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CENOZOIC VOLCANIC GEOLOGY OF THE BASIN AND RANGE PROVINCE IN HIDALGO COUNTY, SOUTHWESTERN NEW MEXICO

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INTRODUCTION

This is a preliminary report on the Cenozoic volcanic geology of an area of about 5,000 km² (fig. 1). Hidalgo County occupies the southwestern corner of New Mexico, a part of the Mexican Highlands section of the Basin and Range province. The region of which it is a part was involved in the mid-Tertiary "ignimbrite flareup" and its volcanic stratigraphy is characterized by numerous sheets of felsic ash-flow tuff. A number of source calderas have been identified and seem to be associated with small mineral deposits. This paper summarizes the stratigraphy and structure of the mid-Tertiary volcanic rocks.

This project began in 1973 and is still in progress. The first stages of the present study, in 1973 and 1974, were supported by NASA grant NGR-32-004-062 from the Planetology Office. For the main part of the present study, the New Mexico authors gratefully acknowledge support from New Mexico Energy Resources Board grants 75-109, 75-117, 76-264, 76-350, and 77-3104 and U.S. Geological Survey grants 14-08-001-G-255 and 14-08-001-G-348. Peterson's work was partly supported by Leonard Resources of Albuquerque, N.M. and the New Mexico Bureau of Mines and Mineral Resources. Damon and Shafiqullah are responsible for K-Ar dating and acknowledge support from NSF grant EAR 76-02590 and the State of Arizona. D. J. Lynch assisted in the analytical work at the University of Arizona.

Previous work by others includes mapping in the Animas Mountains by Zeller (1967) and Zeller and Alper (1965), in the Alamo Hueco Mountains by Zeller (1958), in the Peloncillo Mountains by Gillerman (1958) and Wrucke and Bromfield (1961), in the Pyramid Mountains by Flege (1959) and in the Apache Hills by Strongin (1958). These authors did their work at a time when the relationship of ash-flow tuff sheets to large central caldera complexes was not understood. Our work has involved not only new geologic mapping but also extensive revision of older interpretations. All work, including ours, is limited by lack of knowledge from the border area of Mexico. Also, virtually all information comes from the ranges and very little comes from the intervening basins. Only fragments of the proposed caldera complexes are exposed to view. Considerably

more petrographic and chemical work needs to be done before the stratigraphic correlations between ranges suggested in the paper are firmly established.

SUMMARY OF PREOLIGOCENE EVENTS

The rocks and structures discussed in this paper are Oligocene and younger. They lie on a basement of Precambrian crystalline rocks and Paleozoic and Cretaceous sedimentary rocks (Greenwood and others, 1977). In the northern end of Hidalgo county, Paleozoic and early Cretaceous rocks are missing; late Cretaceous rocks lie on Precambrian rocks (Elston, 1958).

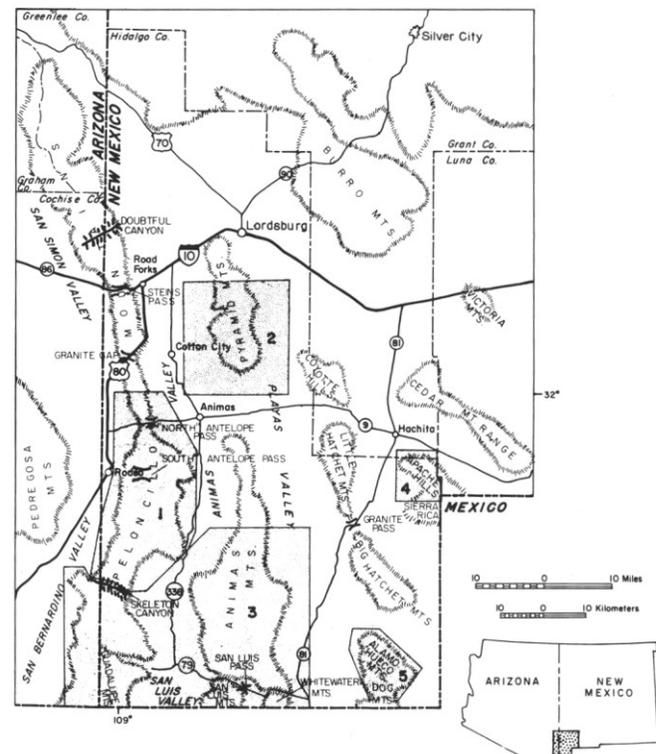


Figure 1. Map of Hidalgo County, New Mexico and vicinity, showing localities mentioned in this paper and the mapping contributions of individual authors. (1) Deal, (2) Deal and Elston, (3) Erb, (4) Peterson, (5) Reiter.

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There is considerable evidence for andesitic volcanism associated with Laramide events. Late Cretaceous and (or) early Tertiary andesite and basaltic andesite are known from the Lordsburg area (Thorman and Drewes, this guidebook), where they were intruded by a mineralized granodiorite porphyry stock dated at 56.6 ± 1.2 m.y. (Table 1, no. 22). In the Peloncillo Mountains, between Steins Pass and Granite Gap, andesite has been tilted nearly vertically along northwest-trending faults (Gillerman, 1958); the same faults barely displace sills of granite or quartz monzonite porphyry dated at 30 to 31 m.y. (Todd and others, 1975). In the Little Hatchet Mountains, andesite may be involved in thrusts generally interpreted as Laramide (Zeller, 1970).

In numerous places in the Animas, Alamo Hueco and Peloncillo mountains, Oligocene and pre-Oligocene rocks are separated by conglomerate with clasts of Paleozoic and Mesozoic sedimentary rock, interbedded with red or pink siltstone and sandstone. In places, these rocks are hundreds of meters thick. The Timberlake Fonglomerate of the Animas Mountains (Zeller and Alper, 1969) is an example.

OLIGOCENE-MIOCENE EVENTS

Summary

Mid-Tertiary volcanism began with eruption of poorly dated andesite flows and breccias, as in many other parts of the Basin and Range province. These were succeeded, between about 37 and later than 24 m.y., by quartz latite to rhyolite ash-flow tuffs, which erupted from at least nine known or suspected central cauldrons (fig. 2). There is a general progression (with some irregularities and reversals) in the succession of rock types. The earliest ash-flow tuffs tend to be crystal-poor

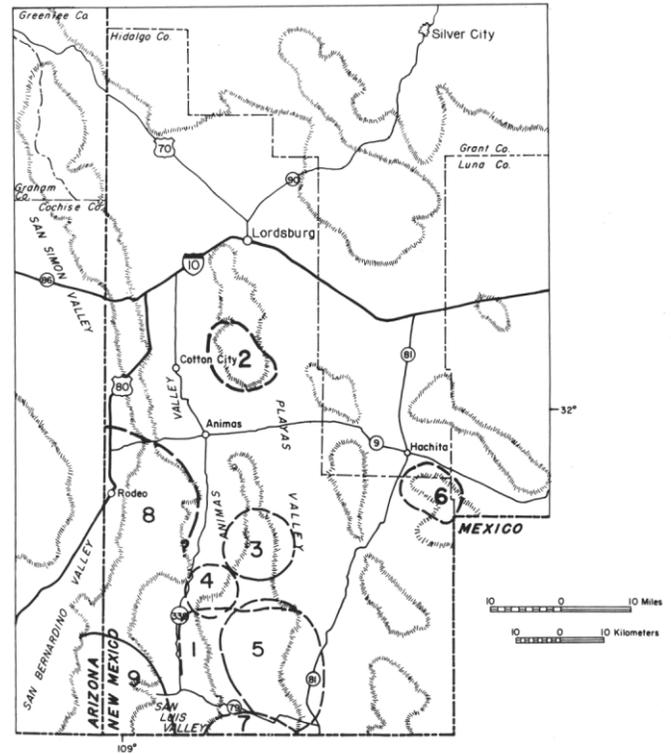


Figure 2. Ash-flow tuff cauldrons of Hidalgo County, New Mexico in approximate order of age. (1) Tullous, (2) Muir, (3) Juniper, (4) Animas Peak, (5) Cowboy Rim, (6) Apache, (7) San Luis, (8) Rodeo, (9) Geronimo Trail. Outlines show the approximate location of the inner cauldron margins.

