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GEOLOGY OF THE
UPPER MARSHALL CREEK DRAINAGE BASIN
SAGUACHE COUNTY, COLORADO

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by

James L. Evans

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A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science in Geology.

Signed: James L. Evans
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ABSTRACT

The thesis area includes parts of the southern flank of the Sawatch Range, the northeastern San Juan volcanic field and the western Bonanza volcanic center. Basement Precambrian and Paleozoic rocks are present in the area, but the primary interest focuses on the volcanic rocks. The Precambrian rocks consist of an older complex of metamorphic rocks and a younger intruded complex of granites and granodiorites. The Paleozoic sedimentary rocks range in age from Ordovician to Pennsylvanian and include the Manitou Dolomite, Harding Sandstone, Fremont Dolomite, Chaffee Formation, Leadville Limestone, and the Belden Formation. There are no Mesozoic rocks in the area.

The oldest volcanic rocks in the area are flows of Rawley Andesite derived from the Bonanza volcanic center to the east. Younger andesites overlie the Rawley and were derived from both the Bonanza center and the Baldy Peak volcanic center. Volcanic units interfingered with the andesite sequence include the Bonanza Tuff and a water-laid tuff. Part of a new volcanic center, named the Baldy Peak volcanic center, comprises the southwestern part of the thesis area. An intrusive lava dome and thick sequences of andesite flows indicate that the Baldy Peak center was a major source of andesites in the area.

Two quartz latite ash-flow tuffs and an autobrecciated quartz latite lava flow cannot be correlated with other units in the area or in the literature. Outcrops of the Sapinero Mesa and Fish Canyon Tuffs were observed along the southern boundary of the area and represent the northeasternmost mapping of these ash-flow sheets.

Structurally, the thesis area is comprised primarily of Laramide high angle reverse faulting and later block faulting associated with the uplift or doming of the Baldy Peak volcanic center and the collapse of the Bonanza caldera. Pre-volcanic Laramide faults have not been significantly reactivated during the volcanic block faulting.

Photogeologic interpretations of low and high altitude color and color infrared photography in comparison to black and white photography indicated the color to be the most efficient. High altitude color photography was particularly useful in structure analysis, and the low altitude color was the most efficient for use as a base map during the field work. The color infrared was of little value in this area.

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INTRODUCTION

The area was chosen for study primarily because of an interest in the volcanic rocks and their relationship to the Bonanza volcanic center. The Bonanza volcanic center is a northeast extension of the much larger San Juan volcanic field, and the study area lies on its northernmost extension. The area also contains Precambrian basement rocks and Paleozoic sedimentary units. The volcanic rocks rest unconformably upon all the older rocks from Precambrian to Pennsylvanian-Permian.

Purpose and Scope

The purpose of this study was to map the geology of the area with principal interest centering on the Tertiary volcanic rocks, and to interpret the geologic history of the volcanic episodes represented. Therefore, the primary objective of this thesis work deals with the description, subdivision, and correlation of the volcanic rocks and the structure affecting the area. In addition, the usefulness of color and color infrared photography was evaluated.

Location and Accessibility

Location of the area is shown on Figure 1. Physiographically, the area forms a part of the southern flank of

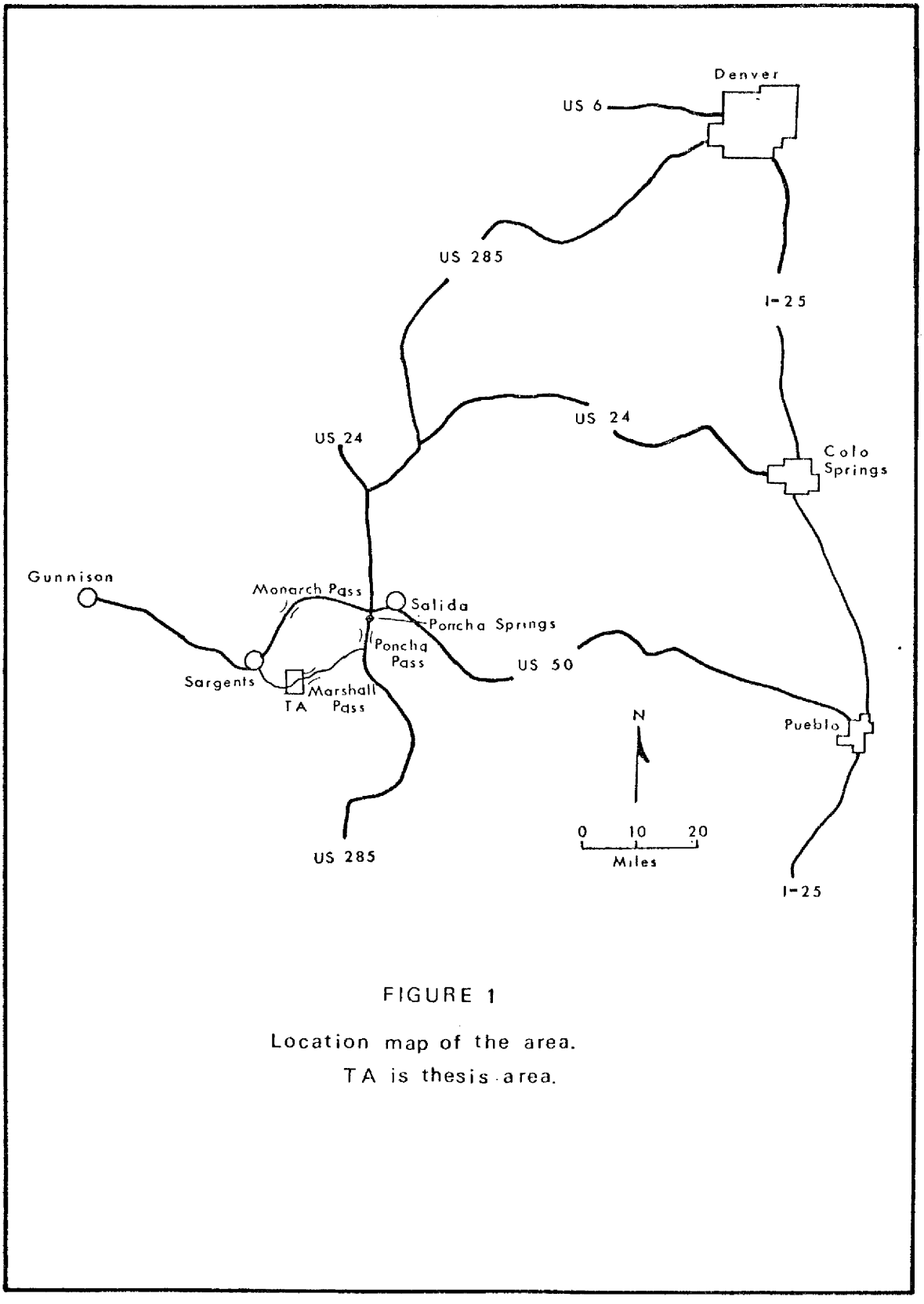

FIGURE 1

Location map of the area.
TA is thesis area.

the Sawatch Range near its junction with the San Juan volcanic field, San Luis Valley, and the Sangre de Cristo Mountains (Figure 2). The regional contact between the volcanic rocks of the Bonanza volcanic center and the underlying pre-volcanic erosional surface passes through the study area (Figure 4).

The small town of Sargents lies west of the thesis area at the intersection of the Marshall Pass road and U. S. Highway 50. The Marshall Pass road runs east from Sargents and crosses over Marshall Pass, and is the main access to the area. From Marshall Pass, the road continues east where it intersects Highway 285 near the town of Poncha Springs. Numerous gravel and dirt roads, many of which are 4-wheel drive jeep roads, provide further access to the area. However, a considerable part of the area is accessible only by foot.

Drainage and Climate

The area is drained by Marshall Creek which flows west and southwest to its confluence with Tomichi Creek west of the thesis area near the town of Sargents. Numerous tributaries of Marshall Creek dissect the area, flowing south-southwest and west-northwest. The largest of these is Indian Creek; other major tributaries are Millswitch Creek, Harry Creek, Tank Seven Creek, Duncan Creek and Jay Creek.

The high elevation of the area, from 8800 feet to 11,800 feet, maintains a cool climate most of the year. The average

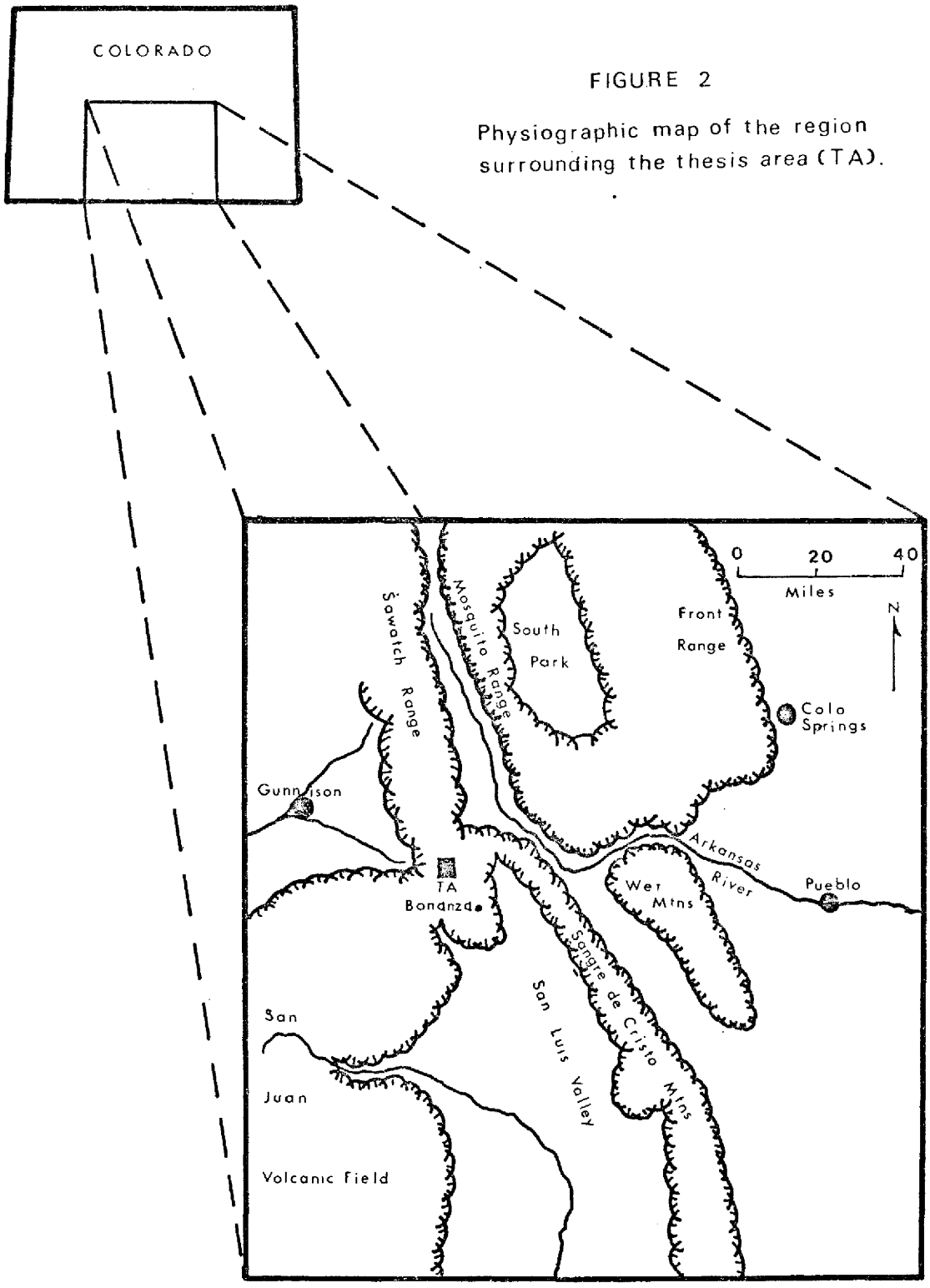

FIGURE 2

Physiographic map of the region surrounding the thesis area (TA).

rainfall is 12 to 15 inches per year. Most of the rain occurs as afternoon thundershowers during the summer, especially from mid-July to mid-September. Five to eight feet of snow is not uncommon during the winter months.

Vegetation and Topography

The area contains abundant vegetation, both timber and undergrowth (Figure 3). Fir, spruce, aspen, and pine are abundant along with sagebrush in the northern parts of the area along Indian Creek and its confluence with Marshall Creek. Undergrowth consists of a wide variety of grasses, shrubs, and flowers with the blue mountain columbine, the Colorado State Flower, being quite common. Very large stands of aspen are present in the protected areas within spruce and pine covered slopes. Geologically, vegetation proved to be of minor value as geologic contacts rarely conformed to vegetation patterns, and then only locally. The water-laid tuff seldom supports stands of pine or spruce, but may contain large stands of aspen and sage. The andesites cover a large part of the study area and support a wide variety of vegetation types.

