VOLCANIC GEOLOGY OF THE DAVIS MOUNTAINS, TRANS-PECOS TEXAS: FIRST-YEAR REPORT

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INTRODUCTION

This report describes the results of the first-year study of the volcanic rocks of the Davis Mountains, Trans-Pecos Texas. Oligocene volcanic rocks in the Davis Mountains (fig. 1) constitute the major part of the eastern, alkalic belt of the Trans-Pecos volcanic field (Barker, 1977; Price and others, 1986). Yet, because of their volcanic and stratigraphic complexity, the Davis Mountains remain the most poorly mapped and least understood part of the field. The geology of the Davis Mountains as shown on the Geologic Atlas of Texas (Fort Stockton sheet; McKalips and others, 1982; Marfa sheet; Twiss, 1979) is based on regional extrapolation of formations established in a few detailed studies. Unfortunately, even these detailed studies commonly grouped a variety of lithologic types of doubtful genetic relationship. Extrapolation of these composite units into areas studied only from aerial photographs has further confused true relations. Very few source areas, calderas or otherwise, have been even tentatively identified. Only one stratovolcano and one caldera have been relatively thoroughly studied (Parker, 1983, 1986).

Nevertheless, the Davis Mountains are worthy of detailed study for several reasons. They are a distinctive, large-scale example of alkalic continental volcanism, comparable in areal extent and volume to major calcalkalic fields such as the San Juan Mountains of Colorado. All igneous rocks are alkalic; several are peralkaline. The volume of individual volcanic units is much greater than in most peralkaline volcanic fields (Mahood. 1984). Many of the ash-flow sheets are rheomorphic; the degree of secondary flow ranges up to extreme examples in which a pyroclastic origin is largely obscured. Additionally, several large-volume silicic units have the outcrop and textural scale features of lavas but the areal dimensions of ash-flow tuffs (Henry and others, 1988). The origin of these units, whether extremely rheomorphic tuffs or unusually large-volume and extensive silicic lavas, is actively debated (Henry and others, in press).

Previous Work

Significant geologic mapping of the Davis Mountains began in the 1950's. Most of the work consists of theses and dissertations done at The University of Texas at Austin. Early work includes Eifler (1951) in the Barrilla Mountains and Rix (1951), Taylor (1952), and Wheeler (1956) in the northern Davis Mountains. More modern work includes Anderson (1968) in the central Davis Mountains, Parker (1972) and McKay and Rogers (1970) in the northeastern Davis Mountains, Gorski (1970), Smith (1975), and Parker (1976) in the southern Davis Mountains, and Hoy (1986) and Henderson (1987) in the western Davis Mountains. These works (except Hoy and Henderson) are incorporated in the Marfa and Fort Stockton sheets of the Geologic Atlas of Texas (Twiss, 1979; McKalips and others, 1982). Recent Baylor University Bachelor's theses have generally focused on individual volcanic units but also provide geologic maps. These include Hicks (1982), Garrigan (1983), Childerss (1984), LaRocca (1984), and Elkins (1986).

Although large-scale geologic maps depict approximately 40% of the Davis Mountains, most of the work contains the problems cited above. Only a few of the modern studies adequately address the complex volcanic stratigraphy, and, where they do, they reveal that previous work was inadequate. As one example, none of the volcanic units mapped by Hoy (1986) in the western Davis Mountains correspond to units previously mapped for the Marfa sheet. Therefore, considerable new mapping and substantial revision of previous work are needed.

Present Work

The eastern and southeastern parts of the Davis Mountains are the initial focus of this study. In that area, the volcanic stratigraphy seemed simplest and best studied of any part of the region. Nevertheless, significant questions were apparent from published work and additional problems were encountered. Initial work included (1) checking existing geologic mapping, formation assignments, and stratigraphic relations; (2) mapping using aerial photographs; (3) detailed mapping and stratigraphic analysis in selected areas; (4) initial, regional correlation of units; and (5) petrographic, petrologic, and geochemical analysis to aid correlation of units. Additionally, samples were prepared for isotopic dating by the $^{40}Ar/^{39}Ar$ method, which will also aid correlation as well as establish the relative and absolute timing of volcanism.

Volcanic units were examined in two adjoining areas. These units are the Bracks Rhyolite of the Sierra Vieja, west of the Davis Mountains, and the Crossen Trachyte, which crops out in an unnamed range that continues to the south from the Davis Mountains (fig. 2). These rocks were studied because they are indistinguishable in outcrop and petrographic characteristics, are stratigraphically equivalent, and have the same K-Ar age as the Star Mountain Formation of the eastern Davis Mountains. Investigation focused on understanding the distribution, stratigraphic equivalence, origin, and genetic relation of the Bracks Rhyolite, Crossen Trachyte, and Star Mountain Formation.

Geologic mapping was done on 1:24,000 color and black-and-white aerial photographs. The mapping was compiled on 1:24,000-scale 7.5-minute quadrangle maps. Aerial photographic or detailed mapping to date covers all or part of nine 7.5-minute quadrangles. Correlations are based primarily on standard field and petrographic methods. For several widespread, complex, but relatively homogeneous units, microprobe analyses of phenocryst minerals were used to help distinguish individual flow units.

Regional Geologic Setting

Volcanism of Trans-Pecos Texas occurred between 48 and 17 Ma in two distinct tectonic settings: a probable continental volcanic arc up to about 31 Ma and Basin and Range extension thereafter (Henry and McDowell, 1986). The volumetrically dominant, older igneous rocks are part of a much larger volcanic province that continues westward into Mexico to include the Sierra Madre Occidental and northward at least into the Mogollon-Datil field in New Mexico (fig. 3). Magmatism during each of the two tectonic episodes has been further divided into two phases (Henry and McDowell, 1986). Rocks of the first two phases are probably the most inland expression of subduction-related volcanism; the paleotrench for this magmatism lay off western Mexico.

The early phase of subduction-related magmatism occurred between 48 and 39 Ma, mostly in the southern part of the Trans-Pecos region. This phase consisted of an extensive basaltic lava sequence, numerous, small, mafic to silicic intrusions, and one small caldera complex.

The transition to the main phase of volcanism 38 Ma is marked by a tremendous increase in the volume of erupted magmas and by the dominance of caldera-related volcanism (Henry and Price, 1984). This magmatism occurred throughout Trans-Pecos Texas but shifted with time and was most voluminous in the central and southern parts.

The change in tectonic setting is indicated by a change in stress orientations at approximately 31 Ma (Price and Henry, 1984). During the premain and main phases, dike and vein orientations indicate that the maximum principal stress (σ_1) was east-northeast, consistent with similarly oriented plate convergence in the mid-Tertiary (Engebretson and others, 1985). A change to east-northeast $\sigma 3$ and vertical $\sigma 1$ at 31 Ma probably marks the beginning of Basin and Range extension (Henry and Price, 1986).

Volcanism during extension is also divided into two phases: an early extensional phase between 31 and 27 Ma and a main Basin and Range phase between 24 and 17 Ma, at which time all magmatism ceased in Trans-Pecos Texas. Several small basalt dikes in the Davis Mountains were emplaced during the main Basin and

Range phase. No examples of the early extensional magmatism have been identified in the Davis Mountains.

The Davis Mountains were active between 38 and 36 Ma (Parker and McDowell, 1979) during the beginning of the main phase of Trans-Pecos volcanism. K-Ar ages generally correlate with relative age relations determined from field work. However, the large analytical uncertainty associated with conventional K-Ar analyses makes it impossible to distinguish individual eruptive events.

STRATIGRAPHY

Stratigraphic columns and established and tentative correlations within the eastern and southern Davis Mountains are shown in figure 4, which also shows the stratigraphic location of samples selected for $^{40}Ar/^{39}Ar$ dating. Figure 5 is a general location map that identifies areas discussed in the text. Among the units shown, the Adobe Canyon, Mount Locke, Goat Canyon, Sheep Pasture, and Aquilla Creek Formations have not yet been studied. Prevolcanic rocks are marly limestones and shales of Cretaceous age. Although mapped along with the Tertiary volcanic rocks, their stratigraphy and lithology are not discussed here.

Huelster and Pruett Formations

The Huelster and Pruett Formations are composite units consisting largely of tuffaceous sediments, mafic to intermediate lavas, and some primary tuffaceous rocks. They are mostly stratigraphically equivalent but are shown separately on the Fort Stockton sheet of the Geologic Atlas of Texas (McKalips and others, 1982) because they occur in different areas. The Huelster Formation was named by Eifler (1951) in the Barrilla Mountains (a northeastern continuation of the Davis Mountains) and is mapped in the eastern and northern Davis Mountains. The Pruett Formation was named by Goldich and Elms (1949) in an area approximately 60 km south of the southeastern Davis Mountains and is mapped from that area as far north as the southeastern Davis Mountains. Revision of terminology and distribution is warranted.

Both formations are the oldest Tertiary units in the area. They unconformably overlie a variety of Upper Cretaceous rocks. The Huelster Formation is overlain by the Star Mountain Formation in the southeastern part of the Davis Mountains. In the northeastern and northern Davis Mountains where the Star Mountain is absent, the Gomez Tuff overlies the Huelster Formation. The Pruett Formation southeast of the Davis Mountains includes the Crossen Trachyte, which may be stratigraphically equivalent to the Star Mountain, and several overlying lava flows. Smith (1975) mapped Pruett Formation in Musquiz dome (fig. 5) in the southeastern Davis Mountains, because he considered a lava that underlies the Star Mountain in the dome to be Crossen Trachyte. In fact, this flow is a mafic trachyte unrelated to the Crossen but similar to mafic lavas that are common in the Huelster Formation (fig. 4b). Therefore, what has been mapped as Pruett in domes in the southeastern Davis Mountains should be Huelster Formation. The following disscusion refers exclusively to the Huelster Formation, although many statements apply equally well to the Pruett Formation.

The Huelster Formation is 120 m thick at its type locality in the northern Barrilla Mountains (fig. 5) (Eifler, 1951). It is continuous but generally only about 75 m thick throughout the eastern and northern Davis Mountains. I estimated approximately 100 m in Barrillos dome (fig. 5). Although Smith (1975) reported 212 m of Pruett Formation in this dome, his estimates are uniformly too high. The formation is commonly covered by talus or landslide debris from overlying massive volcanic rocks; good outcrops for determining lithology or thickness are sparse.

Eifler distinguished a basal conglomerate member, termed the Jeff Conglomerate. It is composed of sandstone and conglomerate containing quartzite and limestone pebbles. The Jeff is 15 m thick at the type locality and averages 8 m in the northeastern Davis Mountains (Eifler, 1951). A basal Tertiary conglomerate occurs throughout most of Trans-Pecos Texas and commonly has been given formation status (Maxwell and Dietrich, 1970).

The bulk of the formation consists of fine-grained tuffaceous sediments in beds a few millimeters to 1 m thick. They are composed of variable proportions of shards, pumice, lithic fragments, and crystals. Although commonly termed tuff in early studies, most deposits are reworked. They include finely laminated tuffaceous mudstones and siltstones, tuffaceous sandstones that locally are crossbedded, and sparse conglomerates. Petrified logs, burrows, and mudcracks are present in a few horizons. Some thicker and more uniformly massive beds that show little or no internal stratification may be primary pyroclastic-flow or air-fall tuffs. Beds of fresh-water limestone consisting of gray micrite are present locally.

