GEOLOGY OF THE NORTHEASTERN DATIL MOUNTAINS, SOCORRO AND CATRON COUNTIES, NEW MEXICO

by

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Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Geology

New Mexico Institute of Mining and Technology

Socorro, New Mexico

September, 1980

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ABSTRACT

The northeastern Datil Mountains has had a complex geologic history from the Oligocene to the present. In the early Oligocene (about 37 to 34 m.y. B.P.), intermediate volcanism resulted in the formation of the Dog Springs volcanic complex. This complex consists of quartz-latitic to andesitic vents, domes and pyroclastic and epiclastic breccias.

After the erosional leveling of the rocks of the Dog Springs volcanic complex, the northeastern Datil Mountains were characterized by a period of basinal filling with little tectonic disturbance. The basin was filled with volcaniclastic sedimentary rocks that show an overall fining-upward sequence and the intercalated tuff of Datil Well, tuff of Main Canyon, tuff of Blue Canyon, and Hells Mesa Tuff (about 32 m.y. B.P.).

Shortly after deposition of the Hells Mesa Tuff, extensional deformation associated with the Rio Grande rift created a southeast-plunging synformal downwarp in the northeastern Datil Mountains. Volcanic rocks deposited under the influence of this downwarp include the unit of South Crosby Peak and the A-L Peak Formation (30 to 32 m.y. B.P.). Northeast-trending, high-angle normal faulting began in the late Oligocene to early Miocene and continued into the Holocene. The youngest volcanic unit in the northeastern Datil Mountains is the Pliocene (?) basalt of Blue Mesa.

Correlations of Oligocene volcanic units made by this thesis include: the Dog Springs volcanic complex with portions of Lopez's (1975) and Bornhorst's (1976) Spears Formation; the Magdalena Project's tuff of Nipple Mountain with Lopez's (1975) and Bornhorst's (1976) tuff of Main Canyon; Chapin's (1974-b) Hells Mesa Tuff with Bornhorst's (1976) tuff of Rock Tank; and the pinnacles member of the A-L Peak Formation with Lopez's (1975) and Bornhorst's (1976) tuff of Wahoo Canyon.

INTRODUCTION

Purpose of the Investigation

The purpose of this investigation is to determine the stratigraphic and structural relationships of the Tertiary volcanic and volcaniclastic rocks in the northeastern Datil Mountains, New Mexico.

The detailed geologic study of this area is important for the following reasons:

1. The study area displays interfingering stratigraphic relationships between volcanic rocks previously studied in the central Datil Mountains (Lopez, 1975, and Bornhorst, 1976) and in the Gallinas and Bear Mountains (Brown, 1972; Chamberlin, 1974; Wilkinson, 1976; Laroche, in prep.) (see fig. 1). Correlation of units between these areas provides a further understanding of the Datil-Mogollon volcanic province and helps unravel the timing of geologic events.

2. A possible ash-flow tuff cauldron, of lower Spears age, exists in the area. The determination of it's areal extent and features are important in evaluating the economic potential of the area.

3. The area lies at the intersection of the Rio Grande

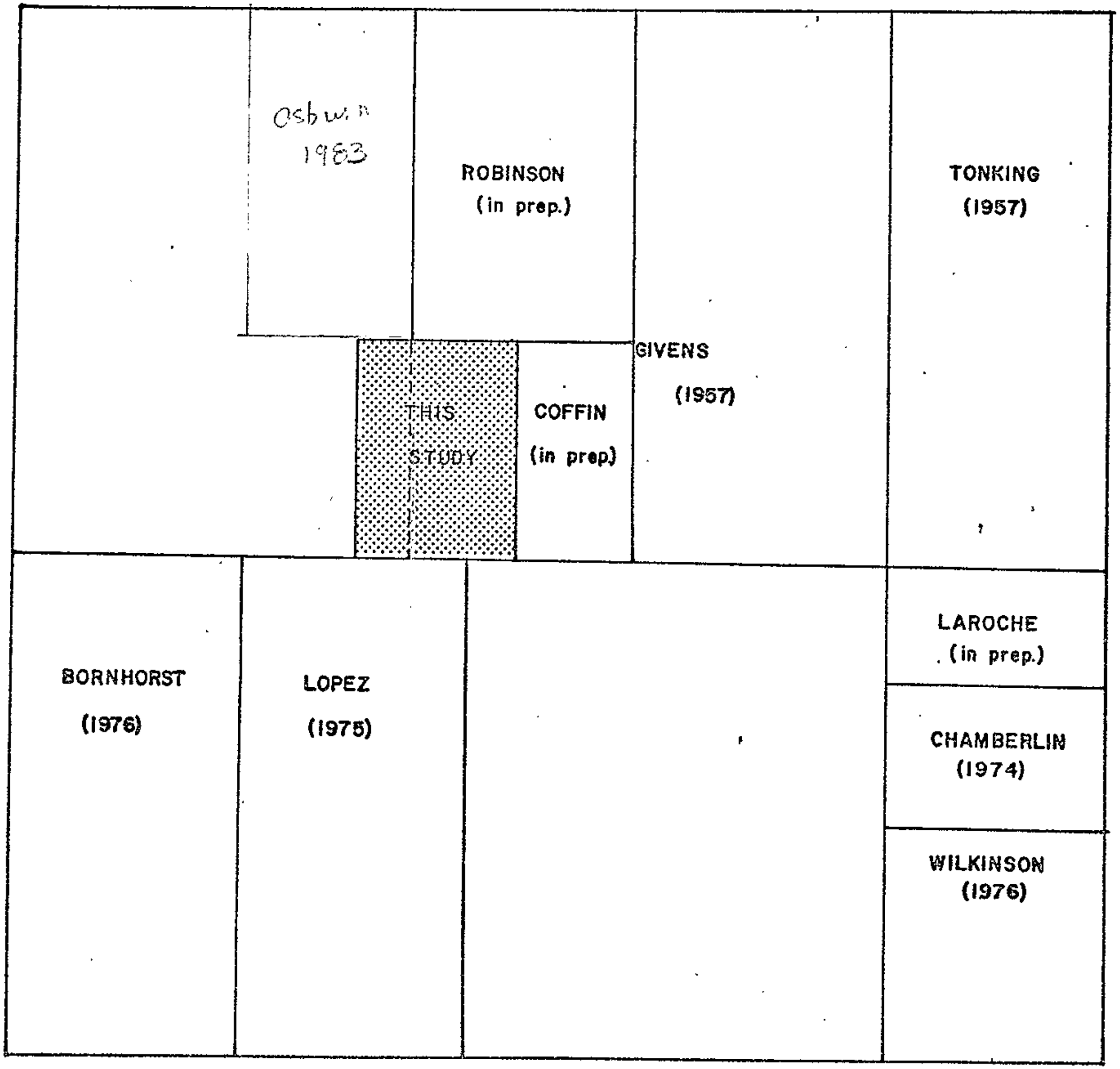


FIGURE 1. DIAGRAM SHOWING RELATIONSHIPS BETWEEN THIS STUDY AREA AND PREVIOUS AND PRESENT STUDY AREAS.

rift and the Colorado Plateau structural provinces. An understanding of the structural evolution of the area is, therefore useful to studies of regional tectonics.

Location and Accessibility

The area of study is located approximately twelve miles north-northeast of Datil, New Mexico. It is situated on the northern margin of the Datil-Mogollon volcanic field, adjacent to the Colorado Plateau. Physiographically, the area encompasses the northeastern Datil Mountains and a narrow portion of the Plains of San Agustin (see fig. 2). The area mapped covers about 48 square miles within the U.S. Geological Survey's Dog Springs and Cal Ship Mesa 7 1/2 minute quadrangles. The area is bounded by latitudes 34° 22' 30"N and 34° 15'N, and by longitudes 107° 41'W and 107° 46' 42"W. The western portion of the area lies within the Cibola National Forest and the eastern portion within the H-H Ranch, owned by J. Taylor.

Access from the southeast is provided by the unpaved North Lake - Red Lake Road and the main H-H Ranch service road which intersects U.S. Highway 60 approximately ten miles east of Datil. Additional access from the north is possible via an unpaved road which runs west out of the Alamo Indian Reservation. Numerous unpaved National Forest and ranch

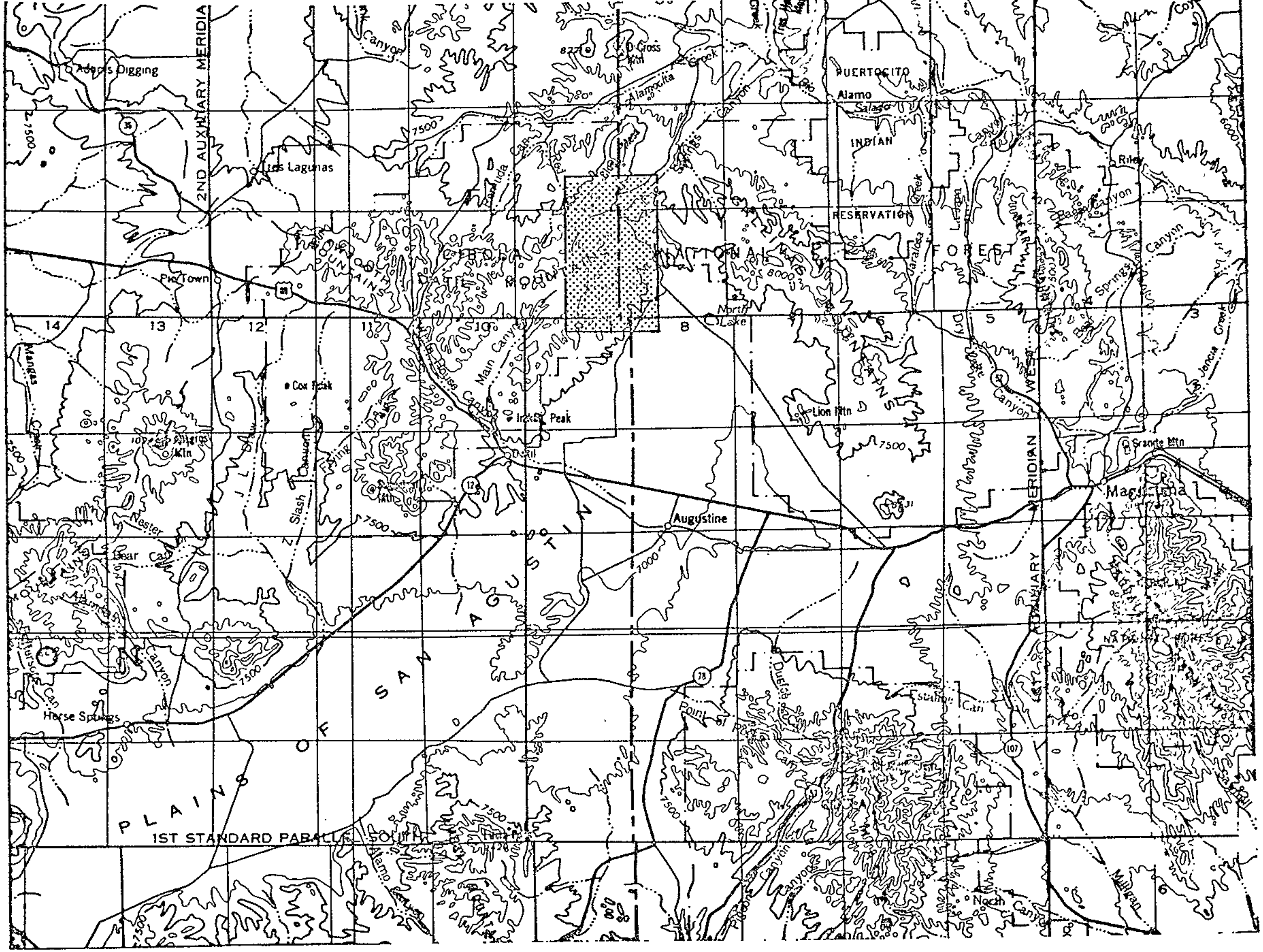


FIGURE 2. DIAGRAM SHOWING LOCATION OF STUDY AREA IN WEST-CENTRAL NEW MEXICO.

roads provide access to within about a mile and a half of any point in the study area.

Previous Works

The earliest geologic investigation in the Datil Mountains was conducted by Herrick (1900) as part of a regional reconnaissance survey of western Socorro and Valencia counties. He interpreted the Datil Mountains as composed of trachyte and rhyolite intrusives.

Winchester (1920) gave the name Datil Formation to the entire Tertiary sequence of tuffs, rhyolites, sandstones, and conglomerates that form the Datil Mountains. His type section, however was measured about 20 miles to the east of the Datil Mountains in the northern Bear Mountains. Wilpolt and others (1946) separated the lower arkosic rocks and mudstones from Winchester's Datil Formation and renamed them the Baca Formation.

Tonking (1957), from work in the Puerticito quadrangle at the north end of the Bear Mountains, expanded the Datil Formation to include the basaltic and basaltic-andesite rocks above Winchester's section. Thus, the Datil Formation of Tonking included the complete sequence of volcanic and sedimentary rocks above the Eocene Baca Formation and below the graben-fill sedimentary rocks of the late Tertiary Santa Fe Group. He subdivided the Datil Formation into a lower, quartz-latite Spears Member; a middle, rhyolite Hells Mesa Member; and an upper, basaltic-andesite La Jara Peak Member.

Givens (1957) informally subdivided the Hells Mesa Member of the Datil Formation into seven units on the basis of stratigraphic position, degree of welding, color and composition. His map of the Dog Springs 15-minute quadrangle in part overlaps the study area and represents the only previous, detailed geologic map of the area. Willard and Givens (1958) published a reconnaissance geologic map of the Datil 30-minute quadrangle.

Willard (1959) compiled a reconnaissance map of northern Catron and Socorro counties, to the west of this study area, in which he subdivided the Datil Formation into interfingering latite facies, volcanic sedimentary facies, rhyolite facies, and andesite facies. He also tentatively correlated the La Jara Peak Member of the Datil Formation with the Mangas basalts of the Mangas Mountains, and observed that the Mangas basalts regionally rested unconformably on all facies of the Datil Formation. Following Willard's observations, Weber (1963) excluded the La Jara Peak Member from the Datil Formation and reassigned it to a post-Datil sequence of basalts and basaltic-andesites. Later Weber (1971) raised the Datil Formation to group status and Chapin (1971-a) raised the Spears, Hells Mesa, and La Jara Peak Members to formation status.

From work in the Bear Mountains, Brown (1972) informally subdivided the Hells Mesa Formation into seven mappable units: the tuff of Goat Springs, a lower and an upper tuff of Bear Springs, the tuff of Allen Well, and three intercalated andesite intervals. Deal and Rhodes (1974) renamed the tuffs of Bear Springs the A-L Peak Rhyolite for exposures on the northeastern flank of A-L Peak, in the northern San Mateo Mountains. Chapin (1974-b) restricted the Hells Mesa Formation to the basal unit of Tonking's Hells Mesa Member which consists of crystal-rich, quartz-rich, quartz-latite to rhyolite ash-flow tuff, correlative to Brown's (1972) tuff of Goat Springs.

Lopez (1975) mapped the area surrounding Datil, New Mexico, immediately to the southwest of this study area, and divided the rocks of the Datil Group into two stratigraphic sections on opposite sides of a major fault. In the northern section, Lopez's upward sequence consists of the Spears Formation, a lower sedimentary unit, the rhyolite tuff of Main Canyon, a middle sedimentary unit, the rhyolite tuff of Blue Canyon, an upper sedimentary unit, the Hells Mesa Rhyolite, the A-L Peak Rhyolite, the basaltic-andesite of Twin Peaks, and the tuff of Wahoo Canyon. In the southern section, his upward sequence consists of the Spears Formation, the rhyolite tuff of Horse Springs, the rhyolite tuff of Ary Ranch, the rhyolite tuff of Crosby Mountain, the A-L Peak Rhyolite, the basaltic-andesite of Twin Peaks, and the tuff of Wahoo Canyon. Bornhorst (1976) described a stratigraphy similar to Lopez's southern section in the Crosby Mountains.

In addition, several masters theses have extended the Tertiary volcanic stratigraphy and structure westward from the Bear Mountains into the Gallinas Mountains as part of the New Mexico Bureau of Mines and Mineral Resources' Magdalena Project. Simon (1973) mapped the Silver Hill area, west of Magdalena, New Mexico; Chamberlin (1974) conducted a study of the Council Rock area in the southeastern Gallinas Mountains; and Wilkinson (1976) studied the geology of the Tres Montosas - Cat Mountain area.

Laroche (in prep.) is conducting an investigation of the central Gallinas Mountains area. Another concurrent thesis is being prepared by Coffin (in prep.) in the northwestern Gallinas Mountains, immediately to the east of this study area.

Methods of Investigation

Detailed geologic mapping was conducted at a 1:24,000 scale using the U.S. Geological Survey's Dog Springs and Cal Ship Mesa 7 1/2 minute topographic quadrangle maps. U.S. Forest Service color areal photographs of the F16-CIB series, 1974-75, were used as a guide to the location and configuration of outcrops. Field work was done during the summer and fall of 1979 and spring of 1980.

Thin-section analysis provided petrographic characteristics of the rocks and helped to support field correlations. Modal analyses of the volcanic units were made by the author using a Zeiss microscope equipped with a Swift automatic point counter. Plagioclase compositions were determined via the Rittmann Zone method using an universal stage. Volcanic rock names introduced by this thesis were adapted from the classification scheme of Lipman (1975, p. 5, fig. 3).

The southeastern portion of the study area lies within the Plains of San Agustin. The spelling used in this thesis is adopted from the original Spanish name for the plains. The U.S. Geological Survey's preferred spelling is Augustin.

Acknowledgements

Appreciation is due to the various people who aided in the preparation of this thesis. Primary regards are extended to Dr. C.E. Chapin, who suggested the problem and provided knowledge, criticism and encouragement; and to the New Mexico Bureau of Mines and Mineral Resources which supported the thesis. Special thanks go to Bob Osburn, who spent time in the field and provided many geologic insights; Greg Coffin, who worked in an adjoining field area and communicated many geologic observations; and to Dr. Richard Chamberlin, who played the role of a friendly 'Devil's Advocate.' Additional thanks go to Dr. C.T. Smith and Dr. D. Norman, who served on the thesis committee and reviewed the manuscript. And a very special, personal thanks goes to my wife Brenda, who provided inspiration and spent considerable time typing this thesis.

STRATIGRAPHY AND PETROLOGY

Pre-Oligocene Rocks

Pre-Oligocene rocks crop out only in the northwestern corner of this study area, on the upthrown side of the Red Lake fault. The area is structurally a gentle monocline dipping at about 4^{o} to the south. This slope was refered to by Fitzsimmons (1957) as the Mogollon Slope, and interpreted as the southern boundary of the Colorado Plateau. The rocks exposed on the slope belong to the Cretaceous Mesaverde Group and the Eocene Baca Formation (Snyder, 1971). The Mesaverde Group, in this study area, consist of yellowish-green sandstones, siltstones, and mudstones. The overlying rocks of the Baca Formation consist of terrestial red to white sandstones, conglomerates, siltstones, and mudstones. Studies of the pre-Oligocene rocks of this area are by to Robinson (in prep.), Snyder (1971), Gadway (1959), Dane and others (1957), Givens (1957), Pike (1947), and Winchester (1920).

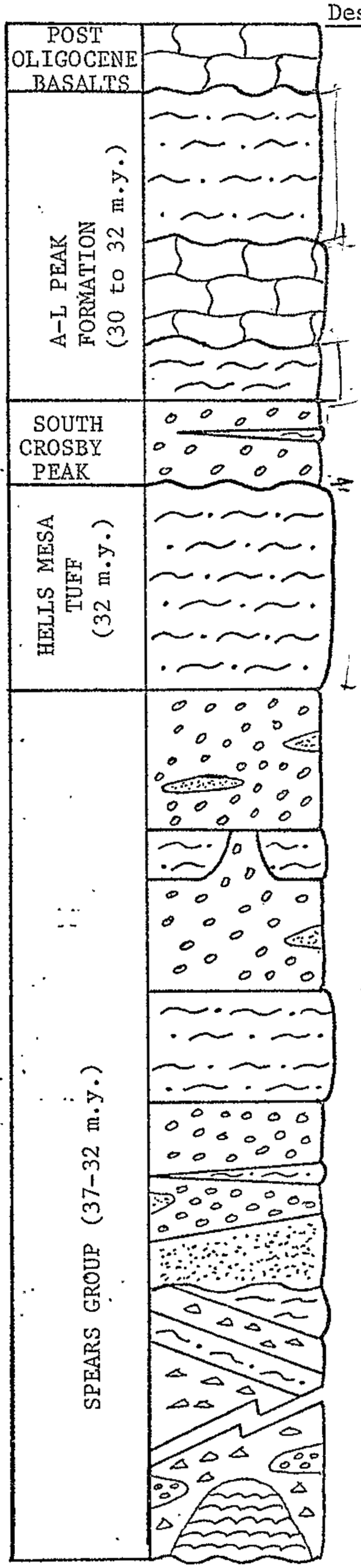
Tertiary Volcanic and Volcaniclastic Rocks

The rocks in the northeastern Datil Mountains consist predominantly of welded ash-flow tuffs, lava flows and intercalated volcaniclastic sedimentary rocks of Tertiary age. These rocks crop out throughout the entire study area except where they are buried by younger gravel deposits and alluvium. Of these rocks, Oligocene volcanic and volcaniclastic rocks dominate, and are divisible into four units. From oldest to youngest, these are the Spears Group, the Hells Mesa Tuff, the volcaniclastic rocks of South Crosby Peak, and the A-L Peak Formation (see fig. 3). The lower portion of the Spears Group in the northeastern Datil Mountains consists of a volcanic complex of unknown thickness. Above this complex, a maximum total thickness for the Oligocene rocks is estimated to be about 2300 ft (700m). A maximum of about 100 ft (30m) of post-Oligocene basaltic rocks overlie the Oligocene units.

Spears Group

The name Spears Ranch Member of the Datil Formation was initially given by Tonking (1957) to the quartz-latite tuffs and andesitic volcaniclastic rocks lying above the arkosic rocks of the Eocene Baca Formation and below the rhyolite Hells Mesa member of the Datil Formation. Tonking's type section is located approximately 1 mile south of the Guy Spears Ranch Headquarters in sec. 8, T.1N., R.4W. Weber (1971) raised the Datil Formation to group status and Chapin (1971-a) raised the Spears Member to formation status.

Figure 3. Composite stratigraphic column of the northeastern Datil Mountains, showing relative maximum thicknesses of the Oligocene volcanic and volcaniclastic sedimentary rocks.



Map Designation	Description
Tbm	Basalt flow of Blue Mesa (0-100 ft, 0-30m) - porphyritic olivine tholeiite basalts.
Talp	Pinnacles member (0-125 ft), 0-76m) - moderately welded, crystal-poor rhyolite ash-flow tuff.
Ttp	Basaltic-andesite of Twin Peaks (0-200 ft, 0-61m) - vesicular, microporphyritic basaltic-andesite flows; vesicules commonly filled with calcite.
Tall	Lower member (0-120 ft, 0-37m) - moderately to densely welded, crystal-poor rhyolite ash-flow tuff; multiple-flow, compound cooling unit.
Tscp	Volcaniclastic unit of South Crosby Peak (0-150 ft, 0-46m) - ash-fall tuffs, reworked ash-fall tuffs, minor pebble to cobble conglomerates and the poorly welded, crystal-poor, pumice-rich ash-flow tuff of South Crosby Peak.
Thm	Hells Mesa Tuff (0-400 ft, 0-122m) - moderately to poorly welded, crystal-rich, quartz-rich rhyolite ash-flow tuff; multiple-flow, simple cooling unit.
Tmsu	Middle sedimentary unit (100-300 ft, 30-91m) - pebble to cobble conglomerates, sandstones lenses; generally fines upward with typical aeolian sandstone deposits near top; above tuff of Blue Canyon.
Tbc	Tuff of Blue Canyon (0-100 ft, 0-31m) - moderately to poorly welded, crystal-rich, quartz-poor quartz-latite ash-flow tuff.
Tmsl	Middle sedimentary unit (0-200 ft, 0-61m) - pebble to cobble conglomerates, sandstone lenses; below tuff of Blue Canyon.
Tmc	Tuff of Main Canyon (150-300 ft, 46-91m) - moderately to poorly welded, crystal-poor, moderately pumice-rich ash-flow tuff.
Tcc Tdw	Volcaniclastic sedimentary unit of Chavez Canyon (150-400 ft, 46-122m) - feldspathic sandstones, pebble to cobble conglomerates, and minor debris-flow breccia; interbedded within this unit is the moderately welded, crystal-rich ash-flow tuff of Datil Well.
Tds	Dog Springs volcanic complex (3000+ ft, 900+m) - quartz-latitic to andesitic vents, domes, and pyroclastic breccias; laharic breccias; minor ash-flow tuffs, sedimentary rocks, and megabreccia blocks.