The relief is moderate to rugged with 20 degree slopes being common. Large flat "parks" are common along the Continental Divide at elevations near 11,000 feet. Stream gradients may vary from as low as 160 feet per mile in the lower reaches of Marshall Creek to as high as 800 feet per

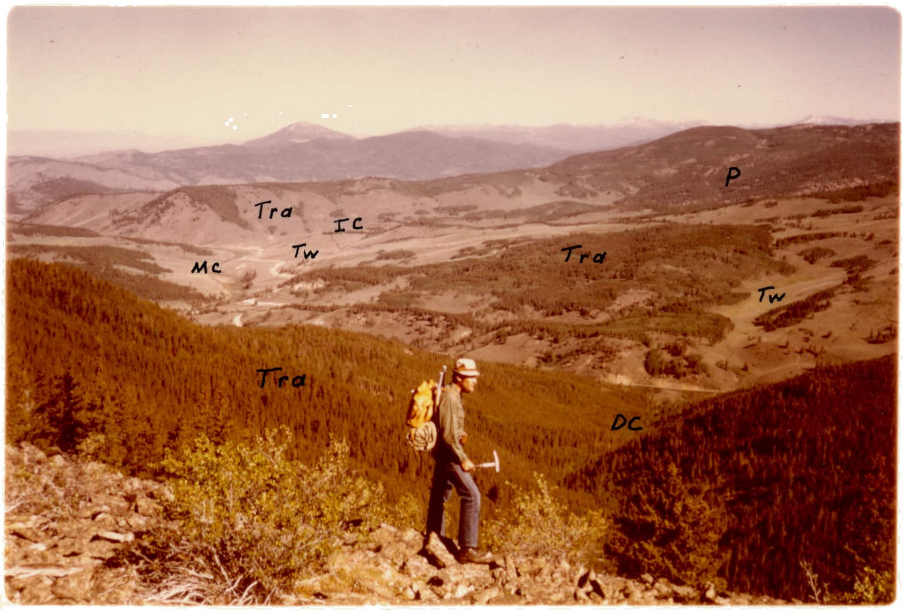

Figure 3. Photograph looking north from the Continental Divide about 2 miles west of Windy Peak. Author is standing on Rawley Andesite flow rock. Symbols used on photograph are as follows: Rawley Andesite (Tra), Water-laid tuff (Tw), Paleozoic sedimentary rocks (P), Marshall Creek (MC), Indian Creek (IC), and Duncan Creek (DC).

mile along Duncan Creek. The highest elevation is 11,885 feet at the crest of Windy Peak on the southern boundary of the area.

Previous Investigations

A voluminous literature has accumulated on the related aspects of volcanism, tectonism, and geologic history of the region. Very little literature deals with local delineation or correlation of the volcanic sequence with regional work.

Epis (1968) edited the results of a symposium on Cenozoic volcanism in the southern Rocky Mountains. Burbank (1932), Gableman (1952), and Litsey (1960) have published important papers on the volcanism and structure of the northern Sangre de Cristo Mountains. Larsen and Cross (1956), Luedke and Burbank (1963 and 1968), and Lipman, Steven and Mehnert (1970) have produced extensive geologic observations of the San Juan volcanic field. The Thirtynine Mile volcanic field to the northeast of the thesis area has been mapped and described by Chapin (1965), Buchanan (1967), Epis and Chapin (1968), DuHamel (1969), and Morris (1969).

The Bonanza topographic map sheet (1:62,000) borders the thesis area to the east, and the area itself lies within the Bonanza volcanic center. Extensive work has been done in the Bonanza area by Patton (1915), Burbank (1932), Karig (1965), and numerous graduate students of the Colorado School of Mines. Currently, Daniel Knepper, a Doctor of Science candidate at

the Colorado School of Mines, is consolidating and field checking the previous work done in the Bonanza quadrangle, and mapping the gaps. Close association and correlation with Knepper's work was undertaken in the present study.

Ranspot (1958) studied the geology of the Indian Creek area in the northern part of the thesis area. His work provides valuable information on the Paleozoic sedimentary units in the area, and the structure in the northern part of the area. Ranspot mapped a rhyolite tuff and a water-laid tuff in the southern part of his area, but he made no attempt to correlate these units outside the thesis area. Preliminary reconnaissance work by Knepper indicated a volcanic sequence existing in the eastern part of the thesis area which differs from the units observed in the Bonanza volcanic center.

Method of Investigation

Mapping was accomplished in the field on aerial photographs at a scale of approximately 1:24,000, and compiled on a 7½ minute quadrangle topographic map of the same scale. Attitudes were measured using a Brunton compass, and hand specimens were collected for petrographic study in thin-section. All field work was accomplished during the summer of 1972.

Acknowledgements

The author expresses appreciation to committee members Dr. L. T. Grose, Dr. J. R. Hayes, and especially to Dr. R. C.

Epis who provided valuable field assistance and chaired the Master of Science committee.

Appreciation is extended to the residents and ranchers of the Sargents area, particularly to the LaCapra family who provided a cabin for my family and myself, and to Bernard Irby and the Means families who gave assistance and information concerning access and property rights in the area.

Financial support was furnished from a Research Assistantship by the National Aeronautics and Space Administration (NASA), Earth Resources Technology Satellite (ERTS) project. The ERTS project also supplied color photography which has been used extensively in this study.

GEOLOGIC SETTING

The thesis area lies on the southern flank of the Sawatch Range (Figure 2). The San Luis Valley and Sangre de Cristo Mountains lie to the east and southeast, and the San Juan volcanic field lies to the southwest. The Sawatch Range is about 100 miles in length and varies from 8.5 to 17 miles in width. The Sawatch Range is a broad anticlinal uplift of more than 60,000 feet of structural relief (Grose, 1972) bounded on the flanks by high angle normal and reverse faulting and thrust faulting. The uplift occurred during Laramide time from late Cretaceous to Eocene. The Sangre de Cristo Mountains were uplifted beginning in late Cretaceous also as a large domal uplift with associated faulting. The uplift included the area of the present San Luis Valley, but by Miocene, the San Luis Valley developed as a collapse feature and is a northern extension of the Rio Grande rift system (Karig, 1964). Collapse of the San Luis Valley and/or uplift of the Sangre de Cristo Mountains is continuous to the present. The San Juan volcanic field represents a large, complex volcanic terrain within which numerous centers have been described (Lipman and Steven, 1968).

The volcanic rocks of the thesis area are part of the pile related to the Bonanza volcanic center which is, in turn, a northeastern extension of the San Juan volcanic field (Figure 4). K-Ar age determinations indicate that most of the volcanic rocks

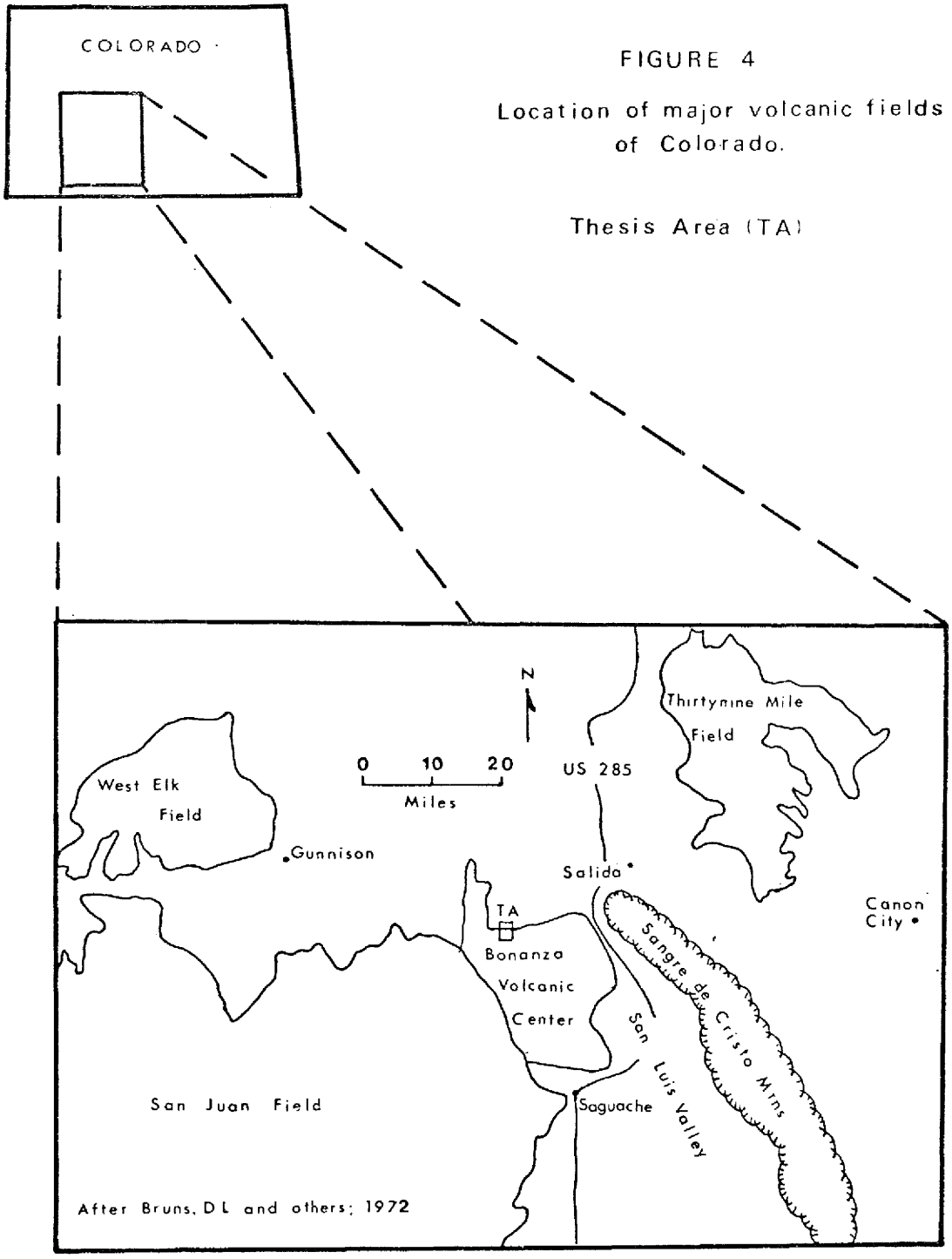

FIGURE 4

Location of major volcanic fields of Colorado.

Thesis Area (TA)

in south-central Colorado were erupted during Oligocene time, and probably represent parts of a single large composite field (Steven and Epis, 1968). The San Juan volcanic field is separated from the Thirtynine Mile volcanic field to the northeast by the Sangre de Cristo Mountains and the San Luis Valley. Part of the resistant Precambrian core of the Sawatch Range was probably a topographic high during post-Laramide times, and may have been only partially covered by the mid-Tertiary volcanic rocks (Steven and Epis, 1968). Much of the tectonic activity that formed the San Luis Valley (Rio Grande rift) took place after the major volcanism of the mid-Tertiary (McKinlay, 1956; and Steven and Epis, 1968).

STRATIGRAPHY

Basement Precambrian rocks outcrop in the area and are directly overlain by either paleozoic sedimentary units or Tertiary volcanic rocks (Figure 5). The Precambrian was not subdivided in this study, but was subdivided in the northeastern part of the area by Ranspot (1958). The Paleozoic section was mapped and described in detail by Ranspot (1958) and was only briefly reviewed in the present work. Previous workers did not subdivide the volcanic units.

Precambrian Rocks

The Precambrian rocks consist of two major divisions; an older metamorphic complex, and a younger intrusive igneous complex which were not subdivided in this study. The older metamorphic complex consists of quartz-feldspar-mica gneisses, amphibolite gneisses, and quartz-mica schists. The strike of the foliation is generally northwest with variable dips. The age of these rocks has been estimated at 1.4 to 1.6 billion years (Edwards, 1966). These rocks are intruded by graphic granites, granodiorites, and granitic pegmatites. The strike of the pegmatites is generally along the northwest trend of the foliation. Large pegmatites observed in the central part of sec. 23, R. 6 E., T. 48 N., contain abundant euhedral and subhedral crystals of magnetite up to several inches in size.

GENERALIZED COLUMNAR SECTION

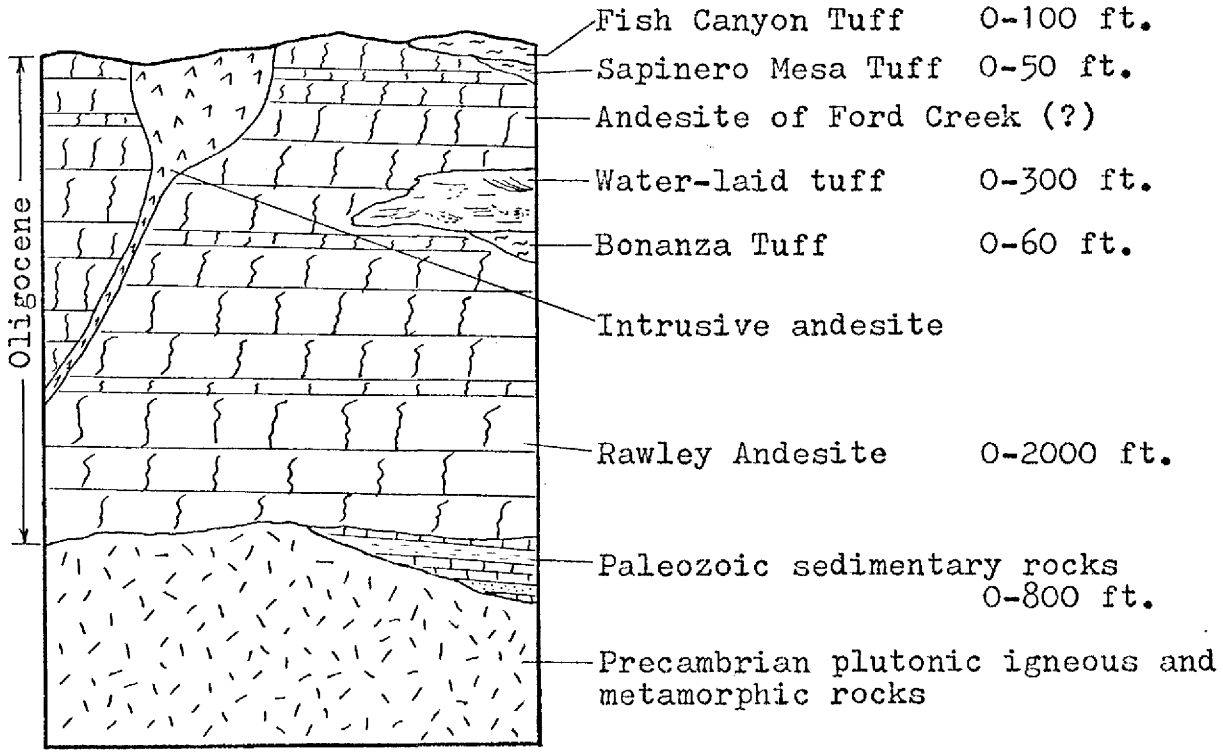

Figure 5. Generalized columnar section of principal stratigraphic units in Marshall Creek drainage basin, Saguache County, Colorado.