Crystal fragments or phenocrysts in the tuffaceous rocks include alkali feldspar, quartz, and biotite in grains mostly up to 1 mm in diameter. Some coarser beds contain pumice and rock and mineral fragments up to 5 mm in diameter. Biotite-bearing beds are common but not abundant. The tuffaceous rocks are zeolitized, probably to clinoptilolite.

Mafic lavas occur irregularly throughout the areal extent of the Huelster Formation. Notable areas of thick flows in the upper part of the formation are in Barrillos Dome, Musquiz dome (the rock called Crossen Trachyte by Smith, 1975), and at Wild Rose Pass (fig. 5). Thick flows also occur in the lower part of the formation at the entrance to Madera Canyon (fig. 5) (Parker, 1986). Future study will attempt to determine the distribution of lavas more thoroughly.

The lavas are aphyric to sparsely porphyritic basalts or mafic trachytes. Plagioclase is generally the only phenocryst. Plagioclase, clinopyroxene, and iddingsite comprise the groundmass. The rocks are commonly amygdular. Two flows in Madera Canyon (Parker, 1986; Henry and others, in press) contain 52 and 54% SiO_2 and are quartz normative, in contrast to most other mafic rocks of the Davis Mountains, which are nepheline or hypersthene normative.

The Huelster Formation is greater than 37 to 38 Ma, the age of the overlying Star Mountain Formation and Gomez Tuff (Parker and McDowell, 1979). Plagioclase from a trachyandesite clast in conglomerate near the base of the formation in Madera Canyon gave an age of 39.3 Ma. Sparse, poorly dated fossils indicate an Eocene or Early Oligocene age (Eifler, 1951; Wilson, 1980).

The mafic lavas were probably derived from local sources, whereas no sources have been positively identified for the tuffs. Mafic flows in Madera Canyon probably mark a source, termed the Madera volcano by Parker (1972). Parker (1986) also suggested that a rhyolite dome in Madera Canyon could be the source for some of the tuffs. However, several similar domes occur throughout the northeastern Davis and Barrilla Mountains; where their age is adequately constrained, they erupted after the Star Mountain Formation, so they cannot be sources of Huelster tuffs. Nevertheless, some of the coarser tuffs seem to require local sources, possibly buried within the Davis Mountains. Biotite has not been found in flow rocks of the Davis Mountains and is chemically incompatible with peralkaline magmas. Thus, the biotite-bearing tuffs may be derived from distant volcanic centers in the western part of Trans-Pecos Texas or in Mexico.

Star Mountain Formation

The Star Mountain Formation is a series of porphyritic quartz trachytic to rhyolitic flows of disputed lava or pyroclastic origin (Gibbon, 1969; Parker and McDowell, 1979; Franklin and others, 1987; Henry and others, 1988, in press). Eifler (1951) named it Star Mountain Rhyolite for thick exposures on Star Mountain. The name has been changed to reflect that most flows are not rhyolites. It everywhere overlies the Huelster Formation and underlies the Gomez Tuff.

The Star Mountain Formation extends over an area of approximately 3000 km^2 in the eastern Davis and Barrilla Mountains from Interstate 10 on the north 70 km to Barrillos Dome on the south (fig. 5). The formation is about 245 m thick at Star Mountain (fig. 5) near the center of its outcrop and thins progressively outward (Gibbon, 1969). However, even at distal ends it is at least 40 m thick.

Individual flows of the Star Mountain Formation are up to 100 m thick, massive, and commonly columnar-jointed. The rock is generally devitrified, massive to flow banded, and locally vesicular. Vitrophyre occurs at the top of the formation in a few places. A breccia consisting of angular to subrounded clasts up to 1 m in diameter in a matrix of more finely clastic material occurs both at the base and at the top of individual flows. The thickness of breccia varies from less than 1 to at least 5 m in lateral distances of a few tens of meters. Breccia clasts include all lithologies seen in massive parts of the flow. Flow folds and ramp structures are common.

The total number of flows, even where well exposed in individual stratigraphic sections, and the areal extent of any individual flow are uncertain. For example, the southeastern, cliff face of Star Mountain is interpreted to be composed of at least six (Eifler, 1951) or three (Gibbon, 1969) flows. The difficulty is illustrated by the section at Wild Rose Pass, where three distinct units are present (Henry and others, in press). The upper and lower units form massive cliff faces that are clearly single, laterally extensive flows. A 1-m-thick lens of tuffaceous sediment separates the upper and middle units. The middle unit is complex. Individual flows cannot be traced laterally and the total number of flows within the middle unit is unknown. Where well exposed in canyons, individual flows can be traced laterally as much as 15 km.

Chemical and petrographic data support these field interpretations. Chemical analyses and feldspar compositions of samples from individual flows identified from field relations are identical and distinctly different from those of other flows. For example, the upper unit at Wild Rose Pass has the highest silica content (71%) and least anorthitic feldspars. The lower flow there has 69% SiO_2 and distinctly more anorthitic feldspars. Future work will attempt to determine the distribution of individual flows more thoroughly.

Phenocrysts in the Star Mountain include alkali feldspar, zoned from sodic anorthoclase to sanidine, iron-rich clinopyroxene, rarely preserved fayalitic olivine, and magnetite. Phenocryst abundance averages about 10%, most of which is feldspar in individual grains and glomerocrysts up to 6 mm in diameter. The mafic phenocrysts are generally about 1 mm. The crystalline groundmass consists of trachytic to finely intergrown alkali feldspar, quartz, and minor sodic amphibole and aenigmatite. Chemical analyses show that the Star Mountain consists of quartz trachytes and rhyolites, ranging in silica content from 66 to 71% (Parker, 1986; Henry and others, in press). Compositions of feldspar phenocrysts determined by microprobe vary with silica content of the host flow. More silicic flows contain alkali feldspar having very low ($\leq$ 1%) anorthite content. Feldspars in more mafic flows contain progressively higher anorthite contents, up to about 12%.

A single K-Ar age of 37.9 Ma has been determined on alkali feldspar from the Star Mountain Formation (Parker and McDowell, 1979). No sources for the flows have been located. Gibbon (1969) suggested a vent in the central thick part of the formation, near a petrographically similar intrusion (Big Aguja intrusion). A caldera source is unlikely because the flows do not pond within a depression. I have identified several dike-like outcrops of Star Mountain Formation on aerial photographs. These will be investigated as possible feeders to flows during future field work.

Bracks Rhyolite

The Bracks Rhyolite is an extensive quartz trachyte lava flow that crops out in the Sierra Vieja approximately 30 km west of the Davis Mountains and 70 km west of the westernmost exposures of Star Mountain Formation. It is similar to the Star Mountain Formation in outcrop, petrography, stratigraphic position, chemical composition, and K-Ar age. Although not the same flow, they probably represent contemporaneous and related magmatic events (Henry and others, 1988).

The Bracks Rhyolite crops out over a 55 by 15 km area (fig. 2). It overlies tuffaceous sediments of the Chambers Tuff and underlies tuffaceous sediments of the Capote Mountain Tuff. Over most of its distribution, it forms a caprock from which younger rocks have been eroded. It reaches a maximum thickness of 110 m in the north-central part of its outcrop and thins gradually to the north and south. It is still about 40 m thick 500 m north of its southern end but then thins abruptly to possibly only 3 m.

The Bracks Rhyolite forms a single thick lava flow that is well exposed along a nearly continuous cliff face formed from an eroded Basin and Range fault scarp. The base is commonly brecciated but locally massive. The breccia contains massive to vesicular blocks in a matrix of granulated Bracks. Vitrophryre is rarely preserved at the base. Most of the flow is massive, devitrified, and columnar-jointed and has faint horizontal partings. An upper breccia and vesicular zone is rarely preserved.

Phenocrysts in the Bracks include alkali feldspar, clinopyroxene, fayalitic olivine, and magnetite. Alkali feldspar up to 8 mm long is most abundant, comprising up to 12% of the rock. Clinopyroxene and olivine make up about 2% as 1 mm equant grains. Microprobe analyses of phenocrysts indicate that they have a narrow compositional range that is the same throughout the formation.

Chemical analyses show that the Bracks Rhyolite is chemically homogeneous and really a quartz trachyte. Eight samples representing most of the areal extent contain about 68 to 69% SiO_2, expressed H_2O free (Henry and others, in press).

Two K-Ar ages of the Bracks Rhyolite are 37.5 and 37.9 Ma (Henry and others, 1986). Paleontologic data on tuffaceous sediments above and below it constrain it to be early Oligocene (Wilson, 1980).

Structural and volcanic features, thickness relations, and sparse flow directions indicate that the Bracks Rhyolite is a single flow erupted from the north-central part of its outcrop. The formation is thickest there, and flow directions indicate outward flow from this general area. More significantly, a group of vitrophyric diapirs occur in a 6-km-long, north-trending belt there. These diapirs are petrographically and chemically identical to the rest of the Bracks, except that they are not devitrified. Individual bodies range from 10 to 300 m in diameter. Most are circular, but irregular bodies are also present. The vitrophyre diapirs have clearly domed the intruded devitrified rock. Flow bands and folds in devitrified rock wrap around the margin of the intruding vitrophyre. Cooling joints in both devitrified rock and vitrophyre are nearly perpendicular to their contact, indicating that final cooling of both followed emplacement of the domes.

Crossen Trachyte

The Crossen Trachyte is a quartz trachyte lava flow that is also similar to the Star Mountain Formation. It occurs approximately 40 km south of the southernmost outcrops of Star Mountain Formation (fig. 2) in an unnamed range that continues from the Davis Mountains. It forms a cap rock over much of Crossen Mesa, which is the source of the name (Goldich and Elms, 1949). Goldich and Elms originally considered it a member of the Pruett Formation, but McAnulty (1955) suggested that it should be a separate member. It overlies tuffaceous sediments of the Pruett Formation and underlies tuffaceous sediments and mafic lava flows in the upper part of the Pruett Formation or in the Sheep Canyon Basalt.

The Crossen Trachyte crops out over 150 km^2 mostly within Crossen Mesa. It thins from about 50 m at its northern limit, where it disappears beneath overlying rocks, to about 35 m at its southmost extent. Some flows shown as Crossen Trachyte farther north on the Fort Stockton sheet, near Alpine, are more mafic trachytes that are probably unrelated.

The Crossen Trachyte is a single lava flow that has all the outcrop characteristics of the Star Mountain flows and Bracks Rhyolite. Additionally, it is petrographically similar to both those units, containing phenocrysts of alkali feldspar, clinopyroxene, fayalitic olivine, magnetite, and minor ilmenite. The phenocrysts show the same size and textures as phenocrysts in the other two units and overlap in composition with them. It is slightly more mafic than the Bracks Rhyolite, containing slightly less SiO_2 and more TiO_2, but overlaps with the compositionally more variable Star Mountain flows.