Vertical Scale

Certain stratigraphic features of the Spears in this study area render it's formation status impracticable. As defined by the Code of Stratigraphic Nomenclature, "A formation is a body of rock characterized by lithological homogeneity." The stratigraphic interval occupied by the Spears contains rock types varying from rhyolite ash-flow tuffs, to quartz-latite ash-flow tuffs and tuff breccias, to basaltic-andesite flows, to volcaniclastic deposits of conglomerates, sandstones and mudflows. In addition, most of the ash-flow tuff sheets within the Spears possess the characteristics of distinctive lithology and mappability, which warrent them formation status in their own right. It is therefore informally proposed that the Spears be elevated to group status and that the major ash-flow tuffs and other mappable units within the Spears be elevated to formation status. Formalization of this proposal is in preparation by C.E. Chapin and G.R. Osburn.

The Spears Group is the basal Tertiary volcanic unit of the northern Datil-Mogollon volcanic field. In that sense, it is temporally correlative to the Rubio Peak Formation of Jicha (1954), Elston (1957), and Jones and others (1967), which represents the basal Tertiary volcanic unit of the southern portion of the volcanic field. Both units are of intermediate, andesite to quartz-latite composition. The Spears Group is also probably correlative to the lower andesite unit of Stearns (1962) and the epiclastic volcanic rocks of Ratte and others (1967), located along the northwestern margin of the Datil-Mogollon volcanic field. A similarity can be drawn between these rocks and the San Juan, Lake Fork, and Conejos Formations of intermediate composition in the San Juan volcanic field, Colorado (Lipman and others, 1970).

Dog Springs Volcanic Complex

Speculations on the existence of a volcanic complex and a possible ash-flow tuff caldera grew out of the mapping of B. Robinson (in prep.) in the southern portion of the D-Cross 7 1/2' quadrangle. There, a thick accumulation of volcanic rocks apparently cross cut rocks of the Cretaceous Mesaverde Group and Eocene Baca Formation. Reconnaissance of the area by C.E. Chapin and G.R. Osburn revealed the presence of several thousand feet of quartz-latite tuff breccias, rhyodacite autobrecciated rocks and minor quartz-latite ash-flow tuffs. The geologic mapping of the Dog Springs 7 1/2' minute quadrangle and the eastern portion of the Cal Ship Mesa 7 1/2' quadrangle, by this thesis and a thesis in preparation by G. Coffin, documents the existence of an Oligocene volcanic complex in this region. The complex is herein referred to as the Dog Springs volcanic complex, for exposures of it's various rock types along Dog Springs Canyon in secs. 29-32, T.2N., R.8W.

tuff breccias

The dominant rock type of the Dog Springs volcanic complex in this study area is hornblende quartz-latite tuff breccia. The term tuff breccia is adopted from Parsons (1967) and applies to "volcanic breccias with a large percentage of fine-grained tuffaceous matrix." The term was originally defined by Norton (1917). Minor amounts of hornblende quartz-latite ash-flow tuffs and lavas are associated with the tuff breccias.

Both heterolithic and monolithic tuff breccias are recognized in the complex. The two types grade into each other with diffuse boundaries and share a similar matrix of pyroclastic material, which is identical to the ash-flow tuffs of the Dog Springs volcanic complex. Phenocrysts of feldspar, hornblende and biotite are most prominent, and there is a notable absence of vesicular and scoriaceous material.

Outcrops of the tuff breccias are generally massive and seldom show stratification. The few exposures that do show bedding are typically alternating sequences of fine-grained lava flows and thin breccia flows. Exposures of the breccias are usually limited to hill crests and valleys, with slopes typically covered by debris.

The heterolithic tuff breccias contain angular to subrounded clasts, which are nonsorted and are extremely heterogenous as to size (see fig. 4). The size range of the

Figure 4. Photograph showing a heterolithic quartz-latite tuff breccia outcrop. Note the nonsorted angular to subrounded clasts of various lithologic types.

Figure 5. Photograph showing a closeup of monolithic tuff breccia in the Dog Springs volcanic complex. The majority of the clasts are of hornblende quartz-latite composition. The red clast marked 1 is a siltstone (Permian Abo or Yeso?); the dark clast marked 2 is a Precambrian schist.

clasts is from a few millimeters across to megabreccia blocks several hundred meters in diameter. Clast compositions include Precambrian schists, amphibolites and granitic gneisses; red siltstones (Permian Abo and Yeso?); limestones (Permian San Andres or Pennsylvanian Madera?); and minor siltstones and sandstones.

The monolithic tuff breccias are volumetrically far greater than the heterolithic type. In essence, however they are never truely monolithic in that they almost invariably contain a few percent of heterolithic fragments of the same lithologies previously mentioned (see fig. 5). Yet, they are considered monolithic in that they are composed of essentially one clast type. This clast type is of hornblende quartz-latite composition and is extremely similar to that of the matrix of the tuff breccias. The clasts are subrounded to angular and generally 2 centimeters or less in diameter. The clasts usually have a light-gray color which contrasts to the usual brownish color of the matrix.

Petrographically, the monolithic breccias are crystal-rich, hornblende quartz-latite tuff breccias, with subrounded inclusions (see fig. 6). They have a pyroclastic textured matrix, which is totally devitrified. Pumiceous material is totally absent, which coupled with the total devitrification of the matrix makes it impossible to determine the degree of welding.

Phenocrysts are conspicuously broken and consist of plagioclase, sanidine, hornblende, biotite, and pyroxene.

Figure 6. Photomicrograph of quartz-latite tuff breccia of the Dog Springs volcanic complex. Note the pyroclastic matrix and the subrounded inclusions. (10x, cross nicols)

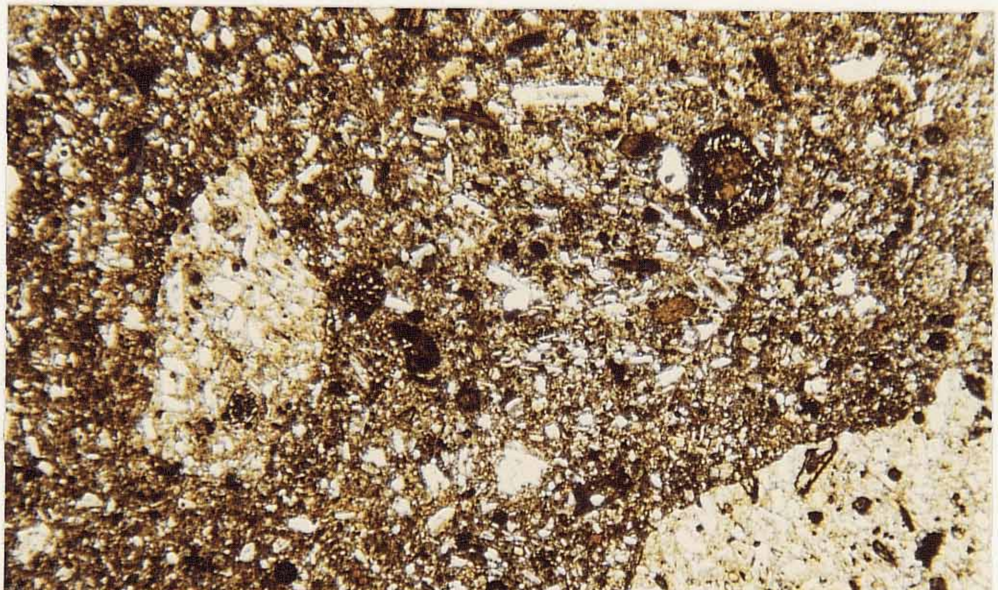


Figure 7. Photomicrograph of laharic breccia of the Dog Springs volcanic complex. Note the pyroclastic matrix similar to above, only more crystal rich, and the angularity of the clasts. The large feldspar grain in the center of the photograph attests to abrasion, as it has apparently been plucked from the large clast to the right. (10x, cross nicols)

Table 1. Modal analyses in volume percent of the quartz-latite tuff breccias in the Dog Springs volcanic complex.

	1	2	3	4
Total Phenocrysts	43.5	35.2	39.6	43
Plagioclase	26.9	20.9	24.0	27.2
Sanidine	5.2	4.3	5.7	5.4
Hornblende	9.1	7.2	5.9	12.1
Biotite	2.3	2.3	3.2	5.9
Pyroxene	trace	0.5	0.8	trace
Points Counted	1818	1959	1863	2010

Modal analyses of four samples are given in Table 1. Plagioclase phenocrysts are euhedral to subhedral, normally zoned from about An_{25} to An_{52}, with an average composition of about An_{40}. Sanidine crystals are typically subhedral to euhedral and highly embayed. Hornblende, biotite, and pyroxene are euhedral to subhedral and commonly oxidized to reddish-brown iron oxides around their margins. Opaque oxides, usually after hornblende, are also present in varying amounts. Replacement of the feldspars and matrix by calcite is very extensive. Alteration of the ferromagnesian minerals to chlorite is common.

The clasts in the monolithic breccias are mineralogically similar to the tuff breccias as a whole and are best described as fragments of hornblende quartz-latite lavas. The clasts have unbroken, euhedral crystals which are crudely aligned in a subparallel, trachytic fashion (see fig. 6). Modal analyses of these clasts are identical to those of the surrounding tuff breccias, indicating a probable genetic relationship.

The tuff breccias of the Dog Springs volcanic complex differ from typical pyroclastic breccias (ash-flow tuffs) in that they lack the pumice and glass shards indicative of rapidly vesiculating magmas. Two types of breccia emplacement could result in rocks similar to the tuff breccias of the Dog Springs complex. They could be derived from either the crumbling of domes, or from underground brecciation and subsequent breccia flows (Parsons, 1967).

Breccia deposits formed by the crumbling of domes should consist of unsorted, angular, monolithic, lava fragments - similar to the monolithic tuff breccias of the Dog Springs complex. However, problems exist in interpreting the origin of the tuff breccias of the Dog Springs complex in this manner. First, the accumulation of a pile of rocks as thick, and as extensive as the Dog Springs complex would require a considerable number of debris yielding domes. But, no dome-like masses of similarly composed material have been encountered. In addition, lava flows within the complex are rare. Whereas there are small, minor lava flows in the complex, they make up less than 1% of the exposed rock.

An alternate emplacement mechanism of underground brecciation and subsequent breccia flows is described by Parsons (1967) in the Absaroka volcanic field. The resulting deposits are unsorted, poorly bedded, heterolithic breccias with a clastic, tuffaceous matrix of lithic and crystal fragments and little vesicular material. Parsons indicates that extrusion occurs as fragmented lava flows, sills and/or dikes due to "volcanic explosions and the upward push of rising magmas." Emplacement of the tuff breccias in the Dog Springs complex by similar means could explain the heterolithic breccias and the monolithic breccias (assuming a moderate congealment of the lava prior to eruption and brecciation), and also could provide a means for flotation of the megabreccia blocks. In addition, this could help explain the dikes of tuff breccia observed by Lopez (1975) and

Bornhorst (1976) in adjacent areas. Various mechanisms for underground brecciation are discussed by Gates (1959) and are summarized by Parsons (1967) as 1) solution stoping 2) explosive eruptions 3) gas fluxing and explosion and 4) rock burst.

megabreccia blocks

Scattered throughout the Dog Springs volcanic complex are blocks of megabreccia (xenoliths). These megabreccia blocks are as large as several hundreds of meters in diameter, and are completely surrounded by tuff breccia. Their attitudes range from nearly horizontal to vertical and are usually discordant to the surrounding rocks.

Lithologies of the megabreccias are dominantly limestone with minor siltstone, shale, sandstone and ash-flow tuff. The limestone blocks are micritic, cherty, and contain fossil fragments of brachipods, corals, bryozoans and crinoid stems. The major limestone units in west-central New Mexico are of Permian and Pennsylvanian age. Unfortunately, the fossil assemblage is not adequate to identify these rocks as either Permian or Pennsylvanian in age. However, Givens (1956, p. 14) indicates that Dr. R.H. Flower believes these limestones to be of Permian affinity. This is supported by Foster's (1957) isopach maps of west-central New Mexico, which show approximately 2500 ft (762m) of Permian rocks and virtually a very thin to absent Pennsylvanian section in the immediate vicinity of the study area.

Immediately to the south of this study area, Lopez (1976) describes large limestone, siltstone, and sandstone blocks within his Spears mudflow breccia in sec. 12 T.1S., R.10W. and sec. 3, T.1S., R.9W. He tenatively identified these blocks as from the Pennsylvanian Madera and Permian Abo and Yeso Formations, respectively. It is probable from their nearby location and similar lithologies, that these blocks are also megabreccia within the Dog Springs volcanic complex.

As defined by Lipman (1976), megabreccias are caldera-collapse breccias in which individual clasts are larger than 1m in diameter. A problem exists in interpreting the megabreccia of the Dog Springs volcanic complex as of collapse origin, as there is no indication of Permian, or older, rocks being available near the surface. In fact, considering a thickness of about 1250ft (435m) for the Baca Formation (Snyder, 1971), and approximately 2000 ft (696m)

Closer to 2000'

for Cretaceous and 800 ft (278m) for Triassic rocks (Foster, 1957), the Permian limestone blocks have been raised at least 4050 ft (1409m) stratigraphically. Regional tumescence of this extent seems unlikely.

Perhaps the most feasible explanation is that these megabreccia blocks were literally floated upward, and perhaps rafted laterally, during deposition of the tuff breccias. An occurrence similar to this is described by Pierce (1963) in a heterolithic breccia vent in the northern Absaroka Range, where a 700-ft-long block of Paleozoic limestone was lifted nearly 1000 ft (300m) within a 2-mile-diameter vent. Pierce described the block's margins as brecciated and the fragments recemented -- a feature commonly observed in the limestone megabreccia blocks of the Dog Springs complex (see fig. 8).

Located near the center of sec. 35, T.1N., R.9W. is a nearly vertical dike-like mass of ash-flow tuff, sandstone and mudstone (see fig. 9). The mass is approximately 150 ft (50m) wide and nearly 1450 ft (440m) long. It is enclosed by the quartz-latite tuff breccia and is discordant to the surrounding rocks. The ash-flow tuff is cut by thin clastic veins and the sedimentary rocks show a truncated lower contact with the tuff breccia (see fig. 10).

Petrographically, the ash-flow tuff is a moderately welded, crystal-rich quartz-latite. It has a partially devitrified, vitroclastic matrix and approximately 43% phenocrysts. Plagioclase is the dominant phenocryst, making up approximately 25% of the rock. The plagioclase crystals are commonly broken, subhedral to anhedral, and have an average composition of An_{29}. Sanidine occurs as euhedral to subhedral crystals and comprises approximately 8% of the rock's volume. Biotite also comprises about 8% of the rock, and occurs typically as euhedral crystals, which often appear to be bent and strained. Rounded quartz phenocrysts make up about 1% of the rock's volume; and pyroxene and hornblende are both present in trace amounts.

Figure 8. Photograph of a limestone megabreccia block in the Dog Springs volcanic complex. Note breccia clasts that have been recemented.

Figure 9. Photograph of megabreccia blocks (?) (foreground and distant) of biotite-rich ash-flow tuff in the Dog Springs volcanic complex. Location is in NE ¼ sec. 3, T.1S., R.9W., and SW ¼ sec. 35, T.1N., R.9W., view is to the north.

Figure 10. Photograph of sedimentary rocks (under hammer) associated with the ash-flow tuff megabreccia block shown in Figure 9. Note the truncated lower contact with the quartz-latite tuff breccia of the Dog Springs volcanic complex.

The origin of these rocks is problematical. They could represent either the intrusion of younger rocks, or the collapse of older rocks into the Dog Springs complex. The presence of clastic veins, vertically bedded sediments and the apparent truncation of the bottom of the mass favor a collapse origin. Lipman (1976, p. 1403) has interpreted andesitic megabreccia blocks in the San Juan Caldera, Colorado, with dimensions similar to those of this megabreccia block and also having associated clastic veins and basal sedimentary rocks as being of collapsed origin.

Reconnaissance in the northwestern Datil Mountains has revealed the presence of an ash-flow tuff of lithology similar to these rocks. However, it's stratigraphic relationship to the Dog Springs complex is unknown. Further geological mapping in that region is required to determine the relationships between these units.

laharic breccias

Interbedded with the tuff breccias are numerous laharic breccia deposits. These breccias have a characteristic appearance of light-gray, porphrytic clasts set in a dark red-brown, sandy to muddy matrix (see fig. 11). They are unsorted and poorly bedded. The laharic breccias are gradational into the tuff breccias.

Figure 11. Photograph of laharic breccia in the Dog Springs volcanic complex. Light-colored clasts are fragments of hornblende quartz-latite rocks identical to the clasts in the tuff breccias.

The clasts in the laharic breccias are identical to the clasts in the monolithic tuff breccias, both petrographically and in hand specimen. They are angular to subrounded in shape, have a trachytic texture, and compositionally are hornblende quartz-latite (see fig. 7). The laharic breccias differ from the monolithic tuff breccias in that their matrix is redder, finer-grained, and more crystal-rich and the clasts show more angularity and abrasion.

Two methods have been envisioned for the formation of laharic breccias. 1) They are the result of the saturation and remobilization of the tuff breccias after initial deposition (Anderson, 1933; Parsons, 1967); or 2) the tuff breccias grade outward into laharic breccias during initial deposition. The latter could result from eruptions through crater lakes, eruptions accompanied by heavy rain falls (Anderson, 1933), or even when pyroclastic flows encounter streams (Williams, 1956). Both mechanisms could have played a role in the formation of the laharic breccias in the Dog Springs complex.

rhyodacite intrusive and extrusive rocks

The youngest volcanic rocks of the Dog Springs complex are rhyodacite intrusive, extrusive rocks, and associated debris-flow deposits. These rocks are dominantly autobrecciated, however they have minor, massive, unbrecciated portions which are irregular in shape. Under Wright and Bowes' (1963) breccia classification, the brecciated rocks would be termed friction breccias. The term applies to autoclastic volcanic breccia which "forms by the disruption of lava by further movement after part of the mass has congealed." Lipman (1975) has referred to similar rocks as explosion-breccias. Whether the autobrecciated rocks of the Dog Springs complex are of explosive derivation, or are the result of the frictional tearing apart of highly viscous magma is undetermined, therefore the term autobreccia is preferred. The rhyodacitic rocks intrude the quartz- latite tuff breccias in the form of plugs, vents, and dikes (see fig. 12). Minor rhyodacitic flow-breccias [friction-breccias which form by unconfined lava flow (Fisher, 1960, p. 974)] are interbedded within the quartz-latite tuff breccias.

In the study area, the rhyodacitic rocks crop out throughout the exposed Dog Springs complex. However, a north-trending belt of vents occurs through the center of the area, with three individual vents located in 1) the north-central portion of sec. 3, T.1S., R.9W.; 2) in secs. 23 and 26, T.1N., R.9W.; and 3) in secs. 1, 11, and 12, T.1N., R.9W. These vent areas are exposed through several hundreds of feet of topographic relief, with no apparent bottom. They cover areas ranging from approximately 1/4 to 1 square mile. Attitudes within the vents are chaotic and commonly very steep. The vents are frequently cut by small faults, probably contemporaneous with deposition, and numerous small,

Figure 12. Photograph of an autobrecciated rhyodacite dike in the Dog Springs volcanic complex.

Figure 13. Photograph of autobrecciated rhyodacite showing the angularity, wide range in size, and monolithic composition of the clasts.

post-depositional tension fractures. The vents also have spotty patches of hydrothermal alteration.

The vents consist largely of autobrecciated rocks, especially around their periphery and in their upper portions. In the lower portions of the vents, massive rhyodacitic rock is common. The massive rocks occur both as irregular bodies which grade into autobrecciated rock, and as dikes which crosscut autobrecciated rocks.

The autobrecciated rocks are poorly sorted, poorly stratified and contain monolithic, angular to subrounded clasts. The clasts are very heterogeneous as to size, with a range from a few centimeters to a meter or more in diameter (see fig. 13). Both the clasts and the matrix are brown, crystal-rich rocks with phenocrysts of plagioclase, hornblende, pyroxene and minor sanidine and biotite.

Petrographically, these rocks are rhyodacitic in composition and contain approximately 45% phenocrysts. The average size of the phenocrysts is about 2mm in diameter. Euhedral to subhedral plagioclase crystals comprise about 31% of the rock. They are normally zoned and average An_{41} in composition. Sanidine makes up only about 1% of the rock and occurs as highly embayed, anhedral crystals. Hornblende comprises about 9% of the rock, clinopyroxene comprises about 4% and biotite is present in trace amounts. The mafic minerals are euhedral to subhedral in shape and commonly are partly oxidized. Calcite typically replaces small patches within the matrix. Holocrystalline inclusions, with a mineralogy similar to the rhyodacitic rocks occur in minor amounts. The rock's matrix consists of fine-grained plagioclase microlites with interstitial micro-crystalline material. There is an overall sub-parallel, pilotaxitic texture.

other intrusive rocks

Two additional, volumetrically minor intrusive rocks occur in the Dog Springs complex. For simplicity, these minor intrusives have been mapped with the rhyodacite intrusive and extrusive rocks. Porphyritic quartz-latite intrusions occur in scattered outcrops in the central part of the study area, usually adjacent to rhyodacite intrusions. No obvious age relationships are apparent.

The quartz-latite intrusions occur both as monolithic autobrecciated rock (see fig. 14) and as massive rock, in a fashion similar to the rhyodacite intrusives. The clasts in the quartz-latite autobrecciated rocks are subrounded to angular and range up to 1 ft or more in diameter. The massive exposures typically show a platy fracture. The quartz-latite intrusions are light-gray, very crystal-rich and nonvesicular. Phenocryst content varies from about 60% to nearly holocrystalline. Phenocrysts consist dominantly of clear to white feldspars, with successively lesser amounts of hornblende, biotite and quartz, and trace amounts of

Figure 14. Photograph of monolithic, autobrecciated quartz-latite intrusive in the Dog Springs volcanic complex. Compare with Figure 13.

magnetite. Feldspar, hornblende and biotite phenocrysts are generally euhedral to subhedral. Quartz grains are typically rounded. The phenocrysts are relatively large and range from about 1mm to 6mm in diameter. The matrix is light-gray, fine-grained and commonly silicified. The rocks also show small solution cavities lined with celadonite.

The second minor intrusive rock is a reddish-brown porphyritic andesite. A principle exposure of the andesite is in SE 1/4 sec. 1, T.1N., R.8W., where it crops out as a small hill surrounded by Tertiary piedmont deposits. In the familar pattern, these rocks occur in both monolithic autobrecciated and massive forms.

The porphyritic andesite is fine-grained and crystal-rich. Phenocrysts consist of white and reddish-brown feldspars, pyroxene and olivine, with minor amounts of magnetite. The ferromagnesian minerals are commonly altered to iron-oxides and celadonite. The matrix is reddish in color and shows a fine-grained, sugary texture. Minute solution cavities are numerous.

sedimentary rocks

Sedimentary rocks compose less than 1% of the Dog Springs complex. They consist of very-fine-grained, mafic-rich, feldspathic sandstones and finely laminated mudstones. The mudstones are only a few inches thick and discontinuous laterally. The sandstones achieve localized thicknesses of 20-30 ft (6-9m) and are also discontinuous laterally. Both sandstones and mudstones are interbedded with the tuff breccias.

genesis of the Dog Springs volcanic complex

The Dog Springs volcanic complex lies on the extreme northern margin of the Datil-Mogollon volcanic field. Stratigraphic relationships indicate that it's age is very near the Eocene-Oligocene boundary, making it possibly the oldest known major volcanic source area asociated with the Datil-Mogollon volcanic field. A K-Ar date of 37.1 m.y. (Burke and others, 1963; Weber, 1971) for a hornblende-bearing tuff breccia from the Joyita Hills area, Socorro County possibly correlates to rocks from the Dog Springs complex.

