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UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

# LATE CRENOZOIC PHYSIOGRAPHIC EVOLUTION OF THE OCATE VOLCANIC FIELD, NORTH-CENTRAL NEW MEXICO

By

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and

Harald H. Mehnert

Open-File Report 80-928
1980

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Abstract

The Ocate volcanic field in northeastern New Mexico lies abreast the transition between the southern Rocky Mountains and the Great Plains physiographic provinces. The field consists of numerous basaltic to dacitic flows of limited extent, ranging in age from late Miocene to Pleistocene. The physiographic expression of these flows reflects their relative age. The oldest flows, 8.3 to 5.7 m.y. old, cap the highest mesas. These flows are underlain by stream gravels and appear to rest on a single surface or a series of nearly equivalent surfaces cut into the mountain interior at elevations near 3,000 m. Numerous accordant ridge tops, subsummits, and parks described by L. L. Ray and J. F. Smith in 1941 and 1943 in the adjacent Taos and Cimarron Ranges are also at elevations near 3,000 m and suggest that this surface was widespread during late Miocene time. This surface cuts across major Laramide structures and the various lithologies of the mountain interior; it extends eastward onto the Great Plains. The early volcanism was followed by episodic uplift and erosion now marked by three lower erosion surfaces. These surfaces are also preserved beneath volcanic rocks that are 4.8 to 4.1 m.y., 3.3 to 3.1 m.y., and 2.2 m.y. old. Of the four erosion surfaces, the two oldest are warped and locally displaced across the older Laramide fault zones, indicating that late Cenozoic uplift of the region involved differential movement between the Rocky Mountains and the Great Plains. Young basalts, having an age of 1.4 m.y., followed major stream valleys and are now nearly 125 m above the present stream levels. Finally, basalts 0.8 m.y. old, were erupted mainly onto older flows.

# Introduction

Volcanic rocks in the vicinity of Ocate, New Mexico (fig. 1) have

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Figure 1.--NEAR HERE

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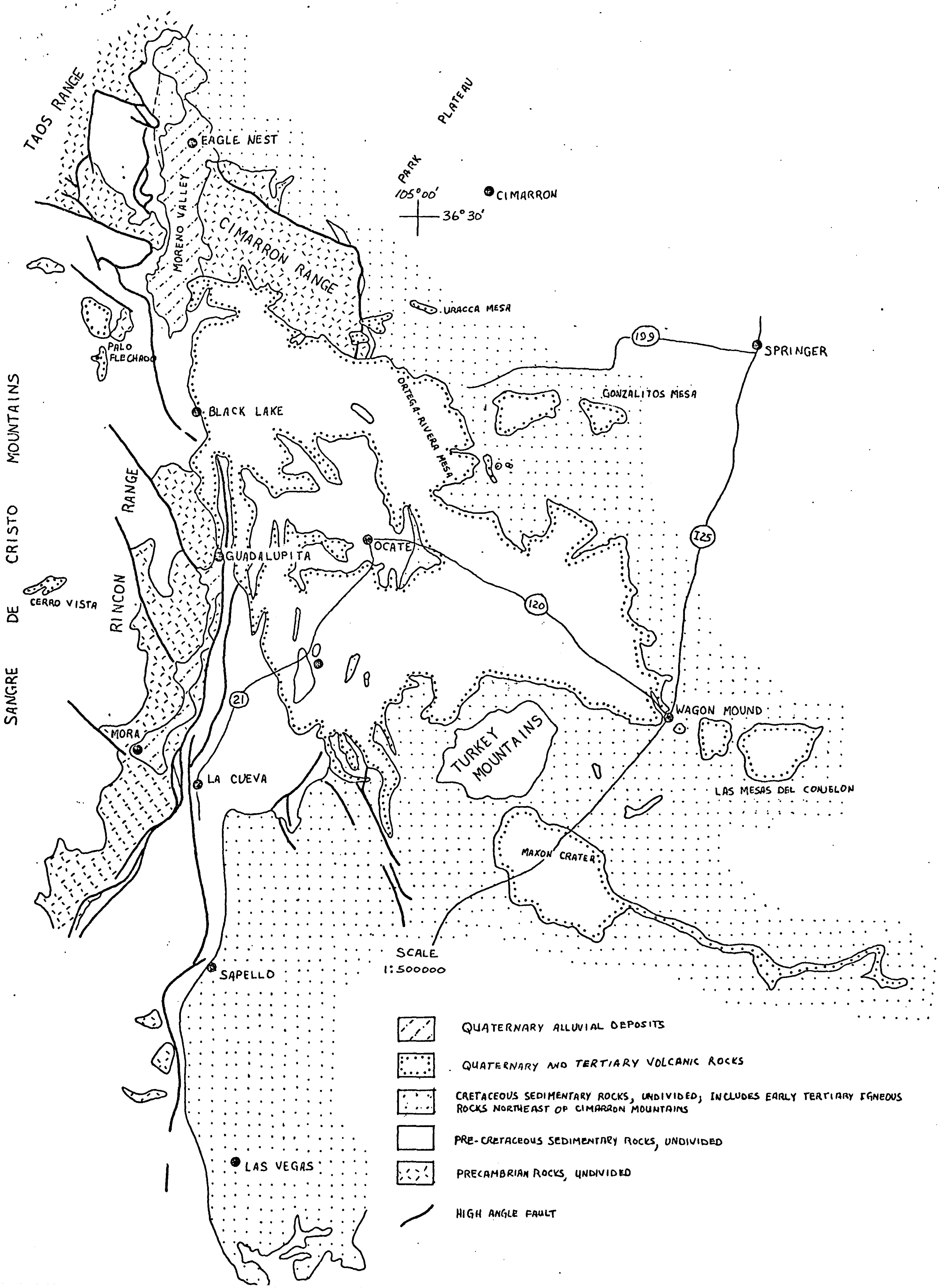
never been studied in detail. These rocks were first mentioned by Stevenson (1881) who described the physiography of the area and designated Ocate Mesa as the lava-capped plateau that extends southward from the Cimarron Range. This plateau almost completely surrounds Ocate Valley and the village of Ocate. Stevenson also recognized the continuity between basalt-capped mesas in the southern part of the volcanic field with Ocate Mesa. In keeping with Stevenson's early descriptions of the region, with his naming of Ocate Mesa, and with the location of Ocate more or less central to the volcanic field, this area will be referred to as the Ocate volcanic field.

The Ocate volcanic field extends from the southern part of the Cimarron Range in the southern Sangre de Cristo Mountains, southeastward to the vicinity of Wagon Mound (fig. 1). The field lies west of Interstate 25 except at Wagon Mound, is bounded on the north by State Road 199 and on the west by the Moreno and Cuadalupita Valleys (fig. 2). The flows extend as far south as the Turkey Mountains but do not completely surround the domal uplift. Flows vented on the southeast side of the Turkey Mountains and flowed eastward, following the drainages of the Mora and Canadian Rivers.

Figure 1.--Generalized geologic map of the Ocate volcanic field and vicinity, New Mexico.


TAOS RANGE
EAGLE NEST
PARK PLATEAU
105°00'
36°30'
CIMARRON
MORENO VALLEY
CIMARRON RANGE
URACCA MESA
PALO FLECHADO
SPRINGER
GONZALITOS MESA
BLACK LAKE
ORTEGA-RIVERA MESA
SANGRE DE CRISTO MOUNTAINS
RINCON RANGE
GUADALUPITA
OCATE
CERRO VISTA
120
199
I25
21
WAGON MOUND
TURKEY MOUNTAINS
MORA
LA CUEVA
LAS MESAS DEL CONJBLON
MAXON CRATER
SCALE
1:500000
SAPELLO
LAS VEGAS
QUATERNARY ALLUVIAL DEPOSITS
QUATERNARY AND TERTIARY VOLCANIC ROCKS
CRETACEOUS SEDIMENTARY ROCKS, UNDIVIDED; INCLUDES EARLY TERTIARY IGNEOUS ROCKS NORTHEAST OF CIMARRON MOUNTAINS
PRE-CRETACEOUS SEDIMENTARY ROCKS, UNDIVIDED
PRECAMBRIAN ROCKS, UNDIVIDED
HIGH ANGLE FAULT

Darton (1928) was the first to completely outline the distribution of volcanic rocks in the field. Detailed geologic mapping around Ocate by Bachman (1953) refined the areal extent of the field. Parts of this area have been mapped and described by Smith and Ray (1943) and Robinson and others (1964) at the southern end of the Cimarron Range, by Simms (1965) south of Rayado, by Schowalter (1969) in the Lucero area, by Ray and Smith (1941) and Petersen (1969) in and near the Moreno Valley, and by Johnson (1974, 1975) in the Rainsville and Ft. Union areas. Radiometric age data have been obtained by Stormer (1972), Hussey (1971) and P. W. Lipman (written commun., 1978) and sampling for geochemical analyses was made along a highway traverse by Aoki and Kudo (1975). The physiography of the eastern part of the Sangre de Cristo Mountains has been described by Lee (1921), Fenneman (1931), Ray and Smith (1941), Smith and Ray (1943), and Levings (1951), but none have dealt directly with the Ocate area.

## Physiographic and Geologic Setting

The volcanic field appears to cross the transition zone between the southern Rocky Mountains and the Great Plains physiographic provinces. This boundary, based on structure and topography, is not clearly defined in northeastern New Mexico. Lower Tertiary strata, gently inclined to the east, rise to more than 3,000 m in elevation on the west side of the Raton Basin before the hogbacks of Cretaceous strata are reached. Lee (1921) drew the boundary between the two provinces along the Cretaceous hogbacks, defining the boundary solely on structural grounds, and described the mountainous Raton Basin as the highest, most severely dissected part of the Great Plains province. Lee continued this boundary southward from Colorado, around the east side of the southeast-trending Cimarron Range and then westward to the southern part of the Moreno Valley. From the Moreno Valley he extended the boundary due south toward Las Vegas along hogbacks held up in part by the Permian Glorieta Sandstone (figs. 1, 2).