A single K-Ar age of a whole rock sample is 38.6 Ma (Henry and others, 1986); however, whole rock ages of silicic volcanic rocks are commonly unreliable. Thickness variations and flow directions indicate that the source of the Crossen Trachyte is probably northwest of its present outcrop.

Unnamed Rhyolitic Domes

Rhyolitic domes or associated pyroclastic and epiclastic debris occur in at least four areas in the northeastern Davis Mountains. Domes have been mapped in Madera Canyon, Bob Manning Canyon, within the Barrilla syncline, and at Saddleback Mountain in the Barrilla Mountains (fig. 5). The dome in Madera Canyon lies on what was to become the ring fracture of the Buckhorn caldera, source of the Gomez Tuff. This may be fortuitous, however, as other domes show no relation to caldera structures. Interpretation of areal photographs suggests that several other domes occur within this area. Previously, these rocks either had not been recognized or had been included with other formations, including the Huelster and Star Mountain Formations. Parker (1972) mapped one dome as the Agua

Grande tuff. Two of the domes clearly lie between the Star Mountain Formation and Gomez Tuff. The stratigraphic position of the other two is uncertain but may be the same. Alternatively, they could be as old as Huelster Formation. Until these domes are more thoroughly understood, they are combined as a single unit.

Two of the domes consist of a thick pile of commonly flow-banded and locally brecciated, sparsely porphyritic rhyolite. The two other "domes" consist only of steeply dipping, pyroclastic and epiclastic deposits exposed in the walls of canyons; the actual rhyolite of the dome must be buried behind the canyon walls. The clastic deposits consist of coarse, angular fragments of rhyolite up to 40 cm in diameter in variably tuffaceous matrix. In Madera Canyon, epiclastic deposits dipping as much as 45 degrees away from the dome progress outward to more shallowly dipping, finer, poorly welded ash-flow tuff. At three locations the dome morphology is preserved. Gomez Tuff clearly overlies thick, steep piles of rhyolite. At the dome in the Barrilla syncline, younger material has been entirely eroded.

Two different petrographic types are present. Rhyolite domes at Saddleback Mountain and in the Barrilla syncline are peralkaline. They contain a few percent alkali feldspar laths up to 3 mm long and interstitial arfvedsonite or alteration products. The rock is strongly flow banded and feldspar phenocrysts are aligned with the banding. The rock is strongly brecciated at the margins and columnar jointed within the interior of the dome.

Sparsely porphyritic, flow-banded clasts in Madera and Bob Manning Canyons probably represent the rhyolite of the domes. Both clasts and matrix contain minor biotite, which suggests that these domes are metaluminous.

Massive, biotite-bearing tuff about 1 m thick occurs between the Star Mountain Formation and Gomez Tuff in several outcrops. It is composed of fine ash, minor pumice and rare lithic fragments up to 2 mm in diameter, and fragments of biotite

(2%, up to 1 mm) and alkali feldspar (1%, 1 mm). The tuff is zeolitized. It must be either air-fall ash or reworked tuffaceous sediment. This tuff layer could be derived from one of the biotite-bearing rhyolite domes or from more distal sources to the west in the western part of Trans-Pecos Texas or in Mexico. The presence of biotite indicates that it is unrelated to either the Star Mountain Formation or Gomez Tuff.

Gomez Tuff

The Gomez Tuff is an extensive peralkaline ash-flow sheet that occurs throughout the eastern and northern Davis Mountains. Because it is a distinctive, widespread, and continuous unit, it is one of the best marker beds in the region. Throughout most of the area, it overlies Star Mountain Formation, commonly with a thin (~1 m thick) air-fall or water-laid tuff between them. Where Star Mountain flows are absent in the northern and northeastern Davis Mountains, it overlies Huelster Formation. Also, locally it rests upon rhyolite domes. It is overlain by tuffaceous sediments of the Frazier Canyon Formation throughout most of the eastern Davis Mountains, by lavas of the Limpia Formation in a small area near Fort Davis, and by other lava flows to the north and northwest.

Eifler (1951) first mapped the Gomez Tuff but called it the lava 1 member of the Seven Springs Formation. Although never formally assigned, the name Gomez Tuff was first used by Parker (1972) and appears on the Fort Stockton sheet of the Geologic Atlas of Texas (McKalips and others, 1982). Parker (1986) designated Gomez Peak, where the tuff is 430 m thick, as the type locality.

The Gomez Tuff is the most widespread volcanic unit in the Davis Mountains. It had an original extent of about 4000 km^2 and a volume of about 200 km^3 (Parker, 1986). Parker showed that the Gomez Tuff is 10 to 20 m thick throughout most of its outcrop. It thickens gradually toward the Buckhorn caldera, its probable source, in the northeastern Davis Mountains (fig. 5). Near but outside the caldera it is commonly about 100 m thick. Within the caldera, it averages more than 300 m and reaches 456 m southwest of Gomez Peak (Parker, 1986). Distal outcrops are as thin as 2 m.

The Gomez Tuff consists of multiple flows but is mostly a single cooling unit. Throughout most of the region, it shows a welding zonation typical of ash-flow tuffs. A poorly welded to nonwelded base less than 1 m thick is overlain by densely welded rock. The tuff is typically densely welded even where no more than a few meters thick. An upper nonwelded zone has been found only in the northeastern Davis Mountains, where it is overlain by lavas of the Adobe Canyon Formation. These lavas may have been emplaced soon enough after the Gomez Tuff that the nonwelded zone was preserved from erosion. Two cooling units, each composed of a single ash flow, occur in outcrops in the northern Barrilla Mountains.

The rock is mostly devitrified. Basal vitrophyre, at the bottom of the densely welded zone, is common in outcrops less than about 20 m thick. The basal nonwelded ash may also have been glassy but is now typically altered to clay minerals.

Lithic and pumice fragments also show zonation typical of ash-flow tuffs. In individual outcrops, lithic fragments are normally graded. In thin distal outcrops, maximum lithic size is typically about 2 mm. Maximum lithic size is greater in thicker outcrops near the inferred source. Near the Buckhorn caldera, they are as large as 1 m diameter. Pumice fragments are reversely graded and are relatively coarse even in distal outcrops. In one outcrop approximately 40 km south of the margin of the Buckhorn caldera, pumice ranges up to 30 cm long. It is commonly granophyrically devitrified. In addition to pumice, near-source outcrops contain what appear to be large, nonvesiculated juvenile clasts at the base of the unit. These dense clasts are petrographically identical to Gomez Tuff but show no indication of compacted shard texture. They must not have been vesiculated or they would have floated in the pyroclastic flow.

The Gomez Tuff has undergone extensive secondary flow (rheomorphism), which is best developed in thicker outcrops (Parker, 1986; Henry and others, in press). Secondary flow features include highly stretched pumice, flow bands and folds, and ramps. Wherever present, this has erased boundaries betweeen individual ash flows of the Gomez Tuff. In Madera Canyon, just within the Buckhorn caldera (fig. 5), extreme rheomorphism has nearly completely obliterated evidence of the primary pyroclastic origin. The rock is strongly flow folded and locally brecciated. Common lithic fragments are the only preserved evidence of ash-flow origin.

The tuff contains about 10% phenocrysts, mostly alkali feldspar, but also minor quartz, ferrohedenbergite, ilmenite, and rare fayalite. Unoxidized samples contain groundmass acmite, arfvedsonite, and aenigmatite (Parker, 1986; Henry and others, in press). The mineral association and chemical analyses (Parker, 1986) demonstrate that the Gomez is strongly peralkaline.

Six K-Ar ages of the Gomez Tuff average 37.4 Ma (Parker and McDowell, 1979; Henry and others, 1986). These ages are indistinguishable from those of the underlying Star Mountain Formation and overlying Adobe Canyon and Sleeping Lion Formations.

The Buckhorn caldera is the probable source of the Gomez Tuff (Parker, 1986). Evidence for this interpretation includes (1) the symmetrical distribution of tuff around the caldera, (2) progressive thinning of tuff away from the caldera, (3) progressive decrease in the size of lithic and pumice clasts away from the caldera, (4) ponding of tuff (up to 450 m thick) within the caldera, and (5) presence of apparent megabreccia blocks within Gomez Tuff within the caldera. The first four points are discussed above. The possible megabreccia blocks are fragments of tuff (Huelster Formation?) and marbleized limestone (Lower Cretaceous?) up to 100 m across. These blocks are far too large to have been uplifted during eruption and were presumably derived by landslides from a former caldera wall. A significant problem with this interpretation is that current outcrops of Lower Cretaceous limestone are topographically below the megabreccia blocks. Therefore it would have been impossible for them to slide into their exposed positions from current outcrops.

The caldera is largely defined by the abrupt thickening of Gomez Tuff into it (Parker, 1986). A caldera wall has been tentatively identified only along the southern margin, in Madera Canyon. At this location the Gomez Tuff thickens from 60 to 300 m. Elsewhere, the caldera wall as postulated by Parker is buried beneath younger volcanic rocks or by landslide debris on top of the Huelster Formation and Upper Cretaceous rocks. More thorough mapping of the Buckhorn caldera is warranted.

Limpia Formation

The Limpia Formation consists of coarsely porphyritic, trachytic to quartz trachytic lavas. It overlies the Gomez Tuff and is overlain by tuffaceous sediments of the Frazier Canyon Formation.

The Limpia Formation crops out in two areas northeast and southeast of Fort Davis (fig. 5). Smith (1975) estimated a maximum thickness of 110 m but stated that thickness was difficult to determine because no complete sections are exposed. Abrupt pinch-out to the northeast and southeast suggests a steep, areally restricted lava pile.

The trachyte forms thick, massive outcrops with little indication of internal stratification or flow boundaries. Locally exposed vesicular and brecciated zones probably mark flow tops, but outcrops are not sufficiently continuous to tell for certain.

Two petrographic types are distinguished within the Limpia Formation. A more coarsely and abundantly porphyritic variety occurs southeast of Fort Davis.

This contains 30 to 40% feldspar phenocrysts up to 1 cm and minor, oxidized clinopyroxene. The feldspars are anorthoclase, some of which have plagioclase cores. A characteristic of this variety is the common presence of rounded inclusions of a fine-grained igneous rock (trachyte?) up to 10 cm in diameter.

A less porphyritic variety occurs northeast of Fort Davis. Anorthoclase phenocrysts comprise 15% and range in size from 1 to 8 mm. Clinopyroxene is also present.

No ages have been determined and no source is known for the Limpia Formation. The outcrop pattern and thickness indicate that the flows must be locally derived, probably from vents now buried beneath it.

Frazier Canyon Formation

The Frazier Canyon Formation is a sequence of tuffaceous sediments and mafic lava flows. It was named for exposures in Frazier Canyon north of Fort Davis (fig. 5). Throughout most of the eastern Davis Mountains it overlies Gomez Tuff. Near Fort Davis, it overlies Limpia Formation. Near Barrillos Dome to the south, Gomez tuff pinches out and the Frazier Canyon Formation locally lies directly on Star Mountain Formation. In the northern Davis Mountains it overlies a variety of lavas that followed the Gomez Tuff. It is overlain by Sleeping Lion Formation in the vicinity of Fort Davis. Through most of the eastern Davis Mountains, the Sleeping Lion Formation is absent and the Barrel Springs Formation overlies the Frazier Canyon Formation. Because the Barrel Springs is a composite unit that includes tuffaceous sediment, the contact between it and the Frazier Canyon Formation is difficult to assign.