The geologic processes which formed the Dog Springs complex are at present enigmatic. Deposition from stratavolcanoes seems unlikely, due to the conspicuous lack of stratification and to the uncharacteristic presence of exotic megabreccia blocks. The possibility that the complex formed by the crumbling of domes is discussed in the 'tuff breccia' section. Another possibility which should be considered is the caldera forming, pyroclastic eruptive process which is most prominent in the Datil-Mogollon volcanic field. Similarities between the Dog Springs volcanic complex and other caldera structures are:

1) A fault pattern which is discordant to regional structural trends. Faults associated with the Rio Grande rift in this region are dominantly northeasterly and northerly (see plate 3). Major east-trending and northwest-trending faults occur within the outcrop area of the Dog Springs complex. Unfortunately, large segments of what could be a caldera margin and associated ring faults have not yet been mapped. Futher investigations around the margin of the Dog Springs complex will be useful in determining the true nature of the volcanic complex.

2) The Dog Springs complex represents a thick accumulation of dominantly volcanic rocks. Cross sections through the complex indicate a thickness on the order of several thousand feet. Such a thickness is consistant with caldera structures.

3) The Dog Springs complex has an apparent centralized location in relation to a possible ash-flow tuff outflow facies. Since caldera collapse is the result of voluminous ash-flow tuff ejection (Smith, 1960-b; Smith, 1979), an outflow facies is usually required for collapse. Possible outflow facies from the Dog Springs complex have been observed in reconnaissance near Madre Mountain, west of the complex, by R. Chamberlin (oral commun., 1980); and on Nigger Head Mountain, east of the complex, by C.E. Chapin, G.R.

Osburn and S. Cather (oral commun., 1980). In addition, samples from the Sun Oil Co. San Agustin Plains unit #1 oil test, located in sec. 29, T.3S., R.9W., show the presence of a hornblende quartz-latite ash-flow tuff in the lower part of the Tertiary volcanic section. This tuff may represent a southerly outflow sheet.

There are, however, inconsistencies between the Dog Springs complex and the general caldera model.

1) From this study, caldera collapse cannot be documented. The only possible caldera margin in this study area is along the Red Lake fault, which is a through-going fault of considerable length (see plate 3). The entire fault cannot be of caldera collapse origin. However, the fault could be tangent to a caldera structure and a segment of the fault could represent a caldera margin.

In addition, collapse breccias are not identifiable in the Dog Springs complex. Such breccias would be expected to contain clasts of the Baca Formation and Mesaverde Group. However, both are notably absent. The only rock of possible collapse origin in the Dog Springs complex is the ash-flow tuff megabreccia block, and neither it's stratigraphic position, nor it's origin are known.

Another problem in interpreting the Dog Springs complex as a collapse structure lies in the fact that younger volcanic and volcaniclastic rocks do not appear to puddle in a depression. Neither the volcaniclastic rocks of Chavez Canyon, nor the tuff of Main Canyon show appreciable thickening in the area. A possible explanation for this lies in the angular unconformity which occurs between the Dog Springs complex and the overlying strata.

2) The conspicuous lack of pumice seems to indicate that the volcanic rocks were not derived from a volatile charged, vesiculating magma characteristic of caldera-forming processes. In contrast, the tuff breccias of the Dog Springs complex appear to be the result of a more viscous, quieter eruption of slowly upwelling magma, capable of lifting large megabreccia blocks several thousands of feet.

Given the present knowledge of the Dog Springs complex, perhaps the best explanation for it's origin is a model similar to that proposed by Gates (1959) for breccia pipes in the Shoshone Range, Nevada - only on a much larger scale. The two basic assumptions of this model are that brecciation occurred underground, prior to extrusion, and that volatiles played an important part in the eruptions.

The major difficulty in applying Gates' model for the formation of breccia pipes to the Dog Springs complex lies in the respective magnitudes of the volcanic centers. The breccia pipes that Gates describes average about 1 mile in longest dimension, while the Dog Springs complex is on the order of 10-15 miles in diameter. It is not proposed that the events outlined occurred in an orifice 10-15 miles across. Rather, it is suggested that they occured in numerous centers (perhaps fissures and/or pipes, etc.) which spread over an area 10-15 miles in diameter. The size of individual orifices must have been on the order of 1/4 mile in diameter, or greater, in order to accommodate the megabreccia blocks.

A possible explanation for formation of the Dog Springs complex based on Gates' model is as follows:

1) The first step involves a rising body of magma which is crystallizing and building up volatile pressure (see fig. 15). The quartz-latite lava clasts in the tuff breccias could represent clots of the congealing, crystallizing magma.

2) Brecciation of the overlying country rock occurs by explosive eruptions, gas fluxing and explosion, rock burst or a combination of these processes (Parsons, 1967; Gates, 1959).

3) Following this brecciation, or simultaneous with it, when access to the surface is achieved via cracks or fissures, an explosive eruption occurs. This leads to the release and expulsion of volatiles, and the upwelling of magma and lithic fragments. It is during this stage that the megabreccia blocks are floated upward.

4) The eruption could also lead to the formation of a pyroclastic outflow sheet. Subsequent to this, blocks of country rock between eruptive centers would collapse into the vacated magma chamber, in a manner similar to Smith and Bailey's (1968) classic caldera-forming process.

5) Later magma pulses result in the formation of domes and minor flows. The rhyodacite vents, flows and domes of the Dog Springs complex would represent this phase.

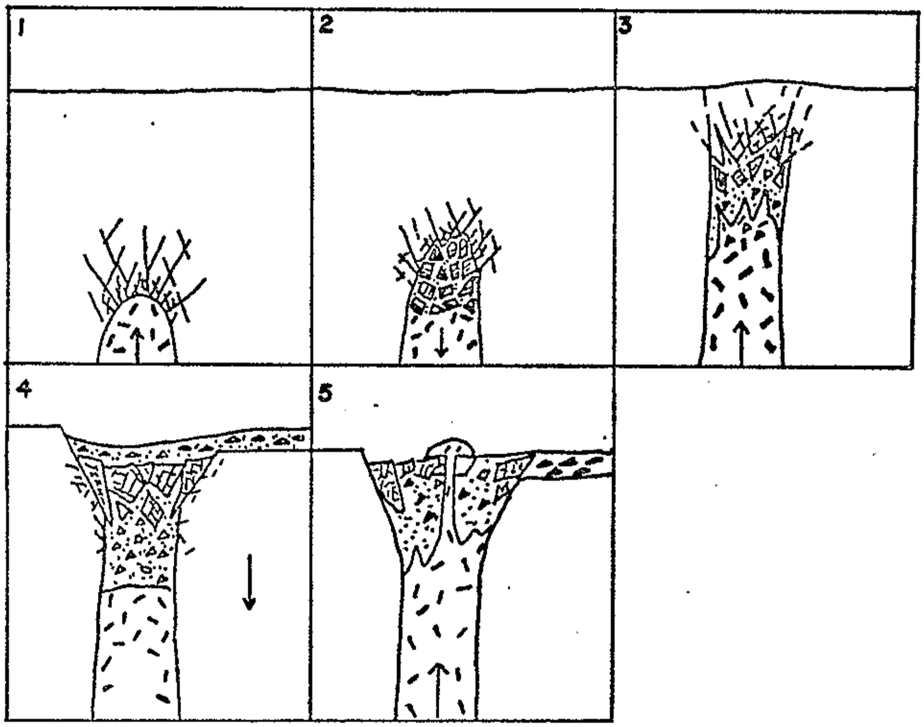


FIG.15. SCHEMATIC DIAGRAM SHOWING THE POSSIBLE FORMATION OF THE DOG SPRINGS COMPLEX (MODIFIED FROM GATES, 1959).

Volcaniclastic Sedimentary Unit of Chavez Canyon

The sedimentary rocks occupying the stratigraphic interval between the Dog Springs volcanic complex and the tuff of Main Canyon have been informally named the volcaniclastic sedimentary unit of Chavez Canyon by Coffin (in prep.) for exposures along Chavez Canyon in secs. 27 and 34, T.2N., R.8W. This unit is probably correlative in part to the feldspathic sedimentary unit of Lopez (1975), and to a combination of the conglomerate and sandstone members of the Spears Formation and the first volcanic sedimentary unit of Bornhorst (1976). In addition, Chavez Canyon is correlative to the uppermost portion of Givens' (1957) Spears Ranch Member of the Datil Formation.

In this study area, the Chavez Canyon unit is divisible into three sedimentary members: a feldspathic sandstone member, a pebble to cobble conglomerate member, and a minor interlayered debris-flow breccia member. The three members are interfingered with one another and show gradational contacts. In general, the sandstone member underlies the conglomerate member. However, in the extreme northwestern part of the area, approximately 200 ft (60m) of conglomerate is present beneath the sandstone and another 25 ft (8m) is interbedded within the sandstone. Also interfingered within this unit, in the southern part of the area, is the rhyolitic ash-flow tuff of Datil Well. The unit of Chavez Canyon directly overlies the Dog Springs volcanic complex with marked angular unconformity. The contact is relatively sharp and shows relief of 150 ft (46m) or less.

sandstone member

The sandstone member is composed dominantly of mafic-rich, feldspathic sandstone beds, with minor lenses of pebble conglomerates (see fig. 16). The sandstone beds are typically planar, with occasional large-scale trough cross bedding. The principal exposures of this member are in the north-central portion of the study area where it forms a continuous belt, and in the northern part of the Blue Mesa Plateau. Unfortunately, these rocks typically form steep, vegetated or talus-covered slopes and are poorly exposed. The sandstone member is covered to the south and west, which makes it impossible to determine it's total areal extent. In this study area the sandstone member is usually from 175 to 200 ft (50 to 60m) thick. Coffin (in prep.) reports thicknesses of 300 ft (100m) in the eastern half of the Dog Springs quadrangle.

The sandstone member of the unit of Chavez Canyon is whitish-gray, friable, medium- to coarse-grained and consists of approximately 70% feldspar grains and 30% ferromagnesian grains in a clay matrix. The ferromagnesian minerals are dominantly hornblende with subordinate biotite. Quartz is virtually absent and lithic fragments are scarce. Tension

Figure 16. Photograph of an outcrop of the feldspathic sandstone member of the volcaniclastic unit of Chavez Canyon.

Figure 17. Photograph of the conglomerate member of the unit of Chavez Canyon. Note the thin sandstone lenses.

cracks, raindrop impressions and concentric concretions have been observed in the sandstone. The concretions are several centimeters in diameter and appear to be localized near the base of the unit.

conglomerate member

The conglomerate member of the unit of Chavez Canyon consists dominantly of pebble to cobble conglomerates with minor sandstone lenses (see fig. 17). The thickness range of the conglomerate member is from about 100 ft (30m) to 225 ft (70m).

The conglomerate member is brown in color and typically planar bedded, although it occasionally shows trough cross bedding. It contains a heterogeneous mixture of basaltic, andesitic, quartz-latitic and rhyodacitic clasts in a matrix of silt- and sand-sized grains of feldspars, ferromagnesian minerals and lithic fragments. Both the quartz-latite tuff breccias and the rhyodacite autobrecciated rocks from the Dog Springs complex are recognized in the clasts, particularly in the lower beds. The clasts are poorly sorted and moderately well rounded. The sandstone lenses are medium- to coarse-grained, tuffaceous, and feldspathic. Transport directions, determined from imbrications and other sedimentary structures, are dominantly to the north and north-northeast (see fig. 18).

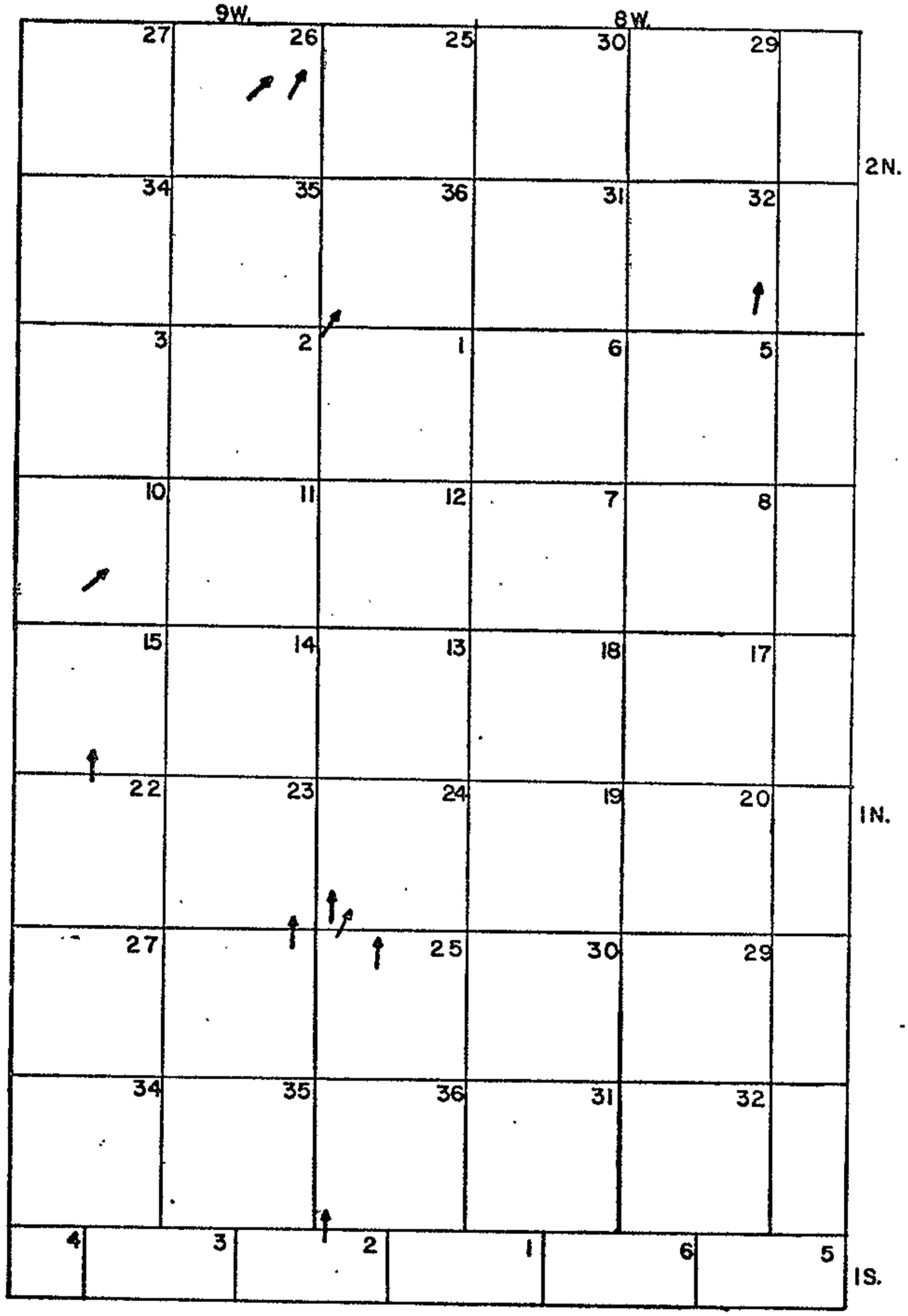


FIGURE 18. DIAGRAM OF FLOW DIRECTIONS IN THE VOLCANICLASTIC UNIT OF CHAVEZ CANYON.

These deposits are typical of bolson deposits that accumulate in arid basins. Analogies can be drawn to the Miocene Popotosa Formation (Bruning, 1973) and the Pliocene-Pleistocene Sierra Ladrones Formation (Machette, 1977).

debris flow member

Interbedded with the sandstones and conglomerates is a minor deposit of debris-flow breccia. The only exposure in this study area is approximately 100 ft (30m) thick and crops out in an area of only a few thousand square feet in SE 1/4 sec. 35, T.1N., R.9W. From the outcrop geometry it appears that this is a valley-fill deposit. Coffin (in prep.) describes similar, yet more extensive debris-flow accumulations in the eastern half of the Dog Springs quadrangle.

In this study area, the debris-flow rocks are slightly heterogeneous, poorly sorted, contain moderately well-rounded clasts, and are dominantly matrix-supported. The rocks are poorly consolidated and form conspicuous spherical cliffs (see fig. 19). There are no recognizable sedimentary structures in the debris-flow deposits and flow directions are unobtainable. However, pebble imbrications in the interbedded conglomerate beds yield a northerly direction.

The clasts are dominantly gray, porphyritic andesite, with subordinate amounts of hornblende quartz-latite ash-flow

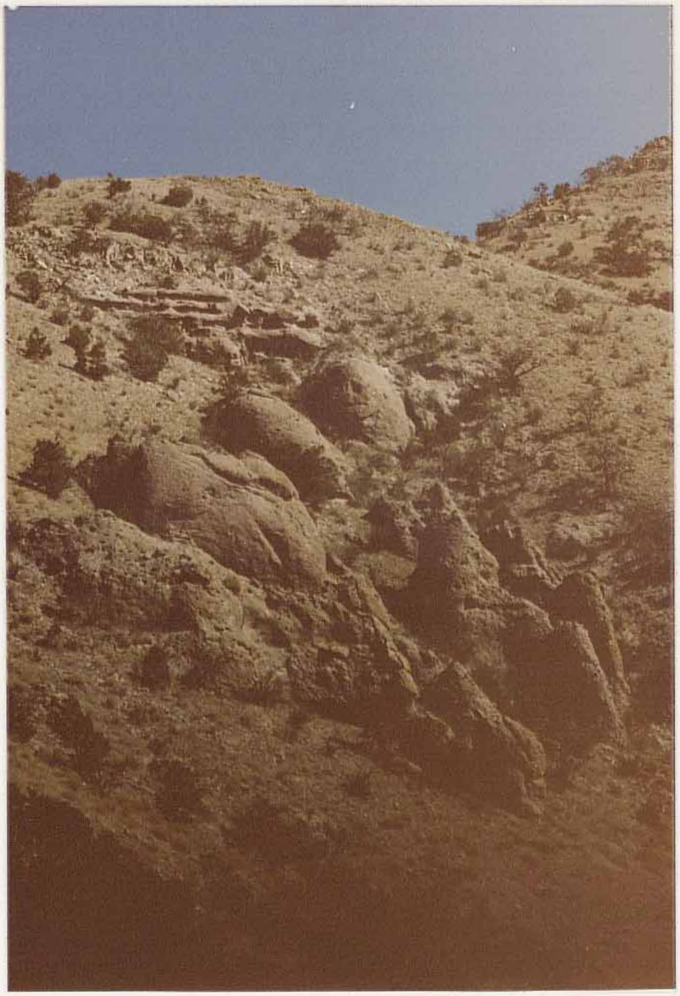


Figure 19. Photograph of the debris-flow member of the volcaniclastic unit of Chavez Canyon overlain by the stratified conglomerate member of the volcaniclastic unit of Chavez Canyon, the intercalated tuff of Datil Well, and the tuff of Main Canyon.

tuffs and tuff breccias, and minor, gray aphanitic andesites. Their size range is from a few centimenters to a meter or more in diameter and they are moderately well rounded.

The porphyritic andesite clasts are characterized by large (greater than 1cm) phenocrysts of plagioclase with minor phenocrysts of clinopyroxene. This andesite is possibly the same as Lopez's (1975) upper porphyritic andesite member of the Spears Formation, and Bornhorst's (1976) porphyritic andesite of White House Canyon.

Tuff of Datil Well

The tuff of Datil Well is a light-gray, moderately welded, crystal-rich quartz-latite ash-flow tuff. The name was proposed by Lopez (1975) for "the rhyolite ash-flow tuff which overlies the Spears Formation" and a type locality was sited as near the Datil Well Campground in sec. 3, T. 2S., R. 10W. The subsequent correlation of the tuff of Nipple Mountain with the tuff of Main Canyon by both Coffin (in prep.) and this thesis, places the tuff of Datil Well stratigraphically within the Spears Group, as previously defined by this thesis. Therefore, Lopez's stratigraphic assignment should be modified, but his descriptions and type locality appear sound.

In the study area, the tuff of Datil Well forms a single V-shaped outcrop in the SE 1/4, SE 1/4, Sec. 35, T. 1N, R.

9W. The tuff is approximately 50 ft (15m) thick and is both overlain and underlain by the conglomerate member of the unit of Chavez Canyon. The outcrop forms a prominent ledge within the conglomerate member (see fig. 19) and has a sharp lower contact and a gradational upper contact with them.

In hand specimen, the tuff of Datil Well is a light-gray, fine-grained porphyritic ash-flow tuff. It has a crystal-poor basal zone which grades upward into a crystal-rich rock with 20 to 25% phenocrysts. Sanidine is by far the most abundant phenocryst and occurs as distinct lath-shaped crystals which occasionally display an irridescent hue. Characteristic apple-green pyroxene and bronze, euhedral biotite crystals are present in minor amounts. Lithic fragments, as much as several centimenters in diameter, of a porphyritic basaltic-andesite are common. Approximately 10% gray, moderately compacted pumice is also present.

Petrographically, the tuff is a moderately welded, porphyritic rock with an almost totally devitrified vitroclastic matrix. Sanidine phenocrysts comprise from 18 to 22% of the rock. They occur as broken, subhedral to euhedral crystals, from less than 0.5mm to about 5mm in length, and are commonly twinned by the Carlsbad law. A light-green clinopyroxene is the next most abundant phenocryst and occurs as fractured, dominantly subhedral crystals. Clinopyroxene comprises 1 to 2% of the rock. These pyroxene crystals have 2V's of about 60° and extinction angles of about 47°, which indicates that they are probably an augite species. Red-brown biotite makes up about 1% of the tuff, with quartz and plagioclase present in trace amounts. The plagioclase has an average composition of about An_{43}.

The source area for the tuff of Datil Well is unknown and the tuff's overall areal extent is poorly known. The tuff has previously been mapped by Lopez (1975) in the central Datil Mountains and by Bornhorst (1976) in the Crosby Mountains area; Elston (1976) has suggested it's correlation with the lower part of Stearns' (1962) $Tdrp_1$ map unit. Thus, the known outcrop pattern of the tuff lies in a northeast-trending belt along the northwest-margin of the Plains of San Agustin (see fig. 20). The single outcrop in this thesis area represents the northeasternmost exposure of the tuff of Datil Well and is very near the ash-flow sheet's distal margin.

Flow direction studies by Lopez (1975) and Bornhorst (1976) indicate possible source areas either to the west or to the southwest of this study area (see fig. 20). Reconnaissance to the west, in the western Datil Mountains and Sawtooth Mountains, has revealed no occurrences of the tuff of Datil Well. This fact, coupled with the tuff's outcrop pattern indicates a most probable buried source under the southwestern Plains of San Agustin, or even further to the southwest.

