BUREAU OF ECONOMIC GEOLOGY
The University of Texas at Austin
Austin, Texas 78712

Peter T. Flawn, Director

Report of Investigations—No. 70

Correlation of Tertiary Rock Units, West Texas

BY

Ross A. Maxwell and John W. Dietrich

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Contents

PAGE

Introduction 1

Acknowledgments 2

Geology and correlation 3

Big Bend National Park 3

Nonvolcanic sequence 3

Black Peaks and Hannold Hill formations 3

Volcanic rocks 4

Canoe Formation 4

Chisos Formation 4

Alamo Creek Basalt Member 5

Ash Spring Basalt Member 5

Bee Mountain Basalt Member 6

Mule Ear Spring Tuff Member 7

Tule Mountain Trachyandesite Member 7

South Rim Formation 9

Wasp Spring Flow Breccia Member 10

Lost Mine Rhyolite Member 10

Burro Mesa Riebeckite Rhyolite Member 10

Source of the volcanic rocks 11

Geographic distribution of the volcanic rocks 12

Southern Davis Mountains 13

Bofecillos Mountains 14

Bofecillos Group 14

Basal conglomerate 15

Chisos Formation 15

Mitchell Mesa Tuff 15

Fresno Formation 16

Santana Tuff 17

Rawls Formation 17

Barrilla Mountains 19

Huelster Formation 19

Star Mountain Rhyolite 20

Seven Springs Formation 20

PAGE

Central Davis Mountains 20
Lower and upper rhyolites 21
Sheep Pasture Formation 21
Merrill Formation 21
Barrel Springs Formation 21
Mount Locke Formation 21
Jones Formation 22
Wild Cherry Formation 22
Medley Formation 22
Goat Mountain Formation 22
Brooks Mountain Formation 22
Rim Rock Country 23
Jeff Conglomerate 23
Gill Breccia 24
Colmena Tuff 24
Buckshot Ignimbrite 24
Chambers Tuff 25
Bracks Rhyolite 25
Capote Mountain Tuff 25
Brite Ignimbrite 25
Petan Basalt 25
Perdiz Conglomerate 26
Chinati Mountains 26
Chinati Peak quadrangle 26
Pinto Canyon area 27
Shafter area 27
Correlation of volcanic rocks near the Chinati Mountains 28
Conclusions 29
References 30
Index 32

Illustrations

PLATE (in pocket)—

I. Correlation of volcanic rocks in Big Bend Region of Texas.

Correlation of Tertiary Rock Units, West Texas

Ross A. Maxwell[1] and John W. Dietrich[2]

INTRODUCTION

Tertiary rocks, including sandstone, conglomerate, shale, pyroclastics, tuff, and lava, are preserved in Big Bend National Park and in a much larger area to the west and northwest. Some of the rocks have distinctive characteristics that enable recognition by their lithology. Others are distinctly dissimilar, although they may have been deposited about the same time. This dissimilarity may be in part due to a different source of material, as the normal behavior of the volcanic rock is to thin and disappear away from the source; also the volcanic rocks disappear by nondeposition and in other places by erosion, so that the casual observer would be unable to develop an orderly stratigraphic sequence over a large area. It was natural that the early investigators named and described rock units from a physical feature within the area where they worked, and commonly, due to lack of time, they did not examine the rocks in adjacent areas. This has led to much confusion in stratigraphic correlation. Multiple names have been applied to the same rock unit in different areas; the same name has been applied to different rock units because of lithologic similarity. Some rock units have distinctive lithological characteristics and can be traced for tens of miles along the outcrops. Other formations have distinctive vertebrate fossils and, to a less extent, invertebrate fossils. Also, some lavas have distinctive paleomagnetic characteristics. It is granted that these differences are only tools with which to work, but by using all the criteria a reasonable correlation can be formulated. Plate I is a possible correlation of the Tertiary volcanic rocks in West Texas.

The Tertiary rock sequence accumulated on a highly irregular surface eroded on Cretaceous and Paleozoic formations and in many places completely covered the older rocks west of a general line drawn along the trends of the Guadalupe, Delaware, Apache, Glass, Del Norte, Santiago, and Sierra del Carmen ranges. Ash-flow tuffs and lava beds ranging in composition from rhyolite to basalt are irregularly distributed throughout a thick section of water-laid clastic sedimentary rocks that range from siltstone to boulder conglomerate. Locally, a few layers of eolian sandstone record episodes of a windy desert environment, and a few lenses of freshwater limestone mark the sites of temporary lakes.

The lava and pyroclastic rock layers in this sequence came from several centers of volcanic eruption, each probably consisting of one or more vents. Detritus eroded from topographically high outcrops of volcanic rocks was deposited at lower elevations and was commonly mixed with debris from nonvolcanic rock outcrops from perhaps Precambrian and unquestionably Paleozoic, Cretaceous, and Early Tertiary formations. The conglomerates flanking the Solitario contain many cobbles of black Maravillas Chert, Caballos Novaculite, and Lower Cretaceous limestone and chert. Conglomerates in the Chisos Mountains contain limestone and igneous debris that may be, in part, from Upper Cretaceous cobbles of Paleozoic and Lower Cretaceous intrusions and also from Early Tertiary

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intrusions and lavas. Thus in West Texas we find a unique succession of lava, ash-flow tuff, and sedimentary rocks deposited in topographically low areas and around centers of eruptive activity. Mappable units near one center of eruptive activity commonly differ from those deposited near another center, whether the centers be only a few miles or several tens of miles apart. In most places the volcanic rock interfingers with other volcanic units and also with the sedimentary rock layers.

The law of superposition and lithostratigraphic correlation supported by vertebrate remains and potassium-argon dating are the most practical tools for determining the relative age of most volcanic rocks in West Texas. The writers have found that the Mule Ear Spring Tuff, Tule Mountain Trachyandesite, and Mitchell Mesa Rhyolite (ash-flow tuff) (with its equivalent, the Brite Ignimbrite) are the most useful units for use as stratigraphic marker beds for determining the relative ages of rocks, the age of various geologic episodes, and the interpretation of structure.

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The writers are grateful to many workers who have published reports on the Tertiary volcanic rocks of West Texas. Special thanks are extended to Professors Stephen E. Clabaugh, Ronald K. DeFord, John A. Wilson, and Samuel P. Ellison, Jr., of The University of Texas at Austin, for helpful comments and criticism and to John F. McKnight, whose work on the Bofecillos Mountains (1968, 1970) was also helpful.

GEOLOGY AND CORRELATION

BIG BEND NATIONAL PARK

In Big Bend National Park, Maxwell et al. (1967) broadly divided the Tertiary rock sequence into a lower nonvolcanic unit and an upper volcanic unit. The lower nonvolcanic unit is mostly sandstone, conglomeratic channel sandstone, and clay of the Black Peaks (Paleocene) and Hannold Hill (Lower Eocene) Formations. The upper volcanic units consists of (1) the Canoe Formation, composed of sandstone, conglomeratic channel sandstone with igneous pebbles, tuffaceous clay and mudstone, vitric tuff, and some lava of Middle Eocene age; (2) the Chisos Formation, a unit of coarse massive conglomerate, tuffaceous sandstone, tuff, and several lavas, not all precisely dated but mostly Upper Eocene age; and (3) the South Rim Formation, largely of lava and flow breccia, probably of Oligocene or younger age (Maxwell et al., 1967, table 6).

NONVOLCANIC SEQUENCE

Black Peaks and Hannold Hill Formations

Mammalian remains found in some of the nonvolcanic rocks have made it possible to date accurately the Black Peaks (Paleocene) and Hannold Hill (Lower Eocene) Formations (Wilson et al., 1952, and Maxwell et al., 1967). They are the oldest known Tertiary deposits in West Texas and have not been found outside of Big Bend National Park. In the Park, the Black Peaks Formation (864 feet thick) was deposited on an erosion surface in the Javelina Formation of uppermost Cretaceous age. It and also the Hannold Hill Formation overlap the Cretaceous rocks toward the west; Tertiary rocks probably did not cover, or were not deposited over, the Cretaceous rocks west of the Terlingua Arch. The Black Peaks is about 50 percent yellowish-gray and whitish sandstone that in addition to the mammalian remains contains much fossil wood and a few fresh-water clams and snails. The interbedded clay is identical in color to some of the clay in both the Aguja and Javelina Formations. The Hannold Hill, about 835 feet thick, is predominantly a clay formation but contains conglomerate and channel sandstone deposits that in a few places are fossiliferous. The clay is identical in color to most of the clay in the Javelina Formation. It is difficult to recognize and to separate either of the Tertiary formations from the underlying Cretaceous rocks except where they contain identifiable fossils. Geologists who are familiar with the continental Upper Cretaceous deposits in other parts of Brewster and Presidio counties are not suprised that the early workers assigned a Cretaceous age to these rocks or that later workers continued to use a Cretaceous designation until vertebrate paleontologists discovered that in some places the rocks contained Tertiary mammalian remains (Wilson et al., 1952).

In Big Bend National Park, there is an angular unconformity between the top of the nonvolcanic Hannold Hill Formation and the basal volcanic Canoe Formation; in some places erosion has removed up to 338 feet of the Hannold Hill before the Canoe Formation was deposited. The basal Canoe beds are a yellowish, conglomeratic sandstone that contains pebbles of novaculite, chert, igneous rock, and in some places concretions probably from the underlying Hannold Hill Formation. At one place there is what appears to be a soil zone at the base of the Canoe sandstone. Above the sandstone is an interval of clay in which the amount of clay increases upward in the section; the upper beds are predominantly tuff. In some places there are basalt flows, but so far as is now known, all of the lava has local distribution. This suggests that the Marathon or Solitario areas and/or Persimmon Gap were high and that erosion furnished the novaculite and chert pebbles. The source of the igneous pebbles has caused some speculation, but K/A dates of the sill at Mariscal Mountain and Cow Heaven anticline (Maxwell et al., 1967) indicate that these intrusions are 50 to 70 million years old. This suggests that erosion along the top of the Mariscal Mountain anticline could have been a source for the igneous pebbles.

VOLCANIC ROCKS

Canoe Formation

The Canoe Formation is 1,160 feet thick in Tornillo Flat where two basaltic lavas are exposed. There is no clear break between the Canoe and the overlying Chisos Formation in the eastern slope of the Chisos Mountains. This is what Udden (1907, p. 65) referred to as a zone of change between his Tornillo Clay (Cretaceous) and the Chisos Beds (Tertiary). On Tornillo Flat the Canoe above the lava has been accurately dated by mammalian remains as Middle Eocene age. It has been suggested that there is not a break between the Canoe and the Chisos Formations on the eastern side of the Chisos Mountains, that parts of the Chisos Mountains were high during the Laramide revolution, and that the basal basalt in the Castolon area is actually equivalent to the local basal outcrops in the Canoe Formation exposed on Tornillo Flat (Maxwell et al., 1967). This must still be proven because the basalts are not similar, and there is a distinct difference between the sedimentary rocks on the eastern side of the Chisos Mountains (Maxwell et al., 1967, Pls. IX and X) and those on the western side of the Chisos Mountains in areas that were probably high during the Laramide revolution. Perhaps the sedimentary deposits and also the Tertiary lavas slipped around the northern end of the Chisos Mountains "high" and were deposited in a low area east of the Terlingua Arch. In any case, the Alamo Creek Basalt that Maxwell et al. (1967) mapped as the base of the Chisos Formation west of the Chisos Mountains does crop out at Lajitas Mesa which is west of the Terlingua Arch. For this correlation, however, the Alamo Creek Basalt may not be important because it does not seem to be a key bed extending across the country; it does, however, appear to be the oldest basalt and the base of the Chisos Formation in most of Big Bend National Park.

Chisos Formation

The Chisos Formation includes about 3,600 feet of massive coarse conglomerate, coarse-grained sandstone, fine- to medium-grained tuffaceous sandstone, tuffaceous clay and mudstone, tuff, indurated tuff, and lava. The thickest section of Chisos Formation is along the eastern side of the Chisos Mountains (Maxwell et al., 1967, Pl. X) and in the area south of the South Rim. Here the section, about 2,000 feet thick, is mostly fine clastic rocks including fine-grained tuffaceous sandstone. Most beds are light gray, well-stratified layers 1 to 2 feet thick. Above this, the rocks are mostly gray or bluish-gray sandstone with interbeds or lenses of tuff or tuffaceous mudstone. The uppermost 200 feet is coarse sandstone interbedded with massive conglomerate. Some of the conglomerate contains cobbles of Comanchean limestone and perhaps Paleozoic limestone as much as 4 inches across and lava boulders 1 foot in diameter. Lava beds have not been found in this sequence.

A different lithology of the Chisos Formation occurs southwest and west of the higher Chisos Mountains. Here the sequence is mostly tuffaceous clay, tuff, and lava. Several of the lava flows in this facies have only limited extent and are probably of local origin, but four flows and one indurated tuff bed have distinguishing characteristics, more extensive distribution, and are designated by named members. In ascending order, these are (1) Alamo Creek Basalt, (2) Ash Spring Basalt, (3) Bee Mountain Basalt, (4) Mule Ear Spring Tuff, and (5) Tule Mountain Trachyandesite (Pl. I). The five members are interbedded with variable thicknesses of clay and mudstone, tuffaceous clay, tuff (in part well indurated), tuffaceous sandstone, coarse massive conglomerate, locally very thick lenses of fanglomerate, and some fresh-water limestone. One or more erosion surfaces occur between each pair of the members, and in some places older units are overlapped by younger members. At all places southwest, west and northwest of the Chisos Mountains where the Cretaceous-Tertiary contact is exposed, the Alamo Creek Basalt rests on an erosion surface in the Javelina Formation (uppermost Cretaceous); the thickness of the underlying Javelina ranges from 50 to 900 feet.