Table 1. K-Ar data on samples from Hidalgo County, New Mexico*

Sample No.	Sample description and location	Percent K	Radiogenic argon-40 ($\times 10^{-12}$ mole/g)	Percent atmospheric argon-40	Age in m.y.
1	Whole rock, basalt, Animas Valley, crops out along New Mexico State Highway 9 east of Antelope Pass.	0.96 ₈	0.925 0.894 0.923	84.9	0.511 ± 0.03
2	Whole rock, porphyritic basalt, San Luis Pass, Animas Mountains, Antelope Wells quad. Lat. $31^{\circ}23'30''$, Long. $108^{\circ}44'38''$	1.34 ₉	15.9	49.4	6.83 ± 0.17
3	Whole rock, rhyolite dike, Pyramid Mountains, Lordsburg quad. Younger than rhyolite of Pyramid Peak Lat. $32^{\circ}16'$, Long. $108^{\circ}43'$	3.48 ₁	138.7	39.2	22.72 ± 0.52
4	Whole rock (minimum age), rhyolite flow of Packers Trail, San Luis Pass, Animas Mountains, Antelope Wells quad. Lat. $31^{\circ}24'$, Long. $108^{\circ}44'08''$	4.12 ₃	166.3 164.7	3.5 3.5	23.00 ± 0.49
5	Sanidine, rhyolite tuff of Guadalupe Canyon, Peloncillo Mountains, Outlaw Mountain, Cochise County, Arizona. Lat. $31^{\circ}29'$, Long. $109^{\circ}04'45''$	8.74	371.0 369.5	1.7 1.9	24.26 ± 0.52
6	Feldspar, monzonite porphyry stock, propylitized and fractured. Sampled about a mile from the contact of the Apache stock, Apache Hills quad. Lat. $31^{\circ}51'2''$, Long. $108^{\circ}18'24''$	2.68	126.2 126.9	27.4 26.4	27.03 ± 0.59
7	Feldspar, quartz monzonite of Apache Hills stock, Apache Hills quad. Lat. $31^{\circ}50'$, Long. $108^{\circ}16'$	1.39 ₁	65.6	39.6	27.18 ± 0.63

8	Chloritized biotite, quartz monzonite from KCM #1 Forest Federal well, Walnut Wells quad., Animas Mountains. Rock was encountered at about 4000 ft in oil wildcat drilled in the Winkler Anticline. Lat. 31°38'36", Long. 108°39'29"	3.32 ₇	155.7 157.4 158.9 160.9	31.0 27.1 34.2 34.2	27.22 ± 0.58
9	Whole rock, pyroxene andesite dike, Swallowfork Peak quad., Pyramid Mountains. Lat. 32°09', Long. 108°46.5'	2.32	120.8 114.7	70.3 71.3	29.43 ± 0.73
10	Sanidine, Park Tuff, Walnut Wells quad., Animas Mountains near O.K. Bar Camp. Lat. 31°36', Long. 108°44'	6.40 ₃	328.5 322.8 333.3	6.9 7.5 5.7	29.62 ± 0.62
11	K-feldspar, basal quartz latite flow or ash-flow tuff of Chapo Formation, Apache Hills. K-feldspar is somewhat sericitized and all the rocks in the area have been propylitized. Apache Hills quad. Lat. 31°48'39", Long. 108°17'36"	9.59	506.5 521.9	68.9 67.8	30.66 ± 1.15
12	Anorthoclase, Double Adobe Latite, Walnut Wells quad., Animas Mountains. Lat. 31°36', Long. 108°37.5'	2.40	128.6 129.0	8.0 8.2	30.69 ± 0.66
13	Biotite, Gillespie Tuff, Walnut Wells quad., Animas Mountains. Lat. 31°37.5' Long. 108°45' (sample #3)	7.05	405.2	7.6	32.88 ± 0.70
14	Whole rock, andesite of Holtkamp Canyon, South Pyramid Peak quad. Lat. 32°6'13", Long. 108°43'15"	2.42	141.0 139.4	8.3 8.6	33.10 ± 0.70
15	Sanidine, rhyolite ash-flow tuff, No. 6 of the Rimrock Mountain Group, Rockhouse Seep, Pyramid Mountains, Pyramid Peak quad. Lat. 32°32'51", Long. 108°43'03"	8.67 ₆	507.9 531.5	7.7 5.2	34.22 ± 0.56
16	Biotite, Walnut Wells monzonite porphyry, from northernmost tip of the stock Walnut Wells quad., Animas Mountains. Lat. 31°43', Long. 108°48'	6.31 ₅	382.4 379.3	20.0 20.1	34.45 ± 0.75
17	Biotite, Animas quartz monzonite porphyry, Walnut Wells quad., Animas Mts. quad. Lat. 31°43', Long. 108°48'	6.96	428.1 420.6	23.5 24.1	34.83 ± 0.78
18	Biotite, Oak Creek tuff, Walnut Wells quad., Animas Mountains. Lat. 31°40', Long. 108°39'	6.66 ₅	415.3 405.3	19.0 18.4	35.16 ± 0.77
19	Biotite, No. 2 tuff of the Rimrock Mountain Group, North Linn Tank, Pyramid Peak quad., Pyramid Mts. Lat. 32°11'19", Long. 108°42'02"		433.2 434.5	25.5 25.8	35.87 ± 0.79
20	Biotite, basal latite flow of Uhl Well, North Linn Tank. Pyramid Peak quad. Pyramid Mtns. Lat. 32°11'24", Long. 108°42'15"	6.67	430.6	23.2	36.64 ± 0.80
21	Biotite, rhyolite tuff of Woodhaul Canyon, near Rattler Well, South Pyramid quad. Lat. 32°06'42", Long. 108°41'56"	6.94 ₄	452.0 448.9 446.2 434.8 446.2 458.9	45.2 45.5 24.9 25.4 45.7 45.6	36.82 ± 0.81
22	Biotite, Lordsburg granodiorite, collected from dump near Dundee shaft, Eight-five mine, Lordsburg quad., Pyramid Mts. Lat. 32°19' Long. 108°45'	7.69 ₈	761.6 770.7	7.5 7.2	56.52 ± 1.2

*Analysts: Paul E. Damon and M. Shafiqullah, University of Arizona.

Constants used:

$$\lambda_{\beta} = 4.963 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda = 5.544 \times 10^{-10} \text{ yr}^{-1}$$

$${}^0\text{K}/\text{K} = 1.167 \times 10^{-4} \text{ atom/atom}$$

quartz latite. They were generally followed by crystal-rich quartz latite ash-flow tuffs (phenocrysts of plagioclase, quartz, sanidine, biotite, hornblende and more rarely, augite), and these were succeeded by relatively crystal-poor quartz-sanidine rhyolite tuffs with little or no plagioclase or biotite. Flows of dark andesite and latite, basaltic andesite and basalt are locally interlayered with ash-flow tuffs. They are not as abundant as in the Mogollon-Datil field farther north (Elston and Northrop, 1976; Chapin and Elston, 1978), but they have a wide stratigraphic range.

Latite-to-rhyolite domes and lava flows are common, especially in the ring-fracture zones of cauldrons. The cauldrons vary widely in size, internal structure and depth of erosion. Some seem to have formed as a result of a single eviscerating eruption or several closely spaced eruptions (fig. 2, nos. 3, 8, 9), while others were the site of many eruptions separated by intervals of sedimentation (fig. 2, no. 1) or lava filling (fig. 2, no. 6). Some resurged (fig. 2, nos. 3, 6, 8, 9, possibly 2), others did not (fig. 2, nos. 1, 5). In some, stocks of quartz monzonite porphyry were emplaced in the subsided cauldron block during a resurgent magma pulse (fig. 2, nos. 2, 6).

