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GEOLOGY OF THE NORTHWESTERN GALLINAS MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

by

Greg C. Coffin

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ABSTRACT

The western Gallinas Mountains have undergone a complex geologic evolution similar to much of the western United States during the Cenozoic era. Initial early Oligocene (38 m.y. B.P.) intermediate volcanism resulted in the formation of the Dog Springs volcanic complex. The complex consists of tuff breccias, monolithic volcanic breccias, mudflow deposits, exotic blocks and minor interbedded sedimentary rocks. The complex is similar to numerous other volcanic breccia fields in the western United States.

Towards the end of Dog Springs time (about 34 m.y. B.P.) a depositional cycle was initiated during which fluviatile sediments characteristic of a braided stream environment were deposited. This cycle continued for the next 2 million years with intermittent interruptions during the emplacement of the tuff of Rock House Canyon, the tuff of Blue Canyon and the Hells Mesa Tuff.

Following the deposition of the Hells Mesa Tuff (33 m.y. B.P.) the formation of the Rio Grande rift resulted in the development of a broad southeast plunging syncline and an extensive surface of

unconformity in the region. Deformation continued throughout the deposition of the volcaniclastic rocks of South Crosby Peak and the A-L Peak Tuff (30 m.y. B.P.). Basaltic-andesite volcanism occurred at this time and signaled the onset of bimodal volcanism in the region.

Development of high angle normal faults may have begun as early as middle Oligocene time (about 34 m.y. B.P.) and were episodically active from late Oligocene to Holocene time. The youngest volcanic unit in the northwestern Gallinas Mountains is a single basalt flow of Pliocene (?) age.

In late Tertiary time, several successive piedmont slopes formed in response to changing base levels. These alluvial deposits buried much of the bedrock geology. During Holocene (?) time the North Lake fault dammed the North Lake embayment and formed a small playa.

INTRODUCTION

Purpose of the Investigation

The objectives of this thesis are to determine the stratigraphic relationships, structural trends, economic potential, and the distribution of various rock units in the eastern half of the Dog Springs 7.5-minute quadrangle, Socorro County, New Mexico. This thesis was undertaken as part of the New Mexico Bureau of Mines and Mineral Resources extensive mapping project of the northeastern portion of the Datil-Mogollon volcanic province.

The previously cited objectives are important for the following reasons:

1. The stratigraphic relationships will provide further data for correlating rock units between previously mapped areas in the Bear, Gallinas, Datil, Crosby, Magdalena, and San Mateo Mountains.

2. An analysis of structural trends will provide a framework for mineral exploration within the area and may serve to define part of the structural margin of an inferred volcanic complex.

3. Distribution of the various rock units in the area will provide a data base with which to interpret the geologic history of the region and with which to put some boundaries on the aerial extent of the inferred volcanic complex.

Location and Accessibility

The eastern portion of the Dog Springs 7.5-minute quadrangle is located approximately sixty-five kilometers northwest of Magdalena, New Mexico (fig.1). The map area is a rectangular region of about seventy-eight square kilometers occupying the eastern half of the Dog Springs quadrangle. The northern portion of the area is in the Cibola National Forest and the southern portion is on private land owned by the HH Ranch. The area is bounded by 34 22′ 30" N. latitude on the north, 34 15′ N. latitude on the south, 107 37′ 30" W. longitude on the east, and 107 41′ 15" W. longitude on the west.

Good access to the area is provided by a light duty Forest Service road, numerous unimproved roads and jeep trails. High clearance vehicles are required for unimproved roads and jeep trails. Four-wheel-drive is required in wet weather.

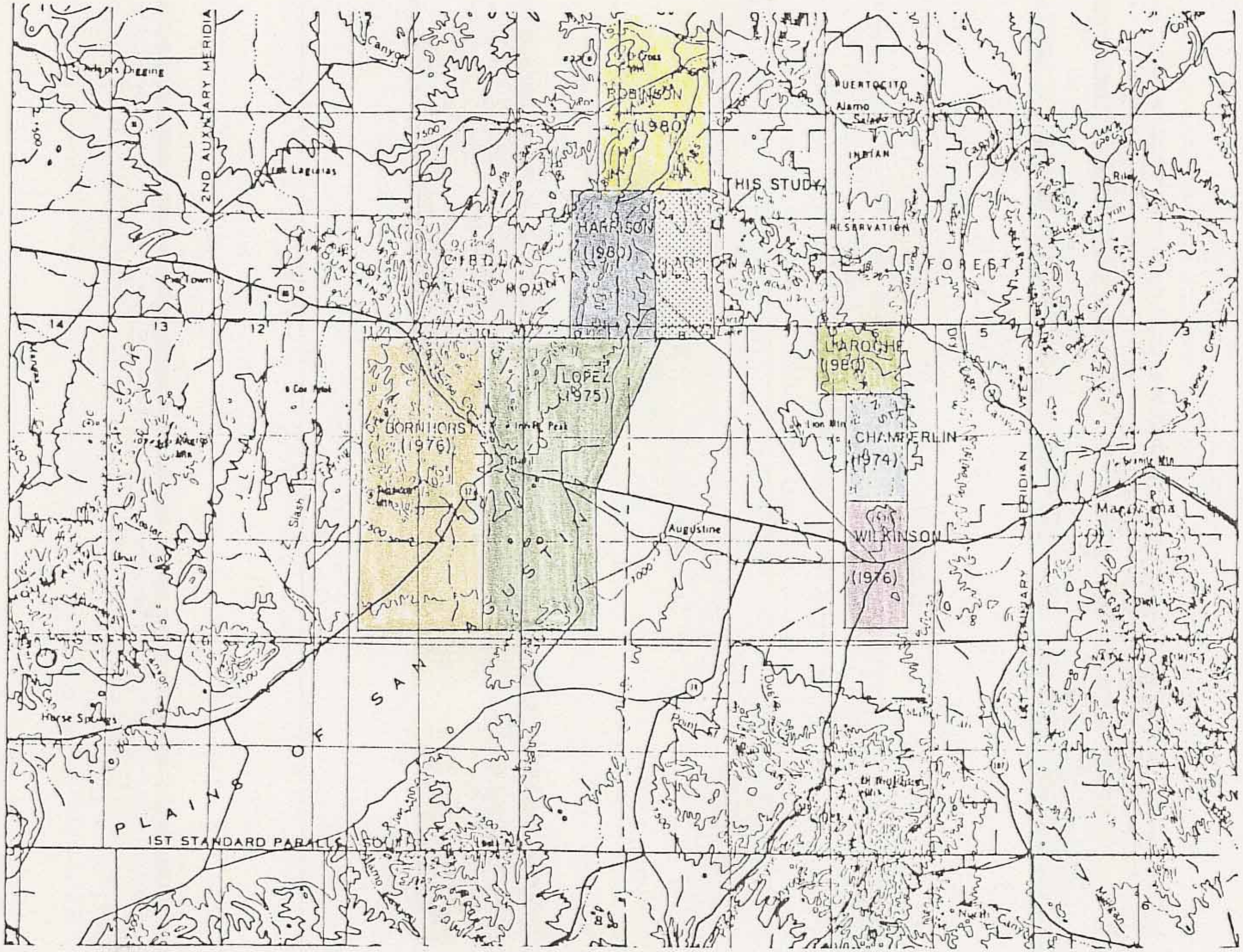


FIGURE 1. DIAGRAM SHOWING LOCATION OF THIS STUDY AREA AND PREVIOUS STUDY AREAS IN WEST-CENTRAL NEW MEXICO.

this study	▨	Bornhorst (1976)	🟧
Laroche (1981)	🟩	Wilkinson (1976)	🟪
Harrison (1980)	🟦	Lopez (1975)	🟩
Robinson (1980)	🟨	Chamberlin (1974)	🟦

Previous Investigations

Previous geologic investigations of the Gallinas Mountains have been mostly of a reconnaissance nature. The earliest recorded work was by Herrick (1900) who undertook a geologic reconnaissance of the western portion of Socorro and Valencia Counties. He briefly mentioned that the Bear, Gallinas and Datil Mountains consisted of trachytic and rhyolitic intrusives. Winchester (1920) conducted a geologic investigation of the Alamosa Creek area, now the Rio Salado, located to the north of the studied region. Winchester reported a series of tuffs, rhyolites, conglomerates and sandstones unconformably overlying Cretaceous rocks. He further described a type section of the Tertiary rocks located in the northern Bear Mountains and named the entire Tertiary section the Datil Formation. Powers (1939 and 1941) investigated the geomorphology of extinct Lake San Augustin and the volcanic rocks of San Augustin Plains.

Loughlin and Koshman (1942) published a detailed report on the Magdalena mining district. Wilpolt and others (1946) removed the lower 208 m from Winchester's Datil Formation and named it the Baca Formation for exposures in Baca Canyon in the northern Bear

Mountains. Givens (1957) and Tonking (1957) completed geologic maps of the Dog Springs and Puertecito 15-minute quadrangles, respectively. Tonking divided the Datil Formation into the Spears, Hells Mesa and La Jara Peak Members. Givens divided the Datil Formation into the Spears Ranch and Hells Mesa Members following Tonking but reported no unit correlative to Tonkings' La Jara Peak Member. Givens further subdivided the Hells Mesa member into 7, lithologically distinct mappable units. Willard (1959) correlated the La Jara Peak Member to the post-Datil Mangas basalt located in Catron County. Weber (1963) separated the La Jara Peak Member from the Datil Formation. Later Weber (1971) elevated the Datil Formation to group status. Chapin (1971a) elevated the La Jara Peak, Hells Mesa, and Spears members of the Datil Group to formational status.

More recently numerous thesis investigations by graduate students of the New Mexico Institute of Mining and Technology and the University of New Mexico have provided information concerning the area. Brown (1972) completed a detailed map of the southern Bear Mountains and presented a detailed analysis of the petrography and stratigraphy of the area. He divided the Hells Mesa Formation into the tuff of Goat Springs and the tuff of Bear Springs. Simons (1973), Chamberlin (1974), Wilkinson (1976), Laroche (1980) and Harrison (1980) have all undertaken detailed mapping projects in the area surrounding this study (fig.1). Deal (1973) did reconnaissance mapping in the northern San Mateo Mountains. Lopez (1975) and Bornhorst (1976) did reconnaissance mapping in the Datil area.

Numerous other studies have also been completed. Elston and others (1968, 1970, 1973, and 1976) have tried to place the Datil-Mogollon volcanic province into an overall volcano-tectonic framework of the western United States. Chapin (1974) restricted the Hells Mesa Formation to Brown's tuff of Goat Springs. Deal and Rhodes (1976) renamed the tuff of Bear Springs the A-L Peak Tuff. Elston (1976) reviewed the significance of mid-Tertiary volcanism in the Basin and Range province.

Several workers have determined radiometric dates for the units of the Datil-Mogollon volcanic province. Weber and Bassett (1963) dated biotite from the basal portion of Tonkings' type section of the Hells Mesa Member. Burke and others (1963) dated a latite boulder in the Spears Formation and two welded samples from the Hells Mesa Tuff. Kottlowski, Weber and Willard (1969) published radiometric dates of Cretaceous and Tertiary igneous rocks of New Mexico. Weber (1971) published five more dates of Tertiary igneous rocks from central New Mexico. Chapin (1971a) reported a date for the La Jara Peak Formation. Elston and others (1973) compiled a summary of all available K-Ar dates for the Datil-Mogollon volcanic province. E.I. Smith and others (1976) provided eight fission track dates for volcanic and plutonic rocks of the Mogollon Plateau.

Methods of Investigation

Geologic mapping at a scale of 1:24,000 using the United States Geological Survey Dog Springs 7.5-minute quadrangle as a base map was undertaken throughout the second half of 1979 and the spring and fall of 1980. United States Forest Service color aerial photographs of the F16-CIB series, 1974-1975, at an approximate scale of 1:17,000 were used to locate and delineate rock units. Aerial photos also proved valuable in the analysis of structural trends and geomorphic features

Forty samples from throughout the study area were collected for petrographic analysis. Modal analysis and staining for potassium feldspar were performed on selected slides. Modal analyses were conducted using a

Zeiss binocular microscope and a Swift automatic point counter. A minimum of 2000 points were counted per thin section. Staining of potassium feldspar was done following the standard procedures outlined by Deere, Howie and Zussman (1976, p.311). Anorthite content of plagioclase was determined with the universal stage (Rittman Zone Method) utilizing the high temperature curves of Troger (1959) and following the Michel-Levy statistical method as outlined by Heinrich (1965, p.360). Rock names were chosen following Travis (1953) and Williams, Turner and Gilbert (1954). Rock colors were determined using the Geologic Society of America Rock Color Chart.

Samples for radiometric dating of several units were collected and results are presented in the text when available.

Physiography

The study area occupies the nose of a broad northwest-trending, southeast-plunging syncline. Topographically, the area is a low saddle of south-facing dip slopes connecting the Datil and Gallinas Mountains. The southern portion of the study area is occupied by the North Lake Basin and the northeastern arm of the Plains of San Augustin. The study area is located in the northeastern portion of the Datil-Mogollon volcanic province on its' boundary with the Colorado Plateau.

Acknowledgments

I gratefully acknowledge the contributions of all the people who made the completion of this project possible. Jay Taylor, owner of the HH Ranch, allowed access to his property. Richard Harrison provided ideas and information during numerous discussions and field trips. A.G. Raby provided field assistance for the interpretation and description of the sedimentary rock units. Glenn R. Osburn provided field and office assistance during the preparation of this report. Dr. John Hawley and Dr. Robert Weber assisted in the interpretation of upper Tertiary and Quaternary units. Dr. Clay T. Smith and Dr. David I. Norman critically reviewed the manuscript and served on the thesis committee. A special thanks is extended to Dr. Charles E. Chapin who suggested the project and served as the thesis committee chairman. The New Mexico Bureau of Mines and Mineral Resources provided financial support and paid for all lab expenses incurred during the study.

I would also like to thank my family and my many friends who provided moral support during the course of this project. I would especially like to thank my parents who encouraged me to pursue a graduate degree.

STRATIGRAPHY AND PETROGRAPHY

Pre-volcanic Rocks

No pre-volcanic units are exposed in the study area. Permian limestones occur as exotic blocks in the Dog Springs volcanic complex but these blocks will be discussed with rocks of the Spears Formation.

Upper Cretaceous age rocks of the Mesaverde Group crop out approximately 6.5 km to the northwest (Givens, 1957) and 14 km to the east of the study area (Tonking, 1957). More recent studies concerning pre-volcanic rocks within the region have been undertaken by Massingill (1979), Mayerson (1979), Cather (1980), Jackson (in prep) and Robinson (1980).

Late Eocene beveling of central New Mexico by erosion produced a surface of low topographic relief prior to the onset of Oligocene volcanism (Epis and Chapin, 1975). Eocene rocks of the Baca Formation are exposed 3 km to the north of the study area. The Baca Formation formed during the erosion of Laramide uplifts and the subsequent deposition of debris in adjacent basins (Snyder, 1971). Contact relationships of the Baca Formation with the overlying volcanic rocks of the

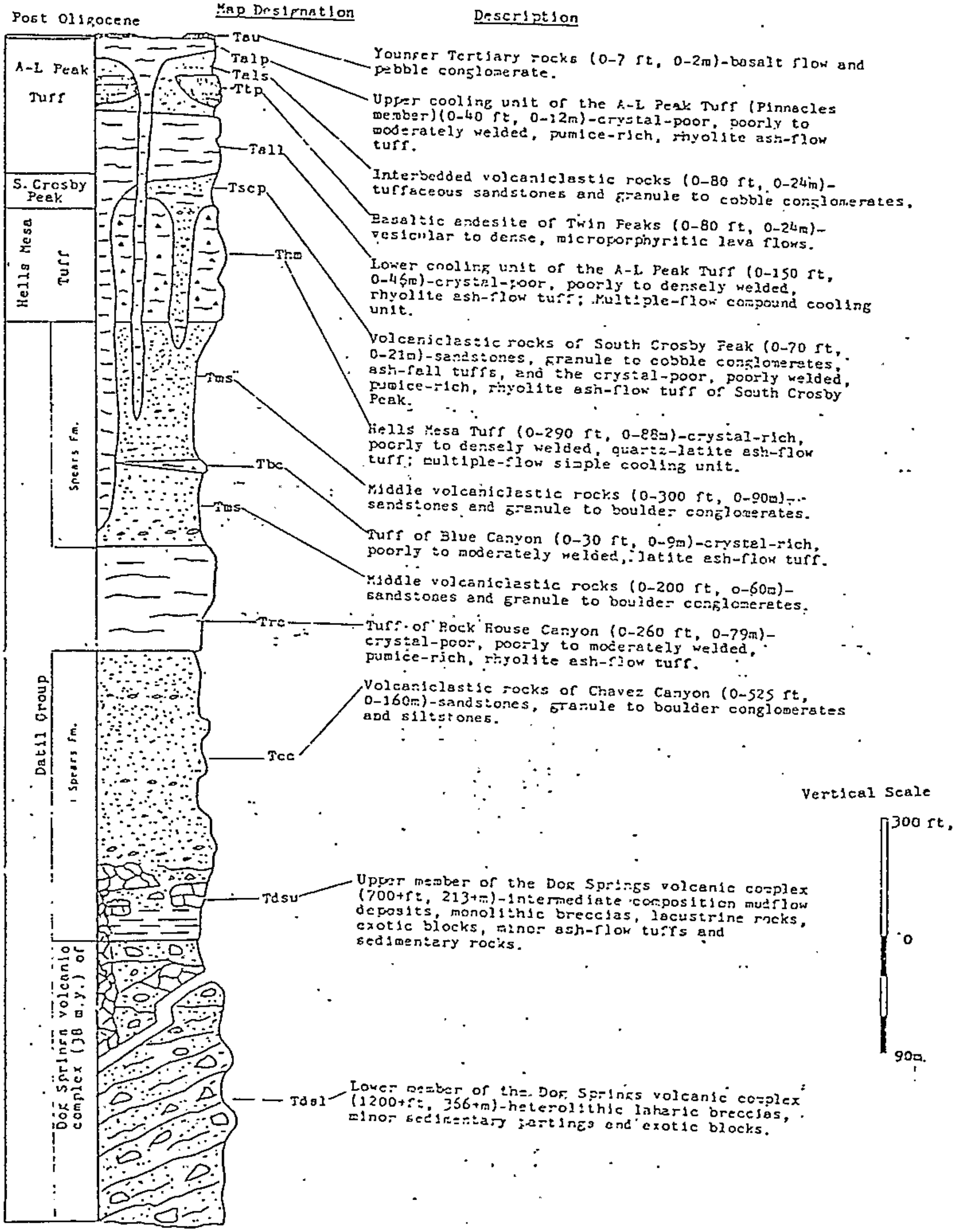
Spears Group vary from conformable near the center of the basin to unconformable near the basin margin.

Tertiary Volcanic Rocks

The majority of the study area is occupied by Tertiary age ash-flow tuffs, volcanic breccias, mudflow deposits and interbedded volcaniclastic rocks. Basaltic-andesite lava flows make up a subordinate portion. This relationship is in direct contrast to the Bear Mountains east of the study area where basaltic-andesite flows are much more common. A maximum exposed thickness of 1166 m of Tertiary volcanic rocks is present in the study area. These include volcanic source areas, outflow facies ash-flow tuffs, and alluvial aprons surrounding volcanic centers.

All volcanic rocks, with the possible exception of the uppermost basalt flow, are thought to be of Oligocene age. Major units from oldest to youngest are the Datil Group, the Hells Mesa Tuff and the A-L Peak Tuff. The A-L Peak Tuff unconformably overlies the Hells Mesa Tuff which conformably overlies the Datil Group (fig.2).

Figure 2. Composite Stratigraphic Column of the Western Gallinas Mountains, Socorro County, New Mexico



Younger Tertiary rocks (0-7 ft, 0-2m)-basalt flow and pebble conglomerate.

Upper cooling unit of the A-L Peak Tuff (Pinnacles member)(0-40 ft, 0-12m)-crystal-poor, poorly to moderately welded, pumice-rich, rhyolite ash-flow tuff.

Interbedded volcaniclastic rocks (0-80 ft, 0-24m)-tuffaceous sandstones and granule to cobble conglomerates.

Basaltic andesite of Twin Peaks (0-80 ft, 0-24m)-vesicular to dense, microporphyritic lava flows.

Lower cooling unit of the A-L Peak Tuff (0-150 ft, 0-46m)-crystal-poor, poorly to densely welded, rhyolite ash-flow tuff; multiple-flow compound cooling unit.

Volcaniclastic rocks of South Crosby Peak (0-70 ft, 0-21m)-sandstones, granule to cobble conglomerates, ash-fall tuffs, and the crystal-poor, poorly welded, pumice-rich, rhyolite ash-flow tuff of South Crosby Peak.

Hells Mesa Tuff (0-290 ft, 0-88m)-crystal-rich, poorly to densely welded, quartz-latite ash-flow tuff; multiple-flow simple cooling unit.

Middle volcaniclastic rocks (0-300 ft, 0-90m)-sandstones and granule to boulder conglomerates.

Tuff of Blue Canyon (0-30 ft, 0-9m)-crystal-rich, poorly to moderately welded, latite ash-flow tuff.

Middle volcaniclastic rocks (0-200 ft, 0-60m)-sandstones and granule to boulder conglomerates.

Tuff of Rock House Canyon (0-260 ft, 0-79m)-crystal-poor, poorly to moderately welded, pumice-rich, rhyolite ash-flow tuff.

Volcaniclastic rocks of Chavez Canyon (0-525 ft, 0-160m)-sandstones, granule to boulder conglomerates and siltstones.

Upper member of the Dog Springs volcanic complex (700+ft, 213+m)-intermediate composition mudflow deposits, monolithic breccias, lacustrine rocks, exotic blocks, minor ash-flow tuffs and sedimentary rocks.

Lower member of the Dog Springs volcanic complex (1200+ft, 366+m)-heterolithic laharic breccias, minor sedimentary partings and exotic blocks.

Datil Group

In this study all units above the Baca Formation and below the Hells Mesa Tuff are collectively referred to as the Datil Group, following the proposal of Chapin, and others (in prep). The units in this interval were previously referred to as the Spears Formation, but for reasons discussed below this terminology has been abandoned. In the study area the Datil Group consists of the Dog Springs volcanic complex, the Spears Formation, the tuff of Rock House Canyon and the tuff of Blue Canyon.

Spears Formation

The Spears Formation was divided into upper and lower members by Brown (1972). The members are separated by the tuff of Nipple Mountain which has been correlated to the tuff of Rock House Canyon (this report) and the tuff of Main Canyon (Harrison, 1980). The lower member as described to the east of the study area consists of latitic to andesitic conglomerates and sandstones (Brown, 1972), quartz latite tuffs, breccias, siltstones, claystones (Tonking, 1957), and minor autobrecciated lava flows (Chamberlin, 1974). The upper member, east of the study area, consists of latitic to andesitic flows, crystal-rich, quartz-poor, ash-flow tuffs (Wilkinson, 1976), mudflow breccias (Chamberlin, 1974); conglomerates and sandstones (Tonking, 1957). Within, and to the west of the study area, the lower member consists of a sequence of intermediate-composition tuff breccias, mudflow deposits, monolithic volcanic breccias, exotic blocks, mudstones, minor fluviatile sedimentary rocks and minor ash-flow tuffs. This sequence lies below an interval of tuffaceous sandstones and conglomerates which underlie the tuff of Rock House Canyon. The upper member, within and to the west of the study area, consists of a single latitic ash-flow tuff, the tuff of Blue Canyon, intercalated within a sequence of volcaniclastic sandstones and conglomerates. Clearly distinct lithologic and stratigraphic differences exist between the Spears age rocks in and to the west of the study area and the Spears age rocks to the east of the study area (Plate II). These differences led Harrison (1980) to propose that the Spears Formation be raised to group status and that the volcaniclastic rocks and ash-flow tuffs within it be raised to formational status. This scheme would involve the naming of all of the volcaniclastic rocks, which have traditionally been called the Spears Formation, but would also eliminate the excess verbiage when referring to the regionally extensive ash-flow tuffs within the Spears Formation (Chapin and others, in prep). Chapin and others (in prep) have recently proposed that the term Spears Formation be reserved for the volcaniclastic rocks in the post-Baca--pre-Hells mesa interval and that the interbedded ash-flow tuffs in this interval be given separate names and formational status. Furthermore they have also proposed that the interval be collectively referred to as the Datil Group. For the sake of clarity a similar scheme has been followed here. However regionally extensive volcaniclastic units that have clear-cut upper and lower contacts have been given informal names.

Within the study area, the Datil Group has been divided into six units. The units in ascending order are the lower member of the Dog Springs volcanic complex, the upper member of the Dog springs volcanic complex, the volcaniclastic rocks of Chavez Canyon, the tuff of Rock House Canyon, the middle volcaniclastic rocks and the tuff of Blue Canyon, which is intercalated within the middle volcaniclastic rocks. The Spears Formation consists of the volcaniclastic rocks of Chavez Canyon and the middle volcaniclastic rocks.

The Dog Springs volcanic complex

The Dog Springs volcanic complex is an informal name proposed for a sequence of, volcanic breccias, minor mudstones, ash-flow tuffs, exotic blocks, and fluviatile conglomerates and sandstones. The unit is correlative to portions of Tds as described by Givens (1957), portions of the latite facies of the Datil Formation as described by Willard (1963), the mudflow breccia and conglomerates of Bornhorst (1976) and the lower portion of the Spears Formation as described by Lopez (1975).

The rocks of the Dog Springs volcanic complex are regionally extensive and form much of the northern margin of the Gallinas and Datil Mountains. The Dog Springs volcanic complex has been reported as far east as the northwest Gallinas Mountains, as far west as the Sawtooth Mountains (this report), as far north as Martin Ranch (Robinson, 1980) and as far south as Flying Draw (Bornhorst, 1976). The unit pinches out to the east of the study area; however Spradlin (1973) reported a hornblende-rich tuff in the Joyita Hills that is similar to some rocks in the Dog Springs volcanic complex. Reconnaissance in the Sawtooth Mountains, which form prominent bluffs visible from

U.S. Highway 60 northwest of Datil, revealed that the bluffs are thick sequences of tuff breccias similar to the tuff breccias in the Dog Springs volcanic complex. Reconnaissance to the east of the study area has shown that the rocks of the Dog Springs volcanic complex extend to the northeast corner of the Gallinas Mountains (fig.3).

The Dog Springs volcanic complex crops out as rounded hills, often covered by gravels, and as south-facing dip slopes. Outcrops are transected by north and east trending canyons which have moderately to steeply sloping walls. The majority of the unit is covered by talus, colluvium, alluvium and regolith. Some of the steeper slopes and more deeply eroded valleys provide outcrops of the less resistant units which are otherwise not seen.

The basal contact of the unit is not exposed anywhere in the study area. Reconnaissance in the Sawtooth Mountains and the Gallinas Mountains indicates that the basal contact is conformable with the underlying Baca Formation, but local unconformities, possibly due to soft sediment deformation, have been observed. The upper contact of the unit with the volcaniclastic rocks of Chavez Canyon is not exposed in the area, but attitudes indicate that the contact is an angular unconformity. However, some of the upper parts of the unit strongly resemble the overlying sandstones and conglomerates and therefore the contact may locally be gradational. Harrison (1980) reported that the upper contact was an angular unconformity.

Within the study area the unit has been divided into two distinctive assemblages of rocks referred to as the upper and lower members of the Dog Springs volcanic complex. The lower member consists of tuff breccias, minor exotic blocks and volcaniclastic rocks. The upper member consists of monolithic andesite breccias, mudflow breccias, lacustrine rocks, and exotic blocks. Individual rock types have been mapped within the members wherever sufficient outcrop was present.