Alamo Creek Basalt Member.—The Alamo Creek Basalt Member is named from Alamo Creek west of the Chisos Mountains where the lava is exposed almost continuously from near Dawson Creek southward to the Rio Grande and locally in Mexico south of the Rio Grande. It is the lowest unit of the western facies of the Chisos Formation and apparently does not extend east of the structural and topographic barrier that is near a line drawn from the high part of the central Chisos Mountains southeastward along the crest of the Cow Heaven anticline. This barrier seems to have arrested the eastern movement of the Alamo Creek Basalt flow and perhaps also accounts for the absence of Lower Eocene and Paleocene age rocks in the western part of Big Bend National Park. Uplift and erosion along this line are indicated at the north end of the Cow Heaven anticline where all the Javelina Formation and about one-half of the Aguja Formation were eroded, and about 500 feet of the basal Chisos Formation was not deposited before the Tertiary sediments were laid down across the erosion-beveled edges of strata belonging to the Javelina and Aguja Formations. At Tortuga Mountain, Chisos beds above the Alamo Creek Basalt lie on about 200 feet of Canoe Formation which truncates middle Aguja beds. Similar conditions were observed in the Basin of the Chisos Mountains.

Most of the Alamo Creek Basalt is a fine-grained, hard, dark rock, but locally there are small phenocrysts. The base is usually scoriaceous and commonly contains inclusions that appear to have been picked from the underlying bedrock. At one place along Blue Creek, near Kit Mountain, the basal lava bed is about 4 feet thick and is overlain by a tuffaceous mudstone that looks like the Javelina Formation.

The thickest exposures of the Alamo Creek Basalt are in the Round Mountain—Kit Mountain—Cerro Castellan area where the Alamo Creek is 150 to 200 feet thick. The lava thins rapidly southward into Mexico and northward and northwestward across the Park. Part of the thinning is due to erosion as there are channels and a well-developed erosion surface on top of the lava at some places. Here above the Alamo Creek Basalt also is a conglomerate bed that some geologists designate as Jeff Conglomerate. The vent from which the lava came has not been located, but thicknesses suggest that it may have been in the southwestern part of the Park or in nearby Mexico.

Potassium-argon dates for the Alamo Creek Basalt range from about 38 to 42 million years. Paleomagnetic properties in eight samples from three localities agree with the present dipole field. However, two samples from the oldest flow on the northeast corner of Black Mesa, mapped as the Alamo Creek (Maxwell et al., 1967), show divergent data; this difference has not been explained.

Ash Spring Basalt Member.—The second lava above the base of the Chisos Formation is the Ash Spring Basalt, named from Ash Spring on the northwest side of the Chisos Mountains where the lava forms a massive ledge. At most places the lava is conspicuously porphyritic with phenocrysts of plagioclase; some are more than half an inch long. The coarse porphyritic texture is characteristic throughout the eastern extent of the outcrop area, but westward the phenocrysts are smaller and less abundant. Where the porphyritic texture is present the rock is lithologically similar to the "birds-eye" subdivision of the Rawls Formation that crops out in and near the Bofecillos Mountains toward the northwest. In the northwestern part of Big Bend National Park where the porphyritic texture is less prominent (typically exposed at Tule Mountain), the Ash Spring consists of two or more flows. The upper part of each flow is vesicular and frothy, but the middle part is a dense porphyritic basalt with plagioclase phenocrysts only 1/8 to 1/4 inch long. At all exposures, the basal 10 feet of the flow is scoriaceous, and many of the openings are filled by secondary minerals.

The Ash Spring Basalt is about 200 feet thick north of the Chisos Mountains but thins in all directions away from that area. At all localities studied, where the Ash Spring is 50 or more feet thick it consists of two or more flows. The basal unit truncates older Chisos beds and at some places the lava occupies old stream valleys. The upper lava surface was also eroded prior to deposition of younger Chisos beds. The post-Ash Spring erosion no doubt accounts for some of the variation in thickness, but there is also believed to be a general thinning of the lava away from the Ash Spring area.

Potassium-argon dates indicate that the Ash Spring Basalt is about 32 to 34 million years old. The lava is so strongly magnetized that it affects field readings with a Brunton compass; this is a recognizable characteristic of the unit at all outcrops examined. The magnetic field determinations from 21 samples at 7 localities show a wild scatter of dipole directions and considerable variation between samples at the same location. This scatter seems to be characteristic of the lava unit. The principal exception to the scatter pattern was obtained from samples at a measured section on the north side of the Chisos Mountains where the magnetism was fairly consistent in an inverse direction to the normal dipole field and similar in direction to the overlying Bee Mountain Basalt.

Bee Mountain Basalt Member.—The Bee Mountain Basalt, named from Bee Mountain on the western side of the Chisos Mountains, is the most extensive lava member in the Chisos Formation. It is present at many localities southwest, west, and northwest of the higher Chisos Mountains and can be physically traced into the higher Chisos Mountains peaks where it is the lowest basaltic lava in that area. This lava unit also extends southward into Mexico, northwestward into the foothills of the Bofecillos Mountains, and is present in the Black Gap area east of the Sierra del Carmen. The Bee Mountain Basalt indicates the first widespread distribution of volcanic flow from the assumed vent in or near the Chisos Mountains.

The basalt is mostly fine to medium grained, consisting of various flows that are conspicuously scoriaceous or vuggy along the contacts. Many of the scoriaceous openings are filled by secondary minerals which produce a mottled appearance. At Bee Mountain, the type locality, several flows are separated by 1- to 6-inch tuff beds and vesicular areas. The basal 1 to 3 feet of each flow is brecciated and some fractures are filled by quartz, including some well-developed crystals. At other places (Casa Grande) an intermediate zone up to 24 feet thick consists of tuffaceous clay or fine-grained sandstone, but in most exposures this central zone is coarsely scoriaceous lava and the many cavities are filled with secondary minerals.

The Bee Mountain Basalt is about 25 to 80 feet thick in the higher Chisos Mountains but the thickness increases southwestward to over 500 feet in the slopes of Cerro Castellan. Here the lava is conspicuously scoriaceous, many cavities are as much as 12 inches across, and most are filled by secondary minerals including quartz and calcite; there is also irregular flow structure.

The Bee Mountain Basalt lies on an erosion surface in the Chisos Formation. Commonly it rests on a conglomerate or conglomeratic coarse-grained sandstone that ranges from 20 to 200 feet thick. This clastic deposit seems to have filled some of the lowland or channel areas and provided a surface over which the lava moved to cover extensive areas. An erosion surface is also present at the top of the lava. At some places stream valleys are cut tens of feet deep into the lava. At Goat Mountain, a stream cut its channel about halfway through the Bee Mountain Basalt; farther southwest toward Cerro Castellan the same stream eroded completely through the Chisos Formation. At Tule Mountain, northwest of the Chisos Mountains, the Bee Mountain Basalt was completely breached, and the channel is now filled by a fanglomerate boulder deposit that locally is up to 900 feet thick.

Potassium-argon dates from samples collected from the Bee Mountain Basalt range from 21.7 to 23.5 million years. These data are erroneous because they indicate a younger age than is shown for the overlying Mule Ear Spring Tuff and Tule Mountain Trachyandesite (*see* pp. 7–9). Paleomagnetism studies indicate that the Bee Mountain is characterized by inverse magnetism, but there is considerable scatter of dipole directions especially in the upper flows of the unit.

Mule Ear Spring Tuff Member.—Tuffaceous rocks are common throughout the Chisos Formation but are most abundant west and southwest of the highest mountain peaks. One of the tuffs is uniform in thickness and lithology and can be traced across the southwestern Park area; it is present in Mexico and extends northwestward into the Bofecillos Mountains and northward to where it disappears on the flank of the Solitario. It is named Mule Ear Spring Tuff Member from Mule Ear Spring southwest of the Chisos Mountains.

In most places the rock is 8 to 12 feet thick; it is punky ash to very hard, brittle, silicified tuff with conchoidal fracture. Freshly broken surfaces are pinkish salmon, brick red, and yellowish gray to bluish gray but the rock weathers brown. In steep slopes the Mule Ear Spring Member forms a conspicuous, persistent, brick-red band along the outcrop. Where the tuff is silicified and resists erosion, it commonly underlies a prominent dip slope or forms a prominent cliff or mesa.

The Mule Ear Spring Tuff truncates middle Chisos beds and probably originated as an ash fall that blanketed an erosion surface of low relief. In some places it rests on the Bee Mountain Basalt Member, but in other places it is separated from that member by about 125 feet of tuffaceous beds in the Chisos Formation. At Tule Mountain it lies directly on a fanglomerate deposit that fills an eroded valley cut through the Bee Mountain Basalt. Normally tuffaceous beds and lava units overlie the Mule Ear Spring Tuff, but at most places close to the highest Chisos Mountains peaks, the overlying tuffaceous rocks have been eroded and the next younger lava unit, the Tule Mountain Trachyandesite, lies directly upon the Mule Ear Spring Tuff. At some places along the west side of Burro Mesa, erosion has cut through the Mule Ear Spring Tuff, and overlying Tule Mountain rests on the underlying Bee Mountain Basalt. Potassium-argon dates from samples of the Mule Ear Spring Tuff indicate an age of about 31 to 32 million years.

Tule Mountain Trachyandesite Member.—The youngest named lava unit in the Chisos Formation is the Tule Mountain Trachyandesite Porphyry, named from Tule Mountain. It is a brown porphyritic trachyandesite that when once studied can be recognized by its lithological characteristics in all outcrops. The validity of field recognition of this unit has been demonstrated by thin-section studies and chemical analyses. This member crops out at many places southwest, west, and northwest of the Chisos Mountains, and the rock has been identified tens of miles toward the northwest by its lithologic, chemical, and petrographic characteristics.

In hand specimen the trachyandesite has a gray or brownish-gray, fine-grained groundmass which encloses feldspar phenocrysts as much as half an inch across. Most of the surfaces are brown or reddish brown. The groundmass is slightly darker than the plagioclase phenocrysts, which produces a distinctive spotted pattern. The member consists of several flows, but the flow units weather alike so that the outcrop commonly forms a thick massive ledge. Where one or more flows are recognized the contacts between flows are purplish, slightly scoriaceous, and in some places tuffaceous. At some places where several flows can be recognized, the lava units weather to produce blocky, step-like ledges; these can be seen along Smoky Creek in Big Bend National Park. The upper flows are commonly dark, or almost black, and they look a great deal like the "birds-eye" of the Rawls Formation but are much older and are especially tough to break with a geologic hammer.

The Tule Mountain Trachyandesite Member ranges in composition from trachyandesite (containing andesine) to trachybasalt. Trachybasalt occurs only on the southwest and northwest sides of the Chisos Mountains, which may suggest gradation in chemical, petrographic, and lithologic characteristics; however, the trachybasalt is found only in the uppermost flow of the unit, which may be of local extent. The most abundant rock contains 15 to 20 percent of calcic andesine phenocrysts, 2 to 5 percent of smaller phenocrysts or microphenocrysts of clinopyroxene, about 1 percent of magnetite-ilmenite phenocrysts, and a trace of about 0.5 percent iddingsite (after olivine) phenocrysts. The principal constituent of the groundmass is alkali feldspar, which occurs in laths, commonly with cores of sodic andesine, grains of clinopyroxene and magnetite-ilmenite, and prisms of apatite. The typical groundmass is generally fine grained or aphanitic. The phenocrysts are as much as 6 by 10 mm and are characteristically square. Altered mafic microphenocrysts form small dark grains or aggregates in the coarse-grained rocks.

The trachyandesite is remarkably uniform mineralogically. Nevertheless, a few specimens contain a trace of interstitial quartz; a single specimen has a trace of brown amphibole, fluorite has been tentatively identified, and a few samples contain analcite. The plagioclase occurs as individual crystals and glomerocrysts. In most specimens the groundmass forms a regular pattern that resembles a perthitic intergrowth. Many plagioclase phenocrysts are thinly mantled by alkali feldspar and many are zoned; some zones are sodic labradorite but the average plagioclase is in the andesine range.

The trachybasalt differs from the more siliceous trachyandesite mainly in amount rather than kind of minerals. The plagioclase of the trachybasalt phenocrysts is largely sodic labradorite, the groundmass plagioclase is more abundant and normally more calcic, and the microphenocrysts of clinopyroxene, magnetite-ilmenite, and iddingsite make up about 15 percent of the rock.

The Tule Mountain Member is the most prominent lava unit in the Chisos Formation and because of its uniformity of mineralogic, chemical, and physical characteristics is the most easily identified. The maximum measured thickness is 348 feet but it thins or is missing by erosion in some places. The base of the lava is irregular and rests on an erosion surface in the Chisos Formation. At Kit Mountain, southwest of the highest Chisos Mountains peaks, 300 feet of tuffaceous Chisos beds separate the Tule Mountain and Mule Ear Spring Tuff Members. At Tule Mountain, northwest of the Chisos Mountains, the Tule Member lies directly on the Mule Ear Spring Tuff. Locally along the west side of Burro Mesa the Mule Ear Spring Tuff has been eroded and the Tule Mountain rests on the Bee Mountain Basalt; farther north it overlaps the Bee Mountain Basalt. At Sierra de Chino, south of the Chisos Mountains, it overlaps Chisos beds down to a level about 100 feet above the top of the Alamo Creek Basalt.