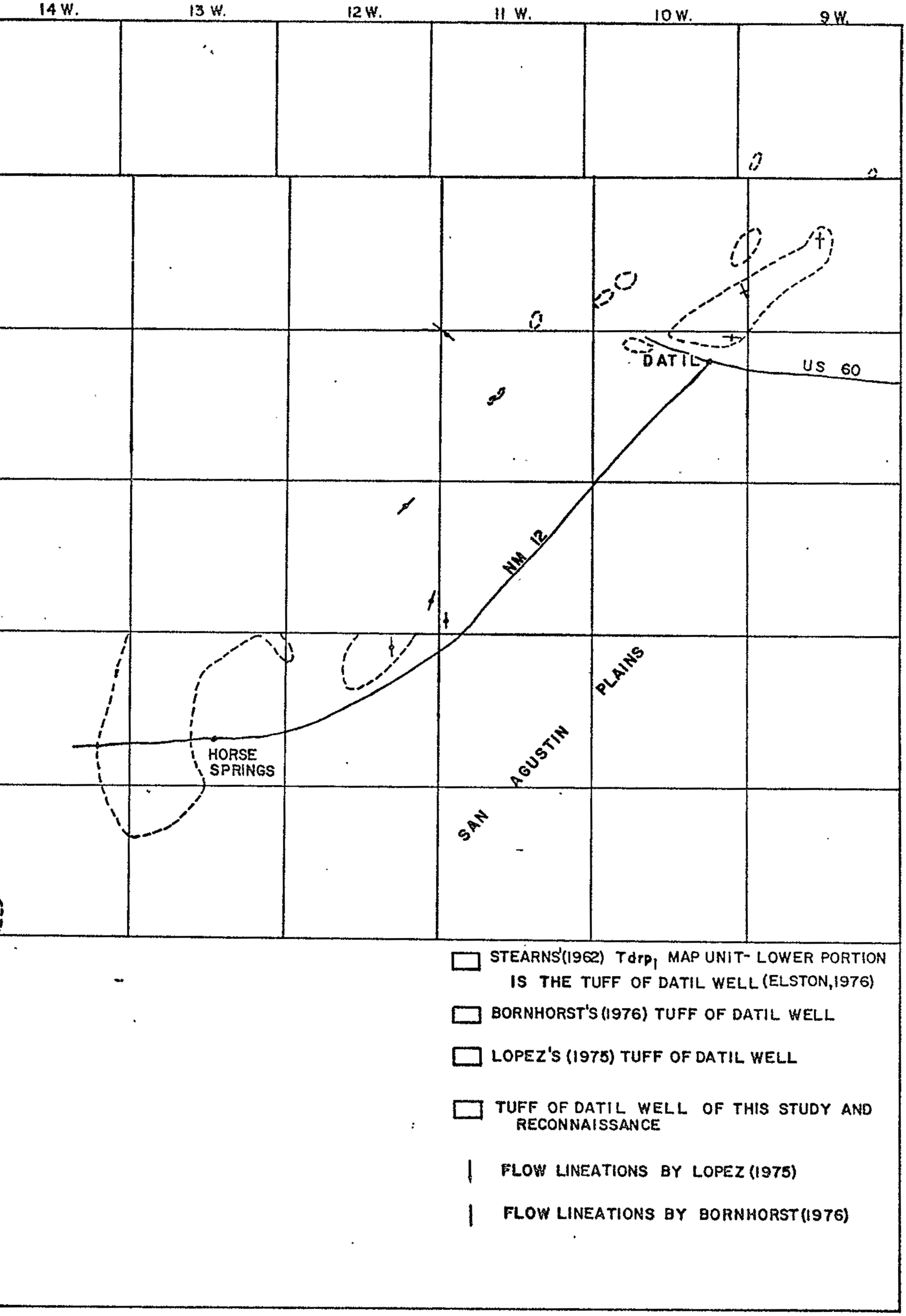


FIGURE 20. DIAGRAM OF THE KNOWN OUTCROP PATTERN OF THE TUFF OF DATIL WELL.

Tuff of Main Canyon

The tuff of Main Canyon is a white to light-gray, poorly to moderately welded, crystal-poor, moderately pumice-rich, rhyolite to quartz-latite ash-flow tuff. Lopez (1975) proposed the name for exposures of the tuff along the Main Canyon drainage system, approximately 7 miles (11 km) north of the town of Datil, in sec. 1 and 12, T.1S., R.10W. This tuff corresponds to the Hells Mesa unit 1 of Givens (1957), which he describes as "the most persistent unit in the Hells Mesa member" throughout the Datil and northern Gallinas Mountains.

An informal name, the tuff of Nipple Mountain, was first used by Brown (1972) and later by Chapin (1974-b) for the pink, moderately to densely welded, crystal-poor ash-flow tuff capping Nipple Mountain, 4.5 miles (7 km) northeast of Magdalena, New Mexico. This name was thereafter used by the various theses of the Magdalena Project and the areal extent of the tuff was traced westward through the Tres Montosas - central Gallinas Mountains region by Chamberlin (1974), Wilkinson (1976) and Laroche (in prep.). Chamberlin also redefined the tuff to include the "turkey track" andesite flows commonly found near the base of the tuff. These flows, however are discontinuous in the central Gallinas Mountains (Laroche, in prep.) and are totally absent in the northwestern Gallinas and northeastern Datil Mountains.

Through reconnaissance of the northeastern Gallinas Mountains and the mapping of the northeastern Datil and northwestern Gallinas Mountains by Coffin (in prep.) and this thesis, the physical correlation between Lopez's tuff of Main Canyon and the Magdalena Project's tuff of Nipple Mountain has been established. The name, tuff of Main Canyon, appears to be more suitable for this unit because it's stratigraphic position is better exposed in Main Canyon than on Nipple Mountain and the tuff is propylitically altered on Nipple Mountain, whereas it is relatively fresh in Main Canyon.

As with most of the ash-flow tuffs in the study area, the tuff of Main Canyon crops out in two distinct patterns. In the central and east-central portions of the area, the tuff forms a broad continuous dip slope which defines the western limb and the nose of a southeast plunging synform. The second pattern occurs in the western portion of the area, where the tuff of Main Canyon outcrops as the capping of isolated hills and minor dip slopes within a complexly faulted region. The tuff has a maximum thickness of about 300 ft (91m) in the east-central and southeastern parts of the study area and thins to approximately 200 ft (61m) in the western portion of the study area.

The tuff's outcrop characteristics are dominated by broad, Juniper- and Pinon-covered dip slopes with steep bluffs along the margins. The bluffs reach as much as 150 ft

(46 m) in height, with well-developed columnar joints and aprons of talus.

Throughout the field area, the tuff of Main Canyon conformably overlies the volcaniclastic sedimentary unit of Chavez Canyon. The tuff's lower contact is relatively sharp and it's upper contact with the middle sedimentary unit is gradational. The attitudes of the tuff and the two sedimentary units are virtually parallel throughout the area. This fact, coupled with the indistinguishable nature of the two sedimentary units, indicates relatively continuous sedimentation with little tectonic disturbance during the deposition of the tuff.

The tuff of Main Canyon, in this study area, is a multiple-flow, simple cooling unit as defined by Smith (1960-a). The unit displays a vertical zonation typical of the distal margins of Smith's type A and B ash-flow sheets (Smith 1960a, plate 20) and, in fact probably represents a gradation between the two types. The zones consist of a lower, poorly to nonwelded basal zone which is thin and intermittent in this area, but becomes more prominent to the east (Coffin, in prep.); a middle zone of partial welding; and an upper, very soft, nonwelded zone, which is commonly absent due to erosion.

The middle partially welded zone can be further divided into distinct cooling structures (see fig. 21). These structures are a lower, massive, columnar-jointed layer; a middle platey layer; and an upper, massive layer which also

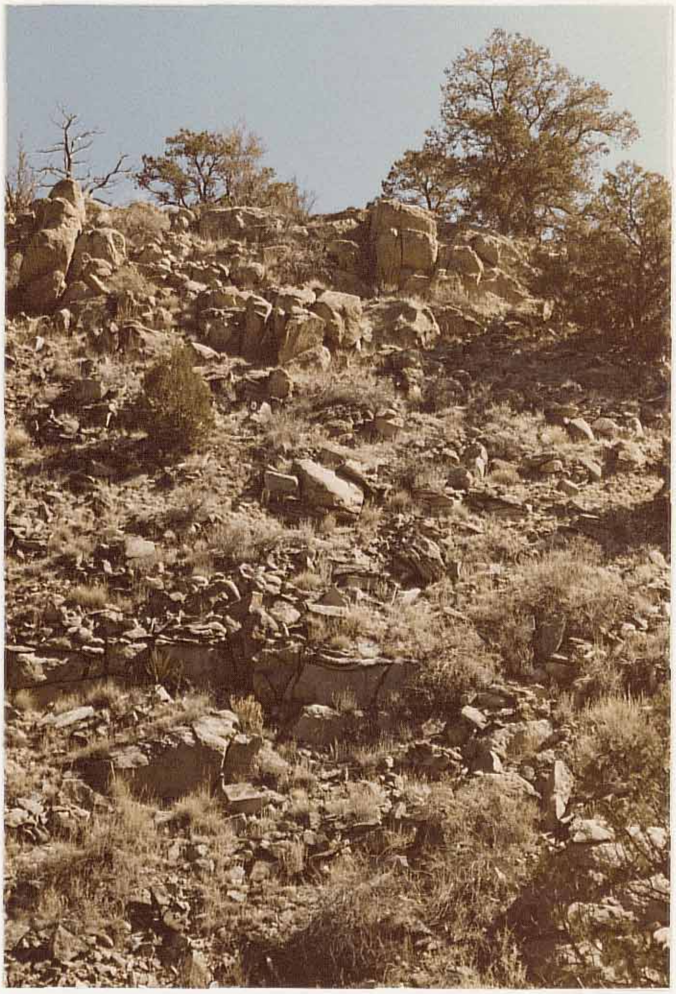


Figure 21. Photograph of subzones within the zone of partial welding in the tuff of Main Canyon. A lower, blocky, columnar-jointed layer, a middle platy layer, and an upper, massive columnar-jointed layer. (Compare to Figure 35)

has columnar joints. A similar sequence of structures is developed within the Hells Mesa Tuff in this area (see fig. 30). Within the tuff of Main Canyon, the lower, massive layer is the most densely welded and the degree of welding decreases upward. Throughout much of the area, the tuff consists predominantly of the upper, poorly welded, massive layer.

Structures similar to these have been described by Spry (1961) in columnar jointed basalt flows. His three divisions include the colonnade which is the lowest zone and consists of regular, straight vertical columns; the entablature zone , which consists of twisted and curved fractures; and an upper colonnade, which shows crude columnar jointing. The resemblance between these basaltic structures and the structures within the partially welded zone of the rhyolitic tuff of Main Canyon (and the Hells Mesa Tuff) probably are the result of similar responses to the thermal stresses brought on by cooling.

Deposition of the tuff of Main Canyon by multiple flows is indicated by otherwise inexplicable changes in pumice content. In the southern Gallinas Mountains - Tres Montosas area, Chamberlin (1974) and Wilkinson (1976) describe distinct cooling breaks within this unit occupied by andesitic to latitic lava flows. However, no visible cooling breaks or partings were observed in this study area.

In hand specimen, the tuff of Main Canyon is a white to light-gray, poorly to moderately welded, crystal-poor ash-flow tuff. The pumice content varies from about 30% of virtually uncollapsed, white pumice in the poorly welded zones to about 10% of partially collapsed pumice in the moderately welded zones. The phenocrysts vary in reverse fashion from about 10% in the moderately welded zones to about 4% in the poorly welded zones. Euhedral to subhedral laths of feldspars dominate, making up from 3 to 9% of the rock; with minor biotite and quartz visible. Occasional subrounded to rounded fragments of a reddish-brown, vesicular basaltic-andesite, with an average long dimension of 2mm, are also present. Minute specks of magnetite are detectable.

Petrographically, this unit is a poorly to moderately welded, crystal-poor rhyolite ash-flow tuff. It has a partially devitrified, vitroclastic matrix. Phenocrysts vary from about 4 to 10% with subhedral to euhedral sanidine crystals in the majority. Plagioclase and biotite each comprise 1% or less of the rock. Quartz, clinopyroxene and opaque oxides are present in trace amounts. The plagioclase has an average composition of about An_{29}. A characteristic feature of the tuff is the abundance of relatively large white pumice, as much as 5cm in long dimension. Axiolitic structures are also commonly found within the pumice.

The source area of the tuff of Main Canyon is unknown. The known outcrop and thickness patterns of the tuff indicate a possible buried source beneath the eastern Plains of San Agustin or further south (see fig. 22). The flow direction lineations of Lopez (1975) and Bornhorst (1976) could be

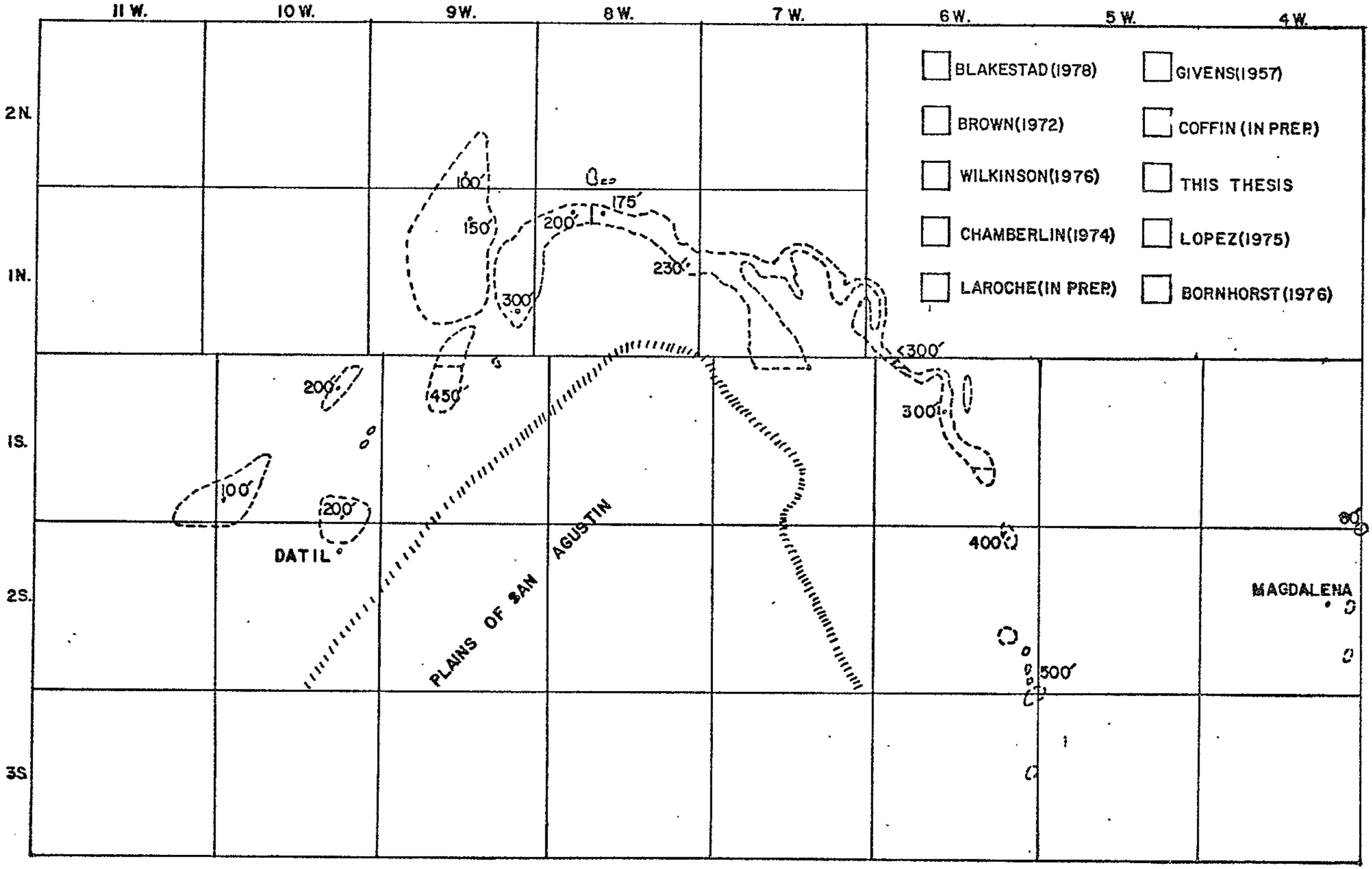


FIGURE 22. DIAGRAM OF THE REGIONAL OUTCROP PATTERN AND GENERALIZED THICKNESSES OF THE TUFF OF MAIN CANYON.

interpreted as substantiating this general source area. Alternatively, the thickening could be the result of a topographic low during the time of deposition and thus be unrelated to the proximity of the source area.

Undoubtedly, the most important regional aspect of the tuff of Main Canyon is it's role as a stratigraphic marker bed. As Smith (1960a, p. 150) foresaw:

> "the potential importance of these rocks (welded tuffs) as stratigraphic marker beds cannot be overemphasized, considering their possible long-distance continuity in terrane where lensing and facies changes, in sedimentary and other volcanic deposits, are common."

Indeed, the tuff of Main Canyon provides an extremely useful time-stratigraphic unit throughout the Datil, Gallinas and Crosby Mountains and in the Magdalena area. Without the long-distance continuity of this unit, the interfingering stratigraphy of the sedimentary and volcanic rocks of the Spears Group would not be as apparent.

The usefulness of this unit as a marker bed has been previously recognized. Brown (1972) used this tuff to subdivide the Spears Formation into an upper member of "andesitic lava flows and latitic ash-flows interbedded with laharic breccias and fluvial sediments," and a lower, latitic to andesitic conglomerate and sandstone member. Chamberlin (1974) used the tuff in a similar manner, noting that it was "an excellent marker horizon between the upper and lower members of the Spears Formation," and Laroche (in prep.) reported that "it provides a distinctive horizon in an otherwise monotonous sequence of volcaniclastic rocks and lava flows." The nearly continuous outcrop of the tuff of Main Canyon from this study area eastward into the Gallinas Mountains and southwestward into the Datil-Crosby Mountains area provides an excellent stratigraphic marker horizon over a region that completely surrounds the northeastern margin of the Plains of San Agustin (see fig. 22).

Middle Sedimentary Unit

The middle sedimentary unit includes all of the volcaniclastic sedimentary rocks between the tuff of Main Canyon and the Hells Mesa Tuff. Interlayered within this unit are discontinuous outcrops of the quartz-latite tuff of Blue Canyon. This tuff has been used to separate the middle sedimentary unit into upper and lower members for mapping purposes only. Where the tuff of Blue Canyon is absent there is no distinguishable break in the middle sedimentary unit. The middle sedimentary unit is correlative to the middle and upper sedimentary units of Lopez (1975), and to the second and third volcanic sedimentary units of Bornhorst (1976). It is also correlative in part to Willard's (1959) volcanic sedimentary facies of the Datil formation.

This unit is present throughout the study area. It's thickness is generally about 100 to 200 ft (30 to 60m) below the tuff of Blue Canyon and from 175 to 300 ft (53 to 91m) above the tuff of Blue Canyon. In areas where the tuff of Blue Canyon is absent, the middle sedimentary unit generally thins to about 100 ft (30m). These areas undoubtedly reflect topographic highs that existed between deposition of the tuff of Main Canyon and Hells Mesa Tuff. The middle sedimentary unit typically forms steep vegetated slopes when capped by tuffs and low rounded, vegetated hills when not capped by a more resistant rock type.

The rocks of the middle sedimentary unit represent a continuation of the arid, basinal deposition that began with the sedimentary unit of Chavez Canyon. The lower two-thirds of the middle sedimentary unit consists of pebble to cobble conglomerate beds, with minor sandstone lenses. Occasional boulder conglomerates are also present. These lower rocks are very similar to the conglomerate member of the unit of Chavez Canyon. The upper one-third of the middle sedimentary unit, however develops increasing amounts of aeolian and fluvial sandstone beds upward (see fig. 23 and 24). Directly beneath the Hells Mesa Tuff the middle sedimentary unit becomes exclusively sandstone deposits.

These upper beds are light-brown, well-sorted, fine-grained, friable, argillaceous, feldspathic sandstones. The grains are sub-rounded, with low sphericity and consist dominantly of feldspar, lithic fragments, and biotite, with minor quartz. These sandstones occur both as sand dune deposits, with steeply dipping cross stratification; and as massive sandstone beds of fluvial origin. The sand dune

Figure 23. Photograph of fluvial sandstone beds that occur in the upper portion of the middle sedimentary unit. Note the broad, low-angle cross-stratification.

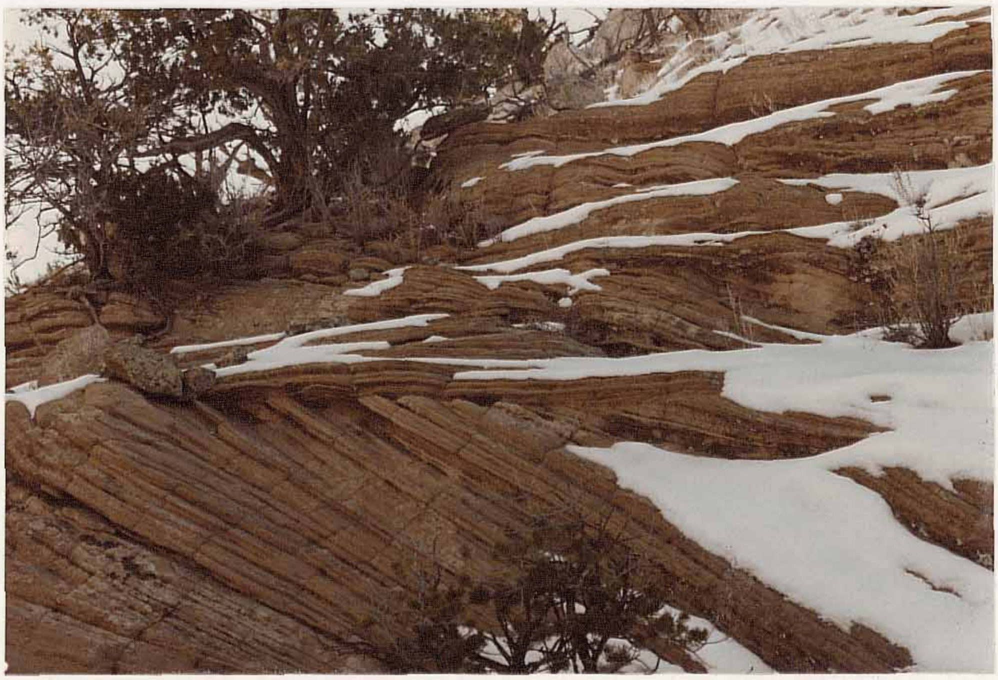


Figure 24. Photograph of sand dune deposits with steeply dipping cross strata in the middle sedimentary unit.

deposits are most common in the northern and western parts of the study area and yield a general southeast-transport direction. The fluvial sandstones are more prominent in the southeastern portion of the area. They contain characteristic marble-sized, spherical concretions. Several springs occur at this stratigraphic horizon in the northeastern portion of the study area.

The fining-upward sequence, from the conglomerate member of the unit of Chavez Canyon to the fine-grained aeolian and fluvial sandstone beds directly beneath the Hells Mesa Tuff probably represents the filling of the depositional basin without appreciable tectonic rejuvenation. Flow directions from pebble imbrications, ripple marks, etc., yield a general northeast-transport direction (see fig. 25).

Tuff of Blue Canyon

Within this study area, the tuff of Blue Canyon is the uppermost ash-flow tuff of the Spears Group. It is a moderately to poorly welded, moderately crystal-rich, quartz-poor, quartz-latite ash-flow tuff. It's name was proposed by Lopez (1975) for exposures in Blue Canyon, sec. 1, T.1S., R.10W. The tuff correlates to the lower portion of Givens' (1957) Hells Mesa unit #3.