The Frazier Canyon Formation occurs throughout the eastern Davis Mountains, where it is generally about 100 to 120 m thick. It thins to the east in the Barrilla Mountains to less than 70 m (Eifler, 1951; Parker, 1972). Similarly, it thins to 67 m and less over the lava pile of the Limpia Formation near Fort Davis (Smith, 1975).

The Frazier Canyon Formation consists dominantly of fine-grained tuffaceous sediments and some primary air-fall or nonwelded ash-flow tuff, interbedded with variable proportions of mafic lavas. The sediments are poorly bedded in layers a few millimeters to several meters thick. Most layers show little or no internal stratification. Clasts, including glass shards, mineral fragments, pumice, and volcanic rock fragments, are mostly less than a few millimeters in diameter but range up to 2 cm. Mineral fragments are dominantly alkali feldspar, but biotite is also present in some beds. Glass shards in the formation are generally replaced by clinoptilolite.

Sandstone and conglomerate lenses up to a few meters thick are common in thicker sections of the formation, particularly in the northeastern Davis Mountains (Parker, 1972). Large clasts in these deposits are generally volcanic rock fragments.

Mafic lavas occur throughout the formation, both stratigraphically and laterally. Smith (1975) grouped lavas into two basalt members, but his data show that they are too irregularly distributed to justify this subdivision. A sequence of basalt flows occurs in the middle of the formation in the northeastern Davis Mountains and Barrilla Mountains (Eifler, 1951; Parker, 1972). The lavas are aphyric to finely and sparsely porphyritic. Phenocrysts are trachytic plagioclase laths up to 2 mm in length. The groundmass contains plagioclase, clinopyroxene, magnetite, and apatite. Basalts in the southern area of outcrop may be distal parts of the Sheep Canyon and Cottonwood Spring Basalts, thick lava sequences that crop out south of the Davis Mountains in the appropriate stratigraphic position.

Neither isotopic nor paleontologic ages have been determined for the Frazier Canyon Formation. Its age is constrained by ages of the Sleeping Lion Formation (average age 37.1 Ma; two analyses; Parker and McDowell, 1979) and Barrel Springs Formation (average age 36.4 Ma; four analyses; Parker and McDowell, 1979).

The mafic lavas of the formation must have been erupted from local sources within their area of distribution. At this time, no vents nor distinctive areas of local accumulations have been identified. The tuffaceous sediments in part represent reworking of a variety of rocks of the Davis Mountains. Additionally, the presence of biotite in many beds indicates a source outside the Davis Mountains, probably in the western part of Trans-Pecos Texas or in Mexico.

Sleeping Lion Formation

The Sleeping Lion Formation is a coarsely porphyritic rhyolite that has been interpreted alternatively as a lava flow (Parker and McDowell, 1979; Hicks, 1982; Henry and others, in press) or as an ash-flow tuff (Gorski, 1970; Smith, 1975; Henry and others, in press). The type locality is Sleeping Lion Mountain next to Fort Davis. It overlies Frazier Canyon Formation and underlies Barrel Springs Formation throughout its extent.

The Sleeping Lion Formation crops out in an area about 30 km across east and south of Fort Davis. It is generally about 50 to 70 m thick except in an area 12 km east of Fort Davis where there appear to be two units that total nearly 150 m thick. Additionally, Smith (1975) and Gorski (1970) reported that it thins to only 10 to 15 m in the northeastern and southwestern limits of its distribution, areas that have not yet been examined in this study.

The Sleeping Lion Formation is massive, resistant, and crudely columnar-jointed. Throughout most of its extent, it is a single cliff-forming flow that commonly caps ridges. In the thick area east of Fort Davis it forms two distinct ledges separated by a gentle slope. Whether two flows are present here has not yet been established.

A typical section through the formation reveals rock having characteristics of a thick, silicic lava. A basal breccia, commonly 1 to 2 m thick, contains angular to subrounded clasts up to 1.3 m of devitrified, massive to coarsely vesicular, and flow-banded Sleeping Lion in a crumbly matrix of finer clasts. Tuffaceous sediment beneath the flow is baked and compacted. The breccia is overlain by massive, devitrified rhyolite that is locally flow banded. Most of the unit is massive, columnar jointed rock with a faint horizontal foliation. Large-amplitude flow folds and ramps occur near the top of the unit. An upper breccia is similar to the lower breccia, except that vitrophyric clasts are also present, clasts are commonly up to several meters across, and flow-folded clasts are more common. Five small foreign rock fragments have been found at one roadcut south of Fort Davis.

A 20- to 30-cm-thick zone at the base near Fort Davis is finely layered, composed of fine vesicular clasts, and crystal enriched. This zone may represent pyroclastic-surge or air-fall deposits that preceded the main Sleeping Lion eruption.

The interval between the Sleeping Lion and Barrel Springs Formations consists of soft, largely reworked tuffaceous rocks. Two to three thin lenses just above the Sleeping Lion are composed dominantly of poorly sorted, angular clasts of that formation up to several centimeters in diameter. These clasts include individual phenocrysts, many of which are broken but not disaggregated, broken parts of phenocrysts, and abundant coarse pumice. Vesicles in different pumice are spherical to highly elongate. Sparse fragments of other rock types are also present. All fragments are unoriented; there is no evidence of compaction. The matrix is still finer pumice. The rock is poorly cemented by clay and opal. These lenses represent sedimentary reworking of soft, upper pumiceous parts of Sleeping Lion that have been mostly eroded.

The rest of this interval consists of massive, fine-grained tuff beds. Individual beds are 0.5 to 1.5 m thick. They are composed of fine ash, pumice, and minor quartz and feldspar grains, all less than 1 mm in diameter. The rock is zeolitized and calcitic. The beds are probably reworked and most likely fine mudflows. This soft, tuffaceous horizon is exposed only in a few roadcuts.

The Sleeping Lion Formation is characteristically coarsely porphyritic. Anorthoclase phenocrysts up to 1.5 cm in diameter comprise about 30% of the rock. Other phenocrysts include clinopyroxene (3%; 1 to 2 mm), zircon, magnetite, and ilmenite. The groundmass in devitrified rocks consists of alkali feldspar and quartz intergrown in "snowflake" texture (Anderson, 1969). Vitrophyres are invariably flow banded and show minor spherulitic devitrification. Vesicles, in places filled with chalcedony, are common in vitrophyres and devitrified clasts in breccias.

Two K-Ar ages have been determined on alkali feldspar separates from the Sleeping Lion Formation. They are 36.8 and 37.4 Ma (Parker and McDowell, 1979; Henry and others, 1986).

On the basis of outcrop pattern and sparse ramp structures, Hicks (1982) suggested that the Sleeping Lion Formation erupted from a source west of Fort Davis, in an area where the formation is covered, and flowed down a paleovalley system, first northeast, then southeast and southwest. The walls of this possible paleovalley are largely eroded, except for the pile of lavas of the Limpia Formation. Total flow distance would have been about 40 to 45 km.

The outcrop and thin-section features of the Sleeping Lion Formation are clearly those of a lava flow. However, the inferred large flow distance is much greater than generally recognized for silicic lavas (Walker, 1973). An alternative origin (proposed by J. A. Wolff in Henry and others, in press) is that it is extremely rheomorphic tuff.

Barrel Springs Formation

The Barrel Springs Formation as currently depicted on the Marfa and Fort Stockton sheets of the Geologic Atlas of Texas is a widespread and complex unit. It includes a wide range of rock types but is mostly composed of flows of petrographically similar porphyritic rhyolite. The origin of most flows is obscure; they have characteristics that could allow them to be either lava flows or pyroclastic flows. Excellent exposures in a few locations reveal that some parts are strongly rheomorphic tuffs in which almost all primary pyroclastic features have been obliterated. Air-fall tuff is also present and tuffaceous sediments are interbedded with unequivocal ash-flow tuffs in distal exposures in the Barrilla Mountains.

The Barrel Springs Formation was named by Anderson (1968) for exposures in the southwestern Davis Mountains. It was mapped as extending throughout the Davis and Barrilla Mountains by P. C. Twiss and J. E. Anderson during mapping for the Geologic Atlas. It includes the lava 3, tuff 4, and lava 4 members of the Seven Springs Formation of Eifler (1951) in the Barrilla Mountains and the Kennedy Ranch member of the Duff Formation of Gorski (1970) in the area south of Fort Davis. The Barrel Springs Formation overlies Sleeping Lion and Frazier Canyon Formation in the eastern Davis Mountains and Barrilla Mountains. It is the stratigraphically lowest exposed rock in the southwestern Davis Mountains. It is the stratigraphically highest exposed rock in much of the southern and eastern Davis Mountains but is overlain by Mount Locke and Goat Canyon Formations in the central Davis Mountains.

Anderson (1965) also defined the Wild Cherry Formation, a lithologically identical unit that overlies the Barrel Springs Formation. In places, the two are separated by distinctive, coarsely porphyritic lava of the Mount Locke Formation. However, in several areas, Anderson mapped Wild Cherry Formation directly on

Barrel Springs Formation. In these places, we consider both to be part of the Barrel Springs.

The Barrel Springs Formation occurs over a nearly 4000 km^2 area in all but the northern Davis Mountains. Preserved thicknesses vary considerably. Including the Wild Cherry Formation, it is about 100 m thick in the type area and ranges up to 135 m in the central Davis Mountains (Anderson, 1965). The greatest thickness is in the southwestern Davis Mountains (Henderson, 1987), including on Blue Mountain west of Fort Davis where Smith (1975) measured more than 300 m. In Davis Mountains State Park, it is approximately 140 m thick and the top is eroded. Eifler (1951) measured about 80 m in the Barrilla Mountains, but this section consists of three thin ash-flow tuffs interbedded with a thick sequence of tuffaceous sediments.

The Barrel Springs Formation has been examined in detail in four sections: (1) southwestern Davis Mountains, (2) Blue Mountain, (3) Davis Mountains State Park, and (4) Barrilla syncline (figs. 4a and 5). Rocks in each area are petrographically similar, but correlation of individual units is tentative. Establishment of a detailed internal stratigraphy of the Barrel Springs Formation is a goal of this study that will greatly aid understanding of volcanism in the region.

Southwestern Davis Mountains

A section south of Highway 166 (fig. 5) consists of two, lithologically identical flow units. The lower is Anderson's original Barrel Springs Formation, whereas the upper is his Wild Cherry Formation (fig. 4a). Both are porphyritic, massive to flow-banded, and mostly devitrified rhyolite. The flow banding is generally defined by thin laminations, including finely vesicular layers. Upper parts that have undergone intense vapor phase crystallization have developed distinct partings along the banding that gives the rock a platy, foliated appearance. This flow banding is everywhere horizontal. The two units are separated by a breccia of vesicular and vitrophyric blocks, but it is not clear to which unit this breccia belongs.