Post-Tule Mountain Trachyandesite erosion also affected the thickness of the lava unit. Erosion along the old stream valley southwest of Goat Mountain locally removed all of the Chisos Formation. A similar valley, probably a tributary, exposed at Kit Mountain, cut through the Tule Mountain Trachyandesite. The lava is absent, presumably removed by erosion, along the eastern and southern flanks of the higher Chisos Mountains peaks. Along the western side of Burro Mesa, however, about 400 feet and on the north side of the Chisos Mountains about 100 feet of Chisos beds overlie the trachyandesite and separate it from the overlying South Rim Formation.

Potassium-argon dates for the Tule Mountain Member range from 28.4 to 28.8 million years. The results from tests of 14 samples from 6 localities showed considerable scatter of magnetic vectors as compared with the direction of the earth's present magnetic field. The scatter may be due to sampling from different flows or different levels in the same flow, or possibly there was differential movement of consolidated parts of a thick lava that hardened at temperatures below the average for the Curie point of the entire mass. Alternatively the rock may be magnetically unstable so that the magnetic field of samples from some individual flows is drifting back toward the direction of the earth's present magnetic field.

The Chisos Formation has not been precisely dated. Mammal and turtle remains, fresh-water snails, and wood have been collected, but not all of the specimens are diagnostic. The mammalian remains were collected from a brownish mudstone bed, 27 to 33 feet thick, exposed in the banks of Blue Creek above the Alamo Creek Basalt about 1 mile west of Cerro Castellan. They include a partial *Uintacyon* sp. skull and partial skeleton, several tooth fragments, a considerable quantity of turtle skeleton elements, and miscellaneous bone scrap. The assemblage is Late Eocene age. Fresh-water gastropods were found in the Chisos Formation at several localities—Kit and Round Mountains and Casa Grande—but they indicate only that the age of the rocks is Tertiary. Fossilized wood is present but not common in the Chisos Formation and is similar in appearance to that found in the older Tertiary outcrops on Tornillo Flat. The eastern facies of the Chisos Formation overlies the Middle Eocene Hannold Hill Formation, which suggests Late Eocene age.

Potassium-argon determinations are available for dating some of the lava members. The results are included in the description of each unit. All of the age determinations were for whole rock analyses, and the average of ages refers to the range of possible analytical errors. The anomalous radiometric age of the Bee Mountain Basalt is considerably younger than is compatible with its stratigraphic position, but the petrography of this lava suggests the reason. The principal constituents of the analyzed specimens appear to be unaltered, but most of the potassium was probably contained in a dark green, cryptocrystalline, formerly glassy, groundmass representing the final alkalic magmatic fraction. Considerable argon leakage *is* known to take place during devitrification of material in this kind of sample, and leakage has probably taken place in the Bee Mountain Basalt to produce an abnormally young age. Considering all data available at present, it appears that most of the rocks of the Chisos Formation are Upper Eocene or Oligocene.

South Rim Formation

The South Rim Formation is highly variable in thickness and for the most part crops out only in places where the rocks could resist erosion or where the outpourings were sufficiently thick and resistant that erosion has not removed them. It is the uppermost Tertiary volcanic formation in Big Bend National Park and consists of thick lava and flow breccia bodies, conglomerate, sandstone, tuff, and tuffaceous mudstone. The base of the South Rim Formation is everywhere unconformable on older rocks and is in contact with rocks that range from the highest known part of the Chisos Formation down to the Pen (Upper Cretaceous) Formation. The South Rim

Formation has not been found outside the boundaries of Big Bend National Park; however, potassium-argon dates suggest that some of the formations that crop out toward the northwest are about the same age.

The basal South Rim unit is mostly brown rhyolite that crops out only in the highest Chisos Mountains peaks where it ranges from 10 to about 800 feet in thickness. The rock ranges from dark plagioclase-bearing lava with a glassy base to light felsite. Some beds are porphyritic, some have flow structures, and a few contain inclusions. Above these basal deposits are three units that have sufficiently distinctive mineral composition and physical character to justify formal names. In ascending order these are (1) the Wasp Spring Flow Breccia Member, (2) the Lost Mine Rhyolite Member, and (3) the Burro Mesa Riebeckite Rhyolite Member.

Wasp Spring Flow Breccia Member.—The Wasp Spring Member is predominantly a flow breccia unit. Except in the higher Chisos Mountains peaks, the Wasp Spring is the basal member of the South Rim Formation. It is about 100 to 350 feet thick in the high Chisos Mountains area, it normally thins rapidly away from the highest peaks, and it is commonly less than 30 feet thick in the peripheral areas of the present outcrop. In addition to the flow breccia units, the member also contains rhyolitic lava, coarse massive conglomerate, and coarse sandstone. Most of the rock, especially the flow breccia units, weathers to a characteristic yellowish-orange color, and erosion formed many overhanging cliff shelters or small shallow caves; most of the rock columns in the Chisos Mountains, such as the "Cowboy Boot" and the "Water Tower" on Emory Peak, are formed by erosion along joints in this formation.

Lost Mine Rhyolite Member.—The overlying Lost Mine Rhyolite Member is mostly a reddish rhyolite porphyry but parts are nonporphyritic; some are glassy and have complex flow banding. The latter range in color from yellowish gray to greenish gray to bluish black. This member is recognized only in the highest part of the Chisos Mountains, where it caps several of the prominent peaks, such as Lost Mine Peak from which it was named.

Burro Mesa Riebeckite Rhyolite Member.—The Burro Mesa Riebeckite Rhyolite Member was named from Burro Mesa, where it forms the highest peak on that mesa's western rim. The Burro Mesa Member caps Emory Peak in the Chisos Mountains and several peaks and ridges southwest of the Chisos Mountains. The rock is highly siliceous, medium-grained, gray rhyolite with quartz phenocrysts in a riebeckite-bearing matrix. The base is finely crystalline to glassy; the glass exposures are in the basal flow on the southwest side of Emory Peak and at several places southwest of the Chisos Mountains. Flow structures are common at some places in the basal 50 feet of the unit where the riebeckite crystals form bands parallel to the flow structure. This feature is well exposed at Trap Mountain and in a small canyon that cuts through the north end of a fault-block ridge about 3 miles toward the southwest.

The Burro Mesa Riebeckite Rhyolite Member normally overlaps the Lost Mine Member and at most places is in contact with the Wasp Spring Member. This contact is exceptionally well exposed at a "pour-off" along the west side of Burro Mesa. Southwest of the Chisos Mountains the Burro Mesa Member overlaps not only the Wasp Spring Member but all of the Chisos Formation, and locally the lava is in contact with the Javelina (uppermost Cretaceous) Formation.

The South Rim Formation, with the Burro Mesa Riebeckite Member at the top, is the youngest of the Tertiary volcanic rocks exposed in Big Bend National Park. Not all the rocks are precisely dated; fossils have not been found, but the rocks overlie the Chisos Formation, which is probably Upper Eocene or Oligocene age. Potassium-argon age determinations for the Burro Mesa range from 29.4 to about

30 million years. Paleomagnetism tests for the Wasp Spring showed considerable scatter of points when plotted on the Schmidt net; this scatter might be expected because of the flow breccia character of the rock. Most samples, however, are fairly consistently magnetized in the direction of the earth's present magnetic field. The Lost Mine Member is mostly magnetized in the direction of the earth's present field, and the Burro Mesa Member is consistently magnetized in that direction.

Source of the Volcanic Rocks

The total aggregate thickness of all volcanic rocks now exposed in Big Bend National Park is about 3,600 feet. Their source presents several problems. It is generally agreed that the central Chisos Mountains were a center of volcanic activity, but large vents have not been recognized, and there is a wide variation in the mineralogical and chemical composition of the rocks. This suggests multiple sources, or extrusion of basic lavas in the early epochs followed by explosive eruptions and extrusion of more acid materials. An easy explanation is that the volcanic rocks came from fissure vents that now have been obliterated by erosion, later uplift and erosion, or that the vents were covered by later periods of volcanic rock deposition. It is easy to postulate that any one or a score of the basalt dikes mapped in Big Bend National Park (Maxwell et al., 1967) was a fissure vent and a possible source for any or all of the three lowest basalt members of the Chisos Formation, and one can further surmise that the present basalt outcrops are thickest close to the original vents. This explanation is satisfactory for the sources of the Alamo Creek, Ash Spring, and Bee Mountain Basalt Members, but it does not pinpoint a source for the Mule Ear Spring Tuff, the intermediate Tule Mountain Trachyandesite, or the very siliceous lavas in the overlying South Rim Formation.

The Mule Ear Spring Tuff Member was apparently deposited as an ash fall over an erosion surface with low relief during the middle Chisos Formation epoch. It has a uniform thickness of less than 20 feet and there is no conspicuous variation of thickness with increasing distance away from the Chisos Mountains. It is, however, commonly more indurated close to the mountains and in places becomes punky at the more distant exposures. Some would classify this indurated tuff bed as an ignimbrite, but there are only a few glass shards in the thin sections examined and no significant welding of the tuffaceous material.

The source of the Tule Mountain Trachyandesite is also undetermined. A curved dike near the eastern end of Sierra de Chino, southern Chisos Mountains, is similar chemically and petrographically to the extrusive Tule Mountain Trachyandesite rocks and may be a source, but to consider a single dike, only about 1 mile in length, as being the only feeder for all the Tule Mountain Trachyandesite type of extrusive rocks exposed in Big Bend National Park is not reasonable.

The general term pluton is used hereafter to designate the principal intrusive complex in the central Chisos Mountains, because the relationships of some parts of the intrusive mass to country rock and to other parts of the intrusion are obscure. The pluton includes the intrusive bodies that form several of the most prominent peaks in the higher Chisos Mountains and several of the conspicuous peaks in the adjacent area. The prominent peaks are probably cupolas that are connected at depth to a single large mass. The pluton is younger than the youngest lava unit previously discussed and appears to have ascended near the intersection of two structural trends. King (1935, p. 247) reported a northeast-trending basin in the Chisos country that is aligned with several synclines south of Marathon. One has only to glance at the geologic map of the Park (Maxwell et al, 1967, Pl. II) to recognize this structural trend. The pluton is also along a northwest-trending structural high, originally described by Udden (1907, pp. 86–87), that extends from Mariscal Mountain northwestward to the Christmas Mountains. The pluton rose near the intersection of the two structural trends.

At most places the contact between the pluton and the country rock is concealed by talus or alluvium. Farther away from the pluton, beds in the Chisos Formation crop out at various attitudes, but commonly the dip is toward the pluton and the high lava-capped peaks in the central Chisos Mountains. Along the northern and western slopes the dip ranges from about 5 to 12 degrees. On the east side the Chisos beds dip beneath the South Rim Formation at angles from 20 to 45 degrees and the dip increases toward the mountains. On the south side, below the South Rim, the dip is again toward the mountains and in most places is 7 to 12 degrees.

The dips indicate that the Chisos Mountains pluton and the lava-capped peaks in the central Chisos Mountains occupy an irregular structural basin that was formed prior to deposition of the South Rim Formation and emplacement of the pluton. The writers postulate that the structural basin is a collapsed caldera, and that the volcanic rocks now included in the Chisos Formation came from that volcanic center. Explosive action probably provided the material for the Mule Ear Spring Tuff ash fall, and subsidence followed the outpouring of the Tule Mountain Trachyandesite. Post-Chisos Formation erosion, deposition of the overlying South Rim Formation, most of which came from the Chisos Mountains center, and emplacement of the pluton covered or destroyed the vent or vents. Small volcanic neck-like bodies, spines, and a few small dikes at some places southwest of the higher Chisos Mountains are riebeckite rhyolite rock; they could have been local sources for the Burro Mesa Member, but their small size and location discourage serious consideration that these bodies were feeders for a riebeckite rhyolite flow that locally is more than 500 feet thick.

Geographic Distribution of the Volcanic Rocks

So far as known the oldest volcanic rocks in West Texas crop out in Big Bend National Park, and the Chisos Mountains Were a general site for these and at least some of the later extrusive rocks. Undoubtedly erosion has decreased the original expanse of these volcanic units and has also isolated some occurrences, making correlation difficult or impossible. A likely place to look for yet unknown extensions of the Park sequence is in Mexico southwest of Lajitas.

The lava units in the Canoe Formation are believed to be of local origin and probably were never extensive. The Alamo Creek Basalt extends intermittently northwestward to the lower slopes of Lajitas Mesa and occurs southward in Mexico at a few places adjacent to the Park. The Ash Spring Basalt has not been recognized outside of Big Bend National Park. The Bee Mountain Basalt has wide distribution in the Park and is also preserved in a structurally low faulted area and in several outliers near Black Gap east of the Sierra del Carmen. It extends southward into adjacent parts of Mexico, northwestward into the slopes of Lajitas Mesa, South Lajitas Mesa, and in a few outlier hills along the Rio Grande northwestward for 7 to 8 miles to near the base of the Big Hill. About 40 miles toward the north Erickson (1953) mapped a basalt in the eastern slope of Bandera Mesa, from about 6 miles southeast to 5 miles north of Wire Gap, that looks like the Bee Mountain Basalt.

The Mule Ear Spring Tuff Member blankets an erosion surface in the Chisos Formation and crops out at many places in Big Bend National Park (Maxwell et al., 1967, Pl. XI). The unit has been recognized in the slopes of Lajitas Mesa, South Lajitas Mesa, and in adjacent parts of Mexico; it caps the prominent butte northwest of the Fresno mine (incorrectly identified by some writers as the Mitchell Mesa Tuff) and caps several mesas near Chimney Rock

(Terlingua quadrangle) east of Fresno Creek. It also crops out northwest of Contrabando Dome and in the Bofecillos Mountains escarpment along the western side of Fresno Canyon (McKnight, 1970). This unit has not been recognized in the central Bofecillos Mountains proper or in the Tascotal Mesa quadrangle to the north, but there is a small outcrop near Three Dike Hill west of the Bofecillos Mountains along Farm Road 170 about 8 miles southeast of Redford.