The tuff of Blue Canyon has a thickness range of from about 100 ft (30m), in the southern part of the study area, to 20 ft (6m) or less in the northern part of the area. In

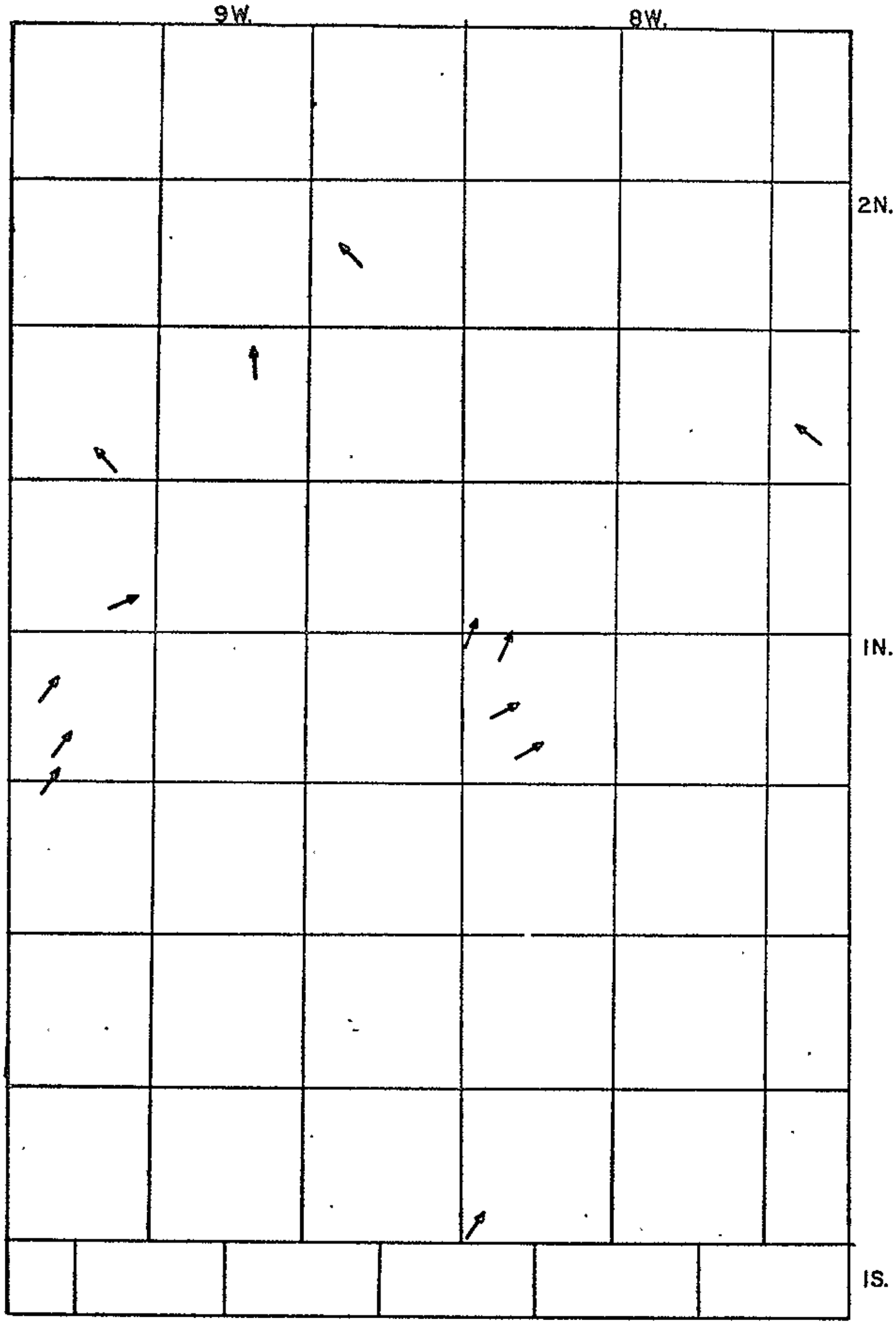


FIGURE 25. DIAGRAM OF THE FLOW DIRETIONS FOR THE MIDDLE SEDIMENTARY UNIT.

at least two localities the tuff is absent from it's stratigraphic position, having apparently pinched out against topographic highs during deposition. Coffin (in prep.) reports that the tuff completely pinches out approximately 4 miles to the east of this study area.

The tuff crops out as a moderate ledge former in a nearly continuous belt in the eastern portion of the study area. In the western part of the area, the tuff of Blue Canyon occurs as discontinuous thin ledges and as caps on hills. Both upper and lower contacts between the tuff and the middle sedimentary unit are sharp (see fig. 26) and conformable.

In hand specimen, the tuff of Blue Canyon is a tan to light-gray, moderately to poorly welded, moderately crystal-rich ash-flow tuff. Phenocrysts of plagioclase, sanidine and biotite comprise from 15-24% of rock, with minor amounts of clinopyroxene, hornblende and quartz present. The rock is characterized by a dominance of plagioclase, generally subordinate sanidine, a relatively large amount of biotite and an almost total lack of quartz. The feldspar grains typically occur as euhedral to subhedral laths, generally 2 to 4 mm in long dimension and are frequently weathered to clays. The biotite phenocrysts are euhedral, both black and bronze in color, and range from 2 to 5 mm in diameter. Quartz is present in minor amounts and occurs as rounded grains generally less than 2 mm in diameter.

Figure 26. Photograph of the lower contact between the tuff of Blue Canyon and the middle sedimentary unit. Lithic fragments within the tuff are a heterogeneous mixture of basalts and andesites similar to the clasts in the underlying sediments.

In this study area, there is little vertical variation in composition or welding in the tuff of Blue Canyon, with the exception of a poorly to non-welded basal zone which is extremely discontinuous. However, several lateral variations do occur. From south to north, the tuff becomes progressively thinner and eventually pinches out entirely. Also, the tuff becomes progressively less welded northward. And finally, whereas phenocryst content does not change appreciably, there is a notable increase in abundance of lithic fragments northward. These lithic fragments are very similar to the clasts of the underlying conglomerates of the middle sedimentary unit. They consist dominantly of aphanitic and porphyritic andesites, with minor basaltic and ash-flow tuff rocks. They are generally well rounded and range in size from a few millimeters to several centimeters in diameter. Since the tuff is near it's distal margin, where topographic controls are their greatest, the lithic fragments are probably inclusions derived from slope talus and stream channels.

Petrographically, the tuff of Blue Canyon is a fine-grained, partially devitrified, quartz-latite ash-flow tuff. It's matrix has a vitroclastic texture. Incipient devitrification around glass shards and vesicles is common (see fig. 27). Total phenocryst content varies from about 16 to 21% (see table 2), with about equal amounts of sanidine and plagioclase, minor amounts of biotite and a fraction of a percent of quartz, clinopyroxene, hornblende and opaque

Figure 27. Photomicrograph of incipient devitrification around the margins of glass shards in the tuff of Blue Canyon. Phenocrysts are biotite, plagioclase and sanidine. (25x, crossed nicols)

Table 2. Modal analyses in volume percent of the tuff of Blue Canyon.

	1	2	3
Total Phenocrysts	21.3	17.8	16.3
Sanidine	9.5	8.9	7.2
Plagioclase (An%)	7.5 (29)	5.7 (29)	7.0 (28)
Quartz	0.6	0.6	trace
Biotite	2.7	1.6	1.5
Clinopyroxene	0.6	0.7	0.6
Hornblende	0.5	0.3	0.3
Opaques	0.4	0.3	trace
Points Counted	2693	2753	2815
Sanidine / Plagioclase	1.3	1.6	1.0

oxides. Plagioclase occurs as euhedral to subhedral laths which typically display albite twinning. The plagioclase is normally zoned and has an average composition of about An_{29}. Sanidine is present as subhedral to euhedral crystals which frequently show carlsbad twinning. Both feldspars have a size range from about 0.2 to 2.5 mm. The ferromagnesian minerals are dominated by euhedral to subhedral biotite crystals, with varying amounts of euhedral to subhedral clinopyroxene and hornblende. These ferromagnesian crystals range in size from about 0.2 to 1.5 mm.

The stratigraphic correlation of the tuff of Blue Canyon is at present uncertain. Other units which have been described in the stratigraphic interval immediately below the Hells Mesa Tuff are: Deal's (1973) crystal-rich latite ash-flow tuff of the Spears Formation, Chamberlin's (1974) upper latite tuffs of the Spears Formation, Wilkinson's (1976) tuff of Granite Mountain, and Spradlin's (1976) Spear's unit #14.

Similarities between these tuffs and the tuff of Blue Canyon are:

1) A common stratigraphic position as the first ash-flow tuff below the quartz-rich Hells Mesa Tuff.

2) A conspicuous lack of quartz.

3) An occurrence of ferromagnesian minerals, dominantly biotite, as 10% or more of the total phenocrysts.

4) Similar total feldspar to total ferromagnesian ratios.

Differences between these tuffs and the tuff of Blue Canyon are:

1) An approximate 2 to 1 ratio in phenocryst content. (The tuff of Blue Canyon contains approximately 20% phenocrysts, while the other tuffs contain about 40% phenocrysts.)

2) Variations in mineral ratios, particularly sanidine to plagioclase (sanidine/plagioclase in the tuff of Granite Mountain is commonly as low as 1/9; and in Blue Canyon is usually within the range of 1/1 to 1/2).

Three possibilities are envisioned for these quartz-poor, quartz-latite to latite tuffs of the upper Spear's Group.

1) Nearly simultaneous eruptions of minor ash flows from two (or more) source areas with similar magma compositions, or

2) Sequential minor eruptions of a zoned magma from a single source area, or

3) A single eruptive event, resulting in a laterally zoned ash-flow sheet. (A decrease in phenocryst content away from the vent area is common, due to crystal settling and a decrease in compaction. In fact, a notable decrease in phenocryst content is found in the Hells Mesa Tuff and the ash-flow tuffs of the A-L Peak Formation within the region, and the tuff of Main Canyon shows an inverse relationship between compaction and phenocryst content. However, the phenocryst ratios should remain approximately the same.)

Hells Mesa Tuff

The Hells Mesa Tuff is a crystal-rich, quartz-rich, moderately to poorly welded, rhyolite ash-flow tuff. In this study area, it is a multiple-flow, simple cooling unit, consisting of a white, poorly welded basal zone and a buff-colored, moderately to poorly welded upper zone.

Originally, the name Hells Mesa was applied to the middle member of Tonking's (1957) Datil Formation. His Hells Mesa Member consisted of the rhyolitic tuff sequence lying between the Spears Ranch and La Jara Peak Members, with it's type exposure located on Hells Mesa in secs. 17 and 20, T.1N., R.4W. Chapin (1971-a) elevated the Hells Mesa Member to formational status. Deal (1973) referred to the formation as the Hells Mesa Rhyolite and restricted it to the lower crystal-rich portion of Tonking's Hells Mesa Member. Chapin (1974-b) referred to the formation as the Hells Mesa Tuff and also restricted it to the quartz-rich, crystal-rich, basal ash-flow sheet of Tonking's Hells Mesa Member. The Hells Mesa Tuff is a multiple-flow, simple cooling unit of quartz-latitic to rhyolitic ash-flow tuffs that occur throughout the Socorro-Magdalena area. Recognition of the tuff in the Datil Mountains was first reported by Lopez (1975).

The Hells Mesa Tuff is correlative to Brown's (1972) tuff of Goat Springs and to Givens' (1957) Hells Mesa unit #4 and the lower three-fourths of unit #5. It is also probably correlative to Lopez's (1975) tuff of Horse Springs and Bornhorst's (1976) tuff of Rock Tank.

The Hells Mesa Tuff crops out throughout the study area with a thickness varying from about 400 ft (122m) in the eastern and southern parts to about 250 ft (76m) or less in the western and northern parts. The tuff's lower contact with the middle sedimentary unit is generally sharp and conformable. At one locality, in the SW 1/4, SW 1/4, sec. 31, T.1N., R.8W., ripple marks in the middle sedimentary unit are well preserved at the tuff's lower contact (see fig. 28). A thin, dense rind has also developed in the underlying sandstones just below this contact. The rind appears to be the result of leaching of silica from the tuff and it's precipitation in the sandstones.

The Hells Mesa's upper contact with the volcanclastic rocks of South Crosby Peak is gradational and shows variable relief. In the eastern half of the Dog Springs quadrangle, Coffin (in prep.) describes a paleovalley which cuts through the Hells Mesa Tuff, and is filled by the tuff of South Crosby Peak. The younger tuff contains lithic fragments of the older Hells Mesa Tuff.

The Hells Mesa Tuff displays a vertical zonation similar to the distal margins of Smith's (1960-a) type A ash-flow sheet. Throughout the study area, a poorly to nonwelded basal zone and an overlying partially welded zone are recognized. The two zones share a common mineralogy and are never separated by any other rock type. The only consistent

Figure 28. Photograph of the lower contact of the Hells Mesa Tuff with the middle sedimentary unit of the Spears Group.

difference in the two zones is in the degree of welding. Coffin (in prep.) has recognized the same characteristics of the Hells Mesa Tuff in the eastern portion of the Dog Springs 7 1/2' quadrangle.

The basal zone is white, moderately pumice-rich, and shows occasional thin sedimentary partings (see fig. 29). The pumice fragments are on the order of a few centimeters in length and are virtually unflattened. The thickness of this zone ranges from about 20 ft to 80 ft (6 to 27m), becoming progressively thicker westward. Coffin (in prep.) reports that the thickness of this zone is inversely proportional to the total thickness of the Hells Mesa Tuff. This phenomenon is described by Smith (1960-a) as characteristic of nonwelded basal zones.

Within the study area, the partially welded zone volumetrically dominates the Hells Mesa Tuff. It's thickness varies from about 250 to 350 ft (76 to 107m). Within the overlying partially welded zone are distinct cooling structures, which are very similar to those developed in the tuff of Main Canyon (compare figs. 21 and 30). These structures consist of a thin, crudely jointed, massive lower layer; a platy fractured middle layer; and a relatively thick, columnar jointed, massive upper layer. Once again, an analogy is drawn to similar structures in basaltic flows (Spry, 1961).

The hand specimen characteristics which typify the Hells Mesa Tuff are it's high percentage of total phenocrysts

Figure 29. Photograph of a sedimentary parting in the poorly welded, basal zone of the Hells Mesa Tuff.

Figure 30. Photograph of an outcrop of the Hells Mesa Tuff that shows the white, poorly welded basal zone and the moderately welded upper zone. The upper zone has developed distinct cooling structures that include a thin, massive lower layer (the prominant ledge one third of the distance up the slope), a slope forming, platy middle layer and a massive columnar-jointed layer.

(35-40%) and it's relatively large percentage of quartz phenocrysts (5-8%). The quartz in the Hells Mesa is the first major occurrence of this mineral as a phenocryst in the Tertiary volcanic stratigraphy of the area. It is largely on this basis that the quartz-poor formations of the Spears Group are separated from the Hells Mesa and other overlying quartz bearing formations. The quartz generally occurs as clear, rounded phenocrysts, but it occasionally is present as doubly terminated, euhedral crystals. The quartz phenocrysts range in size up to about 5mm, with a slight increase in size upward in the unit. Total phenocryst content is generally about 25 to30% feldspars, 5 to 8% quartz, 2 to 4% biotite, with traces of clinopyroxene and hornblende.

Petrographically, the Hells Mesa Tuff is a fine-grained, porphyritic, completely devitrified ash-flow tuff. The matrix shows a vitroclastic texture, with occasional axiolitic structures. The degree of welding varies with vertical location in the sheet, and is never more than moderate. Sanidine is generally twice as abundant as plagioclase, with both occurring as euhedral to subhedral crystals and ranging in size from 0.2 to 3mm. The sanidine commonly shows Carlsbad twinning, while plagioclase is typically twinned by the albite law. The plagioclase is normally zoned and has an average composition of about An_{28}. Quartz occurs as anhedral to euhedral crystals, but is most prevalent as large, rounded, embayed grains. Biotite, clinopyroxene and hornblende all occur as euhedral to subhedral crystals. Magnetite grains are present in trace amounts throughout the rock.

The Hells Mesa Tuff is the largest ash-flow sheet of the northern Datil-Mogollon volcanic field. It has been described in the Joyita Hills (Spradlin, 1975), in the Magdalena Mountains (Blakestad, 1978; Osburn, 1978; Petty, 1979; Allen, 1979; Bowring, 1980; Donze, 1980; Roth, 1980), in the San Mateo Mountains (Deal, 1973; Deal and Rhodes, 1976), in the Bear Mountains (Brown, 1972; Simon, 1973; Massingill, 1979; Mayerson, 1979), in the Gallinas Mountains (Chamberlin, 1974; Wilkinson, 1976; Laroche, in prep.; Coffin, in prep.), in the northern part of the Black Range (Fodor, 1976), and in the Datil Mountains (Lopez, 1976; this thesis). The tentative correlative of Bornhorst's (1976) tuff of Rock Tank with the Hells Mesa Tuff made by this thesis possibly extends the tuff into the Crosby Mountains and even further westward.

This correlation is based on two important similarities between the tuff of Rock Tank and the Hells Mesa Tuff. First, they occupy the same stratigraphic position, lying above the tuff of Blue Canyon and below the volcaniclastic rocks of South Crosby Peak and the A-L Peak Formation (see plate 2). Second, both Hells Mesa and Rock Tank are crystal-rich, rhyolite ash-flow tuffs with nearly identical mineralogy and total phenocryst content. In addition, both represent the lowest stratigrahic ash-flow tuff to contain prominent quartz phenocrysts and both show a regionally atypical zonation from a more mafic base to a more silicic top (Brown 1972; Deal, 1973; Bornhorst, 1976). From the descriptions of the tuff of Rock Tank by Lopez (1975) and Bornhorst (1976) as a white to pinkish-white, poorly welded ash-flow tuff, it appears that the tuff of Rock Tank is probably the poorly to non-welded basal zone of the Hells Mesa Tuff. Following this interpretation, then, the Hells Mesa Tuff is a perfect example of Smith's (1960-a) simple cooling unit which becomes increasingly less welded away from it's source. The source area for the Hells Mesa Tuff is the North Baldy - Socorro caldera (Chapin and others, 1978; Eggleston, in prep.).

The four published dates on the Hells Mesa Tuff are 29.4 m.y. and 31.8 m.y. by Weber and Bassett (1963), and 31.9 m.y. and 32.3 m.y. by Burke and others (1963). The 31.9 m.y. sample was collected by R.W. Foster, of the New Mexico Bureau of Mines and Mineral Resources, from this study area. The sampled location is in the SE 1/4, SE 1/4, sec. 7, T.1N., R.8W.; 34^{o} 19' 11" N., 107^{o} 42' 54"W.

Volcaniclastic Unit of South Crosby Peak

The volcaniclastic unit of South Crosby Peak consists of pebble to cobble conglomerates, ash-fall tuffs, reworked ash-fall tuffs, tuffaceous sandstones and the minor ash-flow tuff of South Crosby Peak. These rocks lie between the Hells

Mesa Tuff and the A-L Peak Formation. The unit was named by Bornhorst (1976) for exposures on South Crosby Peak in secs. 25, 26 and 36, T.2S., R.11W. It is correlative to Lopez's (1975) tuff of Crosby Mountain.

The unit has a maximum thickness of about 200 ft (61m) in the southeastern part of the study area and thins to 50 ft (15m) and less in the western part. At some localities, it is absent. The unit's lower contact with the Hells Mesa Tuff is gradational and reflects moderate relief. It's upper contact with the lower member of the A-L Peak Formation is generally sharp. The sedimentary rocks are conformable to both the Hells Mesa Tuff and the A-L Peak Formation.

Within this study area, the unit of South Crosby Peak is divisible into two members: A lower pebble to cobble conglomerate member and an upper ash-fall tuff, tuffaceous sandstone, ash-flow tuff member. The lower member is the more wide spread. It's thickness is generally only 50 ft (15m) or less throughout the study area, except for a localized thickening to about 200 ft (61m) in the extreme western part of the study area, near the Red Lake fault. This member contains clasts of aphanitic basalts, porphyritic andesites, quartz-latite to rhyolite flow rocks and densely welded Hells Mesa Tuff. The matrix consists of dominantly sand-sized grains of quartz, feldspar and biotite.

The upper member consists of interbedded ash-fall tuffs, tuffaceous sandstones, minor pebble conglomerates and the tuff of South Crosby Peak. This member occurs mainly in a north-northeast-trending belt through the southeastern part of the study area, where it apparently filled a topographic low. It's thickness there is about 100 to 150 ft (30 to 45m). It's presence throughout the rest of the area is scattered and minor. The ash-fall tuffs occur as thin persistant layers of mottled pinkish-white, nonwelded pumice fragments, and show crude fining-upward sequences. The upper portions of individual ash-falls commonly show sedimentary reworking. Lithic fragments and grains of feldspar and quartz are abundant. Their size range is from about 1 to 3mm.

Tuff of South Crosby Peak

Interbedded within the volcaniclastic unit of South Crosby Peak is a pumice-rich, crystal-poor, rhyolite ash-flow tuff. The name tuff of Crosby Mountain was initially proposed by R. C. Rhodes and T. J. Bornhorst for this tuff from exposures on Crosby Mountain, Sec. 25, T.2S., R11W. (Lopez, 1975, p. 44). This name was later changed by Bornhorst (1976) to the volcaniclastic rocks of South Crosby Peak; the type section was changed to Secs. 25, 26, and 36, T.2S., R.10W.; and the ash-flow tuff lowered to minor member status. The name tuff of South Crosby Peak is herein used in reference to this ash-flow tuff.

The tuff crops out only in the southeastern part of the study area, with it's principle exposure in secs. 1 and 2, T.1S, R.9W. It has a maximum thickness of about 25 ft (8m) and rapidly pinches out northwestward. The tuff forms a massive ledge within the sedimentary rocks and displays a sharp lower contact (see fig. 31) and a gradational upper contact.

In hand specimen, the tuff of South Crosby Peak is a white, poorly welded, pumice-rich, crystal-poor ash-flow tuff. The pumice fragments show very minor flattening and are pale yellow in color. Sparse crystals of black biotite, quartz, sanidine and hornblende are visible. Lithic fragments, generally 2 to 4 mm in diameter, of dark basaltic-andesite and red rhyolite or latite comprise about 5% of the rock.

Petrographically, the tuff contains approximately 10.5% total phenocrysts. Subhedral sanidine crystals dominate, comprising about 7% of the rock's volume. Plagioclase comprises approximately 2% of the rock and has an average composition of about An_{30}. Rounded quartz and euhedral biotite each comprise about 1% of the rock. Pyroxene and hornblende are present in trace amounts. The matrix shows a partially devitrified vitroclastic texture with relatively undeformed glass shards. Unflattened pumice fragments comprise approximately 20% of the rock, and lithic fragments of basaltic-andesite and densely welded rhyolite ash-flow

Figure 31. Photograph of the lower contact of the tuff of South Crosby Peak with the volcaniclastic unit of South Crosby Peak.

tuff (Hells Mesa Tuff?) make up about 5% of the rock's volume.

The tuff of South Crosby Peak is a regionally minor ash-flow sheet, cropping out only along the northwestern margin of the Plains of San Agustin in the Datil and Crosby Mountains. It's maximum thickness is 300 ft (91m), reported by Lopez (1975) in the southern Datil Mountains. The thinness and the discontinuous nature of the tuff in this study area suggests that was deposited in valleys near it's distal margin. Coffin (in prep.) describes a paleovalley filled by the tuff of South Crosby Peak near the eastern margin of this study area. The fill is topographically lower than the Hells Mesa Tuff and contains lithic fragments of the Hells Mesa Tuff.

There have been no age dates calculated on the tuff of South Crosby Peak. However, it is bracketed between the 32-m.y.-old Hells Mesa Tuff and the 28 to 30-m.y.-old A-L Peak Formation. The suggested source area for the tuff (and possibly the ash-fall tuffs) is the Crosby Mountain volcano-tectonic depression (Bornhorst, 1976).

A-L Peak Formation

The A-L Peak Formation is a composite ash-flow sheet, consisting of three generally recognized ash-flow tuff members -- the lower gray-massive; the middle flow-banded and the upper pinnacles members (Chapin & Deal, 1976). Two distinct ash-flow tuff members, separated by basaltic andesite flows, are identifiable in this study area. The lower member is a multiple-flow, compound cooling unit (flow-banded, and gray-massive members?) and the upper member is a multiple-flow, simple cooling unit, equivalent to the pinnacles member.

The formation was initially named the A-L Peak Rhyolite by Deal and Rhodes (1974), for exposures on the northeast flank of A-L Peak (secs. 3, 33, 34, and 35, T.4S., R.6W.), in the northern San Mateo Mountains. The name A-L Peak Tuff used in this report is adopted from Chapin and others' (1978) reference to the formation. A fission-track age date of 31.8 m.y. was reported for Deal's A-L Peak Rhyolite in the San Mateo Mountains (Smith and others, 1976). However, recent stratigraphic and geochemical studies have shown that Deal's A-L Peak Rhyolite is not the same stratigraphic unit as the A-L Peak Tuff of the Magdalena Project (Chapin, 1980, oral commun.).