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Figure 2.--NEAR HERE

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Figure 2.--Block diagram of the Ocate volcanic field showing major geographical features.

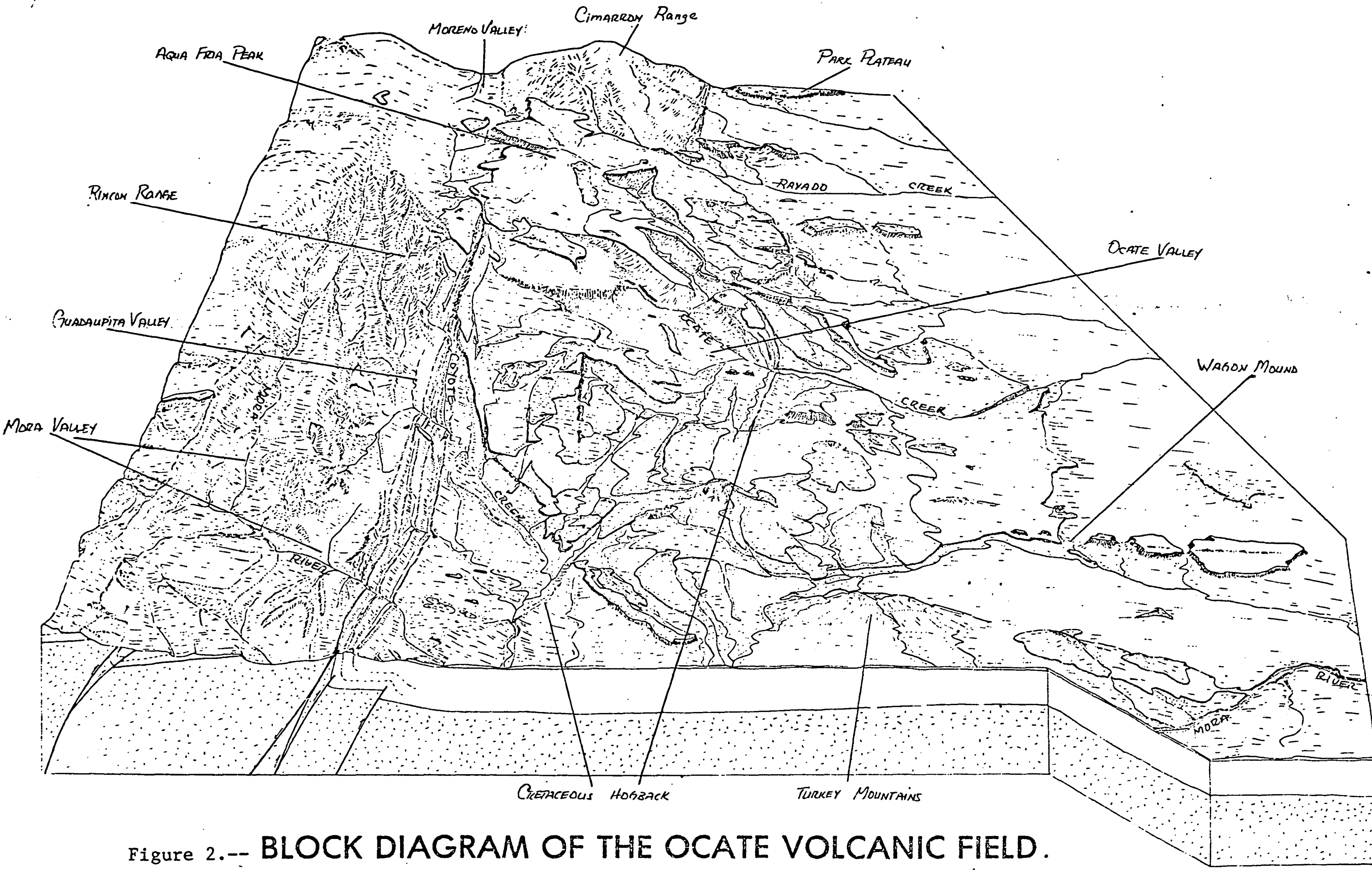


Figure 2.-- BLOCK DIAGRAM OF THE OCATE VOLCANIC FIELD.

Laramide structures in this area suggest instead that this physiographic boundary extends directly south from the Cimarron Range. In the Sangre de Cristo Mountains, Laramide-age structures consist of a series of west-tilted, north-trending basement blocks bounded on the east and west by high-angle reverse faults. From Las Vegas northward, the major frontal fault that bounds the east side of the uplift trends north towards the Moreno Valley (fig. 1); however, in the vicinity of La Cueva, this zone bifurcates, defining another gently west-tilted block on the east. The southeast margin of this block is marked by moderately upturned Paleozoic and Mesozoic sedimentary rocks. This zone trends north-northeast, is locally covered by the Ocate volcanic field, and becomes strongly faulted where it merges with the high-angle faults that mark the eastern boundary of the Cimarron Range. Ray and Smith (1941) referred to the northern part of this basement block as the Cimarron block where it is composed entirely of Precambrian igneous and metamorphic rocks; it is separated from the southern, less strongly uplifted part, by a major northwest-trending high-angle fault. The Cimarron block, defined here as a continuous structural entity, is crecent shaped, convex eastward, and widest in the central part, pinching out north and south where its frontal faults merge with the major frontal faults of the Sangre de Cristo Mountains proper. The Cimarron block is herein interpreted to belong to the Rocky Mountain physiographic province. The western part of the Ocate volcanic field lies within the southern part of the Cimarron block and the western margin of the block roughly defines the westernmost extent of the volcanic field. The volcanic field crosses the eastern margin of the block and extends onto the Great Plains.

## Geomorphic Evolution

The Ocate volcanic field consists of numerous volcanic flows of limited extent, ranging in age from late Miocene to Pleistocene. The field ranges in elevation from over 3,000 m in the Sangre de Cristo Mountains to less than 1,800 m on the Great Plains. The physiographic expressions of these flows reflect their relative ages. Three major and one minor levels of basalt-capped mesas are present (figs. 3, 4). The

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Figures 3 & 4.--NEAR HERE

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highest volcanic rocks are oldest and erupted between 8.3 and 5.7 m.y. ago (table 1). The intermediate level basalts were erupted between 4.8

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Table 1.--NEAR HERE

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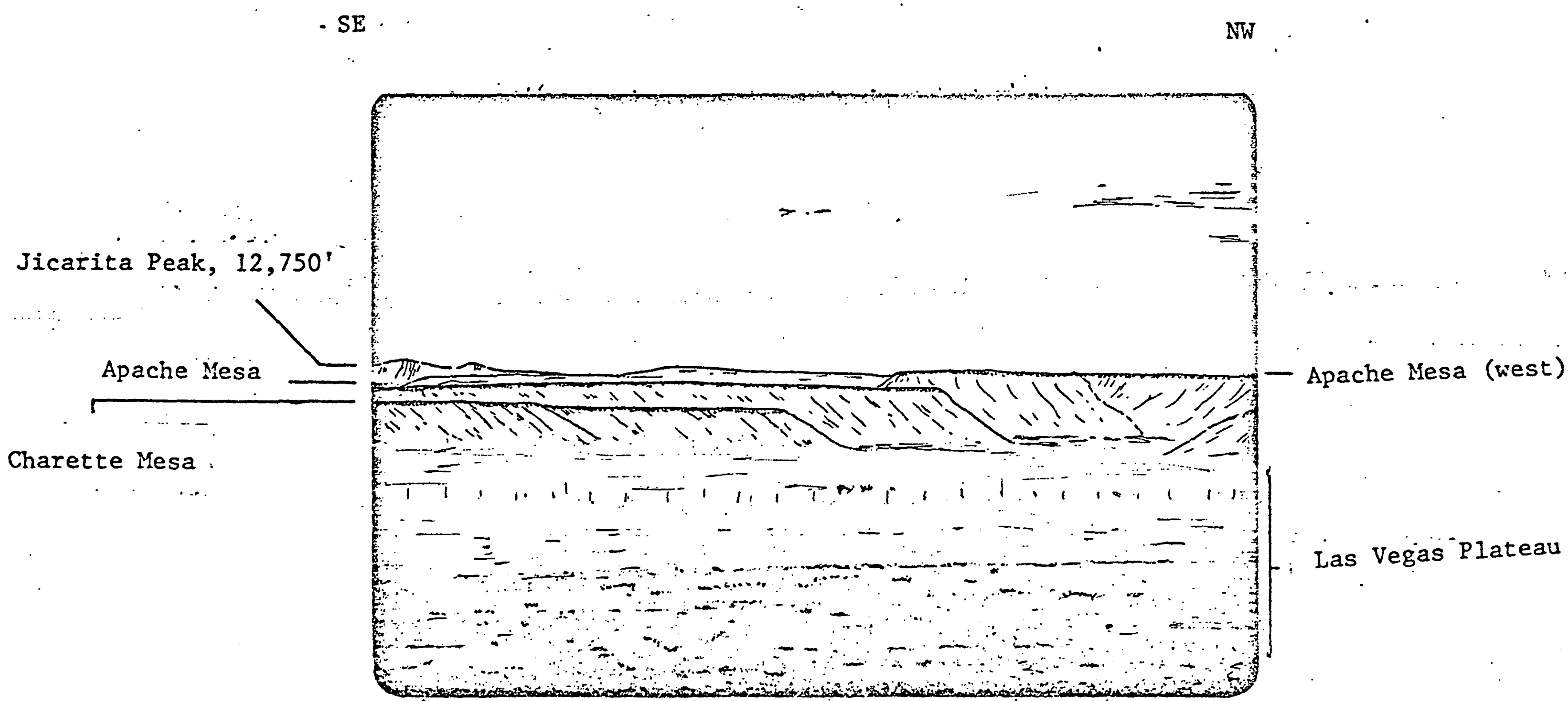
and 4.1 m.y. ago. Flows, 3.3 and 2.2 m.y. old, cap the two lowest pediments in the area. The youngest flows, dated at 0.8 m.y. flowed onto surfaces much as they appear today.