The Tule Mountain Trachyandesite Member has wide distribution in Big Bend National Park (Maxwell et al., 1967, Pl. XI) and is believed to have come from a vent or vents in the Chisos Mountains (pp. 7–9). It forms conspicuous ledges and caps many mesas, ridges, and hills in the Park. Toward the northwest the Tule Mountain Member forms the cap rock on Lajitas Mesa, South Lajitas Mesa, and the adjacent part of Mexico; there is a thick ledge of Tule Mountain rocks at the foot of the Big Hill (southeast end of Santana Mesa) and in the escarpment along the southeastern side of the Bofecillos Mountains that borders the Fresno Canyon drainage. There are also exposures near the mouth of Colorado Canyon and at Three Dike Hill. Within the Bofecillos Mountains the Tule Mountain Member has been recognized at Panther, Primero, and Tapada Domes (McKnight, 1970).

The northernmost recognizable exposure of the Tule Mountain Member found to date crops out near a U. S. Geological Survey bench mark (elev. 3,119 feet) on the west side of Fresno Creek (Terlingua quadrangle). Here the unit is about 20 feet thick and is overlain by about 90 feet of tuff, pebbly tuff, and conglomerate. Those sedimentary beds are in the same stratigraphic position as 400 feet of Chisos Formation sedimentary rocks that overlie the Tule Mountain Member on the west side of Burro Mesa and about 100 feet of Chisos sedimentary rocks that overlie the Tule Mountain unit along the north flank of the Chisos Mountains. At most places in Big Bend National Park and along the lower reaches of Fresno Canyon, erosion has removed the Chisos sedimentary rock interval, and commonly this erosion surface is covered by younger formations. In the Park it is the South Rim Formation; along lower Fresno Canyon it is commonly the Mitchell Mesa Tuff.

SOUTHERN DAVIS MOUNTAINS

Goldich and Elms (1949) pioneered the detailed stratigraphic study of Tertiary volcanic rocks in west Texas. More than 2,300 feet of Tertiary rock crops out in the Buck Hill quadrangle. Flows of basalt, andesite, and trachyte occur near the middle of the thick succession of tuffaceous sedimentary rock; densely welded ash-flow tuff (originally mapped as a rhyolite) caps the higher mesas and is the youngest volcanic rock in the quadrangle.

Goldich and Elms divided the section into four formations: Pruett Formation at the base, Cottonwood Springs Basalt, Duff Formation, and Mitchell Mesa Rhyolite. Together, these form the Buck Hill Volcanic Series as originally described. The Cottonwood Springs Basalt thins southward and pinches out short of the southwest corner of the Buck Hill quadrangle. Three other mappable lava units crop out in limited areas near the northern quadrangle boundary. These were designated the Crossen Trachyte, Sheep Canyon Basalt, and Potato Hill Andesite members of the Pruett Formation.

After Goldich and Elms submitted their manuscript, but before its publication, Goldich and Seward (1948) described for a field trip guidebook the volcanic rocks exposed in Buck Hill quadrangle and a large area to the north, west, and south. A thick section of tuffaceous sedimentary rock capped by basaltic lava crops out above the Mitchell Mesa Rhyolite in the Tascotal Mesa escarpment. The sedimentary section, about 800 feet of tuff, tuffaceous sandstone, and conglomerate, was named Tascotal Formation; the lava cap rock, up to 200 feet thick along the escarpment, was named Rawls Basalt.

Goldich and Seward added the two new formations to the top of the Buck Hill Volcanic Series and suggested a possible correlation of the Rawls Basalt on Tascotal Mesa and basaltic lavas that cap hills of bedded tuff west of the upper valley of Alamito Creek. Later workers in central and northeastern Presidio County followed the suggested correlation and generally mapped basalts younger than the Mitchell Mesa as Rawls.

McAnulty (1955) extended the detailed mapping of volcanic rocks from the Buck Hill quadrangle northward toward Alpine. He found that the volume of flow rock generally increased northward at the expense of the sedimentary beds in the Buck Hill Group. Crossen Trachyte, Sheep Canyon Basalt, and Potato Hill Andesite Members were upgraded to formations with a corresponding restriction of the Pruett Formation. Otherwise, the Buck Hill terminology proved adequate for mapping most of the rocks in the Cathedral Mountain quadrangle. Near the northern boundary, a few flows interfingered with sedimentary rock of the Duff Formation; toward Alpine the flows thickened until the volume of sedimentary rocks in the Duff became insignificant.

Within Cathedral Mountain quadrangle, the rare outcrops of rock younger than Mitchell Mesa consist of tuff overlain by basaltic lava. McAnulty followed the suggested correlation of Goldich and Seward in mapping the tuff as Tascotal and the lava as Rawls Basalt.

Seward (1950) extended the Buck Hill terminology westward into the Jordan Gap quadrangle. Erickson (1953) used the Buck Hill Volcanic Series names in mapping the Tascotal quadrangle to the southwest. Neither found an adequate marker for subdividing the thick succession of sedimentary beds below the Mitchell Mesa. Pruett-Duff was mapped undivided, or a thick "gradational zone" was mapped between Pruett at the base of the section and Duff below the Mitchell Mesa.

Erickson (1953) measured the section exposed above the Mitchell Mesa at Wire Gap to provide the first detailed descriptions of sedimentary beds named Tascotal Formation and lavas named Rawls Basalt by Goldich and Seward (1948). Within the Tascotal Mesa quadrangle, Erickson recognized four subdivisions of the Rawls, but the Rawls thickens southward from the Tascotal Mesa escarpment toward the center of the Bofecillos Mountains.

BOFECILLOS MOUNTAINS

The Bofecillos Mountains are the eroded remnant of a thick succession of flows and pyroclastic materials that accumulated west of the Solitario uplift and the Terlingua monocline. Many of the flows erupted from vents within the Bofecillos Mountains or in adjoining parts of Mexico. The rocks differ sharply in lithology and sequence of flows from the volcanic section mapped as the Buck Hill Volcanic Series (Goldich and Elms, 1949) 40 miles to the northeast. Stratigraphic units established in Big Bend National Park, 50 miles to the southeast, are adequate for mapping only part of the volcanic rocks in the Bofecillos Mountains.

Three geologic maps include parts of the Bofecillos Mountains. Erickson's (1953) Tascotal Mesa quadrangle includes the northeastern margin of the mountains. Dietrich (1966) mapped the north-central and northwestern Bofecillos Mountains as part of the Presidio area. The Bofecillos Mountains area (McKnight, 1970) covers the complex central Bofecillos Mountains and includes the remainder of the mountains north of the Rio Grande.

BOFECILLOS GROUP

The name Bofecillos Group is used as an appropriate collective name for the six formations of Tertiary rock exposed in and near the Bofecillos Mountains. The formations are, in ascending order: a basal conglomerate, Chisos Formation, Mitchell

Mesa Tuff, Fresno Formation (new name), Santana Tuff (new name), and Rawls Formation.

The basal conglomerate is a thin but persistent conglomerate that commonly crops out at the base of the volcanic section in lowlands southeast of the Bofecillos Mountains. Two widespread ash-flow tuffs divide the overlying thick accumulation of volcanic materials into three formations of interfingering flow and sedimentary rocks. Within the Chisos Formation, most of the flows exhibit extensive outcrops; the general distribution suggests eruption from outside the Bofecillos Mountains. The distribution of flow rock within the Fresno and Rawls Formations demonstrates eruption from vents near the center of the Bofecillos Mountains. Most of the flows within the Fresno are latite and trachyandesite, and few Fresno lavas flowed more than 10 miles from the center of the mountains. The Rawls lavas are more varied and more extensive, and flow composition ranges from basalt to trachyandesite. Thick accumulations of the Rawls lava are preserved at distances of 15 or more miles from the center of the mountains.

Basal Conglomerate

A conglomerate up to 20 feet thick commonly crops out at the base of the Chisos Formation where Tertiary volcanic deposits overlie Gulfian strata in lowlands southeast of the Bofecillos Mountains. McKnight (1970) correlated this conglomerate with the Jeff of Eifler (1951). The rock is a conglomerate of well-rounded cobbles and boulders of limestone in a tightly cemented sandstone matrix. Lenses and interbeds of sandstone are common. Variable amounts of weathered, rounded fragments of vesicular igneous rock up to 6 inches across are mixed with the limestone gravel. Angular fragments of petrified wood up to boulder size are locally abundant.

Chisos Formation

The Chisos Formation, within the Bofecillos Mountains, includes the succession of interbedded flows and pyroclastic rocks below the base of the Mitchell Mesa Tuff and either the top of the basal conglomerate, where present, or the irregular surface eroded on Cretaceous strata. The Chisos crops out in lowlands southeast of the Bofecillos Mountains, in a few domes within the mountains, and in upfaulted blocks cut by the Rio Grande 5 to 15 miles west of the mountains.

Four of the five formally named members of the Chisos Formation (Maxwell et al., 1967) extend from Big Bend National Park into the Bofecillos Mountains area. Discussions of the areal extent of these units have been presented under the heading "Big Bend National Park."

Thickness of the Chisos Formation ranges from 1,060 feet at Lajitas Mesa to zero at the pinch-out on the flanks of the Solitario. Throughout most of the Bofecillos Mountains area, the thickness probably ranges from 500 to 800 feet.

Mitchell Mesa Tuff

The Mitchell Mesa Tuff (Mitchell Mesa Rhyolite of Goldich and Elms, 1949) is the lower of the two extensive ash-flow tuffs used to subdivide the succession of volcanic rocks in the Bofecillos Mountains. It is a significant marker bed for the regional correlation of widely separated accumulations of volcanic rock in the Trans-Pecos region.

The ash flow spread across most of the Bofecillos Mountains area; typical thicknesses range from 20 to 50 feet. Locally high areas were not covered. The Mitchell Mesa pinches out within a gravel fan that sloped outward from the Solitario, and it pinches out on a surface eroded on the Tule Mountain Trachyandesite Member of the Chisos Formation on the flanks of the Contrabando Dome.

Mitchell Mesa Tuff is almost continuously exposed along the west wall of Fresno Canyon from southwest of the Solitario to the Rio Grande. It crops out in most of the major domes within the mountains where erosion has cut to its stratigraphic position and in upfaulted blocks west of the Bofecillos Mountains near the cable crossing at a Rio Grande gaging station between Presidio and Redford.

The southeasternmost exposures in Texas are three small outliers on the top of South Lajitas Mesa (McKnight, 1970). The tuff crops out in a large area near river level across the Rio Grande (in Mexico) from the mesa.

Mitchell Mesa Tuff exhibits a wide range of hardness. At places the rock is so hard that it breaks with difficulty and exhibits a conchoidal fracture. At other places the rock is friable and can be easily excavated with power equipment. Commonly the rock is consolidated but "punky"; hammer blows produce a thud instead of a metallic ring. Some of the punky rocks are case-hardened, having an outer shell of harder rock from 1 to 6 inches thick.

Characteristic features at most outcrops include the following: (1) Sanidine crystals are spectacularly abundant and exhibit opalescence; (2) sanidine crystals and quartz phenocrysts commonly protrude from weathered surfaces, even where the rock is very hard; (3) pumice fragments up to 1 foot across are widespread and locally abundant; (4) where the rock is punky, numerous surface pits are formed by the disintegration of pumice fragments.

Fresno Formation

The name Fresno Formation is here proposed for the succession of interbedded flows, tuff, sandstone, and conglomerate between the two extensive ash-flow tuffs in the Bofecillos Mountains. The base of the new formation is at the top of the Mitchell Mesa Tuff; the top of the Fresno is at the base of the Santana Tuff (new name) or, where the Santana is missing, at the base of the Rawls Formation. Fresno Creek, source for the name, heads near the northwest flank of the Solitario and flows southward to join the Rio Grande near Lat. 29° 16.9′ N., Long. 103°51.2′ W.; the Fresno Formation is typically exposed in the west wall of Fresno Creek Canyon near Lat. 29°22′ N.

The Mitchell Mesa Tuff and most of the flows in the Chisos Formation probably erupted from vents at some distances from the Bofecillos Mountains and flowed into the area. At about the time the Mitchell Mesa ash flow covered the region, vents near the center of the Bofecillos became active, and lavas that are mapped as the Fresno Formation were extruded. Near the center of the mountains, outcrops consist predominantly of flows. As the distance from the vent area increases, the lavas thin and interbeds of sedimentary rock thicken. Near the margin of the Bofecillos Mountains, lavas comprise up to one-half of the exposed Fresno section. Boulder conglomerate and conglomeratic sandstones are the typical sedimentary rocks.

Thickness of the Fresno Formation probably ranges from 500 to 800 feet over most of the Bofecillos Mountains area. The formation may have thickened to 1,500 feet near the vent area (McKnight, 1970). Sections less than 500 feet thick accumulated near domes that were rising during the extrusion of Fresno lavas. The formation pinches out eastward against highlands of the Solitario and the Terlingua monocline.