PYRAMID MOUNTAINS

General Statement

Mid-Tertiary volcanic rocks dominate the southern two-thirds of the Pyramid Mountains (fig. 3, column 2) (Deal and Elston, submitted). The structure of the range is dominated by a relatively shallow but complicated cauldron complex, the Muir cauldron, named after the Muir (or Kipp) ranch which occupies part of the Pyramid Mountains. Rocks of the range can be divided into three groups: (1) pre-cauldron andesite of

Holtkamp Canyon, (2) rocks of the cauldron, collectively termed the Pyramid Mountains Volcanic Complex and (3) post-cauldron rocks of the Rimrock Mountain Group.

Cenozoic Stratigraphy

Andesite of Holtkamp Canyon:

Pyroxene-plagioclase andesite of Holtkamp Canyon crops out on the floor of the Muir cauldron, on the cauldron walls and in the ring-fracture zone. It has been named for exposures in Holtkamp Canyon, in secs. 20 and 30, T.25S., R.18W. A K-Ar date of 33 m.y. (Table 1, no. 14) seems to be spurious, because overlying rocks have yielded older dates. Heating during activity of the Muir cauldron or alteration may account for the discrepancy. The andesite is at least 300 m thick but no base is exposed.

Pyramid Mountains Volcanic Complex:

Rocks of the Pyramid Mountains Volcanic Complex tend to be crystal-poor (<5 to 15 percent phenocrysts) and characterized by phenocrysts of plagioclase, biotite and little or no quartz and sanidine. Because of Basin and Range faulting, only a fragment of the Muir cauldron has been preserved (fig. 4). The preserved part of the ring-fracture zone is a broad arc on the northeast side of the cauldron. Its earliest expression consists of a pre-collapse set of domes, flows and minor ash-flow tuff, the rhyolite of Jose Placencia Canyon (type locality in SEY4 sec. 21, T.24S., R.18W.).

Ash-flow tuff cauldron-fill occupies much of the central part of the Pyramid Mountains, southwest of the ring-fracture zone. It forms many high points of the range, such as Lightning Dock Mountain and South Pyramid Peak (see First Day

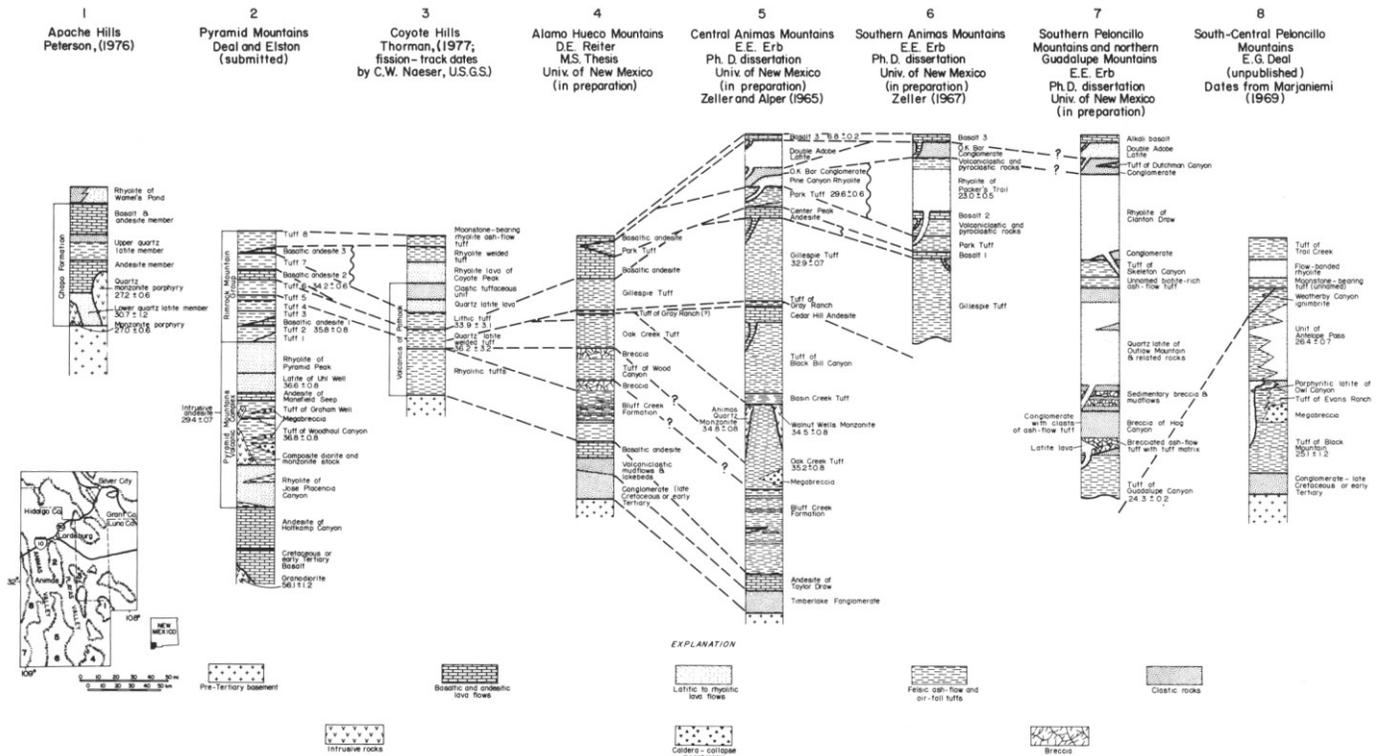


Figure 3. Proposed correlation of mid-Tertiary volcanic rocks of Hidalgo County, New Mexico. Dates are from Table 1, unless credited to other sources. The columns are designed to show stratigraphic relationships and are not drawn to scale. True thicknesses are given in the text.

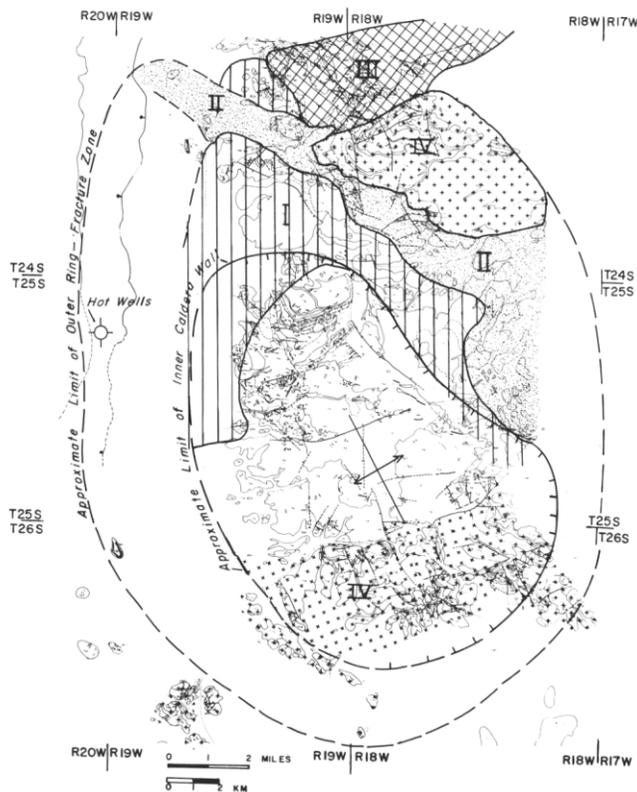


Figure 4. Generalized structure of the Muir cauldron. Tuff of Woodhaul Canyon and tuff of Graham Well are largely confined to the area within the inner caldera wall. Zones I, II and III are successive ring-fracture zones. Zone I includes all outcrops of rhyolite of Jose Placencia Canyon, Zone II the latite of Uhl Well, and Zone III the rhyolite of Pyramid Peak. Zone IV covers occurrences of the post-cauldron Rimrock Mountain Group.

Road Log, this guidebook). Cauldron collapse seems to have occurred in two stages. The first and main stage resulted from eruption of crystal-poor rhyolite tuff of Woodhaul Canyon (type locality in sec. 23, T.25S., R.19W.), of which about 425 m remain around South Pyramid Peak and Lightning Dock Mountain, even though the top has been eroded. Its eruption was accompanied by massive collapse of the caldera wall. The resulting megabreccia is intimately intermingled with the northern two-thirds of the tuff of Woodhaul Canyon. Most of the breccia blocks are of andesite of Holtkamp Canyon but blocks of Paleozoic limestone and Precambrian granite are also common. The largest individual blocks are more than 50 m wide; some zones of blocks can be traced for several kilometers.