Phenocrysts in both units consist of about 10% alkali feldspar to 5 mm long and 1% clinopyroxene to 1 mm in diameter.

Blue Mountain

The section at Blue Mountain consists of numerous individual flow units. The lower two units are identical to those to the southwest and are tentatively correlated with them.

The third unit is a thick, rheomorphic tuff composed of several individual flows. The base consists of distinctive ash-flow tuff containing pumice up to 50 cm long and lithic fragments up to 30 cm in diameter. Phenocrysts are alkali feldspar 3 to 4 mm long and comprising 10 to 15% of the rock. The lithics consist of vesicular, mafic trachyte containing 5% to 10%, rhombic alkali feldspar to 8 mm long.

The tuff shows a gradual transition upward into foliated, flow-banded rhyolite similar to the stratigraphically lower units. Near the transition, pumice is stretched, probably as a result of secondary flow. Neither pumice nor lithic fragments have been found in the foliated rock.

Still higher volcanic rocks up to the top of Blue Mountain are more abundantly and coarsely porphyritic and locally highly vesicular. They are petrographically transitional between the Barrel Springs and Mount Locke Formation, which consists of coarsely porphyritic trachytes. Future work will determine the distribution, stratigraphic occurrence, and petrography of these rocks in more detail.

Davis Mountains State Park

Barrel Springs Formation at this location is approximately 140 m thick and consists of at least two and possibly three individual flow units (fig. 6). The lowest unit is approximately 100 m thick and shows a transition from normal ash-flow tuff in the base to strongly rheomorphic (flow-folded and brecciated) tuff within the upper part.

The lowest unit has a 4-m thick base of devitrified ash-flow tuff (fig. 6). The tuff contains phenocrysts of alkali feldspar that increase in abundance from about 5% near the base to 10% near the abrupt transition to overlying foliated tuff. An oxidized mafic mineral, probably clinopyroxene, is the only other phenocryst. The feldspar phenocrysts are mostly 2 to 4 mm and euhedral, but smaller broken fragments are also present. Moderately flattened pumice fragments, rarely up to 20 cm long, and sparse lithics of fine-grained trachyte(?) to 2 cm comprise a few percent of the rock. Individual shards are quite large, commonly up to 2 mm. Many phenocrysts have thick, formerly glassy rims. Welding increases upward, from poorly welded near the base to moderately welded at the transition. Vertical gas-escape pipes, enriched in phenocrysts, occur in the upper 2 m of the base, and are truncated at the transition to foliated tuff (fig. 19c).

The contact with overlying foliated tuff occurs about 5 m above the base, but the transition starts about 50 cm below the contact. At that point, the gas escape pipes bend toward N80E, and the tuff develops short, indistinct foliations that appear to be incipient to the distinct foliation in rock above the contact. In outcrop, the rock is still clearly pyroclastic, but, in thin section, shard texture is largely obscured. Curvature of the gas pipes and lineations in the foliation surfaces indicate that secondary flow of the rheomorphic tuff was slightly north of east. The amount of curvature indicates about 40 to 70 cm displacement just below the contact with distinctly foliated tuff. Pyroclastic features disappear over a few centimeters distance at the contact, and a distinct planar foliation consisting of 1 to 10 cm long partings spaced about 1 cm apart develops. Scattered lithics, identical to those in the underlying rock, are the only preserved evidence of the primary pyroclastic origin. These lithics range up to 11 cm diameter and are found at least into the upper brecciated part of the first unit. Foliation wraps around lithics, some of which are rotated, further indicating secondary flow. Other pyroclastic features, such as pumice, shards, or gas pipes, are not preserved in the foliated tuff. Nevertheless, the lithics, sharp but still gradational contact, and similarity in size, abundance, and composition of alkali feldspar phenocrysts tie the foliated rock to the basal tuff.

Upward through the section, the foliation becomes more pronounced and closer spaced (about 0.5 cm). Broad, open folds begin to develop; dips on foliation gradually increase and reach 40 degrees. In places a second foliation consisting of short, nearly flat partings cross cuts the more prominent, dipping foliation.

More pronounced folds and minor breccias first occur in the middle of the lowest unit (fig. 6). The foliation is a distinct flow banding that shows contorted, almost ptygmatic folds. Breccias are minor.

Above a thin covered interval, the lowest unit is intensely brecciated (fig. 6); breccias and flow folds within fragments persist to the top of the unit. The folds are commonly recumbent; much of the flow banding is vertical. Blocks in the breccia range up to 2 m diameter and are angular to moderately rounded. Breccia fragments and matrix grade irregularly from glassy and hydrated to spherulitically devitrified. Feldspar phenocrysts are similar to those in lower parts; that is, they are mostly euhedral, but some delicate glomerocrysts and some smaller, broken fragments are present. Sparse lithics occur within blocks at least in the lower parts of the breccia. The matrix consists of still finer and randomly oriented fragments, including some with highly elongate vesicles. It is cemented by a fine mosaic of opal or chalcedony.

Overlying flow units fill valleys in the top of the lowest unit. Contacts between them are marked by a clay-altered zone about 0.7 to 1 m thick that probably is the base of the upper unit. Alternatively, it may represent reworking of fine material from the top of the first unit. Massive, foliated rock overlies the clay-altered material. Foliation is largely planar but parallels the contact with the underlying first unit.

Whole-rock and feldspar compositional data indicate that the first and third units are chemically similar (Henry and others, in press). Microprobe analyses of feldspar phenocrysts in four samples through the sequence of units show that they are anorthoclase or sodic sanidine. The compositions vary widely, but over the same range in each sample. The variation reflects both zoning of individual phenocrysts and significant differences between different phenocrysts. For example, individual feldspars in the basal tuff show variable zoning but have relatively constant anorthite contents (fig. 20). The similarity between all four samples, including the upper unit, suggests that they are comagmatic.

I interpret the lower unit as rheomorphic tuff. Following initial pyroclastic emplacement, the base of the flow cooled rapidly and was frozen in place. Greater heat retention above the base in the moderately alkalic and low-silica rhyolite allowed secondary flow. Total displacement at the top of the clearly tuffaceous part was at most 70 cm, on the basis of curvature of the gas pipes. Secondary flow in the base of foliated rock may have been only slightly more but was sufficient to obliterate pyroclastic features. The amount of flow increased progressively upward, as indicated by the development of flow folds and breccias. Breccias may mark a transition from initial, plastic secondary flow of the rheomorphic tuff to massive, brittle failure. Failure probably occurred as the total strain, represented by distance of flow, increased and as the upper part of the flow cooled and became more brittle.

The origin of the upper units is less certain. The similarity in general lithology and in bulk-rock and feldspar compositions to the lower unit indicates that they are comagmatic. However, unlike the lower unit, no pyroclastic features are preserved; most importantly, the upper units lack pyroclastic bases. The similarities between the rocks and difficulty in determining their origin illustrates the problems of interpreting other rocks of the Davis Mountains.

Barrilla Syncline

Barrel Springs in the Barrilla syncline (fig. 5) consists of three thin ash-flow tuffs interbedded with tuffaceous sediment. The lowest ash-flow tuff (lava 3 of Eifler, 1951) is picked as the base of the formation. However, because it overlies tuffaceous sediment of the Frazier Canyon Formation that is identical to sediment above the tuff, the choice is somewhat arbitrary.

The lowest tuff is about 15 m thick. It lacks both lithic and pumice fragments. At all but the base, it is densely welded and devitrified and has undergone extensive vapor phase crystallization. A strongly banded, basal lens consists of alternating vitrophyric and spherulitically devitrified layers. Some bands are folded, and feldspar phenocrysts are aligned with banding. Phenocrysts are mostly alkali feldspar (8%, up to 5 mm), some of which are glomerocrysts. Former clinopyroxene is now largely altered to chlorite and opaques. The groundmass consists of intergrown finely crystalline alkali feldspar, quartz, and opaques. Shard texture is poorly preserved only in the basal, banded layer.

The middle tuff is approximately 2.5 m thick, densely welded, devitrified, and silicified. A few flattened pumice fragments up to 3 cm long are present. It contains phenocrysts of alkali feldspar (3%, 1 to 4 mm) and oxidized clinopyroxene? (1%, less than 1 mm). Large, faintly preserved shards in the groundmass are reminiscent of the large shards in the basal tuff at Davis Mountains State Park.

The highest tuff is also the stratigraphically highest preserved rock in the Barrilla area. It is about 10 m thick, devitrified, densely welded, and strongly foliated similar to other parts of the Barrel Springs Formation. It contains sparse lithics up to 5 mm in diameter. The highest tuff is distinctly more coarsely and abundantly porphyritic than the lower two and than other Barrel Springs rocks. Phenocrysts consist of alkali feldspar (15%, up to 1 cm) both as individual grains and as glomerocrysts, clinopyroxene? (2%, 1 mm) altered to serpentine, and minor opaques, many of which are in glomerocrysts with clinopyroxene.

Correlation of Barrel Springs Flows

Definite correlation of different parts of the Barrel Springs Formation is unwarranted at this time. Nevertheless, the two flow units in the southwest are lithologically identical to the lowest two units at Blue Mountain and are tentatively correlated. Aerial photograph inspection indicates that the flows at Davis Mountains State Park dip beneath the higher units on Blue Mountain and may occupy the same stratigraphic position as the lowest two flows. This interpretation does not require that they be the same flows. Aerial photographic interpretation also indicates that the higher units at Blue Mountain are stratigraphically above all Barrel Springs units at the other three sections. However, they may correlate with rocks in the Mount Locke area in the central Davis Mountains. Rocks in the Barrilla syncline are too dissimilar to other Barrel Springs rocks and too distant for even speculative correlation. Future field work will focus on the area between the Barrilla syncline and the Fort Davis area.

Four K-Ar ages on the Barrel Springs Formation from the Fort Davis area and the Barrilla syncline average 36.4 Ma (Parker and McDowell, 1979; Henry and McDowell, 1986). Distribution and thickness variations of the Barrel Springs Formation suggest a source in the southwestern Davis Mountains. Smith (1975) suggested a caldera centered on Blue Mountain, whereas Henderson (1987) suggested a caldera slightly west of there.

VOLCANIC EVOLUTION OF THE DAVIS MOUNTAINS - PRELIMINARY STATEMENT

The oldest identified volcanism in the Davis Mountains consists of mafic lavas that erupted from several scattered volcanoes at 38 to 39 Ma. The number and thickness of flows indicate that all volcanoes were small. The existence of silicic eruptive centers at the same time is not established. None have been identified, and some of the tuff in the Huelster Formation may be derived from distal sources in western Trans-Pecos Texas and Mexico. However, the coarseness of some tuff deposits suggests local sources, which must be buried within the Davis Mountains.

The Star Mountain Formation is the first major eruptive rock of the Davis Mountains. Although no sources have been identified, its distribution and thickness indicate that any sources must be in the eastern Davis Mountains. Several thick, extensive quartz trachyte to rhyolite lava flows spread over an area of about 3000 km^2. Similarity of the Star Mountain Formation to the Bracks Rhyolite of the Sierra Vieja and to the Crossen Trachyte south of the Davis Mountains (fig. 2) suggests that they represent related and contemporaneous eruptions approximately 37 to 38 Ma over a wide area of Trans-Pecos Texas.