The Fresno Formation is almost exactly equivalent to the Tascotal Formation; distinct differences in lithology make the new name desirable. The Tascotal is almost devoid of flows in outcrops near the Bofecillos Mountains. Flaggy tuff beds that are glaring white in the sunshine are characteristic of the Tascotal in outcrops that are almost continuous from about 6 miles south of Marfa to the Solitario. In the Tascotal Mesa escarpment, where the Tascotal Formation was named (Goldich and Seward, 1948) and originally studied (Erickson, 1953), the formation is about 800 feet thick. The lower half is thin-bedded, flaggy, white to light gray tuff and sandy tuff; the upper half is massive to thick-bedded, gray-buff, coarse-grained sandstone and conglomeratic sandstone.

The name Fresno is appropriate for outcrops where lavas from vents in the Bofecillos Mountains form a conspicuous part of the formation. The name Tascotal is appropriate for equivalent rocks away from active centers of eruption.

Santana Tuff

The name Santana Tuff is here proposed for the ash-flow tuff that caps Santana Mesa near the southeastern margin of the Bofecillos Mountains. Santana Mesa, the type locality and source for the proposed name, is a prominent mesa adjacent to the Rio Grande in Lajitas quadrangle near Lat. 29° 18.5′ N., Long. 103° 57.5′ W.

The ash flow covered a broad belt south, east, and northeast of the center of the Bofecillos Mountains. In Texas, the thickness exceeds 100 feet only in outcrops on downdropped blocks of the Redford-Lajitas fault zone where the Santana crops out as prominent brownish-orange bluffs 100 to 500 feet high. McKnight (1970) reported a maximum thickness of near 550 feet at the mouth of Panther Canyon west of Santana Mesa. Changes in thickness along the trend of the faults are gradual. Abrupt changes in thickness across the faults probably reflect movements while or immediately before the Santana was erupted. In Mexico, neither the thickness nor the areal extent of the Santana has been determined.

Santana Tuff pinches out northwestward in Three Dike Hill west of Tapada Canyon and northward on the slopes of Fresno lava flows that accumulated on the flanks of the Bofecillos vents. When emplaced the tuff extended southeastward an unknown distance beyond the present outcrops that overlook the Contrabando Dome but probably did not cross the Terlingua monocline. Outcrops along the east flank of the Bofecillos Mountains are generally less than 20 feet thick in the upstream half of Fresno Canyon. The ash extended northward to the present position of the Tascotal Mesa escarpment. From the eastern end of the escarpment to within 4 miles of Wire Gap, 5 to 20 feet of Santana are recognizable in the upper 50 feet of the sedimentary section that Erickson (1953) mapped as the Tascotal Formation.

The Santana Tuff is made up of a series of ash flows. Multiple cooling units are evident in the thicker outcrops near the Rio Grande; McKnight (1970) reported at least six at some outcrops. Where the tuff is thin, one or two cooling units can be identified. A thin interbed of sedimentary rock separates two layers of ash-flow tuff in the Santana near the western end of the Tascotal Mesa escarpment.

The formation consists of nonwelded to highly welded vitric-crystal tuff. Glassy sanidine crystals are abundant, but opalescent crystals are generally rare as compared to the concentration in the Mitchell Mesa Tuff. Pumice fragments range from common to abundant; other rock fragments range from rare to common. In the more highly welded zones, eutaxitic texture is pronounced.

Rawls Formation

Goldich and Seward (1948) named the lava that caps Tascotal Mesa the Rawls Basalt from the Rawls ranch which occupies most of the mesa. Basalt was used in the field sense—the rock is dark-colored, fine-grained lava. Erickson (1953) first studied the Rawls in detail as he mapped the Tascotal Mesa quadrangle. He mapped four distinct rock types within the Rawls: basalt, trachybasalt porphyry, trachyandesite, and volcanic breccia. Dietrich (1966) mapped nine subdivisions of the Rawls and proposed that the term “basalt” be dropped in favor of “Formation.” McKnight (1970) found the formation to be more complex near vent areas in the central Bofecillos Mountains. He used the general framework of nine members with subscript annotation to permit mapping of additional units that interfingered with the dominant rock in each member.

Basalt, trachybasalt porphyry, and trachyandesite are the common lavas in the Rawls at some distances from the center of the Bofecillos Mountains. Nearer the vents, appreciable thicknesses of latite, latite porphyry, trachyte, ash-flow tuff, and volcanic mud flows are present.

Rawls flows covered the whole area now known as the Bofecillos Mountains with the possible exception of the topographically high Bofecillos vents. Most members of the Rawls surrounded the vent area, but the thicknesses of individual members and the total thickness of the Rawls Formation were generally greater to the north and west of the center of the mountains than to the south or east. Four of the nine members have thicknesses exceeding 500 feet at different places in the northern or western Bofecillos, but maximum thickness of the total Rawls Formation probably is on the order of 1,200 feet.

Toward the northwest, Rawls lavas thin and pinch out. In all other directions Rawls flows have been eroded back from the pinch-out areas. Field relationships suggest that the loss in outcrop area has not been great. Probably the Rawls flows extended no more than 1 to 5 miles beyond the present outcrop limits.

Some basalts in east-central and northeastern Presidio County have been incorrectly mapped as Rawls. These are now known to be different lava units. Basalt in the Rancheria Hills and along the west side of the upper valley of Alamito Creek is Petan Basalt (*see* pp. 25–26). Outcrops mapped as Rawls in the Cathedral Mountain quadrangle are neither Rawls nor Petan and should be reexamined and probably assigned a new formation name.

Two distinctive members of the Rawls Formation warrant further discussion. These are the Tr4 trachybasalt porphyry and Tr7 mafic ash-flow tuff of Dietrich (1966).

Lava that was originally named Rawls Basalt in the Tascotal Mesa escarpment overlooking Wire Gap is the Tr7 trachybasalt porphyry. This is the subdivision of the Rawls that Erickson (1953) nicknamed the "birds-eye porphyry" because of the conspicuous, large, tabular plagioclase phenocrysts that weather to a light gray and contrast sharply with the dark gray to brownish-gray fine-grained groundmass. Birds-eye porphyry is one of the more widespread Rawls lavas. Thickness is variable. Over much of Tascotal Mesa northeast of the Bofecillos Mountains the thickness of the porphyry ranges from 100 to 400 feet. South and southeast of the center of the mountains the thickness is only 5 to 50 feet. The thickest accumulation of the "birds-eye" is west of La Mota Mountain, north of the center of the Bofecillos, where within an area of several square miles the formation thickness ranges from 500 to 800 feet.

At most outcrops the trachybasalt porphyry consists of numerous flows ranging from 5 to 50 feet thick. Flow tops are vesicular and the bottoms are rubbly. Amygdules of secondary minerals, typically calcite or chalcedony, are locally abundant. The "birds-eye" crops out as a series of steps; the nonvesicular center of each flow forms a near-vertical bluff that is separated from adjacent bluffs by flats eroded on the vesicular and rubbly zones.

Although the "birds-eye" porphyry is distinctive, it is not unique. Older rocks of similar composition and appearance crop out at two widely separated localities: in Big Bend National Park (Ash Spring Basalt of the Chisos Formation) and southeast of the Chinati Mountains (Tm2 basalt porphyry of the Morita Ranch Formation).

The other distinctive Rawls flow unit is the Tr7 mafic ash-flow tuff. Erickson mapped this unit as "volcanic breccia." The distribution of outcrops suggests the tuff formed a continuous belt around the Bofecillos vents when it was extruded. Thickness of the tuff is highly irregular. Part of the irregularity in the topography is due to erosion in the underlying rocks over which the tuff spread; some is due to local accumulations on top of mounds or hills where the unit is thickest. Over much of the area the tuff is 10 to 100 feet thick; maximum thickness is near 400 feet in the north wall of Bofecillos Creek Canyon a few miles northwest of the Bofecillos vents.

Where the formation is less than 20 feet thick, outcrops are poor because the tuff is easily eroded and tends to be covered by upslope debris.

The ash-flow tuff is nonwelded to highly welded lithic-vitric tuff. In most outcrops a pronounced eutaxtic texture is characteristic of all but a thin layer at the top and bottom of the member. Lithic fragments commonly make up as much as 15 percent of the volume. Crystals of olivine, augite, hornblende, and biotite have been identified in thin sections of the tuff matrix. Chemical analyses show the rock to be of intermediate composition, with silica content ranging from 60 to 63 percent (Kurt Fredriksson, personal communication to Dietrich, 1969).

Where the mafic ash-flow tuff is thin, the tuff generally is a simple cooling unit of one or more ash flows. Where the tuff is more than 100 feet thick, multiple cooling units can be detected in most outcrops because of variations in resistance to erosion.

BARRILLA MOUNTAINS

Eifler (1951) named and described the rocks in the Barrilla Mountains, northeast of the higher Davis Mountains, which are a highland mass separated from the Davis Mountains. Eifler was the first to do systematic work in that area, and it is believed that there is a reasonable correlation between most of the rock units described by him (1951) and those in the central Davis Mountains named and described by Anderson (1968).

Eifler (1951) described a volcanic rock sequence, thickness about 1,500 to 1,700 feet, that overlies the marine Cretaceous rock in the Barrilla Mountains. He named the sequence the McCutcheon Volcanic Series; it includes five lava units alternating with five tuffs, some of which contain sandstone, breccia, fresh-water limestone, and conglomerate. The base of the lowest formation is a sandstone and conglomerate unit (Jeff Conglomerate Member) which in the Barrilla Mountains overlies marine Cretaceous rocks. The top is a lava rock exposed along a syncline crossed by the Fort Davis-Toyahvale highway (State Highway 17) north of Star Mountain.

Apparently the spread of one volcanic unit rapidly succeeded the deposition of another, for there is little evidence of erosion between the members, and nowhere is there evidence of channeling as is clearly recognized in the Chisos and Bofecillos Mountains areas. However, a few sandstone and conglomerate beds contain fragments of older lavas; this suggests erosion elsewhere in the Davis Mountains. The lava units spread widely over fairly flat surfaces, yet they are silicic. Lavas of this composition generally are highly viscous. Possibly the units are ash-flow tuffs (ignimbrites), which spread widely while retaining a fairly uniform thickness and lithologic character. Eifler subdivided the sequence into three formations. From base to top, they include (1) the Huelster Formation, with Jeff Conglomerate at base, (2) the Star Mountain Rhyolite, and (3) the Seven Springs Formation.

Huelster Formation

The Jeff Conglomerate, basal member of the Huelster Formation, lies with slight angular unconformity upon eroded Cretaceous rocks. The contact is sharp, but at many places it is not well exposed because of slump and alluvial cover. The sandstone beds are moderately well sorted and vary from light tan to yellow. The conglomerate is mainly well-sorted pebbles and cobbles, but there are boulders, 1 foot or more in size, at some places. Bedding is commonly poor, but in some places there is distinctive cross-bedding, and in others fine-grained sandstones are distinctly laminated.

The highest member of the Huelster Formation is a tuff unit underlying the Star Mountain Rhyolite. Tuff beds are common throughout the formation, but there are also layers and lenses of sandstone, conglomerate, fresh-water limestone, and lava. The tuffs are distinctly bedded in layers a few inches to a few feet thick, and locally they seem to grade into lacustrine deposits. At a few places the tuff layers are interbedded with fresh-water limestone. The limestone is commonly light lemon yellow to dark gray and contains many irregular purplish-blue and ochre-yellow chert bodies of secondary origin. Lenses of dark igneous rock, probably lava, occur in the upper part of the formation. These rock layers are most common in the western part of the Barrilla Mountains and at Wild Rose Pass in the Davis Mountains. This rock is mostly black and fine grained and at most exposures is a porphyritic olivine trachydolerite. The tuffaceous beds contain fossil wood; the limy beds, especially the fresh-water limestone, contain fossil gastropods and algae. A definite age assignment cannot be made, but the fossil list suggests Eocene.

Star Mountain Rhyolite

The thick rhyolitic lava beds overlying the Huelster Formation were named from Star Mountain. The base overlies the Huelster Formation and the top is immediately beneath the Seven Springs Formation. In the high vertical cliffs, on the east side of Star Mountain, there are at least six and possibly more flows. The rock typically weathers black to brownish black, but some parts are green, greenish gray, and lavender. The formation is best exposed in the vertical cliffs east of Star Mountain, the northeast part of the Barrilla Mountains, and along Limpia Canyon in the Davis Mountains. The flows commonly exhibit palisade structures and in some places joints extend through several flows. Flow structure is common at the top of some beds, a few flows are highly vesicular, and the cavities are commonly filled with blue to gray chalcedony. Phenocrysts are conspicuous in some layers; the aphanitic groundmass is a riebeckite soda rhyolite.

Seven Springs Formation

The Seven Springs Formation contains lava, tuff, and sedimentary rock layers that were subdivided into four lava and four tuff members. The tuff layers are mostly white, gray, or lemon yellow and at most places are interbedded with variable amounts of sediments, including clay, sandstone, and conglomerate. Locally the conglomerate is well cemented and contains igneous rock boulders up to 2 feet in size. The lava beds range from a vitrophyre at the base of some flows to granophyre, rhyolite porphyry, and basalt. Common colors are purplish red, maroon, reddish brown, chocolate brown, and blue black. Some layers are scoriaceous with chalcedonic amygdules that give the rock a conglomeratic appearance; others are aphanitic, and there are porphyries. Palisade structures and platy flow layers are present in some of the lava units.

CENTRAL DAVIS MOUNTAINS

Anderson (1968) divided the extrusive rocks in the central Davis Mountains into four general types, based on rock composition. These are rhyolite, latite, trachyte, and basalt. Most of the rhyolitic strata are ignimbrites and are composed largely of glass shards and crystal fragments, especially feldspar. Zones of welding and devitrification can be recognized in some of the central Davis Mountains volcanic rock units, but the zones are not as consistent nor as clearly developed as in ignimbrites in some other areas.