Collapse was followed by a stage of hydrothermal alteration. Subsequently, a minor ash-flow tuff, the tuff of Graham Well, erupted with further collapse of the northern cauldron wall. Only small patches of outflow of tuff of Woodhaul Canyon have been found beyond the cauldron wall. A composite stock of diorite, monzonite porphyry and rhyolite was emplaced on the northwest side of the cauldron at an unknown time after eruption of the tuff of Woodhaul Canyon, but before eruption of the Rimrock Mountain Group, as were numerous dikes and sills, mainly of andesitic composition. An intrusive andesite has been dated at 29.4 ± 0.7 m.y. (Table 1, no.

9). Some of the intrusions and the post-collapse ring-fracture deposits may be the products of a resurgent magma pulse.

Two concentric sets of post-collapse ring-fracture deposits are preserved on the northeast side of the Muir cauldron. The inner one consists of domes and flows of latite of Uhl Well (type locality W1/4 sec. 11, T.25S., R.18W.), a rock characterized by flakes of brassy biotite in a cryptocrystalline matrix. Locally, the hornblende-augite andesite of Mansfield Seep (type locality NW/4 sec. 18, T.24S., R.18W.), up to 30 m thick, lies at its base. The outer ring-fracture zone consists of rhyolite of Pyramid Peak (type locality in NW/4 sec. 8, T.24S., R.18W.), made up of flows and domes with about 2 percent phenocrysts of oligoclase-andesite and black biotite, perlite zones, tuffs, pumice flows, sandstones, conglomerate and laminated lakebeds (including fresh-water limestone).

The rocks of the Muir cauldron are difficult to date, because of pervasive alteration. The most reliable K-Ar biotite date, 36.8 ± 0.8 m.y. (Table 1, no. 21), comes from a tuff on the edge of the cauldron, tentatively correlated with the upper part of the tuff of Woodhaul Canyon. Latite of Uhl Well yielded a K-Ar biotite date of 36.6 ± 0.8 m.y. (Table 1, no. 20). A K-Ar biotite age of 35.9 ± 0.8 m.y. (Table 1, no. 19) was reported from Tuff 2 of the Rimrock Mountain Group, which is clearly younger than the latite of Uhl Well. Early Oligocene age seems reasonably well established for the Muir cauldron.

Rimrock Mountain Group:

The post-cauldron Rimrock Mountain Group consists of eight ash-flow tuff outflow cooling units, three intercalated basaltic andesite units and sedimentary beds. It is preserved on the northern and northeastern flank of the Muir cauldron, where it dips north and northeast, and on the southern flank. There, dips are irregular because of local faulting but tend to be southerly. Outliers are exposed in isolated hills in Animas Valley.

Mineralogy of ash-flow tuffs of the Rimrock Mountain Group does not follow a simple progression, probably because tuff sheets came from several centers. Tuff 1 is thin (<10 m) and has sparse (<5 percent) phenocrysts of sanidine, minor quartz and traces of plagioclase and biotite. It occurs only in a small area southwest of Pyramid Peak and no correlative unit is known elsewhere. Tuff 2, 40 to 120 m thick, has about 25 percent phenocrysts, mainly of plagioclase with biotite and minor hornblende, sanidine and clinopyroxene. It may correlate with the Tuff of Black Bill Canyon in the Animas Mountains. Tuff 3, up to 150 m thick, contains 5 to 15 percent phenocrysts of quartz, sanidine, calcic oligoclase and minor biotite and a trace of hornblende. It may correlate with the tuff of Gray Ranch in the Animas Mountains. Tuff 4, up to 60 m thick, and Tuff 6, over 75 m thick in places, resemble the crystal-rich (up to 50 percent phenocrysts of oligoclase, sanidine, quartz, biotite, hornblende and traces of clinopyroxene and sphene) Gillespie Tuff of the Animas Mountains. Tuff 6 forms prominent cliffs throughout the region. Its age of 34.2 ± 0.6 (Table 1, no. 15) agrees more or less with the age of 32.9 ± 0.7 (Table 1, no. 13) for Gillespie Tuff of the Animas Mountains and a zircon fission-track age of 36.2 ± 3.2 m.y. for a probably correlative cliff-forming unit in the Coyote Hills (Thorman, 1977). Tuff 5, intercalated between tuffs 4 and 6, is crystal poor, with only about 2 to 5 percent phenocrysts of

sanidine, plagioclase and rare quartz and biotite. No correlative unit is known.

Tuffs 7 and 8 are typical of the high-silica rhyolites that occur at the top of the mid-Tertiary felsic section through much of New Mexico. Both have correlative units in the Coyote Hills. Tuff 7, up to 250 m thick (including pumiceous sandstone at the base and top) has 10 to 15 percent phenocrysts of chatoyant sanidine ("moonstone"), quartz, sparse copper-colored biotite and traces of augite and hornblende. Tuff 8, up to about 100 m thick, has 25 to 35 percent phenocrysts of chatoyant sanidine, quartz, minor oligoclase and a trace of biotite.

Dark-colored rocks, from basaltic andesite to latite in composition and up to 150 m thick, locally separate tuffs 2 and 3, tuffs 6 and 7, and tuffs 7 and 8. Sandstone and conglomerate occur throughout the section, especially between tuffs 6 and 7.

Structure

The inner part of the Muir cauldron is filled with several hundred meters of tuff of Woodhaul Canyon (fig. 4). It forms a broad northwest-trending arch, about 16 km long and up to 11 km wide, cut by longitudinal and transverse faults. The arch may be a resurgent dome. Only the northeast segment of the inner cauldron wall is preserved. Beyond the inner wall, three major ring-fracture zones are marked by concentric outcrop bands of the pre-collapse rhyolite of Jose Placentia Canyon and the post-collapse latite of Uhl Well and rhyolite of Pyramid Peak.

The Rimrock Mountain Group once covered most or all of the Pyramid Mountains. The block that has been preserved at the southern end of the range is within the inner part of the Muir cauldron; the block at the northern end lies in a down-faulted belt within the ring-fracture zone. Both blocks form segments of a broad arch. It is possible that the Rimrock Mountain Group buried the Muir cauldron prior to resurgent doming. Alternatively, arching may have occurred as part of post-volcanic Basin and Range faulting. If so, magma from a resurgent pulse invaded the tuff of Woodhaul Canyon to form intrusive bodies, without causing significant doming.

CENTRAL AND SOUTHERN ANIMAS MOUNTAINS

General Statement

The central and southern part of the Animas Mountains has been mapped by Erb (Erb, 1978, and Ph.D. dissert., in preparation). Stratigraphic terms for the Animas Mountains (fig. 3, columns 5 and 6), if not otherwise defined, are from Zeller and Alper (1965), partly reinterpreted by Elston and Erb (1977).

Tullous Cauldron

A basal andesite, the andesite of Taylor Draw (type locality NWIA sec. 6, T.32S., R.19W.), locally crops out at the base of the mid-Tertiary volcanic section on the western foot of the Animas Mountains. Its eruption was followed by eruption of Bluff Creek Formation and collapse of the Tullous cauldron, named after Tullous Creek in sec. 6, T.32S., R.17W.

Bluff Creek Formation consists of numerous sheets of crystal-poor ash-flow tuff (less than 15 percent phenocrysts of quartz, sanidine, plagioclase) with a maximum aggregate thickness of about 750 m on the west flank of the range and about 350 m on the east flank. Layers of reworked air-fall tuff,

conglomerate and sandstone are intercalated between ash-flow tuff beds. Only fragments of the Tullous cauldron are preserved. To the north, Bluff Creek Formation pinches out abruptly along a fault interpreted as a cauldron wall; the southern edge of the cauldron is buried. The Tullous cauldron did not resurge and no ring-fracture domes are exposed. Clasts of flow-banded rhyolite, of the type that characterizes ring-fracture domes, are common in Bluff Creek Formation on the west flank of the range. Their source, however, is buried under the Animas Valley or the Peloncillo Mountains. The lowest ash-flow tuff sheets in the Alamo Hueco Mountains and Coyote Hills have tentatively been interpreted as outflow sheets of Bluff Creek Formation.