Lower Member

The lower member of the Dog Springs volcanic complex consists of intermediate-composition, tuff breccias and minor volcaniclastic rocks. The term tuff breccia is adopted from Parsons (1967) and refers to "volcanic breccias with a large percentage of tuffaceous matrix". The term tuff breccia is favored over other

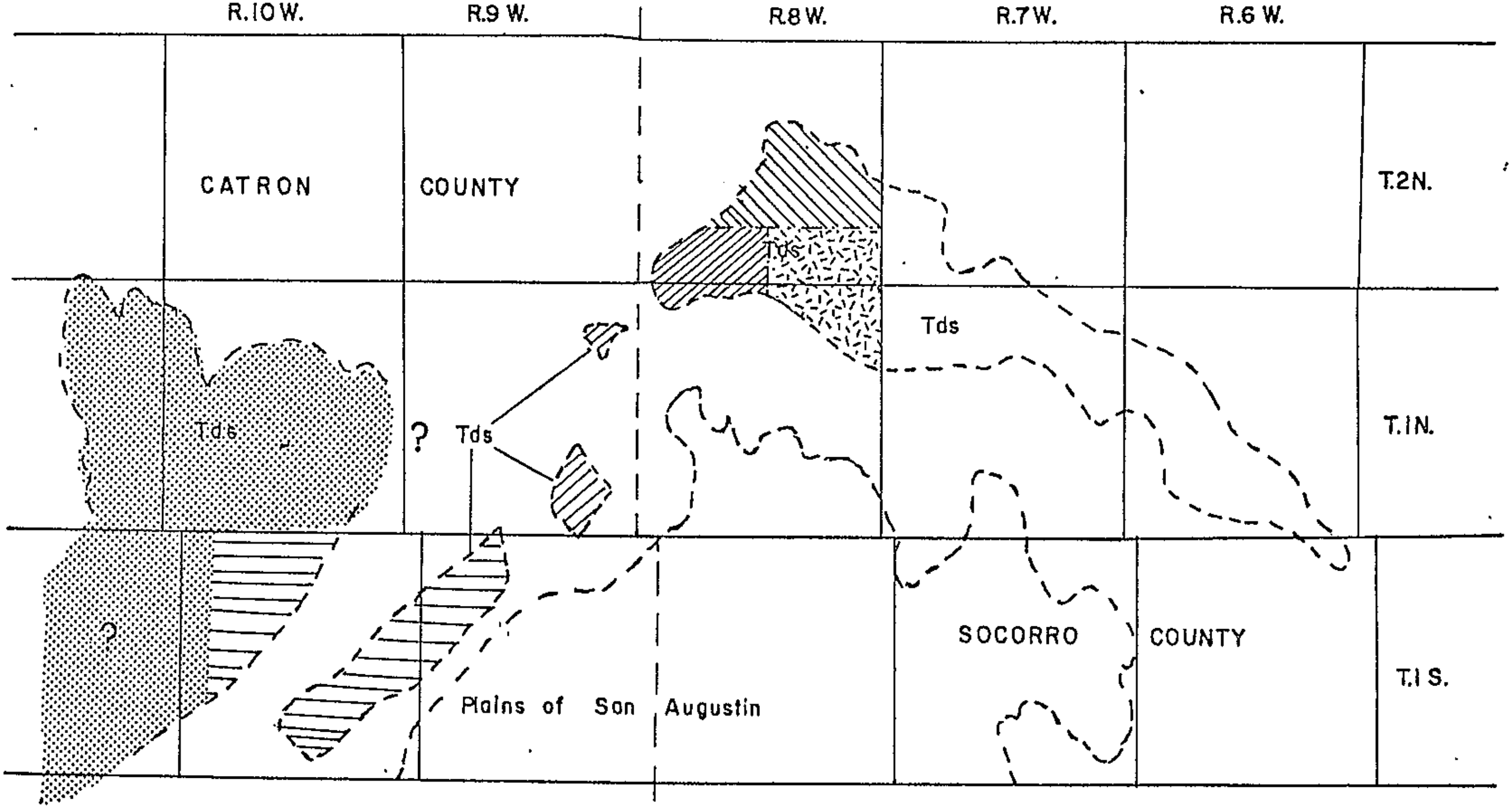


FIGURE 3. SKETCH MAP OF DISTRIBUTION OF ROCKS OF THE DOG SPRINGS VOLCANIC COMPLEX (Tds)

- ⁘ This thesis
- ▨ Harrison (1980)
- ▧ Robinson (1980)
- ▤ Lopez and Bornhorst (1978)
- ▒ Willard (1957), and Willard and Givens (1958)

terms because it is descriptive rather than genetic. The lower member is equivalent to the tuff breccias of Harrison (1980), portions of the Spears Formation as described by Lopez (1975) and Bornhorst (1976), and portions of the latite facies of the Datil Formation as described by Willard (1963). No source has been determined for the lower member within the study area. A K-Ar date on a clast from the lower member yielded an age of 38 m.y. B.P. (C.E. Chapin, unpublished data).

Similar looking rocks have been observed during reconnaissance as far north as Martin Ranch (Sec.15,T.2N., R.8W.), as far east as North Basin Well (Sec.18,T.1N.,R.7W), as far west as the Sawtooth Mountains (Sec.7,T.1N.,R.11W.), and as far south as Main Canyon (Sec.27, T.1S.,R.10W.). Spradlin described a hornblende rich tuff from the Joyita Hills of similar composition.

The lower member covers approximately 3.9 square kilometers of the study area and is volumetrically subordinate to the upper member in this area. The lower member forms a discontinuous outcrop pattern south of the Chavez Well-Thompson Canyon fault and along the northern boundary of the study area. Outcrops of the lower member occur along ridges, in drainages and on hillsides, but rarely exceed 150 m in maximum dimension. The lower member has a maximum exposed thickness of 370 m in the study area.

Reconnaissance to the north and east of the study area has revealed that the lower member forms a physiographically distinct, volumetrically significant, northeast-trending outcrop belt approximately 3 to 6 km wide and 30 km long that forms the northeast margin of the Gallinas Mountains. The region is characterized by steeply sloping hills with several hundred meters of relief occupying approximately 130 square kilometers. The hills characteristically have large blocks of tuff breccia exposed on their tops and sides. A maximum estimated thickness of 600 m of the lower member is exposed in the region.

The lower member consists of intermediate-composition rocks that are mineralogically and petrographically similar to the overlying upper member of the Dog Springs volcanic complex. Distinct differences, however, exist between the members when viewed in outcrop and hand specimen. Outcrops of the lower member tuff breccias display non-sorted clasts ranging in size from 4 mm to 2 m in diameter. Individual flows are discernible and impart a layering to the tuff breccias, but no stratification is apparent within the flows themselves. The bases of the individual flows have irregular surfaces (fig.4). This can be explained by the presence of load deformation and/or channeling. Outcrops of the lower member are more resistant than most of the units in the upper member and tend to form steeper hills with more exposure. Bedding planes are much easier to recognize in the lower member than in the upper member, however bedding is often chaotic due to soft-sediment deformation.

Clasts are predominantly porphyritic andesites which tend to be less dense and lighter in color than rocks of similar composition in the overlying upper member. No vesicular material or glass was observed in hand specimen or in thin section in the lower member. A few clasts of Precambrian granitic rocks and amphibolites, and Late Paleozoic limestones and red sandstones and siltstones were observed in the lower member. These non-volcanic clasts rarely exceed a few centimeters in maximum dimension and are volumetrically minor (fig.5). Harrison (1980) and Osburn (oral commun., 1980) have both observed large limestone blocks in similar units outside of the study area; however, only one large block was observed in the lower

Figure 4. Photograph of undulatory base of a typical tuff breccia in the lower member of the Dog Springs volcanic complex.

Figure 5. Photograph of tuff breccia in the lower member of Dog Spring volcanic complex. Note dark red clasts of siltstone (Abo?) and gray amphibolite clasts.

member within the study area. The heterolithic nature of the tuff breccias in the lower member, especially near the top of the member, is not so much revealed by large variations in clast composition as by variations in texture, color and degree of weathering displayed by clasts of similar composition. Parsons (1969) described similar relationships in tuff breccias of the Absaroka volcanic field.

Matrix in the tuff breccias consists of lithic fragments, crystal fragments, and aphanitic material. Matrix varies in color from light gray to reddish brown and is compositionally very similar to the fragments. Generally clasts can be distinguished from the surrounding matrix by color and tonal differences, however sometimes they are so similar that only the igneous textures displayed by the clasts serve to distinguish them.

The lower portion of the lower member predominantly consists of tuff breccias that have a dominant lithologically distinct clast type. These tuff breccias are informally referred to as the tuff breccia of Martin Ranch (fig.6) for good exposures of the unit just south of Martin Ranch (Sec.15, T.2N., R.8W.). The predominant clast type which serves to distinguish the tuff breccia of Martin Ranch is a light-gray porphyritic andesite with conspicuous phenocrysts of hornblende, milky-white feldspar and minor phenocrysts of biotite set in an aphanitic groundmass. Amphibolites occur as exotic clasts in the tuff breccia and as xenoliths in the fragments of the tuff breccia.

Petrographically, the clasts in the tuff breccia of Martin Ranch are seriate, porphyritic, and contain in decreasing order of abundance, phenocrysts of plagioclase, hornblende, biotite and magnetite. Phenocrysts account for 40 to 45 percent of the rock by volume and range in size from 0.2 mm to 4.0 mm in maximum dimension. The groundmass consists of low birefringent greenish-gray cryptocrystalline material (fig.7).

Euhedral to subhedral laths of plagioclase, 0.2 mm to 4.0 mm in length, occurring singly and in clusters, account for 20 to 25 percent of the rock by volume. Plagioclase crystals exhibit normal, reversed and oscillatory zoning. Albite and carlsbad twins are common; pericline twins are rare. Margins of plagioclase phenocrysts are sharp, corroded or rounded, and rarely embayed. Cores of some plagioclase

Figure 6. Photograph of tuff breccia of Martin Ranch in the lower member of the Dog Springs volcanic complex. Note monolithic and unsorted nature of the unit.

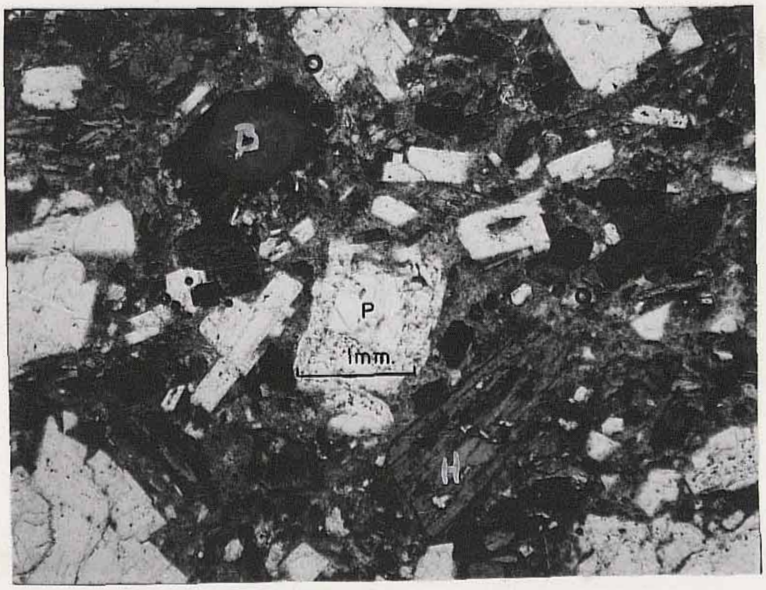


Figure 7. Photomicrograph of typical clast of the tuff breccia of Martin Ranch in the lower member of the Dog Springs volcanic complex. Phenocrysts are plagioclase (P), hornblende (H) and biotite (B). Note zoned inclusions in plagioclase phenocryst in the center of the photomicrograph.

phenocrysts have been removed; other plagioclase phenocrysts contain zoned inclusions with dusty borders (fig.7). Anorthite content of plagioclase was determined for 6 grains (Rittman Zone Method) which yielded an average value of An22 (oligoclase). Euhedral, light-green or clear inclusions of apatite, randomly oriented and with their long dimensions parallel to cleavage, are common within plagioclase phenocrysts.

Subhedral to euhedral hornblende phenocrysts, 1.5 mm in maximum dimension, account for 18 to 22 percent of the rock by volume. Hornblende is pleochroic and ranges in color from yellowish brown to greenish brown. Hornblende occurs as elongate laths and six-sided cross sections typical of amphiboles. Rims are corroded, embayed and commonly mantled by opaque minerals. Hornblende phenocrysts are commonly zoned, twinned and occasionally replaced by biotite.

Biotite also occurs as subhedral to euhedral laths 1.0 mm in maximum dimension and accounts for approximately 4 percent of the rock by volume. Biotite is pleochroic and displays colors ranging from dark brown to golden-yellow brown. Biotite also exhibits color zonation within individual crystals; cores are commonly lighter than rims. Margins of biotite phenocrysts are commonly corroded and occasionally embayed. Magnetite occurs as subhedral to euhedral cubes 0.4 mm in maximum dimension and accounts for about 1 percent of the rock by volume. Phenocryst of magnetite occur as single crystals and in clusters. Magnetite also occurs as mantles on hornblende phenocrysts.

Above the tuff breccia of Martin Ranch is a sequence of biotite-rich, heterolithic, tuff breccias and monolithic volcanic breccias of intermediate composition. Although similar in outcrop characteristics to the underlying tuff breccia of Martin Ranch these breccias can be distinguished by their characteristic clast content. The heterolithic tuff breccia has all of the clast characteristics of the underlying tuff breccia of Martin Ranch and biotite andesite clasts that have phenocrysts of feldspar, biotite and hornblende. The monolithic breccia can be distinguished by the dense, dark, subangular clasts which appear to be derived from lava flows or hypabyssal rocks rather than from tuffs. Although similar to the overlying andesite breccias of the upper member of the Dog Springs volcanic complex, the monolithic breccia can be distinguished by the larger percentage of matrix material which is characteristically dull-red in color. The monolithic breccia also seems to be altered very easily and often appears to be propylitized. Manganese staining is also characteristic of the altered portions of the monolithic breccia.

In hand specimen and outcrop, the heterolithic tuff breccias of the lower member are light brown to buff when weathered and light to medium gray when fresh. Clasts are angular to subrounded and range in color from gray to buff. Clasts range in size from ash to blocks (Fisher, 1960) and show little or no sorting. Igneous clasts consisting of hornblende andesites, identical to those in the underlying tuff breccia of Martin Ranch, and biotite andesites make up over 99 percent of the clast content by volume. The heterolithic breccias are moderate to well-indurated and crop out as discontinuous beds.

Petrographically, the tuff breccia consists of porphyritic clasts of intermediate composition set in a light-brown matrix of cryptocrystalline material, crystal fragments, lithic fragments and minor opaque material which is compositionally similar to the clasts it encloses. Porphyritic clasts can be distinguished from the surrounding matrix by their tonal differences and poorly developed pilotaxitic texture (fig.8). Only hornblende andesite and biotite andesite clasts, which volumetrically dominate the total clast content, were observered in thin section.

Biotite andesite clasts possess, in decreasing order of abundance, phenocrysts of plagioclase, biotite, hornblende and sanidine set in a groundmass of low birefringent cryptocrystalline material. Clasts are approximately 40 percent phenocrysts.

Subhedral to euhedral phenocrysts of plagioclase account for about 23 percent, by volume, of the biotite andesite clasts. Plagioclase phenocrysts occur singly and in aggregates and do not exceed 3.0 mm in maximum dimension. Plagioclase displays carlsbad, pericline and albite twinning. Phenocryst margins may be either sharp or corroded. Phyllosilicate alteration is common on plagioclase phenocrysts. Anorthite content of plagioclase (Rittman Zone Method) is about An 23 (oligoclase).

Biotite which accounts for about 14 percent of the biotite andesite clasts by volume is subhedral and mantled or totally replaced by magnetite. Biotite is 1.2 mm in maximum dimension and, when unaltered,

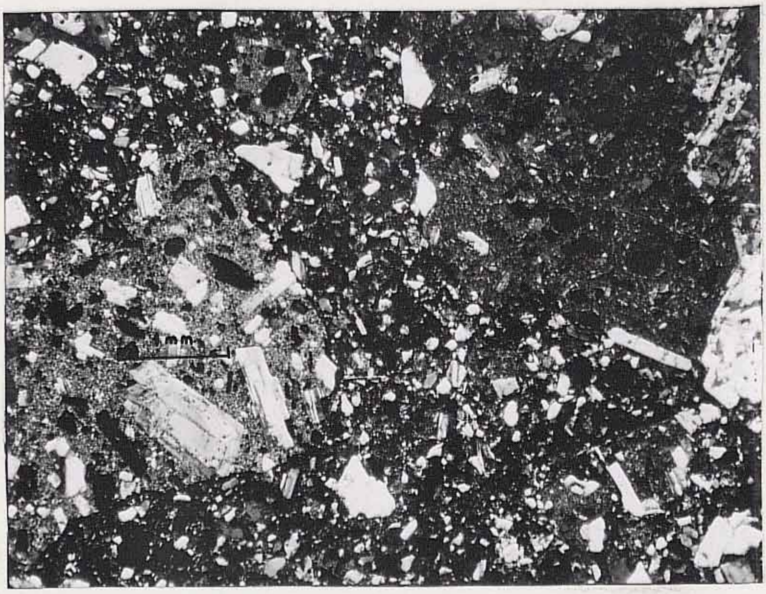


Figure 8. Photomicrograph of a typical heterolithic tuff breccia in the lower member of the Dog Springs volcanic complex. Note that the clast on the right has a groundmass of plagioclase microlites and opaque material whereas the clast on the left has a groundmass of light colored cryptocrystalline material.

exhibits pleochroic colors ranging from pale yellow to dark reddish brown. Subhedral to euhedral hornblende is 0.4 mm in maximum dimension and displays pleochroic colors ranging from golden-yellow to dark reddish brown. Hornblende accounts for 3 percent of the rock by volume. Trace amounts of sanidine are also present.

In hand specimen, the monolithic andesite breccia of the lower member is reddish brown when weathered and consists of gray clasts surrounded by a dull-red matrix when fresh. Subangular clasts rarely exceed a few centimeters in maximum dimension and display phenocrysts of feldspar and hornblende in a light-gray aphanitic matrix. This rock type is volumetrically minor within the study area but is widespread throughout the region. The monolithic andesite breccias of the lower member are correlative to the laharic breccias of Harrison (1980).

Petrographically, the monolithic hornblende andesites of the lower member of the Dog Springs volcanic complex are porphyritic and contain in decreasing order of abundance phenocrysts of plagioclase, hornblende, biotite, clinopyroxene, magnetite and sanidine. Groundmass consists of low birefringent cryptocrystalline material, chlorite, felted plagioclase microlites and opaque material. Phenocrysts account for approximately 24 percent of the rock by volume. Clasts account for 20 to 80 percent of the rock by volume and are surrounded by a dull-red matrix of crystal fragments, low birefringent cryptocrystalline material, chlorite, and opaque material (fig.9).

Plagioclase is by far the most abundant phenocryst present and accounts for approximately 12 percent of the rock by volume. Plagioclase phenocrysts are 2.0 mm in maximum dimension and display albite, carlsbad and pericline twinning. Plagioclase is anhedral to euhedral and displays normal, reversed and oscillatory zoning. Margins of plagioclase phenocrysts are corroded or sharp. Anorthite content of plagioclase was determined using the Michel-Levy statistical method which yielded a value of An 48 (andesine).

Euhedral to subhedral hornblende phenocrysts account for 5 percent of the rock by volume and are 0.5 mm in maximum dimension. Hornblende is commonly partially or totally replaced by phyllosilicate minerals and magnetite. Biotite phenocrysts account for 2 percent of the rock by volume and rarely exceed 0.5 mm in maximum dimension. Biotite phenocrysts are

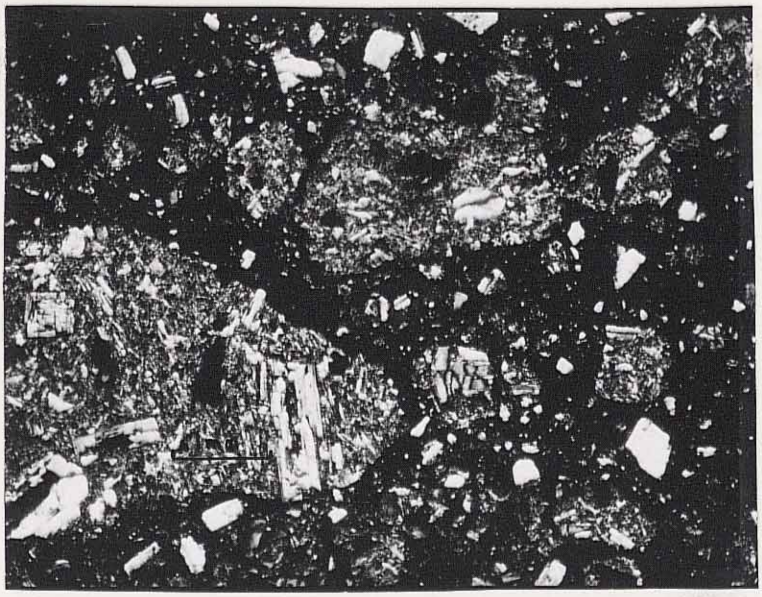


Figure 9. Photomicrograph of a monolithic andesite breccia in the lower member of the Dog Springs volcanic complex.

subhedral and elongate. Biotite is commonly replaced or mantled by magnetite and displays pleochroic colors ranging from light to medium green. Clinopyroxene accounts for 2 percent of the rock by volume and occurs as anhedral to subhedral blebs 0.4 mm in maximum dimension. Magnetite occurs as anhedral to subhedral cubes and accounts for one percent of the rock by volume. Chlorite occurs as anhedral masses in the groundmass and accounts for 1 percent of the rock by volume. Trace amounts of sanidine 0.5 mm in maximum dimension are also present. Sanidine displays sharp or corroded margins and carlsbad twinning.

Upper Member

The upper member of the Dog Springs volcanic complex consists of hornblende andesite breccias, intermediate-composition mudflow deposits, mudstones, exotic blocks, minor volcaniclastic rocks and ash-flow tuffs. The member represents part of the vent facies of the Dog Springs volcanic complex. No date has been determined for the member.

The upper member has been mapped as far north as the mouth of Middle Canyon (Sec.27, T.2N., R.8W.) and as far south as the head of Middle Canyon (Sec.12, T.1N., R.8W.) (this report). The member has been observed during reconnaissance as far south and west as eastern Catron County (Sec.30, T.1N., R.9W.) and as far east as the central Gallinas Mountains (Sec.10 T.1N., R.7W.). The upper member is not as regionally extensive as the lower member and may represent deposits that were localized in a volcano-tectonic depression.

The upper member forms a distinctive terrain within, and to the east of, the study area characterized by low, flat-topped hills which rarely exceed 60 m in relief. The upper member forms isolated outcrops on hill sides and tops and in recently eroded stream drainages. The abundance of outcrops of a particular rock type within the member is relative to resistivity to weathering and abundance. A maximum thickness of 215 m of the upper member is exposed in the study area. The upper member forms two continuous bands across the northern and north-central portions of the study area and covers approximately 10 square kilometers.

mudflow deposits

Mudflow deposits occur throughout the upper member and are thought to be the most common rock type. The mudflow deposits appear to have gradational contacts with the underlying lower member tuff breccias and the overlying volcaniclastic rocks of Chavez Canyon. Mudflow deposits are rarely seen in outcrop but some exposures do occur in recently eroded stream drainages. Pyroxene andesite float characteristic of the mudflow deposits covers much of the upper member.

The mudflow deposits of the upper member have a heterolithic assemblage of clasts ranging in size from a few millimeters to several meters in maximum dimension. Clasts of pyroxene andesites dominate the assemblage which also consists of clasts characteristic of the lower member tuff breccias, and exotic blocks. Clasts are subrounded to angular and very poorly to moderately sorted. Mudflow deposits occasionally display graded bedding and medium-scale trough cross-stratification. Clasts are supported by a muddy matrix in these poorly indurated mudflow deposits (fig.10).

Figure 10. Photograph of typical mudflow breccias in the upper member of the Dog Springs volcanic complex. Note poorly developed stratification.

In hand specimen, the pyroxene andesite clasts, which dominate the upper member mudflow deposits, are reddish brown when weathered and dark-green when fresh. Dark-green to black phenocrysts of blocky pyroxene and elongate hornblende dominate the rock in hand specimen. Plagioclase phenocrysts are translucent and best viewed on a cut surface. Phenocrysts are surrounded by a dense, dark-green, aphanitic groundmass.

Texturally, the pyroxene andesites are porphyritic, seriate, and trachytic. Phenocrysts make up 24 percent of the rock by volume and, in decreasing order of abundance, consist of plagioclase, clinopyroxene, magnetite, and hornblende. Aphanitic groundmass consists of plagioclase laths, chlorite, and clinopyroxene.

Euhedral to subhedral plagioclase is by far the most common phenocryst and makes up approximately 17 percent of the rock by volume. Plagioclase is also the dominant mineral in the groundmass. Phenocrysts of plagioclase display normal and oscillatory zoning, pericline, carlsbad and albite twins, and occur as single or composite grains. Phenocrysts of plagioclase are 2.5 mm in maximum dimension and occur as elongate and equant crystals. Plagioclase phenocrysts have sharp or corroded margins and commonly exhibit cores which have been altered to phyllosilicate minerals. Euhedral inclusions of apatite have random orientations and also are oriented with their long dimensions parallel to cleavage. Anorthite content of plagioclase phenocrysts was determined using the Michel-Levy statistical method which yielded a value of An47 (andesine).

Approximately 12 percent of the rock by volume is chlorite which occurs as alteration products of groundmass and phenocrysts. Dark-green chlorite occurs primarily as anhedral to subhedral plates which have replaced mafic phenocrysts. Chlorite also occurs as interstitial groundmass and fibrous aggregates in the groundmass. Pale-yellow phenocrysts of clinopyroxene account for 5 percent of the rock volume. Subhedral, equant phenocrysts of clinopyroxene are 2.0 mm in maximum dimension, pervasively fractured, and commonly have their cores removed. Opaque minerals, probably magnetite, account for 2 percent of the rock by volume. Subhedral phenocrysts of hornblende, 1.0 mm in maximum dimension, account for 1 percent of the rock by volume. Hornblende phenocrysts are pleochroic and display colors ranging from pale yellow to reddish brown.

Hornblende phenocrysts have corroded margins which are commonly mantled by opaque minerals.

The mudflow deposits can be distinguished from the lower member tuff breccias by several characteristics. The major distinguishing feature of the mudflow deposits is the dominance of the pyroxene andesite clasts over all other clast types. These clasts are darker in color and denser than the clasts which characterize the lower member tuff breccias and are definitely not tuffaceous. The mudflow deposits also form low hills and poorly exposed, unstratified or poorly stratified, outcrops as opposed to the steeper hills and better outcrops formed by the lower member tuff breccias.

monolithic breccias

Monolithic hornblende andesite breccias occur as extrusive and intrusive rocks within the upper member. Generally the extrusive rocks are found above the lacustrine rocks of Middle Canyon and the intrusive breccias are found throughout the Dog Springs volcanic complex. The monolithic hornblende andesite breccias are correlative to the rhyodacite intrusive and extrusive rocks of Harrison (1980). These breccias are locally derived from vents within and directly to the west of the study area. Possible source areas occur along the northern and eastern margins of the study area (Secs.26, 27 and 28, T.2N., R.8W.). These source areas are characterized by abnormally thick accumulations of breccia, tens to hundreds of meters thick, which appears to display cross cutting relationships with the surrounding rocks. Intrusions are also locally vesiculated, sheet jointed and have a prefered alignment of elongate phenocrysts with respect to the margins of the intrusive body. Harrison (1980) defined a north-trending vent zone to the west of the study area. Further evidence for a local source is provided by the numerous monolithic hornblende andesite dikes that intruded the lower member of the Dog Springs volcanic complex. The monolithic nature of these breccias would not be preserved if if they where transported long distances as flows.