Many formational contacts in the central Davis Mountains are covered by talus, some formations are found only in local areas, other rock units thicken or thin rapidly, a few disappear by overlap of younger formations, and there are some erosion surfaces. Lithology, petrography, and superposition are the most useful tools for dividing the volcanic rocks into formations. By using these methods, Anderson (1968) mapped and described eleven formations in the central Davis Mountains. In ascending order, these are the lower and upper rhyolites and the Sheep Pasture, Merrill, Barrel Springs, Mount Locke, Jones, Wild Cherry, Medley, Goat Canyon, and Brooks Mountain Formations.

Lower and Upper Rhyolites

The lower rhyolite was first described in the northern Davis Mountains by Rix (1951), who used the field term "T50" to designate the unit. In the central Davis Mountains the lowest exposed part of the lower rhyolite forms nearly vertical cliffs above which are gentle to moderate talus slopes; in the field it partly resembles the Star Mountain Rhyolite that Eifler (1951) mentioned in Limpia Canyon. The rock is pinkish-gray to brown, aphanitic, fairly well-foliated rhyolite. The base is not exposed. The upper rhyolite (Anderson, 1968) was also described by Rix (1951) in the northern Davis Mountains where he used the field term "T60" to designate the unit; it is also similar in general appearance to the Star Mountain Rhyolite (Eifler, 1951). The rocks in the upper rhyolite unit closely resemble the lower member in outcrop appearance, hand specimen, and thin section; in the field, the two units are distinguished only by stratigraphic position. Their contact is inferred from the position of a pronounced increase in the slope of the talus deposit a few feet below the lowermost outcrop of the upper rhyolite member. In the northern Davis Mountains the two units are separated by a tuff bed.

Sheep Pasture Formation

The Sheep Pasture Formation is mostly a grayish-purple to reddish-brown, foliated, slightly porphyritic rhyolite, commonly with snowflake texture. Locally the top of the formation is an indurated to friable, fine-grained, vitric tuff. This tuff bed is an important marker in the field and is used to separate the Sheep Pasture from the overlying Merrill Formation.

Merrill Formation

The Merrill Formation consists mostly of hard, reddish-brown latite porphyry with translucent, colorless to pink phenocrysts. On weathered surfaces the rock is brown to yellowish brown and is pitted. Locally at the top of the formation is a fine to coarse-grained vitric tuff. The Merrill Formation weathers to form low, rounded hills with hummocky surfaces, and it is the lowest of three latitic porphyry units that have characteristics more suggestive of a lava flow than of an ignimbrite.

Barrel Springs Formation

The Barrel Springs Formation is characterized by four rock types: (1) black, foliated vitrophyre; (2) pinkish-gray to purplish-brown, foliated, porphyritic rhyolite; (3) nonfoliated, porphyritic rhyolite; and (4) indurated to friable, fine-grained vitric tuff. The formation thins gradually but consistently westward across the central Davis Mountains. In some places the lower contact with the Merrill Formation is covered, but in others the Merrill is absent and the Barrel Springs has a distinct overlapping contact with the Sheep Pasture. At most places in the southwestern part of the area, the Barrel Springs is overlain by the Wild Cherry Formation, but toward the northeast, the Mount Locke Formation lies between the Barrel Springs and Wild Cherry. At some places in the southwestern part of the central Davis Mountains, the Mount Locke Formation is absent and the Jones Formation rests upon the Barrel Springs. In some places Anderson (1968) did not differentiate the Barrel Springs and the Wild Cherry Formations, and locally within that sequence, he also described the Eppenauer Ranch Basalt: This is a dark brown to black, hard, aphanitic and massive vesicular rock. Phenocrysts are generally absent or where present occur only in trace amounts. Both the lower and upper contacts are covered. Also, rocks within both the Barrel Springs and Wild Cherry Formations are highly siliceous, and altered portions of them constitute the kaolin deposits of the Medley mine.

Mount Locke Formation

The Mount Locke Formation is mostly gray latite porphyry with translucent, gray to pinkish-gray phenocrysts. Alkalic feldspar in orthophyric, felted, and trachytic arrangements is the most abundant constituent of the matrix. The weathered surface is rough and ranges from brownish gray to reddish brown. The rock ledges form steep cliffs near the base of the formation, but the slopes decrease upward and the surface becomes hummocky.

Jones Formation

The Jones Formation is a hard, black basalt that forms low gentle hills with many cobbles and boulders on the surface. Petrographically the Jones is much like the Eppenauer Ranch Basalt (p. 21), but the outcrops are not connected; however, both bodies may have been extruded from the same magma chamber at about the same time. The Jones rock contains small colorless to light brown phenocrysts, with intergranular augite and chlorite after augite. The olivine in the Jones is commonly altered to iddingsite and antigorite. Olivine in the Eppenauer is altered only to iddingsite.

Wild Cherry Formation

The Wild Cherry Formation consists of black foliated vitrophyre, foliated porphyritic rhyolite, and indurated to friable, fine-grained vitric tuff. The porphyritic rhyolite is commonly purplish gray to brown with white phenocrysts and has a purplish-red weathered surface. The contact with the Mount Locke Formation is mostly covered, but in the southwestern part of the central Davis Mountains, the basal Wild Cherry is commonly a black foliated vitrophyre.

Medley Formation

The Medley Formation is a latite porphyry similar to if not identical with the Mount Locke Formation. It is vesicular with the abundance of vesicles increasing upward in the formation. In some places where the Medley overlies either the Barrel Springs or the Wild Cherry Formation, the rocks are not altered. This suggests that the Medley may be unconformable with the underlying volcanic rocks.

Goat Mountain Formation

The Goat Mountain Formation consists of one or more lava flows of hard, gray to greenish-gray, porphyritic trachyte with a trachytic matrix and white alkalic feldspar phenocrysts. It weathers to grayish-white or yellowish-brown rock with platy surfaces and commonly forms high, steep cliffs.

Brooks Mountain Formation

The Brooks Mountain Formation is composed of brown, aphanitic to fine-grained porphyritic rock with an orthophyric matrix and colorless to gray feldspar phenocrysts. The rock weathers to grayish brown on exposed surfaces, forms steep to vertical cliffs, and commonly there are large prominent piles of talus at the base.

Overlying and interbedded with the several formations listed above are isolated bodies of various rock types that Anderson (1968) referred to as rhyolite-trachyte undifferentiated. Most of these masses occur in the vicinity of Sawtooth Mountain. Some of them could be local, having originated from that intrusion, but none of them were assigned to a specific formation.

The volcanic rocks in the central Davis Mountains are relatively high in the Tertiary volcanic rock sequence of West Texas. Few of the rock units appear to be older than early Oligocene. It is believed that the Davis Mountains were a center of extrusive activity; many of the rock unite appear to be from local vents and few of them can be traced laterally for more than a score of miles. It is reasonable to correlate Anderson's (1968) lower and upper rhyolites with Eifler's (1951) Star Mountain Rhyolite and with Rix's (1951) "T50" and "T60," but further correlation is not practicable at this time. Colton (1957) correlated at least part of Rix's (1951) "T60" (Anderson's (1968) upper rhyolite) with the Brite Ignimbrite of the Rim Rock Country. Colton further suggested that the upper rhyolite is equivalent to the Means Formation in the Wylie Mountains. The correlation is shown on Plate I. Maxwell believes, however, that further studies may show that one of the tuff beds, perhaps No. 3, in Eifler's (1951) Seven Springs Formation, a tuff bed of the Wild Cherry Formation in the central Davis Mountains, and part of the Bell Valley Formation in the Wylie Mountains may be correlative with the Brite-Mitchell Mesa Ignimbrite. This would lower the rock columns as now shown in Plate I and perhaps fit the regional correlation picture more satisfactorily. One objection to this suggestion is that the Star Mountain Rhyolite contains the mineral riebeckite, and in areas toward the south and southeast, riebeckite has not been recognized in rocks older than the South Rim Formation.

RIM ROCK COUNTRY

An impressive sequence of Tertiary volcanic rocks crops out in the region variously termed the Sierra Vieja, Vieja Rim, Rim Rock Country, and on some older maps the Tierra Vieja. Although the area is far to the west-northwest of the Chisos-Bofecillos Mountains, certain formations exposed in the two areas can be correlated. There are many gaps in the outcrops of some formations. At some places the gaps are only a few miles, but at others, highland masses such as the Chinati Mountains, or the extensive gravel-covered plains south of Marfa, separate like units by greater distances. Nevertheless, by examining thin sections, comparing chemical analyses, vertebrate fossil remains, and potassium-argon dates, and observing superposition of beds at the outcrop, a reasonable correlation can be demonstrated for some formations.

Many geologists have worked in the Rim Rock Country. DeFord (1958), assisted by graduate students from The University of Texas at Austin, divided the rock layers into formational units, named, described, and mapped them, and prepared the groundwork to make correlation possible. DeFord (1958) expanded the original Vieja Series of Vaughan (1900) to include all of the rocks in the Vieja Rim. He designated and described nine formations in the Vieja Group that in ascending order are Jeff Conglomerate, Gill Breccia, Colmena Tuff, Buckshot Ignimbrite, Chambers Tuff, Bracks Rhyolite, Capote Mountain Tuff, Brite Ignimbrite, Petan Basalt. The writers prefer to exclude the Brite and Petan from the Vieja Group because they are extended far beyond the Vieja region. Ramsey (1961) described the Perdiz Conglomerate. Wilson et al. (1968) published on the stratigraphic succession, potassium-argon dates, and vertebrate fauna of DeFord's Vieja Group. Page C. Twiss is refining the maps of earlier workers.

The Vieja Group in the Rim Rock Country rests unconformably upon Upper Cretaceous rocks. In many places the contact appears concordant, but in others the Upper Cretaceous formations were deformed and eroded prior to deposition of the Vieja Group. The minimum unconformity is probably near San Carlos, where there is an absence of some Upper Cretaceous rocks, all of the Paleocene rocks, and part of the Eocene (*see also* pp. 3–5). At other places most of the Upper Cretaceous rocks also appear to be missing.

Jeff Conglomerate

Eifler (1951) named and described the Jeff Conglomerate from a locality in the Barrilla Mountains about 70 miles northeast of the Vieja Rim. There the rock is the basal sandstone-conglomerate member of Eifler's Huelster Formation; it is about 25 feet thick. The Jeff lies with slightly angular contact upon Taylor and Austin age rocks of the Upper Cretaceous. Some beds are mainly sandstone; these are moderately well sorted and medium to coarse grained, varying from white to yellow or tan. Some conglomerate beds have well-sorted pebbles and cobbles with little sandstone matrix. The cobbles consist of quartzite, dark limestone, white, black, pink, and gray chert, quartz, and fossils.

A basal conglomerate overlies Upper

Cretaceous or older rocks at many places in West Texas. Goldich and Elms (1949) recognized such a conglomerate in the Buck Hill quadrangle, and McKnight (1970) mapped the Jeff along the western bank of Fresno Creek to near Big Bend National Park. The Jeff has not been recognized within the Park, where at most places the Alamo Creek Basalt is the basal Tertiary, but it is possible that a conglomerate overlying the Alamo Creek Basalt at many places in the Park could be correlative with the Jeff.

By mapping outcrops geologists have traced the Jeff Conglomerate as a more or less continuous body around the north end of the Davis Mountains, and many of the conglomerate bodies west and southwest of the Davis Mountains are probably Jeff equivalent, but there is a 30-mile gap between recognized Jeff outcrops and the basal conglomeratic beds in the Rim Rock Country. In the northern part of the Vieja Rim an appreciable thickness of conglomerate lies in an interval between the Buckshot Ignimbrite and base of the Vieja Group, which is also conglomeratic. At some places in the southern part of the Vieja Rim, the Gill Breccia lies between the Colmena Tuff and the conglomerate. Northward the Gill pinches out and the lower part of the Colmena Tuff appears to grade into conglomerate. Maxwell believes that not all the basal conglomerates associated with volcanic rocks in West Texas are the Jeff of Eifler (1951); that all were deposited on an irregular surface; and that they should be restudied and perhaps some renamed because all may not be the same age.

Gill Breccia

At a few places in the southern Rim Rock Country the lowest identified unit is the Gill Breccia. Sewell (1955) described three rock types in the Gill. In ascending order these are (1) medium gray fragments in a grayish-red matrix; (2) mottled pink, green, yellow, and gray fragments in a darker greenish-gray to orange-pink groundmass; and (3) brecciated to massive light olive-green to dark greenish-gray rock. The rock composition varies from trachyandesite to basalt, and the breccia is notable for the huge blocks of Lower Cretaceous limestone found at some places within it. Some blocks are as large as a three-story building. Sewell (1955) listed several hypotheses as to their origin. Among the explanations considered were klippen, landslide blocks, peaks of buried mountains, crests of eroded anticlines, results of sedimentary intrusions, and blocks brought up by the magma that formed the Gill Breccia.

Colmena Tuff

The Colmena Tuff is a light brown tuffaceous conglomerate interbedded with variegated tuff, and at some places most of the rock consists of rhyolite tuff beds. Some conglomerate beds include pebbles and cobbles of Gill Breccia and Lower Cretaceous limestone; at other places there are cobbles of tuffaceous nonmarine limestone, silty claystone, and glassy flow rock. The formation was deposited over an irregular surface and ranges up to about 450 feet thick.