At least four, small rhyolitic domes erupted in the northeastern Davis Mountains. Two of the domes are peralkaline whereas two contain biotite and are metaluminous. Where stratigraphic relations have been determined, these formed between eruption of the Star Mountain Formation and Gomez Tuff. However, some domes may be as old as Huelster Formation (Parker, 1986). One of the domes formed along what was to become the ring fracture of the Buckhorn caldera. Others are clearly unrelated to the caldera. A thin layer of biotite-bearing tuff that commonly lies between the Star Mountain Formation and Gomez Tuff may be derived from these domes.

The peralkaline, rhyolitic Gomez Tuff was the first major ash-flow eruption in the Davis Mountains. It erupted from the Buckhorn caldera in the northeastern Davis Mountains, where it ponded to as much as 450 thick (Parker, 1986). It is probably the most widespread volcanic unit of the region, spreading over approximately 4000 km^2 in the eastern and northern Davis Mountains. Several lava-flow sequences (not yet studied) overlie the Gomez Tuff within and around the caldera and may be related to the caldera magma system. K-Ar ages and field relations suggest that the Gomez Tuff erupted soon after emplacement of the Star Mountain Formation.

The Limpia Formation consists of a thick pile of porphyritic trachyte to quartz trachyte lavas that must be derived from local sources east of Fort Davis. They may represent the youngest silicic magmatism in the eastern Davis Mountains.

Following eruption of the Limpia Formation, the area was blanketed by tuffaceous sediments of the Frazier Canyon Formation. Older deposits in the eastern Davis Mountains were only locally eroded. The tuffaceous deposits mark either the end or posssibly a hiatus in silicic volcanism in the eastern Davis Mountains. Tuffaceous material in the formation could have been derived from sources in other parts of the Davis Mountains, or, as with the tuffaceous deposits of the Huelster Formation, sources in western Trans-Pecos Texas and Mexico. Mafic lavas in the Frazier Canyon Formation probably represent both local eruptions and distal parts of thick sequences of basalts from the south.

The Sleeping Lion Formation overlies the Frazier Canyon Formation. It was probably erupted from a source west of Fort Davis and flowed down a paleovalley remaining from the Limpia Formation. Although separated from both the older Gomez Tuff and younger Barrel Springs Formation by sedimentary intervals, the Sleeping Lion Formation cannot be distinguished from either by K-Ar ages.

Eruption of the composite Barrel Springs Formation at 36 Ma represents a major shift in the locus of volcanism. Its distribution and thickness suggest a source in the Blue Mountain area or farther west. From there, numerous flows, including several rheomorphic tuffs spread throughout most of the Davis Mountains. Its areal distribution rivals that of the Gomez Tuff, but the distribution of individual parts of the Barrel Springs Formatin is not yet understood. Field evidence and K-Ar ages indicate that the Barrel Springs Formation erupted considerably later than the older rocks discussed here. To the east, it overlies progressively older rocks, indicating that they were substantially eroded before emplacement of the Barrel Springs flows.

EXTENSIVE SILICIC ROCKS - RHEOMORPHIC TUFFS AND LAVA FLOWS

The origin of some extensive silicic volcanic rocks of the Davis Mountains, whether ash-flow tuff or lava, has been a longstanding controversy (Anderson, 1969; Gibbon, 1969; Parker and McDowell, 1979; Franklin and others, 1987; Henry and others, 1988, in press). The basic problem is that several units have outcrop and petrographic features exclusively of lava flows but have the areal dimensions and aspect ratios considered typical of ash-flow tuffs. Viscosities of magmas of these compositions seem too high for individual flows to have traveled great distances. A related problem is that many unequivocal tuffs have undergone secondary flow (rheomorphism) and have acquired some lava-flow features. One purpose of this study has been to investigate the origin of these rocks, in part by thoroughly documenting the distribution and thickness of individual flows. My interpretation is that ash-flow tuffs, strongly rheomorphic tuffs, and extensive silicic lavas are all present.

Ash-flow tuffs in Trans-Pecos Texas range from conventional welded tuffs showing no rheomorphic features to rheomorphic tuffs in which primary features are well preserved to strongly rheomorphic tuffs in which primary features are only locally preserved. The Gomez Tuff is an unequivocal ash-flow tuff that falls into the second and third categories. In thin outcrops distant from its source in the Buckhorn caldera, it shows no rheomorphic features. As it thickens toward its source, flow bands, folds and ramp structures are irregularly developed. The thick section of Gomez Tuff ponded just within the caldera at Madera Canyon underwent extreme secondary flow, resulting in spectacular flow banding and folding and obliteration of almost all pyroclastic features, except for sparse lithic fragments. The extreme secondary flow probably reflects low viscosity of the peralkaline magma, thickening of the tuff within the caldera, and the steep slope of the caldera margin. Nevertheless, the pyroclastic origin of the Gomez Tuff is readily discernible in almost all outcrops.

Some flow units of the Barrel Springs Formation exhibit still more intense secondary flow. Throughout most of the central part of its outcrop, only lava- flow features are recognized. However, at several locations, most notably the lower unit at Davis Mountains State Park, a thin pyroclastic base is preserved (fig. 6). This pyroclastic base passes upward into foliated, flow-banded and folded, and even brecciated rock. Lithic fragments are the only preserved evidence of pyroclastic origin in this upper rheomorphic part. Additionally, recognition that the contact between the base and the rheomorphic part represents a transition rather than a contact between separate flows demonstrates the pyroclastic origin. The origin of other flow units in the Barrel Springs Formation is still not established.

In contrast, no such subtle indications of pyroclastic origin have been found for the Star Mountain Formation, Bracks Rhyolite, and Crossen Trachyte; I interpret them to be extensive silicic lavas. These rocks show abundant features typical of lavas, including breccias at the tops and bottoms of flow units, flow banding and folding, ramp structures. vitrophyres at the tops, and elongate vesicles. Additionally, they lack any suggestion of pyroclastic features such as shards, pumice, lithic fragments, or any welding zonation. Although extensive, they are clearly less extensive and thicker (and therefore have a higher aspect ratio) than definite ash-flow tuffs such as the Gomez Tuff. These lavas developed their great areal extent probably because they erupted large volumes of magma at relatively high rates.

PLANS FOR THE SECOND YEAR

Work in the Davis Mountains in the second year will proceed largely as it has for the first year, with emphasis on regional and locally detailed geologic mapping. Considerable emphasis will be placed on correlating individual flow units of the Barrel Springs Formation, as they could be widespread units that will make throughgoing stratigraphic markers comparable to the Gomez Tuff. For example, mapping between Fort Davis and the Barrilla syncline will attempt to determine the relationship between Barrel Springs units in those areas.

Additionally, specific problems in individual units will be addressed. Work will continue on determining the number and extent of individual flows in the Star Mountain Formation. Possible source areas for it will also be examined. Flow directions and the possible upper flow unit of the Sleeping Lion Formation east of Fort Davis will be examined, also to constrain source areas. Mafic flows in the Huelster and Frazier Canyon Formations will be studied to attempt to establish regional correlations for them.

Isotopic dating by the $^{40}Ar/^{39}Ar$ method will be used to aid correlation by more traditional methods. Seventeen samples of alkali feldspar separates from the Star Mountain Formation, Gomez Tuff, Sleeping Lion Formation, Barrel Springs Formation, Bracks Rhyolite, and Crossen Trachyte have been prepared for dating in the first year. Stratigraphic locations of the samples are shown on Figure 4. Unfortunately, dating has been postponed due to shutdown of the USGS's TRIGA reactor in Denver. It is hoped that these samples can be analyzed in the fall of 1988. Future dating will fill in between these units in the stratigraphic section (for example, the rhyolite domes), expand coverage of key units such as the Barrel Springs Formation, and extend to stratigraphically higher units. Additionally, dating may be applied to tuffaceous sediments and mafic flows of such units as the Huelster and Frazier Canyon Formations if biotite and whole rock samples are appropriate.

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Figure Captions

1. Index map of Trans-Pecos Texas, showing the Davis Mountains, Basin and Range province, known and suspected calderas, and alkalic and alkali-calcic belts of volcanism.

2. Distribution of Star Mountain Formation, Bracks Rhyolite, and Crossen Trachyte. Similarity in the outcrop and petrographic characteristics, stratigraphic position, K-Ar age, and composition suggest that they represent distinct and related eruptive events in Trans-Pecos Texas.

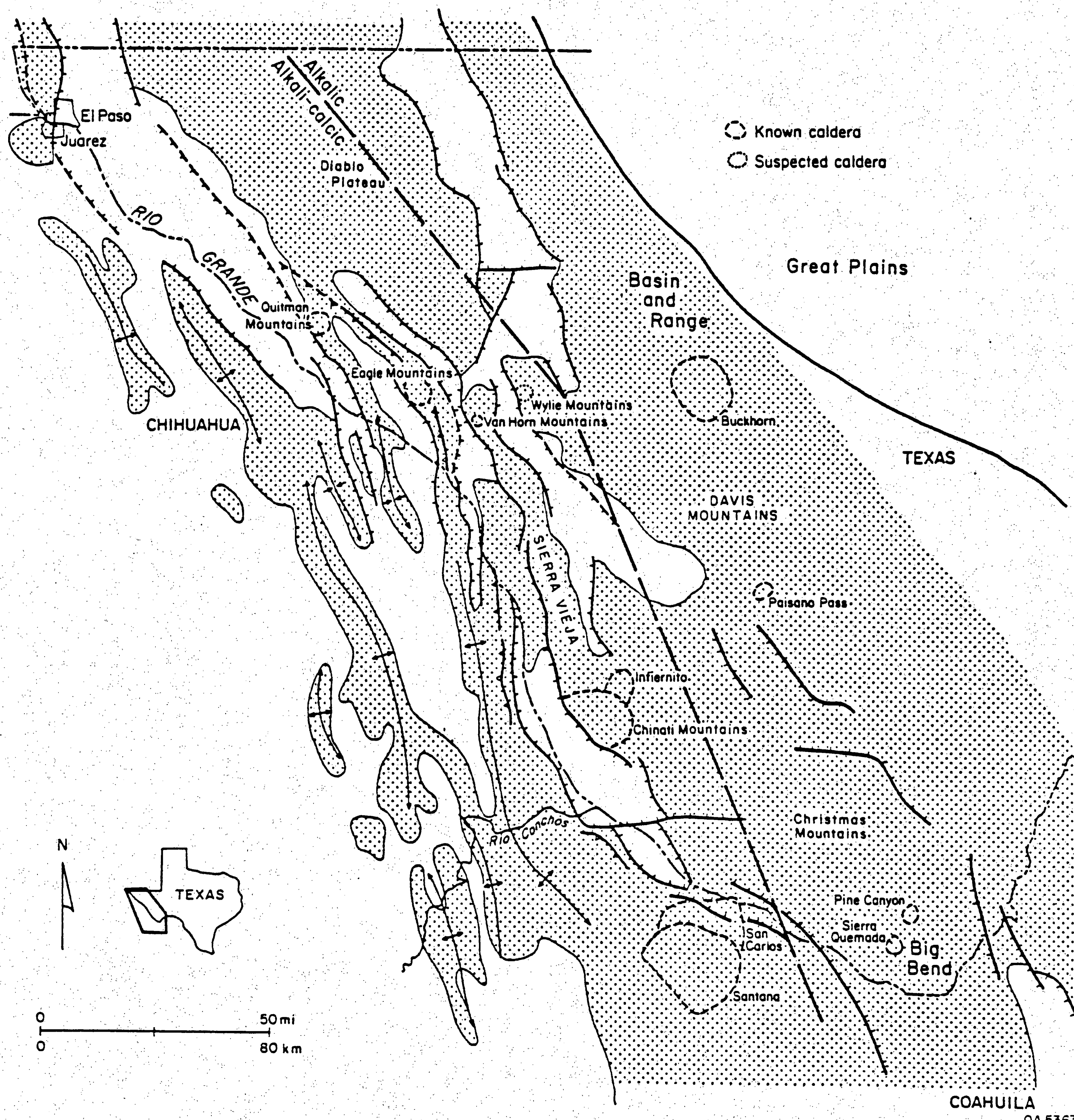
3. Volcanic field of Trans-Pecos Texas in relation to other mid-Tertiary volcanic areas of southwestern North America.