Outcrops of the breccia are generally massive (fig.11), but occasionally contain horizontal stratification (flows)(fig.12), and steep cross-cutting relationships (dikes)(fig.13). Outcrops occur on hillsides and along recently eroded stream drainages and consist of subangular to angular clasts which range in size from a few millimeters to several meters in maximum dimension. Very little matrix is present in these hornblende andesite breccias.

In hand specimen, hornblende andesites of the upper member range in color from brownish red when weathered to a dark olive green when fresh. Phenocrysts of dark-green to black hornblende and translucent green plagioclase are visible in hand specimen. Phenocrysts are set in a dark-green aphanitic groundmass.

Petrographically, the hornblende andesite clasts are porphyritic and pilotaxitic. Phenocrysts, in decreasing order of abundance, are plagioclase, hornblende, clinopyroxene and magnetite. Phenocrysts are generally randomly oriented but some are aligned in a subparallel manner. Groundmass consists of a felted mass of plagioclase microlites which wrap around the phenocrysts and a subordinate portion of anhedral opaque blebs. Phenocrysts account for approximately 40 percent of the rock by volume (fig.14).

Plagioclase is by far the most common phenocryst and accounts for about 20 percent of the rock by volume. Euhedral to subhedral laths of plagioclase, 2.5 mm in maximum dimension, show normal and

Figure 11. Photograph of a massive outcrop of autobrecciated monolithic hornblende andesite in the upper member of the Dog Springs volcanic complex. Note unsorted nature, angularity of clasts and lack of significant matrix.

Figure 12. Photograph of monolithic hornblende andesite breccia flow in the upper member of the Dog Springs volcanic complex.

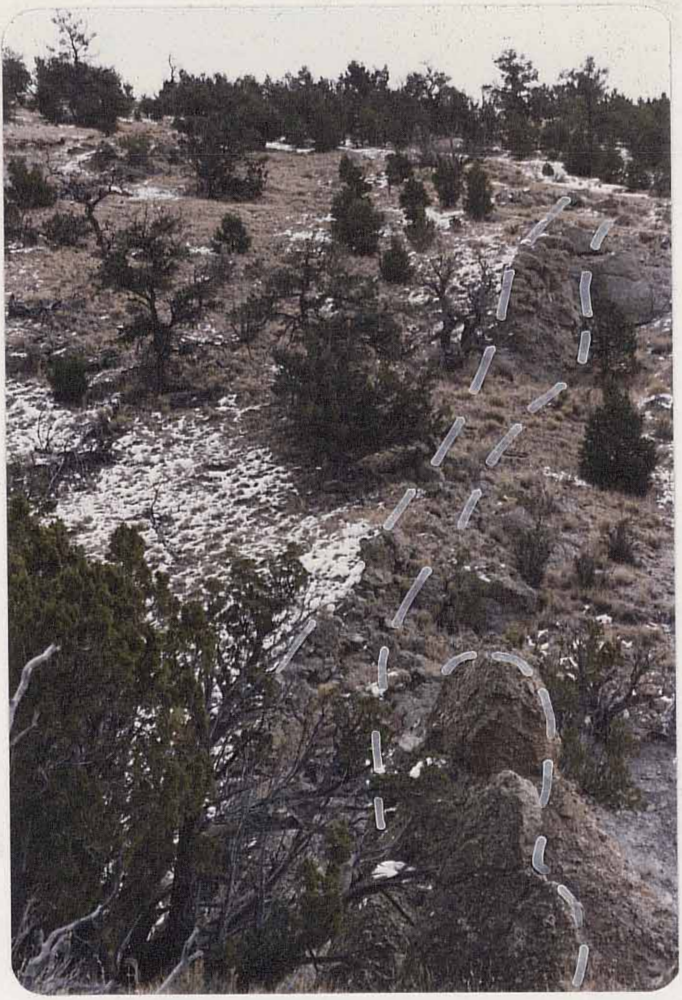


Figure 13. Photograph of monolithic hornblende andesite breccia dike in the Dog Springs volcanic complex.

Figure 14. Photomicrograph of hornblende andesite clast from the upper member of the Dog Springs volcanic complex. Note dark patches of euhedral hornblende in upper right corner and anhedral bleb of chlorite in lower left corner.

oscillatory zoning. Plagioclase exhibits albite, carlsbad and pericline twinning. Margins are usually sharp but occasionally embayed or corroded. Plagioclase occurs as single and composite phenocrysts. Anorthite content was determined using the Michel-Levy statistical method which yielded a value of An 40 (andesine).

Hornblende accounts for approximately 11 percent of the rock by volume. Subhedral phenocrysts of hornblende are commonly mantled by a thick rind of magnetite and often contain inclusions of plagioclase. Hornblende phenocrysts may be twinned and exhibit pleochroic colors ranging from light yellow to reddish brown. Fracturing and zoning is also present in some hornblende phenocrysts.

Euhedral to subhedral phenocrysts of clinopyroxene account for 7 percent of the rock by volume. Clinopyroxene phenocrysts are 2.0 mm in maximum dimension and commonly occur in aggregates with plagioclase crystals. Clinopyroxene crystals have sharp margins and are often fractured. Clinopyroxene phenocrysts are rarely twinned and commonly have inclusions of magnetite and plagioclase. Two percent of the rock volume consists of anhedral to euhedral phenocrysts of magnetite, 0.3 mm in maximum dimension. Chlorite occasionally has replaced mafic phenocrysts and groundmass.

Several criteria serve to distinguish hornblende andesite breccias from the underlying lower member breccias. Characteristically, the hornblende andesite breccias consist of dark, dense clasts that are not tuffaceous. Another distinguishing characteristic is the general lack of significant amounts of matrix. Massive outcrops ,which rarely show any stratification, and the generally angular clasts also help to distinguish these hornblende andesite breccias.

Lacustrine Rocks of Middle Canyon

The lacustrine rocks of Middle Canyon is an informal name proposed here for a sequence of thinly laminated to thinly bedded mudstones and very-fine-grained sandstones (fig.15), that represent lake or pond deposits and occur near the top of the Dog Springs volcanic complex. The unit is named for exposures near the mouth of Middle Canyon (Secs.26 and 27, T.2N., R.8W.) in the northern portion of the study area. No other workers in the area have reported units equivalent to these mudstones, however,

Figure 15. Photograph of typical outcrop of the lacustrine rocks of Middle Canyon.

reconnaissance to the west of the study area, in the region mapped by Harrison (1980), did reveal at least one outcrop of similar rocks. Similar rocks have also been observed to the east of the study area in Long Canyon.

The lacustrine rocks of Middle Canyon have been mapped as a separate unit in the study area whenever sufficient outcrop is present. The unit forms a discontinuous outcrop pattern across the northern portion of the study area north of the Chavez Well-Thompson Canyon fault and occurs as isolated outcrops across the north-central portion of the study area south of the Chavez Well-Thompson Canyon fault. Despite the poor outcrop characteristics, the unit is the only good stratigraphic marker in the upper member of the Dog Springs volcanic complex. The unit covers a total of about 1.3 square kilometers of the study area and forms low hills with colluvium covered slopes. The unit is only exposed where recent erosion has been active. It is thought that the unit may be nearly continuous from Chavez Canyon through Middle Canyon to Old Canyon, and that this large area of exposure may represent the deposits of a large lake or a series of small ponds at about the same stratigraphic interval. Isolated outcrops, such as those south of the Chavez

Well-Thompson Canyon fault, are thought to represent small ponds formed in drainages disrupted by mudflows.

The lacustrine rocks of Middle Canyon conformably underlie the monolithic andesite breccias and mudflow deposits characteristic of the upper portion of the Dog Springs volcanic complex. Nowhere in the area is the basal contact of the unit clearly exposed, but it is thought that the unit lies conformably above, or in slight local unconformity with, the upper member mudflow deposits.

In hand specimen, the unit varies from pinkish tan or reddish brown when fresh to light gray when weathered. In outcrop the unit is pervasively fractured and often has calcite veins. Calcite veins as much as 10 cm in width are especially abundant near the intersection of Chavez and Middle Canyon. Manganese dendrites are also commonly developed along fractures and bedding planes. Small plates of biotite and muscovite are visible with the aid of the hand lens but account for only a minor portion of the rock volume. The majority of the rock volume consists of smectitic clays that quickly absorb moisture. In outcrop, the unit is usually damp within a meter of the surface.

Petrographically, the lacustrine rocks of Middle Canyon are a mass of tiny, low-birefringent and opaque minerals set in a reddish-brown matrix. The only identifiable minerals are biotite and plagioclase. Subangular grains of plagioclase are more common than biotite and usually exhibit some sort of phyllosilicate alteration. Plagioclase may also display normal zoning and albite twinning. Elongate subangular grains of biotite are pleochroic and range in color from pale yellow to reddish brown. Elongate grains in the unit are oriented with their long directions roughly parallel to bedding.

A single outcrop of similar looking mudstones has been observed in the lower member of the Dog springs volcanic complex. The outcrop is located in Old Canyon about 1.6 kilometers south of the Chavez Well-Thompson Canyon fault and suggests that caution must be used when these rocks are used to determine stratigraphic position within the Dog Springs volcanic complex.

ash-flow tuffs

A few outcrops of crystal-poor, trachytic, poorly welded ash-flow tuffs are present in the upper member of the Dog Springs volcanic complex. These outcrops are located in the northeast corner of section 3, township 1 north, range 8 west and are volumetrically insignificant; however, they do represent the only glassy vesicular material in the complex.

In hand specimen, these ash-flow tuffs are light gray when fresh and yellow gray when weathered. Phenocrysts of feldspar and lithic fragments are visible in hand specimen.

Petrographically, these crystal-poor ash-flow tuffs are porphyritic and have subhedral phenocrysts of sanidine that account for about 1 percent of the rock by volume. Groundmass consists of poorly preserved glass shards, axiolitic growths, and low-birefringence cryptocrystalline material. Void space and matrix material has been partially filled or replaced by calcite and light-green pleochroic chlorite.

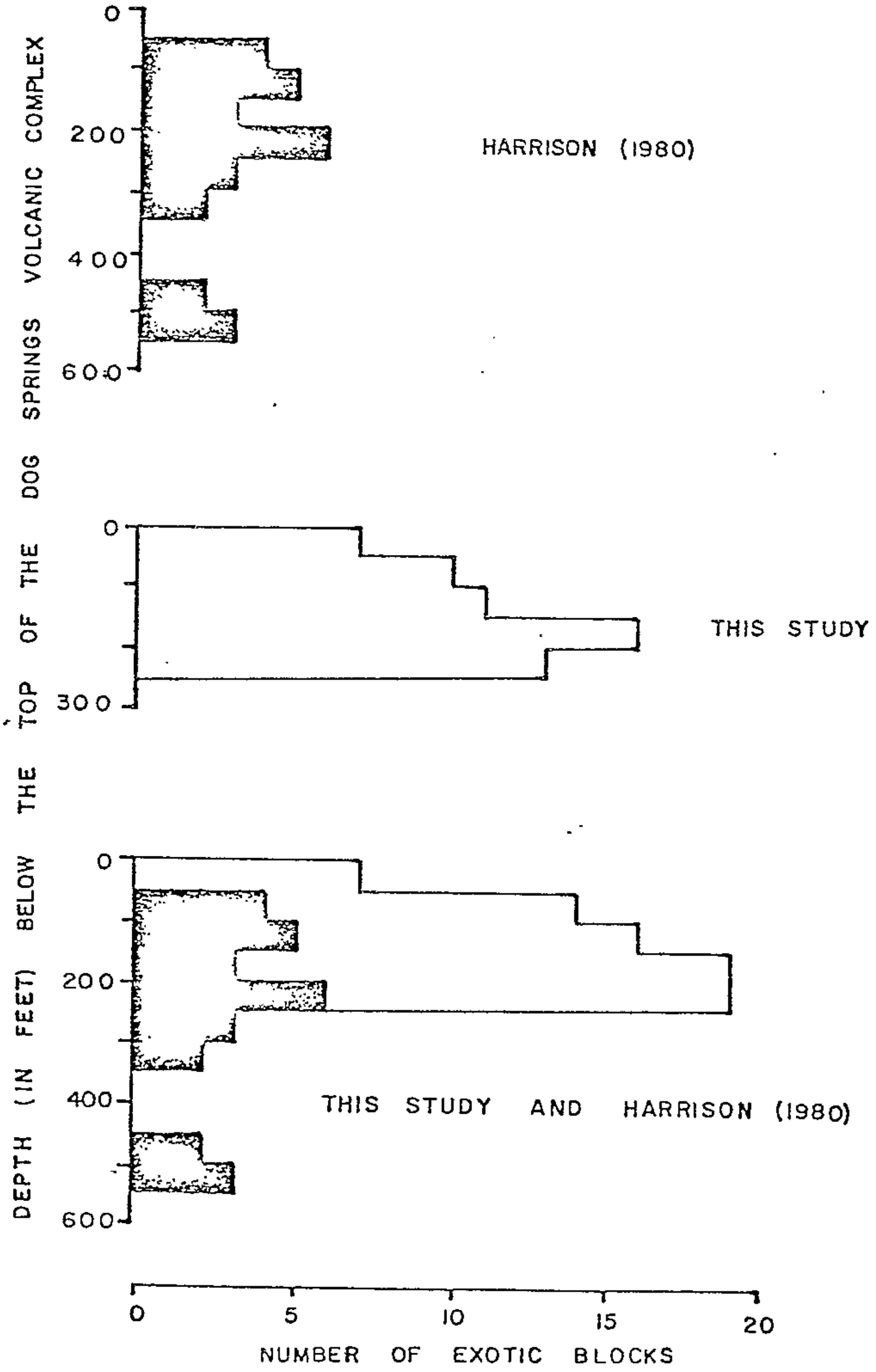
sedimentary rocks

Minor fluviatile volcaniclastic rocks are also present in in the study area. Sandstones and conglomerates occur throughout the upper member but are rarely traceable for more than a few meters along strike.

exotic blocks

Exotic blocks consist primarily of Pennsylvanian to Permian limestones, monolithic, intermediate-composition breccias of unknown age and, occasionally reddish-brown sandstones and siltstones of the Permian Abo Formation. Several workers in the northeastern corner of the Datil-Mogollon volcanic province (Givens, 1957; Lopez, 1975; Harrison, 1980 and Robinson, 1980) have described such blocks. Harrison mapped limestone blocks and monolithic tuff blocks several hundred meters in diameter to the west of the study area and referred to them as "megabreccia blocks". The term exotic blocks is used here for these and similar blocks in the study area because it refers to "rock occurring in a lithologic association foreign to that in which the mass was formed" (Bates and Jackson, 1980), and unlike the term megabreccia has no genetic significance. In the study area, discordant, rootless blocks of limestone, intermediate-composition monolithic volcanic breccias and heterolithic volcanic breccias are the only mappable exotic blocks present. Within the region the majority of known exotic blocks occur in the upper 122 m of the Dog Springs volcanic complex (fig.16).

FIGURE 16. DIA[illegible]M OF THE STRATIGRAPHIC D[illegible]RIBUTION OF EXOTIC BLOCKS IN THE DOG SPRINGS VOLCANIC COMPLEX.



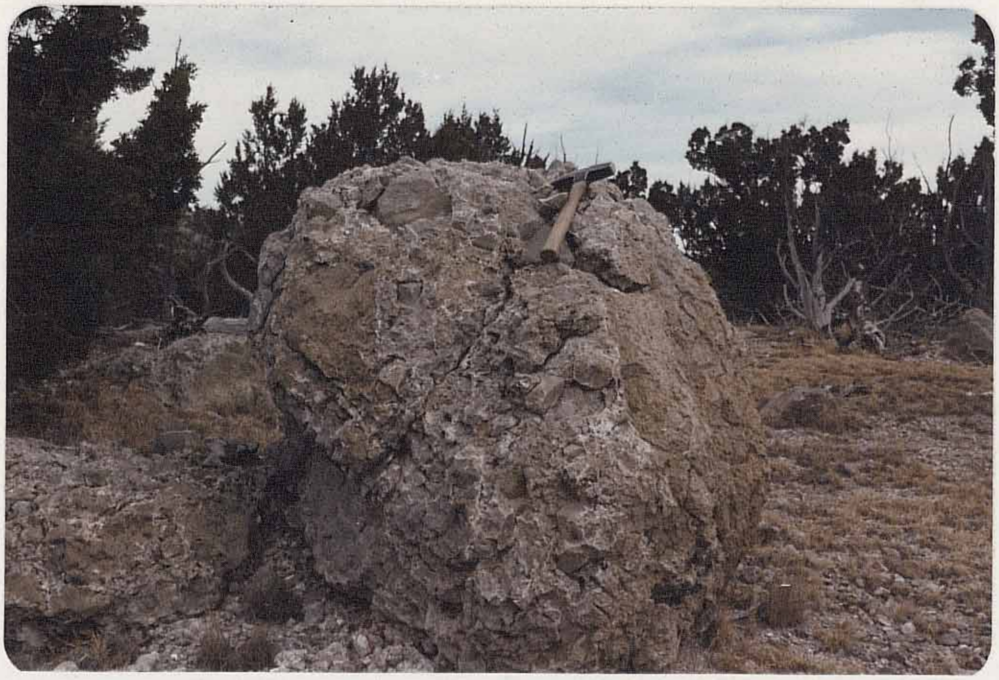


Figure 17. Photograph of exotic block of limestone in the Dog Springs volcanic complex.

Figure 18. Photograph of exotic block of crystal-rich, monolithic breccia in the Dog Springs volcanic complex.

The limestone blocks are micritic and generally have fractures filled by blocky spar (Folk, 1974)(fig. 17). Fossils consist of brachiopods, corals, bryozoa and crinod stems. This fossil assemblage is not diagnostic of Permian or Pennsylvanian age. Givens (1956, p.14) indicated that Dr. R.H. Flowers believed that these limestones were of Permian age. Lopez (1975) reported that the limestones resembled the Pennsylvanian Madera Formation and Laroche (1980) reported a Pennsylvanian fusulinid date from a limestone block to the east of this study area. Regardless of age the presence of these light greenish gray, locally cherty, limestones ~~are~~ is quite enigmatic.

In the study area, limestone blocks occur throughout the Dog Springs volcanic complex but are primarily found in the upper member. The largest limestone blocks occur in the pyroxene andesite mudflow deposits of the upper member above the Lacustrine Rocks of Middle Canyon.

Dacitic to andesitic, monolithic, crystal-rich, breccias also occur as exotic blocks in the study area (fig.18). These breccias are similar in appearance to a quartz latite tuff megabreccia block described by Harrison (1980) to the west of the study area.

However, the tuff described by Harrison has more sanidine and quartz than this breccia. No date is available for the breccia.

These breccias are the most resistant rock type in the upper member and therefore tend to crop out the most. Outcrops of the breccia form east-trending ridges and isolated knobs which are easy to distinguish from the rest of the upper member. Dike-like blocks of the breccia are traceable for as much as 0.8 km and vary from a meter to several meters in width. The east-west trend of the blocks is probably stratigraphically controlled and may represent a particularly thick mudflow in the upper member. The monolithic breccias are sometimes difficult to recognize within the lower member tuff breccias and have not always been distinguished from them in the study area.

Exotic, monolithic breccia blocks are generally found in a discrete east-trending band approximately 1.6 km wide across the north central portion of the study area. The breccias cover an area of about 2.6 square kilometers.

Outcrops of the breccias are generally unstratified and pervasively jointed. Clasts range in size from a few millimeters to several centimeters, but rarely exceed a meter in maximum dimension. Clasts are angular to subrounded and may be either subordinate or dominant relative to the surrounding matrix. Some clasts appear to have been stretched suggesting initial emplacement while still hot enough to be plastically deformed.

In hand specimen, the breccias are reddish brown when weathered and light-gray to reddish gray when fresh. Clasts are light-gray to greenish gray and are surrounded by a red or gray matrix. Clasts are crystal-rich and contain phenocrysts of milky-white feldspar, black biotite, black hornblende and occasional quartz. Matrix in these breccias consists of lithic fragments, crystals, crystal fragments, and aphanitic material.

Petrographically, the breccias consist of monolithic, porphyritic clasts of intermediate composition, set in a light-gray to dull-red matrix. The matrix consists of low-birefringent cryptocrystalline material, crystals, lithic fragments, crystal fragments and opaque material. Matrix is compositionally similar to the clasts it encloses but can be distinguished by the lack of igneous textures and different color (fig.19).

Clasts consist of crudely aligned phenocrysts set in a groundmass of low-birefringent cryptocrystalline material and opaque minerals. Phenocrysts, in decreasing order of abundance, are plagioclase, hornblende, biotite, sanidine and clinopyroxene. Phenocrysts account for 30 to 45 percent of the rock by volume.

Plagioclase is always the most abundant phenocryst present and accounts for 17 to 25 percent of the rock by volume. Subhedral to euhedral phenocrysts of plagioclase are 2.0 mm in maximum dimension and have both sharp and corroded margins. Plagioclase displays normal and oscillatory zoning, antiperthitic unmixing, and occurs as single and composite grains. Albite and carlsbad twinning are common in plagioclase phenocrysts. Anorthite content was determined for 24 grains (Rittman Zone Method) and yielded an average value of An 24 (oligoclase).

Hornblende content varies from 5 to 22 percent of the rock by volume. Subhedral to euhedral phenocrysts of hornblende have both sharp and corroded margins and

Figure 19. Photomicrograph of crystal-rich, monolithic breccia from an exotic block in the Dog Springs volcanic complex. Note similarities of clasts and matrix material.

are often mantled by opaque minerals. Hornblende phenocrysts occur as single and composite grains, are 2.0 mm in maximum dimension and are occasionally twinned. Hornblende is pleochroic and ranges in color from pale yellow to dark reddish brown or green. Biotite accounts for 1 to 4 percent of the rock by volume. Biotite has sharp and corroded margins, often mantled by opaque minerals and occurs as elongate crystals that may display bent lamella. Biotite is 1.0 mm in maximum dimension and displays pleochroic colors ranging from golden brown to dark reddish brown. Opaque minerals, probably magnetite, account for as much as 5 percent of the rock by volume. Opaque minerals occur as phenocrysts, groundmass, and mantles on mafic phenocrysts. Subhedral phenocrysts of sanidine account for a trace to 1 percent of the rock by volume and display carlsbad twinning. Clinopyroxene phenocrysts are present in trace amounts.

These monolithic breccias can be distinguished by their monolithic nature and massive outcrop characteristics. In hand specimen, the breccias crystal-rich character and conspicuous, milky-white feldspar phenocrysts serve to distinguish it.

Minor outcrops of heterolithic volcanic breccia similar to lower member tuff breccias, have been observed in the upper member. These heterolithic tuff breccias may represent exotic blocks in mudflow deposits, paleo-topographic highs or a gradational contact.

Several hypothesis have been forwarded for the origin of these exotic blocks. Givens (1957) reported that the blocks were "brought up by the outpouring tuffs". Lopez (1975) observed that the blocks were rootless, and therefore not basement highs, and that they had definitely been rafted laterally by lahars. Harrison (1980) combined these two ideas and concluded that the exotic blocks where floated upwards and then rafted laterally by the tuff breccias. A collapse origin, as with a caldera, can be disregarded as there are no rocks present to act as a source area (Harrison, 1980). Similar large limestone blocks have been reported in the Absaroka volcanic field of northwestern Wyoming. Detachment faults, such as the Heart Mountain detachment fault, have been employed to explain the existence of these blocks that have traveled as much as 50 km from their proposed source area (Pierce, 1963).

Detachment faults consist of a high angle breakaway fault, a bedding-plane fault, a transgressive fault and a former land surface fault (fig.20). Such faults, with the exception of the breakaway fault, are of low angle. The transgressive fault is thought to have dipped at no more than 10 degrees and the other faults did not exceed 2 degrees in dip (Pierce, 1973).

The problem with detachment faults is the existence of a viable mechanism for reducing friction and thus facilitating movement along such gentle slopes. High fluid pressure (Hubbert and Rubey, 1959) and hovercraft tectonics (Hughs, 1970), where blocks are floated by laterally injected volcanic gas, have both been proposed but the low confining pressure thought to be present during detachment faulting argues against such mechanisms (Pierce, 1973). The idea that detachment faults are landslides (Hsu, 1969) can be disregarded by the difference in the amount of surface area involved (Pierce, 1973). Gravity sliding along low-viscosity strata (Kehl,1970, p.1658) is ruled out because the Heart Mountain detachment fault occurs in high-viscosity strata directly above a low-viscosity shale bed (Pierce, 1973). Earthquake oscillations (Pierce, 1963), common in active volcanic regions,

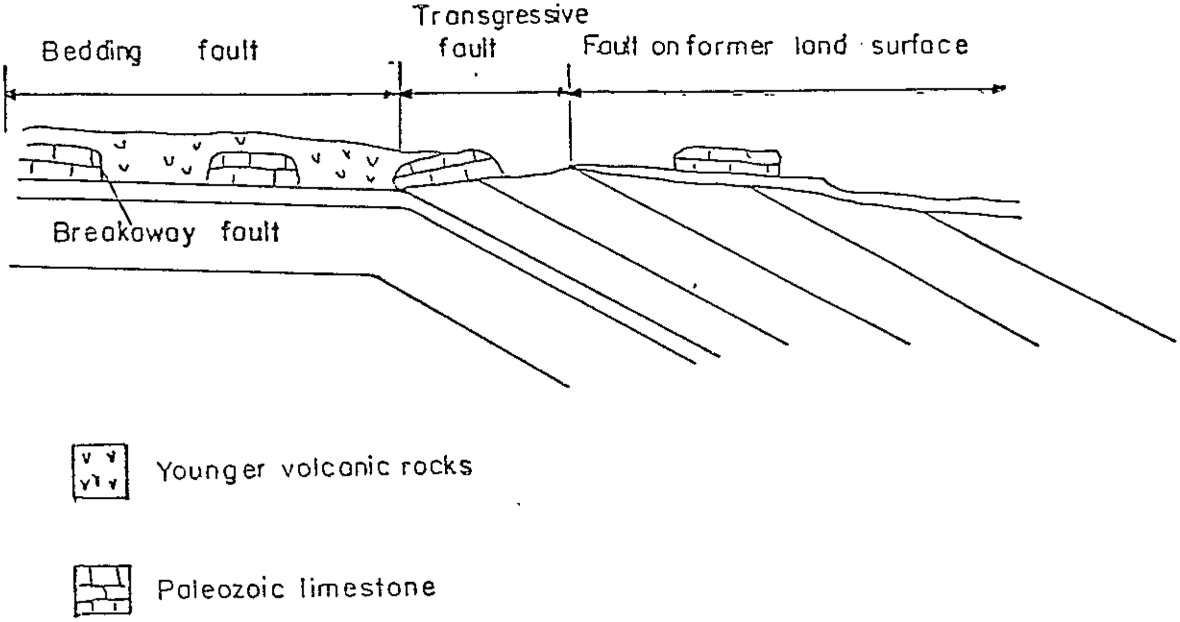


FIGURE 20. DIAGRAM OF VARIOUS ELEMENTS OF A DETACHMENT FAULT (MODIFIED FROM PIERCE, 1973)

appear to be the most reasonable mechanism for reducing friction along detachment faults.

The rootless discordant exotic blocks that occur throughout the Dog Springs volcanic complex can be explained by three separate hypotheses or a combination of three hypotheses. The first hypothesis is that they were rafted in by mudflows; the second hypothesis is that they were floated upwards and rafted laterally, either by tuff breccias or by the hornblende andesite breccias; and the third hypothesis is that they represent the transgressive portion of a detachment fault. Lack of sufficient outcrops makes it impossible to determine the true origin of these exotic blocks. Cather (1980) postulated a laramide highland to the south of the region which could have provided a source area for the limestone blocks. This, and the presence of exotic blocks within mudflow deposits suggests that the exotic blocks were brought in by mudflows from the south.