Other pegmatites consist entirely of muscovite and quartz with the muscovite forming up to 60 percent of the rock. Kouther (1968) studied the Precambrian rocks in more detail northeast of the present area of investigation.

Paleozoic Sedimentary Rocks

The Paleozoic sedimentary rocks crop out along the northern boundary of the area and as windows in the volcanic rocks. The Paleozoic sequence contains rocks ranging in age from Ordovician to Pennsylvanian and the entire sequence can be ovserved along the Indian Creek roadcut. There are no Mesozoic rocks in the area. Mesozoic sedimentary units that were deposited in this area were eroded prior to the deposition of the Tertiary volcanic rocks.

Manitou Dolomite

The Manitou Dolomite is the oldest sedimentary unit in the area and rests unconformably on Precambrian rocks. It is Ordovician in age and measures approximately 280 feet thick. The Cambrian Sawatch Quartzite was either eroded before the deposition of the Manitou or was never deposited in this area. The Manitou is light gray, thin- to thick-bedded, locally sandy, and contains numerous nodules of white and black chert. An unconformable surface forms the upper contact of the Manitou with the Harding Sandstone.

Harding Sandstone

The Ordovician Harding Sandstone is 40 feet thick and less competent than the dolomites in the thesis area. The Harding is a variable unit of conglomeratic medium- to coarse-grained quartz sandstones and interbedded thin, white silicified sandstones. Commonly, the Harding is thick-bedded and jointed. The contact between the Harding and the overlying Fremont Dolomite is conformable and gradational.

Fremont Dolomite

The Fremont Dolomite (Figure 6) is Ordovician in age and measures 180 feet thick in the study area. It varies from thin- to thick-bedded, is fossiliferous, and commonly weathers to a rough, blocky surface. The Fremont is a dense, hard, highly resistant blue-gray dolomite, and locally contains a few dark gray chert nodules. The Fremont is the youngest Ordovician unit in the area, and an unconformable surface exists at its upper contact with the Chaffee Formation.

Chaffee Formation

The Chaffee Formation is Devonian in age and consists of two primary members. The lower member is the Parting Quartzite which measures only 10- to 20-feet thick. Overlying the Parting is the Dyer Dolomite which measures approximately 150 feet thick. The Parting is a blocky, tan to gray quartzite,



Figure 6. Photograph of the resistant, cliff forming Fremont Dolomite along Indian Creek. Note massive character of the dolomite and vertical jointing. Photograph was taken looking southerly in direction of dip.

and a ridge former in the area. The Dyer Dolomite is commonly thin-bedded, sandy, and fossiliferous.

Leadville Limestone

Overlying the Chaffee Formation by gradational contact is the Mississippian Leadville Limestone which measures over 400 feet thick. The Leadville is a thin-bedded to massive, finely crystalline, gray to blue-gray limestone with local silicification zones, and locally contains chert. Erosion created an extensive karst topography on the surface of the Leadville prior to the deposition of the Belden Formation (Ranspot, 1958).

Belden Formation

The Belden Formation is Pennsylvanian in age and unconformably overlies the Leadville Limestone in the study area. Ranspot (1958) estimated the total thickness of the Belden to be 500- to 750-feet. The lower part consists of shales, silty limestones, and interbedded arkoses. According to Ranspot, it grades upward into a light- to medium-gray shale. Only the lower 150- to 200-feet is present in the study area.

Tertiary Volcanic Rocks

The Tertiary volcanic rocks crop out primarily in the southern 2/3 of the area and overlie the erosional surface cut across Paleozoic and Precambrian rocks. Based on the correlation of these units with other work in the San Juan volcanic

field (Figure 7), and the K-Ar dating by Lipman and others (1970), the volcanic units were determined to be Oligocene in age.

Rawley Andesite

The Rawley Andesite consists primarily of andesite flows (Figure 8) and covers about 2/3 of the thesis area. It is up to 2500 feet thick, but usually ranges from 1000- to 2000-feet thick. Individual flows range from a few tens of feet up to 200 feet thick. They tend to have columnar jointing and are commonly porphyritic with phenocrysts up to several millimeters (Appendix). The color of the flows is usually gray to black except where they have been altered to chlorite minerals and appear green. All the flows of the Rawley are magnetic and a concentration of magnetite on the surface of fractures is common.

The Rawley rests unconformably on the Precambrian and Paleozoic rocks and corresponds in age with the Conejos Formation of the San Juan volcanic field (Bruns and others, 1972). Lipman, Steven and Mehnert (1970) place the age of the Rawley at 33.4 to 34.2 m.y. (early Oligocene) which corresponds to their "earlier intermediate rocks" and predates the advent of major ash flow activity. Mayhew (1969) indicates that the Rawley is also contemporaneous with the Hayden Peak Latite of the Bonanza volcanic center.

Modified after Lipman, Steven, and Mehnert (1970)	Bruns and others (1972)	This Report	
Hinsdale Formation ..... Basalt (4.7 - 23.4 m.y.) and Rhyolite (4.8 - 22.4 m.y.)	Hinsdale Formation		
ASH-FLOW TUFFS AND RELATED ROCKS			
Carpenter Ridge Tuff- Bachelor Mtn. Rhyolite	Carpenter Ridge Tuff		
Fish Canyon Tuff-La Garita Qtz. Latite (27.8 m.y.)	Fish Canyon Tuff	Fish Canyon Tuff	
	Andesite of Saguache Creek		
	Water-laid and air-fall tuffs of Saguache Creek		
Tuff of Masonic Park (28.2 m.y.)	Sapinero Mesa Tuff	Sapinero Mesa Tuff	
Treasure Mtn. Rhyolite (29.8 m.y.)	Andesite of Ford Creek	Andesite of Ford Creek (?)	Purple Breccia Ash Flow 2
		Water-laid tuff	Ash Flow 1
	Bonanza Tuff	Bonanza Tuff	
EARLY INTERMEDIATE LAVAS AND BRECCIAS			
Conejos Formation (31.1-34.7 m.y.), Lake Fork Fm., West Elk Breccia and San Juan Formation (Included Bonanza volcanic pile)	Rawley Andesite	Rawley Andesite	

Figure 7. Summary correlation chart of volcanic stratigraphy. Modified after Bruns and others (1972).



Figure 8. Photograph of an andesite lava flow of the Rawley Andesite as it crops out ½ mile west of Tank Seven Creek and about 2 miles south of the confluence between Marshall and Tank Seven Creeks. Flow layering can be seen perpendicular to vertical columnar jointing.

Thin section analyses of nine separate flows show textures of aphanitic and porphyritic-aphanitic (Appendix). The majority of the flows are porphyritic-aphanitic and may be either holocrystalline or hypocrystalline (Figures 9 and 10). They range in composition from augite-andesine and/or labradorite to augite-biotite and biotite-hornblende andesite. Magnetite commonly forms from 5- to 15-percent of the phenocrysts. Alteration to clays and sericite is common, and replacement of plagioclase by calcite was observed in one thin section. The intrusive lava dome (Plate 1) is composed of unaltered, holocrystalline, porphyritic-aphanitic, biotite-augite andesite. Geodes commonly occurred in the andesite flows north of Marshall Creek and were either crystalline quartz or chalcedony in composition.

Bruns and others (1972, p. 187) in their discussion of the andesites of Ford Creek south and southeast of the map area have indicated that the flows thicken both to the northwest and northeast, "...and appear to have been derived from separate centers in these respective directions...". In the vicinity of Duncan Creek and its confluence with Marshall Creek, the andesites overlie the water-laid tuff which in turn overlies the Bonanza Tuff. This would indicate that some of the Baldy Peak andesites are younger than the Rawley Andesite. Bruns (1971) separated these two periods of andesite deposition by the presence of the intervening Bonanza Tuff. In the study area, however, the Bonanza Tuff is not stratigraphically

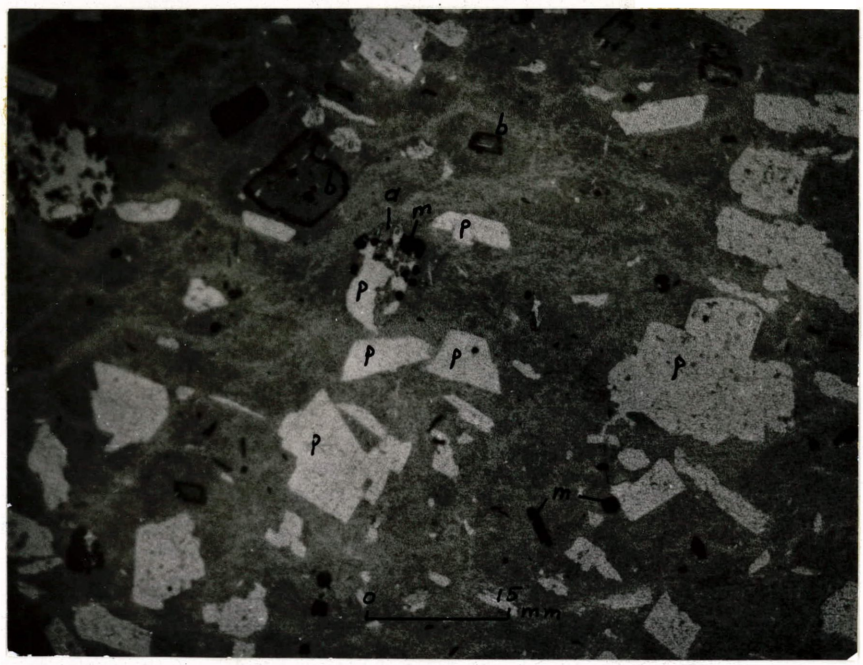

Figure 9. Thin section, ordinary light, projected to a screen. Photomicrograph of hypocrystalline, porphyritic-aphanitic, augite-biotite andesite. Note phenocrysts of augite (a), biotite (b), magnetite (m), and plagioclase (p). Groundmass is cryptocrystalline and glassy and shows good flow structure from left to right.

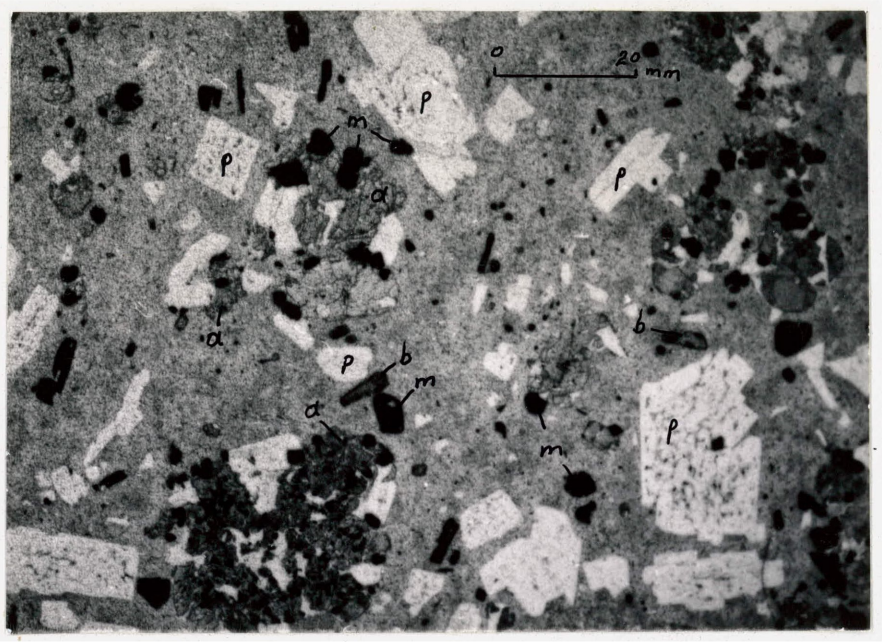

Figure 10. Thin section, ordinary light, projected to a screen. Photomicrograph of holocrystalline, porphyritic-aphanitic, biotite-augite andesite flow. Note abundance of magnetite (m), along with phenocrysts of augite (a), biotite (b), and plagioclase (p). Groundmass consists primarily of plagioclase microlites and shows a pilotaxitic structure.

important because of its limited aerial extent (Plate 1). However, the author feels that andesites of Ford Creek overlie the Rawley Andesite in the area, but was unable to separate them for mapping purposes.

Bonanza Tuff

The Bonanza Tuff (Mayhew, 1969, p. 14-15 and p. 25-26) exists as erosional remanants in the thesis area with an extremely limited aerial extent (Plate 1). The Bonanza Tuff is found only along Marshall and Indian Creeks near their confluence suggesting that these were also paleovalleys during the Oligocene when the Bonanza Tuff was deposited. The fact that Bonanza Tuff lies directly on the Paleozoic rocks suggests that the Rawley Andesite was eroded along these paleovalleys prior to the deposition of the Bonanza or possibly never deposited.