Juniper Cauldron

The resurgent Juniper cauldron (fig. 2, no. 3) has already been described by Elston and Erb (1977). Its fill consists of at least hundreds of meters (no base is exposed) of crystal-rich Oak Creek Tuff (35.2 ± 0.8 m.y.; Table 1, no. 18); the Basin Creek Tuff and associated flows and domes make up most deposits and ring-fracture domes. All of these rocks contain about 35 percent coarse phenocrysts of quartz, sanidine, oligoclase-andesine and shiny black biotite. The central part of the Juniper cauldron was invaded by the Animas stock (34.8 ± 0.8 m.y.; Table 1, no. 17); its ring-fracture zone by the Walnut Wells monzonite porphyry stock (or latite porphyry lava dome; 34.4 ± 0.7 m.y.; Table 1, no. 16) and a quartz monzonite (minimum age 27.2 ± 0.6 m.y.; Table 1, no. 8) encountered by KCM No. 1 Forest Federal well (Thompson, 1977). Caldera-collapse breccias are well developed along the inner cauldron wall. A talus breccia, the Bennett Creek Breccia of Zeller and Alper (1965), accumulated along a topographic caldera wall, which was controlled by an outer ring fracture about 5 km south of the inner caldera wall. The north side of the cauldron has not yet been mapped in detail.

Outflow sheets of Oak Creek Tuff have been identified in the southern part of the Animas Mountains and in the Alamo Hueco Mountains. They may be present in the Coyote Hills, as part of the quartz latite welded tuff member of the volcanics of Pothook.

Animas Peak Cauldron

Only a fragment of the proposed Animas Peak cauldron is now exposed, on the northwest flank of the highest part of the Animas Mountains. Its fill is the tuff of Black Bill Canyon (type locality in sec. 30, T.31S., R.19W.), a crystal-rich and rather mafic tuff which contains up to 50 percent phenocrysts of plagioclase, pyroxene and biotite. The exposed section is about 350 m thick, but the base is covered. The domes of Cedar Hill Andesite of Zeller and Alper (1965) form an arc around the north and northeast side of the proposed cauldron, in the expected position of ring-fracture domes.

Outflow sheets of tuff of Black Bill Canyon have been identified on Gillespie Peak in the central Animas Mountains. Tuff 2 of the Rimrock Mountain Group in the Pyramid Mountains has tentatively been correlated with tuff of Black Bill Canyon. The tuff of Gray Ranch (type locality NE $\frac{1}{2}$ sec. 20, T.31S., R.19W.), a thin crystal-poor pink tuff that lies over tuff of Black Bill Canyon at its type locality, has tentatively been correlated with tuff 3 of the Rimrock Mountain Group and also has been seen in the Alamo Hueco Mountains.

CENOZOIC VOLCANIC GEOLOGY

Cowboy Rim Cauldron

Over 800 m of crystal-rich Gillespie Tuff occupies much of the southwestern part of the Animas Mountains. It resembles the Oak Creek Tuff but has much less biotite and a greater proportion of sanidine to plagioclase. The basin that it occupies has tentatively been interpreted as a source area, the Cowboy Rim cauldron (Erb, 1978). Its northern margin corresponds closely to that of the Tullous cauldron; the western margin is a major fault. No other margins are exposed. The Cowboy Rim cauldron, named after a cliff in the vicinity of secs. 14, 15 and 23, T.31 S., R.18W., does not seem to have resurged. There are no obvious ring-fracture domes or moat deposits. The Gillespie Tuff gradually thins northward to about 300 m and then abruptly to no more than 30 m along the northern cauldron margin. The Center Peak Latite forms a dome within the cauldron and may be a late-stage mafic lava related to the Gillespie Tuff. Because of the lack of obvious cauldron-margin features, the possibility that the Gillespie Tuff originated elsewhere, and merely fills a pre-existing 800-m depression in the Animas Mountains, cannot be precluded. Zeller long ago recognized the regional nature of Gillespie Tuff. Outflow sheets of Gillespie Tuff have been tentatively identified in the Alamo Hueco Mountains, the Pyramid Mountains (tuffs 4 and 6 of the Rimrock Mountain Group) and in the Coyote Hills.

San Luis Cauldron

A possible cauldron is centered on the Sierra San Luis in Sonora and Chihuahua. Reconnaissance has shown the Sierra San Luis to be surrounded on the north and east sides by domes and flows of crystal-poor alkali rhyolite, resembling ring-fracture domes. They extend across the International Border near San Luis Pass and have been named the rhyolite of Packer's Trail (23.0 ± 0.5 m.y.; Table 1, no. 4; type locality sec. 14, T.34S., R.19W.). Pumiceous tuff breccias, resembling moat fill, have been seen in the Mexican part of the range. These rocks lie above outflow sheets of a crystal-poor quartz-sanidine (moonstone) tuff, possibly correlative with the Park Tuff of the Animas Mountains (29.6 ± 0.6 m.y.; Table 1, no. 10) or with the tuff of Skeleton Canyon in the Peloncillo Mountains (younger than 24.3 ± 0.5 m.y.). The interior of the Sierra San Luis is exceedingly rugged and has not yet been studied. Thick masses of silicic rocks dip quaquaversally from the center of the range.

SOUTHERN PELONCILLO AND NORTHERN GUADALUPE MOUNTAINS

Geronimo Trail Cauldron

The geology of the southern Peloncillos south of Skeleton Canyon and the northern Guadalupe Mountains is being mapped by Erb (Ph.D. dissert., in preparation). The stratigraphic succession is summarized in Figure 3, column 7. It is dominated by the Geronimo Trail cauldron, named after the unnumbered road from Cloverdale, N.M. to Douglas, Arizona in T.32S., R.21, 22W. (Erb, 1978). The tuff of Guadalupe Canyon (type section in sec. 20, T.23S., R.12W.) fills the Geronimo Trail cauldron. It is a compound cooling unit with local intercalations of rhyolite lava. The tuff of Guadalupe Canyon contains about 30 percent phenocrysts of quartz, black biotite, sanidine (including chatoyant "moonstone") and plagioclase. Lithic clasts are especially abundant near the top.

The unit is 420 m thick in the cauldron with no base exposed and has not yet been found as outflow sheets.

The southern part of the Geronimo Trail cauldron is in Mexico and has not yet been mapped. In the U.S. part, the cauldron fragment preserved in the Guadalupe and Peloncillo mountains is bordered on the north and east side by three concentric zones of ring-fracture and moat deposits. The innermost zone consists of a remarkable breccia, the breccia of Hog Canyon (type locality SE' sec. 21, T.22S., R.32E.). Its lower part consists of clasts of densely welded latite ash-flow tuff in a welded to partly welded matrix of the same material. This is overlain, successively, by massive and bedded breccia with latite ash-flow clasts with a sandy and tuffaceous matrix. The unit is up to 120 m thick except in sec. 21, T.32S., R.32E., where it thickens greatly, so as to suggest a vent. The second zone consists of a coarsely porphyritic rock, the latite of Outlaw Mountain (type locality sec. 22, T.32S., R.32E.), with abundant large (to 2 cm) phenocrysts of plagioclase and smaller sparse biotite and hornblende. It occurs as flows, as clasts in massive mudflows and as clasts in bedded conglomerate. The outermost zone consists of fine-grained flow-banded rhyolite, the rhyolite of Clanton Draw (type locality sec. 18, T.32S., R.21W.).

The main mass of the tuff of Guadalupe Canyon is locally capped by volcanoclastic sediments and an ash-flow tuff that resembles tuff of Guadalupe Canyon but is coarser and richer in quartz. Considerable thicknesses of similar rock were seen on a traverse of the Mexican part of the Guadalupe Mountains. At present, it is not known whether this tuff is a late-stage product of the Geronimo Trail cauldron, or whether it erupted from a separate center in Mexico.