Genesis of the Dog Springs volcanic complex

Investigation of the Dog Springs volcanic complex began when initial reconnaissance of the area indicated that a thick sequence of relatively undescribed volcanic rocks was present in the region. This induced suspicions that an ash-flow tuff caldera, older than any previously recognized in the region, might exist in the area. Since work was initiated on the Dog Springs volcanic complex the following ideas for its´ origin have been proposed: 1)the Dog Springs volcanic complex represents the earliest ash-flow tuff caldera in the region; 2) the Dog Springs volcanic complex represents a dissected stratovolcano similar to those associated with the Conejos Formation of the San Juan volcanic field, and; 3) the Dog Springs volcanic complex is an intermediate-composition volcanic breccia complex similar to other such complexes located throughout the western United States.

Harrison (1980) reported similarities and differences between the Dog Springs volcanic complex and the current models for ash-flow tuff cauldrons. Similarities consisted of a discordant fault pattern, a thick accumulation of fragmental volcanic rocks, and a central location with respect to a proposed outflow sheet. Mapping in the study area and reconnaissance to the north and east of the study area support Harrison´s observations. However, these observations could also be explained by the presence of an intermediate-composition volcanic breccia complex.

Complications with interpreting the Dog Springs volcanic complex as a caldera include no conclusive documentation of collapse, very little vesicular material, and the lack of a well-defined structural or topographic margin (Harrison, 1980).

Lack of vesicular material in the Dog Springs volcanic complex seems to indicate that violent pyroclastic eruptions, which characterize ash-flow tuff volcanism, did not occur. In the San Juan Mountains of southwest Colorado sequences of intermediate-composition volcanic rocks that underlie the ash-flow tuffs capping the field have been interpreted as representing stratovolcanos (Lipman and others, 1972). Similar age and tectonic setting suggests that the Dog Springs volcanic complex might have had a similar origin; however, the general lack of a well-stratified sequence of interbedded lava flows, tuffs and breccias argues strongly against the stratovolcano model (Harrison, 1980).

Numerous intermediate-composition volcanic breccia fields of much larger volume, but similar to the Dog Springs volcanic complex, are scattered throughout the western United States. Such fields include the Tuscan and Mehrten Formations in California, the Absaroka

Supergroup in Wyoming, the basal portion of the Thirtynine Mile volcanic field in Colorado, and the Conejos Andesite of the San Juan volcanic field. Such fields are characterized by a vent facies surrounded by an alluvial facies (Parsons, 1969) and a complex transition zone between the two facies. Intermediate calc-alkaline magmatism characteristic of such complexes has been attributed to active subduction (Lipman and others, 1972). Lydon (1969) attributed emplacement of such breccia complexes to stratovolcanos, intrusive dike clusters and hidden sources. Chapin and Wyckoff (1968) have presented a model for brecciation and fluidization in the vents of widely scattered, small breccia cones in the Thirtynine Mile volcanic field. It is thought that the Dog Springs volcanic complex represents a small portion of an intermediate composition volcanic breccia field.

The Dog Springs volcanic complex consists primarily of three, lithologically distinct, breccias. These breccias are, the monolithic hornblende andesite breccias, the lower member tuff breccias and the upper member mudflow deposits. This suggests that several brecciation processes were active during formation of the Dog Springs volcanic complex. Numerous methods for formation of volcanic breccias have been proposed.

Parsons (1969) modified Wright and Bowes (1963) classification of volcanic breccias and cited various structural features, fragment characteristics and groundmass characteristics that may distinguish genetically different volcanic breccias. The criteria cited by Parsons have been employed in this report to try and determine the origin of the volcanic breccias in the Dog Springs volcanic complex.

The tuff breccias of the lower member are the most enigmatic of all the breccias in the study area. Structural features, fragment characteristics and groundmass characteristics are not indicative of a single origin. The tuff breccias may represent alloclastic breccia flows, laharic breccias, debris that accumulated on the flanks of fragmenting domes, or a combination of these processes.

Salient features of the tuff breccias, possibly indicative of their origin, have been summarized below.

1) The tuff breccias are nonsorted, show no internal stratification and have subangular to angular clasts as much as several meters in diameter.

2) The tuff breccias occur as flows several meters to tens of meters thick, which may show steep or chaotic bedding, and are rarely traceable for more than a few tens of meters in outcrop.

3) Locally individual flows are separated by an undulatory surface or a thin sedimentary parting.

4) Flows are completely brecciated.

5) The lower-portion of the lower member tuff breccias is nearly monolithic and consists of the tuff breccia of Martin Ranch, which is dominated by clasts of hornblende andesite.

6) The tuff breccia of Martin Ranch has xenoliths of Precambrian amphibolite, as well as exotic clasts of Pennsylvanian limestones and Permian sandstones and siltstones of the Abo Formation.

7) The tuff breccias above the tuff breccia of Martin Ranch are heterolithic and are dominated by clasts of biotite and hornblende andesite. These tuff breccias have exotic clasts of Permian sandstones and siltstones and Pennsylvanian limestones, but no xenoliths of Precambrian amphibolite.

8) Tuff breccia clasts are non-vesicular and porphyritic.

9) Groundmass in the tuff breccias is compositionally similar to the clasts and consists of lithic fragments, crystal fragments and interstitial cryptocrystalline material.

10) No glassy or vesicular material is present in the tuff breccias.

Many of the characteristics of alloclastic breccia flows, as described by Parsons (1969), are quite similar to the tuff breccias of the Dog Springs volcanic complex. These similarities have been summarized below.

1) Alloclastic breccia flows are unsorted, unstratified and have subrounded to angular clasts as much as 6 m in diameter.

2) Alloclastic breccia flows form beds as much as a hundred meters thick and may have steep initial dips near their source.

3) Alloclastic breccia flows are completely brecciated.

4) Alloclastic breccias are heterolithic; however, the main variations may be in texture, color, weathering characteristics, and type or percentage of phenocrysts present rather than gross compositional differences.

5) Clasts are dense and either porphyritic or aphanitic.

6) Pumice and scoria is usually absent.

7) Groundmass is fragmental material, compositionally similar to the clasts, and consists of lithic fragments, crystal fragments and interstitial microcrystalline material.

Clearly, numerous similarities exist between alloclastic breccia flows and the tuff breccias of the Dog Springs volcanic complex. However, two problems do exist with this interpretation. These problems are, the lack of a recognizable source area, and the exotic clast content.

Alloclastic breccias are formed by the subsurface brecciation of any pre-existing rock by volcanic processes (Wright and Bowes, 1963). When extruded, alloclastic breccias form breccia flows that without an identifiable source area are almost impossible to distinguish from some laharic breccias (Parsons, 1969). Fluidization of subsurface breccias may occur in vents, due to the infiltration of stored meteoric water (Chapin and Wyckoff, 1968), resulting in the eruption of alloclastic breccias as hot lahars. Alloclastic breccia flows may also become water saturated and transported as lahars once they are erupted. Clearly a source area is needed to determine if a volcanic breccia is alloclastic or not. Vents consist of small cone structures, which may locally have steep initial dips, (Parsons, 1969; Chapin and Wyckoff, 1968) and dikes (Durrell, 1944). Although no cone structures have been recognized, steep initial dips are common in the tuff breccias. Lopez (1975) and Bornhorst (1976) have both reported tuff breccia dikes southwest of the study area. However, reconnaissance to the east revealed an outcrop of tuff breccia, with interbedded sedimentary partings, that has near vertical beds overlain by moderately dipping beds of tuff breccia. This suggests that large-scale soft sediment deformation occurred during the deposition of the tuff breccias, and furthermore indicates that such a process may be responsible for steep dips and dike-like bodies observed in the tuff breccias. Chamberlin (1981, oral commun.) has observed similar soft sediment deformation and "pseudo" dikes to the west.

To understand the importance of exotic clasts when interpreting the tuff breccias as alloclastic breccia flows it is helpful to be aware of the numerous methods proposed for the formation of alloclastic breccias. Mechanisms of formation include gas explosion (Johnston and Lowell, 1961), rock burst (Gates, 1959), rock spalling (Curtis, 1954), forceful injection of magma into wall rock, and fragmentation and subsequent mobilization by fluidization (Parsons, 1969). All of these mechanisms, with the exception of rock spalling, are relatively violent and result in the mixing of igneous rock, responsible for the brecciation, and wall rock, presumably the exotic clasts, surrounding it. The nearly monolithic character of the tuff breccia of Martin Ranch suggests that a quiet process, as described by Curtis (1954), coupled with fluidization in the vent and subsequent eruption, as outlined by Chapin and Wyckoff (1968), may have been responsible for the formation of the lower portion of the lower member tuff breccias. In addition to wall rock included at the time of brecciation, clasts characteristic of the overlying rocks, which must be intruded for breccias to be extruded, should also be included as exotic clasts. Although there is a thick section of Mesozoic and Eocene sedimentary rocks overlying the Paleozoic section in the area no exotic clasts characteristic of this section have been observed. This argues against the tuff breccias being alloclastic breccia flows.

Laharic breccias also have numerous characteristics, which are summarized below following the criteria presented by Parsons (1969), that are similar to the lower member tuff breccias.

1) Laharic breccias are generally poorly sorted, generally lack internal bedding and may contain large blocks weighing several tons.

2) Laharic breccias occur in beds as much as a hundred meters thick and contain angular to rounded fragments.

3) Laharic breccias may have thin sedimentary partings.

4) Fragments are generally dense and heterolithic.

5) Groundmass is compositionally similar to the larger fragments, has a clastic texture and consists of angular to rounded lithic fragments, primary mineral grains and clay.

It should be noted that a complete gradation exists between alloclastic breccia flows, hot lahars, cold lahars, epiclastic volcanic breccias and volcaniclastic conglomerates (Parsons, 1969). This coupled with the fact that the composition of a laharic breccia is dependent on the material available at the time of transport and subsequent deposition, make for a wide variability in the character of laharic breccias. The above criteria are only gross generalizations that are true for some, but not all laharic breccias.

Interpreting the tuff breccias of the lower member as laharic breccias is an attractive idea, especially since laharic breccias may display a wide variety of characteristics other than those listed above. However numerous problems do exist with such an interpretation. Laharic breccias are usually interbedded with other rock types such as explosion breccias, tuffs and lava flows in the vent facies, and volcanic sandstones, conglomerates, air fall tuffs and/or lake beds in the alluvial facies of a volcanic field (Parsons, 1969).

Regional reconnaissance has failed to reveal any of these characteristics in the tuff breccias of the Dog Springs volcanic complex. Furthermore a suitable explanation for the existence of exotic clasts observed throughout the tuff breccias seems to be lacking. That is to say, if exotic clasts are incorporated into lahars during their formation and subsequent transportation it would follow that the supply of exotic clasts would be either exhausted or covered by the initial lahars and thus concentrated at the base of the volcanic pile; however, as stated, this is not observed. This point could be explained by a source area in canyons where Permian and Pennsylvanian strata is slumping off steep canyon walls.

Autoclastic breccias produced by the fragmentation of domes and spines share many characteristics of the lower member tuff breccias, especially the tuff breccia of Martin Ranch. These characteristics, as cited by Parsons (1969), are presented below.

1) Deposits are unsorted, usually unbedded, and thin rapidly away from source areas.

2) Clasts are monolithic, dense, holocrystalline or glassy, and are quite angular.

3) Groundmass consists of small fragments of material identical to the material it encloses.

4) Glass shards are not present.

This third hypothesis for the origin of the lower member tuff breccias is an attractive explanation for the formation of the tuff breccia of Martin Ranch, due to the almost monolithic character of this tuff breccia. However, unless mixing of debris shed off domes of slightly different composition ,perhaps due to remobilization by lahars, occurred it is hard to explain the heterolithic nature of the upper tuff breccias. Numerous other problems also exist with this interpretation. Precambrian amphibolites occur as xenoliths in the tuff breccia of Martin Ranch, but not in the overlying tuff breccias. This suggests that the magma chamber was rising and is consistent with the formation of a dome complex. However, the absence of any xenoliths of the Paleozoic, Mesozoic, or Cenozoic rocks that occur in the area argues against the magma chamber rising near to the surface and therefore argues against the formation of a widespread dome complex. Furthermore, Harrison (1980) pointed out that to form a volcanic complex with the volume of the Dog Springs, a large number of domes would be needed. Domes clearly contemporaneous with formation of the tuff breccias have not yet been recognized.

It should be stated that none of the models presented here explain all of the features of the lower member tuff breccias. It is possible that any number of variables were present during the formation of the tuff breccias and that several sets of variables could result in the observed characteristics of the tuff breccias. Therefore, without more data, it is impossible to formulate a single model for the formation of these breccias.

The monolithic hornblende andesite breccias and mudflow deposits that make up the remainder of the breccias in the Dog Springs volcanic complex are much simpler to interpret. The monolithic hornblende andesite breccias are autoclastic breccias and the mudflow deposits are the result of mudflows.

Autoclastic volcanic breccias, or friction breccias, form by autobrecciation of dikes, flows, domes or spines. Autobrecciated flows are monolithic, and show no sorting or small-scale bedding. Autobrecciated flows may have a nonbrecciated core and consist of angular fragments, which may be quite scoriaceous, in a groundmass of similar composition

(Parsons, 1969). Autoclastic breccias which form from the fragmentation of domes or spines are unsorted, unstratified, contain no glass shards, are monolithic, dense, may be glassy or holocrystalline, and may contain microvesicles (Parsons, 1969). The monolithic breccias of the upper member are interpreted as being autoclastic volcanic breccias. They are monolithic, devoid of glass shards, dense, angular and have a groundmass of composition similar to the clasts. Monolithic upper member volcanic breccias occur as dikes, flows, exotic blocks and possibly domes.

The autoclastic volcanic breccias are present as both intrusive and extrusive rocks in the study area and therefore define a vent facies. Formation of autoclastic breccias has been attributed to several different mechanisms. Wright and Bowes (1963) suggested that such breccias form by explosive fragmentation of semi-solid or solid lava due to the release of gases contained in the lava, or by further movement of lava after it has partially congealed. Curtis (1954) discussed a method by which microvesiculation, dilation forming low pressure areas, and subsequent rock spalling into void spaces resulted in the subsurface formation of autoclastic volcanic breccias. Changes in slope (Thompson and others, 1965) and flows moving over ice or snow (Fiske and others, 1963) are also thought to result in autoclastic volcanic breccias. Since underground brecciation is known to have occurred and since no evidence of explosive activity is present, a mechanism of formation similar to that described by Curtis (1954) is preferred.

The mudflow deposits of the upper member of the Dog Springs volcanic complex are characterized by crude graded bedding, sedimentary partings, localization in troughs, poor sorting, clasts as much as several hundred meters in diameter, a heterolithic assemblage of angular to subrounded clasts, clasts in several different stages of weathering, and a lack of pumice and vesicular material. These characteristics indicate that the deposits were water-laid. Furthermore, the mixture of very large clasts with very small clasts indicates these deposits are the result of mudflows.

Mudflows occur when volcanic debris become mixed with sufficient water to flow downslope. Saturation may be caused by catastrophic release of water from a crater lake or other impoundment, by eruption through a lake, by heavy rainfall, by rapid melting of snow (Anderson, 1933) or by infiltration of water into a vent (Chapin and Wyckoff, 1968). Mudflows may also result from flow breccias or pyroclastic flows intersecting active drainages.

Volcaniclastic Rocks of Chavez Canyon

The volcaniclastic rocks of Chavez Canyon is an informal name proposed here for a sequence of interbedded sandstones and conglomerates of Oligocene age, derived by the erosion of volcanic terrain, which occur stratigraphically above the Dog Springs volcanic complex and below the tuff of Rock House Canyon. The unit is named for exposures at Chavez Canyon located in the north central portion of the study area (Secs.27 and 34, T.2N., R.8W.). The unit can be divided into upper and lower members but due to lack of exposure has been mapped as a single unit. The upper member is equivalent to the lower sedimentary unit of Lopez (1975), and the first volcanic sedimentary unit of Bornhorst (1976). The lower member is correlative to the feldspathic sandstone member of Lopez (1975) and Bornhorst (1976) and the conglomerate and sandstone member of Bornhorst (1976). Bornhorst (1976) correlated the the unit to the lower and middle sedimentary units of Rhodes and Smith (1976) and to Tdvsl of Stearns (1962). However, Rhodes and Smith reported only upper and lower sedimentary units so there seems to be some confusion in Bornhorst's statement. Bornhorst postulated that the unit represents the distal alluvial facies of the sedimentary rocks described by Rhodes and Smith southwest of the study area in the Tularosa Mountains. Paleocurrent data for the lower member indicates a north to northwest transport direction (fig.22) and thus could support Bornhorst's hypothesis. This is not true for the upper member which exhibits a northwest transport direction (fig.23).

The volcaniclastic rocks of Chavez Canyon is an extensive unit of regional importance. The unit is well documented as far north as Chavez and Middle Canyons (Secs.26, 27, and 28, T.2N, R.8W.) and as far east as Long Canyon (Sec.13, T.1N., R.8W.) (this report). Correlation of the unit to the lower sedimentary unit of Rhodes and Smith as suggested by Bornhorst (1976) places the western and southern limits of the unit at Wagon Tongue Mountain (Secs.19, 20 and 21, T.5S., R.16W.). Reconnaissance to the east has revealed a 152 m thick section of the volcaniclastic rocks of Chavez Canyon in the central Gallinas Mountains (Sec.14, T.1N., R.7W.).

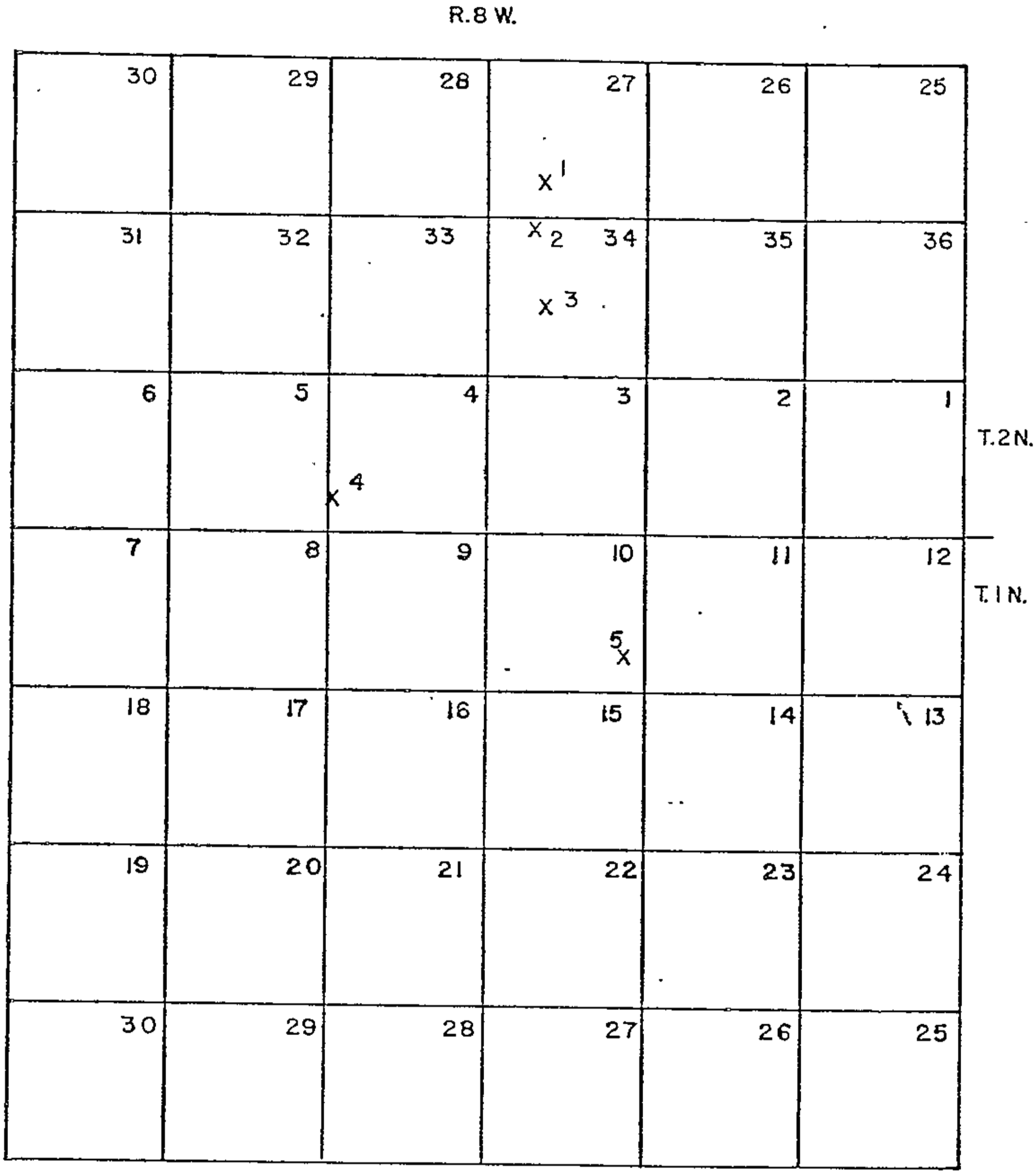


FIGURE 21. DIAGRAM SHOWING THE LOCATION OF PALEOCURRENT DATA

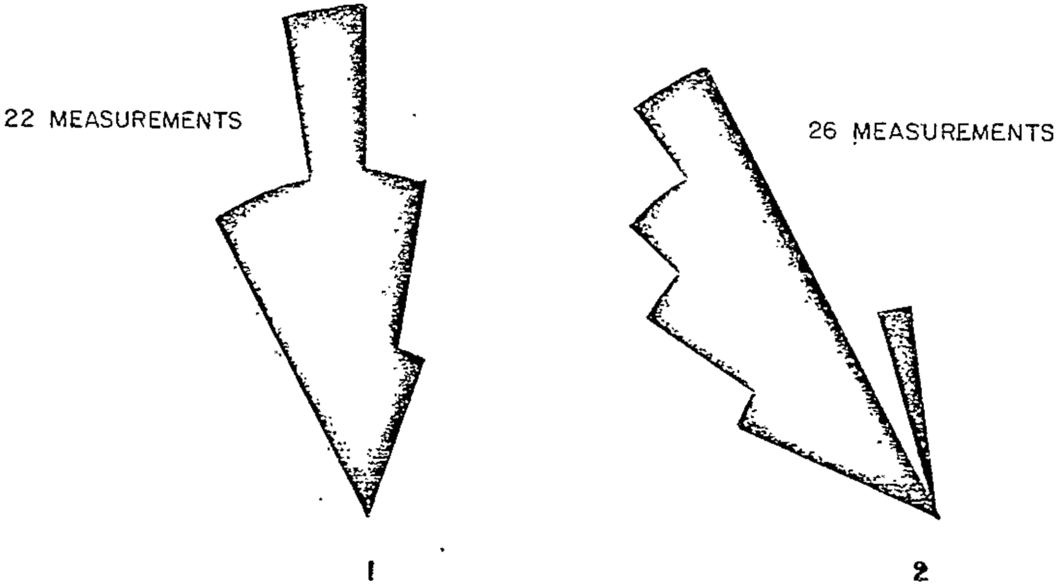


FIGURE 22. ROSE DIAGRAMS OF PALEOCURRENT DIRECTIONS FROM THE LOWER MEMBER OF THE VOLCANICLASTIC ROCKS OF CHAVEZ CANYON

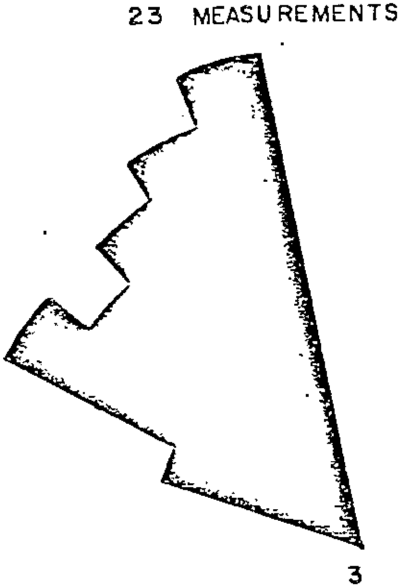


FIGURE 23. ROSE DIAGRAM OF PALEOCURRENT DIRECTIONS FROM THE UPPER MEMBER OF THE VOLCANICLASTIC ROCKS OF CHAVEZ CANYON

The volcaniclastic rocks of Chavez Canyon crop out as steep slopes and as small ledges in canyon floors throughout the northern portion of the study area. More commonly, the unit forms steep colluvium covered slopes on which outcrop is obscured by several meters of cover. The unit forms two east-trending outcrop belts across the northern portion of the study area and covers approximately 7.8 square kilometers of the study area. The unit varies in thickness from 75 m to 160 m. The observed variations in thickness are on the up and down sides, respectively, of the Chavez Well-Thompson Canyon fault and may date the earliest movement along the fault.

The volcaniclastic rocks of Chavez Canyon unconformably overlie the Dog Springs volcanic complex (Harrison, 1980). Nowhere in the study area is the basal contact of the unit exposed; however, attitudes indicate that the contact is an angular unconformity. Locally the contact appears to be gradational. The tuff of Rock House Canyon conformably overlies the unit.

Lower Member

The lower member of the volcaniclastic rocks of Chavez Canyon consists of subequal amounts of sandstones, which display minor shale partings, and conglomerates (fig.24). Paleocurrent data for the member indicates a source area to the southeast of the study area for the lower portion of the member and a source area to the south for the upper portion of the member. The lower member varies in thickness between approximately 45 m and 140 m.

Conglomerates vary in color from light gray (N7) to light brownish gray (5YR 6/1) when fresh to a moderate yellowish brown or light olive gray (5Y 6/1) when weathered. Conglomerates are poorly to moderately sorted and display clast sizes ranging from very fine sand to boulder-size on the Wentworth Scale. Granule to boulder-sized clast lithology is dominated by subrounded to subangular clasts of andesite accompanied by a subordinate amount of tuffaceous clasts similar to the clasts in the underlying tuff breccias and mudflow deposits of the Dog Springs volcanic complex. Rounded to subrounded, granule to boulder-sized, tuffaceous clasts are usually fresh; however, some of the groundmass in the larger clasts has been altered to a

Figure 24. Photograph of typical outcrop in the lower member of the volcaniclastic rocks of Chavez Canyon.

yellow-ochre clay. Granule to boulder-sized clasts account for 30 to 50 percent of the rock volume in these poorly to moderately indurated matrix-supported conglomerates. Very poorly to poorly sorted (Compton, 1953), sand-sized matrix accounts for 50 to 70 percent of the rock volume. Matrix consists of angular to subangular grains of lithic fragments, tuffaceous debris, feldspar, quartz, amphibole, biotite, and magnetite. Lithic fragments in the matrix are predominately tuffaceous clasts with a subordinate amount of andesite clasts.

Conglomerates display numerous sedimentary structures such as poorly developed pebble imbrications and cut-and-fill structures into underlying sandstones. Conglomerates are localized in trough-shaped lenses which may have poorly developed graded bedding. Clast size and overall abundance of conglomerates decrease upward in the lower member.

Sandstones vary in color from light gray (N7) when fresh to greenish gray (5GY 6/1) when weathered. Sandstones consist of tuffaceous debris, feldspar, lithic fragments, quartz, hornblende, biotite, and magnetite. Lithic fragments consist of tuffaceous clasts and andesites. Pumice is observed occasionally.

Grains are subrounded to angular and vary in size from very fine sand to very coarse sand on the Wentworth Scale. Sorting varies between individual beds from poor to moderate with finer grained beds displaying a greater degree of sorting. Flat or elongate minerals such as biotite and amphibole are commonly arranged with their long dimension parallel to bedding planes, and sometimes localized in mafic-rich layers. Sandstones vary from poor to well-indurated.