Specimens of the Bonanza Tuff were compared both in hand specimen, and petrologically in thin section with the work of Marrs (1973) and Bruns (1971). Marrs, in describing his proposed principal reference section for the Bonanza Tuff, delineated eight separate flow units on the basis of mineralogy. He grouped flows 1, 3, 5 and 8 as being compositionally similar and flows 2, 4, and 6 as being similar. Thin section analysis of the Bonanza in the thesis area (Appendix) indicates that it falls in the group of flows 1, 3, 5, and 8, as described by Marrs, and compares best with flows 5 and 8.

The Bonanza is a moderately welded latite ash-flow tuff and weathers a dark reddish-brown. In hand specimen, it is biotite rich, and compaction layering can be observed where flattened pumice lapilli have been weathered out. The Bonanza is from 0- to 60-feet thick and is comprised of a simple cooling unit of a single flow. In thin section (Figure 11), it exhibits a eutaxitic structure and well developed devitrification. Percentage estimates show that the plagioclase to sanidine ratio is about 5:3. Biotite is the major mafic mineral and comprises 5- to 10-percent of the crystals. The feldspar and biotite crystals are often partially altered to clays and chlorite minerals.

Water-laid tuff

The water-laid tuff generally overlies andesite lava flows and the Bonanza Tuff, but locally is covered by andesite flows (Plate 2). It is the only volcanic unit in the area that contains fossil plant material (Figure 12). For this reason, several carbon-rich samples were prepared and analyzed for pollen spores. Although the pollen spore analysis confirmed and aided in the identification of plant fragments, it did not contain any index fossils for an accurate age determination. Plant fragments were identified as bark, grasses, and pine needles; the latter being similar to the present day Lodgepole pine, Pinus contorta. Leaves were identified as mountain mahogany (Cercocarpus) and a second broad leaf as Rhododendron

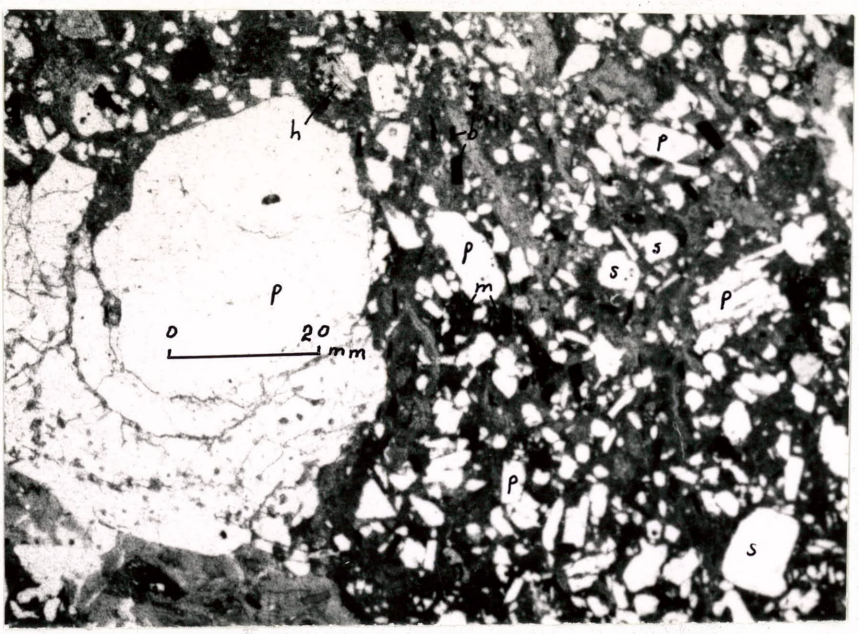

Figure 11. Thin section, ordinary light, projected to a screen. Photomicrograph of Bonanza Tuff showing eutaxitic structure and crystal content (about 35 percent). Note phenocrysts of plagioclase (p) sanidine (s), biotite (b), magnetite (m), hornblende (h), and lithics (l).

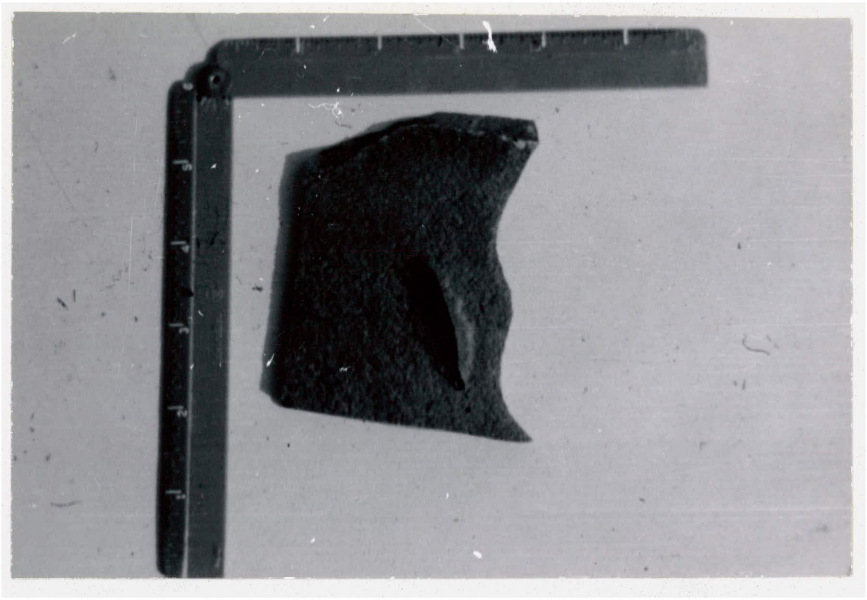

Figure 12. Photograph of a mountain mahogany (Cercocarpus) leaf found in the water-laid tuff along Marshall Pass road about 1 mile northeast of the intersection of Marshall Creek and the Marshall Pass road.

sp. (?) (MacGinitie, 1972, personal communication). Pollen spore identification generally indicated the presence of pines (Pinus), spruce (Picea), and fir (Aldies); however, small amounts of pollen from a "rock moss" (Selaginella) were also found (Lewis, 1973, personal communication). The presence of these plants would indicate a paleoclimate very similar to the present day conditions. The area was probably mountainous, cool, and moist with elevations greater than 6,000 feet.

The water-laid tuff ranges in thickness from 0- to about 300-feet and is commonly cross-bedded, channeled and exhibits graded bedding. Some areas contain abundant layers of only fine ash material and could be air-fall tuffs. Small lenses of conglomeratic material in channel fills contain abundant Precambrian and andesite pebbles in a tuffaceous matrix. The unit is nonresistant and tends to form a subdued topography with low-profile hills. The most abundant outcrops of the water-laid tuff are between Marshall Creek and Indian Creek (Plate 1) and generally are vegetated with sagebrush and grasses. The matrix material is usually extensively altered to clay minerals. Locally, the water-laid tuff weathers into brittle, iron oxide-stained "plates" ranging from less than 1/10 inch up to several inches thick. Fault zones in the unit commonly contain post-fault calcite crystallization along fractures.

Sapinero Mesa Tuff

The Sapinero Mesa Tuff (Olson, Hedlund and Hansen, 1968) overlies the Rawley Andesite and has a very restricted occurrance near the point of intersection between the Chester-Middle Creek fault and the Continental Divide (Plate 1). It has been correlated in both hand specimen, and petrologically in thin section with the work of Bruns (1971), and in hand specimen with outcrops along Highway 114 between Saguache and Gunnison. It is distinguished from the Carpenter Ridge Tuff (Olson, Hedlund and Hansen, 1968) by its stratigraphic position below the Fish Canyon Tuff. It has been dated by Lipman and others (1970) at 27.8 to 28.4 m.y., and was probably derived from the caldera areas in the western part of the San Juan field (Bruns and others, 1972). In the thesis area, it is a moderately to densely welded, reddish-brown, quartz latite ash-flow tuff. The unit is about 50 feet thick, and forms a single cooling unit.

In thin section the Sapinero Mesa is a partially welded, devitrified, quartz latite ash-flow tuff containing 10- to 15-percent phenocrysts of sanidine, plagioclase (andesine), and biotite with trace amounts of quartz, magnetite, and zircon (Appendix). Pumice fragments are flattened and devitrification with abundant spherulites occurs.

Fish Canyon Tuff

The Fish Canyon Tuff is a crystal-rich quartz latite ash-flow tuff that was derived from the La Garita caldera about

40 miles southwest of the thesis area approximately 28 m.y. ago (Lipman, Steven and Mehnert, 1970). It has a very restricted occurrance similar to the Sapinero Mesa Tuff (Plate 1). Specimens from this locality have been compared in hand specimen and petrologically with the work of Bruns (1971) and with outcrops along Highway 114 between Saguache and Gunnison. This represents the northeasternmost known extension of both the Sapinero Mesa and the Fish Canyon. Although both units probably extended farther north at one time, uplift in this area and renewed erosion removed them.

In hand specimen the Fish Canyon is light to buff in color and is distinctively crystal rich containing 50- to 60-percent phenocrysts. In thin section it is moderately compacted, partially welded, contains little devitrification, and is comprised primarily of plagioclase (andesine) and sanidine (Appendix). Biotite is well developed and is the most common mafic mineral with hornblende comprising up to 4 percent of the crystal content by volume percent. Quartz is present in trace amounts, and lithic fragments are conspicuously absent. Flattened pumice lapilli are also present.

Bruns (1971) found the Fish Canyon Tuff to be up to 500 feet thick in the Lake Mountain NE quadrangle, but indicated that it thinned to the north where it was uplifted due to the doming of the Baldy Peak volcanic center. In the thesis area, the Fish Canyon is less than 100 feet thick, and is comprised of a single cooling unit.

Ash flows 1 and 2 and the purple breccia

Ash flows 1 and 2 and the overlying flow breccia are anomalous not only to the thesis area, but also to the regional volcanic sequences as described by Bruns (1971), Raines (1971), and workers in the Bonanza volcanic center. The author has been unable to correlate these units with any others in the thesis area or with units described in the literature. These units are restricted in occurrance to the ridge separating Marshall and Millswitch Creeks and are best exposed in the roadcut along the north side of this ridge (Plate 1). Ash flow 1 lies unconformably on the Precambrian surface and is overlain by ash flow 2. The flow breccia overlies the Precambrian surface and both ash flows.

Ash flow 1 is about 120 feet thick and consists of a densely welded, eutaxitic zone overlain by a nonresistant vitrophyre zone (Figure 13). In hand specimen ash flow 1 is commonly brown to flesh colored with an excellently developed eutaxitic structure. Flattened pumice lapilli and lithic fragments of andesite and crystalline (Precambrian) material are quite distinctive of the unit.

In thin section (Figure 14) ash flow 1 consists primarily of sanidine and quartz with lesser amounts of plagioclase (An_{20}-An_{32}), biotite and magnetite. The sanidines are commonly chatoyant, and the biotites are dark red-brown. The most distinctive feature of ash flow 1 is the presence of abundant lithic fragments of aphanitic felsic material. These fragments



Figure 13. Photograph of ash flow 1 as it crops out along Marshall Creek on the north slope of the ridge separating Marshall and Millswitch Creeks. Photograph shows the contact (dashed line) between the moderately to densely welded zone below and the black, nonresistant, vitrophyre zone above. Rock hammer (H) shown for scale.

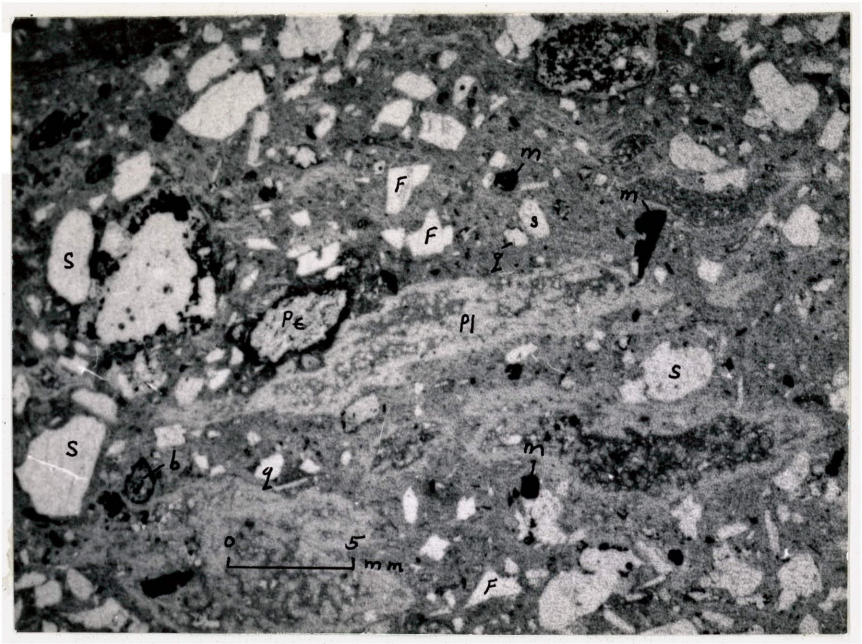

Figure 14. Thin section, ordinary light, projected to a screen. Photomicrograph of ash-flow 1 showing good eutaxitic structure. Selected lithic fragments of felsic material (F) and Precambrian (Pc) rocks are labeled along with phenocrysts of sanidine (s), quartz (q), biotite (b), and magnetite (m). Matrix consists of glass shards and flattened pumice lapilli (Pl).

are quite angular and are commonly associated with magnetite, some biotite, and few phenocrysts of feldspar (sanidine ?). Lithic fragments of schists, gneisses and andesites are also common along with minor amounts of calcite (recrystallized dolomite ?). The unit is well compacted; partially welded, and nearly completely devitrified and commonly exhibits a granophyric texture. Minor amounts of secondary hematite and clay alteration are also present. Both ash flows 1 and 2 are quartz latites although ash flow 2 contains considerably less quartz.