The Geronimo Trail cauldron was gently domed, probably during resurgence. The tuff of Guadalupe Canyon has been dated at 24.2 ± 0.5 m.y. (Table 1, no. 5). At least two more ash-flow tuff sheets and a dark latite flow unit are younger than the tuff of Guadalupe Canyon. The lower ash-flow tuff, the tuff of Skeleton Canyon, has not yet been correlated with certainty. It contains quartz and "moonstone" sanidine. It somewhat resembles the Park Tuff of the Animas Mountains and (or) the tuff that has been found in the Sierra San Luis. Correlation with Park Tuff is in conflict with K-Ar dates, according to which Park Tuff is appreciably older than tuff of Guadalupe Canyon. Alternatively, it may correlate with part of the Rhyolite Canyon Formation of the Chiricahua Mountains (Enlows, 1955). All of these rocks have compatible stratigraphic positions. Detailed laboratory studies may determine how many moonstone-bearing tuffs are actually present. The upper ash-flow tuff, the Tuff of Dutchman Canyon, is poorly welded and exceedingly crystal poor. It lies between flat-lying conglomerate units, possibly derived from incipient Basin and Range fault blocks.

SOUTH-CENTRAL PELONCILLO MOUNTAINS

Rodeo Cauldron

The south-central segment of the Peloncillo Mountains, from Skeleton Canyon north to lat. 32° N., is being mapped by E. G. Deal. Its geology is dominated by the eastern margin of the newly-discovered Rodeo cauldron, named after the settlement of Rodeo, N.M., in the southwestern part of T.28S., R.21W. This is a preliminary report; the names of units (fig. 3, column 8) and their limits and interpretation are subject to change.

Pre-cauldron rocks consist of Paleozoic limestone (mainly Pennsylvanian Horquilla Formation), Cretaceous orthoquartzite (Mojado or Johnny Bull Formation), late Cretaceous or early Tertiary redbeds and conglomerate (probably equivalent to the Timberlake Formation) and andesite flows. The fill of Rodeo cauldron consists mainly of about 1,000 m of tuff of Black Mountain (type locality sec. 12, T.30S., R.21W., unsurveyed), a compound ash-flow tuff cooling unit of somewhat variable composition. It most commonly contains about 25 to 30 percent phenocrysts of sanidine, quartz and lesser amounts of plagioclase, as well as abundant lithic inclusions of andesite and flow-banded rhyolite. Three zones have been recognized, characterized, respectively, by (1) abundance of biotite, (2) scarcity of biotite, and (3) clots of quartz-free rock, darker than the enclosing tuff. In general, the lower part of the tuff of Black Mountain is densely welded and massive; the upper part tends to be less welded, more variable in mineralogy, and interrupted by cooling breaks.

Cauldron fill of the tuff of Black Mountain has been found in the Chiricahua Mountains of Arizona, in and around Horseshoe Canyon, as well as in the Peloncillo Mountains. The center of the Rodeo cauldron seems to be buried beneath San Simon Valley. Dips of the tuff of Black Canyon suggest that the inner part of the Rodeo cauldron has been domed.

Flows and domes of porphyritic quartz latite of Owl Canyon (type locality sec. 17, T.29S., R.21 W.) intrude and overlie the tuff of Black Mountain, both in the Peloncillo and Chiricahua mountains. It differs from tuff of Black Mountain in larger size of phenocrysts (feldspars to 1 cm) and more mafic composition. Among phenocryst minerals, quartz is absent and hornblende and pyroxene are present. The porphyritic latite of Owl Canyon has been interpreted as part of the fill of the Rodeo cauldron.

A thick complex of rhyolite flows and domes and layered tuff crops out in an arc near the eastern margin of the Rodeo cauldron. It has been named the unit of Antelope Pass. The type locality is in "south" Antelope Pass in sec. 26, T.28S., R.21W. (not to be confused with "north" Antelope Pass, which is traversed by State Highway 9 between Animas and Rodeo). The unit of Antelope Pass has been interpreted as ring-fracture and moat deposits of the Rodeo cauldron. North of "north" Antelope Pass, crystal-poor rhyolite lavas dominate and cover an area of about 50 km². Farther south, at least three major rhyolite flows are interlayered with lithic tuff and sedimentary rocks. In the Chiricahua Mountains, the Cave Creek Formation of Raydon (1952) and Marjaniemi (1969) resembles the unit of Antelope Pass in rock type and stratigraphic position.

The unit of Antelope Pass lies on either the tuff of Black Mountain or on the quartz latite of Owl Canyon. Locally, fault scarps in tuff of Black Mountain were buried by the unit of Antelope Pass. At the head of Big Creek, in the northeast corner of T.29S., R.21W., 3 m boulders of welded tuff, probably tuff of Black Mountain, occur in tuff of the unit of Antelope Pass.

Geologic conditions verge on chaotic near the inferred margins of the Rodeo cauldron, at "north" Antelope Pass and Tank Mountain. The most spectacular map unit here is a megabreccia consisting of blocks of andesite, Cretaceous quartzite and Paleozoic limestone in a tuffaceous matrix, probably a caldera-collapse megabreccia that slumped off the caldera wall during collapse (Lipman, 1976). The most obvious blocks are up to 30 m long, but hills of quartzite and limestone up to 500 m long can be interpreted as exceptionally large blocks. The

megabreccia rests on tuff of Black Mountain (?) and beneath an ash-flow tuff mapped as tuff of Evans Ranch (type locality sec. 32, T.27S., R.20W.). The tuff of Evans Ranch probably is an upper member of the tuff of Black Mountain. Volcaniclastic sedimentary rocks and andesitic to rhyolitic lavas lie between tuff of Evans Ranch and the main unit of Antelope Pass. They probably were erupted from marginal fractures of the cauldron and were preserved in low spots along the irregular caldera wall.

The Rodeo cauldron seems to have formed in the following stages: (1) Eruption of tuff of Black Mountain with concurrent catastrophic caldera collapse and formation of megabreccia; (2) eruption of porphyritic latite of Owl Canyon; (3) doming of cauldron fill, probably as a result of intrusion of a resurgent magma pulse, and faulting; (4) eruption of the unit of Antelope Pass, as magma from the resurgent pulse reached the surface; and (5) faulting. Some faults follow the northerly Basin and Range trends but a west-trending set is more conspicuous.

Rocks that seem to be unrelated to the Rodeo cauldron occur in a number of places. The most widespread is an unnamed crystal-poor moonstone-bearing tuff, of uncertain correlation. It lies above the main mass of the unit of Antelope Pass but beneath flow-banded rhyolite that may be a late stage of the unit of Antelope Pass. North of "north" Antelope Pass, the Weatherby Canyon Ignimbrite of Gillerman (1958) lies beneath this moonstone-bearing tuff and above the unit Antelope Pass. It consists of two cooling units, the lower 60 to 90 m thick, the upper over 200 m thick. The lower unit has about 15 percent feldspar (mainly sanidine) phenocrysts and lacks visible quartz, the upper unit has quartz and feldspar phenocrysts and becomes richer in crystals (to about 30 percent) toward the top. The youngest ash-flow tuff is the tuff of Trail Creek (type locality, sec. 32, T.28S., R.21 W.), a crystal-rich rock (30 to 40 percent sanidine, quartz and biotite) with abundant compressed pumice streaks up to 30 cm long. It locally fills an ancient valley cut into the moonstone-bearing tuff and the unit of Antelope Pass. It may correlate with one of the members of the rhyolite Canyon Formation from the Turkey Creek caldera, Chiricahua Mountains (Enlows, 1955; Marjaniemi, 1969).

Some of the sanidine K-Ar dates determined by Marjaniemi (1969) and recalculated for the new ⁴¹K decay constants give an indication of the age of the Rodeo cauldron. His sample DM-6-67 from Horseshoe Canyon, Chiricahua Mountains, is probably our tuff of Black Mountain and was dated at 26.4 ± 0.7 m.y. DM-5-67, collected near the base of the Weatherby Canyon Ignimbrite, was dated at 26.9 ± 0.8 m.y. and the Chiricahua Tuff was dated at 25.5 ± 0.7 m.y. (DM-3-67) and 25.6 ± 0.8 m.y. (DM-2-67). All these dates were determined on sanidines, which tend to give minimum ages. A minimum age of 26 m.y. for the Rodeo cauldron seems reasonable.