Sandstones of the lower member display numerous sedimentary structures which aided in paleocurrent determinations. Low angle sets of medium-scale, tabular-shaped, planar cross-stratification and wedge-shaped, trough cross-stratification (McKee and Weir, 1953) are common throughout the central portion of the member. Flute casts, parting lineations, and elongate mafic-rich lenses are common along bedding surfaces. Thickness of individual beds ranges from thinly cross-laminated to thinly cross-bedded (McKee and Weir, 1953) and display a direct relationship to grain size. Graded sandstones occasionally display thinly laminated shales at their tops. Shales exhibit ripple marks and mud cracks, which have been preserved in some cases by infilling with sand.

Upper Member

The upper member of the volcaniclastic rocks of Chavez Canyon consist of sandstones and conglomerates (fig.25). The upper member is similar to the lower member but can be distinguished from it by its' yellowish brown color, generally coarser grain size and stratigraphic position. Paleocurrent data indicates a source area to the southeast of the study area for the upper member. The upper member varies in thickness from 24 m to 37 m and overlies the lower member along an erosional surface that is locally unconformable (fig.26).

Conglomerates are the major rock type present in the upper member. Conglomerates range in color from light brown (5YR 6/4) when fresh to pale yellowish brown (10YR 6/2) when weathered. Conglomerates exhibit poor to moderate sorting and clast sizes ranging from fine sand to boulder on the Wentworth Scale. Granule to boulder-sized clasts consist of about 85 percent andesite fragments and about 15 percent tuffaceous fragments, both of which resemble rocks in the underlying Dog Springs volcanic complex. Granule to boulder-sized clasts account for 10 to 60 percent of the rock volume. Conglomerates exhibit poor to

Figure 25. Photograph of typical outcrop of the upper member of the volcaniclastic rocks of Chavez Canyon.

Figure 26. Photograph of local unconformity between the upper and lower members of the volcaniclastic rocks of Chavez Canyon.

moderate induration and are matrix supported. Pebble imbrications are better developed in the upper member than in the lower member. The matrix is composed of lithic fragments, tuffaceous material, feldspar, quartz and minor mafic minerals. Grains are subangular to rounded and vary in size from fine sand to very coarse sand on the Wentworth Scale. Conglomerates display trough cross-stratification and cut-and-fill structures.

Sandstones in the upper member vary in color from light brown (5YR 6/4) when fresh to pale yellowish brown (10YR 6/2) when weathered. Sandstones are composed of lithic fragments (similar to those in the conglomerates), tuffaceous debris, feldspar, quartz, and minor mafic minerals. Grains range in size from very fine sand to very coarse sand on the Wentworth Scale. Grains are randomly arranged and vary from subangular to rounded. Sandstones are poorly to moderately indurated, and exhibit poorly developed parting lineations. Sandstone beds are thinly cross-stratified and display medium-scale trough cross-stratification.

Interpretation

The upper and lower members of the volcaniclastic rocks of Chavez Canyon share a number of features that are indicative of their depositional environment. Both members display an overall fining-upwards sequence and paleocurrent data indicates that both members were deposited by low sinuosity streams. Both members consist of subrounded to angular grains and clasts which can be interpreted as locally derived first-cycle sediments. Both members show extreme lateral and vertical variations in grain size and angularity. Both members display trough cross-stratification and cut-and-fill structures. In addition, the lower member exhibits shale partings, mud cracks, ripple marks, and increased sorting as grain size decreases. Shelly (1978, p.41) indicated that low sinuosity is characteristic of braided streams. Reineck and Singh (1975) indicated that cut-and-fill structures and fining-upward trends are characteristic of braided stream environments. Furthermore Reineck and Singh indicated that the top of local fining upward sequences are commonly occupied by horizontal layers of mud or fine sand, which may exhibit mud cracks, similar to that observed in the lower member, and that these finer grained sediments are less common in mountainous (high gradient) streams. Matthews (1971, p.140) discussed the extreme variation in grain sizes present in braided streams and the large degree of local variability in grain size distribution exhibited by braided streams. Matthews also stated that medium to fine-grained sands commonly exhibit better sorting than coarser grained sediments, as observed in the lower member. Therefore it is concluded that the environment present was that of braided streams of moderate to steep gradient.

tuff of Rock House Canyon

The tuff of Rock House Canyon is a moderately to poorly welded, crystal-poor, latitic to quartz latitic, ash-flow tuff which separates the upper and lower portions of the Spears Formation. The unit was named by Chapin and others (in prep) for exposures at Rock House Canyon, located in the central portion of the study area (Secs.3, 4, 10, 11, 12 and 13, T.1N., R.8W). The tuff of Rock House Canyon is correlative to the the tuff of Main Canyon (Lopez, 1975; Bornhorst, 1976 and Harrison, 1980), the tuff of Nipple Mountain (Brown, 1972; Chamberlin, 1974; Wilkinson, 1976; and Laroche, 1980) and to Tdhl (Givens, 1957). Chamberlin redefined Brown's tuff of Nipple Mountain to include

" turkey track " andesites commonly found at the base of the unit. Chamberlin reasoned that the common association of andesite lava flows at the base of the unit and the interbedding of andesite lava flows within the tuff called for such a definition. Wilkinson reported similar stratigraphic relationships and adopted Chamberlin's definition. No interbedded andesites have been observed in the tuff of Rock House Canyon in the study area. No date or source has been reported for the unit, however the unit is currently bracketed between the 37.5 m.y. B.P. date for volcaniclastic rocks of the Spears Formation and the 33 m.y. B.P. date for the Hells Mesa Tuff. A sample was collected for K-Ar dating of sanidine, but the results are not yet available.

The tuff of Rock House Canyon is an extensive ash-flow sheet which provides the only good stratigraphic marker between the upper and lower portions of the Spears Formation. It has been mapped as far north as Chavez Canyon (Sec.34, T.2N., R.8W.) (this report), as far south as East Sugarloaf Mountain (Sec.4, T.2S., R10W.) (Bornhorst, 1976), as far west as Rene Spring (Sec.2, T.2S., R.11W.) (Bornhorst, 1976) and as far east as Nipple Mountain (Sec.1, T.2S., R.4W.) (Brown, 1972). Within the study area, the tuff is a multiple-flow simple cooling unit. Chamberlin (1974) and Wilkinson (1976) reported that the unit was

> "a multiple-flow compound cooling unit with cooling breaks occupied by thin andesitic to latitic flows." (Wilkinson, 1976, p.28).

The tuff of Rock House Canyon crops out as pervasively jointed cliffs, isolated outcrops (fig.27) and south-facing dip slopes throughout the study area. The unit forms a nearly continuous, 1.2 kilometer wide, northwest-trending band of outcrops across the central portion of the study area, and a much narrower, discontinuous, east-trending band of outcrops across the northern portion of the study area, where it has been preserved on the down side of the Chavez Well-Thompson Canyon fault. The unit covers approximately 7.8 square kilometers of the study area. The unit varies in thickness between 50 m and 80 m. The observed variation can be explained by an interaction of paleotopography at the time of deposition and erosion immediately following deposition. An anomalous thickness of 190 m is present in the central portion of Rock House Canyon. This can be explained by a paleovalley or the presence of a northwest-trending fault with down-to-the-north

Figure 27. Photograph of pervasively jointed outcrop of the tuff of Rock House Canyon.

displacement of approximately 60 m, similar to one thought to cut through the overlying middle volcaniclastic rocks directly to the south. Reported thicknesses of 122 m to the east of the study area (Chamberlin, 1974) and 0 m to the west of the study area (Bornhorst, 1976) indicate that the unit thickens to the east and thins to the west.

The tuff of Rock House Canyon overlies, with local unconformity, sandstones and conglomerates of the upper member of the volcaniclastic rocks of Chavez Canyon. This lower contact is exposed on hill 7787 ft (Sec.25, T.2N., R.8W.). The tuff of Rock House Canyon underlies the sandstones and conglomerates of the middle volcaniclastic rocks. The upper contact of the tuff of Rock House Canyon is not exposed anywhere in the study area. Harrison (1980) reported that the upper contact is gradational with the overlying sedimentary rocks.

Poorly welded hand specimens of the tuff of Rock House Canyon vary in color from light brownish gray (5YR 6/1) when fresh to light yellowish gray (5Y 8/1) when weathered. Moderately welded hand specimens vary in color from medium light gray (N7) when fresh to light brownish gray (5YR 6/1) when weathered. Undeformed pumice as much as 3 cm long is common in poorly welded specimens as is mildly deformed, elongate pumice in more densely welded specimens.

In thin sections, the tuff of Rock House Canyon is porphyritic and glomeroporphyritic. Phenocrysts account for 3 to 4 percent of the rock volume and vary in length from 0.3 mm to 2.0 mm. Phenocrysts, in decreasing order of abundance, are plagioclase, sanidine, magnetite, and biotite. The groundmass consists of glass shards, devitrification products, and fine opaque dust. Lithic fragments are present, but generally account for less than 1 percent of the rock volume.

Plagioclase accounts for 2 to 3 percent of the rock volume and occurs as single and composite grains. Anhedral to subhedral plagioclase phenocrysts are 1.3 mm in maximum length and display sharp, corroded and embayed margins. Plagioclase exhibits albite, carlsbad and pericline twinning. Normal and oscillatory zoning are both present in plagioclase phenocrysts.

Anorthite content was determined for 4 grains (Rittman Zone Method) and yielded an average anorthite content of An20 (oligoclase) with very little deviation from the mean. Subhedral to euhedral phenocrysts of sanidine occur as single grains as much as 2.0 mm in length and account for 1 to 2 percent of the rock by volume. Sanidine displays carlsbad twinning and may have either sharp, corroded, or embayed margins. Trace amounts (less than one percent) of anhedral to euhedral opaque material, thought to be magnetite, display a cubic form and a maximum length of 0.4 mm. Subhedral laths of biotite are present in trace amounts and exhibit pleochroic colors ranging from dark brown to dark reddish-brown.

Groundmass, pumice fragments, and lithic fragments account for the remaining 97 to 98 percent of the rock volume. Dark reddish-brown and light-green lithic fragments are rounded and aphanitic but appear to be of igneous origin. Pumice fragments have been replaced by aggregates of low birefringent minerals and may form axiolitic textures. The remainder of the rock is composed of mildly deformed or undeformed glass shards, and opaque dust which imparts a greenish to yellowish-brown color to the groundmass. Glass shards are partially devitrified and commonly exhibit axiolitic textures. Glass shards are deformed around lithic fragments and phenocrysts. Poorly developed spherulites are also present. Approximately 1 percent of the rock volume near the top of the unit is composed of quartz which occurs as anhedral, monocrystalline and polycrystalline blebs in the center of glass bubbles.

middle volcaniclastic rocks

The middle volcaniclastic rocks are a sequence of Oligocene fluviatile sandstones and conglomerates which occur above the tuff of Rock House Canyon and below the Hells Mesa Tuff. The unit contains both aeolian and fluviatile sediments. The unit can be divided into upper and lower members when the tuff of Blue Canyon is present; however, in the study area the tuff of Blue Canyon crops out as a discontinuous belt and therefore both members have been mapped as a single unit. The unit is equivalent to Tdh2 and Tdh3 of Givens (1957), the second and third volcaniclastic sedimentary units of Bornhorst (1976), the middle and upper volcaniclastic sedimentary units of Lopez (1975) and the middle sedimentary unit of Harrison (1980). Paleocurrent data for the unit indicates a north-to-northwest transport direction for both members (fig.28). This does not agree with the observations of Bornhorst (1976) who reported a southeast transport direction for the lower portion of the unit near Sugarloaf Mountain (Sec.21, T.2S., R.11W.), or with

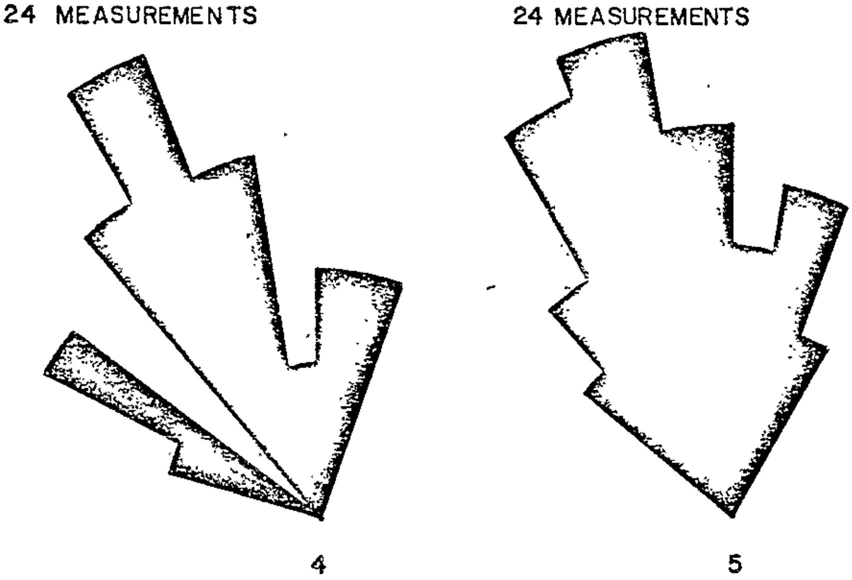


FIGURE 28. ROSE DIAGRAM OF PALEOCURRENT DIRECTIONS FROM THE MIDDLE VOLCANICLASTIC ROCKS

data presented by Harrison (1980) which indicated a northeast transport direction for the unit.

The middle volcaniclastic rocks have been mapped over a regional extent of approximately 50 kilometers. The unit crops out as far west as Flying V Draw (Sec.5, T.2S., R.11W.)(Bornhorst, 1976), as far east as Long Canyon (Sec.18, T.1N., R.7W.)(this report, and Givens, 1957), as far north as Thompson Canyon (Sec.36, T.2N. R.9W.)(Harrison, 1980) and as far south as Sugarloaf Mountain (Bornhorst, 1976). Reconnaissance has revealed exposures of the unit as far east as the central Gallinas Mountains (Sec.14, T.1N., R8W.).

The middle volcaniclastic rocks form steep obsequent slopes and highly dissected south-facing dip slopes. The unit forms a discontinuous, northwest trending outcrop belt across the central portion of the study area and covers approximately 3.9 square kilometers of the study area. The unit reaches a maximum thickness of 170 m along the western margin of the study area and thins eastward to 60 m along the eastern margin of the study area. Givens (1957) map of the Dog Springs 15-minute quadrangle shows the unit pinching out to the east of the study area, however reconnaissance has revealed that the unit extends farther east than Givens mapped it. Minor sandstones and conglomerates have been reported in the same stratigraphic interval to the east of the study area (Chamberlin, 1974 and Wilkinson, 1976), however they are not the dominant lithology. To the west of the study area, thicknesses between 120 m and 150 m have been reported (Lopez, 1975; Bornhorst, 1976 and Harrison, 1980). An anomalous thickness in excess of 300 m is indicated by cross sections constructed through the southern portion of Rock House Canyon. This can be explained by a northwest-trending, high-angle fault with approximately 120 m of down-to-the-north displacement or the presence of a paleovalley. No definite evidence for either explanation exists; however, since the unit represents a constructional depositional sequence the existence of a fault is favored.

The middle volcaniclastic rocks conformably overlie the tuff of Rock House Canyon. The unit unconformably underlies the Hells Mesa Tuff, the volcaniclastic rocks of South Crosby Peak and the A-L Peak Tuff. These relationships are due to several deep paleovalleys formed along an erosional surface present between the Hells Mesa Tuff and the A-L Peak Tuff. A more detailed discussion of this surface is presented in the section on the Hells Mesa Tuff. The erosional surface has been documented by several studies in the region (Wilkinson, 1976; Harrison, 1980 and this report).

Conglomerates are the dominant lithology in the lower portion of the unit; they become less common, but are still present, up section. Light-brown to buff-colored conglomerates exhibit moderate to poor sorting of clasts ranging in size from boulder to very fine sand on the Wentworth scale. Granule to boulder-sized clasts are dominantly andesites with a subordinate amount of locally derived tuffs. Granule to boulder-sized clasts were derived from the interbedded tuff of Blue Canyon, the underlying tuff of Rock House Canyon and the Dog Springs volcanic complex. Cobble-sized clasts of limestone have occasionally been noted towards the base of the unit. Granule to boulder-sized clasts account for 15 to 50 percent of the rock by volume in these poorly to moderately indurated matrix-supported conglomerates. Matrix is composed of sand and silt-sized tuffaceous debris, lithic fragments, feldspar, quartz, biotite, and magnetite. Subangular to subrounded grains of matrix vary in size from very fine sand to very coarse sand on the Wentworth scale. Conglomerates have well-developed pebble imbrications, cut-and-fill structures, trough and planar cross-stratification, and poorly developed graded bedding.

Light-brown to buff-colored sandstones range in size from very coarse sand to very fine sand on the Wentworth scale and become more common towards the top of the unit in this fining-upwards sequence. Sandstones are composed of subrounded to angular grains of feldspar, quartz, biotite, magnetite,lithic fragments and interstitial tuffaceous debris. Tuffaceous debris is especially common directly above the tuff of Blue Canyon where the unit is composed almost entirely of reworked detritus from the tuff. Sandstones are poorly to moderately sorted and range from poorly to moderately indurated. Flute marks, cut-and-fill structures, trough and planar cross-stratification and alignment of elongate minerals parallel to bedding planes are all present in sandstones of the unit (fig.29).

Throughout the unit, sandstones and conglomerates show evidence of a fluviatile origin similar to the underlying volcaniclastic rocks of Chavez Canyon. Moreover, with the exception of the presence of lithic fragments of younger rocks the unit strongly resembles

Figure 29. Photograph of a typical outcrop of the middle volcaniclastic rocks. Compare to photograph of the upper member of the volcaniclastic rocks of Chavez Canyon (fig. 29).

Figure 30. Photograph of steeply dipping cross-stratified sandstones, interpreted as dunes, near the top of the middle volcaniclastic rocks.

the upper member of the volcaniclastic rocks of Chavez Canyon, and paleocurrent data indicates a similar source area. Unlike the underlying volcaniclastic rocks of Chavez Canyon, the unit occasionally has steeply dipping cross bedded sandstones near its' top that have been interpreted as dunes (fig.30). Occurrences of similar aeolian sandstones near the top of the unit are regionally extensive and have been documented to the west of the study area by Harrison (1980) and Bornhorst (1976). Therefore it is thought that the middle volcaniclastic rocks represent a continuation of the depositional cycle initiated with the deposition of the upper member of the volcaniclastic rocks of Chavez Canyon. This cycle continued until the deposition of the Hells Mesa Tuff, with only momentary interruptions during the deposition of the tuff of Rock House Canyon and the tuff of Blue Canyon. Furthermore it is postulated from the occurrence of dunes, the style of sedimentation and the total absence of organic debris that deposition occurred in an arid to semiarid environment.

Tuff of Blue Canyon

The tuff of Blue Canyon is a moderately to poorly welded, crystal-rich, latitic, ash-flow tuff in the upper portion of the Spears Group. The tuff of Blue Canyon was named by Lopez (1975) for exposures at Blue Canyon (Sec.1, T.1S., R.10W.), located 10 km southwest of the study area. The unit is equivalent to the lower portions of Givens' (1957) Tdh3, portions of Stearns' (1962) Tdrpl and Tst2 of Mayerson (1979. Bikerman (1976) reported a K-Ar date of 32.0 +/- 2 m.y. B.P. for an ash-flow tuff located in the south Crosby Mountains (Sec.36, T.4S., R14W.). Bornhorst (1976) indicated that the sample dated was from the Tuff-Breccia of Horse Springs that directly overlies the tuff of Blue Canyon at that location. No definite source for the unit has been determined. Lopez (1975) postulated a source for the unit somewhere to the northeast of his study area. However, Bornhorst (1976), working with an expanded data base, indicated that the source of the unit was to the south of his study area. Field mapping of the area northeast of Lopez (this report and Harrison, 1980) has revealed no source for the unit; therefore, a source to the south as postulated by Bornhorst is favored by this writer.

The tuff of Blue Canyon has been mapped as far east as Jaralosa Canyon (Mayerson, 1979), as far west as Horse Springs (Bornhorst, 1976) as far north as the head of Rock House Canyon (this report) and as far south as Horse Springs (Bornhorst, 1976). A unit similar to the tuff of Blue Canyon has been reported in the Joyita Hills by Spradlin (1973), but has yet to be satisfactorily correlated to the tuff of Blue Canyon. To the east of the study area, in the same stratigraphic interval, Chamberlin (1974) and Wilkinson (1976) have described the tuff of Granite Mountain and upper Spears crystal-rich latite tuffs, respectively. These units display higher phenocryst contents and lower sanidine to plagioclase ratios than the tuff of Blue Canyon, but are otherwise petrographically similar. In the study area, the tuff of Blue Canyon is a simple cooling unit.

The tuff of Blue Canyon crops out as a thin ledge former when an overlying unit is present and as south-facing dip slopes when no overlying unit is present. The unit weathers to rounded, joint-bound blocks. The unit forms a northwest-trending, discontinuous, outcrop pattern across the central portion of the study area and covers about 2.6 square kilometers of the study area. The discontinuous outcrop pattern is caused by erosion, alluvial cover and the localizing of the unit in broad, shallow paleodepressions at the time of deposition. The unit varies in thickness from 0 to 10 m and thins eastward. Reported thicknesses of 24 m (Harrison, oral commun., 1980) and 46 m (Bornhorst, 1976) indicates that the unit thickens westward.

The tuff of Blue Canyon overlies with local unconformity the sandstones and conglomerates of the middle volcaniclastic rocks (fig.31). This contact can best be observed near the head of Rock House Canyon where the tuff of Blue Canyon is localized in a palaeochannel. The tuff of Blue Canyon conformably underlies the upper portions of the middle volcaniclastic rocks.

In hand specimen, the tuff of Blue Canyon varies in color from pinkish gray (5YR 8/1) when fresh to pale yellowish brown (10YR 6/2) when weathered. The unit is usually poorly welded which makes attitude determinations difficult. Phenocrysts of plagioclase, sanidine and biotite account for approximately 20 percent of the rock volume. Conspicuous black or copper-colored hexagonal plates of biotite and the units characteristic phenocryst content make the tuff

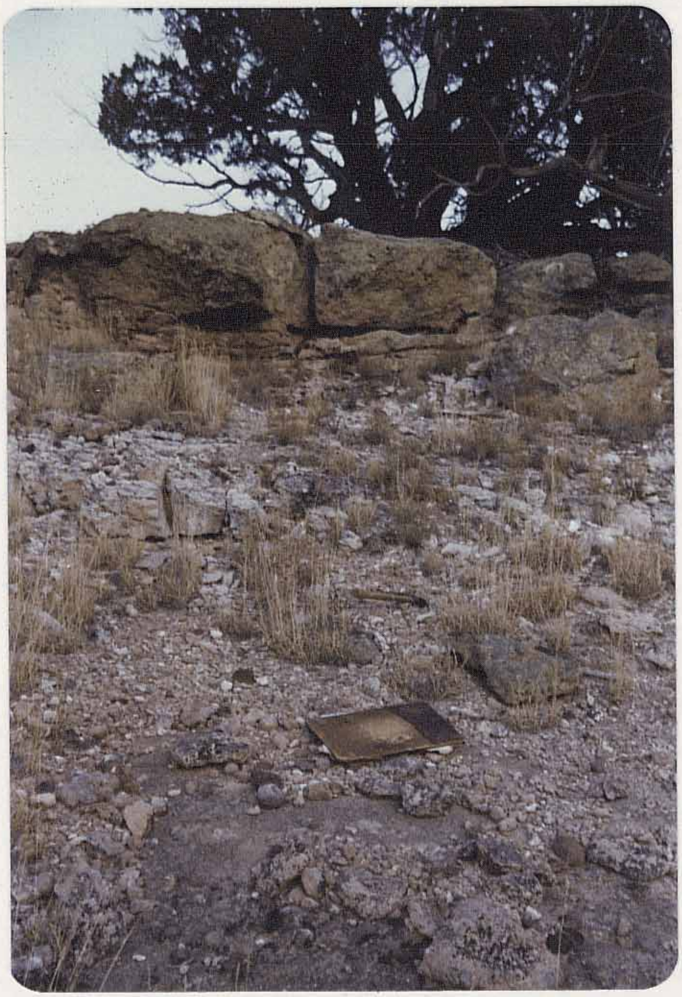


Figure 31. Photograph of the basal contact of the tuff of Blue Canyon.

of Blue Canyon easy to recognize in the field. Brownish gray (5YR 4/1) subangular to subrounded aphanitic lithic fragments ranging in size from fine sand to cobble on the Wentworth Scale account for as much as 3 percent of the rock volume. Slightly elongate pumice fragments, cavities formed by pumice fragments that have subsequently been removed by weathering, and other cavities, which may be gas cavities, comprise from 1 to 10 percent of the rock volume. The cavities and pumice fragments range in length from 2.0 mm to 25.0 mm and display a long to short dimension ratio of about 10:1. Cavities commonly contain tiny white crystals, possibly quartz and feldspar, growing inward from their margins. Pumice fragments are generally smaller than the cavities.

Petrographically, the tuff of Blue Canyon is porphyritic and possesses, in decreasing order of abundance, phenocrysts of plagioclase, sanidine, biotite, clinopyroxene, and hornblende. Phenocrysts account for 15 to 20 percent of the rock volume and range in size from 0.3 mm to 4.0 mm in length. The groundmass consists of mildly deformed glass shards, glass, poorly developed devitrification products, and crystal fragments. Lithic fragments are locally abundant and minor amounts of vapor phase minerals are also present (Table 1).

Subhedral to euhedral laths of plagioclase from 0.3 mm to 4.0 mm in length are the most abundant phenocryst. Plagioclase accounts for 7 to 12.5 percent of the rock volume. Plagioclase crystals are normally zoned, commonly with the more calcium-rich cores removed, and pervasively fractured. Albite and carlsbad twinning is common, as is rounded corners. Anorthite content was determined for 22 grains (Rittman Zone Method) and ranged from An42, for calcium-rich cores, to An28, for grain margins. An average anorthite content of An33 indicates that the plagioclase is andesine. Euhedral crystals of apatite, oriented both randomly and with their long dimension oriented parallel to cleavage directions, are common inclusions in plagioclase phenocrysts.

Subhedral sanidine accounts for 5.5 to 7.5 percent of the rock volume. Sanidine ranges in length from 0.3 mm to 2.5 mm and commonly exhibits carlsbad twinning. It occurs as equant and elongate grains with rounded edges and occasional embayments. Subhedral to euhedral, irregularly embayed, laths of biotite account for 2 percent of the rock volume. Biotite ranges from

Table 1. Modal analyses in volume percent of the tuff of Blue Canyon

	BC-1	BC-2	BC-3	BC-4
Total Phenocrysts	15.0	19.1	21.9	16.1
Plagioclase	7.4	10.9	12.5	7.3
(An%)	(34)	(34)	(33)	(32)
Sanidine	5.5	6.2	7.5	6.0
Biotite	2.0	1.4	1.5	1.8
Opaques	0.1	0.3	0.2	0.6
Clinopyroxene	0.0	0.3	0.3	0.3
Quartz	0.0	0.0	0.0	0.1
Lithics	0.3	1.2	0.1	3.4
Points Counted	2000	2000	2000	2000
Sanidine/Plagioclase	0.7	0.6	0.6	0.8

0.5 mm to 3.0 mm in length, is pleochroic and ranges in color from reddish brown to dark brown. Biotite is altered to opaque iron oxides around the margins. Rounded, subhedral to euhedral phenocrysts of clinopyroxene, probably augite, are present in trace amounts (less than 1%) and vary in length from 0.3 mm to 1.5 mm. Clinopyroxene sometimes occurs in composite grains with opaque material and plagioclase. This association may indicate that the clinopyroxene is derived from the lithic fragments. Trace amounts of pleochroic, subhedral, hornblende phenocrysts ranging in color from greenish yellow to reddish brown are also present. Hornblende is 0.5 mm in maximum length and is altered to iron oxides around the margins. Minor amounts of low-birefringent minerals, probably quartz and alkali feldspar line cavities in the upper portion of the unit and may represent vapor phase minerals.