Ash flow 2 consists of a densely welded, resistant, black vitrophyre about 80 feet thick (Figure 15). The unit contains an upper zone of brown, nonresistant material which could represent either a poorly welded zone or a zone of alteration resulting from the heat of the overlying flow breccia at the time of emplacement. Ash flow 2 is broken by vertical columnar jointing and contains andesite and Precambrian lithic fragments up to several inches in diameter.

In thin section ash flow 2 is relatively crystal poor containing only 20- to 25-percent phenocrysts in a zone where compaction is at a maximum. The phenocrysts consist primarily of plagioclase (An_{27}-An_{32}), and sanidine with considerable biotite and minor amounts of magnetite, hornblende, and quartz. Lithic fragments comprise 10- to 15-percent of the rock and are principally andesites and metamorphic rocks with minor amounts of quartzite (Paleozoic ?) and calcite (recrystallized



Figure 15. Photograph of ash flow 2 as it crops out along the Marshall Pass road near the confluence between Marshall and Harry Creeks. Photograph shows the contact (dashed line) between the densely welded black vitrophyre zone below and the less welded, altered zone above.

dolomite ?). Minor amounts of the lithic aphanitic felsic material, as found in ash flow 1, are present in some sections. The unit is almost completely devitrified and granophyric in texture. Few sanidines are chatoyant as compared to ash flow 1, the overall composition is more mafic, and some accessory (?) sphene exists in ash flow 2.

The purple breccia is mainly a flow breccia but also contains a few laharic flows up to 30 feet thick. The entire unit is over 200 feet thick. As is the case with ash flows 1 and 2, the flow breccia is best exposed in the roadcut along the Marshall Pass road (Figure 16). In hand specimen the flow breccia contains 50- to 60-percent clasts ranging in size from a few millimeters up to 5 centimeters in diameter. The clasts contain 10- to 15-percent phenocrysts of quartz, plagioclase, sanidine, and biotite in a glassy groundmass. The larger clasts show good flow structure, and are usually angular. Laharic flows within the breccia contain abundant Precambrian and andesite material besides fragments of the flow breccia itself.

In thin section (Figure 17) the flow breccia contains 60- to 70-percent clasts in a matrix of the same material. Clasts contain 15- to 20-percent crystal material in a glassy and aphanitic matrix. Crystals are primarily plagioclase (An_{27}-An_{38}), sanidine, quartz, biotite and minor magnetite. The feldspars are highly altered to clay and minor sericite.



Figure 16. Photograph of the purple flow breccia where it crops out along the north side of the ridge separating Marshall and Millswitch Creeks. Outline of clasts of hypocrystalline, porphyritic-aphanitic quartz latite are visible on weathered surface.

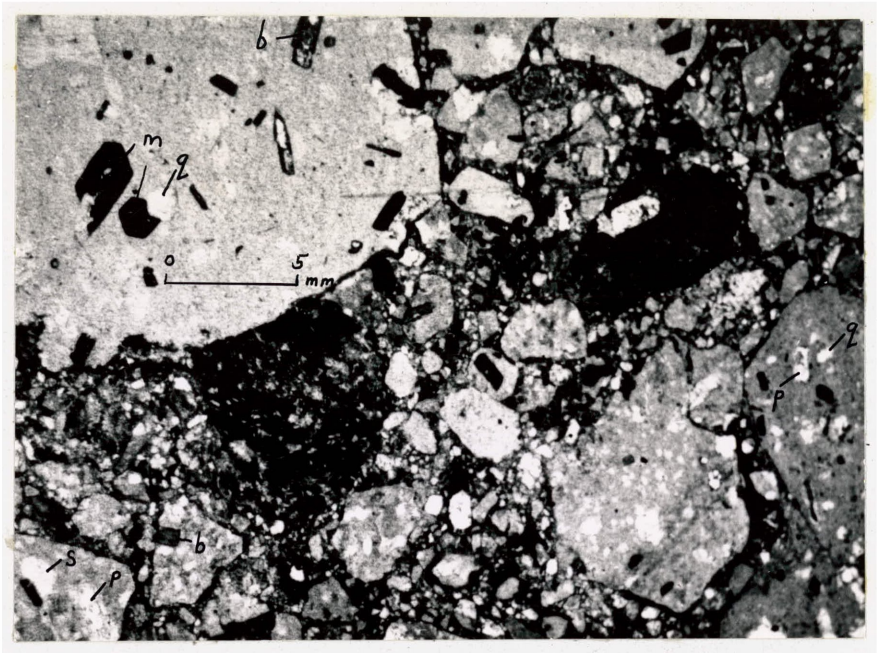

Figure 17. Thin section, ordinary light, projected to a screen. Photomicrograph of the purple flow breccia. Clasts consist of quartz latite porphyry with phenocrysts of quartz (q), plagioclase (p), sanidine (s), magnetite (m), and biotite (b) in a hypocrystalline groundmass. Matrix consists of glass and microcrystalline plagioclase, sanidine, quartz, biotite and magnetite.

The breccia is considered to be autoclastic and represents a monolithologic autobrecciated lava flow containing nonbrecciated lenses. One nonbrecciated "pod" observed in the flow breccia was about the size of a pick-up truck. Thin section analysis of a sample of this "pod" indicated that it was a flow rock of the same composition (Appendix). The pod is altered and contains calcite veins in addition to abundant calcite replacement of the feldspar crystals. Compositionally, the flow is a quartz latite. As previously mentioned, the flow has not been correlated with other units regionally and possibly was derived from the Baldy Peak volcanic center. Hopefully, additional work west of the thesis area in the vicinity of Baldy Peak will produce evidence for correlating this entire sequence of rocks with other rocks of the region.

Quaternary - Tertiary (?) stream gravel

On the west slope of the same ridge containing ash flows 1 and 2 and the flow breccia, is a gravel deposit representing the location of a paleodrainage. This outcrop does not have sufficient aerial extent to determine the orientation of the paleodrainage, and does not cross the fault zones represented topographically by the present location of Marshall and Millswitch Creeks. The gravel in this stream deposit includes boulder size material and is comprised of abundant Precambrian and volcanic material. The volcanic material is mainly andesite

quartz latite ash-flow tuff, and quartz latite flow breccia. Its age is uncertain and could be either Tertiary or Quaternary.

Quaternary Deposits

Quaternary deposits in the thesis area consist primarily of Holocene alluvium along the valley floors of present drainages. The upper reaches of these drainages have steep gradients and are essentially erosional valleys on bedrock. Locally, beaver ponds collect minor amounts of sediments. The drainages passing through the timberline parks, such as Sawmill Park, contain boulders, cobbles and pebbles of andesite and are essentially monolithologic. The alluvium of the valley floors of the perennial streams is composed of unsorted debris eroded from their respective drainage basins.

Three landslides were mapped (Plate 1) and are composed of the bedrock material from their sources. The landslide in Precambrian and the slide in the water-laid tuff are nearly monolithologic and contain little if any foreign material, whereas the slide along Millswitch Creek near its confluence with Marshall Creek contains a mixture of flow breccia, Precambrian rock, and andesite.

STRUCTURAL GEOLOGY

The structural geology of the area can be divided into three major stages of deformation. They are: (1) structures related to the Laramide Orogeny and uplift of the Sawatch Range prior to volcanism, (2) faulting associated with the volcanic activity in and around the area, and (3) later block faulting associated with the collapse of the San Luis Valley (Rio Grande rift).

Pre-volcanic Structure

Regionally, topographic linears, faults and/or fractures, trend north-south, northeast, and northwest (Figure 18). The fractures shown with heavy lines are either located in pre-volcanic rocks, or are known to be major pre-volcanic faults from the literature. Topographic linears shown with light lines are in volcanic rocks and may or may not be related to the pre-volcanic structures. The simulated low sun-angle photography (LSAP) shown in Figure 18 was taken using artificial light and the Montrose quadrangle (1:250,000) plastic relief map. The plastic relief map was first painted white with several coats of paint to remove the printing lines and to enhance the contrast when photographed. The map and camera were placed so that the film plane was parallel to the plane of the map and focused on the particular area of interest.

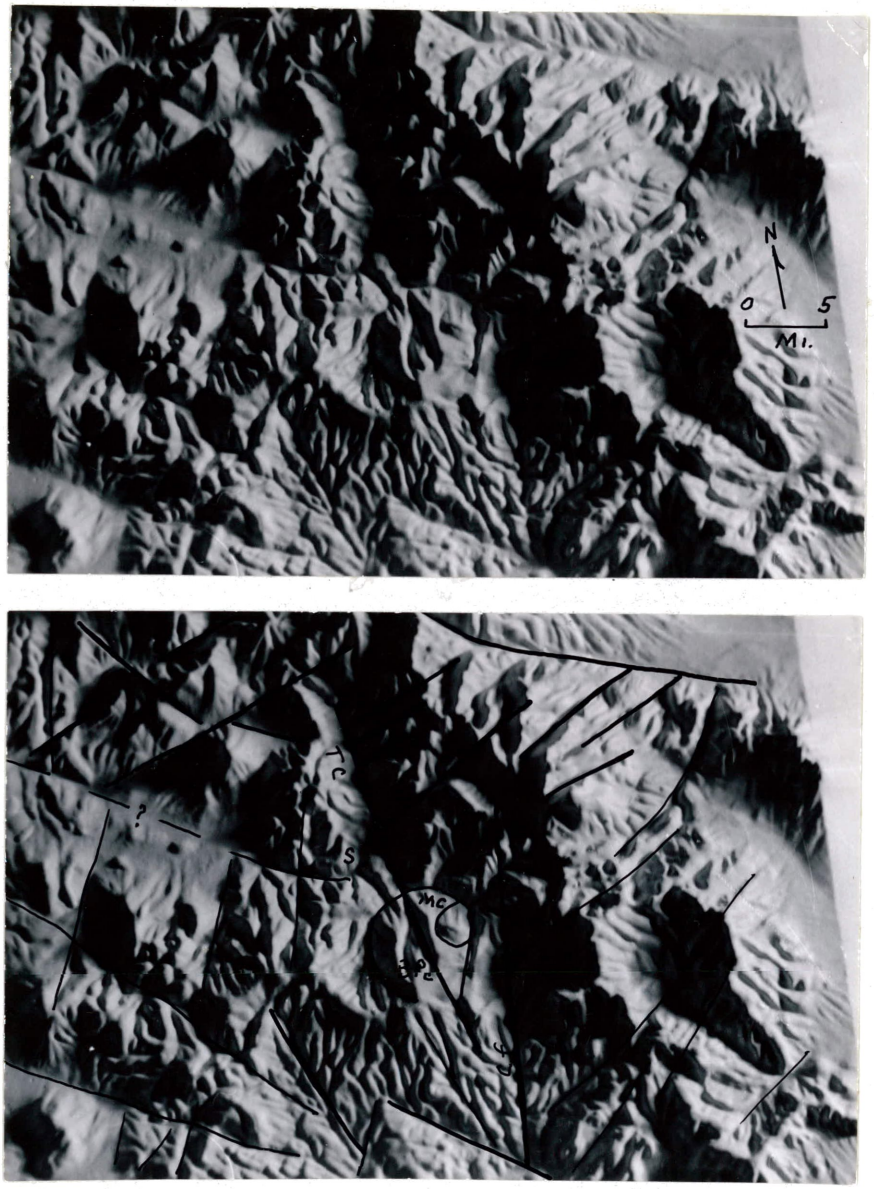

Figure 18. Simulated low sun-angle photograph (LSAP) using east illumination at approximately 15 degrees to the horizontal on the plastic relief map of the Montrose quadrangle (1:250,000). (See text for complete discussion.) Photo shows the north-south, northeast, and northwest trends of topographic linears in the area. Symbols used are: Sargents (S), Tomichi Creek (TC), Marshall Creek (MC), Chester fault (Cf), and Baldy Peak volcanic center (BPc).

In this way, a flood lamp could be arbitrarily placed so that any sun-azimuth and sun-angle could be simulated. In general, structures (topographic linears) tend to show up best when the light direction is perpendicular to the linear and the sun-angle is low (10- to 20-degrees).

The area also lies within the boundaries of the northeast-trending Colorado mineral belt which follows a zone of weakness of Precambrian ancestry (Tweto and Sims, 1963). The major pre-volcanic structure in the study area is the north-south trending Chester fault (Ranspot, 1958). Ranspot, from underground mapping in the Pinnicle Mines ½ mile north of the area, classified the Chester fault as a high angle reverse fault with a minimum of 1000 feet of displacement during the Laramide. This amount of displacement is evident in the study area where the entire Paleozoic stratigraphic section has been faulted out, and the Belden Formation is in fault contact with the Precambrian. An extensive shear zone of nearly 1000 feet in width exists along the fault zone where the Chester fault is exposed on the north slope of the Marshall Creek valley. This shear zone can be traced across Marshall Creek to the south in the Precambrian rocks, but is not present in the volcanic andesite lava flows overlying the Precambrian. Recent bulldozer pits exposing the fault zone immediately to the north of the thesis area have exposed slickensides in the Precambrian plunging southerly at about 60 degrees. This evidence indicates that the Chester fault might be more appropriately termed an oblique-slip fault, dipping 80- to 85-degrees westerly.

South of Marshall Creek the Chester fault is difficult, if not impossible, to locate on the ground in the Rawley Andesite as there has been little, if any, movement after the initiation of volcanism. However, the Chester fault linear is clearly discernable on the NASA Mission 211, high altitude, color photography, and can be traced, on strike across the Continental Divide to connect with the Middle Creek fault as mapped by Bruns (1971) in the Lake Mountain NE quadrangle. Bruns likewise indicated that the major displacement along the Middle Creek fault probably occurred prior to volcanism, with little or no post-volcanic movement. The presence of the Sapinero Mesa and Fish Canyon Tuffs along the Continental Divide at the same location where the Chester-Middle Creek fault crosses the Divide suggests that Middle Creek was also a site of a paleodrainage which extended farther to the north during Oligocene time. The Sapinero Mesa and Fish Canyon Tuffs probably flowed down and filled this paleovalley and were later uplifted to their present position by the continued uplift or doming of the Baldy Peak center.