The A-L Peak Tuff is correlative to the upper part of Tonking's (1957) Hells Mesa Member of the Datil Formation and to Brown's (1972) tuff of Bear Springs. The lower cooling unit corresponds to the upper portion of Givens' (1957) Hells Mesa unit #5; the intercalated basaltic-andesite to his Hells Mesa unit #6; and the upper cooling unit (pinnacles member) to his Hells Mesa unit #7. Lopez (1974) and Bornhorst (1976) refer to the lower cooling unit as the A-L Peak Rhyolite; to the basaltic-andesite interval as the basaltic-andesite of Twin Peaks; and to the upper cooling unit as the tuff of Wahoo Canyon. The A-L Peak Formation is also possibly correlative to the tuff of Davis Canyon of southwestern New Mexico (J. Ratte, 1980, oral commun.).

lower member

Within this study area, the lower member of the A-L Peak Formation is a multiple-flow, compound cooling unit. The lower member is thickest in the southwestern portion of the study area, where it is about 150 ft (45m) thick. In the southeastern part of the study area, the lower member has a thickness of about 90 to 100 ft (27 to 30m) and shows considerable vertical variation in welding and compaction. An upward sequence (see fig. 32) begins with a lower 10 ft (3m) of light-brown, massive, moderately-welded tuff, which has only slightly compacted foliation at the base, and grades upward into approximately 22 ft (7m) of densely welded, red-brown tuff with well-developed eutaxitic foliation. Within this densely welded tuff are lenses of black, vitrophyre; containing brown sperulites, from 1 to 4mm in diameter, enclosed within the black obsidian. The lower 12 ft (3.7m) of this densely welded zone is massive, the next 8 ft (2.4m) develops a platy nature and the upper 2 ft (0.6m) is massive in character. This relatively thin, upper massive

Description

upper vitrophyre zone (0-2')-intermittant dense, red vitrophyre with well-developed eutaxitic foliation.

vapor-phase zone (50-60')-partially welded, massive tuff, welding and eutaxitic foliation increase upward.

reversal in welding

upper densely welded zone (2')-massive tuff, slight decrease in welding and eutaxitic foliation upward.

densely welded zone (20')-lower 2/3 massive, upper 1/3 platy, vitrophyre lenses of both platy and massive varieties, common vitually uniform eutaxitic foliation.

gradational contact

lower partially welded zone (10')-massive tuff, becomes more densely welded upward, eutaxitic foliation increases upward.

Scale 1"=10'

gure 32. Diagram of the lower member of the A-L Peak Formation based on variations eutaxitic foliation and degree of welding.

layer shows a slight decrease in welding and eutaxitic foliation.

Overlying this basal sequence, with a marked reversal in welding, is a relatively thick, 50 to 60 ft (15 to 18m), vapor-phase zone. This zone grades from a moderately welded tuff upward into a more densely welded tuff with well-developed eutaxitic foliation. The entire sequence is discontinuously capped by a thin, red vitrophyre zone. The rocks of this upper vitrophyre zone have a dull, resinous luster typical of pitchstones.

To the west and north, the lower member thins to 50 ft (15m) or less, due largely to the disappearance of the vapor-phase zone. The flows associated with the vapor-phase zone appear to have puddled in a topographic low located in the southeastern part of the study area. The topographic low apparently deepens to the northeast as Coffin (in prep.) reports thicknesses of 100 to 150 ft (30 to 46m) for the lower member of the A-L Peak Formation. In addition to the northwest-thinning, the lower part of the ash-flow sheet becomes increasingly less welded to the northwest and grades into a light-brown, poorly welded, moderately pumice-rich tuff.

In the southwestern portion of the study area, the lower member conformably overlies the unit of South Crosby Peak. However, in other portions of the study area the lower member lies upon the unit of South Crosby Peak, the Hells Mesa Tuff, and the middle sedimentary unit with slight angular unconformity. The lower member lies beneath the basaltic-andesite of Twin Peaks throughout most of the field area, with the exception of the northwestern part of the area where the basaltic-andesite of Twin Peaks is absent. There, the lower member lies directly beneath the pinnacles member of the A-L Peak Tuff. The overlying units are conformable with the lower member of the A-L Peak Formation throughout the study are, with the exception of two outcrops along the Blue Mesa Plateau where the pinnacles member of the A-L Peak Formation overlies the lower member of the A-L Peak Formation with slight angular unconformity.

Petrographically, the lower member consists of densely to moderately welded, crystal-poor rhyolite ash-flow tuffs (see table 3). The total phenocryst content ranges from about 3 to 7% with euhedral to subhedral sanidine crystals by far the dominant phenocryst. The sanidine phenocrysts are from 0.5mm to 2mm in length and commonly show Carlsbad twinning. Biotite, rounded quartz, plagioclase and clinopyroxene all occur in minor amounts, with sphene and magnetite present in trace amounts. The ferromagnesian minerals are commonly rimmed or totally replaced by opaque oxides. Lithic fragments vary from less than 2% to about 5%.

The vapor-phase minerals are intergrowths of euhedral alkali feldspars and quartz. The crystals lining the pumice are generally coarser grained than those nearer the center, which have a fine-grained, sugary texture. Many of the vapor

Table 3. Modal analyses in volume percent of the A-L Peak Formation.

	Lower Member							Pinnacles Member	Pinnacles Member
	Partially Welded Zone	Lower Densely Welded Zone	Vitrophyre in Densely Welded Zone	Upper Densely Welded Zone	Lower Vapor-Phase Zone	Upper Vapor-Phase Zone	Upper Red Vitrophyre Zone		
Total Phenocrysts	5.1	6.4	3.5	5.6	3.1	6.8	4.1	0.7	1.2
Sanidine	4.3	5.8	2.1	4.8	2.6	5.8	3.6	0.7	1.2
Plagioclase (An%)	0.1 (25)	0.3 (24)	0.2 (31.5)	0.2 (36.5)	0.1 (24.5)	0.2 (28.5)	trace (38)	trace	trace
Quartz	0.4	trace	0.3	0.1	trace	0.1	0.2	trace	trace
Biotite	0.3	0.1	0.2	0.4	0.2	0.5	0.3	trace	trace
Clinopyroxene	trace	0.2	0.1	0.1	0.2	0.2	trace	trace	trace
Points Counted	2211	2541	2102	1975	2425	2834	2455	2752	2597

phase minerals are partially altered to clays and/or coated with secondary silica.

Whereas the phenocryst mineralogy and abundance are very similar throughout the lower member, petrographic variations other than those in welding do occur. In particular, these variations occur in primary textures and structures, in type and extent of crystallization, and in the An content of the plagioclase phenocrysts.

The lower, partially welded zone has a slightly devitrified, vitroclastic matrix with minor axiolitic structures developed in the pumice. Plagioclase has an average composition of An_{25}. This zone grades upward into the densely welded zone.

The densely welded zone has a slightly devitrified matrix with a vitroclastic texture. It also has well-developed eutaxitic structure (see fig. 33) and common axiolitic and spherulitic structures in the pumice. Plagioclase has an average composition of about An_{24}. The vitrophyre in this zone also has a slightly devitrified matrix with a strong eutaxitic structure. Glass shards are well defined and commonly wrap around crystals and lithic fragments. The pumice fragments are characterized by crystal aggregates of quartz and alkali feldspars and commonly show fiamme structure. The plagioclase crystals have a composition of about An_{31}.

The upper partially welded zone has a partially devitrified matrix with a eutaxitic structure. The

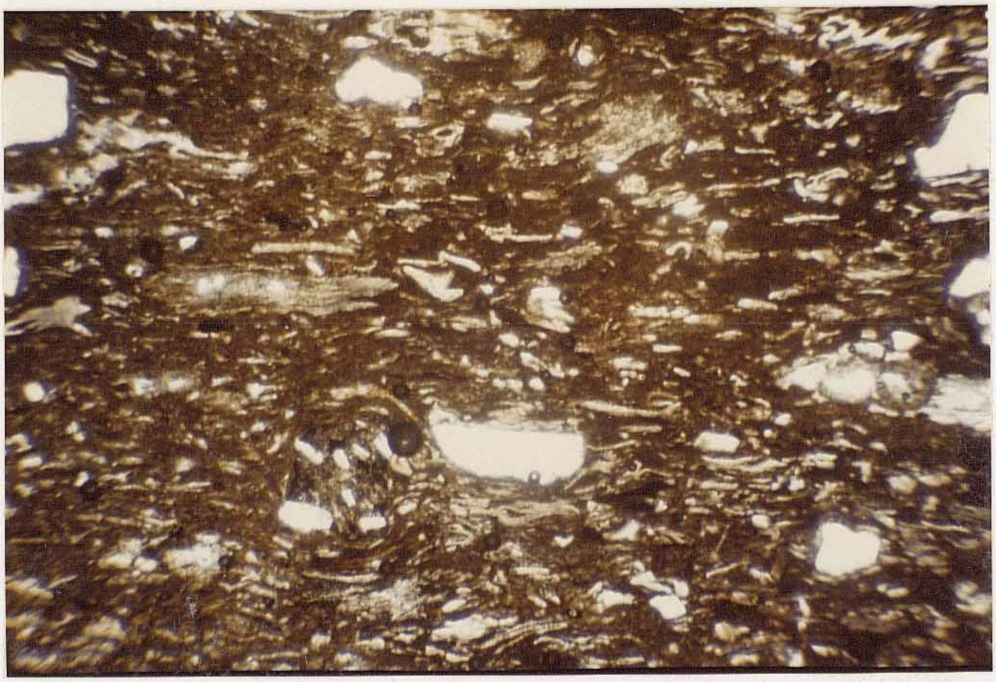


Figure 33. Photomicrograph of the densely welded zone of the lower member of the A-L Peak Formation that shows vitroclastic texture. Note the pressure shadows around the lithic fragment in the lower left center of picture.

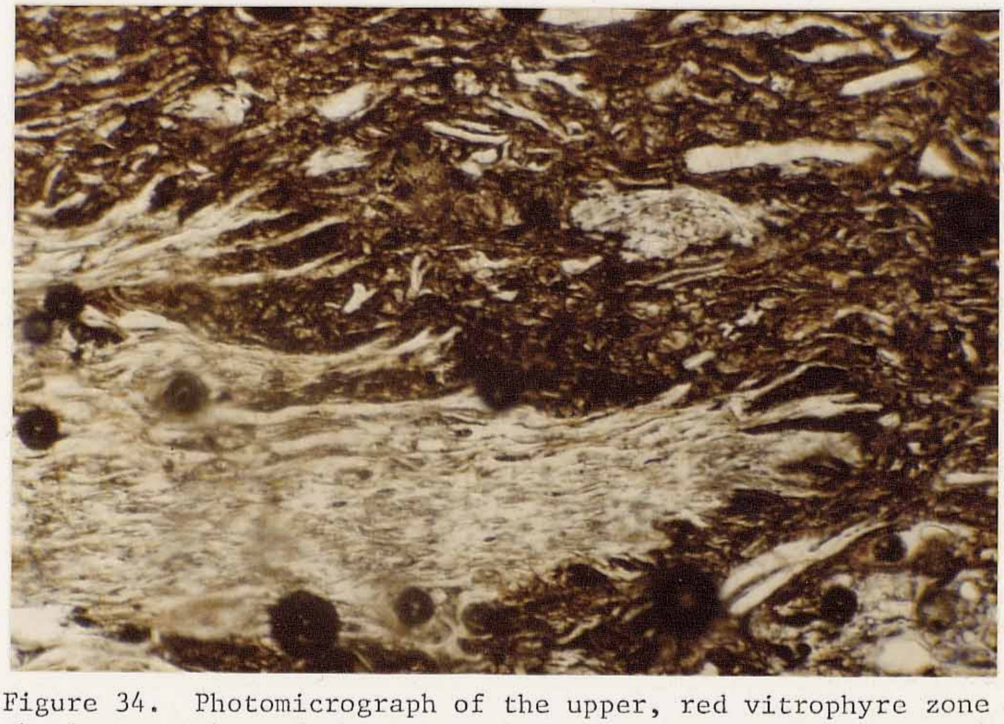


Figure 34. Photomicrograph of the upper, red vitrophyre zone of the lower member of the A-L Peak Formation that shows vitroclastic texture and fiamme structure.

plagioclase in this zone has an average composition of about An_{36}.

The lower portion of the vapor-phase zone has a completely devitrified matrix with a vitroclastic texture. Pumice fragments and open pore spaces contain aggregates of vapor-phase minerals with minor axiolitic structures. The plagioclase has an average composition of about An_{24}. The upper portion of the vapor-phase zone is partially devitrified, has a eutaxitic matrix, and has both crystal aggregates and axiolitic structures in open spaces. Plagioclase has an average composition of about $An_{28.5}$. The upper, red vitrophyre zone has a nondevitrified matrix of visible glass shards and a eutaxitic structure. The matrix of the vitrophyre has a vitroclastic texture. It's pumice fragments generally show well-developed fiamme tails (see fig. 34). The plagioclase crystals have an average composition of about An_{38}.

Chapin and Lowell (1979) describe primary laminar flow structures within ash-flow tuffs which result from aggutination and collapse of glassy particles during deposition, prior to the cessation of movement. Features related to primary welding in the A-L Peak Formation have been previously reported by Deal (1973a), Deal (1973b), and Chapin and Deal (1976). In this study area, there is no direct evidence for primary welding in the lower member of the A-L Peak Formation. Pumice fragments within the lower member are not obviously lineated. And, no primary folds were observed. However, in the southeastern part of the study area where attitudes of the units consistently dip from ten to fifteen degrees to the southeast, measured attitudes on flattened pumice fragments and gas cavities in the lower member of the A-L Peak Formation are as high as forty degrees to the southeast. Thus, the possibility of low amplitude folds is indicated by such anomalously high foliation attitudes.

The stratigraphic nature of the A-L Peak Formation is extremely complex, and at the present is poorly understood. For this reason, correlations between the lower member described in this thesis and either the flow-banded or gray-massive members of Chapin and Deal (1976) is not attempted.

It is suggested, however, that the lower member of the A-L Peak Formation in this area is stratigraphically and petrologically equivalent to the lower and middle members of Chamberlin's (1974) A-L Peak Formation, to a portion of Wilkinson's (1976) A-L Peak Tuff, and to Lopez's (1975) and Bornhorst's (1976) A-L Peak Rhyolite Tuff (see plate 2). The probable source area for the lower member of the A-L Peak Formation is the Magdalena Caldron described by Blakestad (1978), Allen (1980), Bowring (1980), Donze (1980), and Roth (1980).

Characteristics which the lower member of the A-L Peak Formation in this area has in common with the above mentioned units are:

1) They all are multiple flow, compound cooling units.

2) They all have similar phenocryst mineralogy and percentage [an exception to this is the minor amount, 0.1 to 0.2%, of clinopyroxene present in this study area and to the southwest (Lopez, 1975; Bornhorst, 1976) which has not been observed to the east (Chamberlin, 1974; Wilkinson, 1976)].

3) They are all stratigraphically above the Hells Mesa Tuff.

4) Most of the units show some indication of primary laminar flow structures [Bornhorst (1976) does not mention such structures].

A possible stratigraphic marker horizon across these units is a dense, black vitrophyre horizon which occurs near the base of Deal's (1973) A-L Peak Rhyolite in the San Mateo Mountains; near the base of Chamberlin's (1974) middle cooling unit of the A-L Peak Formation in the Gallinas Mountains; near the base of the lower member in this area; and near the base of Lopez's (1975) A-L Peak Rhyolite in the southern Datil Mountains.

basaltic-andesite of Twin Peaks

Intercalated between the lower member of the A-L Peak Formation and the pinnacles member is the basaltic-andesite of Twin Peaks. The name was proposed by Lopez (1975) for exposures on Twin Peaks, secs. 18 and 19, T.2S., R.9W. This unit correlates with Givens' (1957) Hells Mesa unit 6.

The Twin Peaks is a multiple flow unit that crops out discontinuously throughout the southern two-thirds of the study area. The most prominent exposures of this unit occur adjacent to the Plains of San Agustin where it reaches a maximum thickness of about 200 ft (61m). A similar thickness is observed in the extreme southwestern corner of the study area. It thins to 50 ft (15m) or less to the west and is absent from the northern one-third of the area.

The basaltic-andesite of Twin Peaks commonly caps the highest peaks in the area, but it is not a major bluff-former. Instead, it characteristically forms rounded crests coated with basaltic-andesite rubble. As a result, the lower contact is typically obscured and is mapped as the uppermost occurrence of float from the lower member of the A-L Peak Formation. Where the pinnacles member of the A-L Peak Formation overlies the basaltic-andesite of Twin Peaks, it occurs in small patches filling shallow depressions and generally has a sharp contact.

In hand specimen, the basaltic-andesite of Twin Peaks is a dark-gray, vesicular, microporphyritic rock. Small (less than 1mm) phenocrysts of plagioclase, pyroxene, and olivine are recognizable under a hand lens. The vesicles are commonly lined with calcite.

Petrographically, this unit consists of 3 to 4% phenocrysts of dominantly euhedral to subhedral olivine and minor pyroxene, partly to completely oxidized to goethite and/or iddingsite(?). The phenocrysts have an average size of about 1mm. The matrix is composed of plagioclase microlites, about 0.3mm in length, enclosed in subhedral clinopyroxene and black glass. The plagioclase makes up approximately 50% of the matrix and has an average composition of about An_{46}.

Similar basaltic-andesites, occupying the same stratigraphic interval between the flow-banded and pinnacles members of the A-L Peak Formation, are described by Brown (1972) in the Bear Mountains, by Blakestad (1978) in the Kelly mining district, and by Chamberlin (1980) in the Lemitar Mountains. No radiometric dates have yet been obtained on these basaltic-andesites. Samples of the Twin Peaks basaltic-andesite from this study area have been collected by C. E. Chapin for future dating.

pinnacles member

The upper member of the A-L Peak Formation is a very-crystal-poor, moderately pumice-rich, moderately welded rhyolite ash-flow tuff. It is also a multiple-flow, simple cooling unit. The pinnacles member crops out as isolated patches throughout virtually the entire area, with a normal thickness of about 20 to 40 ft (6 to 12m). One atypical hill located in the northwestern part of the area, adjacent to the Red Lake fault, is capped by approximately 200 ft

(61m) of the pinnacles member. This anomalous thickness is probably due to the tuff's filling of a paleostream channel or other topographic low.

In the southeastern part of the study area, the pinnacles member occurs both as a planar outflow sheet that conformably overlies the basaltic-andesite of Twin Peaks, and as a channel fill that unconformably overlies the middle sedimentary unit and the Hells Mesa Tuff. The channel fill trends west-northwest, at nearly right angles to the present day axis of the synform. Along Blue Mesa, in the Red Lake fault zone, the pinnacles member overlies the Hells Mesa Tuff with angular unconformity. These relationships indicate that 1) between the time of deposition of the lower and pinnacles members of the A-L Peak Formation there was movement along the Red Lake fault zone (possibly associated with relative uplift of the Colorado Plateau), and 2) that a synformal basin, similar to the present day synform, was developing simultaneously.

In hand specimen, the pinnacles member is a light-gray, crystal-poor, moderately pumice-rich ash-flow tuff. It is moderately welded with a well-developed eutaxitic structure. Compacted pumice fragments often reach 3 to 4 in. (8 to 10cm) in long dimension. No prominent lineations were identified in the study area. Sparse, large laths of sanidine are practically the only phenocrysts present and these comprise only 1 to 3% of the rock's volume. Occasionally the sanidine phenocrysts show a chatoyant blue color. Biotite, quartz and pyroxene phenocrysts are visible in trace amounts. Vapor-phase crystals are prominent inside pumice fragments and other open spaces. Lithic fragments, generally from 2 to 5mm in diameter and dominantly andesitic in composition, comprise from 2 to 5% of the rock.

Modal analyses of two thin sections of the pinnacles member are given in Table 3. These rocks are composed of a brown, partially devitrified, vitroclastic matrix with from 1 to 3% total phenocrysts. Sanidine is the most common phenocryst and is usually euhedral, ranging from 2 to 6mm in length, and commonly displays Carlsbad twinning. Many of the sanidine crystals are fractured and highly embayed. Biotite, pyroxene, quartz and plagioclase are present in trace amounts. The only plagioclase crystal found in the two thin sections was normally zoned from An_{26} to An_{32}.

A characteristic petrographic feature of the pinnacles member is the conspicuous vapor-phase crystallization in pumice fragments and open pore spaces. The crystals are an aggregate of euhedral alkali feldspar and cristobalite which appear to grow inward away from the pumice walls (see fig. 35). Alteration of the alkali feldspars to clay and the development of secondary silica in the form of chalcedony are both common.

It is becoming apparent that the pinnacles member of the A-L Peak Formation forms an extensive ash-flow sheet that crops out around most of the San Agustin Plains. Westward extension of the stratigraphy from the Magdalena area by

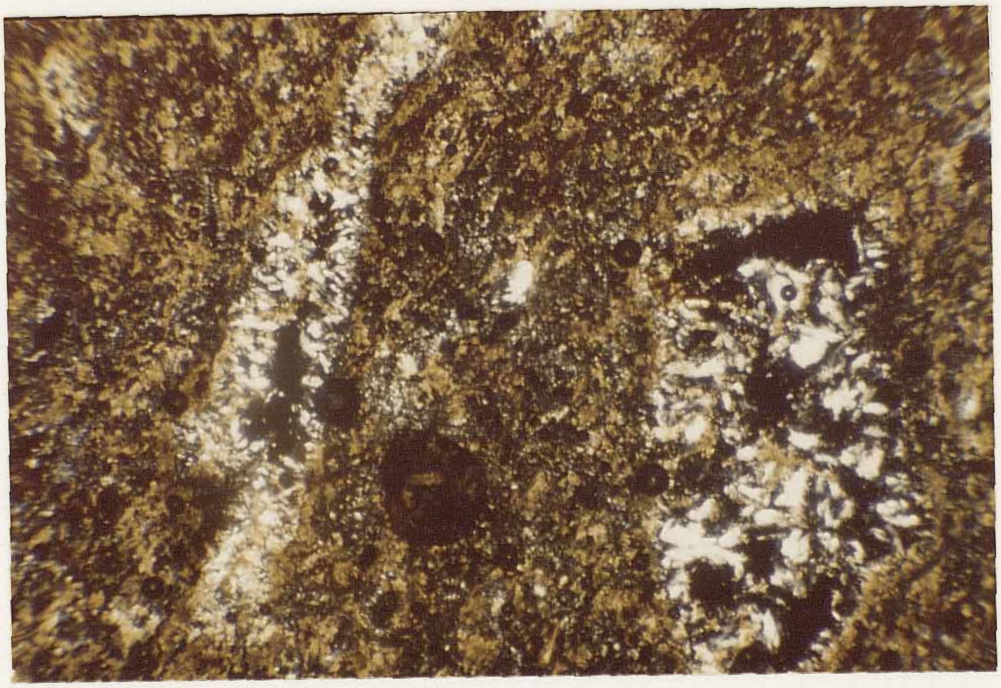


Figure 35. Photomicrograph of the pinnacles member of the A-L Peak Formation that shows vapor-phase mineralization within pumice and other voids.

Simon (1973), Chamberlin (1974), Wilkinson (1976), and Laroche (in prep.), traced the pinnacles member into the central Gallinas Mountains, adjacent to the Dog Springs 15' quadrangle mapped by Givens (1957). The correlation between the pinnacles member and Givens' Hells Mesa unit #7 is herein made on the basis of common stratigraphic position and common mineralogy and textures. Lopez (1975) and Fodor (1978) have correlated a mineralogically and stratigraphically similar tuff in the northern Black Range with Givens' (1957) Hells Mesa unit #7. This tuff was named the tuff of Wahoo Canyon by Fodor (1978) and a type section was given by Elston (1978) in secs. 2, 3, 4, 9, 10 and 11, T.8S., R.9W. The mapping performed for this thesis has confirmed the correlation between Givens' Hells Mesa unit #7 and Lopez's (1975) tuff of Wahoo Canyon. It thus appears geologically sound to extend the correlation of the pinnacles member to Fodor's (1978) tuff of Wahoo Canyon. The pinnacles member can possibly be further extended, around the southern margin of the Plains of San Agustin by the correlation of the tuff of Wahoo Canyon with a portion of Stearn's (1962) $Tdrp_2$ unit, as proposed by Fodor (1978).

Basalt of Blue Mesa

The basalt of Blue Mesa is the name herein applied to the post-Oligocene basalt flows that cap the Blue Mesa

Plateau in the northwest-portion of this study area and immediately to the north in the D-Cross Mountain 7 1/2 minute quadrangle. Givens (1957) referred to these rocks as the Santa Fe basalts and considered them to be part of the Santa Fe Formation.

These basaltic rocks crop out as isolated patches in the northwestern corner of this study area, with a maximum thickness of approximately 80 ft (24m). They typically form steep bluffs, with crude columnar jointing. Within the study area, they conformably overlie the Hells Mesa Tuff and rocks of the Dog Springs volcanic complex.