4. Generalized stratigraphy and correlation of volcanic units of the eastern and southern Davis Mountains. Asterisk (*) indicate stratigraphic location of samples collected for $^{40}Ar/^{39}Ar$ dating. (A). Correlation from southwestern Davis Mountains through area of Davis Mountains State Park to Barrilla syncline. (B). Correlation from Barrillos Dome (southeastern Davis Mountains) through Fort Davis area to Buckhorn caldera (northern Davis Mountains).

5. Locations discussed in text.

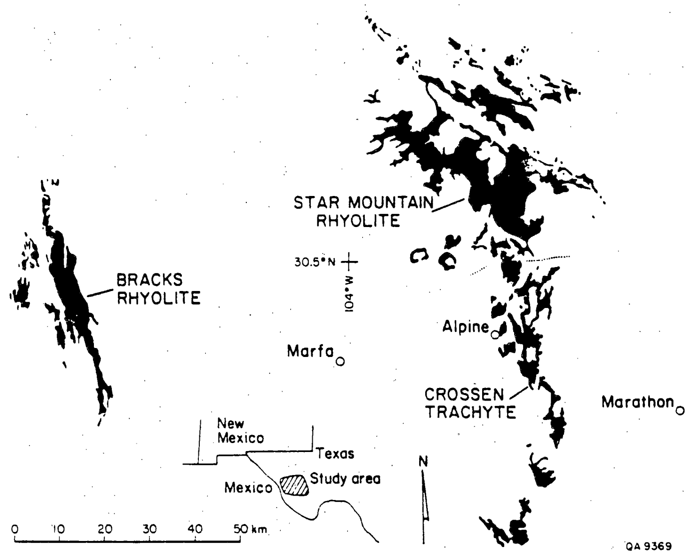
6. Stratigraphic section through rheomorphic tuff of the Barrel Springs Formation in Davis Mountains State Park.

Figure 1



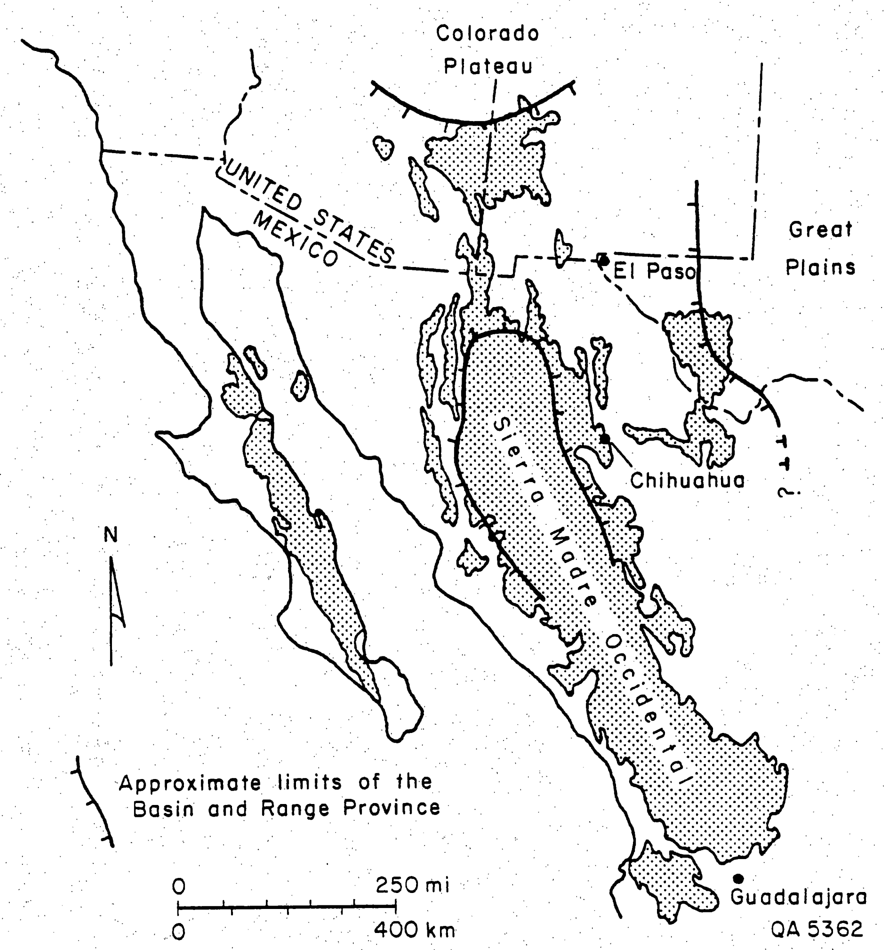
Alkalic
Alkali-calcic
El Paso
Juarez
Diablo Plateau
Known caldera
Suspected caldera
RIO GRANDE
Great Plains
Basin and Range
Quitman Mountains
Eagle Mountains
Wylie Mountains
Van Horn Mountains
Buckhorn
CHIHUAHUA
TEXAS
DAVIS MOUNTAINS
SIERRA VIEJA
Paisano Pass
Infiernito
Chinati Mountains
Rio Conchos
Christmas Mountains
N
TEXAS
Pine Canyon
Sierra Quemada
San Carlos
Big Bend
Santana
0 50 mi
0 80 km
COAHUILA
QA 5363

Figure 2



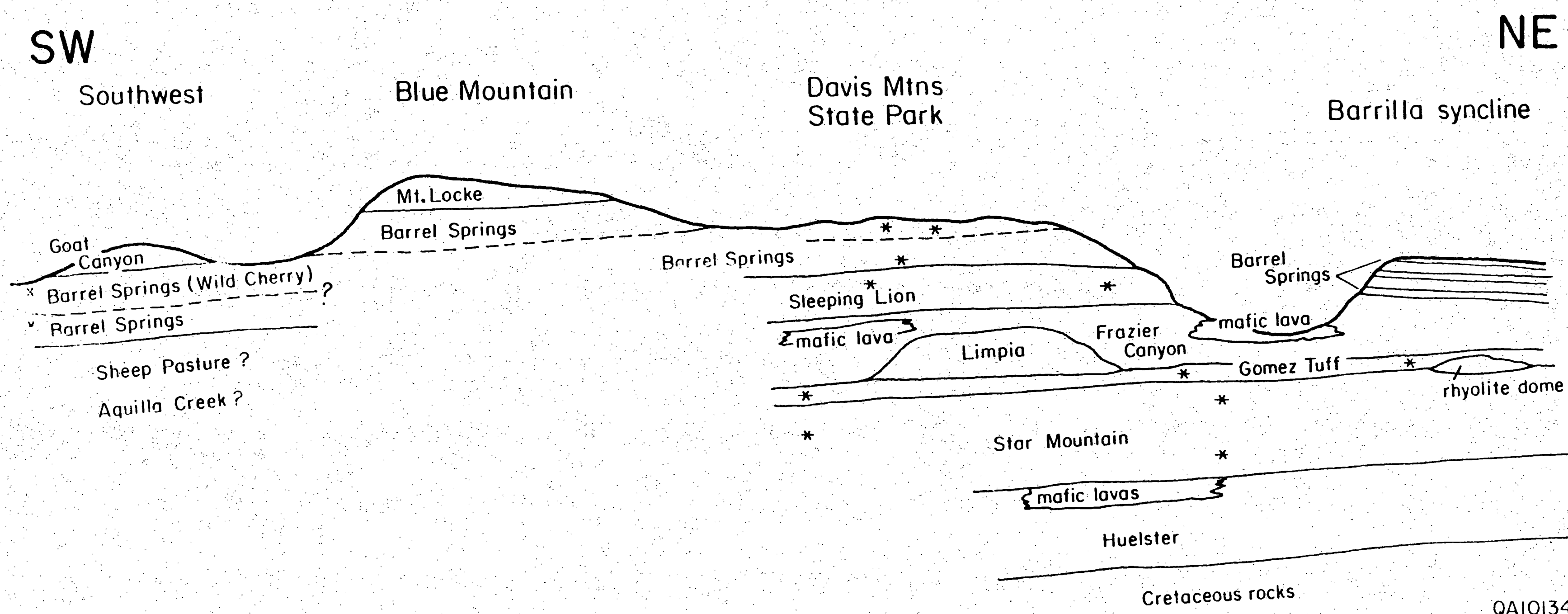
STAR MOUNTAIN RHYOLITE
BRACKS RHYOLITE
30.5°N
104°W
Alpine
Marfa
CROSSEN TRACHYTE
Marathon
New Mexico
Texas
Mexico
Study area
N
0 10 20 30 40 50 km
QA 9369

Figure 3



Colorado
Plateau
UNITED STATES
MEXICO
El Paso
Great
Plains
Sierra Madre Occidental
Chihuahua
N
Approximate limits of the
Basin and Range Province
0
250 mi
0
400 km
Guadalajara
QA 5362

Figure 4A



SW
Southwest
Blue Mountain
Davis Mtns
State Park
NE
Barrilla syncline
Goat
Canyon
Barrel Springs (Wild Cherry)
Barrel Springs
Sheep Pasture ?
Aquilla Creek ?
Mt. Locke
Barrel Springs
Barrel Springs
Sleeping Lion
mafic lava
Limpia
Frazier
Canyon
Barrel
Springs
mafic lava
Gomez Tuff
rhyolite dome
Star Mountain
mafic lavas
Huelster
Cretaceous rocks
QA10134