The second major pre-volcanic linear which can be traced through the study area is the north-northwest trending Tomichi Creek fault (Raines 1971) which can be traced quite easily on the NASA Mission 211, high altitude, color photography (Figures 18 and 23). From north to south, the linear can be traced down the Tomichi Creek valley, up the lower reaches of Marshall Creek, along a small section of Big Bend Creek, up

Deadmans Creek, across the Continental Divide, down Bear Creek, and possibly all the way to its intersection with the Middle Creek Fault. The only part of this feature which lies within the study area is in the southwestern corner along the upper reaches of Deadmans Creek. There is little, if any, movement along this feature in the volcanic rocks, and its pre-volcanic history cannot be determined from surface exposures.

Very little else can be said about the pre-volcanic deformation in this area. Ranspot (1958) indicated the Paleozoic sedimentary rocks were gently folded with the axis of the folds plunging southward into the thesis area. However, these folds cannot be recognized based on evidence within the area itself.

Volcanic Structures

Most of the structural deformation in the area is faulting associated with volcanic activity in and around the area. This faulting is primarily related to the regional volcanic activity. This faulting in the area is related to the development of a caldera in the Bonanza area to the east, and to the uplift or doming of the Baldy Peak volcanic center lying partially within the map area to the southwest and extending about 8 miles to the west. The faulting is predominately high-angle faulting and expresses itself topographically by either controlling or affecting the drainage. Where the faulting is exposed only in the andesites, it is difficult to recognize and is evidenced

only by topographic expression and lack of outcrop continuity across the inferred fault zone. It is the author's experience that where andesite flows were found to be distinct and easily recognized in the field, they could not be traced across fault zones. This would indicate the possibility of considerable vertical displacement along at least some of the faults. Assuming that these faults are primarily related to the volcanic activity, they have been interpreted as being high-angle, dip-slip faults. Therefore, where the Paleozoic section is faulted and crops out on both sides of the fault zone, it is possible to determine the amount of dip-slip movement (Plates 1 and 2).

Baldy Peak volcanic center

The possibility of a major volcanic center located in the Baldy Peak area has long been suggested (Epis and Knepper, personal communication, 1972). Certainly the most striking feature is the topographic expression of the area (Figures 18 and 23). Gravity maps of Colorado (Behrendt and Bajwa, 1972) show a negative circular gravity anomaly in the Baldy Peak area (Figure 19). A circular gravity low over the Bonanza caldera is also shown on Figure 19. Eaton, Steven, and Ratte (1972) in their study of the geophysics of 17 large ash flow-related calderas in the southwestern U. S. concluded that "...no simple geophysical model of a caldera of this type can be constructed that is universally applicable.". However,

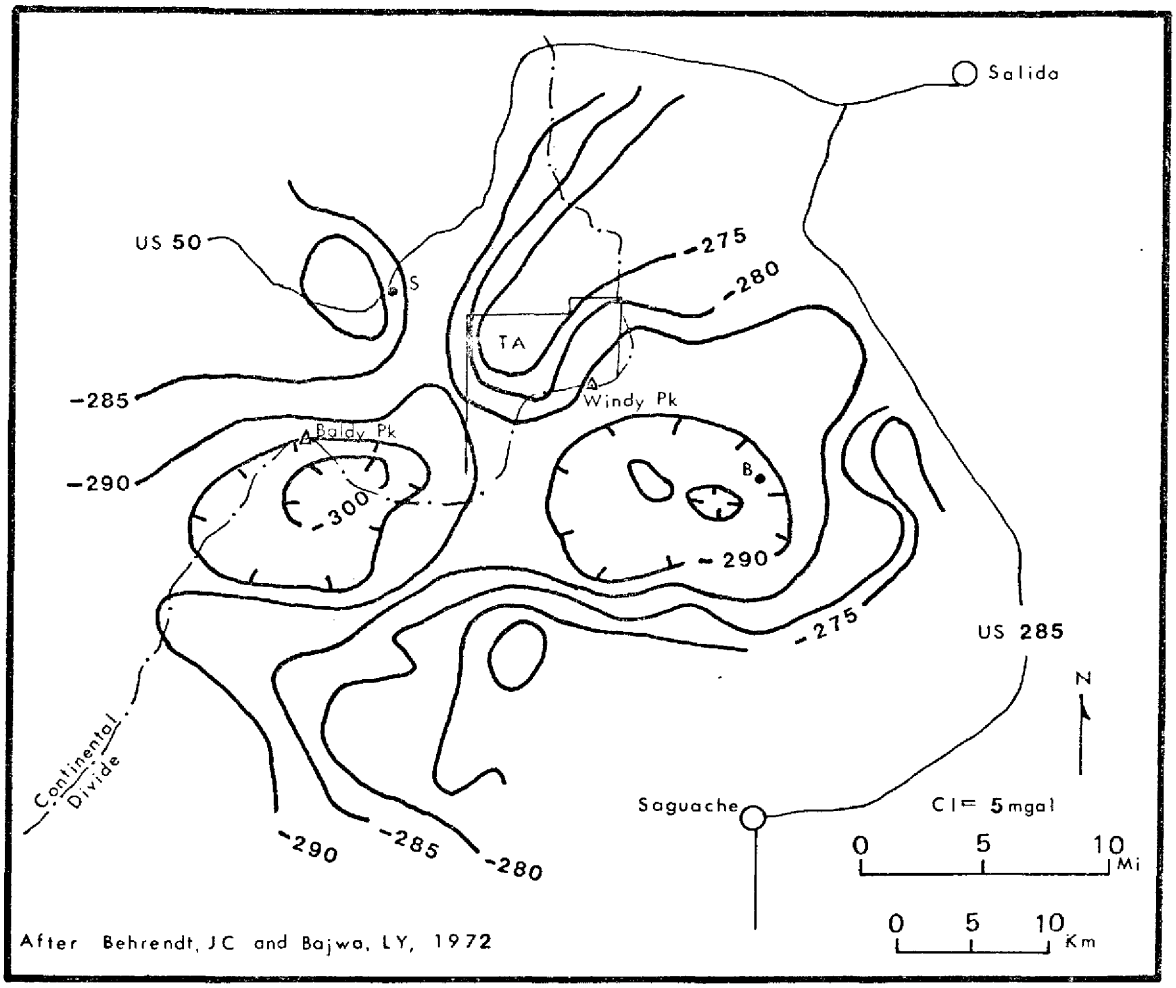

FIGURE 19

Bouguer gravity map of the Baldy Peak area. Note location of thesis area, TA, and towns of Sargents, S, and Bonanza, B.

they also stated, "In spite of the disparity in geophysical expression of the different calderas, individual structures may be clearly reflected by gravity and/or magnetic data.". Work done in the Trickle Mountain and Lake Mountain NE quadrangles (Bruns and others, 1972) about three miles south and southeast of the area refers an unknown source to the northwest in conjunction with the known source of the Bonanza caldera to the northeast.

Deformation within the Baldy Peak center is primarily circular faulting caused by the uplift or doming of the center. The center contains at least two sets of ring fractures (Figure 23 and Plate 1) and the relative vertical displacement of each is upward toward the center (Plate 2). The outer set and most striking in the photography is the Tank Seven Creek-Marshall Creek-Long Branch Creek ring fracture. Although only a part of this structure lies within the mapped area, reconnaissance work by the author indicates it is a major fault zone containing andesites in the center and numerous laharic flows, silicic intrusives, and ash flows west of Long Branch Creek. The inner ring fracture lies entirely within the thesis area (Plate 1) and is expressed in the drainages of Milk Creek, and Marshall and Tank Seven Creeks near their confluence. The relative sense of movement across this ring fault is also upward toward the center. The inner most circular structure forms the surface expression of the contact between an intrusive andesite lava dome and the surrounding lava flows (Figures 20

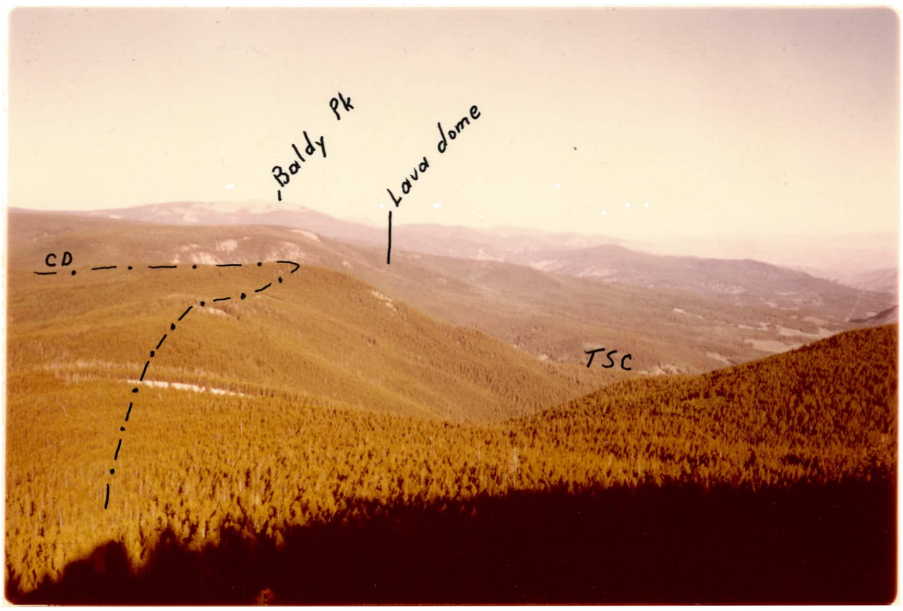

Figure 20. Photograph taken looking west along the Continental Divide toward Baldy Peak from a point about 2 miles west of Windy Peak showing the circular erosional surface expression of the intrusive lava dome. Baldy Peak can be seen on skyline and Tank Seven Creek (TSC) is seen at center right. Note the abrupt change in direction from east-west to north-south of the Continental Divide (CD) as it circumscribes the Baldy Peak volcanic center.



Figure 21. Photograph of the intrusive andesite lava dome where it crops out along the southeast side of the inner most circular feature of the Baldy Peak volcanic center. Note near vertical flow fracturing. Scale is approximate.

and 21). The forceful emplacement of this lava dome into the flows suggests a period of pressure build-up in the magma chamber after the effusion of the lavas and a resurgence within the Baldy Peak volcanic center. The possibility that the Baldy Peak center is an ash flow-related caldera has already been mentioned. Evidently, there was little, if any, explosive activity at this center as evidenced by the lack of ash-flow sheets around the center and the lack of collapse structures within the center. It is hoped that subsequent work in the Baldy Peak area will further evaluate this possibility. It is the opinion of the author, based upon regional studies, photo interpretation, and field work that a major volcanic center exists in the vicinity of Baldy Peak.

Later Block Faulting

The faulting in the vicinity of Duncan and Tank Seven Creeks has been interpreted as being genetically related to the uplift or doming of the Baldy Peak center because of their close spacial relationship with the circular faulting. However, the Windy Peak fault (Plate 1) has been interpreted as a later block fault associated with the collapse of the San Luis Valley (Rio Grande rift) to the east. The actual evidence for this interpretation is tenuous at best. The fault cuts the Rawley Andesite and could be related to the radial faulting associated with the collapse of the Bonanza caldera. However, it trends more north-south than northwest,

and has a marked affect on the topography suggesting a more recent movement. Relative movement on this fault is down to the east but the amount of vertical separation is unknown.

GEOLOGIC HISTORY

The Precambrian rocks, prior to Cambrian time, were metamorphosed, deformed, and intruded by granites and granodiorites. An erosional surface of low relief was developed on the Precambrian rocks and was covered periodically from Cambrian to Mississippian time by a series of epicontinental seas. If the Cambrian was deposited in the area, it was eroded prior to the deposition of the Orodovician rocks. Beginning in Mississippian time, uplift of the ancestral Rocky Mountains occurred and the Mississippian limestones were eroded to form a karst topography which was covered by the deposition of clastic material eroded from the highlands. Before the end of Pennsylvanian time, the marine seas again invaded the area and deposited the black shales and interbedded limestones of the Belden Formation.

The ancestral Rocky Mountains were nearly removed by erosion by Mesozoic time and Mesozoic sediments were deposited in the area. The Laramide Orogeny began in late Cretaceous time with the uplift, folding and faulting of the Sawatch Range in this area. Mesozoic rocks and parts of the Paleozoic section were subsequently removed by erosion.

Volcanic activity began in early Oligocene with doming and eruptions of andesite flows from the Bonanza center. This early doming was probably accompanied with fracturing and

and faulting around the center. Collapse and further faulting of the region accompanied the eruption of the Bonanza Tuff. A period of erosion removed most of the Bonanza Tuff before the doming and eruption of andesite and basalt flows from the Baldy Peak center. Continued eruptions of andesitic flows from the Bonanza center probably occurred contemporaneously with the development of the Baldy Peak center. Continued doming, faulting, and intrusive activity occurred in the Baldy Peak center with the resultant circular faulting, and lava dome emplacement. A period of erosion probably occurred at this time during which the Fish Canyon and Sapinero Mesa ash-flow sheets were erupted from calderas lying southwest of the area. These ash-flow sheets probably filled most of the major paleo-valleys. Uplift continued at the Baldy Peak center, uplifting and folding the Fish Canyon and Sapinero Mesa Tuffs from the south and forming the major part of the present topography and controlling the location of the Continental Divide.