Buckshot Ignimbrite

The Buckshot is resistant to erosion and at most places on the Buckshot Rim it forms a cap rock 40 to 75 feet thick. The rock exhibits well-developed vertical joints and breaks with a conchoidal fracture. The fresh rock is grayish red to yellowish brown but weathers to pale or dark reddish brown. The term Buckshot was selected for the formational name because much of the rock is characterized by dark reddish-brown spots about the size of buckshot. From a distance it looks like a rhyolite porphyry. Some of the reddish spots have grayish centers with dark red to blackish rims. Most of the phenocrysts are sanidine, some are orthoclase, and a few are quartz. Thin sections show glass shards and other pyroclastic materials. McGrew (1955) concluded that the rock is ignimbrite.

Chambers Tuff

The Chambers Tuff is a moderately to well-bedded yellow-brown to grayish tuff in the upper 250 feet of the formation; it is pale red to reddish brown toward the base. In the southern Rim Rock Country the formation contains layers of coarse sandstone with lenses of conglomerate. Where typically exposed the Chambers Tuff rests upon the Buckshot Ignimbrite, but where the Buckshot is absent Chambers Tuff rests on Colmena Tuff and in these places the contact is commonly difficult to identify.

Bracks Rhyolite

At most places the Bracks is the key to the Tertiary stratigraphy in the Rim Rock Country. It is the pantellerite of Lord *(in* Vaughan, 1896, 1900) and forms the chief rim rock of the country. It is mostly light olive-gray to greenish-black rhyolite, but in places it is dark reddish brown. The San Carlos basin, location of the abandoned coal-mining town, is almost completely rimmed by the Bracks Rhyolite. The thickest outcrops, about 300 feet, are near San Carlos; from this general location the formation thins in all directions.

Capote Mountain Tuff

The Capote Mountain formation is characterized by whitish tuff in most of the Vieja region. Sewell (1955) described a three-part sequence that contains about 1,300 feet of white to pinkish-gray tuff at the top, a mid-layer of red siltstone about 10 to 40 feet thick, and a brown to grayish-red basal unit about 200 feet thick south of Capote Creek. At Capote Peak, Peterson (1955) described a lower 1,350-foot thick layer of red and grayish-red tuff overlain by an upper unit of white tuff. The formation is mostly fine- to coarse-grained, noncalcareous, rhyolitic tuff, about three-fourths of which is volcanic glass accompanied by some quartz and a few opaque minerals. In some places there are beds of pebbly to bouldery conglomerate, in others, commonly near the mid-section, a layer of resistant siltstone cemented with calcite, but predominantly the formation consists of tuffaceous volcanic rocks. It is overlain, with sharp contact, by the Brite Ignimbrite.

Brite Ignimbrite

The top of Capote Mountain (Shipman, 1926; Darton, 1933; and Keith, 1950), which towers above the Brite ranch, is the type locality of the Brite Ignimbrite. The mountain's cap rock is about 100 feet thick. It resembles a sanidine rhyolite porphyry, but in thin section the rock shows faint outlines of glass shards and other pyroclastic materials. The sanidine phenocrysts are opalescent and the rock surface weathers so that many crystals stand out in relief. The fresh rock is light colored, ranging from orange pink to light brownish gray. Ramsey (1961) showed that the rocks mapped as Brite Ignimbrite and Mitchell Mesa (Rhyolite) Tuff are part of the same unit *(see also* pp. 13, 15–16).

Petan Basalt

The Petan Basalt was named by DeFord (1958) from outcrops on the Petan ranch. The Petan crops out on the back slope of the Capote Rim and along Capote Draw from near the southern boundary of the Brite ranch to near the head of Pinto Canyon. Amsbury (1958) described the formation in more detail at outcrops in the Pinto Canyon area where part of the lava is a trachyandesite. There a composite section of lenticular units suggests a thickness of about 500 feet, and the type locality was designated as the steep hill upon which the Cleveland Triangulation Station is located. At most places the formation is dark gray or brownish-gray, tough, vesicular, porphyritic, fine-grained, plagioclase trachyte that weathers to dark brown or dark gray. Ramsey (1961) demonstrated that most basaltic outcrops west of U. S. Highway 67 (Marfa-Presidio road) and outcrops west of the upper valley of Alamito Creek are Petan. These basaltic lavas have been erroneously designated Rawls by some geologists (West Texas Geol. Soc., 1948, 1953, 1964).

Perdiz Conglomerate

The Perdiz Conglomerate (Ramsey, 1961) consists of several hundred feet of alternating beds of granule to cobble size conglomerate and tuffaceous sandstone. Although many fragments of sedimentary rock are present, the Perdiz is conspicuous for its high percentage and wide variety of volcanic rock fragments. The formation is typically exposed in road cuts along U. S. Highway 67 (Marfa-Presidio road) in the Frenchman Hills. The conglomerate caps most of the Cuesta del Burro and other low elevated areas northeast of the Chinati Mountains. Southeast of the Chinati Mountains, Perdiz Conglomerate surrounds the Cienega Mountains and extends to the western end of the Tascotal Mesa escarpment. The conglomerate was deposited as a fan that spread outward from the Chinati Mountains with some contribution of detritus from local high areas such as the Oak Hills and possibly the Rim Rock Country.

Throughout most of its outcrop area, the Perdiz is the youngest unit exposed. Until Ramsey found fossils that demonstrated its Tertiary age, the thick fan north and east of the Chinati Mountains had been mapped as Quaternary gravel. Where its base is exposed in that area, the Perdiz unconformably overlies Petan Basalt, Brite Ignimbrite, or the Shely Group (Amsbury, 1957, 1958). Where its base is exposed southeast of the Chinati Mountains, the Perdiz Conglomerate overlies a deeply dissected surface cut on the Morita Ranch Formation (Dietrich, 1965, 1966) and Comanchean strata. Near the western end of the Tascotal Mesa escarpment, the thin edge of the Perdiz fan interfingers with the upper part of the Tascotal Formation, and near its pinchout south of Casa Piedra, Perdiz Conglomerate underlies lava in the Rawls Formation.

Because the Brite and Mitchell Mesa are the same unit (Ramsey, 1961), one can assume that all rocks below the Brite in the Vieja Group of the Rim Rock Country are equivalent to at least part of the Chisos Formation in the Bofecillos Mountains and Big Bend National Park (Maxwell et al., 1967) and to the Buck Hill Volcanic Series, below the Mitchell Mesa north of the Solitario (Goldich and Elms, 1949). Also, that most rocks from the top of the Brite through the Petan in the Rim Rock Country are correlative with some rocks between the top of the Mitchell Mesa and top of the Rawls north of the Solitario. Such a correlation is not simple, because the rocks came from multiple sources, were deposited in varied environments, and there are many wide gaps in the rock exposures.

CHINATI MOUNTAINS

Three different successions of volcanic strata crop out in and near the Chinati Mountains. Erosion has carved the higher mountain block and adjacent foothills to the northeast from several thousand feet of trachyte and rhyolite flows in the Chinati Mountain Group. At the northwest and southeast ends of the mountains, distinctly different and thinner successions of volcanic rock crop out. Lavas and ash flows of the Shely Group are well exposed in the Pinto Canyon area at the northwest end of the mountains. At the southeast end of the Chinatis, low hills near the community of Shafter are eroded from the interbedded flow rock, tuff, and conglomerate of the Morita Ranch Formation.

Chinati Peak Quadrangle

The Chinati Peak quadrangle includes most of the higher peaks in the Chinati Mountains and marginal hills to the north and east. Folded fault blocks of Pennsylvanian, Permian, and Cretaceous strata crop out at low elevations in a discontinuous, rough arc extending from southeast to north of the higher mountain block. Interbedded flows and tuff overlie the pre-Cenozoic strata and crop out in low hills east of the arc. Thick accumulations of lava with rare sedimentary interbeds make up the higher mountain block. No conglomerate equivalent to the Jeff of Eifler (1951) has been mapped at the base of the volcanic section in the Chinati Peak quadrangle.

Rix (1953, 1954) subdivided the volcanic rocks into 8 units. Four units, designated as Units T1 through T4 of the Buck Hill Volcanic Series, were mapped in the low hills east of the pre-Cenozoic outcrops. These units are discussed further under the heading "Shafter Area" (pp. 27–28).

Rix proposed the name Chinati Mountain Volcanic Series for the intermediate to silicic flows exposed in the higher mountain block. Four subdivisions (T5 through T8) of the Chinati Mountain Group were mapped.

Pinto Canyon Area

Deeply dissected sedimentary rocks in the exhumed Loma Plata anticline separate the high smooth rims characteristic of the Rim Rock Country from the higher rugged peaks typical of the Chinati Mountains. Deep canyons of Pinto Creek and its tributaries cut through the volcanic deposits on the eastern flank of the anticline and carve deeply into highly faulted pre-Cenozoic rock as old as Wolfcampian near the crest of the anticline.

The Loma Plata anticline is a Laramide fold that remained topographically high during the early phases of volcanic activity. As flows and pyroclastic debris accumulated on lower parts of the irregular surface, erosion of the deformed Permian and Cretaceous strata continued through most of the Pinto Canyon area. The Jeff, Gill, Colmena, Buckshot, Chambers, and Bracks Formations of the Vieja Group thin and pinch out southward on the north flank of the anticline.

Near the northern boundary of the Pinto Canyon area, Capote Mountain Tuff interfingers with flows of the Shely Group (Amsbury, 1957, 1958) which directly overlies pre-Cenozoic strata on the flanks of the Loma Plata anticline south of Cleveland Triangulation Station. The Brite and Petan flow rocks probably are younger than all units of the Shely Group. Although these younger units overlie Shely flows as young as Ts6 near the margin of the Shely outcrop, there is no physical evidence that either the Brite or the Petan covered the higher peaks in the Shely deposits.

Amsbury (1958) formally proposed the name Shely Group for the succession of tuff, conglomerate, rhyolite, trachyte, and ignimbrite that interfingers with the Capote Mountain Tuff of the Vieja Group. He recognized 8 mappable units that are designated by the letter-number symbols Ts1 through Ts8. Beds of tuff in Ts1 are laterally continuous with beds in the Capote Mountain Tuff. Flow rock units other than Ts6 crop out only within limited areas in and adjacent to the Pinto Canyon area. Ignimbrite Ts6 has been traced more than 20 miles southeastward from Pinto Canyon.

The Chinati Mountain Group is in contact with the Shely Group along a major east-west fault near the north base of West Chinati Peak. Amsbury recognized 5 subdivisions (Tc1 through Tc5) of the Chinati Mountain Group. Three units were correlated with the lower three subdivisions recognized by Rix in the Chinati Park quadrangle. In addition, Amsbury mapped a small outcrop of Tc1 basal conglomerate and up to 1,000 feet of Tc3 trachyandesite exposed as multiple flows in the north face of West Chinati Peak.

Shafter Area

The low hills near Shafter are carved from interbedded sedimentary rock and flows that crop out in parts of four quadrangles. Geologic mapping in many parts of Trans-Pecos Texas after Rix completed his map has shown Buck Hill Group to be an inappropriate name for rocks exposed near Shafter. A greater variety of rocks occurs within this sequence than was exposed at outcrops in the Chinati Peak quadrangle. After detailed mapping in the Presidio and

Ocotillo quadrangles and reconnaissance surveys in the Cienega quadrangle, Dietrich (1966) formally proposed the name Morita Ranch Formation for the volcanic rocks that overlie a surface eroded on pre-Cenozoic strata and underlie the Perdiz Conglomerate at the southeastern end of the Chinati Mountains.

In contrast with the silicic to intermediate compositions typical of the Chinati Mountain and Shely Groups, a high proportion of the flows in the Morita Ranch Formation are basaltic. The basalt Rix mapped as Unit T1 pinches out north of Shafter in the Chinati Peak quadrangle. Outcrops of basalt porphyry Tm2 (Rix's Unit T2) are extensive near Shafter and in northern Presidio quadrangle. Ash-flow tuff Tm3a, which Rix mapped as Unit T3, occurs within a thick sequence of rhyolitic flows and tuffs (Tm3b) exposed in the Presidio, Ocotillo, and Cienega quadrangles. The rhyolitic sequence also includes beds that probably are laterally continuous with the flow breccia Rix mapped as the lower part of Unit T4. Both the trachyte (Rix's upper part of Unit T4) and basalt Tm4 are younger than the rhyolitic sequence, but relative age of the trachyte and basalt has not been determined. Additional members of the Morita Ranch Formation probably will be found during detailed mapping in the Cienega quadrangle.

Correlation of Volcanic Rocks near the Chinati Mountains

Relative age of the Shely and Vieja Groups is well established from nearly continuous exposures in the Pinto Canyon area. The basal flows of the Shely interfinger with tuff beds above the red siltstone marker in the Capote Mountain Tuff. Brite Ignimbrite overlies Shely units as high as Ts6; probably all of the Shely Group is older than the Brite.

Relative age of the Shely and Chinati Mountain Groups cannot be directly established by superposition. A major east-west fault separates volcanic rocks in the two groups in the Pinto Canyon area. Relative movement on the fault (down to the south) is established by outcrops of Chinati Mountain Group volcanic rocks south of the fault at the same elevation as pre-Cenozoic outcrops north of the fault. Although structural complications could alter the picture, the probable relative age is Shely older than Chinati Mountain Group (Pl. I).

The Shely Group and the Morita Ranch Formation have one common point for correlation. Ignimbrite Ts6 of the Shely Group is a distinctive rock characterized by abundant lithic fragments. Similarity in lithology led Amsbury (1957, 1958) to suggest a correlation of Ts6 and the lower part of Rix's "Unit T4 of the Buck Hill Volcanic Series." Identification of this distinctive rock in several small outcrops along the face of Cuesta del Burro between the Pinto Canyon area and northeastern Chinati Peak quadrangle has confirmed the correlation. The relative age of lower units in the two different successions of volcanic rocks cannot be determined with available data.