CENTRAL PELONCILLO MOUNTAINS

The central Peloncillo Mountains were mapped by Gillerman (1958); the Kimball mining district, directly north of Gillerman's map area, was mapped by Elston (1963). There has recently been extensive remapping by members of the U.S. Geological Survey (A. K. Armstrong, H. Drewes). The northern part of the Peloncillo Mountains, in Arizona and New

Mexico, has not yet been mapped but will shortly be covered by D. H. Richter (U.S.G.S.).

South of Granite Gap, where U.S. 80 crosses the Peloncillo Mountains, Tertiary volcanic rocks generally dip south. North of Steins Pass, where 1-10 crosses the Peloncillo Mountains, they generally dip north. The arch in between is made up of Precambrian granite, Paleozoic and Cretaceous sedimentary rocks, and granite or quartz monzonite porphyry older than 30 to 31 m.y. (Todd and others, 1975; Hoggatt and others, 1977). These rocks are tightly folded, cut by northwest-trending faults, and intruded by a variety of 26 to 32 m.y. dikes, sills and plugs of granitic to latitic composition (Todd and others, 1975).

In the Kimball mining district, north of Steins Pass, the section is basal andesite overlain by about 350 m of the Quarry Peak rhyolitic complex of Gillerman (1958), which consists of flows and bedded breccias and tuffs. This is locally followed by dark feldspathic flow rock, about 10 m thick, and by about 1,000 m of densely welded rhyolite ash-flow tuff, the Steins Mountain Quartz Latite Porphyry of Gillerman (1958). It contains 25 to 30 percent phenocrysts of quartz, sanidine and plagioclase. It resembles the upper part of Weatherby Canyon Ignimbrite except for a greater abundance of lithic inclusions. Above this tuff are over 100 m of bedded rhyolite tuff and over 500 m of andesite tuff, breccia and flows. These rocks are intruded by crystal-poor rhyolite, including northwest-trending bodies near the Beck mine (sec. 31, T.23S., R.21W.), and north-trending bodies in SW $\frac{1}{4}$ sec. 16 and W1/2 sec. 21, T.23S., R.21 W., near the Volcano Mine. Similar domes, flows and interlayered pumiceous tuff occur as a large complex from Volcano Canyon to the north side of Doubtful Canyon and beyond. The rhyolite complex is of the type commonly associated with ring fractures of ash-flow tuff cauldrons. Conceivably, the entire arch of pre-Tertiary rocks between Granite Gap and Steins Pass was once covered by Weatherby Canyon-Steins Mountain ash-flow tuff and constitutes the deeply eroded resurgent dome of a cauldron. However, the identity of the Weatherby Canyon and Steins Mountain Formations has not been established, and no southern cauldron margin is known at present. Also, the area north of the Kimball district has not yet been mapped.

ALAMO HUECO AND DOG MOUNTAINS

The Alamo Hueco and Dog mountains are being mapped by Reiter (M.S. thesis, in preparation). The range consists of layered mid-Tertiary volcanic rocks (fig. 3, column 4) above a conglomerate with limestone and sandstone cobbles, which resembles the Timberlake Fonglomerate of the central Animas Mountains (Zeller and Alper, 1965). The ash-flow tuffs of the Alamo Hueco Mountains are outflow sheets from sources elsewhere, mainly in the Animas Mountains. The range has been intensely broken by a set of northwest to north-northwest trending faults.

The lowest volcanic unit consists of about 20 m of volcaniclastic rocks, mainly mudflow breccia with clasts of basaltic andesite and fine-grained laminated mudstone, probably lake beds. Basaltic andesite flows are also present. These are overlain by about 30 m of fine-grained basaltic andesite flows, with microphenocrysts of oxidized olivine ("iddingsite"). The first felsic unit has been correlated with the Bluff Creek Formation of the Animas Mountains. It consists of about 150 m of multiple crystal-poor ash-flow tuff cooling units, interlayered (especially in the upper third) with sedimentary beds, thin

basaltic andesite flows and a crystal-rich ash-flow tuff. Near the top of the unit there is a widespread layered monomict breccia, up to 50 m thick, with blocks of Bluff Creek Tuff up to 2 m, in either a sandy or a tuffaceous matrix.

The next highest ash-flow unit is the tuff of Wood Canyon (type locality NW $\frac{1}{4}$ sec. 32, T.32S., R.15W.) which is about 100 m thick but has not been identified elsewhere. It is a compound cooling unit that is transitional in appearance between Bluff Creek Tuff and Oak Creek Tuff. It differs from the Oak Creek Tuff of the Animas Mountains in having a much lower content of quartz and a greater abundance of black biotite. Breccia zones occur near the top of the unit. These rocks could be an early product of the Juniper cauldron. In the Juniper cauldron, the base of the Oak Creek Tuff is not exposed.

Typical Oak Creek Tuff forms the next 200 m of the section. It includes at least three cooling units; cross-bedded tuff at the base of the lower two units may be pyroclastic-surge deposits. The lowest cooling unit is more poorly welded and richer in the lithic inclusions than in the upper two units. Oak Creek Tuff is separated from the overlying Gillespie Tuff by about 5 m of pink lithic tuff that resembles the tuff of Gray Ranch of the Animas Mountains. Gillespie Tuff is about 220 m thick and has 10 to 15 m of vitrophyre at the base and 20-25 m of highly pumiceous, crystal-poor, unwelded tuff at the top. The section is overlain unconformably by up to 125 m of fine-grained vesicular basaltic andesite with an intercalated zone of volcaniclastic sandstone and ash-flow tuff near the top. The ash-flow tuff resembles the moonstone-bearing tuff at San Luis Pass, between the Animas Mountains and the Sierra San Luis.

APACHE HILLS

The geology of Apache Hills was described by Peterson (1976), a revision of the earlier description by Strongin (1958). In spite of pervasive alteration and poor exposures in the low area on the southwest side of Apache Hills, there is evidence for the resurgent Apache Hills cauldron.

Tertiary volcanic rocks (fig. 3, column 1) lie on Cretaceous sedimentary rocks and on klippen of Paleozoic limestone. The main mass of volcanic rocks, the Chapo Formation (type section in sec. 8, T.29S., R.14W.) consists of four members with a total thickness of about 1600 m. The four members consist of lower quartz latite (400 m), andesite (230 m), upper quartz latite (230 m), and a basalt and andesite member (700 m, with the top removed by faulting). The basal unit of the lower quartz latite member has been dated at 30.6 ± 1.1 m.y. Both quartz latite members contain about 50 to 60 percent phenocrysts of plagioclase, potassium feldspar, quartz, opaque oxides and biotite replaced by chlorite and sericite. Because of alteration in the groundmass, the primary nature of the rocks is difficult to discern, but Peterson (1976) interpreted the lower quartz latite and the upper part of the upper quartz latite as lava flows and the lower part of the upper quartz latite as ash-flow tuff.

The andesite member is characterized by labradorite phenocrysts up to 1 cm long, which make up 15 to 25 percent of the rock. The matrix consists of andesine, altered hornblende and augite; abundant secondary epidote coats fractures. The basalt and andesite member consists of fine-grained dark rocks, commonly vesicular. The andesitic part generally has sparse (2

to 10 percent) and small (1 to 3 mm) plagioclase phenocrysts and altered hornblende or augite in the matrix. The basalt part, which forms the upper 200 m of the 700-m unit, contains 5 to 8 percent "iddingsite." Correlative units of the Chapo Formation have not yet been found outside the Apache Hills.