Major block faulting related to the collapse of the San Luis Valley (Rio Grande rift) occurred near or after the cessation of volcanism and reactivated the pre-existing volcanic faulting to some degree. This faulting could still be active in the area as regional studies indicate that the uplift of the Sangre de Cristo Mountains and/or the collapse of the San Luis Valley is currently active.

PHOTOGEOLOGIC INTERPRETATION

The area is included within the boundaries of the NASA Bonanza test site; therefore, high quality, low and high altitude, color and color infrared photography was available. The scale of the low altitude photography is about 1:20,000 and the high altitude photography about 1:100,000. The photography was interpreted prior to the initiation of field work, during field work, and in making final refinements after field work. The advantages of having this type of data in addition to the standard U.S. Forest Service black and white photography merits some discussion.

Low Altitude Color Photography

Of particular interest is the area on either side of Marshall Creek from its confluence with Indian Creek to its confluence with Tank Seven Creek (Plate 1). This area was not included in the original proposed area. However, as the author passed through this area each day to attain access to the original area, observations were made along the road and interest was aroused. For this reason, a photogeologic map was made of the area on both black and white photography and color photography. Both were at a scale of about 1:20,000. The interpretations were based on the familiarity of rock types in the area and the observations made along the road. At a later time, this entire area of interest was added to

the thesis area and subsequently the photogeologic maps were field checked in detail. Table 1 is a qualitative evaluation of the ability to discriminate possible lithologic contacts on the black and white photography as compared with the color photography.

Table 1. Comparison of photo types in making Lithologic Discriminations

G-Good F-Fair P-Poor

Possible Discriminations	B&W Photography	Color Photography
andesite--dolomite	F	G
andesite--water-laid tuff	G	G
andesite--granite	P	F
granite--dolomite	P	F
water-laid tuff--ash-flow tuff	P	P

Figure 22 is an example of the color photography. The photo was made by photographing a single transparency of one frame of Mission 184 photography on a light table with a 35mm camera. In general, a great deal of detail is lost in reproduction and photos of this type do not adequately demonstrate the usefulness of the original data. For this reason, photographic comparisons are not made in this report.

Nine-by-nine inch prints of the low altitude color photography were used as base maps for the field mapping over the entire area with the exception of a NW-SE strip about 1 mile

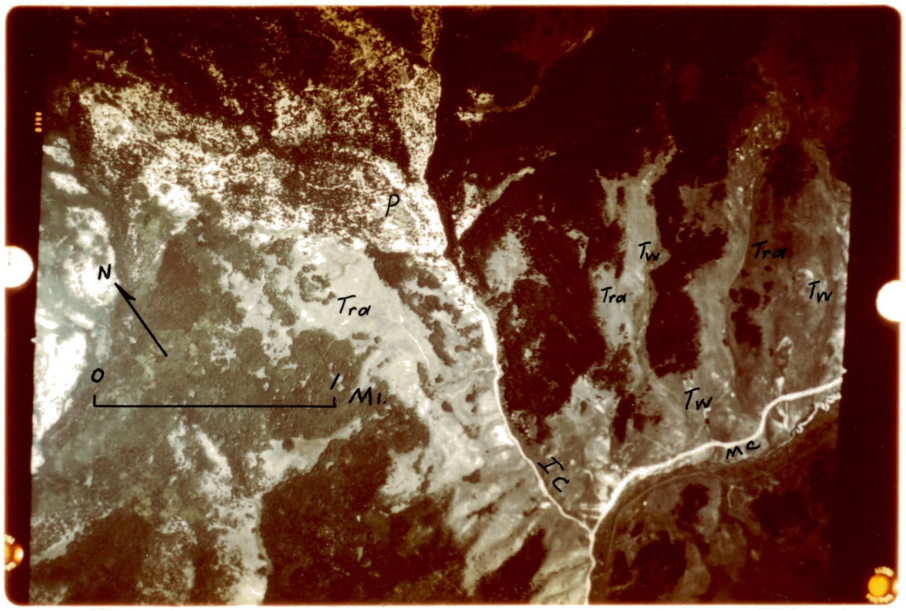

Figure 22. Photograph of the low altitude, Mission 184, aerial photography showing the area in the vicinity of Marshall and Indian Creeks (MC and IC). Symbols used are: Rawley Andesite (Tra), Paleozoic sedimentary rocks (P), and water-laid tuff (Tw). Scale is approximate.

wide running through the area in the vicinity of the Chester Fault. Because of lack of side lap between flight lines, this area was not available on the color photography and was mapped using the black and white photography as a base map. A comparison of the effectiveness of these two data types, based on this field experience, indicates that the color photography is the more efficient. No attempt was made, however, to quantify these results in terms of time spent to obtain a final map for each photo type because there are too many other variables such as terrain type, vegetation cover, complexity of the geology in local areas, and weather. However, in qualitative terms, the author determined that location of ground position was easier, faster, and more accurate on the color photography, and transfer of information to a topographic base map was faster. More detailed lithologic and structural information could be obtained from the color photography prior to field work, and refinements and final interpretations after field work were easier and faster. In the author's opinion, it was also easier to visualize topography viewing a single frame of color photography as compared to black and white photography.

High Altitude Color Photography

The high altitude (1:100,000) color and color infrared photography was primarily used in the location and interpretation of faults in the thesis area. Using this data it was possible to view, in two stereo pairs, the entire area plus

several miles of additional terrain around the area, and to relate structures within the area with structures outside the area. This provided a broader structural picture and a more inter-related interpretation. Figure 23 is a reproduction in both color and black and white of part of a single frame of the Mission 211 color photography. The black and white is shown in order to provide a base for the interpretation of the color photo for the reader's benefit. Several structural features are quite striking on this photo. The faulting along Tank Seven Creek and Marshall Creek are seen to be only part of a much larger circular fracture pattern. The Tank Seven Creek fault can be observed to intersect the circular faulting to the south and continue south of the Continental Divide. The linear along Deadmans Creek can be interpreted as an extension of the Tomichi Creek valley linear (Raines, 1971) to the north, and on strike with the Bear Creek linear (Bruns, 1971) south of the Continental Divide. The Chester fault can be interpreted as being a northern extension of the Middle Creek fault (Bruns, 1971). This latter interpretation made it possible to explain the restricted location of the Fish Canyon and Sapinero Mesa Tuffs within the area (Plate 1) in relation to the regional setting. That is, that they were deposited in the Middle Creek paleovalley which extended farther to the north at the time of deposition.

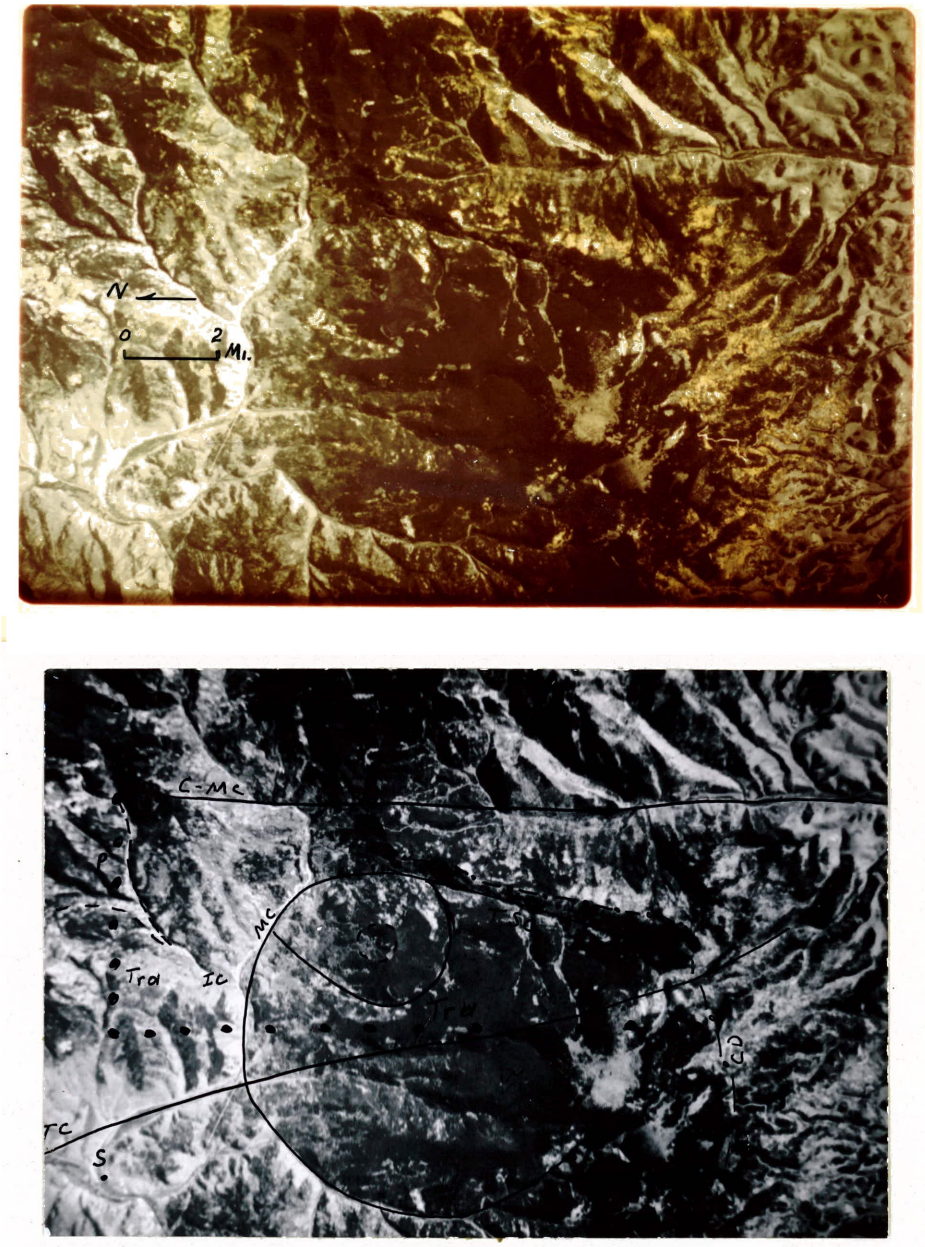

Figure 23. Photograph of the high altitude, Mission 211, photography showing the major structures in the vicinity of the Baldy Peak volcanic center. Note the circular faulting and the configuration of the Continental Divide (CD). Symbols used are: faults (solid lines), lithologic contacts (dashed lines), thesis area boundaries (dotted lines), Chester-Middle Creek fault (C-MC), Tomichi Creek linear (TC), Tank Seven Creek fault (TSC), Rawley Andesite (Tra), intrusive lava dome (Tir), Paleozoic sedimentary rocks (P), Marshall Creek (MC), Indian Creek (IC), and town of Sargents (S). Scale is approximate.

Color Infrared Photography

A comparison between interpretations of color photography with interpretations of the color infrared (CIR) photography indicated that there is little additional information on the CIR that is not already available from the color photography. In general, the color infrared enhanced the tonal variations between vegetation types and enhanced stream location and stream patterns. Perhaps CIR photography would be of more value in areas where vegetation patterns conformed more closely to lithologic boundaries and/or structural features such as faults and fractures. Several springs were readily located on the CIR that were not discernable on the color or the black and white photography because of the enhancement of lush vegetation around the springs. Field work indicated that most of these springs were discharging in areas of andesite, probably from contacts between individual lava flows.

Summary

Low altitude color photography was determined to be more efficient for use as base maps during field work in comparison to black and white photography, and in general, more accurate for making photogeologic interpretations. High altitude color photography was an extremely useful tool in the analysis of structural patterns and their relationship with the regional structural setting.

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APPENDIX

PETROLOGIC DESCRIPTIONS OF INDIVIDUAL ROCK SPECIMENS FROM THIN SECTIONS

(All percentages are estimated)

Rock Unit — Page

Rawley Andesite. 67

Bonanza Tuff 71

Ash Flow 1 73

Ash Flow 2 75

Purple Breccia 76

Water-laid tuff (Pollen Mounts). 77

Sapinero Mesa Tuff 78

Fish Canyon Tuff 78

NOTE: All specimens described are located under Petrological Reference Collection (PRC) number 92.