Figure 3.--Great Plains Province, northeastern New Mexico. View to the southwest; snow-capped Sangre de Cristo Mountains in background. There are four major physiographic levels. They are, from highest to lowest: Apache Mesa (west), Apache Mesa, Charette Mesa, and the Las Vegas Plateau.



SE
NW
Jicarita Peak, 12,750'
Apache Mesa
Charette Mesa
Apache Mesa (west)
Las Vegas Plateau

Figure 4.--Schematic topographic profile showing the physiographic relations between various erosion surfaces and their overlying basaltic rocks in the Ocate volcanic field and the Raton Basin. Dashed lines connect correlative surfaces.

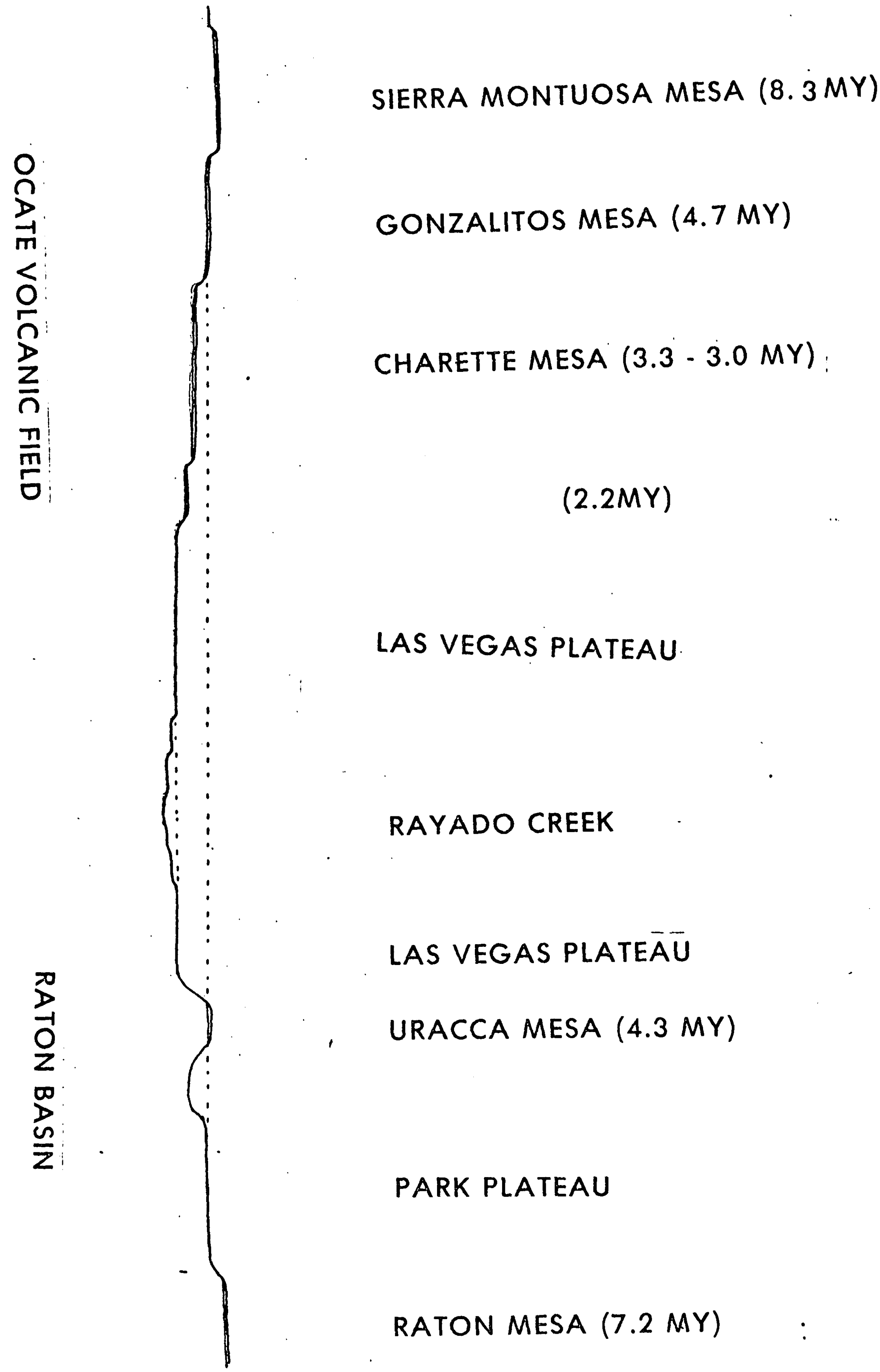

OCATE VOLCANIC FIELD
RATON BASIN
SIERRA MONTUOSA MESA (8.3 MY)
GONZALITOS MESA (4.7 MY)
CHARETTE MESA (3.3 - 3.0 MY)
(2.2MY)
LAS VEGAS PLATEAU
RAYADO CREEK
LAS VEGAS PLATEAU
URACCA MESA (4.3 MY)
PARK PLATEAU
RATON MESA (7.2 MY)

Table 1.--Late Cenozoic K-Ar ages of basaltic flows of the Ocate volcanic field, northeastern New Mexico.

Table 1.--Late Cenozoic K-Ar ages of basaltic flows of the Ocate volcanic field, northeastern New Mexico

| Locality | Field no. | Location (Long. W., Lat. N.) | $K_2O$ (percent) | $*Ar^{40}$ ($10^{-10}$ moles/gram | $*Ar^{40}$ (percent) | Age ±2 (m.y.) |
|---|---|---|---|---|---|---|
| Cerro del Oro | CMV-1 | 36°04′, 105°55′ | 1.93, 1.95 | 0.022 | 15.1 | 0.81±0.14 |
| Maxon Crater | 68L-189 | 35°53′, 104°52′ | 1.15, 1.15 | 0.023 | 20.9 | 1.37±0.15* |
| Wagon Mound (lower mesa) | 68L-228 | 36°03′, 104°42′ | 1.31, 1.29 | 0.041 | 32.3 | 2.20±0.17* |
| Charette Mesa | 68L-187 | 36°01′, 104°42′ | 0.74, 0.74 | 0.033 | 21.5 | 3.07±0.34* |
| White Peak | OMV-2WPA | 36°07′, 105°02′ | 2.08, 2.08 | 0.098 | 8.3 | 3.53±1.20 |
| Guadalupita Valley | 1C2a | 36°04′, 105°17′ | 2.40, 2.38 | 0.132 | 18.0 | 3.83±0.46 |
| Do | 1C2b | do do | 2.36, 2.38 | 0.155 | 52.7 | 4.53±0.18 |
| La Mesa (south end) | 1L2 | 36°03′, 105°09′ | 1.29, 1.32 | 0.078 | 47.2 | 4.19±0.25 |
| El Cerro Colorado | 4C2 | 36°04′, 105°15′ | 2.13, 2.10 | 0.128 | 48.2 | 4.12±0.24 |
| Guadalupita Valley | 2C2 | 36°04′, 105°16′ | 2.64, 2.66 | 0.165 | 25.4 | 4.32±0.44 |
| Blake Lake | 68L-196 | 36°17′, 105°16′ | 1.98, 1.96 | 0.127 | 57.9 | 4.47±0.23 |
| Gonzalitos Mesa | GV-2 | 36°08′, 105°11′ | 1.64, 1.64 | 0.106 | 35.9 | 4.52±0.34 |
| Cerro Montoso | CMV-2 | 36°23′, 104°47′ | 1.17, 1.19 | 0.079 | 40.7 | 4.67±0.32 |
| Cerro Vista | 6CV-3 | 36°08′, 105°26′ | 1.48, 1.47 | 0.122 | 47.3 | 5.74±0.34 |
| Las Mesas del Conjelon | 68L-188 | 36°00′, 104°42′ | 1.16, 1.18 | 0.100 | 55.7 | 5.94±0.40* |
| Sierra Montuosa | GV-6 | 36°14′, 105°09′ | 1.79, 1.80 | 0.214 | 46.9 | 8.34±0.50 |

Constants: $K^{40} = 0.581X10^{-10}/yr$ $= 4.963X10^{-10}/yr$ $K^{40}/K = 1.167X10^{-4}$

* Ages provided by P. W. Lipman and H. H. Mehnert

Volcanic rocks older than 5 million years

Basalts older than 5 m.y. preserve beneath their cover the highest gravel-covered surfaces in this area. The oldest basalts, dated at 8.3 m.y., are present on Sierra Montuosa in the northwestern part of the field (fig. 5).

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Figure 5.--NEAR HERE

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Basalts dated between 5 and 6 m.y. were erupted from widely separated vents. At Wagon Mound Basal flows at Las Mesas del Conjelon (fig. 5) have been dated at 5.9 m.y. High flows along the west side of the field (fig. 5) and at the present drainage divide of the Sangre de Cristo Mountains in the Cerro Vista 7 1/2 Quadrangle have been dated at 5.7 m.y.

