alteration are associated with joint sets, faults, and dikes.

Propylitic, argillic, and phyllic facies of hydrothermal alteration exist in a zonal pattern around the Alum Creek porphyry. Propylitic, argillic, and quartz-alunite facies of solfataric alteration exist in a zonal pattern around the volcanic vents. The spatial relationships suggest a vertical transition of solfataric alteration that grades downward into hydrothermal alteration.

SIGNIFICANCE OF VOLCANIC ASSOCIATION

Field relations and petrology have indicated a spatial and genetic association of extrusive, hypabyssal, and epizonal plutonic rocks with associated solfataric and hydrothermal alteration in the Alum Creek area. This relationship indicates a volcanic association. These calc-alkaline rocks of a volcanic association have characteristic petrologic features similar to Bowen's reaction series. In the Alum Creek area the associated solfataric alteration is suggested to grade downward into hydrothermal alteration as exposed over a vertical range of some 2,000 feet.

In conclusion, the rocks presently exposed in the Alum Creek area strongly suggest important petrologic and alteration correlations. A lower level of erosion in the earth's crust probably would have removed the geological evidence needed to establish a volcanic association and a vertical transition of solfataric to hydrothermal alteration.

REFERENCES

Barton, P. B., 1959, The chemical environment of ore depositions and the problem of low temperature ore transport: Researches in Geochemistry, ed. Abelson, New York, John Wiley & Sons, Inc.

Buddington, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. America Bull., p. 671-748.

Burnham, C. W., 1956, Facies and types of hydrothermal alteration: Econ. Geology, v. 57, p. 768-784.

Creasy, S. C., 1959, Some phase relations in the hydrothermal altered rocks of porphyry copper deposits: Econ. Geology, v. 57, p. 351-373.

——— 1966, Hydrothermal alteration *in* Geology of the Porphyry Copper Deposits: Tucson, University of Arizona Press, p. 51-74.

Hemley, J. J., and Jones, W. R., 1964, Chemical aspects of hydrothermal alteration with emphasis on hydrogen metasomatism: Econ. Geology, v. 59, p. 538-569.

Kennedy, W. Q., 1938, Crustal layers and the origin of magmas: Bull. Volcanol., series 2, v. 3, p. 23-41.

Larsen, E. S., Jr., Irving, Jr., Gonyer, F. A., and Larsen, E. S. 3d., 1936-1937-1938, Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colorado: Am. Mineralogist, v. 21, p. 667-701; v. 22, p. 889-905; v. 23, p. 227-257 and p. 417-429.

Larsen, E. S., Jr., and Cross, Whiteman, 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

Lipman, P. W., Steven, T. A., and Mehnert, H. H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by potassium-argon dating: Geol. Soc. America Bull., v. 81, p. 2329-2352.

Lipman, P. W., and Steven, T. A., 1970, Reconnaissance geology and economic significance of the Platoro caldera, southeastern San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 700-C, p. C19-C29.

Lowell, J. D., and Guilbert, J. M., 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geology, v. 65, p. 373-408.

Mukaiyama, H., 1959, Genesis of sulfur deposits in Japan: Jour. of Faculty of Sci., Univ. of Tokyo, v. 2, sec. 2.

Osborne, E. F., 1962, Reaction series for subalkaline igneous rocks based on different oxygen pressure conditions: Am. Mineralogist, v. 47, p. 211-226.

Slemmons, D. B., 1962, Determination of volcanic and plutonic plagioclases using a three- or four-axis universal stage: Geol. Soc. Amer. Spec. Paper 69.

Steven, T. A., and Ratté, J. C., 1960, Geology and ore deposits of the Summitville district, San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 343, 70 p.

Turner, F. J., and Verhoogen, J., 1960, Igneous and metamorphic petrology: New York, McGraw Hill Book Company.

Vance, J. A., 1962, Zoning in igneous plagioclase; normal and oscillatory zoning: Am. Jour. Sci., v. 260, p. 746-760.

White, D. E., 1955, Thermal springs and epithermal ore deposits: Econ. Geology, 50th Volume, Part I, p. 99-154.

Wones, D. R., and Eugster, H. P., 1965, Stability of biotite: Experiment, theory and application: Am. Mineralogist, v. 50, p. 1228-1272.