Emplacement of the Chapo Formation was followed by intrusion of a stock, with concurrent doming. The main phase of the stock is unmineralized quartz monzonite, dated at 27.2 ± 0.6 m.y. (Table 1, no. 7). Because of alteration, this must be regarded as a minimum date. Irregular dikes and sills of monzonite, dated at 27.0 ± 0.6 m.y. (Table 1, no. 6), are present in Cretaceous rocks on the southwest side of the quartz monzonite body. Skarn with copper sulfide mineralization occurs at the contact between monzonite and Cretaceous U-Bar Limestone. Subsequently, dikes and plugs of rhyolite, porphyritic rhyolite and bedded rhyolite breccia were emplaced. Most of the exposures of rhyolite are in zones on the northeast and southwest flanks of the Apache Hills and can be interpreted as ring-fracture and moat deposits of a cauldron that was resurgently domed by invasion of the stock. A massive dike of rhyolite porphyry was emplaced along the faulted southwestern margin of the quartz monzonite stock, the Apache fault. A thin but persistent skarn zone developed along contacts of this dike with Cretaceous limestone. Copper was the chief metal mined in the Apache No. 2 mining district. A downfaulted segment of the stock may exist in the subsurface southwest of the Apache fault; rocks on the surface have undergone widespread propylitic and silicic alteration.

COYOTE HILLS

Coyote Hills have been mapped by C. H. Thorman of the U.S. Geological Survey. This summary is based on personal communications and a published map (Thorman, 1977). The range consists mainly of outflow sheets of ash-flow tuff, interlayered with clastic and pyroclastic rocks, and lava flows of intermediate composition. A rhyolite flow, up to 400 m thick, locally appears near the top of the section. The total thickness is about 2,000 m.

Coyote Hills are cut by faults, most of which trend northwest to west-northwest. One fault is younger than the volcanic rocks. It has steep southwesterly dips and displacements from a few meters to 1500 m. Another fault set also dips southwesterly and seems to flatten with depth. Changes in thickness of volcanic units across the second set suggest that it was active during volcanism as well as later (Thorman, pers. comm.).

A composite stratigraphic section is shown in Figure 3, column 3. The lower part of the volcanics of Pothook seems to correlate with the Bluff Creek Formation of the Animas Mountains. The middle part of the volcanics of Pothook, quartz latite welded tuff, probably correlates with Gillespie Tuff of the Animas Mountains; some Oak Creek Tuff may be present also. The upper part of the volcanics of Pothook, lithic tuff unit, seems to correlate with tuff 7 of the Rimrock Mountain Group of the Pyramid Mountains. The uppermost unit, a moonstone-bearing rhyolite ash-flow tuff, resembles tuff 8 of the Rimrock Mountain Group. The two underlying units, the rhyolite welded tuff and the rhyolite lava of Coyote Peak, have not been seen in the Pyramid Mountains.

MIOCENE TO HOLOCENE EVENTS

Events leading to present Basin and Range topography have not yet been adequately dated in Hidalgo County. As far as known, distribution of the mid-Tertiary ash-flow tuff sheets is

not controlled by the present-day configuration of basins and ranges; block faulting that controls present topography began at an unknown time after eruption of the youngest dated sheet, the tuff of Guadalupe Canyon (24.2 ± 0.5 m.y., Table 1, no. 5). Younger sheets exist, but have not yet been dated. The distribution of basalt flows at San Luis Pass dated at 6.8 ± 0.2 m.y. (Table 1, no. 2) is controlled by present topography. Unbrecciated dikes of basalt follow Basin and Range faults in the Animas Mountains but have not yet been dated. A belt of domes of Double Adobe Latite extends from the Animas Mountains across the Animas Valley to the Peloncillo Mountains and was possibly emplaced after the present topography began to take shape. The reported date, 30.7 ± 0.7 m.y., (Table 1, no. 12) seems to be out of stratigraphic order.

Toward the end of mid-Tertiary volcanism, shallow sedimentary basins had formed. As a result, basin-fill conglomerate is interbedded with the undated tuff of Dutchman Canyon in the Peloncillo Mountains and with the upper tuffs (also undated) of the Rimrock Mountain Group of the Pyramid Mountains. The O.K. Bar Conglomerate of Zeller (1967) overlies the youngest rhyolitic rock of the Animas Mountains. It is not known whether these conglomerates are thicker in the present basins than in the ranges, because they are exposed only in the ranges. Consequently, it is not known whether their accumulation was influenced by present Basin and Range structures. Distribution of the upper members of the Rimrock Mountain Group does not seem to have been influenced by Basin and Range topography. Tuff of Dutchman Canyon is so patchy that it cannot be determined whether modern Basin and Range topography affected its distribution.

At the northern end of Hidalgo County, the Gila River has cut into fill of the Animas Valley. The earliest post-rhyolite valley-fill sediments are bedded sandstone, in contrast to overlying coarse fan material derived from Basin and Range fault scarps. The fine-grained fill is interbedded with basaltic andesite dated at 20.9 ± 1.5 m.y. (Elston and others, 1973, recalculated with new ^{40}K decay constants). This date is as close to the beginning of Basin and Range faulting as one can get with present data. Basin and Range faulting continues into the present. There are scarps in Holocene valley fill on both sides of Animas Valley and In San Simon Valley (Reeder, 1957; Gillerman, 1958).

There is at present a gap in dated rocks between early Miocene and Pleistocene. The youngest valley-fill sediments in the Animas, San Luis, Playas, Lordsburg and Hachita valleys are late Pleistocene to Holocene lake beds, stream deposits and alluvial fans. A Pleistocene basalt flow (0.5 ± 0.03 m.y.; Table 1, no. 1) in the Animas Valley erupted from a cone in NE1/4 sec. 15, T.28S., R.20W. Another cone is in San Simon Valley, near Rodeo (NE1/4 sec. 32, T.28S., R.21W.) and four more are about 9 km farther south, in WA sec. 30, T.29S., R.21W. The occurrences near Rodeo seem to be a northern extension of the San Bernardino volcanic field of southeastern Arizona (fig. 5)

The main Basin and Range border faults truncate all earlier structures, including ash-flow tuff cauldrons. In general, the trends of truncating Basin and Range faults are parallel to the trends of the present mountains, northerly in the western part of Hidalgo County (Peloncillo, Guadalupe, Pyramid, Animas, Whitewater and Little Hatchet mountains) and northwesterly in the eastern and northern part (Coyote Hills, Apache Hills, Sierra Rica, Big Hatchet and Alamo Hueco mountains and the

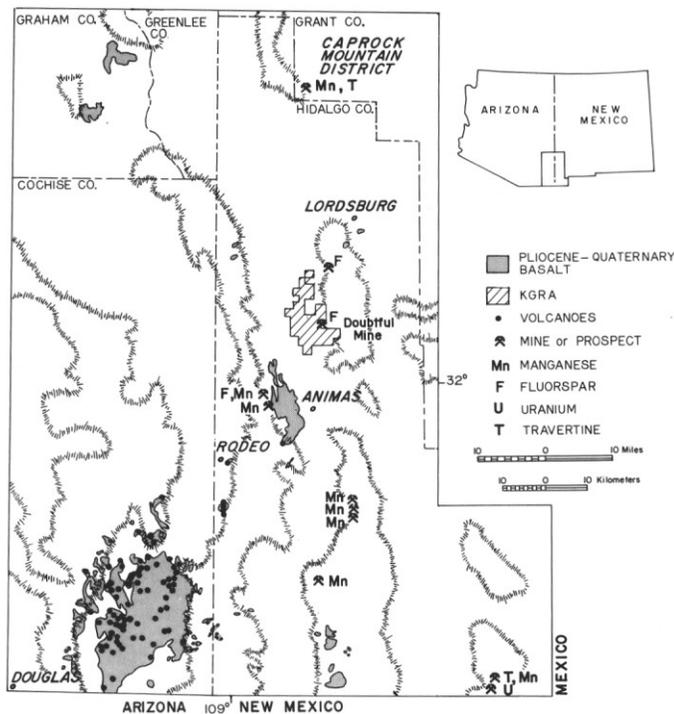


Figure 5. Location of the Lightning Dock KGRA, Pliocene-Quaternary basalts, and veins presumed to be Miocene and younger.

area along the Gila River). Some of the faults that formed the collapse of Oligocene cauldrons and during Laramide activity moved again during Basin and Range activity.

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