Thin Section: 92-1

Rock Unit: Rawley Andesite

Texture: Hypocrystalline, porphyritic-aphanitic, scoriaceous

Composition:

Phenocrysts (¼ - 2 mm)		45%
Plagioclase (An_{42}-An_{48})	35%	
Augite	6%	
Magnetite	4%	
Groundmass (microcrystalline)		55%
Plagioclase microlites with some magnetite		

Petrographic Designation: Andesite (flow)

Thin Section: 92-2

Rock Unit: Rawley Andesite

Texture: Holocrystalline, porphyritic-aphanitic, scoriaceous

Composition:

Phenocrysts (¼ - 3mm)		45%
Plagioclase (An_{38}-An_{42})	35%	
Augite	7%	
Magnetite	3%	
Groundmass (microcrystalline)		55%
Plagioclase microlites with some magnetite and pyroxene		

Petrographic Designation: Andesite (flow)

Thin Section:	92-3	
Rock Unit:	Rawley Andesite	
Texture:	Holocrystalline, porphyritic-aphanitic, scoriaceous	
Composition:	Phenocrysts ($\frac{1}{4}$ - $\frac{1}{2}$ mm)	2%
	Plagioclase	
	Groundmass (microcrystalline)	98%
	Plagioclase microlites with some magnetite and secondary chlorite	
Petrographic Designation:	Andesite (flow)	

Thin Section:	92-4		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic		
Composition:	Phenocrysts ($\frac{1}{2}$ - 4 mm)		40%
	Plagioclase (An_{48})	25%	
	Augite	10%	
	Magnetite (altered to hematite)	5%	
	Groundmass (microcrystalline)		60%
	Plagioclase microlites with some pyroxene and magnetite		
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-5		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic		
Composition:	Phenocrysts ($\frac{1}{2}$ - 4 mm)		15%
	Plagioclase (An_{48}-An_{50})	9%	
	Biotite	3%	
	Augite	2%	
	Magnetite	1%	
	Groundmass (cryptocrystalline)		85%
	Microlites of feldspar with some magnetite and pyroxene (?)		
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-6		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic, pilotaxitic		
Composition:	Phenocrysts ($\frac{1}{4}$ - 3 mm)		25%
	Plagioclase (An_{36})	18%	
	Augite	4%	
	Biotite	1%	
	Magnetite	2%	
	Groundmass (microcrystalline)		75%
	Plagioclase microlites with some magnetite, biotite and pyroxene		
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-7		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic, pilotaxitic		
Composition:	Phenocrysts (¼ - 2 mm)		45%
	Plagioclase (An_{48}-An_{50})	37%	
	Magnetite (altered to hematite)	5%	
	Pyroxene (?) (altered to chlorite)	3%	
	Groundmass (microcrystalline) Plagioclase microlites with magnetite and secondary hematite and chlorite		55%
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-8		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic		
Composition:	Phenocrysts (¼ - 2 mm)		35%
	Plagioclase (An_{42})	25%	
	Augite	6%	
	Magnetite	4%	
	Groundmass (microcrystalline) Plagioclase microlites with some magnetite and secondary hematite		65%
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-9		
Rock Unit:	Rawley Andesite		
Texture:	Holocrystalline, porphyritic-aphanitic		
Composition:	Phenocrysts ($\frac{1}{2}$ - 2 mm)		30%
	Plagioclase (An_{44})	22%	
	Augite	4%	
	Magnetite	2%	
	Biotite	2%	
	Groundmass (cryptocrystalline)		70%
	Microlites of feldspar with some magnetite and pyroxene (?)		
Petrographic Designation:	Andesite (flow)		

Thin Section:	92-10		
Rock Unit:	Bonanza Tuff		
Texture:	Pyroclastic, moderately welded, devitrified		
Composition:	Vitric		60%
	Pumice lapilli	20%	
	Glass shards	40%	
	Crystal		35%
	Plagioclase (An_{46})	20%	
	Sanidine	8%	
	Biotite	5%	
	Magnetite	2%	
	Lithic		5%
	Andesite	4%	
	Granitic gneiss	1%	
Petrographic Designation:	Latite Ash-Flow Tuff		

Thin Section:	92-11		
Rock Unit:	Bonanza Tuff		
Texture:	Pyroclastic, moderately welded, devitrified		
Composition:	Vitric		55%
	Pumice lapilli	20%	
	Glass shards	35%	
	Crystal		40%
	Plagioclase (An_{44})	21%	
	Sanidine	9%	
	Biotite	7%	
	Magnetite	2%	
	Hornblende	1%	
	Lithic		5%
	Andesite	5%	
Petrographic Designation:	Latite Ash-Flow Tuff		

Thin Section:	92-12		
Rock Unit:	Bonanza Tuff		
Texture:	Pyroclastic, moderately welded, eutaxitic		
Composition:	Vitric		55%
	Pumice lapilli	15%	
	Glass shards	40%	
	Crystal		40%
	Plagioclase (An_{42})	20%	
	Sanidine	12%	
	Biotite	6%	
	Magnetite	2%	
	Lithic		5%
	Andesite	5%	
Petrographic Designation:	Latite Ash-Flow Tuff		

Thin Section:	92-13		
Rock Unit:	Ash Flow 1		
Texture:	Pyroclastic, eutaxitic, granophyric		
Composition:	Vitric		75%
	Pumice lapilli	25%	
	Glass shards	50%	
	Crystal		15%
	Sanidine	9%	
	Biotite	2%	
	Quartz	3%	
	Magnetite	1%	
	Lithic		10%
	Microcrystalline felsic material	5%	
	Granitic gneiss	3%	
	Andesite	2%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section:	92-14		
Rock Unit:	Ash Flow 1		
Texture:	Pyroclastic, eutaxitic, granophyric		
Composition:	Vitric		70%
	Pumice lapilli	25%	
	Glass shards	45%	
	Crystal		20%
	Sanidine	10%	
	Quartz	4%	
	Biotite	3%	
	Magnetite	2%	
	Plagioclase (An ?)	1%	
	Lithic		10%
	Microcrystalline felsic material	8%	
	Granitic gneiss	2%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section:	92-15		
Rock Unit:	Ash Flow 1		
Texture:	Pyroclastic, granophyric, eutaxitic		
Composition:	Vitric		65%
	Pumice lapilli	15%	
	Glass shards	50%	
	Crystal		20%
	Sanidine	13%	
	Quartz	4%	
	Biotite	3%	
	Lithic		15%
	Granitic gneiss	10%	
	Calcite	4%	
	Microcrystalline felsic material	1%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section:	92-16		
Rock Unit:	Ash Flow 1		
Texture:	Pyroclastic, vitrophyre		
Composition:	Vitric		60%
	Pumice lapilli	15%	
	Glass shards	45%	
	Crystal		20%
	Sanidine	14%	
	Quartz	3%	
	Biotite	2%	
	Plagioclase (An ?)	1%	
	Lithic		20%
	Granitic gneiss	20%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section:	92-17		
Rock Unit:	Ash Flow 2		
Texture:	Pyroclastic, vitrophyre		
Composition:	Vitric		65%
	Pumice lapilli	15%	
	Glass shards	50%	
	Crystal		20%
	Sanidine	11%	
	Plagioclase (An_{20})	4%	
	Biotite	3%	
	Magnetite	1%	
	Quartz and Hornblende	Tr	
	Lithic		15%
	Granitic schist and gneiss	9%	
	Calcite	6%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section:	92-18		
Rock Unit:	Ash Flow 2		
Texture:	Pyroclastic, vitrophyre		
Composition:	Vitric		65%
	Pumice lapilli	15%	
	Glass shards	50%	
	Crystal		20%
	Sanidine	12%	
	Plagioclase	4%	
	Biotite	3%	
	Quartz, Magnetite and Hornblende	Tr	
	Lithic		15%
	Granitic schist and gneiss	14%	
	Microcrystalline felsic material	1%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

Thin Section: 92-19

Rock Unit: Purple Breccia

Texture: Hypocrystalline, porphyritic-aphanitic, brecciated

Composition:

Clasts			60%
Phenocrysts		20%	
Sanidine	6%		
Quartz	5%		
Plagioclase (An ?)	5%		
Biotite	3%		
Magnetite	1%		
Groundmass (cryptocrystalline) Microlites of feldspar with some quartz, biotite and magnetite		40%	
Matrix			
Glass with some microcrystalline quartz and feldspar			40%

Petrographic Designation: Quartz Latite (flow breccia)

Thin Section:	92-20		
Rock Unit:	Inclusion in Purple Breccia		
Texture:	Hypocrystalline, porphyritic-aphanitic		
Composition:	Phenocrysts (¼ - 1 mm)		15%
	Sanidine	5%	
	Plagioclase (An ?)	5%	
	Quartz	2%	
	Biotite	2%	
	Magnetite	1%	
	Groundmass (microcrystalline)		85%
	Plagioclase microlites with some sanidine (orthoclase ?), quartz and magnetite		
Petrographic Designation:	Quartz Latite (flow)		

Pollen Mount: 92-21 (4 slides)

Water-laid tuff

Pollen Mount: 92-22 (4 slides)

Water-laid tuff

Pollen Mount: 92-23 (4 slides)

Water-laid tuff

Thin Section:	92-24		
Rock Unit:	Sapinero Mesa Tuff		
Texture:	Pyroclastic, moderately welded		
Composition:	Vitric		90%
	Pumice lapilli	20%	
	Glass shards	70%	
	Crystal		10%
	Sanidine	6%	
	Plagioclase (An_{23})	3%	
	Magnetite	1%	
	Biotite	Tr	
Petrographic Designation:	Latite Ash-Flow Tuff		

Thin Section:	92-25		
Rock Unit:	Fish Canyon Tuff		
Texture:	Pyroclastic, moderately welded		
Composition:	Vitric		55%
	Pumice lapilli	10%	
	Glass shards	45%	
	Crystal		45%
	Sanidine	20%	
	Plagioclase (An_{38})	13%	
	Biotite	4%	
	Magnetite	2%	
	Hornblende	5%	
	Quartz	1%	
Petrographic Designation:	Quartz Latite Ash-Flow Tuff		

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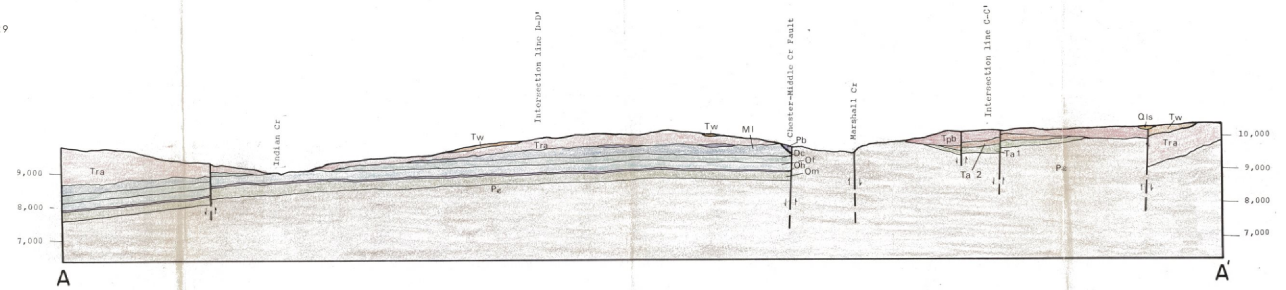
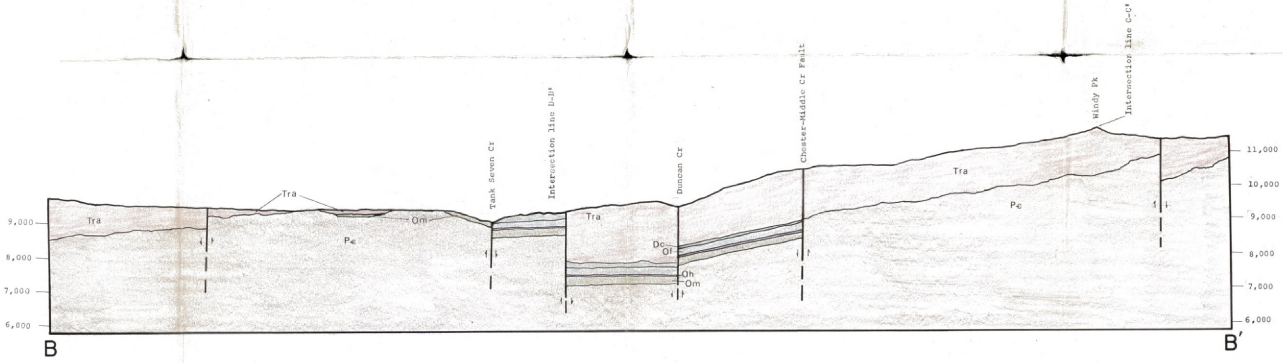
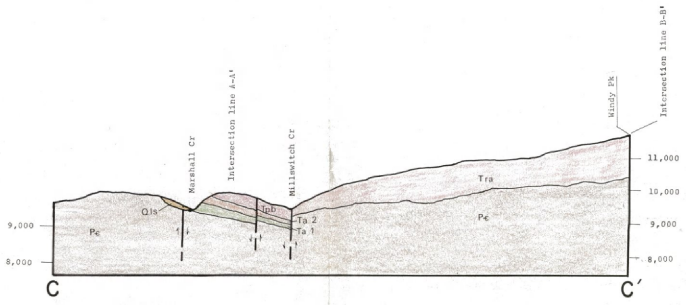
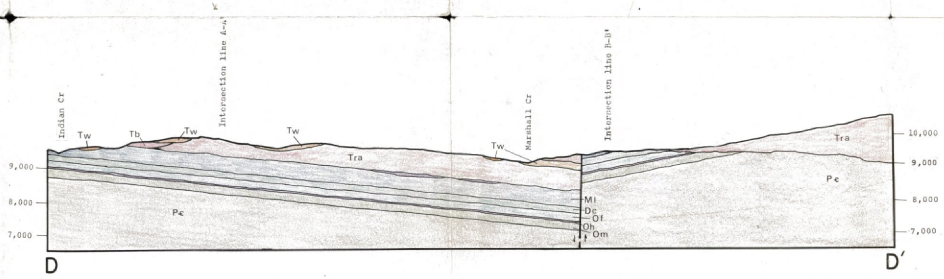
GEOLOGIC CROSS SECTIONS ACROSS THE UPPER MARSHALL CREEK DRAINAGE BASIN, SAGUACHE COUNTY, COLORADO

T-1529









EXPLANATION

Qls	Landslide deposit
Tf	Fish Canyon Tuff
Ts	Sapinero Mesa Tuff
Tw	Water-laid tuff
Tb	Bonanza Tuff
Tpb	Purple breccia
Ta-2	Ash flow 2
Ta-1	Ash flow 1
Tra	Rawley Andesite
Pb	Belden Formation
Ml	Leadville Limestone
Dc	Chaffee Formation
Of	Fremont Dolomite
Oh	Harding Sandstone
Om	Manitou Dolomite
Pe	Precambrian rocks

SCALE 1:24 000
HORIZONTAL = VERTICAL



FEBRUARY 1973

JAMES L EVANS