Groundmass and lithic fragments account for the remaining 80 to 85 percent of the rock volume. The brown groundmass is composed of glass, glass shards, poorly developed low birefringent devitrification products and crystal fragments. Glass shards are well preserved and are commonly wrapped around phenocrysts and lithic fragments. Lithic fragments account for as much as 3 percent of the rock volume. Lithic fragments have an aphanitic groundmass of plagioclase, opaque dust and glass that surrounds phenocrysts of plagioclase, clinopyroxene, and biotite, or hornblende. Biotite and hornblende in the lithic fragments have been completely replaced by magnetite.

Hells Mesa Tuff

The Hells Mesa Tuff is a moderately to densely welded, crystal-rich, latitic to rhyolitic, ash-flow tuff. The unit was named by Tonking (1957) for exposures at Hells Mesa located in the Bear Mountains (Secs.17 and 20, T.1N., R. 4W.). The Hells Mesa Tuff as restricted by Chapin (1974) is equivalent to the lower, crystal-rich portion of Tonkings' Hells Mesa Member of the Datil Formation; it is also equivalent to Tdh4 and the lower portion of Tdh5 of the Hells Mesa Member of the Datil Formation as described by Givens (1957) and to the tuff of Goat Springs (Brown, 1972). The unit has been dated by several workers. Weber and Bassett (1963) obtained K-Ar dates of 31.8 m.y. B.P. and 29.4 m.y. B.P. for biotite near the base of the unit at the type locality. K-Ar dates of 32.1 and 32.4 m.y. B.P. have been determined for the unit in the Gallinas Mountains and in the Joyita Hills, respectively (Burke and others, 1963). Chapin (unpublished data) has dated the unit at 33 m.y. B.P. The source of the Hells Mesa Tuff is the very large North Baldy-Socorro Cauldron (Chapin and others, 1978; Eggleston, in prep).

The Hells Mesa Tuff is an extensive ash-flow sheet of regional importance. It has been mapped as far west as the Datil Mountains (Lopez, 1975), as far east as the Joyita Hills (Spradlin, 1971), as far north as Thompson Canyon in the eastern Datil Mountains (Harrison, 1980), and has been reported as far south as the northern portion of the Black Range (Elston, 1975). The Hells Mesa Tuff is a multiple- flow simple cooling unit.

The unit crops out as massive cliffs when an overlying unit is present and as south-facing dip slopes when no overlying unit is present. The unit weathers to large rounded, joint-bound, blocks or to platy outcrops (fig.32). Within the study area the unit generally varies from 90 m to 60 m in thickness when present. This observed variation in thickness is not systematic throughout the area, but occurs over the relatively short distance of 0.4 kilometers, and can be explained by one or a combination of three different factors: 1) underlying paleotopography, 2) inaccurate

Figure 32. Photograph of a somewhat platy outcrop of the Hells Mesa Tuff.

location of the basal contact due to poor exposure, and 3) an overlying surface of unconformity. The outflow facies of the Hells Mesa Tuff thickens to 243 meters to the east of the study area (Chamberlin, 1974) and thins to 46 meters to the west of the study area (Lopez, 1975).

The Hells Mesa Tuff is in local unconformity with concretionary, aeolian and fluviatile sandstones of the middle volcaniclastic rocks (fig.33). The contact between the base of the Hells Mesa Tuff and the middle volcaniclastic rocks is poorly exposed and difficult to map. To the west of the study area, Harrison (1980), and Bornhorst (1978) have reported similar contact relationships; however, to the east of the study area, the unit overlies the tuff of Granite Mountain (Chamberlin, 1974) or the tuff of Nipple Mountain (Laroche, 1980). The basal unwelded zone of the Hells Mesa Tuff varies from 3 to 9 meters in thickness and displays an inverse relationship with respect to the thickness of the unit. This observation is in agreement with zonal variations in ash-flow tuffs as described by R.I. Smith (1960) and indicates that a surface of relatively low relief existed when the Hells Mesa Tuff was deposited. The A-L Peak Tuff and the volcaniclastic rocks of South Crosby Peak unconformably

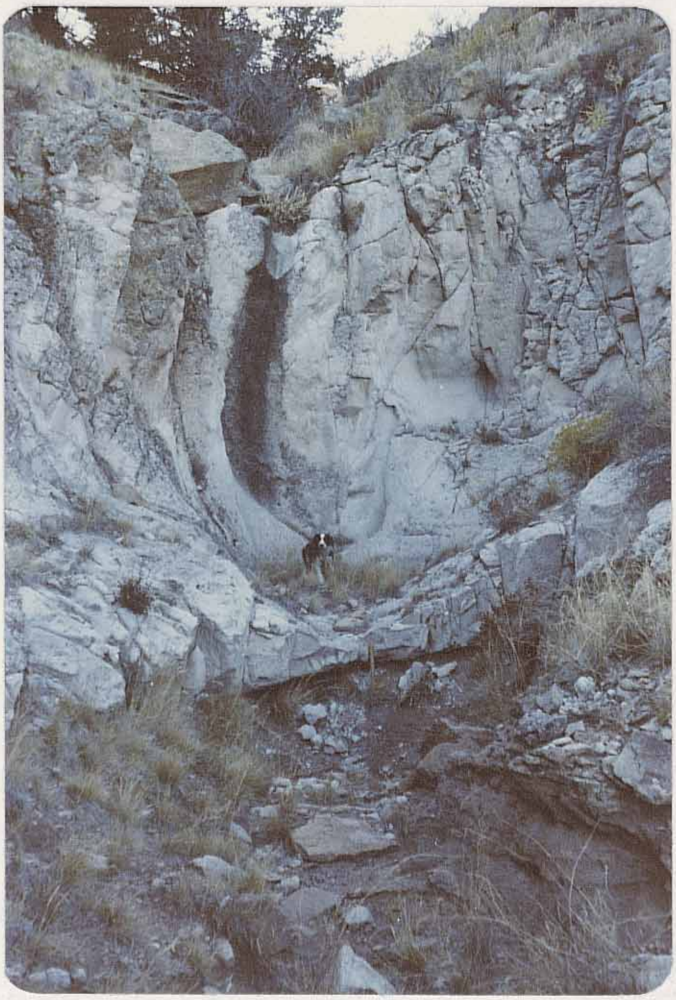


Figure 33. Photograph of the basal non-welded portion of the Hells Mesa Tuff.

overlie the Hells Mesa Tuff along a regionally extensive surface of unconformity. This surface of unconformity is cut by several deep paleovalleys. Exposures of paleovalleys that have cut completely through the Hells Mesa Tuff are present on hills 7777 ft (Sec.12, T.1N., R.8W.), and 7770 ft (Sec.12, T.1N., R.8W.), and between hills 8221 ft and 8145 ft (Sec.9, T.1N., R.8W.). An exposure of a paleovalley in which all but a few meters of the Hells Mesa Tuff has been removed is present on hill 7443 ft (Secs.23 and 24, T.1N., R.8W.).

In hand specimen, the Hells Mesa Tuff varies from grayish pink (5R 8/2) when fresh to light brown (5YR 6/4) when weathered. Densely welded hand specimens vary in color from grayish red (10R 4/2) when fresh to moderate brown (5YR 4/4) when weathered. Phenocrysts of sanidine, plagioclase quartz and biotite are visible in hand specimen. Lithic fragments are locally abundant and flattened gray pumice is present in the more densely welded portions of the unit.

In thin section, the Hells Mesa Tuff displays seriate and porphyritic textures. Phenocrysts account for 30 to 35 percent of the rock volume and vary in size from 0.2 mm to 3.0 mm in maximum length.

Phenocrysts in decreasing order of abundance, are sanidine, plagioclase, quartz, biotite, clinopyroxene and hornblende. The groundmass consists of glass shards, devitrification products, fine opaque dust and crystal fragments (Table 2).

Sanidine is the most abundant phenocryst and accounts for 13 to 14 percent of the rock by volume. Sanidine occurs as subhedral to euhedral grains ranging in size from 3.0 mm to 0.2 mm in maximum dimension. It commonly exhibits rounded corners and alteration to low-birefringence minerals around the margins. Carlsbad twinning is present in some crystals and perthitic unmixing is occasionally present.

Plagioclase occurs as subhedral to euhedral phenocrysts and makes up 11 to 12 percent of the rock by volume. Plagioclase phenocrysts commonly have rounded corners and occasionally have embayed margins. Plagioclase phenocrysts have albite, carlsbad, and pericline twinning and have normal or oscillatory zoning. Anorthite content was determined for 26 grains (Rittman Zone Method) and varied from An21 to An30 with an average anorthite content of An25 (oligoclase). In general, anorthite content decreases from the base to the top of the unit. Randomly arranged euhedral

Table 2. Modal analyses in volume percent of the Hells Mesa Tuff

	HM-1	HM-4
Total Phenocrysts	34.2	31.4
Sanidine	14.0	13.0
Plagioclase (An%)	11.5 (22)	12.1 (25)
Quartz	6.0	4.0
Biotite	2.1	2.0
Clinopyroxene	0.4	0.3
Hornblende	0.2	0.1
Lithics	0.8	0.4
Points Counted	2000	2000
Sanidine/plagioclase	1.2	1.1

crystals of apatite and apatite crystals arranged with their long dimension parallel to cleavage are common inclusions in the plagioclase phenocrysts.

Four to 6 percent of the rock volume is composed of anhedral to subhedral quartz grains from 4.0 mm to 0.2 mm in maximum dimension. Margins of quartz grains are rounded and occasionally embayed. Conchoidal fractures are present in the majority of grains as are slightly deformed optic axis figures which may indicate minor strain.

Non-opaque mafic minerals account for 2.5 percent of the rock volume. Biotite is the most common mafic mineral and accounts for 2 percent of the rock volume. Biotite crystals are subhedral, 2.0 mm in maximum dimension, and partially or completely altered to opaque iron oxides. Biotite is pleochroic with colors ranging from yellow to dark reddish brown. Some biotite grains have bent lamellae, possibly due to compaction. Subhedral grains of hornblende, 2.0 mm in maximum dimension, are present in trace amounts. Hornblende exhibits rounded or corroded margins, partially removed cores and pleochroism ranging in color from greenish yellow to dark reddish brown.

The remainder of the rock is composed of lithic fragments, and groundmass. Groundmass is gray to grayish brown and accounts for 65 to 70 percent of the rock by volume. Groundmass consists of glass, glass shards, low-birefringence devitrification products, fine opaque dust and crystal fragments. Poorly preserved glass shards commonly wrap around phenocrysts and lithic fragments. Axiolitic textures and spherulites are present. Spherulites are better developed in more densely welded portions of the unit. Rounded lithic fragments, which have a dark aphanitic groundmass of opaque minerals and glass surrounding laths of plagioclase, account for about 1 percent of the rock volume.

Brown (1972) and Chamberlin (1974) reported vertical compositional variations in the Hells Mesa Tuff. Brown reported that the ratio of quartz to feldspar increases from the base to the top of the unit and that the anorthite content of plagioclase in the unit also increases slightly up section. Similar data was generated by this study. Chamberlin reported a decrease in the anorthite content of plagioclase from the bottom of the unit to the top of the unit, opposite of that reported by Brown and this report. From unpublished data supplied by Deal and Rhodes, Chamberlin reported an upwards decrease in CaO and a slight increase in Na2O. Chamberlin also suggested that an observed decrease in the 2V of sanidine, from the base to the top of the unit, was due to the variation in Na2O content (Troger, 1959) or perhaps due to the degree of ordering of the Al+3 cations.

Volcaniclastic Rocks of South Crosby Peak

The volcaniclastic rocks of South Crosby Peak are a sequence of interbedded ash-fall tuffs, ash-flow tuffs, tuffaceous sandstones and conglomerates. The unit was named by T.J. Bornhorst (1976) for exposures on the west side of South Crosby Peak (Secs.25, 26, and 36, T.2S., R.10W.). The unit is equivalent to the tuff of Crosby Mountain as described by Lopez (1975). Bornhorst postulated that the unit represents the fill of a poorly documented cauldron, located in the area of the type section and referred to as the Crosby Mountain depression. This is not the case in the study area where the unit does not exceed 21 m in thickness. Poorly documented paleocurrent data, from pebble imbrications, indicates a north-northeast transport direction for the unit in the study area. This is in agreement with a northeast transport direction reported for the unit by Bornhorst (1976).

The volcaniclastic rocks of South Crosby Peak are a volumetrically minor, but regionally extensive unit, that form a discontinuous outcrop pattern throughout the region. The unit crops out as far north and east as Rock House Canyon (Secs.4 and 10, T.1N, R.8W.) (this report), as far south as Anderson Peak (Sec.6, T.3S., R.9W) (Bornhorst, 1976) and as far west as Sugarloaf Mountain (Sec.21 T.2S., R.11W.) (Bornhorst, 1976). No units similar to the volcaniclastic rocks of South Crosby Peak have been recognized to the east of the study area.

The volcaniclastic rocks of South Crosby Peak crop out as steep obsequent slopes, minor ledges and gently sloping resequent slopes in the study area. The unit forms a discontinuous outcrop pattern throughout the south central portion of the study area and covers approximately 0.65 square kilometers of the study area. The discontinuous outcrop pattern of the unit is attributed to a combination of erosion of the unit and localization of the unit in paleovalleys. One such paleovalley is located near the head of Rock House Canyon where the unit is topographically below the older Hells Mesa Tuff. The unit varies in thickness from 0 m to 21 m in the study area and reaches a maximum recorded thickness of 320 m at the type locality, located approximately 30 km to the southwest of the study area (Bornhorst, 1976).

The volcaniclastic rocks of South Crosby Peak unconformably overlie the Hells Mesa Tuff and the middle volcaniclastic rocks. The unit unconformably overlies the middle volcaniclastic rocks where it has been localized in a paleovalley approximately 75 m deep located between hills 8221 ft and 8145 ft near the head of Rock House Canyon (Sec.4 T.1N., R8W,). The unit conformably underlies and is in local unconformity with the lower cooling unit of the A-L Peak Tuff.

Within the study area, the unit is predominantly composed of light-brown to buff-colored conglomerates. Clast sizes in in these poorly to moderately indurated matrix-supported conglomerates range from very fine sand to cobble on the Wentworth scale. Granule to cobble-sized clasts are dominated by intermediate composition non-vesicular porphyritic andesites with subordinate tuff clasts, and account for 10 to 30 percent of the rock by volume. Granule to boulder-sized tuff clasts are usually derived from the underlying Hells Mesa Tuff. Very fine grained to coarse-grained sand-sized matrix in the conglomerates is composed of tuffaceous debris, quartz, feldspar, biotite and lithic fragments. Crudely developed pebble imbrications are the only noticeable sedimentary structures in these conglomerates.

The remainder of the unit is composed of extremely tuffaceous sandstones, thought to be reworked ash-fall or ash-flow tuffs, plus the tuff of South Crosby Peak and volcaniclastic sandstones. The volcaniclastic sandstones are poorly to moderately sorted, coarse to medium-grained, poorly to moderately indurated and composed of angular to subrounded grains of quartz, feldspar, biotite, lithic fragments and interstitial tuffaceous debris. The quartz-rich volcaniclastic sandstones in the unit are quite similar to the underlying Hells Mesa Tuff and are thought to be rewoked detritus derived from it by erosion. The matrix of the conglomerates probably had a similar origin.

The tuff of South Crosby Peak is a poorly welded, crystal-poor, pumice-rich, rhyolitic ash-flow tuff. The unit was originally named the tuff of Crosby Mountain by R.C. Rhodes and T.J. Bornhorst (Lopez, 1975) for exposures on Crosby Mountain (Sec.25, T.2S., R.11W.). However, Bornhorst (1976) later renamed the unit the volcaniclastic rocks of South

Crosby Peak and included within the unit all of the volcaniclastic rocks in the stratigraphic interval above the tuff of Rock Tank and below the A-L Peak Tuff (the Hells Mesa Tuff has been correlated to Bornhorst's tuff of Rock Tank by Harrison (1980)). Harrison (1980) referred to the unit as the tuff of South Crosby Peak and for clarity the same format has been followed here. That is the rocks in the stratigraphic interval above the Hells Mesa Tuff and below the A-L Peak Tuff are referred to as the volcaniclastic rocks of South Crosby Peak and the ash-flow tuff intercalated within this interval is referred to as the tuff of South Crosby Peak. The source of the tuff of South Crosby Peak is thought to be a poorly documented cauldron known as the Crosby Mountain depression (Bornhorst, 1976) located southwest of the study area. No dates are available for the unit but it has been bracketed between dates of approximately 33 m.y. B.P. for the underlying Hells Mesa Tuff and 30 m.y. B.P. for the overlying A-L Peak Tuff.

The tuff of South Crosby Peak crops out in two locations within the study area. The first location is in a paleovalley located between hills 8145 ft and 8221 ft near the head of Rock House Canyon. At this

Figure 34. Photograph of a typical outcrop of the tuff of South Crosby Peak. Note light blue lithic fragments of Hells Mesa Tuff.

location, the unit unconformably overlies the upper portion of the middle volcaniclastic rocks and contains numerous lithic fragments from the older Hells Mesa Tuff. Lithic fragments of Hells Mesa Tuff at this location are as much as 0.5 m in maximum dimension and are tinted a light blue (fig.34). At this location, the unit is approximately 75 m below the base of the Hells Mesa Tuff. The second location where the tuff crops out is approximately 1.6 kilometers to the southeast in the saddle between hills 8185 ft and 8247 ft (Sec.9, T.1N., R.8W.). At this location, the tuff is intercalated within the sandstones and conglomerates of the volcaniclastic rocks of South Crosby Peak. The tuff varies from 0 m to 9 m in thickness and commonly weathers to rounded joint-bound blocks. Within the study area, the tuff of South Crosby Peak is one of the least resistive units to weathering.

In hand specimen, the tuff of South Crosby Peak varies from light tan when fresh to buff when weathered. The tuff is crystal-poor but does have phenocrysts of feldspar, biotite and quartz. Lithic fragments consisting of andesites, unidentified lower-section tuffs, Hells Mesa Tuff, and pumice fragments are locally abundant. Lithic fragments vary in maximum dimension from 1.0 mm to 50 cm with the larger clast sizes dominated by the Hells Mesa Tuff. Pumice fragments are slightly elongate, rarely exceed 4.0 mm in length and may be imbricated.

Petrographically, the tuff of South Crosby Peak is porphyritic and has, in decreasing order of abundance, phenocrysts of sanidine, plagioclase, and biotite. Although present in hand specimen, no lithic fragments or phenocrysts of quartz were observed in thin section. Phenocrysts account for an estimated 6 percent of the rock by volume and range in size from 0.2 mm to 4.0 mm in maximum dimension. The remaining 94 percent of the rock volume is composed of poorly preserved glass shards, and low-birefringent devitrification products which impart a greenish tint to the rock when viewed under plane light.

Anhedral to subhedral phenocrysts of sanidine account for 4 percent of the rock by volume. Sanidine crystals are as much as 2.0 mm in maximum dimension and commonly have rounded corners. Sanidine phenocrysts are usually fractured and occasionaly display perthitic unmixing. Sanidine crystals are normally zoned and display carlsbad twinning. Phenocrysts of plagioclase are subhedral to anhedral and account for 1 percent of the rock by volume. Plagioclase phenocrysts are as much as 4.0 mm in maximum dimension, but average about 1.5 mm in maximum dimension and have rounded corners. Plagioclase crystals are normally zoned and twinned following the albite law. An anorthite content of An32 (andesine) was determined for the plagioclase using the Michel-Levy statistical method (Heinrich, 1965). This value is in good agreement with data presented by previous workers (Lopez, 1975; Bornhorst, 1976; Harrison, 1980) whose anorthite values cluster around An30. Biotite is present in trace amounts (less than 1 percent) and exhibits pleochroism ranging from dark reddish brown to reddish brown. Biotite is subhedral and has a maximum dimension of 0.5 mm.

A-L Peak Tuff

The A-L Peak Tuff, in the study area, consists of three poorly to densely welded, crystal-poor, rhyolitic, ash-flow tuffs separated by an interval of volcaniclastic rocks and interbedded basaltic-andesite lava flows. Deal (1973) and Deal and Rhodes (1976) named the tuffs the A-L Peak Rhyolite for exposures in the San Mateo Mountains. Chapin and others (1978) referred to the unit as the A-L Peak Tuff. Parts of the unit are correlative to the banded rhyolite of Loughlin and Koshman (1942), the upper portion of

Tonkings′ (1957) Hells Mesa Member, Givens′ (1957) Tdh7, Tdh6, and portions of Tdh5, Brown′s (1972) tuff of Bear Springs, and the tuff of Wahoo Canyon as described by Fodor (1975). The interbedded mafic flows are correlative to the basaltic andesite of Twin Peaks as described by Lopez (1975). Within the study area, four mappable units are present in the A-L Peak Tuff. The age of the A-L Peak Tuff is bracketed between 33 m.y. B.P. for the underlying Hells Mesa Tuff (Burke and others, 1963) and 28 m.y. B.P. for the overlying Lemitar Tuff (Chapin, unpublished data). This is in good agreement with a date of 28-28.3 m.y. for the Anchor Canyon Stock (Weber and Bassett, 1963) which intrudes the unit (Chapin, 1971-a) and a date of 30.1 m.y. B.P. for the intercalated basaltic andesite of Twin Peaks (Chapin, unpublished data).

The A-L Peak Tuff forms an extensive ash-flow sheet throughout the northeast corner of the Datil-Mogollon Volcanic Province. The unit outcrops as far east as the Joyita Hills (Spradlin, 1973), as far west as the Crosby Mountains (Bornhorst, 1976), as far north as the Bear Mountains (Brown, 1972) and as far south as the San Mateo Mountains (Elston, 1975).

The outflow facies of the A-L Peak Tuff has been divided into upper and lower cooling units by Chapin and Deal (1976). The lower cooling unit is a multiple-flow compound cooling unit composed of the flow-banded and gray-massive members. The upper cooling unit is a multiple-flow simple cooling unit consisting of the pinnacles member. The cooling break between the upper and lower cooling units is commonly occupied by an interval of basaltic-andesite flows and volcaniclastic rocks (Chapin and Deal, 1976). Similar relationships to those described above are present in the study area.

Lower Cooling Unit

The lower cooling unit of the A-L Peak Tuff in the study area is a multiple-flow compound cooling unit consisting of two crystal-poor, moderately to densely welded, rhyolitic ash-flow tuffs. The two tuffs are thought to be correlative to the gray-massive and flow-banded members of the A-L Peak Tuff as described by Brown (1972). A distinct cooling break in the form of a reversal in welding can be identified between the two tuffs. The cooling break is poorly exposed throughout the study area so the two ash-flow tuffs have been mapped as a single unit.

The lower cooling unit of the A-L Peak Tuff crops out as moderate to steep obsequent slopes, poorly defined ledges and south-facing dip slopes. The unit crops out as a north-trending belt along the ridge east of North Lake Canyon and as a northwest-trending belt along the ridge south of Rock House Canyon. Isolated outcrops of the unit are located on hills 7777 ft and 7770 ft along the eastern margin of the study area (Secs.12 and 24, T.1N., R.8W.) where the unit was deposited in paleovalleys. The unit covers about 3.9 square kilometers of the study area. The unit generally varies in thickness from 45 m to 30 m when it is present and unaffected by surface erosion. Rapid variations in thickness occur due to the localization of the unit in paleovalleys.

The lower cooling unit unconformably overlies the Hells Mesa Tuff and conformably overlies the volcaniclastic rocks of South Crosby Mountain when they are present. Along the eastern margin of the study area, the unit has been deposited in paleovalleys and unconformably overlies the tuff of Rock House Canyon and the upper member of the Dog Springs volcanic complex. The lower cooling unit unconformably underlies volcaniclastic rocks and the basaltic andesite of Twin Peaks that occupy the cooling break between the upper and lower cooling units of the A-L Peak Tuff.

In hand specimen, densely welded samples vary from grayish black (N2) or grayish red (5R 4/2) when fresh to grayish red (10R 4/2) or brownish gray (5YR 4/1) when weathered. Moderately welded samples vary in color from pale red purple (5RP 6/2) or light brownish gray (5YR 6/1) when fresh to pale yellowish brown (10 YR 6/2) when weathered. Phenocrysts of sanidine, quartz and biotite as well as lithic fragments, pumice fragments and gas cavities are visible in hand specimen.

In thin section, the lower cooling unit is porphyritic and has phenocrysts of sanidine, biotite, plagioclase, clinopyroxene, opaque minerals and sphene (Table 3). No quartz was observed in thin section but trace amounts are present in hand specimen. Groundmass consists of well-developed devitrification products, vapor-phase minerals, glass and opaque dust. Lithic fragments are abundant and characteristic of the lower cooling unit.

Sanidine is the most abundant phenocryst and accounts for 3 to 5 percent of the rock volume. Phenocrysts of sanidine are subhedral to euhedral, 1.5

Table 3. Modal analyses in volume percent of the lower cooling unit of the A-L Peak Tuff

	AL-1	Al-2	Al-3
Total phenocrysts	5.1	3.9	4.2
Sanidine	5.0	3.3	3.7
Plagioclase (An%)	0.2 (42)	0.1 (30)	0.0 (N.O)*
mafics	0.4	0.2	0.3
Opaques	0.2	0.3	0.2
Lithics	2.4	5.0	4.9
Points counted	2000	2000	2000

* none observed

mm in maximum length and commonly fractured. Sanidine is normally zoned and exhibits carlsbad twinning. Sanidine has either sharp or corroded margins with occasional embayments. Plagioclase, biotite, clinopyroxene, opaques and sphene are all present in amounts less than 0.5 percent. Anhedral to subhedral plagioclase, 0.5 mm in maximum length, is commonly fractured, has albite twinning, and corroded margins. Anorthite content was determined for 3 grains (Rittman Zone Method) which yielded an average anorthite content of An36 (andesine). Subhedral to anhedral biotite, 1.0 mm in maximum length, is pleochroic with colors ranging from reddish brown to golden brown. Biotite exhibits both sharp and corroded margins. Pale-green, euhedral to subhedral clinopyroxene, 0.7 mm in maximum length, is present but may represent foreign material derived from lithic fragments. A single honey brown, diamond-shaped crystal of sphene, 0.5 mm in length, was observed. Subhedral to euhedral opaque cubes, 0.5 mm in maximum length, are probably magnetite.

Lithic fragments and groundmass account for the remaining 95 to 97 percent of the rock volume. Very well-developed devitrification products dominate the groundmass. Devitrification products consist of low birefringent minerals, probably tridymite, cristobalite, and alkali feldspars (Ross and Smith, 1961), which are particularly well developed as platy or radiating aggregates in elongate pumice fragments. Vapor-phase minerals are present in lithophysal cavities. Small amounts of glass are preserved and glass shards can be seen wrapped around phenocrysts and lithic fragments. Red iron oxide dust is common throughout the groundmass and when present imparts a red color to the rock; otherwise the groundmass is light gray. Lithic fragments account for 2 to 6 percent of the rock volume. Lithic fragments are porphyritic and pilotaxitic. Subparallel alignment of clinopyroxene, plagioclase and opaque phenocrysts in a groundmass of opaque dust and plagioclase microlites is characteristic of the lithic fragments.

interbedded volcaniclastic rocks

The interval between the upper and lower cooling units of the A-L Peak Tuff is occupied by a sequence of fluviatile volcaniclastic sandstones and conglomerates and the basaltic andesite of Twin Peaks. The sedimentary rocks are present throughout the study area. The sedimentary rocks generally form moderately sloping, colluvium-covered hills capped by the upper cooling unit. The sedimentary rocks form a discontinuous outcrop pattern that covers approximately 0.78 square kilometers across the central portion of the study area. The sedimentary rocks rarely crop out, but good exposures of the unit are present on the hill south of the saddle marked 7809 ft (Sec.15, T.1N., R.8W.). Similar sedimentary rocks have been reported in the same interval on a regional scale by Chapin and Deal (1976).