Figure 5.--Distribution of volcanic rocks erupted prior to 5.5 m.y. ago. Areas identified on the diagram are outcrops of these rocks.

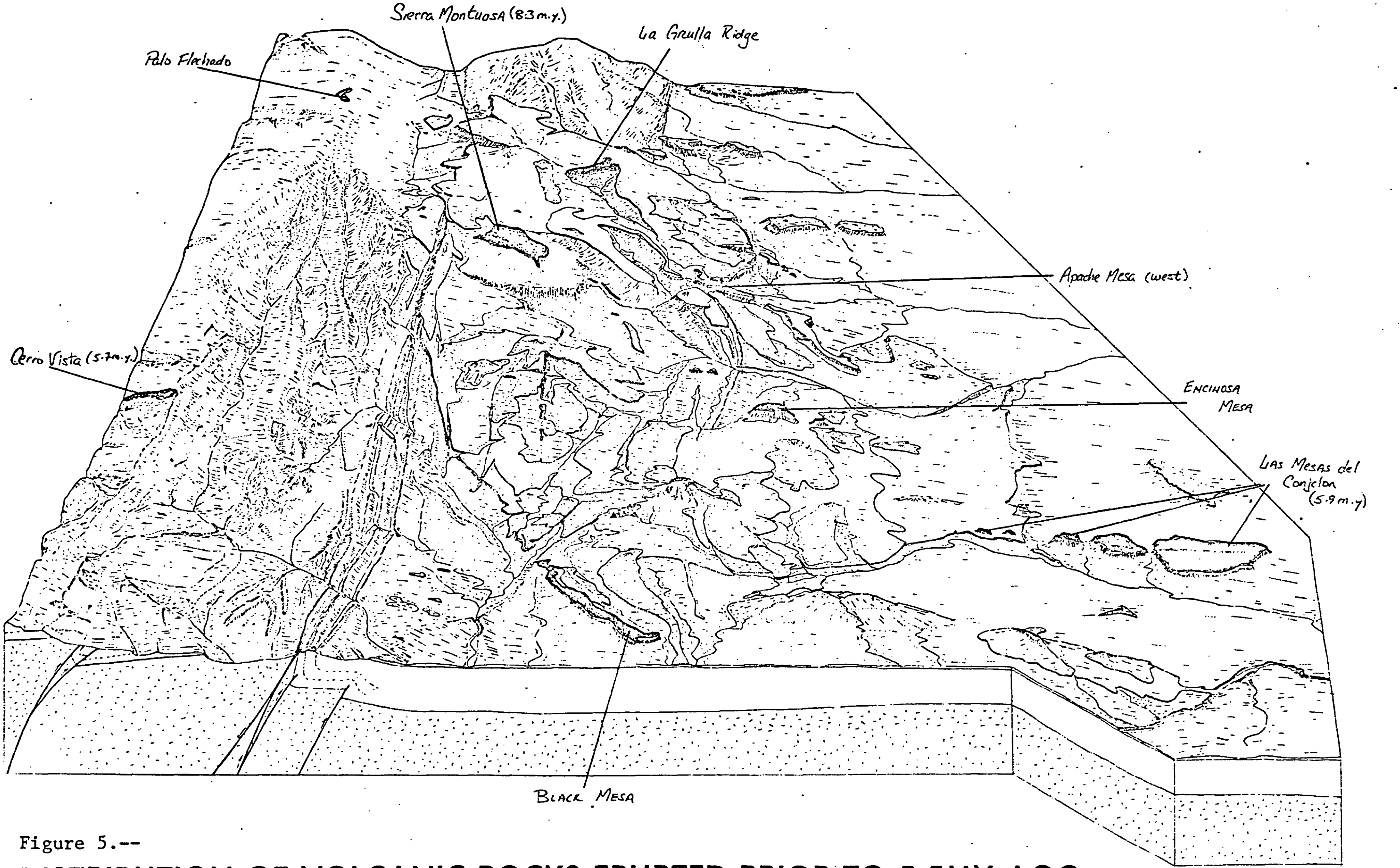


Figure 5.--

DISTRIBUTION OF VOLCANIC ROCKS ERUPTED PRIOR TO 5.5MY AGO

Sierra Montuosa Mesa is a northwest elongate mesa held up by basalt, reaching an elevation of 3,136 m. The mesa stands above the slightly lower Ocate Mesa, a surface held up by the largely flat lying Permian Glorieta Sandstone.

The base of the flows along the southwest side of the mesa is about 100 m higher than on the northeast side, suggesting that the flows occupy, in part, a gentle depression. Well-rounded stream gravels, cobbles, and boulders are well exposed at the base of the flows along the southwest side of the mesa.

High basalts, east of Aqua Fria Peak, cap the 3,000 m high La Grulla Ridge (Figure 5). The basalts overlie abundant, rounded pebbles of Precambrian granite, quartz-feldspar-muscovite gneiss, and pegmatite. The underlying sedimentary rocks and gravels are not exposed along the northwest side of the ridge where younger basalt flows have covered this contact. The base of the basalts is about the same elevation as those on the northeast side of Sierra Montuosa Mesa. The similarity in elevation of these basalts suggests that they are roughly equivalent in age. The source of the basalts on La Grulla Ridge is not known; because they lie at a slightly lower elevation than the basalts of Sierra Montuosa Mesa, they may represent the more distal parts of the same flow system.

Olivine basalts in the Cerro Vista area, dated at 5.7 m.y., consist of a northeast-trending flow-capped ridge about 3 km in length. The base of the basalts is inclined to the southwest, ranging in elevation from about 3,017 m at the divide to near 2,395 m at the southwesternmost exposure; maximum elevation of the basalts is 3,060 m. The base of the basalts is higher southeast of the axial part of the exposure, suggesting that the flows occupy a southwesterly inclined paleovalley. The basalts were deposited on the Pennsylvanian Sandia Formation, and locally pebbles and cobbles of well-rounded Precambrian igneous and metamorphic rocks are present at this contact. These gravels are separated from the nearest Precambrian outcrops in the Rincon Range to the east by the Mora River valley (fig. 2). The valley floor is nearly 600 m below the base of the basalts and the underlying gravels. The crest of the Rincon Range rises nearly 900 m above the valley floor.

Several basalt flows near Palo Flechado Pass west of the Moreno Valley (Peterson, 1969) are described as thin local flows resting on lag gravels of the Miocene Carson Conglomerate (Just, 1937). The flows aggregate less than 15 m in thickness. Their geomorphic expression is similar to that of the 5.7 m.y. old basalts located in the Cerro Vista Quadrangle to the south.

High-level olivine basalts at Wagon Mound stand as a series of east-west trending buttes and mesas that represent both volcanic necks and basalt-capped mesas (fig. 2). Santa Clara Mesa and The Wagon Mound are two highly dissected volcanic necks east of the main sequence of basalts that cap Las Mesas del Conjelon. These basalts lie on the Dakota Sandstone, Niobrara and Benton Formations, but are separated from them by thin gravels composed principally of Precambrian cobbles and pebbles. The base of the basalts is approximately 225 m above the lowlands to the south and about 100 m above the younger Charette Mesa flows to the northwest. The flows on Las Mesas del Conjelon were erupted from a series of vents and fissures that are alined with or parallel to the east-trending line defined by the two dissected vents that lie to the west of the mesa. These flows probably did not extend far beyond their present limits. Thickness of the flows is variable: as much as 75 m thick near vents, decreasing to 20-30 m at the present margins of the mesa.

Three mesas east and south of Ocate, capped by basalts older than about 5 m.y., rise 60 m above the widespread surface on which the 4 to 5 m.y. old basalts lie. They are, from north to south, Apache Mesa (west), Encinosa Mesa and Black Mesa (fig. 5). The source for these older basalts is not known. All flows are sinuous in plan, trend northwest, and the surface on which they lie dips gently southeast. At least one flow, the Apache Mesa (west) flow, is underlain by a thin veneer of gravel composed mainly of Precambrian pebbles and cobbles. Although these flows are widely separated, they all lie very close to the eastern margin of the Laramide-age Cimarron block. These basalts appear to be about the same age, older than the 4 to 5 m.y. volcanic sequence, were derived from individual centers probably located near the eastern edge of the Cimarron block, and may have been confined to broad, southeasterly inclined stream valleys.

The nearly equivalent elevations, near 3,000 m, of the highest basalts at Sierra Montuosa, La Grulla, Cerro Vista, and perhaps the Palo Flechado area (fig. 5), and their underlying gravels, suggest that these basalts were erupted onto the same surface or a series of surfaces of nearly the same elevation. This surface extended across major topographic depressions of today, as indicated by the source of gravels underlying these basalts. The numerous accordant ridge tops, subsummits and parks (Ray and Smith 1941; Smith and Ray 1943) in the adjacent Taos and Cimarron Ranges are probably remnants of this widespread surface.

The surface beneath the basalts on Las Mesas del Conjelon appears to represent the eastward extension of the surface beneath the physiographically highest basalts to the west. The basalts of Encinosa Mesa, Black Mesa, and Apache Mesa (west) rest on a surface that is physiographically equivalent to and apparently approximately coeval with those segments to the east and west. The surface beneath Las Mesas del Conjelon rises 9.5 m/km to Apache Mesa (west), then increases to 32m/km to the base of the basalts capping Sierra Monturosa Mesa. The change in gradient occurs at the eastern margin of the Cimarron block.