In hand specimen, these basalts are dark, greenish-gray, porphyritic rocks. Phenocrysts of plagioclase, green augite and relatively unaltered olivine are recognizable, all 2mm or less in size.

Petrographically, they consist of approximately 36% plagioclase, 9% olivine, 4% augite, 2% magnetite, and less than 1% apatite phenocrysts in a fine-grained matrix. The plagioclase has an average composition of about An_{58}, occasionally shows partial resorption features, and has augite-filled fractures. The plagioclase laths seldom exceed 2mm in length and commonly contain opaque inclusions. The olivine occurs as euhedral to subhedral, strongly birefringent crystals with occasional alteration rims. They range in size from 0.5 to 2mm. The augite phenocrysts occur as pale-green, anhedral to subhedral, prismatic crystals with moderate birefringence. The apatite is present as euhedral six-sided crystals, about 1mm in diameter.

Stratigraphically, these basaltic rocks are the youngest volcanic rocks in the area; they overlie older rocks with angular unconformity. Givens (1957) relates the basaltic rocks of Blue Mesa to similar basaltic rocks that cap D-Cross Mesa, Tres Hermanos Mesa, and Table Mountain Mesa to the north and northeast of this study area. However, at present there are no age dates for any of these rocks and such a correlation is not warranted. Another possible source is a poorly exposed basaltic vent at the northern end of the Blue Mesa Plateau (B. Robinson, 1980, oral commun.).

Petrographically, these basaltic rocks resemble the augite-bearing olivine basalts described by Aoki (1967) from the Pliocene olivine-tholeiites of the Taos, New Mexico, area. The Blue Mesa basalts also closely fit the petrographic description of Lipman & Moench's (1972) late basalts of the Mount Taylor volcanic field. No chemical data on the basalt of Blue Mesa is yet available.

Mafic Dikes

Only three minor mafic dikes were found in the study area. One is located in the northwestern corner of the area along the southeastern margin of Blue Mesa Plateau. It is about 480 ft (146m) long, 6 ft (2m) wide, strikes N40^{o}W and dips 60^{o} to the southwest. This dike cuts through the Hells Mesa Tuff and the middle sedimentary unit and is truncated to the north by a fault. The dike is a fine-grained porphyritic rock, containing phenocrysts of pyroxene, plagioclase and olivine, with minor amounts of magnetite. Opaque minerals after pyroxene and olivine are common. The matrix is a very-fine-grained mosaic of the above minerals.

A second dike is located in the SW 1/4, sec. 24, T.1N., R.9W. It is about 15 ft (4.5m) wide, approximately 100 ft (30m) long and strikes N10^{o}W with a near vertical dip. This dike is fine-grained and vesicular, attesting to near-surface emplacement. It has chilled margins which are more resistant to weathering than the dike's center, giving the dike a concave upward surface expression. This dike cuts only the Dog Springs complex, and it's relative age to the other stratigraphic units is unknown. The strikes of these first two dikes are in good agreement with the trend of other Cenozoic dikes in west-central New Mexico (Dane and Bachman, 1965).

The third dike is located in the NW 1/4 sec. 25, T.1N., R.9W. (unsurveyed). It is about 10 ft (3m) wide and is exposed for only about 20 ft (6m) along strike. It trends approximately N45^{o}E, with a near vertical dip. This strike is atypical to that of other dikes of the region (Dane and Bachman, 1965). The dike cuts only rocks of the Dog Springs volcanic complex and is possibly more related to it than the other two mafic dikes.

The third dike is a fine-grained, porphyritic basalt with phenocrysts of plagioclase, pyroxene, olivine, and magnetite. The ferromagnesian minerals are partially altered to iron-oxides. The matrix is dark-gray, very-fine-grained and intensely silicified.

Surficial Deposits

Alluvium

Present day stream deposits were mapped as Quaternary alluvium. The deposits include stream channels and terraces, and consist of unconsolidated gravel, sand and loam deposits. These deposits are the result of active incision by present stream courses on the existing topography.

Colluvium

Colluvium deposits, within the study area, consist of mountain valley and hillslope deposits.

Piedmont Deposits

The oldest surficial deposits in the study area are poorly-consolidated piedmont deposits. These piedmont deposits contain a heterogeneous collection of pebbles, cobbles and boulders from the entire Tertiary volcanic pile as well as sand- and silt-sized grains. Locally, these gravels can take a homogeneous nature. Caliche zones are common in the southernmost gravels.

Within the study area, two distinct piedmont surfaces are recognized. The oldest, Tertiary or possibly early Pleistocene in age, forms a large northeast-trending deposit within the Dog Springs drainage basin and smaller deposits in valleys around the North Lake Basin in the southeast-portion of the study area. Givens (1957) referred to the deposits in the Dog Springs drainage basin as part of the Santa Fe Formation and interpretted them as "either (1) the remnant gravels of an old stream course, or (2) a sliver of the Santa Fe formation preserved because of its proximity to the Red Lake Valley fault." This deposit is as much as 150 ft (45m) thick in this study area and shows a sequence of Oligocene volcanic rocks overlain by dominantly porphyritic basaltic rocks similar to the basalt of Blue Mesa. The present day drainage streams are incised as much as 200 ft (61m) below the base of the Tertiary piedmont deposit.

Remnants of similar piedmont deposits occur as isolated patches along Thompson Canyon, in valleys around the San Agustin Plains, and as two large areas along the south-central margin of the study area. These latter two deposits are at an elevation of about 8,500 ft (2600m), whereas the deposit in the Dog Springs drainage basin is at an elevation of about 7400 ft to 7500 ft (2250 to 2290m).

The youngest piedmont deposits within the study area are probably of Quaternary age. These deposits occur surrounding the Dog Springs drainage basin and in the North Lake Basin.

They are graded to the present day topography and are incised by active intermittent streams.

Additional Quaternary piedmont deposits are present adjacent to large faults. These piedmont deposits consist entirely of rock types derived from the topographically high fault block. In the case of the Red Lake fault, which shows reversed topography, deposits of Tertiary rocks overlie the Baca Formation and Mesaverde Group.

Landslides/Talus

Landslide and talus deposits occur in many parts of the study area. In general, these deposits were only mapped when they obscured geologic contacts or structure.

STRUCTURE

Regional Structure

The regional structure of west-central New Mexico has evolved in a fashion similar to that of most of the southwestern United States. During the Laramide orogeny, of late Cretaceous - early Tertiary time, uplifts, folds and thrust faults resulted from compressional stresses due to the convergence and subduction of the Farallon plate beneath the North American plate (Atwater, 1970; Christiansen and Lipman, 1972).

During the late Eocene (40-50 m.y.) a period of tectonic quiessence allowed for the erosional development of an extensive surface of low relief (Epis and Chapin, 1975). In west-central New Mexico, detritus from the carving of this surface formed the arkosic Baca Formation, which filled a west-trending basin between Laramide highs (Snyder, 1971).

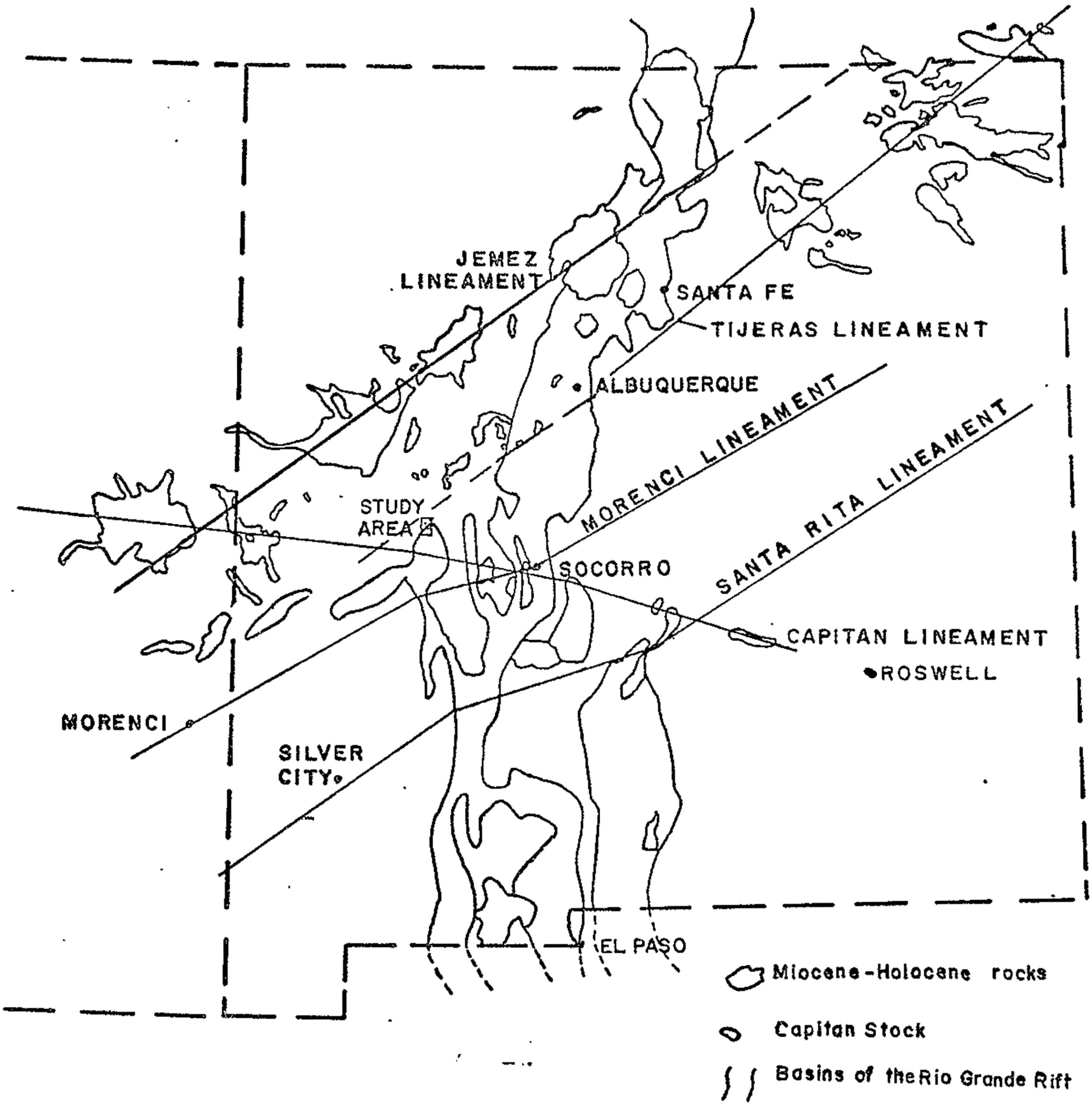
Upon this erosional surface, volcanic rocks from the Datil-Mogollon volcanic field began to accumulate approximately 37 m.y. ago. The initial volcanism was of intermediate, calc-alkaline affinity (Eaton, 1979). Approximately 32 m.y. ago, normal faulting accompanied by bimodal volcanic eruptions began along the Rio Grande rift (Chapin, 1979; Eaton, 1979). The regional trend of the faulting was north to north-northwest in central New Mexico.

However, in the vicinity of the San Agustin Plains, rift faulting has an anomalous northeast trend. Chapin (1971-b) has interpreted the San Agustin Basin as a bifurcation of the Rio Grande rift, possibly controlled by the northeast-trending Morenci lineament. Similar trending basins have been described by Ratte and others (1969) in the Blue Ridge Primitive Area southwest of Reserve, New Mexico.

Another possible lineament control on the west-central New Mexico regional structure is the Tijeras lineament (see fig. 36). This lineament is well documented by Lisenbee and others (1979) east of Albuquerque and by Chapin and others (1979) in the Riley-Puertecito area. It is possible that the San Augustin Basin owes it's existence to it's location between the Morenci and Tijeras lineaments (Chapin, 1980, oral commun.). Also, it is possible that the Tijeras lineament served as a control for the Dog Springs volcanic complex, in a role similar to that played by the Morenci and Capitan lineaments on the calderas of the northeastern Datil-Mogollon volcanic field (Chapin and others, 1978).

Local Structure

The northeastern Datil Mountains can be divided structurally into three domains, a homocline, a complexly faulted zone, and a southeast-plunging synform (see plate 3). In this study area, the monocline occupies the extreme



IGURE 36 . LOCATION OF STUDY AREA IN RELATIONSHIP TO THE MAJOR LINEAMENTS OF NEW MEXICO

(AFTER CHAPIN AND OTHERS, 1978, AND CHAPIN, 1980, ORAL COMMUN.)

northwestern corner where rocks of the Tertiary Baca Formation and the Cretaceous Mesaverde Group crop out. Southwest from this area, the honocline extends well into the Datil Mountains. The region has a gentle, southerly dip of about 3 to 5^{o}, and is virtually unfaulted. This structural domain was referred to by Fitzsimmons (1957) as the Mogollon Slope and was interpreted by him as the southern boundary of the Colorado Plateau.

Southeast of the homocline is a complexly faulted domain. The boundary between the two domains is the northeast-trending Red Lake fault. In general, the majority of the faults in the complexly faulted domain are parallel or subparallel to the Red Lake fault. There are, however, two additional trends. The most important of these is the east-trending Thompson Canyon fault and related lesser faults in the northeastern part of the study area. The second trend consists of a series of northwest-trending faults which are present throughout the area. The crisscrossing of faults from all trends, with little or no change in displacement or direction, indicates that the faults of various trends developed nearly simultaneously. A large, diamond-shaped horst block, which covers about 4 square miles in the southern portion of the study area, provides some of the best exposures of the Dog Springs volcanic complex.

The faults in the area studied are all high-angle normal faults. Their stratigraphic throw ranges from 3000 ft+

(900m+) on the Red Lake fault to 50 ft (15m) or less on minor faults. The few fault planes that are measurable yield attitudes that are within 30° of vertical. The nearly straight surface expressions of the faults are also indicative of nearly vertical fault planes. The faulted domain consists largely of horst and wedge-shaped graben blocks.

The exact age of the beginning of the faulting is difficult to ascertain, as rocks of all ages are displaced. The rocks overlying the Dog Springs complex reveal a long period of tectonically undisturbed basin filling through deposition of the Spears Group and the Hells Mesa Tuff. Higher in the section, however local angular unconformities exist between the Hells Mesa Tuff and the unit of South Crosby Peak, between the lower member of the A-L Peak Formation and the basaltic-andesite of Twin Peaks, and between the Twin Peaks and the pinnacles members of the A-L Peak Formation. While these unconformities do not directly substantiate the beginning of regional structural deformation, they do indicate a change in tectonic style away from the conformable basin fill of the Spears Group and the Hells Mesa Tuff. This change is particularly notable in the complexly faulted domain.

Several lines of evidence indicate that faulting has occurred from the late Tertiary through the Quaternary. First, Tertiary piedmont deposits cover major faults along the south-central margin of the study area. These gravel deposits consist of cobbles from the A-L Peak Formation and are at a present elevation of about 8500 ft (2600m). Second, the Pliocene (?) basalt of Blue Mesa is displaced by a northeast-trending fault near the Red Lake fault. Third, Tertiary piedmont gravels in the northeastern portion of the Dog Springs quadrangle either abut against a scarp of the Thompson Canyon fault, or are cut by the fault (Coffin, in prep.). These deposits are equivalent to the deposits in the Dog Springs drainage basin of this study area; the upper portion of the Dog Springs' piedmont deposits consists dominantly of basaltic debris from the unit of Blue Mesa. Holocene faulting in the region can be documented along the North Lake fault. This fault exists approximately 3 1/2 miles east of this study area and cuts alluvium in the North Lake Basin (Givens, 1957; Coffin, in prep.).

The third structural domain in the northeastern Datil Mountains is a southeast-plunging synform. The synform extends southeastward from the northwestern corner of the study area into the North Lake Basin, where it probably veers to a more southerly direction. Cross section B-B', plate 1, is approximately along it's axis. The synform was first noted by Givens (1957) who described it and a small anticline on it's eastern limb. An antiform is also present on it's western limb, but appears more faulted than folded (see cross-section A-A', plate 1). This antiform coincides with the complexly faulted domain. The northwesternmost portion of the synform is downdropped into a graben structure bounded on the northwest by the Red Lake fault and on the southeast by an unnamed major fault system that trends north-south through the center of the study area. Such a relationship suggests that synformal development began prior to major faulting.

The beginning of synclinal development appears to have begun shortly after deposition of the Hells Mesa Tuff. The Hells Mesa Tuff and older rocks show relatively uniform thickness distributions throughout the area, considering the expected gradual thinning downslope from their source. The rocks overlying the Hells Mesa Tuff, however show irregular thickness distributions. In the southern portion of the area, the volcaniclastic rocks of South Crosby Peak thin from about 200 ft (61m) along the western limb of the synform to 50 ft (8m) or less in the complexly faulted domain. This thinning is largely achieved by the omission of the upper ash-fall tuffs and ash-flow tuffs.

A similar pattern is observed in both the lower member and Twin Peaks members of the A-L Peak Formation. They have a combined thickness of about 300 ft (91m) along the western limb of the synform and thin to 50 ft (8m) or less northwestward. The basaltic-andesite of Twin Peaks pinches out entirely to the northwest. These units also show a combined thickness of about 300 ft (91m) in the extreme southwestern corner of the study area. The expected thickening along the synformal axis is obscured in this study area due to erosion.

Additional support for the development of the synform during the late Oligocene is provided by paleovalleys filled with the pinnacles member of the A-L Peak Formation. Two remnants of one paleovalley are exposed in the south central portion of the area. There, the pinnacles member overlies the Hells Mesa Tuff and the upper portion of the middle sedimentary unit with angular unconformity. The trend of the two remnants is in a west-northwest-direction. From the downcutting relationship of the two outcrops, it appears that the paleovalley deepened to the southeast. This southeast-direction is parallel to the present drainage pattern and to the present-day dip of beds along the western limb of the southeast-plunging synform.

A second paleovalley filled with the pinnacles member of the A-L Peak Formation is located in the northwestern portion of the study area, along the southern end of the Blue Mesa Plateau. In this paleovalley, approximately 200 ft (61m) of the pinnacles member accumulated. This paleovalley trends northwest and overlies the lower member of the A-L Peak Formation with angular unconformity. The lower member in turn lies with angular unconformity upon the Hells Mesa Tuff. Cross section C-C', plate 1, reveals the relationship betwen the synform and the pinnacles' paleovalley fill.

A third paleovalley filled with the pinnacles member of the A-L Peak Formation is located in the SE 1/4, sec. 2, T.1N., R.9W. The exposure is small, but appears to trend east-southeastward. The pinnacles member in this paleovalley lies with angular unconformity upon the Twin Peaks member and the lower member of the A-L Peak Formation and the unit of South Crosby Peak. Coffin (in prep.) observes yet another paleovalley along the eastern limb of the synform, which displays similar relationships. These paleovalleys suggest that a well-developed and incised drainage net existed during deposition of the pinnacles member of the A-L Peak Formation in contrast to the more subdued terrain that existed prior to, and during, deposition of the Hells Mesa Tuff. The southeast-direction of drainage for the paleovalleys is also in contrast to the northerly drainage for pre-Hells Mesa sedimentary rocks.

Thus, it appears that the local structures in the northeastern Datil Mountains began developing just prior to A-L Peak time, approximately 32 m.y. B.P., and that the southeast-plunging synform and antiform developed prior to faulting. Faulting began shortly after folding and downdropped the northwestern portion of the synform. This age appears in good agreement with the beginning of Rio Grande rift extension (Chapin, 1979; Eaton, 1979). It is probably not coincidental that the first major occurrence of basaltic rocks in the study area also occurs at about this time.

Structures similar to those found in the northeastern Datil Mountains have been formed experimentally by Cloos

(1968) in experiments with clay models under tension. Structure across the southern portion of the study area (see cross section A-A', plate 1) is very similar to Cloos' symmetrical graben formed by asymmetrical pull (see Cloos, 1968, fig. 8, p. 425). In both cases, most major faults are down-to-basin, faults generally dip toward the basin, and synform-like sags developed just prior to faulting. The bedding in the study area does, however show greater rotation than the bedding in Cloos' experiment. Additional structures which resemble the structures of the northeastern Datil Mountains have also been produced by Stewart (1971, fig. 12), using a deep zone of asymmetrical extension on mortar.

Structures which can be definitely associated with the Dog Springs volcanic complex are difficult to decipher in the study area due to the imprint of later tectonics. Even the possible existence of basement structures older than the Dog Springs volcanic complex should be considered. The only clear-cut structural margin of the complex in the study area is along the Red Lake fault, where a segment of the fault runs tangential to the complex. Other possible structural features related to the complex could be the relatively high fault density and complexity of the area, the abnormal east-trending Thompson Canyon fault and related lesser faults, and the arcuate fault pattern through the center of the study area. Another possible basement influence on faulting in the study area is suggested by the northeast and northwest-trending shear zones and dikes that are restricted to the Dog Springs volcanic complex. Several younger faults show short deflections along similar trends.

ALTERATION AND MINERALIZATION

Hydrothermal alteration within the study area is restricted to the Dog Springs volcanic complex, which is propylitically altered throughout most of it's area. The alteration mineral assemblage consists of chlorite, calcite and very minor epidote. No pyrite was observed. The degree of alteration varies considerably and commonly increases near major faults. Even more pervasive than the propylitic alteration in the Dog Springs complex is the occurrence of a secondary green iron silicate. This is tentatively identified as celadonite, since that mineral is most common in intermediate volcanics.

Vein mineralization is virtually absent in the area. A single, barren calcite vein, less than 10 ft (3m) long and about 3 in. (8cm) wide, was encountered within the Dog Springs volcanic complex. Manganese stains and dendrites are common throughout the complex.

Several samples from the Dog Springs complex were fire assayed for silver and gold by the chemistry lab of the New Mexico Bureau of Mines and Mineral Resources. Three of the samples, collected from mildly propylitically altered rhyodacite intrusive rock, yielded 0.25, 0.33, and 0.18 ounces of silver per ton. No gold was found in any of the samples. The sampled locations are the NE 1/4, sec. 29, T.2N., R.8W. (unsurveyed); the SE 1/4, NW 1/4, sec. 36, T.1N., R.8W. (unsurveyed); and near the midpoint (quarter corner) between secs. 26 and 27, T.2N., R.9W. respectively. The best economic potential in the study area lies in the possibility of small supergene silver deposits at, or near, the water table and in disseminated deposits.

CONCLUSIONS

Geologic evolution of the northeastern Datil Mountains

Utilizing the stratigraphic and structural relationships observed in the study area, the following sequence of events is developed for the northeastern Datil Mountains.

1) During the early Oligocene (about 37 to 34 m.y. B.P.), intermediate volcanism associated with the Datil-Mogollon volcanic field began in the area with the formation of the Dog Springs volcanic complex. This complex is the earliest known source area within the volcanic field. It lies on the northern periphery of the field, on the boundary between the Colorado Plateau and the Rio Grande rift structural provinces. The Dog Springs complex consists of quartz-latitic to andesitic vents, domes and pyroclastic breccias. Collapse is not positively identified from this study.

Alteration and mineralization within the study area is limited to the Dog Springs complex. Fire assays have shown that highly propylitized rocks contain small amounts of silver.

2) After the formation of the Dog Springs complex, a period of erosion largely leveled the complex, such that it's contact with the overlying sedimentary unit of Chavez Canyon shows relief of 150 ft (46m) or less. This contact is an

angular unconformity, probably due to steeply dipping primary attitudes within the complex.

3) The time period between the leveling of the Dog Springs complex and the deposition of lower member of the A-L Peak Formation (about 32 m.y. B.P.) is characterized by a basinal accumulation of volcaniclastic sediments and ash-flow tuffs. Sedimentary structures indicate a strong, northward transport direction (see figs. 22 and 29), away from the main mass of the Datil-Mogollon volcanic pile.

The ash-flow tuffs which accumulated within this basin are, from oldest to youngest, the tuff of Datil Well, the tuff of Main Canyon, the tuff of Blue Canyon and the Hells Mesa Tuff (about 32 m.y. B.P.). These tuffs are largely conformable with the intercalated basin sediments.

The entire basinal fill shows a fining-upward sequence, from the pebble to cobble conglomerates in the unit of Chavez Canyon to fine-grained fluvial and aeolian sandstone beds beneath the Hells Mesa Tuff. This is probably due to the filling of the basin and a decrease in stream gradients.