The contact of these sedimentary rocks with the underlying lower cooling unit is an erosional unconformity along which the portion of the lower cooling unit above the uppermost densely welded zone has been removed. This relationship is not present on the ridge east of North Lake Canyon where the basaltic andesite of Twin Peaks rests directly on the lower cooling unit of the A-L Peak Tuff. The contact of the volcaniclastic rocks with the overlying upper cooling unit of the A-L Peak Tuff is conformable. Contact relationships with the intercalated basaltic andesite of Twin Peaks are generally conformable but both upper and lower local unconformities do exist. The volcaniclastic rocks have been localized in paleodepressions and vary between 6 m and 25 m in thickness.

Light-gray to buff-colored sedimentary rocks which characterize the interval are poorly indurated and commonly pumice-rich. Some of the pumice-rich lenses exceed 60 percent pumice by volume and exhibit pumice fragments as much as 13 cm in maximum dimension. Poorly sorted sandstones and matrix-supported conglomerates are composed of pumice, feldspar, tuffaceous debris, quartz and biotite. Randomly oriented pumice is the main clast type in the conglomerates but basaltic-andesite fragments are also present. The unit displays cut-and-fill structures, reverse and normal graded bedding, planar parallel laminations, small-scale low-angle planar trough cross-stratification, and bedding thicknesses ranging from thinly laminated to thinly bedded. Vertical variations consist of an overall increase in sorting, pumice size and bedding thickness, and a decrease in tuffaceous debris from bottom to top. It is thought that the unit represents reworked ash-fall tuffs and pumice flows which occurred prior to the eruption of the upper cooling unit of the A-L Peak Tuff.

basaltic andesite of Twin Peaks

The basaltic andesite of Twin Peaks is composed of basaltic-andesite lava flows which have vesicular tops and dense cores. The unit was named by Lopez (1975) for exposures at Twin Peaks, located in the Datil Mountains (Secs.18 and 19, T.2S., R.9W.). The basaltic andesite of Twin Peaks is equivalent to portions of Tdh6 as described by Givens (1957). To the east of the study area, Chamberlin (1974), Wilkinson (1976), Simon (1973) and Spradlin (1973) have all reported basaltic-andesites in the same interval and, to the west of the study area, Bornhorst (1976) reported a basaltic-andesite directly above the lower cooling unit of the A-L Peak Tuff. It appears that the basaltic andesite of Twin Peaks represents the first mafic igneous activity in the study area associated with the onset of bimodal volcanism which now characterizes much of central New Mexico. The unit was sampled for K-Ar dating (this report and Harrison, 1980) which yielded a date of 30.1 m.y. B.P. (Chapin, unpublished data). No source for the unit was found in the study area.

The basaltic andesite of Twin Peaks is located in a stratigraphic interval occupied by basaltic-andesites on a regional scale. Stratigraphically equivalent units have been reported as far east as the Joyita Hills (Spradlin, 1973), as far west as the Crosby Mountains (Bornhorst, 1976), as far north as the Gallinas Mountains (this report) and as far south as the Crosby Mountains (Bornhorst, 1976).

The basaltic andesite of Twin Peaks crops out as thin ledges and south-facing dip slopes, when present. The unit weathers to form a dark-brown soil and blocky talus slopes which cover the underlying units. This characteristic is particularly evident when viewing aerial photographs. The unit varies in thickness from 0 m to 25 m. The observed variations in thickness can be explained by the localization of the unit in paleochannels. This localization can be observed at the base of the hill just south of the saddle marked 7809 ft (Sec.15, T.1N., R.8W.) and on the ridge east of North Lake Canyon (fig.35). The unit is absent on hill 7545 ft (Sec.23, T.1N., R.8W.) and on the eastern slope of the hill directly south of the saddle marked 7809 ft (Sec.15, T.1N., R.8W.). The unit covers approximately 0.65 square kilometers of the study area.

The basaltic andesite of Twin Peaks is in local unconformity with underlying volcaniclastic rocks when they are present, otherwise the unit unconformably

Figure 35. Photograph showing the localization of the basaltic andesite of Twin Peaks in a shallow paleodepression.

overlies the lower cooling unit of the A-L Peak Tuff. The unit generally conformably underlies the volcaniclastic rocks but local unconformities do exist.

In hand specimen, the unit varies in color from greenish black (5G 2/1) when fresh to light olive gray (5Y 5/2) when weathered. The unit is highly magnetic and is capable of deflecting a compass needle 180 degrees. Dark-green phenocrysts of olivine can occasionally be distinguished with the aid of a hand lens. Amygdules are commonly filled with calcite.

Petrographically, the basaltic andesite of Twin Peaks has an intergranular and porphyritic texture. Phenocrysts, in decreasing order of abundance, are plagioclase, olivine and clinopyroxene. Phenocrysts account for 3 to 4 percent of the rock volume and vary in length from 0.5 mm to 1.5 mm. The groundmass is composed of plagioclase laths, magnetite, clinopyroxene and calcite. The groundmass is almost as coarse as the phenocrysts and, as such, makes the distinction between the two rather arbitrary.

Subhedral to euhedral laths of plagioclase are the most abundant mineral present. Plagioclase accounts for 1 percent of the phenocryst content and 32 to 47 percent of the groundmass. Plagioclase ranges in length from 0.3 mm to 1.0 mm in length and occasionally shows antiperthitic unmixing. Plagioclase has albite, carlsbad and pericline twinning. Plagioclase often has randomly arranged inclusions of apatite. Anorthite content was determined for 8 grains (Rittman Zone Method) and varied from An36 to An55 with an average value of An41 (andesine). Euhedral to subhedral phenocrysts of olivine are pervasively fractured and account for approximately 3 percent of the rock volume. Olivine is 1.5 mm in maximum length and occurs as phenocrysts only. A 2v of approximately 90 degrees indicates that the olivine is forsterite. Olivine commonly has embayed margins and opaque inclusions. Water-clear olivine is commonly mantled by iddingsite alteration. Anhedral to subhedral clinopyroxene, which locally show subophitic textures with plagioclase laths, occurs throughout the groundmass. Clinopyroxene accounts for 15 to 39 percent of the rock volume. Clinopyroxene is light brown to light green in color, is 0.9 mm maximum length and contains randomly arranged, euhedral inclusions of apatite. Anhedral to euhedral opaque material occurs throughout the groundmass as intersertal dust and as cubes 0.3 mm in maximum length. The opaque material, probably magnetite and dark glass, accounts for 8 to 45 percent of the rock volume. Anhedral to subhedral calcite has been deposited in amygdules and resembles blocky spar as described by Folk (1974).

Upper Cooling Unit

The upper cooling unit of the A-L Peak tuff is a moderately to poorly welded, crystal-poor, pumice-rich, rhyolitic, ash-flow tuff. Harrison (1980) has correlated the upper cooling unit to the pinnacles member of the A-L Peak Tuff. The upper cooling unit is equivalent to the tuff of Wahoo Canyon as described by Fodor (1975) and as mapped by Lopez (1975). The upper cooling unit is correlative to portions of Tdh5 and Tdh7 as mapped by Givens (1957) and has been correlated to Tdrp2 of Stearns (1962) by Fodor (1975). The upper cooling unit is a multiple-flow simple cooling unit in the study area.

The upper cooling unit crops out as pervasively jointed ledges and south-facing dip slopes throughout the area. The unit forms a discontinuous pattern of outcrops throughout the central portion of the study area, localized along the highest peaks and ridges. The unit has a maximum thickness of 12 m in the study area and covers approximately 0.65 square kilometers of outcrop area. The upper cooling unit conformably overlies the volcaniclastic rocks which occupy the interval between the upper and lower cooling units and underlies a thin layer of pebble conglomerate. The unit unconformably overlies the Hells Mesa Tuff where it was localized in a 120 m deep paleovalley exposed on hill 7443 ft (Secs.23 and 24, T.1N., R.8W.).

In hand specimen, the upper cooling unit varies from light gray (N7) or very light gray (N8) when fresh to moderate yellowish brown (10YR 5/4) when weathered. Pumice fragments and phenocrysts of sanidine and quartz are visible in hand specimen. Pumice fragments as much as 3 cm long have been observed in the unit. Samples from hill 7101 (Sec.26, T.1N., R.8W.) are noticeably enriched in silica and opaque mineral content. This enrichment is secondary and maybe due to the units proximity to a suspected fracture zone.

In thin section, the upper cooling unit is porphyritic with phenocrysts of sanidine, biotite, plagioclase and opaque minerals accounting for 1 to 4 percent of the rock volume (Table 4). No quartz was observed in thin section. Groundmass consists of well-developed devitrification products, vapor-phase minerals, glass, and opaque dust. Lithic fragments are present but not nearly as abundant as in the lower cooling unit. Sanidine accounts for 1 to 3 percent of the rock volume and is the most abundant phenocryst. Euhedral to subhedral sanidine phenocrysts, 1.5 mm in maximum length, commonly show carlsbad twinning and perthitic unmixing. Fracturing is common in sanidine phenocrysts which also have either sharp or corroded margins that are occasionally embayed. Biotite, plagioclase and opaque minerals are all present in minor amounts. Subhedral biotite, 0.7 mm in maximum length, has sharp or corroded margins which are occasionally embayed. Biotite is pleochroic and has colors ranging from reddish brown to dark brown. Plagioclase phenocrysts 0.2 mm in maximum length are less abundant than biotite phenocrysts and commonly exhibit corroded margins. Plagioclase is normally zoned and exhibits albite twins. Anorthite content was determined for 4 grains (Rittman Zone Method) which yielded an average anorthite content of An19 (oligoclase). Subhedral blebs of opaque minerals, 0.25 mm in maximum length account for the remainder of the phenocryst content.

Groundmass and lithic fragments account for the remaining 96 to 99 percent of the rock volume. Well-developed, low-birefringence devitrification

Table 4. Modal analyses in volume percent of the upper cooling unit of the A-L Peak Tuff

	WC-1	WC-2	WC-3
Total phenocrysts	3.9	1.3	2.2
Sanidine	3.2	1.0	1.8
Plagioclase (An%)	0.1 (N.D.)*	0.1 (21)	0.1 (18)
Biotite	0.1	0.1	0.1
Opaques	0.5	0.1	0.2
Lithics	0.4	0.4	0.2
Points counted	2000	2000	2000

* not determined

products dominate the groundmass. Pumice and glass shards have axiolitic textures and aggregates of spherulites are locally present. Lithic fragments account for less than 1 percent of the rock volume. Lithic fragments are rounded, 5.0 mm in maximum length and consist of laths of plagioclase surrounded by an opaque groundmass.

Younger Tertiary Rocks

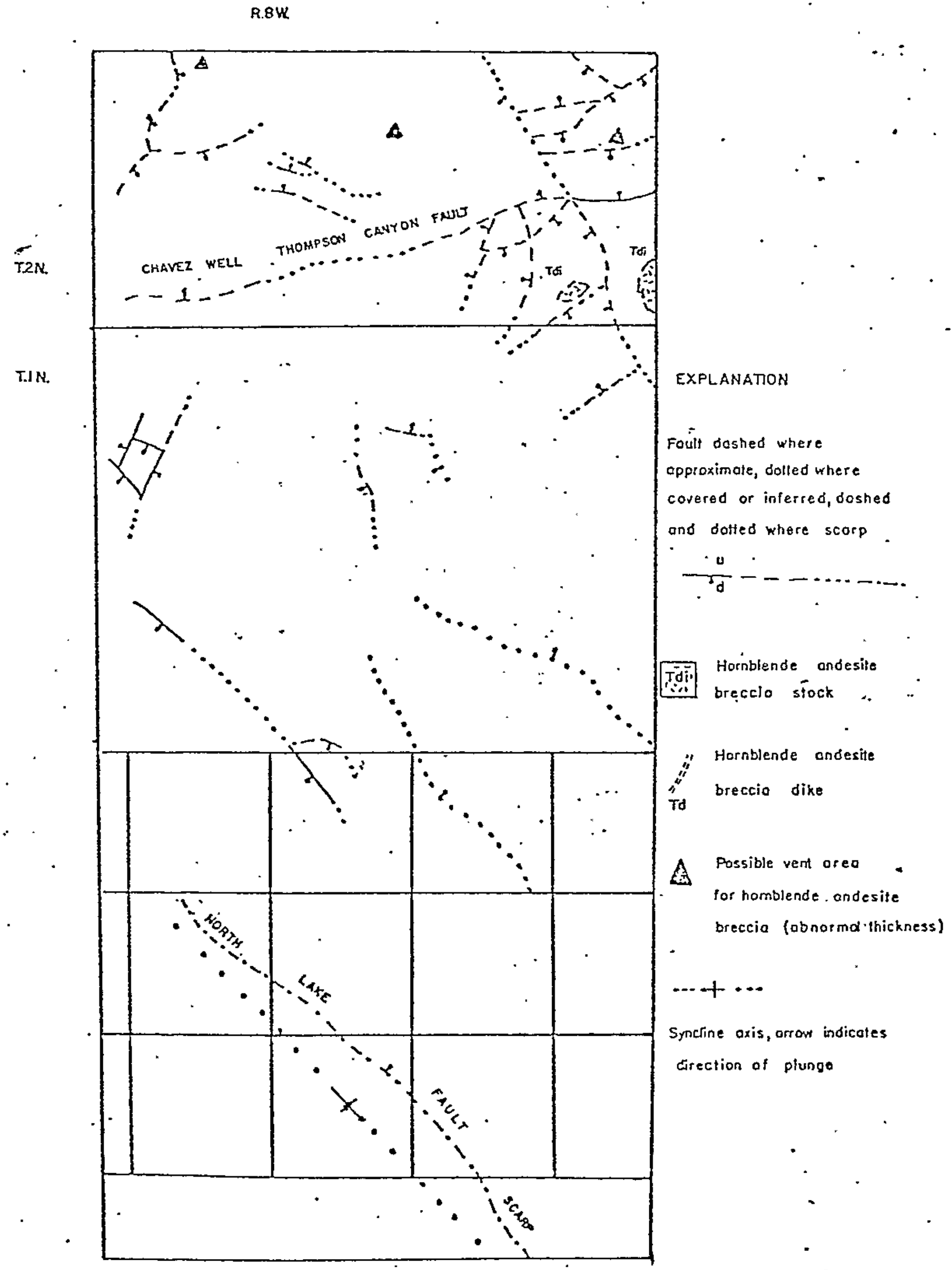
Tertiary rocks younger than the upper cooling unit of the A-L Peak Tuff consist of a 0.5 m bed of conglomerates which underlies a 1 m thick basalt flow. These younger units form isolated outcrops on hill 7545 ft (Sec.26,T.1N., R.8W.) and are always found together. The basalt flow is correlative to portions of Givens' (1957) Tdh6 and are probably correlative to the basalt of Blue Mesa (Harrison, 1980).

Intrusives

Monolithic, hornblende andesite breccias of the upper member of the Dog Springs volcanic complex are the only intrusive rocks in the study area. These breccias intrude the upper and lower members of the Dog Springs volcanic complex and are correlative to the rhyodacite intrusives of Harrison (1980). Monolithic hornblende andesite breccia intrusions occur as dikes and small domes. Due to poor exposure, intrusives are difficult to distinguish from their extrusive equivalents. Good exposure of a breccia dike is provided by an outcrop located on the southeast side of Dog Springs Canyon (Sec.28,T.2N., R.8W.) (fig.13). Cross-cutting contact relationships of hornblende andesite breccias with lower member tuff breccias, along the northeast margin of the study area (Sec.36, T.2N., R.8W.), probably represent the margins of two small domes. An outcrop along the margin of the easternmost of these two bodies is sheet jointed, has a preferred alignment of elongate minerals parallel to sheet joints, and contains xenoliths of baked clay similar to the country rock that surrounds it. Abnormally thick accumulations of hornblende andesite breccia are scattered along the northern and eastern margins of the study area and may represent small stocks, domes or fissures (fig.36).

Outcrops of the breccias are generally massive and only occasionally show discordant relationships. In hand specimen, the hornblende andesites are brownish red when weathered and dark olive green when fresh. Dark-green to black phenocrysts of hornblende and

FIGURE 36 MAJOR STRUCTURES AND INTUSIVE ROCKS OF THE WESTERN GALLINAS MOUNTAINS, SOCORRO COUNTY, NEW MEXICO



translucent green plagioclase phenocrysts set in an aphanitic groundmass are characteristic of the breccia clasts. Matrix consists of lithic fragments that are compositionally identical to the larger clasts. Very little pore space is present in these breccias.

Petrographically, the hornblende andesite clasts have porphyritic and pilotaxitic textures. Phenocrysts range from 0.3 to 2.5 mm in maximum dimension and account for about 40 percent of the rock by volume. Plagioclase is the most abundant phenocryst present and accounts for about 20 percent of the rock by volume. Hornblende is the most abundant mafic phenocryst present and accounts for about 11 percent of the rock by volume. The remainder of the phenocryst content consists of clinopyroxene (7%) and magnetite (2%). Groundmass consists of a felted mass of plagioclase microlites, which wrap around the phenocrysts, and a subordinate portion of anhedral opaque blebs. Occasionally, groundmass and mafic phenocrysts have been replaced by chlorite. A more detailed petrographic description of these hornblende andesites is presented in the previous section on monolithic breccias of the upper member of the Dog Springs volcanic complex.

Surficial Deposits

Piedmont Deposits

Piedmont deposits consist of an unconsolidated, heterogeneous mixture of volcanic fragments in a matrix of sand to silt-sized detritus. Volcanic fragments, consisting of basaltic-andesites and tuffs, are subrounded to angular and range from granule to boulder on the Wentworth scale. Tuff fragments generally consist of the more resistant tuffs which occur above the Dog Springs volcanic complex and there is a notable absence of rock types of the Dog Springs volcanic complex. Piedmont deposits usually are coarser and form steeper slopes near their source. Locally one clast type may dominate but this can usually be attributed to proximity to bedrock exposure or possibly to a function of the clasts durability.

Within the study area, the piedmont deposits have been mapped as six separate units. Four of the units are localized to the south of the drainage divide formed by the ridge north of Rock House Canyon and will be referred to as the southern piedmonts. The remaining units will be referred to as the northern piedmonts. No age relationship can be determined between the northern and southern piedmonts within the study area.

The southern piedmonts consist of four geomorphically distinct surfaces. The oldest southern piedmont covers approximately 10 square kilometers in the southwest corner of the study area. This unit is correlative to the younger piedmont deposit of Harrison (1980) and is mantled by the Augustin soil (479) as mapped by the United States Soil Conservation Service (Job no. 35902). The unit is composed predominantly of sand to silt-sized detritus that is reddish brown near the land surface, where residual concentrations of volcanic fragments occur, and dark brown a meter below the surface. The unit forms a gentle, south-facing, grass-covered slope.

The next younger piedmont covers 2 square km of the study area and is found near the base of the hills that surround the North Lake embayment and Rock House Canyon. The unit is mantled by the Majada soil (456) as mapped by the Soil Conservation Service (Job no. 35902). The unit forms moderately steep grass, juniper and pinion covered slopes and has a higher clast to matrix ratio than the Augustin soil (479) of the oldest piedmont.

The next younger piedmont is confined to the North Lake basin and covers approximately 2.6 square kilometers of the study area. The unit is similar to the Augustin soils (479) in composition but can be distinguished from the older piedmont by its lower topographic position. The unit is mantled by the Manzano (424) soil as mapped by the Soil Conservation Service (Job no. 35902) and forms moderately to gently sloping, grass covered slopes.

The youngest piedmont of the southern piedmonts covers approximately 9 square kilometers in the southeast corner of the study area and is restricted to the lower portion of Rock House Canyon and the North Lake embayment. The unit forms very gentle slopes and is composed primarily of silt and sand-sized detritus along with a few larger clasts. The unit is mantled by the Manzano (424) soil as mapped by the Soil Conservation Service (Job no. 35902) and represents the currently active alluvial surface.

Unconsolidated debris mantles an extensive piedmont surface present across the northern portion of the study area which forms the oldest northern piedmont. Detritus consists of basaltic-andesite and upper section tuff fragments set in a matrix of sand

and silt. The debris covers approximately 4 square kilometers of the study area and is especially well preserved north of the Chavez Well-Thompson Canyon fault. The unit is mantled by the Luzena Soil (442) as mapped by the Soil Conservation Service (Job no. 35902), and is correlative to the Santa Fe Formation of Givens (1957) and the older piedmont unit of Harrison (1980). Givens (1957) and Harrison (1980) both reported thicknesses of 46 m for the unit. Difficulty in locating the base of the unit on steep, colluvium-covered slopes in the study area precluded thickness determination.

The youngest northern piedmont is located near the head of Middle Canyon and occurs intermittently along the base of the northern side of the drainage divide. The piedmont covers approximately 3 square kilometers of the study area and is mantled by the Luzena Soil (442) as mapped by the Soil Conservation Service (Job no. 35902). The unit forms moderate to gentle slopes covered by grass and groves of pinon and juniper trees. Clasts of the tuff of Rock House Canyon characterize the steeper slopes with finer-grained detritus dominating the gentle slopes and flatter portions of the unit. In contrast to the southern piedmonts, the deposit appears to be only a thin veneer over the underlying bedrock.

Playa Deposits

Recent lake sediments composed of clay and silt are present in the North Lake Basin. Cultural activity and active piedmonts have obscured much of the paleo-shoreline of ancient North Lake. Tentative identification of two paleo-shorelines outside of the study area indicates that shorelines existed at the 7040 ft and 7020 ft elevations (Weber, 1979, oral commun.). Aerial photographs that predate agricultural activity show a distinct tonal anomaly at about the 7020 ft elevation and thus support this as the general location of the paleo-shoreline.

Older Alluvium

Older alluvial deposits, similar to recently deposited alluvium, has been mapped in Rock House Canyon where it has been isolated above the currently active alluvial surface. The unit covers about 2.6 square kilometers of the study area.

Talus and Colluvium

Talus and colluvium occur on most of the slopes in the study area and obscure large portions of the bedrock geology. This phenomenon is especially well-developed on the slopes that cover the Dog Springs volcanic complex, the volcaniclastic rocks of Chavez Canyon and the middle volcaniclastic rocks. Talus and colluvium is mapped where it has completely obscured the underlying geologic relationships.

Alluvium

No perennial streams exist in the study area, but intermittent flow does occur after heavy rainfall. Currently the area is undergoing degradation but in the 1800's the area was undergoing aggradation (Givens, 1957). Recent terraces and currently active stream channels have been mapped as quaternary alluvium. In the study area, alluvium consists of poorly consolidated sands and gravels as much as 6 m thick.

STRUCTURE

The western portion of the Gallinas Mountains, which occupy the study area, are cut by northwest, northeast and east-northeast-trending high-angle normal faults (fig.36). A south-dipping homocline occupies the northern portion of the study area and a southeast-plunging syncline occupies the southern portion. No evidence of pre-Oligocene tectonic events is present in the study area.

Folds

The southern portion of the study area is occupied by the eastern arm of a broad southeast-plunging syncline. The syncline is bounded on three sides by high-angle normal faults and disappears beneath the San Augustin Plains on the fourth. To the west of the study area, the syncline has been down faulted and disrupted by a north-trending, complexly faulted zone mapped by Harrison (1980). To the east of the study area, reconnaissance revealed that the syncline is uplifted and terminated along the western Gallinas fault of Givens (1957). Within, and to the west and east of the study area, the nose of the syncline is cut by the east-northeast-trending, down-to-the-north Chavez Well-Thompson Canyon fault. North of the Chavez Well-Thompson Canyon fault, synclinal development, if it occurred at all, has been masked by poor exposure, faulting and steep initial dips in the rocks of the Dog Springs volcanic complex.

Initial synclinal development began directly following the emplacement of the Hells Mesa Tuff, about 33 m.y. B.P. (Harrison, 1980). At this time, an erosional surface transected by paleovalleys as much as a hundred meters deep (Harrison, 1980; this report) formed along the top of the Hells Mesa Tuff. Harrison reported a southeast trend of paleovalleys to the west of the study area and that units above the Hells Mesa Tuff thin to the north. Harrison concluded that this was indicative of synclinal development. Within the study area, the localization of the volcaniclastic rocks, occurring between the upper and lower cooling units of the A-L Peak Tuff, near the syncline axis, is also indicative of synclinal development. Paleovalleys, presumably formed following the emplacement of the Hells Mesa Tuff, were actively eroded into late A-L Peak time. This relationship is apparent from paleovalleys in which all of the rocks between the upper cooling unit of the A-L Peak Tuff and the Hells Mesa Tuff have been removed, such as on hill 7443 ft (Sec.23 and 24, T.1N., R.8W.). Thus synclinal development was active at least until late A-L Peak time. Non-deposition of the tuff of South Canyon which occurs directly to the south of the study area, and presumably pinched out against the southeast plunging syncline, provides a possible upper limit for the period of synclinal development. The initiation of basaltic-andesite volcanism in the area, concurrent with synclinal development, reflects the begining of regional extension and the formation of the Rio Grande rift.

Faults

High-angle, east-northeast-trending normal faults and fractures are common throughout the northern portion of the study area and form a system of conjugate faults and fractures dominated by the Chavez Well-Thompson Canyon fault. The Chavez Well-Thompson Canyon fault has a maximum down-to-the-north displacement of 366 m and can be traced for several kilometers to the east and west of the study area. Numerous other transverse faults in the study area display both down-to-the-north and down-to-the-south displacement but they are rarely traceable for over a few kilometers. Laroche (1980) reported similar transverse faults in the northeastern Gallinas Mountains as did Lopez (1975) and Bornhorst (1976) to the southwest of the study area. Reconnaissance to the east of the study area and analysis of aerial photos and topographic maps suggest that such transverse faults are common throughout the Gallinas Mountains.

The Chavez Well-Thompson Canyon fault has greater displacement and lateral extent than any fault in the study area. Initial activity along the fault may have begun during the deposition of the volcaniclastic rocks of Chavez Canyon. At this time it was a growth fault as evidenced by the greater thickness of sediments deposited on the down-thrown side of the fault. Activity continued along the fault until late Tertiary or early Quaternary time as demonstrated by the termination of piedmont gravels along the fault.

The Chavez Well-Thompson Canyon fault commonly displays reverse drag. Numerous suggestions for the origin of reverse drag have been outlined by Hamblin (1965), who concluded that rather than being due to locally present conditions such as salt ridges, faulted monoclines, compression after faulting, double movement, elastic rebound, or faulted anticlines,

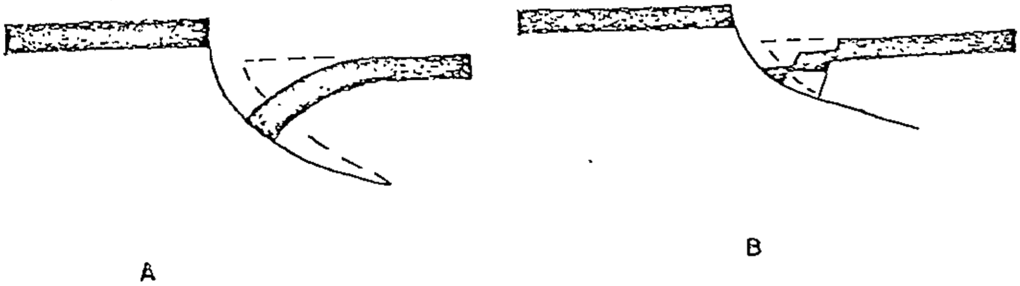


FIGURE 37. DEVELOPMENT OF REVERSE DRAG BY FLEXURE (A) RATHER THAN GRABEN DEVELOPMENT BY FRACTURE (B) (AFTER HAMBLIN, 1965)

reverse drag was a much more widespread phenomenon than such fortuitous situations would allow. Hamblin suggested that reverse drag is the result of movement normal to an arcuate fault plane which approaches horizontal at depth. Subsequent flexing rather than fracturing results in the formation of reverse drag (fig.37). Theoretical evidence for such arcuate fault planes has been presented by numerous workers (Evison, 1959 and Kanizay, 1962). Cloos (1968) experiments with clay blocks that were pulled apart on thin tin slabs that slide beneath one another formed reverse drag and fault patterns remarkably similar to transverse faults mapped in the study area.