This surface cuts across diverse rock types and sharp structural breaks, suggesting that late Miocene time was marked by major erosion and pediplanation in the absence of tectonic activity. This surface is probably coextensive with the widespread late Miocene erosion surface in the front ranges of Colorado and Wyoming (Scott, 1963, 1975; Knight, 1953; Moore, 1959). And this surface probably represents the upland erosional area which supplied sediment for the Miocene and Pliocene Ogallala Formation, envisioned to have been deposited during a period of major crustal stability, characterized by pediplanation in the mountain interior, and by thin, sheet-like deposition in the adjacent plains (Scott, 1975; Frye and Leonard, 1957, 1959).

Volcanic rocks erupted between 4 and 5 million years ago

Basalts, andesites and minor dacites of the second age group are most abundant in the northwestern part of the volcanic field (fig. 6). These rocks cap Urraca, (4.3 m.y. old (Hussey, 1971)) Fowler,

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Figure 6.--NEAR HERE

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Rayado and Gonzalitos (4.7 m.y. old) Mesas located east-southeast of the Cimarron Range, and are the lowermost basalts of the Ortega and Rivera Mesas northeast of Ocate. Rocks of this age group apparently constitute the majority of the flows in and around the Aqua Fria Peak area and interfinger with 4.5 m.y. old volcanic rocks at Black Lake. Flows erupted from the north end of La Mesa and from Cerro Montoso (4.7 m.y. old) flooded the southern part of La Mesa (4.2 m.y. old) and parts of Le Febres Mesa. The basalt-capped Gallina Mesa, directly north of Ocate, is at equivalent elevations and distance above the present-day streams and is interpreted to belong to this period of volcanism. Four to 5 m.y. old basalts are present in Guadalupita Valley (4.3 m.y. old), to the north along Coyote Creek (4.7 m.y. old (Stormer, 1972)) and cap El Cerro Colorado (4.1 m.y. old).

Figure 6.--Distribution of volcanic rocks erupted between 4.0 and 5.0 m.y. ago. Areas identified on the diagram are outcrops of these rocks.

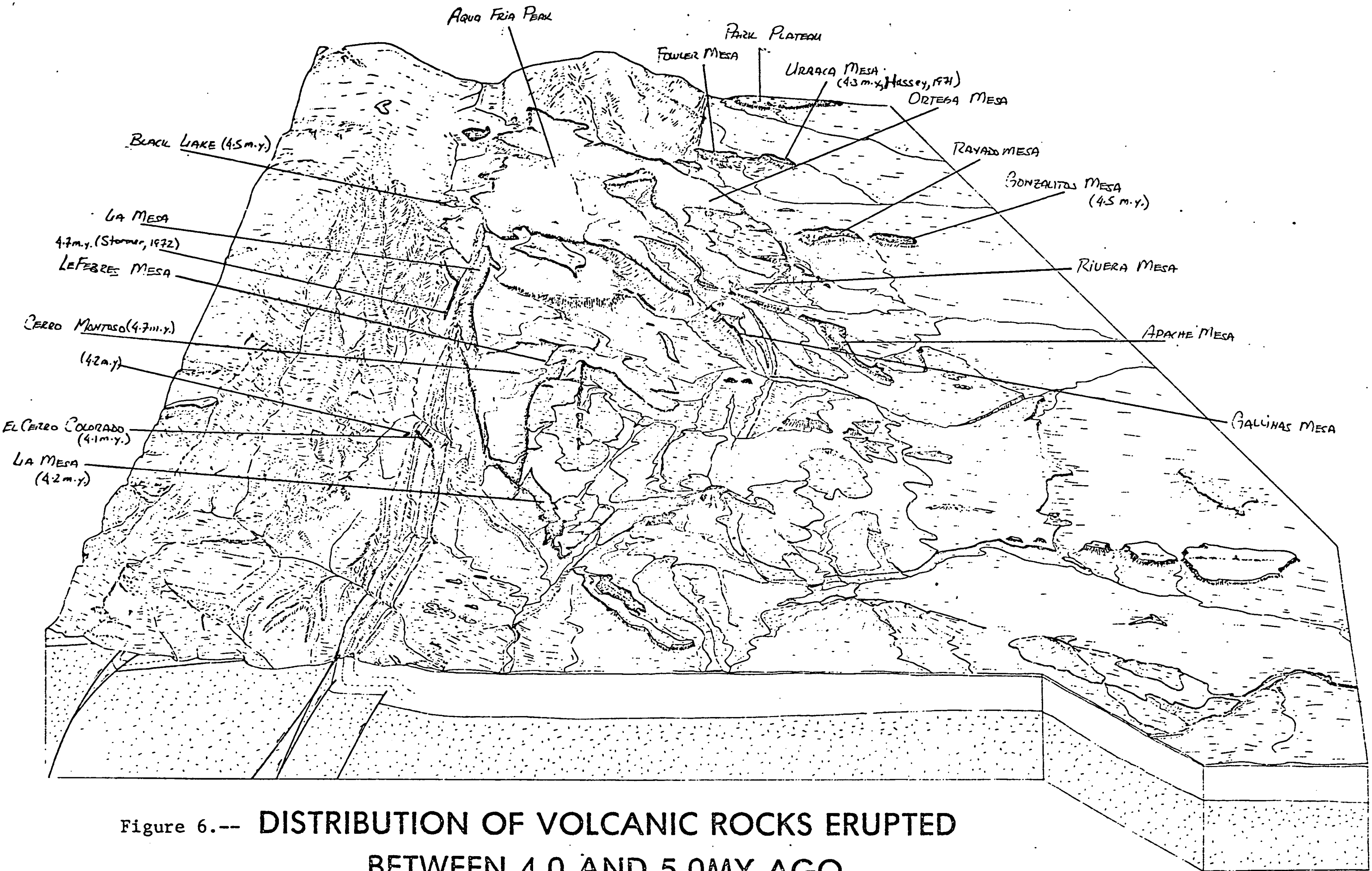


Figure 6.-- DISTRIBUTION OF VOLCANIC ROCKS ERUPTED BETWEEN 4.0 AND 5.0 M.Y. AGO.

Basalts in the northwestern part of the volcanic field, (fig. 6) rest on a southeasterly inclined surface covered by sparse to abundant gravels composed largely of Precambrian metamorphic and igneous rocks. This surface appears to be a compound surface formed in the early Pliocene by lateral corrasion of the ancestral Rayado Creek, but surmounted by small basalt capped mesas that preserve the late Miocene surface.

This surface extends from the Moreno Valley eastward onto the Great Plains, and includes Rayado, Gonzalitos and Urraca Mesas, which are east of the frontal faults bounding the Cimarron Range (fig. 6). Smith and Ray (1943) named the surface defined by these three mesas and the adjacent Fowler and Ortega-Rivera Mesas, the Urraca surface. They tentatively correlated this surface with the erosional surface of the Park Plateau, 10 km north of Urraca Mesa. The Park Plateau, which extends from Raton, New Mexico south to the Cimarron Range, is the highest surface beneath the late Miocene Raton Mesa surface, capped by 7.2 m.y. old (Stormer, 1972) basalts. The Urraca surface is equivalent to the Rayado surface of this report, which is the highest surface preserved beneath the 8.3 m.y. basalts of Sierra Montuosa Mesa. Basalts from Urraca Mesa were dated at 4.3 m.y. (Hussey, 1971) and those from the nearby Gonzalitos Mesa yielded a date of 4.7 m.y. By reason of the physiographic similarity between the Rayado surface and Sierra Montuosa surface in the Ocate area, and between the Park Plateau and the Raton Mesa surface to the north (figs. 2, 4), and the equivalence in elevation of the Park Plateau and the Urraca Mesa, near the Cimarron Range, the Park Plateau and the Rayado surface are interpreted to be the same.

This surface formed at some time between 5.7 m.y. ago (the age of the youngest basalts on a surface roughly equivalent to the Sierra Montuosa surface) and 4.3 m.y. ago (the age of the basalts on Urraca Mesa).