Perdiz Conglomerate is younger than the Chinati Mountain Group because the conglomerate contains abundant clasts from lavas in the Chinati Mountain Group. A thin edge of the Perdiz extends eastward to Tascotal Mesa where it separates the Tascotal and Rawls Formations. Indirectly, this suggests the Chinati Mountain Group is older than the Rawls Formation of the Bofecillos Mountains.

CONCLUSIONS

A thick deposit of interbedded flows and sediments accumulated in the area that is now Presidio, Brewster, and Jeff Davis counties during the episode of Tertiary volcanism. Subsequent erosion carved the deposit into precipitous mountain masses separated by relatively flat intermontane areas.

Flow rocks are conspicuous because they resist erosion and generally crop out in mountains, hills, or mesas, but the volcanic deposits are predominantly sediments. Lavas ranging from rhyolite to basalt and ash-flow tuffs are distributed irregularly through the thick deposit.

Flows and pyroclastic debris that formed this deposit came from several centers of eruption, each consisting of one or more vents. Deposits that accumulated near a vent during the eruptive episode were predominantly flow rock. Ash and other sediments would be preserved only in isolated pockets that locally separated the flows. The proportion of flow rock decreases sharply with increase in distance from the vent; flow rock is rare between widely separated eruptive centers.

A unique succession of volcanic deposits accumulated around each center of eruption. Future geologic work should include more detailed descriptions of the rock units in several vent areas. Interfmgering mappable units provide one or more points of correlation between units erupted from different centers. Rare widespread units provide a correlation between several successions of volcanic rock.

The Mitchell Mesa-Brite Ash-flow Tuff is a regional marker bed that permits correlation of volcanic rocks over much of the area under consideration in this report. The chart (Pl. I) of stratigraphic sections has been constructed with this extensive tuff as the datum.

Basal volcanic deposits are not of uniform age throughout the area. Flows and pyroclastic debris began accumulating in some areas while other areas were still eroding. Fossils and radiometric dating methods can provide relative ages for units that exhibit considerable differences. The methods are less precise than physical correlation through superposition for units near the same age.

Beds near the base of the volcanic section in Big Bend National Park probably are the oldest volcanic deposits within the area. In contrast, the basal beds in volcanic deposits overlying pre-Cenozoic highs in the Chinati Mountains and near the Solitario in the Bofecillos Mountains are quite young.

Significant sections of rocks younger than the Mitchell Mesa-Brite Ash-flow Tuff are present in the Chisos Mountains of Big Bend National Park, Bofecillos Mountains, and Chinati Mountains. Better correlation data may demonstrate sections of younger rocks in the Davis Mountains. The Chinati Mountain Group probably is older than the Rawls Formation, so the youngest volcanic rocks in the Big Bend region of Trans-Pecos Texas are either in the Chisos or the Bofecillos Mountains.

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Index

age, dating, potassium-argon: 2, 4, 5, 6, 7, 9, 10
Aguja Formation: 5
Alamito Creek: 14, 18, 26
Alamo Creek: 5
Alamo Creek Basalt: 4, 5, 8, 9, 11, 12, 24
Alpine, Texas: 14
Amsbury, D. L.: 25, 26, 27, 28
Anderson, J. E., Jr.: 19, 21, 22
Apache Mountains: 1
Ash Spring Basalt: 4, 5, 6, 11, 12, 18

Bandera Mesa: 12
Barrel Springs Formation: 20, 21, 22
Barrilla Mountains: 19–20, 23
basal conglomerate: 15
Bee Mountain: 6
Bee Mountain Basalt: 4, 6, 7, 8, 11, 12
Bell Valley Formation: 23
bench mark, Tule Mountain Member near: 13
Big Bend National Park: 1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 18, 24, 26, 29
Big Hill: 12, 13
"birds-eye" subdivision of Rawls Formation: 5, 8, 18
Black Gap: 6, 12
Black Mesa: 5
Black Peaks Formation: 3
Blue Creek: 5, 9
Bofecillos Creek Canyon: 18
Bofecillos Group: 14–19
Bofecillos Mountains: 2, 6, 7, 13, 14, 15, 16, 17, 18, 19, 23, 26, 28, 29
Bracks Rhyolite: 23, 25, 27
Brewster County: 3, 29
Brite Ignimbrite: 2, 22, 23, 25, 26, 27, 28
Brite ranch: 25
Brooks Mountain Formation: 20, 22–23
Buck Hill Group: 14, 27
Buck Hill quadrangle: 13, 14, 24
Buck Hill Volcanic Series: 13, 14, 26, 27, 28
Buckshot Ignimbrite: 23, 24–25, 27
Burro Mesa: 8, 9, 10, 13
Burro Mesa Riebeckite Rhyolite: 10, 11, 12

Caballos Novaculite: 1
Canoe Formation: 3, 4, 5, 12
Capote Creek: 25
Capote Draw: 25
Capote Mountain: 25
Capote Mountain Tuff: 23, 25, 27, 28
Capote Peak: 25
Capote Rim: 25
Casa Grande: 9
Casa Piedra: 26
Castolon area: 4
Cathedral Mountain quadrangle: 14, 18
Cerro Castellan: 5, 6, 7, 9
Chambers Tuff: 23, 24, 25 27
Chimney Rock: 12
Chinati Mountain Group: 26, 27, 28, 29
Chinati Mountain Volcanic Series: 27
Chinati Mountains: 18, 23, 26–28, 29
  pluton: 12
Chinati Peak quadrangle: 26–27, 28
Chisos Formation: 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 18
Chisos Mountains: 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 19, 23, 29
Cienega Mountains: 26
Cienega quadrangle: 28
Clabaugh, Stephen E.: 2
Cleveland Triangulation Station: 25, 27
collapsed caldera: 12
Colmena Tuff: 23, 24, 25, 27
Colorado Canyon: 13
Colton, C. R.: 22
Comanchean limestone: 4
conglomerate, basal: 15
Contrabando Dome: 13, 15, 17
correlation, volcanic rocks, near Chinati Mountains: 28
Cottonwood Springs Basalt: 13
Cowboy Boot: 10
Cow Heaven anticline: 4, 5
Cretaceous: 1, 3
Crossen Trachyte: 13, 14
Cuesta del Burro: 26

Darton, N. H.: 25
Davis Mountains: 19, 20, 24, 29
  central: 20–23
  northern: 21
  southern: 13
Dawson Creek: 5
DeFord, Ronald K.: 2, 23
Delaware Mountains: 1
Del Norte Mountains: 1
Dietrich, J. W.: 14, 17, 18, 28
Duff Formation: 13, 14

Eifler, G. K., Jr.: 15, 19, 21, 22, 23, 24, 27
Ellison, Samuel P., Jr.: 2
Elms, M. A.: 13, 14, 15, 24, 26
Emory Peak: 10
Eocene, Lower: 5
  Middle: 3, 4
Eppenauer Ranch Basalt: 21, 22
Erickson, R. L.: 12, 16, 17

Fort Davis-Toyahvale highway: 19
fossil wood: 3
Frenchman Hills: 26
fresh-water clams: 3
  gastropods: 9

Fresno Canyon: 13, 15, 16, 17
Fresno Creek: 12, 13, 16, 24
Fresno Formation: 15, 16–17
Fresno mine: 12

gaging station, Rio Grande: 16
gastropods, fresh-water: 9
geology and correlation: 3–28
Gill Breccia: 23, 24, 27
Glass Mountains: 1
Goat Canyon Formation: 20, 22
Goat Mountain: 7, 8
Goldich, S. S.: 13, 14, 15, 16, 17, 24, 26
Guadalupe Mountains: 1

Hannold Hill Formation: 3
Hazzard, R. T.: 3, 4, 5, 11, 13, 15, 26
Huelster Formation: 19–20, 23

Javelina Formation: 3, 5, 10
Jeff Conglomerate: 5, 15, 19, 23–24, 27
Jeff Davis County: 29
Jones Formation: 20, 21, 22
Jordan Gap quadrangle: 14

Keith, N. L.: 25
King, P. B.: 11
Kit Mountain: 5, 8, 9

Lajitas Mesa: 4, 12, 13, 15
Lajitas quadrangle: 17
Lajitas, Texas: 12
La Mota Mountain: 18
Laramide fold: 27
Laramide revolution: 4
Limpia Canyon: 20, 21
Loma Plata anticline: 27
Lonsdale, J. T.: 3, 4, 5, 11, 13, 15, 23, 26
Lost Mine Rhyolite Member: 10, 11
lower and upper rhyolites: 20, 21, 22

McAnulty, W. N.: 14
McCutcheon Volcanic Series: 19
McGrew, B. J.: 24
McKnight, John F.: 2, 13, 14, 15, 16, 17, 24
mammalian remains: 9
Marathon area: 3
Maravillas Chert: 1
Marfa, Texas: 16, 23
Mariscal Mountain: 4, 11
marker bed, Mitchell Mesa—Brite Ash-flow Tuff: 29
Maxwell, R. A.: 3, 4, 5, 11, 13, 15, 23, 24, 26
Means Formation: 23
Medley Formation: 20, 22
Merrill Formation: 20, 21
Mexico: 5, 6, 7, 12
Mitchell Mesa—Brite Ash-flow Tuff marker bed: 29
Mitchell Mesa Ignimbrite: 23, 26
Mitchell Mesa Rhyolite: 2, 13, 15
Mitchell Mesa Tuff: 12, 13, 14, 15–16, 17, 25
Morita Ranch Formation: 18, 26, 28

Mount Locke Formation: 20, 21–22
Mule Ear Spring Tuff: 2, 4, 7, 8, 11, 12

Ocotillo quadrangle: 28

Paleocene: 5
Paleozoic: 1
  limestone: 4
paleomagnetic properties: 5
paleomagnetism studies: 7
  tests: 11
Panther Canyon: 17
Panther Dome: 13
Pen Formation: 9
Perdiz Conglomerate: 23, 26, 28
Persimmon Gap: 3
Petan Basalt: 18, 23, 25–26, 27
Petan ranch: 25
Peterson, J. E.: 25
Pinto Canyon: 25, 26, 28
  area: 27
pluton: 11, 12
potassium-argon age dating: 2, 4, 5, 6, 7, 9, 10
Potato Hill Andesite: 13, 14
Precambrian: 1
Presidio County: 3, 14, 18, 29
Presidio quadrangle: 27, 28
Presidio, Texas: 16
Primero Dome: 13
Pruett Formation: 13, 14
pumice fragments: 16

Quaternary gravel: 26
Quinn, J. H.: 3, 23

Ramsey, J. W., Jr.: 23, 25, 26
Rancheria Hills: 18
Rawls Basalt, Formation: 5, 14, 15, 16, 17–19, 26, 28, 29
Rawls ranch: 17
Redford, Texas: 13, 16
rhyolites, lower and upper: 20, 21, 22
Rim Rock Country: 22, 23–26, 27
Rio Grande: 5, 14, 15, 17
  gaging station: 16
Rix, C. C.: 21, 22, 27, 28
Round Mountain: 5, 9

San Carlos: 23, 25
  basin: 25
sanidine crystals: 16
Santana Mesa: 13, 17
Santana Tuff: 15, 16, 17
Santiago range: 1
Sawtooth Mountain: 22
Seven Springs Formation: 19, 20, 23
Seward, C. L.: 13, 14, 16, 17
Sewell, C. R.: 24, 25
Shafter area: 27–28
Shafter, Texas: 26, 28
Sheep Canyon Basalt: 13, 14
Sheep Pasture Formation: 20, 21

Shely Group: 26, 27, 28
Shipman, O. L.: 25
Sierra de Chino: 8, 11
Sierra del Carmen range: 1, 6, 12
Sierra Vieja: 23
Smoky Creek: 8
snails: 3
Solitario: 1, 15, 16, 26, 29
  area: 3
  uplift: 14
South Lajitas Mesa: 12, 13, 16
South Rim: 4
South Rim Formation: 3, 9–11, 13
Star Mountain: 19
Star Mountain Rhyolite: 19, 20, 21, 22, 23

T50 unit: 21, 22
T60 unit: 21, 22
Tapada Canyon: 17
Tapada Dome: 13
Tascotal Formation: 14, 26, 28
Tascotal Mesa: 13, 14, 16, 17, 26
  quadrangle: 13, 17
Terlingua Arch: 3, 4
Terlingua monocline: 14, 16, 17
Terlingua quadrangle: 13
Tertiary, Early, volcanic rocks: 1
Three Dike Hill: 13, 17
Tierra Vieja: 23
Tornillo Clay: 4
Tornillo Flat: 4
Tortuga Mountain: 5
Trap Mountain: 10
Tule Mountain: 6, 7, 8
Tule Mountain Trachyandesite: 2, 4, 7, 8, 9, 11, 12, 13, 15
Twiss, P. C.: 23

Udden, J. A.: 4, 11
Uintacyon sp.: 9

Vaughan, T. W.: 23, 25
Vieja Group: 23, 24, 26, 27, 28
Vieja region: 25
Vieja Rim: 23, 24
volcanic rocks, correlation of, near Chinati Mountains: 28
  source of: 11–12

Wasp Spring Flow Breccia: 10, 11
Water Tower: 10
West Chinati Peak: 27
West Texas Geological Society: 26
Wild Cherry Formation: 20, 21, 22, 23
Wild Rose Pass: 20
Wilson, John A.: 2, 3, 4, 5, 11, 13, 15, 23, 26
Wire Gap: 12, 14, 17, 18
Wolfcampian age: 27
Wylie Mountains: 23