The experiments of Cloos (1968) suggest that a north-northwest movement normal to the fault system occurred. Such movement might have been due to the northwest drift and clockwise rotation of the Colorado Plateau as postulated by Chapin (1971b). However, timing of initial faulting seems too early for opening of the Rio Grande rift and rotation of the Colorado Plateau. Alternatively these transverse faults may have originated as strike-slip faults along a zone of decoupling between the Colorado Plateau and the batholithically anchored Datil-Mogollon volcanic field. This strike-slip movement may have been due to the clockwise rotation of the Colorado Plateau, in which case it would be left-lateral, or to the opening of the southern segment of the Rio Grande rift an order of magnitude greater than the central segment (Chapin, 1978), in which case it would be right-lateral. Additional mapping to the east and west is needed to further document the fault patterns, timing, and sense of displacement.

Numerous high-angle northwest- and northeast-trending normal faults, which are more characteristic of the regional fault pattern, also transect the study area. These north-trending faults trend between N.45W. and N.45E., with northwest-trending faults more common. These faults are rarely traceable for more than 3 km and show displacement ranging from 6 to 150 m, with northwest-trending faults generally showing greater displacement. Cross-cutting relationships suggest that these faults were active concurrently throughout part of their history. Northeast-trending faults cut no units older than the Hells Mesa Tuff in the study area, whereas northwest-trending faults, such as the North Lake fault, disrupt late Tertiary to Quaternary units (fig.38).

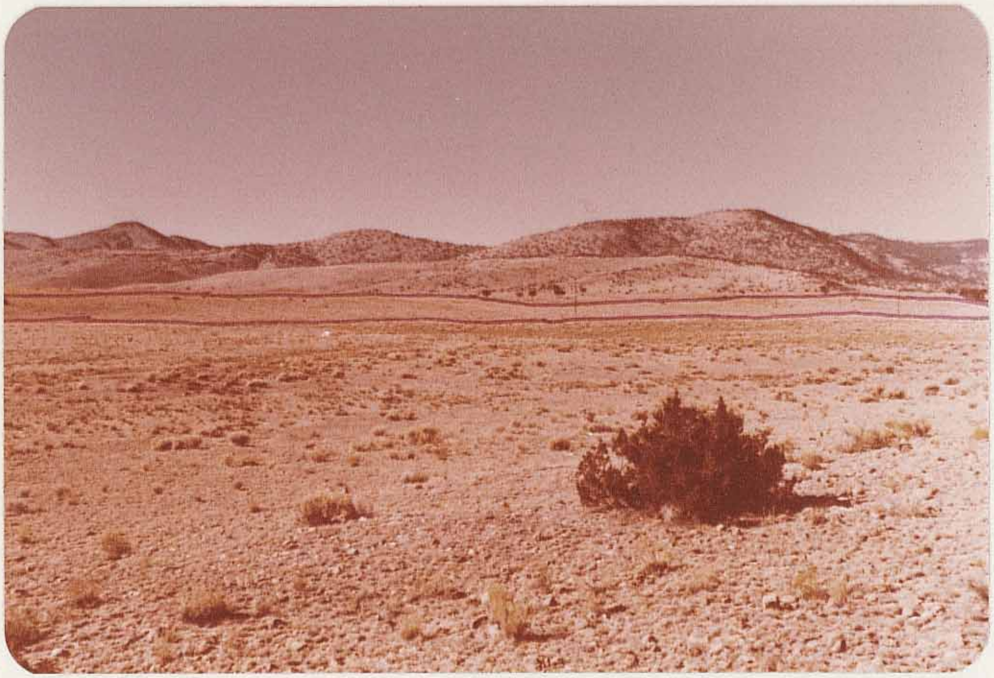


Figure 38. Photograph of North Lake Fault scarp.

ALTERATION MINERALIZATON AND ECONOMIC POTENTIAL

Alteration and mineralization in the study area is almost entirely restricted to the Dog Springs volcanic complex. The only exception is a mildly silicified outcrop of the upper cooling unit of the A-L Peak Tuff located in the North Lake embayment (Sec.26, T1N., R8W.). Alteration minerals in the Dog Springs volcanic complex consist of silica, chlorite, sericite, epidote and calcite. Mild propylitic alteration is present throughout the Dog Springs volcanic complex and generally increases in intensity near known or suspected fracture zones. Widespread green staining of the rocks in the Dog Springs volcanic complex has been attributed to the presence of celadonite (Harrison, 1980) and epidote.

Three types of vein mineralization are present in the study area. The most common veins are composed of calcite with no other visible mineralization present. Calcite veins are most abundant in the lacustrine rocks of Middle Canyon. Calcite veins are as much as 10 cm wide and can be traced for as much as 15 m (fig.39) Well-formed crystal faces indicate that the veins are the result of open-space filling of fractures. Good

Figure 39. Photograph of a calcite vein in the lacustrine rocks of Middle Canyon.

exposures of the calcite veins are located along the northern boundary of the study area. Blue-green veins of chalcedony are present in the upper member breccias of the Dog Springs volcanic complex. These veins are less than 25 mm in width, discontinuous, and appear to occupy zones of secondary fractures. No visible mineralization is present in the chalcedony veins which sometimes exhibit colloform textures. Small discontinuous hematite-magnetite veinlets (fig.40) are exposed throughout the Dog Springs volcanic complex and are especially well developed in the mudflow deposits of the upper member. These veinlets are generally zoned with hematite walls and magnetite cores. Veinlets are discontinuous and rarely exceed 12 mm in width. Fire assay of veinlet material collected near the mouth of Middle Canyon (of Sec.26, T.2N., R.8W.) yielded a silver value of 3.20 oz/ton and a gold value of 0.01 oz/ton. Fire assay of altered material, composed predominately of clay and minor magnetite, which surrounds some of the veinlets yielded no silver and only a trace of gold. Manganese dendrites and stains are common throughout the study area.

No other significant occurrences of mineralization are present within the study area but the presence of ground water and the possible presence of uranium add

Figure 40. Photograph of hematite-magnetite veinlets in a mudflow deposit in the upper member of the Dog Springs volcanic complex. Note that the cores are magnetite and the walls are hematite.

considerably to the economic potential of the area. Ground water is abundant in the study area and thus makes cattle ranching economically feasible. Two springs flow year round in Chavez Canyon and the relatively shallow water table in the northern portion of the study area has been tapped for several water wells. The North Lake embayment provides a semiclosed drainage basin from which several deep water wells pump large amounts of irrigation water. The water is used to irrigate hay and alfalfa which is grown in the North Lake Basin for cattle feed.

Small uranium occurrences in the Eocene Baca Formation are well documented (Anonymous, 1959; Chapin and others, 1979) along the southern margin of the Colorado Plateau. No exposures of the Baca Formation are present in the study area but exposures occur at Martin Ranch approximately 3 km north of the study area. If the Dog Springs volcanic complex is a volcano-tectonic depression or a cauldron the chances of finding the Baca Formation at a reasonable depth are slight, but if the Dog Springs volcanic complex is a wedge of intermediate composition volcanic breccias and mudflow, deposits the Baca Formation may be at a reasonable depth and possibly below the zone of surface oxidation, thus greatly enhancing the possibility of economic uranium occurrences. Some uranium potential may exists in the Tertiary or Quaternary sediments that underlie the North Lake Basin.

CONCLUSIONS

Geologic Evolution of the northwestern Gallinas Mountains

Stratigraphic and structural data from the study area suggest the following sequence of events for the evolution of the northwestern Gallinas Mountains.

1) During early Oligocene time (38-33 m.y. B.P) intermediate composition volcanism was active, along the northern margin of the Datil-Mogollon volcanic field. Initial activity resulted in the formation of the lower member of the Dog Springs volcanic complex, a thick sequence of tuff breccias. A thinner interval of monolithic andesite breccias, andesitic mudflow deposits, exotic blocks and interbedded sedimentary rocks, referred to as the upper member of the Dog Springs volcanic complex, was deposited upon the lower member. The monolithic hornblende andesite breccias of the upper member occur as intrusions and extrusives and thus define a vent facies.

Alteration and mineralization are generally limited to the rocks of the Dog Springs volcanic complex. Small amounts of silver-bearing magnetite-hematite veinlets are the only occurrence of potentially valuable mineralization.

2) Concurrent with, and following the formation of the Dog Springs volcanic complex, a period of deposition of fluviatile sediments characteristic of a braided stream environment began. Initial movement along east-northeast trending high-angle normal faults such as the Chavez Well- Thompson Canyon fault may have begun at this time. Sedimentary structures indicate a north-northwest transport direction for these sedimentary rocks. Active volcanism shifted to the southeast and southwest of the study area and fluviatile deposition was interrupted momentarily during the emplacement of the tuff of Rock House Canyon, the tuff of Blue Canyon and the Hells Mesa Tuff, but the generally northward transport direction of the fluvial system was not disrupted.

3) Following emplacement of the Hells Mesa Tuff (33 m.y. B.P.), the formation of the Rio Grande rift resulted in the formation of a broad southeast-plunging syncline and an extensive erosional surface within the region. The study area occupies the eastern flank of this syncline. Local unconformities between the volcaniclastic rocks of South Crosby Peak and the

various members of the A-L PeAk Tuff indicate that deformation was active throughout A-L Peak time. Deformation was concurrent with extrusion of the basaltic andesite of Twin Peaks which marks the onset of bimodal volcanism in the study area.

4) Development of high angle normal faults occurred from late Oligocene into Holocene time. However fault development has not been extensive in the study area and large areas are relatively intact.

5) Volcanic activity ceased in the area after deposition of the A-L Peak Tuff (30 m.y. B.P.) except for emplacement of a thin basalt flow during Pliocene (?) time.

6) Extensive development of piedmont deposits occurred from late Tertiary (?) to the present. During this period displacement along the North Lake fault dammed the North Lake embayment and resulted in the formation of a small playa.

Stratigraphic Correlations

Stratigraphic correlations of major volcanic units in the northwestern Gallinas Mountains with other volcanic units in the northeast corner of the

Datil-Mogollon volcanic field are summarized below. Some of these correlations are diagrammatically presented on Plate II (in pocket).

1) The Dog Springs volcanic complex is correlative to the Spears Formation of Cather (1980), the lower portions of the Spears Group as described by Lopez (1975) and Bornhorst (1976), the latite facies of Datil Formation as described by Willard (1957), portions of the Spears Ranch Member of the Datil Formation of Givens (1957) and portions of the Spears Member of the Datil Formation of Tonking (1957).

2) The tuff of Rock House Canyon is correlative to the tuff of Main Canyon (Harrison, 1980; Bornhorst, 1976 and Lopez, 1975) and the Tuff of Nipple Mountain (Laroche, 1980; Wilkinson, 1978; Chamberlin, 1974 and Brown, 1972).

3) The tuff of Blue Canyon is correlative to the tuff of Blue Canyon as mapped by Harrison (1980), Bornhorst (1976) and Lopez (1975), Tst2 as mapped by Mayerson (1979), and to Tdrspl as mapped by Stearns (1962).

4) The Hells Mesa Tuff is correlative, at least in part, to the tuff of Rock Tank as mapped by Lopez and Bornhorst (1979).

5) The pinnacles member of the A-L Peak Tuff is correlative to the tuff of Wahoo Canyon as mapped by Lopez and Bornhorst (1979) and Fodor (1975)(Harrison, 1980).

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This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Adviser

Clay T. Smith

David I. Norman

5/26/81

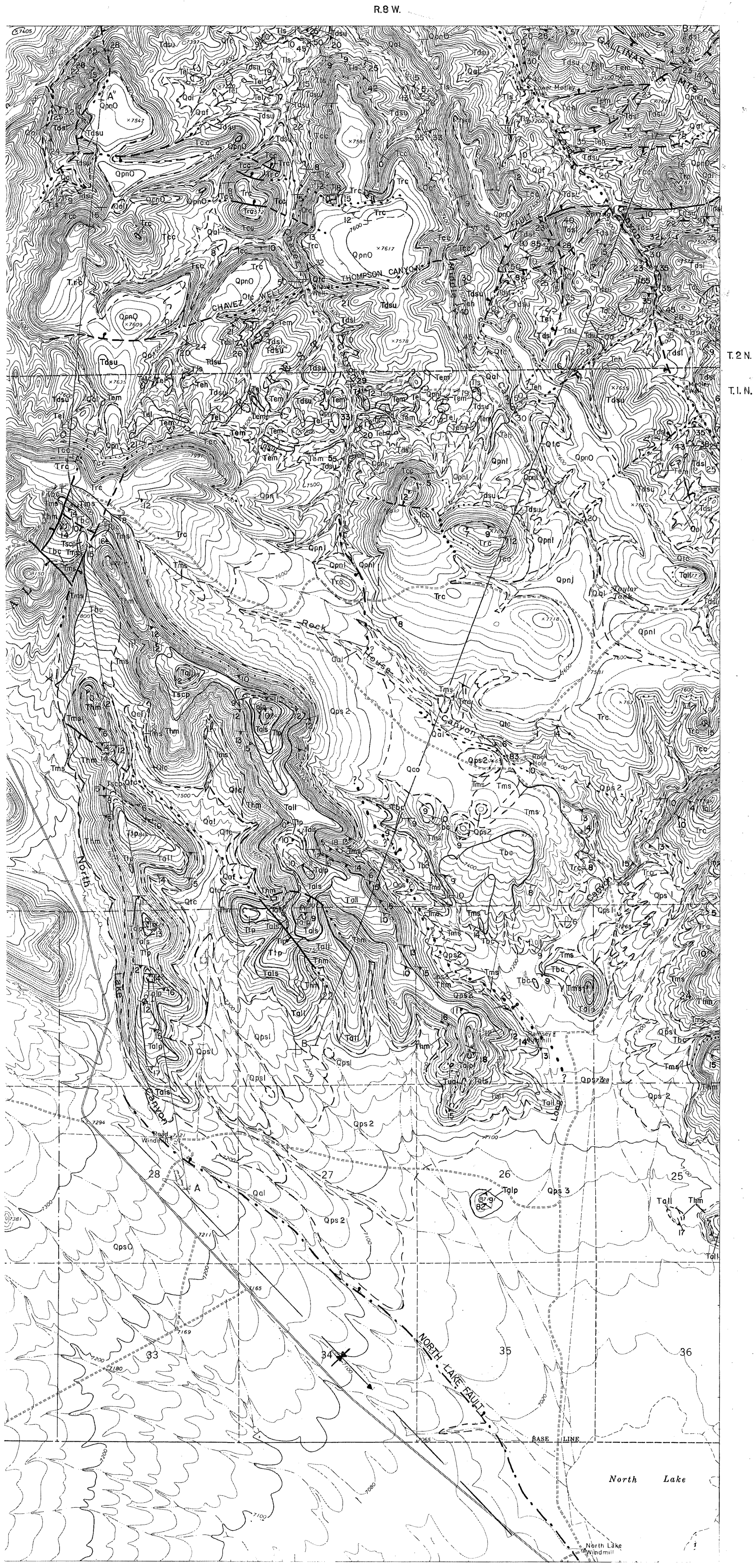
Date

PLATE I

GEOLOGIC MAP AND SECTIONS OF THE WESTERN GALLINAS MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

BY

GREG C. COFFIN



SCALE 1:24000

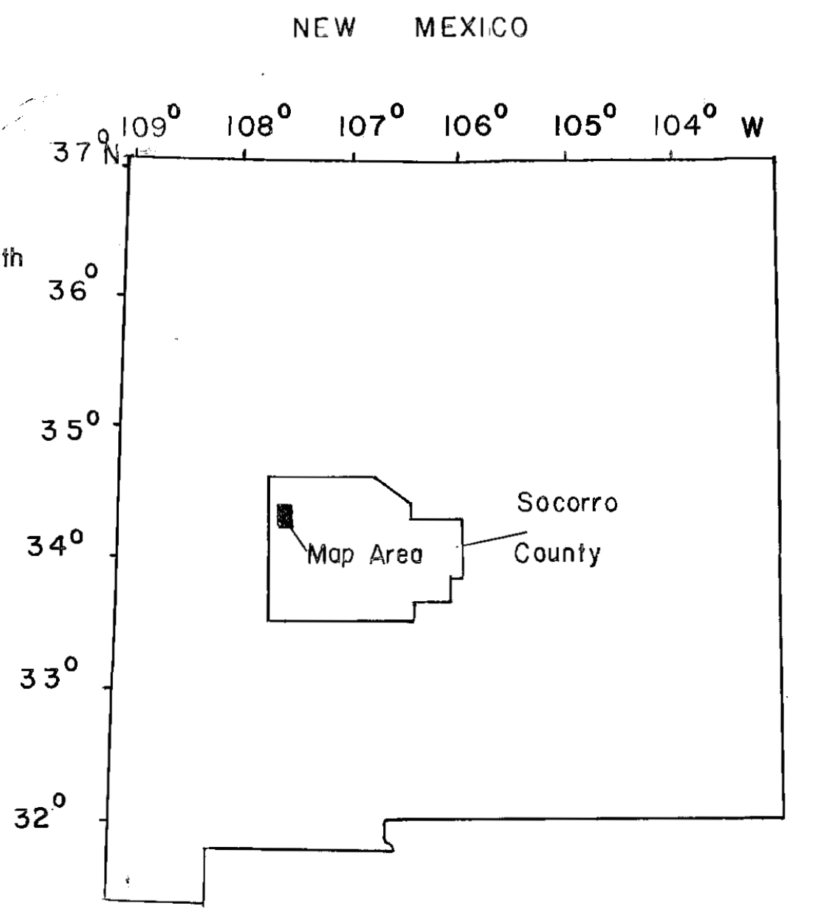
1 1/2 0 1 MILES

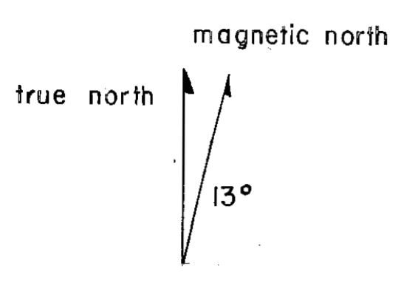
4000 2000 0 4000 FEET

1 0.5 0 1 KILOMETERS

CONTOUR INTERVAL 20 FEET

EXPLANATION





SURFICIAL DEPOSITS

QUATERNARY

Qal Alluvium

Qao Older alluvium

Qaf Alluvial-fan deposits

QUATERNARY-LATE TERTIARY

Qtc Colluvium

Qal, Qps3, Qps2, Qpsl, QpsO Southern Piedmont Deposits

Qpnl, QpnO Northern Piedmont Deposits

Tua Upper basalt and conglomerate

OLIGOCENE

Talp Pinnacles member of the A-L Peak Tuff: crystal-poor rhyolite ash-flow tuff.

Tals, Ttp Interbedded volcaniclastic rocks (Tals), and the basaltic andesite of Twin Peaks (Ttp).

Tall Lower cooling unit of the A-L Peak Tuff: crystal-poor rhyolite ash-flow tuff.

Tscp Volcaniclastic rocks of South Crosby Peak: sandstones, conglomerates and the crystal-poor, rhyolite, ash-flow tuff of South Crosby Peak

Thm Hells Mesa Tuff: crystal-rich, quartz latite ash-flow tuff.

DATIL GROUP

Spears Fm.

Tms Middle volcaniclastic rocks: sandstones and conglomerates of the Spears Formation above and below the tuff of Blue Canyon

Tbc Tuff of Blue Canyon: crystal-rich, latite ash-flow tuff.

Trc Tuff of Rock House Canyon: crystal-poor, latite ash-flow tuff.

Spears Fm.

Tcc Volcaniclastic rocks of Chavez Canyon: sandstones and conglomerates of the Spears Formation.

DOG SPRINGS VOLCANIC COMPLEX

Tdsu, Tls, Tem, Teh, Tel Upper member of the Dog Springs volcanic complex: intermediate-composition monolithic breccias, heterolithic mudflow deposits, interbedded mudstones and very-fine-grained sandstones (Tls) (pond deposits), and exotic blocks (Te-),

Exotic blocks: (Tel) limestone; (Teh) tuff breccia; (Tem) monolithic, crystal-rich, andesite breccia

Tdsl Lower member of the Dog Springs volcanic complex: intermediate-composition tuff breccias.

Contact, dashed where approximate, dotted where covered or inferred

Fault, dashed where approximate, dotted where covered, dashed and dotted where scarp.

approximate location of syncline axis, arrow points in direction of plunge

12 strike and dip of bedding

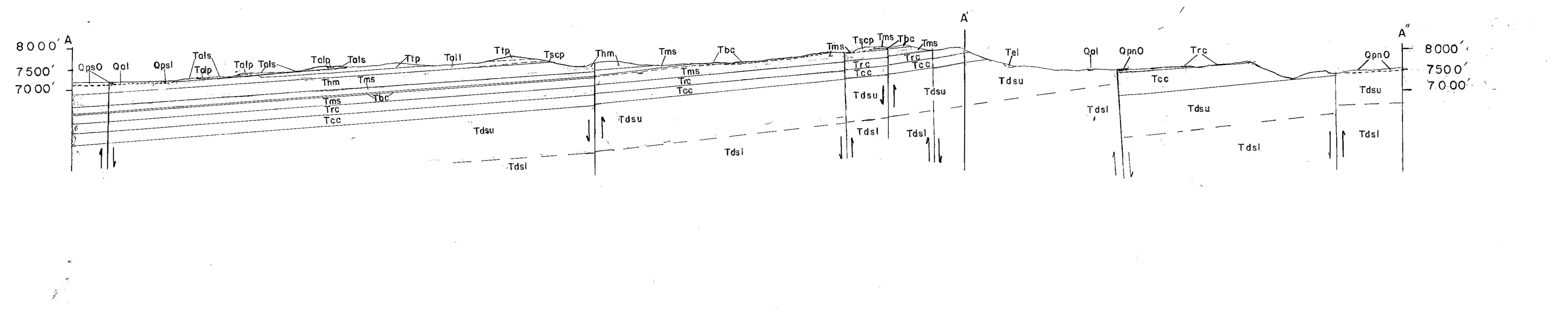
45 strike and dip of foliation

86 strike and dip of joint surface

Intrusive Rocks

Tdi Hornblende andesite breccia stock

hornblende andesite breccia dike Td



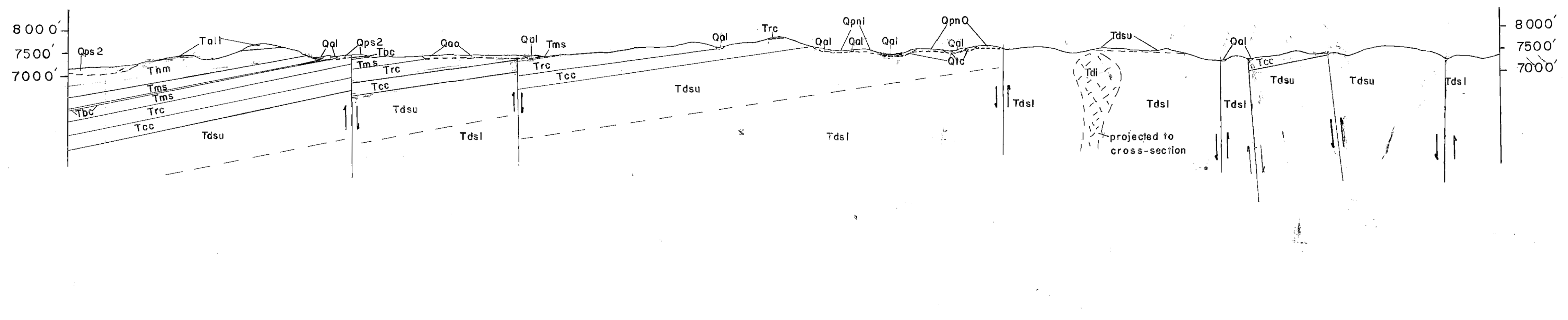


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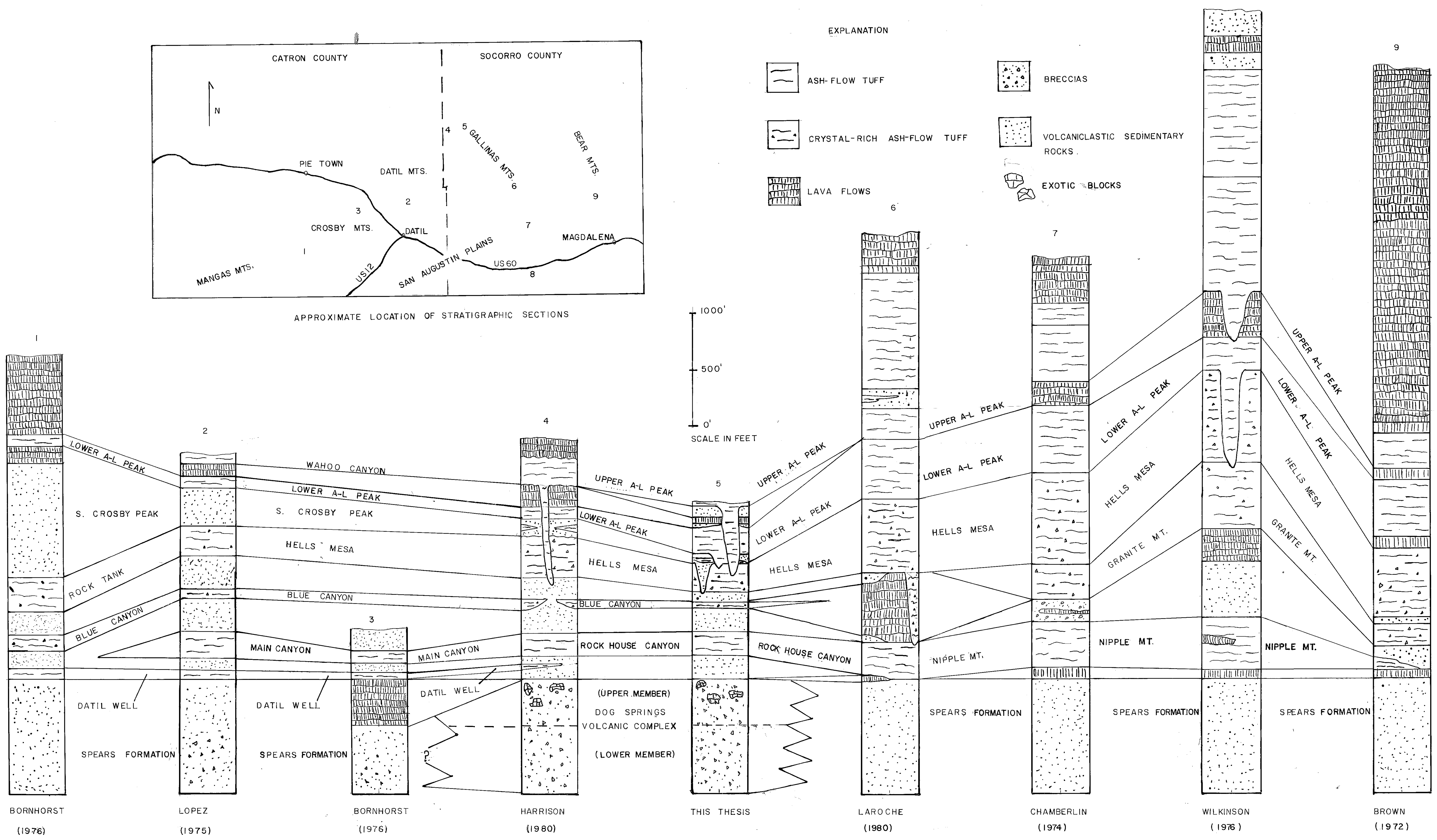
PLATE 2. CORRELATION OF MAJOR ASH-FLOW SHEETS ALONG THE NORTHERN MARGIN OF THE SAN AUGUSTIN PLAINS



APPROXIMATE LOCATION OF STRATIGRAPHIC SECTIONS