Figure 7 depicts, in a general way, the early Pliocene topography

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Figure 7.--NEAR HERE

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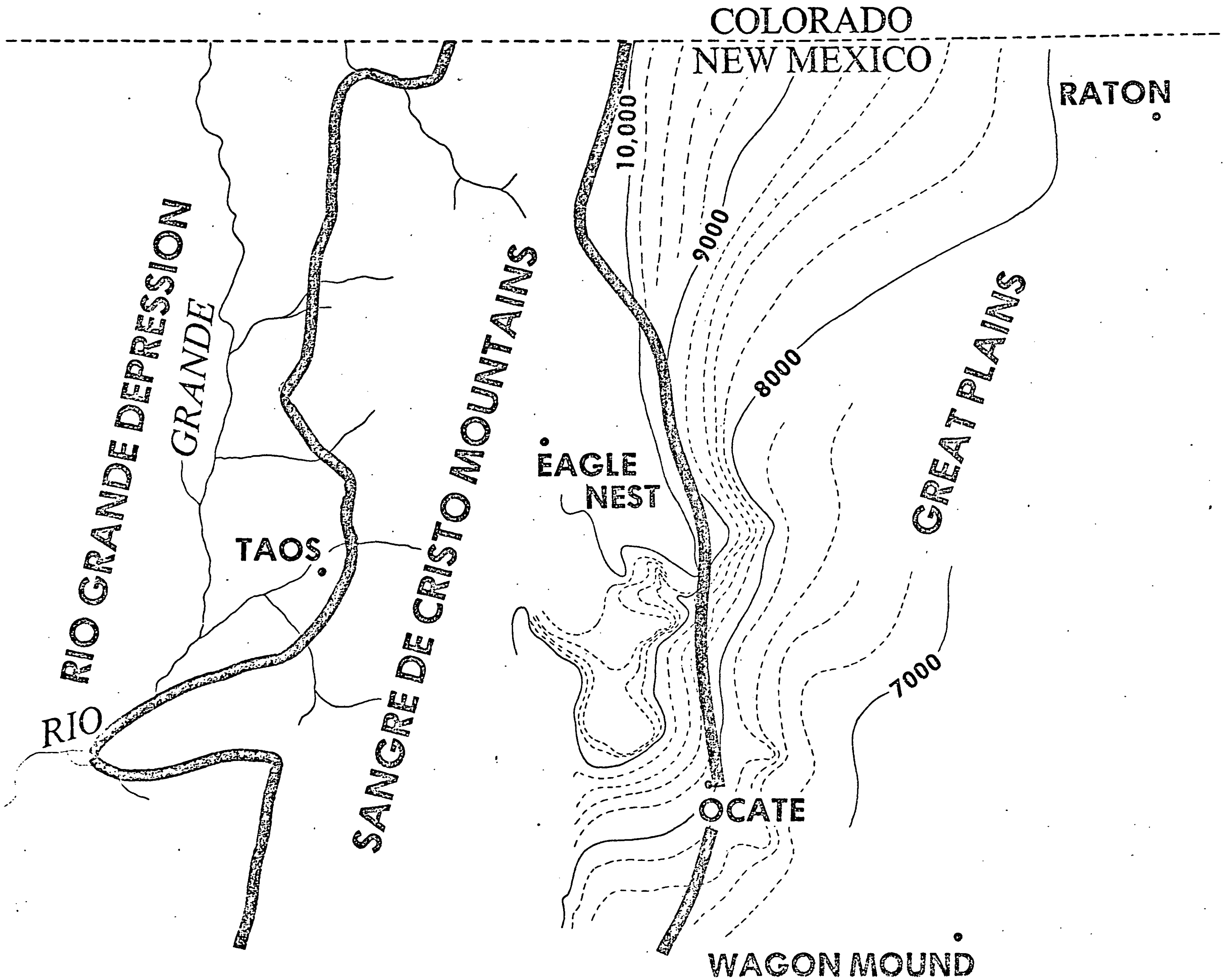
of this surface. The Park Plateau is marked by a gentle southeast slope with a concave upward profile. The steepest gradient is present near the Sangre de Cristo frontal faults. Southward, this surface contains areas of variable slope and profiles are both concave upward and downward. From the Moreno Valley on the west to La Grulla Ridge, the elevation of the Rayado surface decreases from nearly 3,000 m to about 2,850 m. East of La Grulla Ridge, the surface becomes more steeply inclined before again assuming a gentle southeast dipping gradient (figs. 2, 7). The zone of oversteepened gradient is roughly coincident with the eastern margin of the Laramide-age Cimarron block and with north-trending linear features observed on air photographs that cut across the basalts. Structure contours on this surface suggest that streams locally dissected this surface east of La Grulla Ridge before it was covered by volcanic rocks.

Figure 7.--Structure contour map drawn on the 4-5 m.y. old surface in the Ocate volcanic field and in the Park Plateau in the Raton Basin. Contour interval is 200 feet. Thousand foot contour lines are solid; intervening contour lines are dashed. Contour lines are approximately located.


COLORADO
NEW MEXICO
RATON
10,000
9000
8000
7000
GREAT PLAINS
EAGLE NEST
OCATE
WAGON MOUND
SANGRE DE CRISTO MOUNTAINS
TAOS
RIO GRANDE DEPRESSION
RIO
GRANDE

The overall planar character of the Rayado surface and its truncation of various lithologies and of major structural zones, are indicative of planation formed by the lateral corrosive action of streams. The break in slope east of La Grulla Ridge cannot be considered to have been present when this surface was formed. It is concluded that (1) the oversteepened gradient observed on the Rayado surface represents warping of that surface; (2) warping represents differential uplift between the Sangre de Cristo Mountains, to include the Cimarron block, and the Great Plains; and (3) the warping may have occurred prior to volcanism, as well as after this period of volcanic activity.

Basalts erupted from the Aqua Fria Peak area lie on the Rayado surface, and are continuous with the basalts in the Moreno Valley at Black Lake. But the Black Lake flows lie some 100 m below this surface. The youngest flows, which have not been dated, appear to have cascaded over an arcuate west-facing scarp held up by steeply dipping Paleozoic sedimentary rocks and that now separates the two levels (fig. 2). The basalts on both levels appear to be essentially the same age; radiometric age data indicate that their lateral equivalents were erupted between 4.8 and 4.1 m.y. ago.

The ancestral Rayado Creek was a major drainage system in early Pliocene time, and cut a large, east-southeast trending plain on predominantly gently folded Glorieta Sandstone and older sandstone and shale prior to 4.8 m.y. ago. This drainage appears to have been captured by Coyote Creek that followed the less resistant Laramide structural zone, parallel to the mountain front (fig. 2). This zone is marked by high-angle reverse faults and nearly vertical sandstone and shale and is much less resistant to erosion than the gently inclined Glorieta Sandstone that is present in the upper reaches of the Rayado Creek drainage. With capture, pediplanation by the ancestral Rayado Creek would be arrested. The plain cut by it is perched above the surface carved by the ancestral Coyote Creek. Erosion along the ancestral Coyote Creek reduced the westernmost part of the original pediplain several tens of meters before volcanism occurred; flows belonging to this period of volcanism and dated at 4.7 m.y. (Stormer, 1972) appear to be confined to a shallow valley on the west side of the volcanic field, and are now present in the northern part of Guadalupita Valley. The pediplain cut by the ancestral Coyote Creek apparently extended over much of La Mesa and Le Febres Mesa, and may have extended over the area now occupied by the Ocate Valley. Small streams flowing east, out of the Rincon Range, were apparently graded to the Coyote Creek drainage, as indicated by perched, basalt-covered gravels on El Cerro Colorado. These overlying basalts were dated at 4.1 m.y. Coplanar pediments, not capped by basalts but preserved between El Cerro Colorado and La Mesa, appear to be remnants of this surface. The Guadalupita Valley did not exist at this time. Rather, the basalts in this valley were probably coextensive with the volcanic rocks on La Mesa.

Down-to-the-west normal faulting may have initiated the Coyote Creek erosion cycle. This is reflected in the lower level of the Black Lake flows, the basalt cascade over the scarp, and in the slightly lower elevation of the flows on La Mesa than flows on Rivera Mesa. North-trending, down-to-the-west normal faults are present directly north of this area and mark the east boundary of the Neogene Moreno Valley (Clark and Read, 1972; Ray and Smith, 1941) and offset some of the Aqua Fria flows (fig. 1). To the south, the basalts that cap El Cerro Colorado, and dated at 4.1 m.y., end abruptly at Guadalupita Valley on the west. 275 m below, in the valley and directly west of the basalts, are flows interpreted to be the down-faulted extension of the El Cerro Colorado flows. Farther south faults are seen to cut older alluvium on the east side of the valley (Baltz and O'Neill, 1980a, b). Geophysical data of Mercer and Lapalla (1970) show an eastward thickening wedge of valley fill in the Mora Valley. Additional evidence for structural control of the valley is given in the comparison of stream profiles from the Ocate volcanic field (fig. 8). Of those major creeks whose headwaters are

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Figure 8.--NEAR HERE

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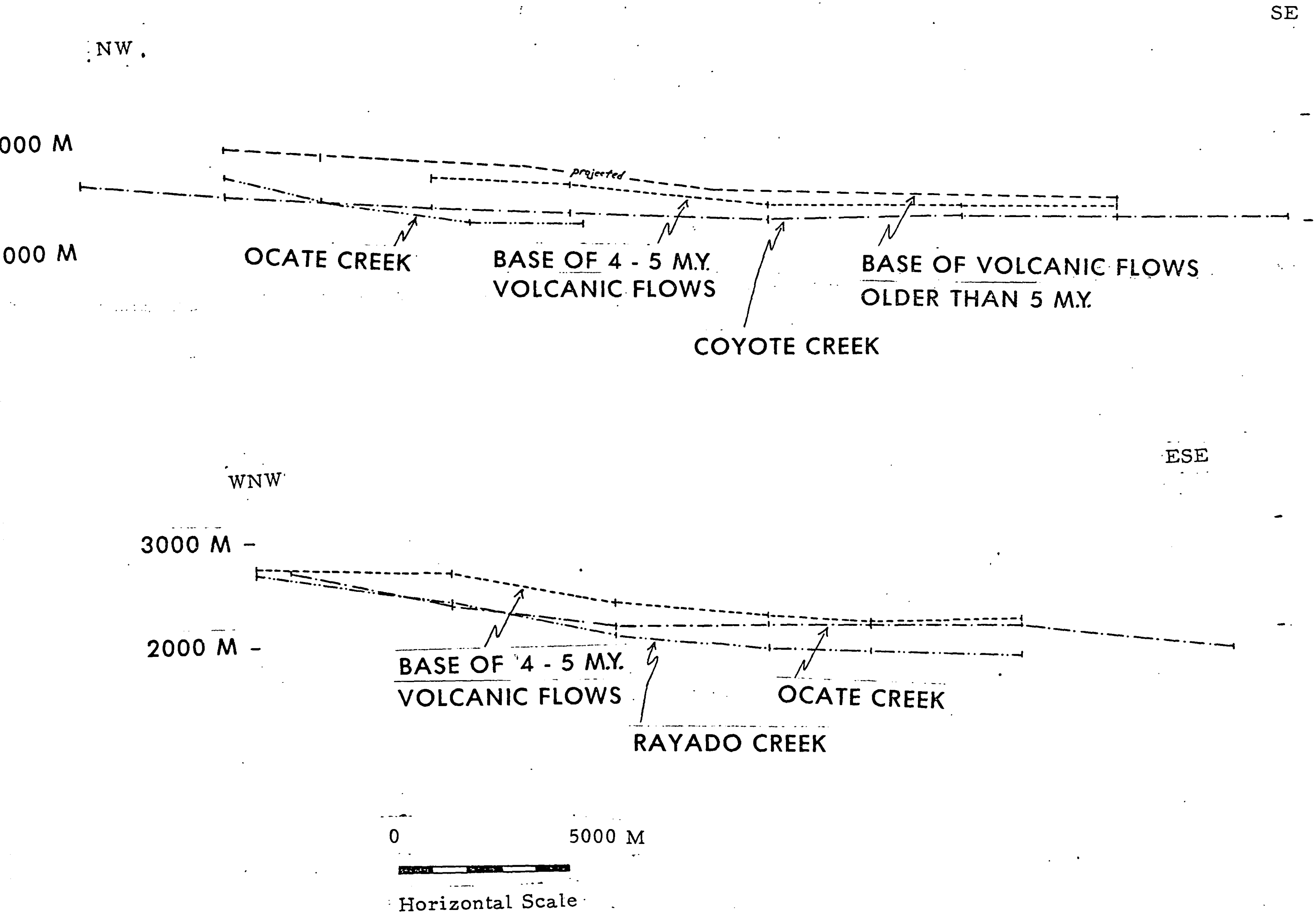
located in or adjacent to the volcanic field, only Coyote Creek shows a decidedly flat, albiet concave upward profile; this is in marked contrast to the typically more concave upward profiles of Rayado and Ocate Creeks. The Coyote Creek profile does not converge upstream with these other stream profiles, nor with the surfaces upon which the Sierra Montuosa and Rayado basalts lie. Instead, the Coyote Creek profile diverges from these profiles in an upstream direction. This upstream