Figure 4B

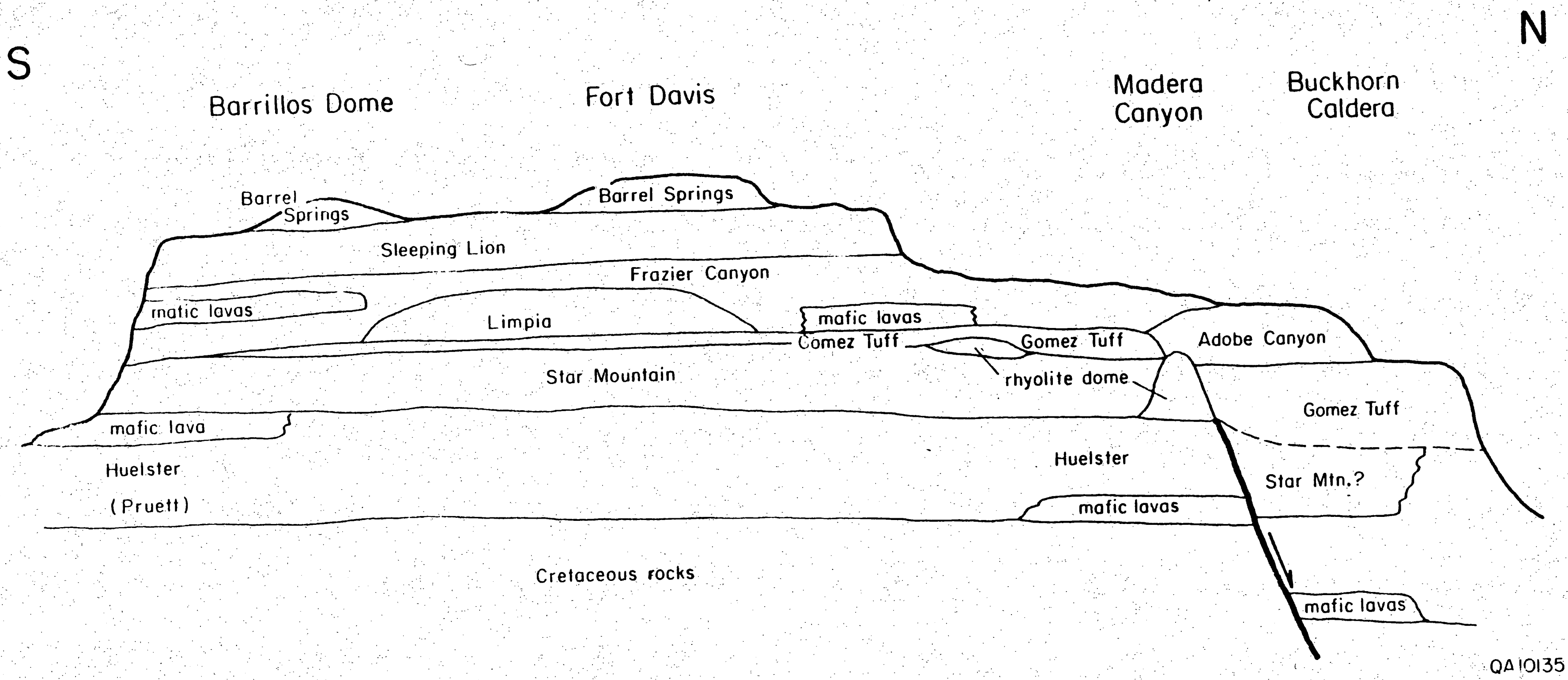
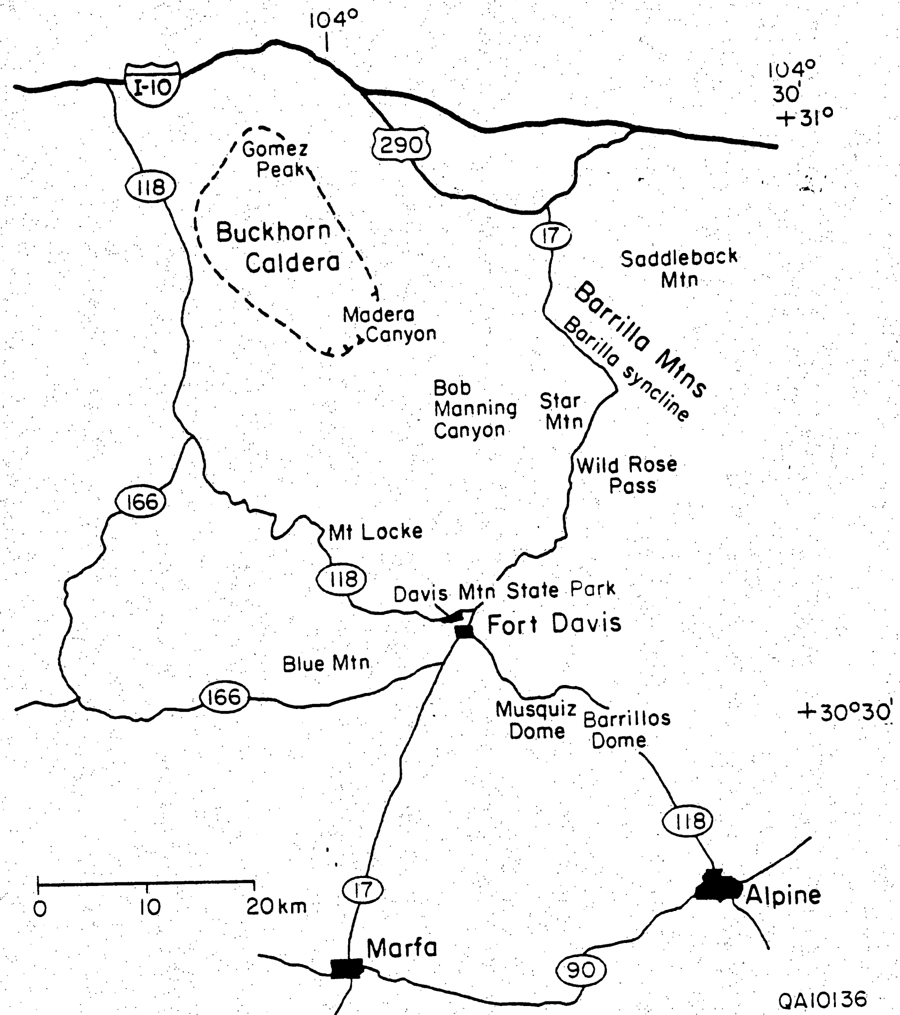
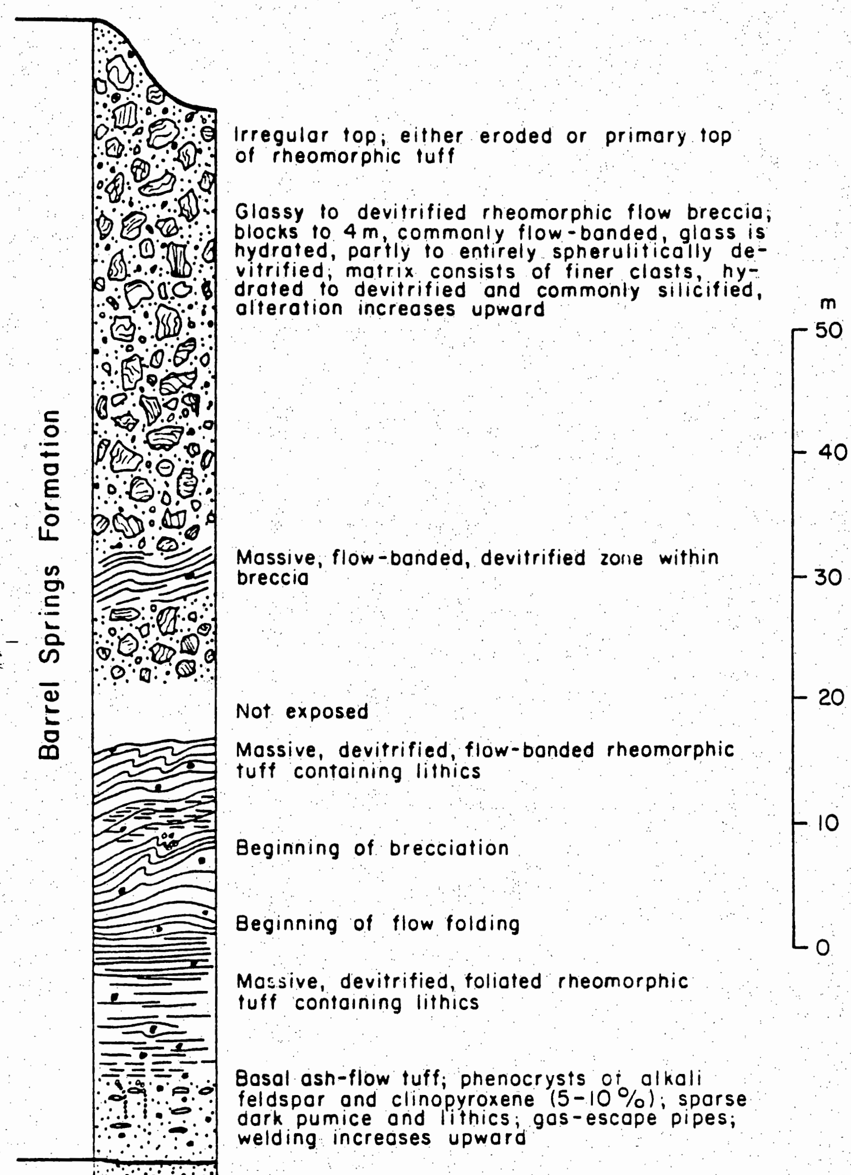

S
N
Barrillos Dome
Fort Davis
Madera Canyon
Buckhorn Caldera
Barrel Springs
Barrel Springs
Sleeping Lion
Frazier Canyon
mafic lavas
Limpia
mafic lavas
Gomez Tuff
Gomez Tuff
Adobe Canyon
rhyolite dome
Star Mountain
Gomez Tuff
mafic lava
Huelster
(Pruett)
Huelster
Star Mtn.?
mafic lavas
Cretaceous rocks
mafic lavas
QA10135

Figure 5



104°
104°
30'
+31°
I-10
290
118
17
Gomez
Peak
Buckhorn
Caldera
Madera
Canyon
Saddleback
Mtn
Barrilla Mtns
Barilla syncline
Bob
Manning
Canyon
Star
Mtn
Wild Rose
Pass
166
Mt Locke
118
Davis Mtn State Park
Fort Davis
Blue Mtn
166
Musquiz
Dome
Barrillos
Dome
+30°30'
118
0
10
20 km
17
Alpine
Marfa
90
QA10136

Figure 6


Barrel Springs Formation
Irregular top; either eroded or primary top of rheomorphic tuff
Glassy to devitrified rheomorphic flow breccia; blocks to 4 m, commonly flow-banded, glass is hydrated, partly to entirely spherulitically devitrified; matrix consists of finer clasts, hydrated to devitrified and commonly silicified, alteration increases upward
Massive, flow-banded, devitrified zone within breccia
Not exposed
Massive, devitrified, flow-banded rheomorphic tuff containing lithics
Beginning of brecciation
Beginning of flow folding
Massive, devitrified, foliated rheomorphic tuff containing lithics
Basal ash-flow tuff; phenocrysts of alkali feldspar and clinopyroxene (5-10 %); sparse dark pumice and lithics; gas-escape pipes; welding increases upward
m
50
40
30
20
10
0
QA 9815