4) Shortly after deposition of the Hells Mesa Tuff, the northeastern Datil Mountains changed from a stable area of deposition to one of erosion and deformation. A major southeast-plunging synform and associated antiform developed which controlled depositional thicknesses of the A-L Peak Formation (about 32 m.y. B.P.). Paleovalleys controlled by the synform are commonly filled with the pinnacles member of the A-L Peak. Along the antiform, local angular

unconformities exist between the Hells Mesa Tuff and the unit of South Crosby Peak; between the unit of South Crosby Peak and the lower member of the A-L Peak Formation; between the lower member of the A-L Peak Formation and the basaltic-andesite of Twin Peaks; and between the Twin Peaks member and the pinnacles member. The pinnacles member of the A-L Peak Formation represents the youngest Oligocene volcanic unit within the area.

5) In the late Oligocene to early Miocene, northeast-trending, high-angle normal faults associated with Rio Grande rift extension cut the northeastern Datil Mountains. The most important of these faults is the Red Lake fault, which marks the margin of the Colorado Plateau. Another major fault system through the center of the study area downdropped the northwest-portion of the synform approximately 2500 ft (760m). Faulting continued through the Miocene and Pliocene and into the Holocene.

6) The youngest volcanic event in the area resulted in deposition of the Pliocene (?) Blue Mesa basalt flows. Possible source areas for these basalts are nearby vents to the north of the Datil Mountains.

7) The youngest geological deposits in the area are Tertiary and Quaternary piedmont deposits and Quaternary alluvium.

Stratigraphy around the northern margin of the Plains of San Agustin

Correlations of the major ash-flow sheets around the northern margin of the Plains of San Agustin are as follows (see plate 2):

1) The oldest volcanic unit in the area is the Dog Springs volcanic complex and it's related outflow facies. Rocks of the Dog Springs volcanic complex are only exposed in the extreme northern portions of the Datil and Gallinas Mountains and are correlative with an undifferentiated portion of Lopez's (1975) and Bornhorst's (1976) Spears Formation.

2) The oldest extensive ash-flow sheet in the region is the tuff of Datil Well. This tuff is restricted to the western margin of Plains of San Agustin and becomes increasingly more important to the southwest, where it's probable source lies.

3) Overlying the tuff of Datil Well is the tuff of Main Canyon (Nipple Mountain). This is the most extensive ash-flow sheet in the lower part of the stratigraphic section. It is thickest in the Tres Montosas - Cat Mountain area, thins westward, and pinches out between the Crosby and Mangas Mountains.

4) Along the eastern margin of the Plains of San Agustin, the tuff of Granite Mountain overlies the tuff of Main Canyon, however along the western margin, the tuff of

Blue Canyon overlies the tuff of Main Canyon. The similarities and differencs between these two tuffs have been listed in the section on the tuff of Blue Canyon. Without a good physical correlation, these should be treated as separate units.

5) The most prominent ash-flow sheet in the region is the Hells Mesa Tuff (Rock Tank). It crops out around the entire northern margin of the plains, with a minimum thickness of about 300 ft (91m). The only appreciable change in the tuff through the region is the expected decrease in welding away from it's source in the Magdalena Range.

6) Above the Hells Mesa Tuff is the A-L Peak Formation. The densely welded lower member of the A-L Peak Formation extends across the entire region, but thins considerably westward. The upper pinnacles member (Wahoo Canyon) forms an extensive ash-flow sheet throughout the Gallinas and Datil Mountains, however it is absent in the Mangas Mountains.

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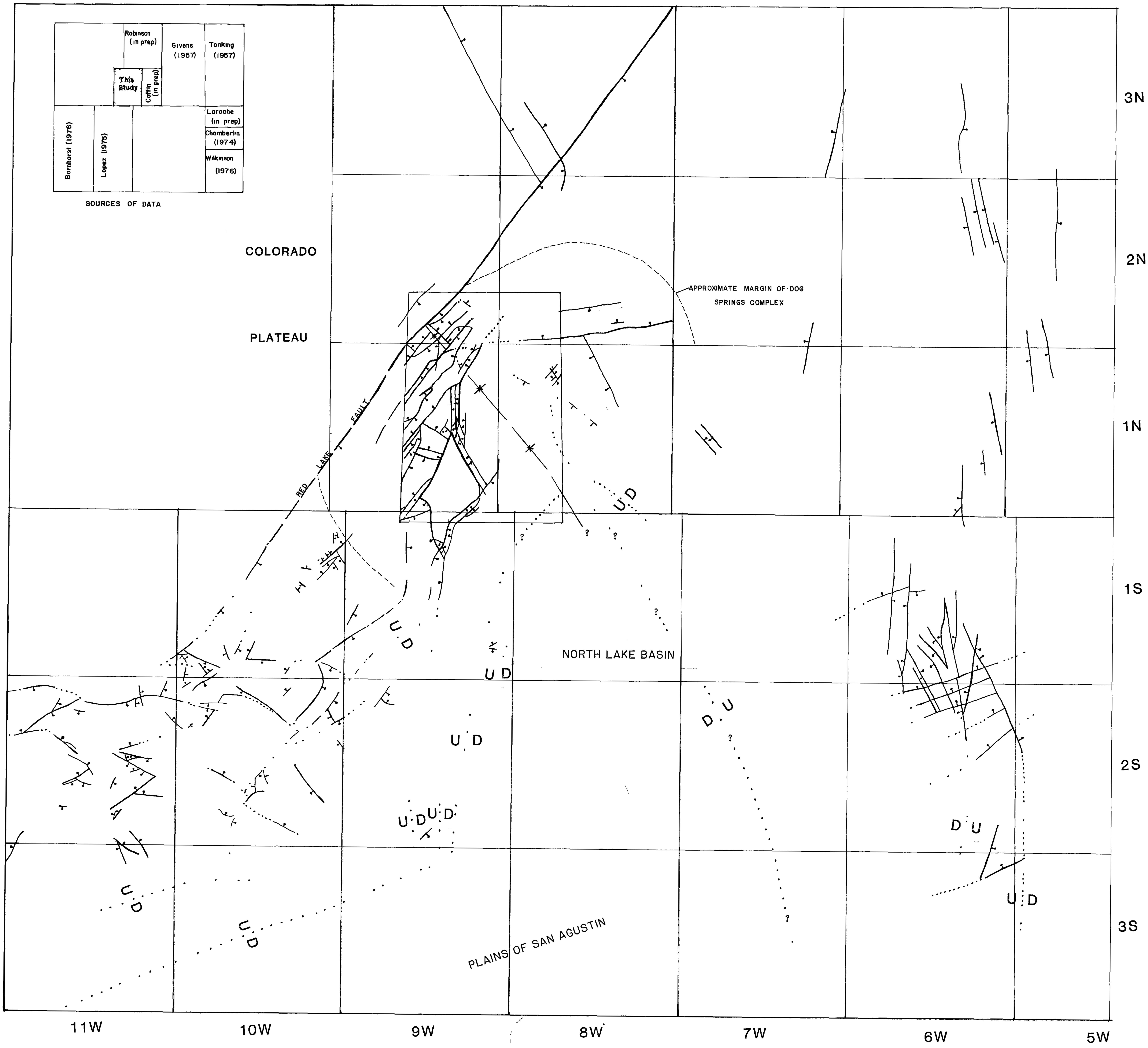
PLATE 3. TECTONIC SKETCH MAP AROUND THE NORTHERN MARGIN OF THE PLAINS OF SAN AGUSTIN.



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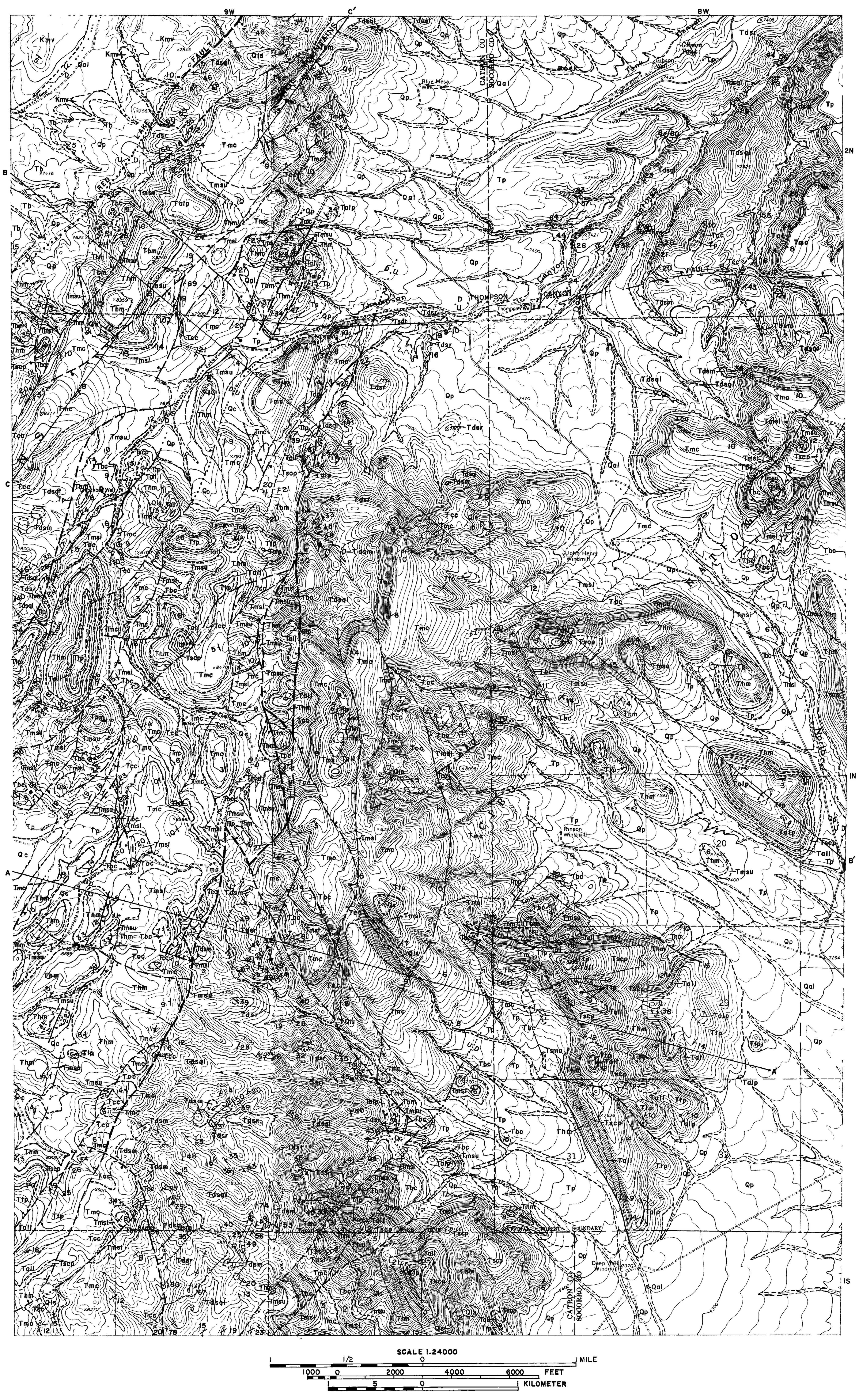
GEOLOGIC MAP AND SECTIONS OF THE NORTHEASTERN DATIL MOUNTAINS, SOCORRO AND CATRON COUNTIES, NEW MEXICO

by

Richard Harrison

1980



EXPLANATION

QUATERNARY

- Qal — QUATERNARY ALLUVIUM
- Qls — QUATERNARY LAND SLIDE DEPOSITS
- Qp, Qc — QUATERNARY PIEDMONT AND COLLUVIUM DEPOSITS

PLIOCENE(?)

- Tp — TERTIARY PIEDMONT DEPOSITS
- Tbm — BASALTS OF BLUE MESA- PORPHYRITIC OLIVINE THOLEIITE BASALTS

OLIGOCENE

- Tolp — A-L PEAK FORMATION-PINNACLES MEMBER- MODERATELY WELDED, CRYSTAL POOR RHYOLITE ASH-FLOW TUFF
- Ttp — A-L PEAK FORMATION- TWIN PEAKS- MICOPORPHYRITIC BASALTIC ANDESITE FLOWS
- Toll — A-L PEAK FORMATION-LOWER MEMBER- MODERATELY TO DENSELY WELDED, CRYSTAL POOR RHYOLITE ASH-FLOW TUFFS
- Tscp — VOLCANICLASTIC ROCKS OF SOUTH CROSBY PEAK- PEBBLE-COBBLE CONGLOMERATES, ASH-FALL TUFFS, REWORKED ASH-FALL TUFF AND A POORLY WELDED, CRYSTAL POOR, PUMICE RICH ASH-FLOW TUFF
- Thm — HELLS MESA TUFF- MODERATELY TO POORLY WELDED, CRYSTAL RICH RHYOLITE ASH-FLOW TUFF

SPEARS GROUP

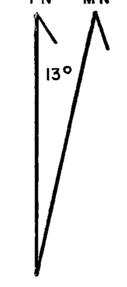
- Tms — MIDDLE SEDIMENTARY UNIT- PEBBLE-COBBLE CONGLOMERATES AND SANDSTONES, GENERALLY FINES UPWARD WITH TYPICAL AEOLIAN SANDSTONES NEAR TOP
- Tmsu — MIDDLE SEDIMENTARY UNIT- ABOVE TUFF OF BLUE CANYON
- Tbc — TUFF OF BLUE CANYON- MODERATELY TO POORLY WELDED, CRYSTAL RICH, QUARTZ POOR QUARTZ-LATITE ASH-FLOW TUFF
- Tmsl — MIDDLE SEDIMENTARY UNIT- BELOW TUFF OF BLUE CANYON
- Tmc — TUFF OF MAIN CANYON- MODERATELY TO POORLY WELDED, CRYSTAL POOR, MODERATELY PUMICE RICH ASH-FLOW TUFF
- Tcc, Tdw — VOLCANICLASTIC SEDIMENTARY UNIT OF CHAVEZ CANYON- FELDSPATHIC SANDSTONES, PEBBLE-COBBLE CONGLOMERATES, AND MINOR DEBRIS FLOW BRECCIA- INTERBEDDED WITHIN THIS UNIT IS THE MODERATELY WELDED, MODERATELY CRYSTAL RICH ASH-FLOW TUFF OF DATIL WELL
- Tdsr — DOG SPRINGS VOLCANIC COMPEX- RHYODACITE VENTS, DOMES AND FLOWS
- Tdsm, Tdsql — DOG SPRINGS VOLCANIC COMPLEX- DOMINANTLY QUARTZ-LATITE TUFF BRECCIAS, ALSO INCLUDES LAHARIC BRECCIAS, MINOR ASH-FLOW TUFFS AND SEDIMENTARY ROCKS, AND Tdsm-MEGABRECCIA BLOCKS

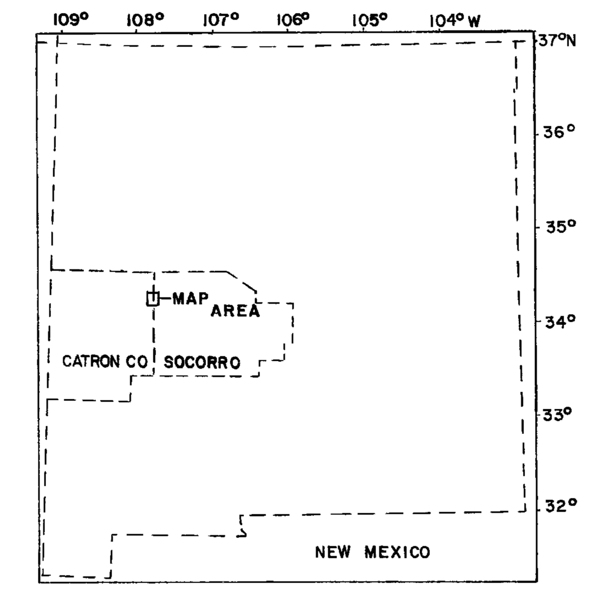
PRE-OLIGOCENE

- Tb — BACA FORMATION- EOCENE CONGLOMERATES, RED TO WHITE SANDSTONES, SILTSTONES, AND MUDSTONES
- Kmv — MESAVERDE GROUP- CRETACEOUS, YELLOWISH SANDSTONES, SILTSTONES, AND MUDSTONES
- MAFIC DIKES

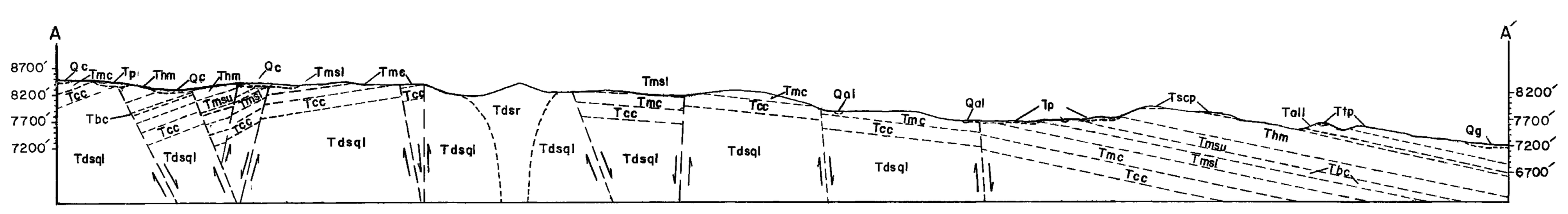
SYMBOLS

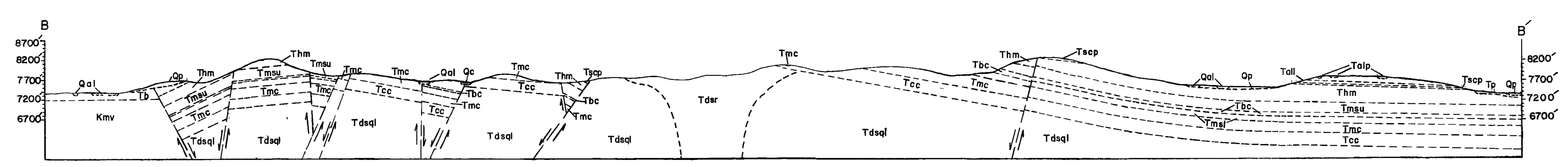
- CONTACT, DASHED WHERE APPROXIMATE
- U / D — FAULT, DOTTED WHERE COVERED, BALL AND HACHURE ON DOWNTHROWN SIDE U ON UPTHROWN SIDE AND D ON DOWNTHROWN SIDE
- 12 — STRIKE AND DIP OF BEDDING
- 12 — STRIKE AND DIP OF BEDDING, UNCERTAIN
- 34 — STRIKE AND DIP OF FOLIATION
- SHEAR ZONE, DIRECTION OF DISPLACEMENT UNKNOWN





INDEX MAP





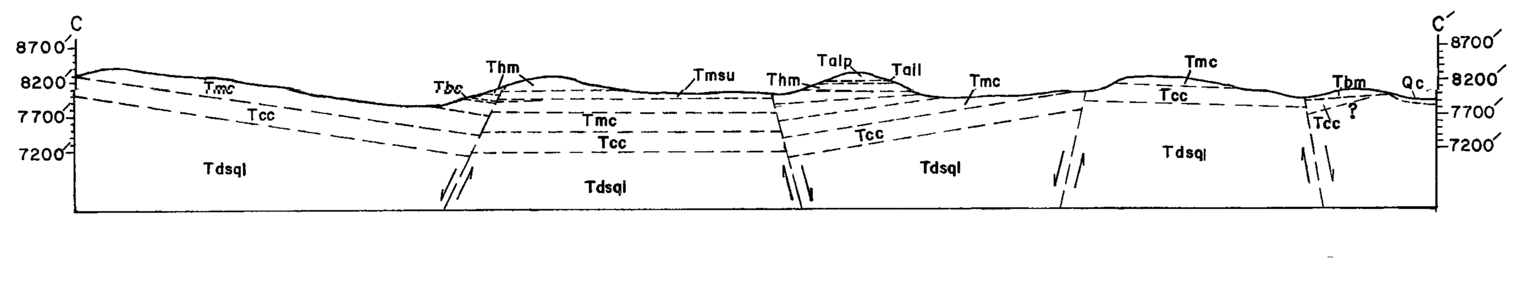
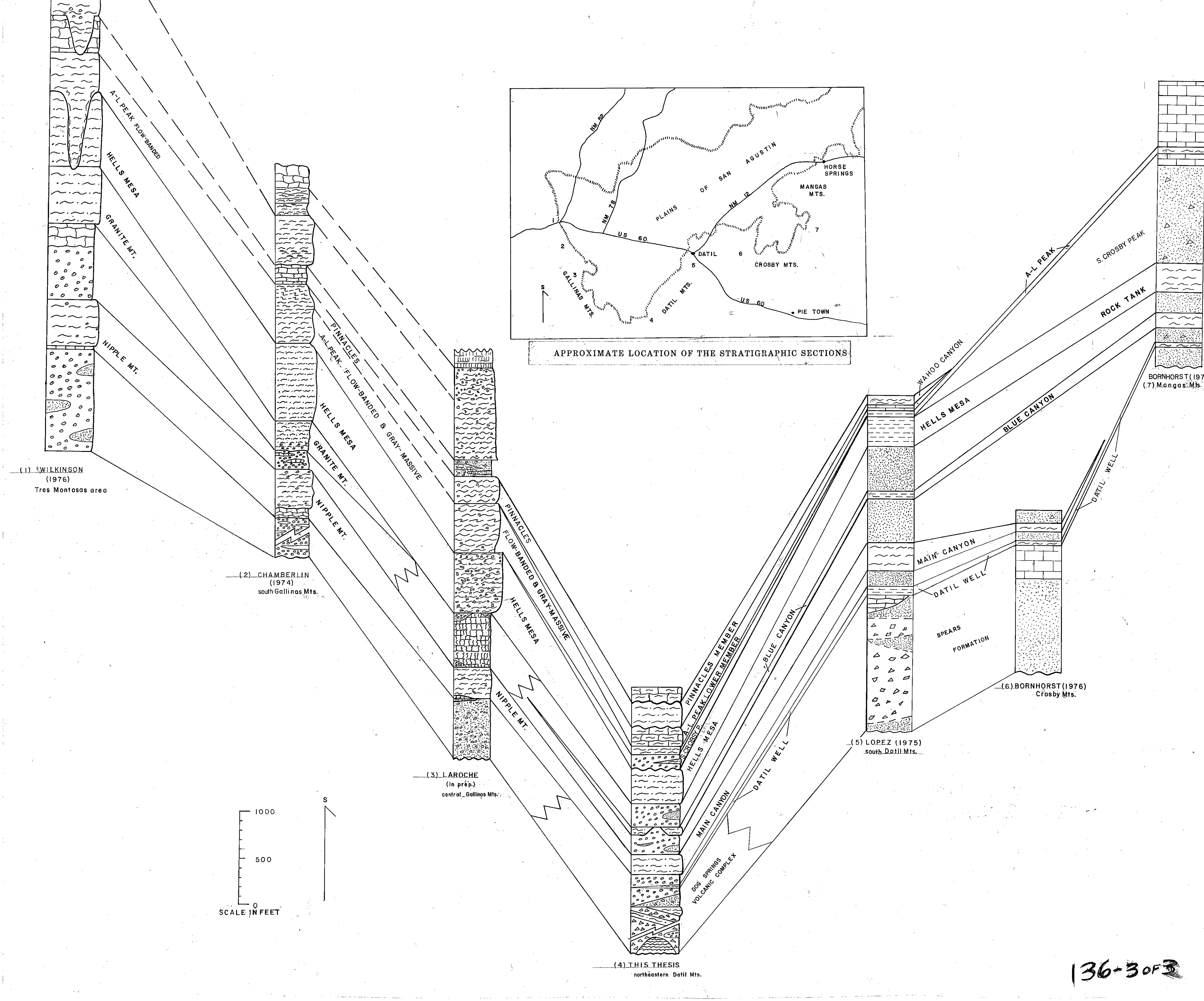


PLATE 2. CORRELATION DIAGRAM OF THE MAJOR ASH-FLOW SHEETS AROUND THE NORTHERN MARGIN OF THE PLAINS OF SAN AGUSTIN



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