Figure 8.--Comparison of stream profiles of Rayado and Ocate Creeks and Coyote and Ocate Creeks as projected onto a line located along their interfluve and alined subparallel to the two drainages. The profile of the base of the 4-5 m.y. old volcanic rocks, as projected onto this line, is shown on both diagrams; the profile of the base of volcanic rocks older than 5 m.y. is shown on the Coyote-Ocate Creek projection only.


NW
SE
000 M
000 M
projected
OCATE CREEK
BASE OF 4 - 5 M.Y.
VOLCANIC FLOWS
COYOTE CREEK
BASE OF VOLCANIC FLOWS
OLDER THAN 5 M.Y.
WNW
ESE
3000 M
2000 M
BASE OF 4 - 5 M.Y.
VOLCANIC FLOWS
RAYADO CREEK
OCATE CREEK
0
5000 M
Horizontal Scale

divergence suggests structural dropping of the Coyote Creek drainage. The Mora-Guadalupita Valley appears to be a half graben, bounded on the east by normal faults.

Volcanic rocks younger than 4.0 million years old

Basalts of this age group are volumetrically the most abundant flows, account for the majority of the flows in the Great Plains Province, and also cover a large part of the southern Cimarron block. Some volcanic centers that expelled these flows are alined along the structural boundary between these two provinces. Age relations among these basalts are known largely from superposition and physiographic expression; however, five K-Ar age dates from these flows indicate that they range in age from 3.5 to 0.8 m.y.

Flows that cap Charette Mesa are physiographically the oldest flows in this age group and define the highest surface below the Rayado surface (fig. 9). Charette Mesa is a broad flat feature, named for

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Figure 9.--NEAR HERE

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Charette Lakes. In this report, the name is applied to the surface that extends westward from Wagon Mound to Cerro Pelon and the Ocate Valley. The eastern part of the mesa, capped by multiple basalt flows that aggregate about 5-10 m in thickness, defines a very flat surface. In the central part of the mesa, small knobs and isolated buttes and small mesas rise above this surface and the terrain becomes one of slightly hummocky relief produced by basalt flows expelled from local vents. The youngest basalts in the Ocate volcanic field are in this part of the Charette Mesa.

Figure 9.--Distribution of volcanic rocks erupted since 4.0 m.y. ago. Areas identified on diagram are outcrops of these rocks.

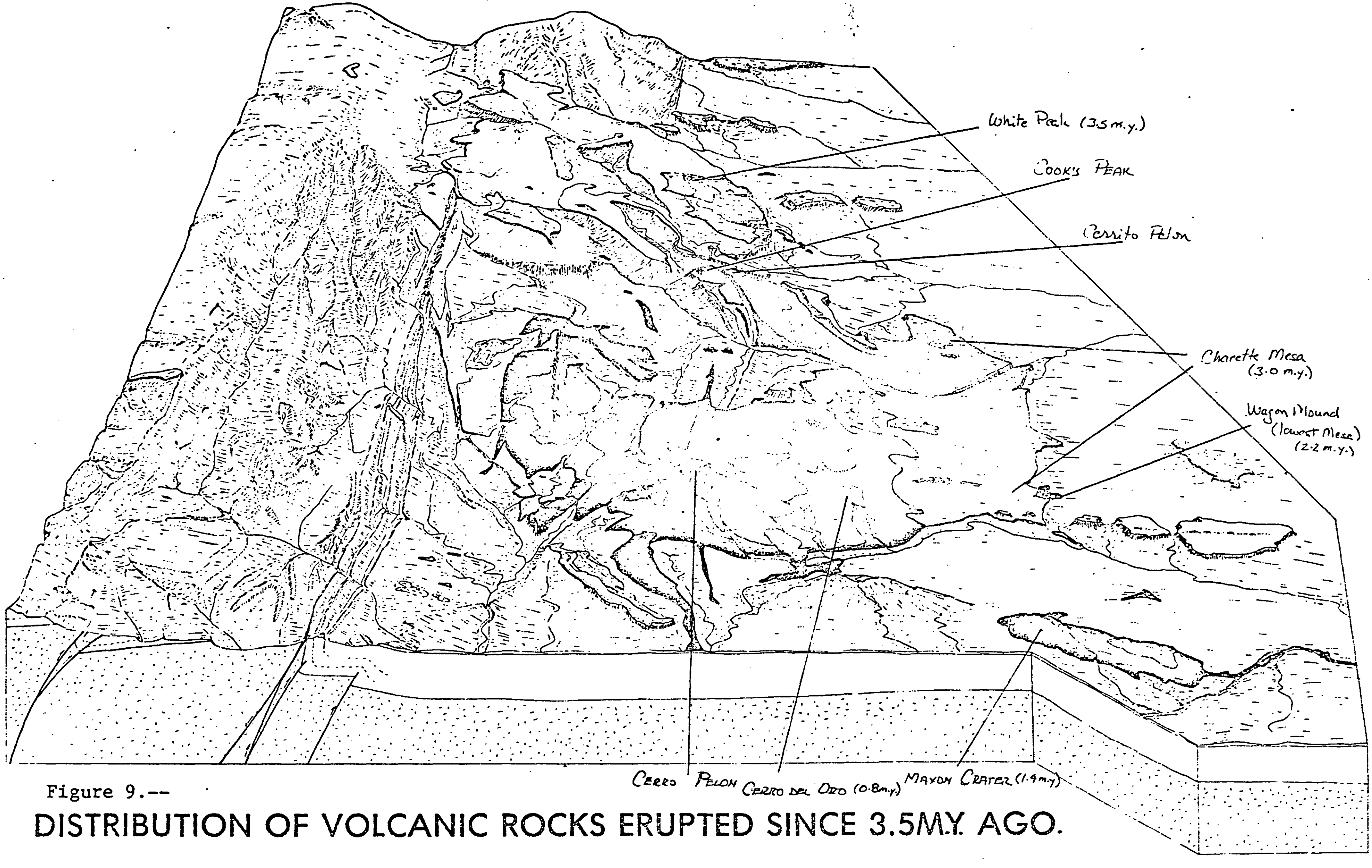


Figure 9.--

DISTRIBUTION OF VOLCANIC ROCKS ERUPTED SINCE 3.5MY AGO.

Basalt capped mesas and buttes directly east of Ortega Mesa and south of Rayado Mesa are the same elevation as the Charette Mesa flows and lie 60 m lower than the 4-5 m.y. old Rayado surface. Flows on Charette Mesa are also 60 m below the 4-5 m.y. flows that cap Apache Mesa.

The oldest volcanic rocks on Charette Mesa are multiple olivine basalt flows. The flows are underlain by coarse stream gravels composed mainly of Precambrian metasedimentary and igneous rocks and minor basalt that are locally well cemented by calcium carbonate. These lowest flows at Wagon Mound have been dated at 3.3 m.y. by Stormer (1972) and 3.1 m.y. from samples submitted by P. W. Lipman (written commun., 1928). Westward, these flood basalts are overlain by successively younger, less voluminous flows erupted from composite cones that stand as rounded knobs and mounds with 30 to 100 m of relief. These can be divided into three major groups: an older series of vents which may have expelled the basalts to the east; an intermediate age group around which subdued basalt flows can be recognized and mapped; and a very young series of flows showing well-preserved flow morphology and associated with moderately eroded cinder cones.

Flanks of the older cones generally dip between 5 and 10 degrees. Dikes and small plugs intruded these cones and resulted in locally steep cone flanks. Volcanic breccia, scoriaceous material and oxidized vesicular basalt compose these vent structures; most of these rocks occur as thin layers that dip gently toward the center of the vent. Radial dikes are common and some vents appear to have held small lava lakes in their centers.

Intermediate age vents are present south of Apache Mesa, on either side of State Highway 122, and expelled the majority of basalts that cover the central part of Charette Mesa. Cooks Peak and Cerrito Pelon northeast of Ocate expelled basalts that also flooded the area between Apache Mesa and Encinosa Mesa. These basalts interfinger with each other and hence appear to be contemporaneous.

Basalts on Charette Mesa are underlain by coarse stream gravels composed of Precambrian metasedimentary and igneous rocks, Paleozoic sedimentary rocks and minor basaltic rocks. These gravels and the flat surface on which they rest appear to represent a broad surface formed by an east flowing stream that headed in the vicinity of Ocate and coalesced with streams flowing south and southeast from the Cimarron Range. These streams reduced the landscape some 60 m below the 4-5 m.y. old volcanic flows that cap the Rayado surface and before the eruption of the 3.3-3.1 m.y. old basal basalts on Charette Mesa.

The basalts within the Ocate Valley were not dated, hence, neither the age of the basalts nor the minimum age of the underlying Las Feveres Formation is known. That this valley did not exist during the 4-5 m.y. volcanism, but had essentially assumed its present physiographic expression by the beginning of this period of volcanism, 3.3 to 3.1 m.y. ago, is indicated by the following evidence.

(1) Ocate Valley is a large, roughly elliptical depression that is drained by Ocate Creek. The valley is bounded on the east by upturned and beveled sedimentary rocks that mark the eastern margin of the Cimarron block. The north and west sides of the valley are bordered by high mesas capped by 4.8 to 4.1 m.y. old basalts that do not spill into the depression. It appears that the Ocate Valley began to form after the 4 to 5 m.y. period of volcanism.

(2) Like the flows near Wagon Mound, the flows east and southeast of Ocate rest on a beveled bedrock surface. The plan of these flows and the surface on which they lie broadens to the east, toward Wagon Mound (fig. 9). The surface and the overlying flows are constrained by Apache Mesa and Apache Mesa (west) on the north and by the Turkey Mountains on the south. Remnants of this surface north of Apache Mesa and adjacent to Ortega Mesa suggest that several streams coalesced near Wagon Mound to form a broad surface over much of this region. This surface rises to the west toward Ocate along a gradient of 10 m/km. Profiles drawn along Ocate Creek are concave upward; the steepest gradients are north and west of Ocate Valley, becoming noticeably flat in and east of the valley (fig. 8). The flattest part of the profile is coincident with the surface on which the Charette Mesa volcanic rocks rest and suggest that Ocate Creek was graded to this surface prior to 3.0 to 3.1 m.y. volcanism. Hence, this surface may be interpreted to represent a broad pediplain developed in part along the ancestral Ocate Creek.

(3) The basal basalts on Charette Mesa at Wagon Mound, dated at 3.3 to 3.1 m.y., are laterally continuous with Cerro Pelon flows that fill Ocate Valley. The lateral relations are complicated by younger volcanic vents and flows erupted onto the older flows. However, the absence of well-preserved flow morphology in basalts expelled from Cerro Pelon indicates that these flows are among the older flows erupted during this period of volcanism. Thus Ocate Valley appears to have been present during the earlier stages of this period of volcanism.

(4) Basalts erupted from Cerrito Pelon, located about 5 km east of Ocate Valley, are nearly 35 m above Ocate Creek. These basalts interfinger with intermediate age flows erupted from centers in the central part of Charette Mesa. In the Ocate Valley, basalts from Cerro Pelon are 20 m above Ocate Creek and interfinger with basalts erupted from a small center located on Le Febres Mesa. Basalts on Le Febres Mesa flowed into the western part of Ocate Valley.

The gravels below the basalts that cover Charette Mesa and the flat surface on which they lie probably represent the ancestral Ocate Creek pediplain as it existed prior to about 3 m.y. ago. The approximately equivalent elevation of basalts above the creek, both within the valley and 5 km east of the valley, and the fact that these flows appear to be only slightly younger than the oldest flows on Charette Mesa, suggest that the Ocate Valley was a significant physiographic depression when this period of volcanism began.

(5) The Las Feveres Formation, a fine-grained fluvial valley fill covers much of the floor of Ocate Valley. This deposit indicates a period of deposition that is in general opposite to the pervasive scheme of erosion and denudation that characterizes the Pliocene-Pleistocene history of the front ranges of the southern Rocky Mountains (Ray and Smith, 1941; Smith and Ray, 1943; Levings, 1951; Scott, 1963, 1975). Infilling of the valley must have been produced by blockage of the Ocate drainage system. That the Las Feveres Formation is restricted to the Ocate Valley (Bachman, 1953) suggests that this blockage occurred very near the present stream outlet to the valley. Whether this blockage was produced by basalt that dammed the stream system, or by faulting prior to volcanism, was not determined. Flows lacking distinct flow morphology and belonging to the third period of volcanism rest directly on the Las Feveres Formation indicating that this valley had formed by late Pliocene time.

A small basalt-capped mesa, located 4.5 km north of Wagon Mound, lies 20 m below the Charette Mesa flows and about 15 m above the adjacent lowlands. Basalts on this mesa, dated at 2.2 m.y., were erupted from a low shield vent directly west on Charette Mesa.

Gravel covered surfaces similar in their physiographic expression to the 2.2 m.y. old basalt capped mesa are preserved as isolated buttes extending from Rayado Creek southward toward Rivera Mesa. These small buttes define the lowest surface preserved in this area except for those stream terraces only preserved adjacent to Rayado Creek. Gravel covered buttes are also preserved southeast of El Cerro Colorado in the large valley drained by Coyote Creek (fig. 9). These small buttes define the lowest gravel covered pediment surface in this valley, rising some 40 m above the valley floor. Their age is not known, but their physiographic position indicates that they are younger than the Charette Mesa surface.

Maxon Crater, a large basaltic shield volcano, is located about 12 km south of Wagon Mound and directly west of I-25. Basalts expelled from this volcano flowed east. Maxon Crater vent is located near the western side of the shield and is marked by a large east-trending depression more than 1 km long. Basalts collected from these flows exposed in the roadcut along I-25 gave a K-Ar date of 1.4 m.y. Basalts expelled from Maxon Crater flowed 90 km eastward, through the canyon carved by the Mora River, and then a short distance beyond the confluence of the Mora and Canadian Rivers. At the confluence of the two rivers the flows lie 100 m below the rim of the canyon, and 125 m above the present level of the rivers.

The youngest volcanic rocks are in the central part of Charette Mesa, south of New Mexico Highway 21. The basalts consist of two thick, very viscous flow systems, each erupted from one major and at least one minor vent and covering about 16 $km^2$. The surfaces of the flows are very hummocky and scattered with volcanic bombs and scoriaceous material. Numerous pressure ridges and flow ramparts are present, standing as elliptical knobs 7 to 10 m above the surrounding basalts. The cores of these structures show blocky, oxidized basal flows overlain by dense, aphanitic, non-vesicular and somewhat platy basalt. The flows that show these features best were erupted from the Cerro del Oro cinder cone. The flanks of this cone consist of outward dipping cinders, ash, bombs, volcanic breccia and agglomerate. The original crater has been partly eroded by a south-draining gully. Basalts flowed southward from this cone. A specimen collected from basalt interlayered in the cinder cone was dated at 0.8 m.y.

## Summary

Volcanic flows older than 5 m.y. preserve beneath their cover the physiographically highest gravel-covered surfaces in the Ocate area. These flows range in age from 8.3 to 5.7 m.y. The flows appear to rest on a surface or series of nearly equivalent surfaces that slope gently southeast. This surface cuts across diverse rock types and sharp structural breaks, suggesting that late Miocene time was marked by erosion and pediplanation in the absence of tectonic activity.

The drainage divide in this part of the Sangre de Cristo Mountains was located east of the present divide, probably near the Rincon Range. Strong erosion has occurred along the eastern part of the Sangre de Cristo Mountains since late Miocene time, cutting canyons as much as 600 m deep.

About 5.5 m.y. ago, the crustal stability that had characterized the southern Rocky Mountains during the late Miocene ended. Uplift caused moderate dissection of the late Miocene surface and formed a younger, lower surface. This younger surface, cut several tens of meters lower, wraps around the mesas capped by the older basalts and around the Cimarron Range and is continuous with the vast, uninterrupted surface of the Park Plateau in the Raton Basin. This surface truncates diverse rock types and structures. It is characterized by a southeast-dipping erosion surface, largely carved by the ancestral Rayado and Coyote Creeks. Much of the upper reaches of this surface was covered by second stage volcanic rocks erupted between 4.8 and 4.1 m.y. ago.

Profiles drawn on this and the older surface are both concave upward and downward, indicating that they have been warped. Deflection of the surfaces is roughly coincident with the Cretaceous hogbacks that mark the eastern margin of the Cimarron block. Warping involved nearly 200 m of uplift of the Cimarron block with respect to the adjacent Great Plains. The Rayado-Coyote surface is also cut by significant down-to-the-west normal faults on the west side of the field. These faults extend from the Moreno Valley south to at least the Mora Valley; displacement is as great as 275 m.

After this period of broad uplift and volcanism, major erosion was confined to the southeast side of Sierra Montuosa Mesa, marking the formation of Ocate Valley. The ancestral Ocate Creek cut this valley to about its present configuration, as the present floor of the valley is graded to the surface beneath the 3.3 to 3.1 m.y. old basalts that cap Charette Mesa. Renewed third stage volcanism occurred on the present Charette Mesa, east of Ocate valley on the floodplain of Ocate Creek. These basalts apparently dammed the drainage and raised the base level which resulted in the deposition of the alluvial-fluvial Las Feveras Formation in Ocate Valley.

This volcanism was followed by continued uplift; associated denudation is marked by the formation of the lowest erosion surfaces and overlying gravels in the area, now preserved as isolated gravel-capped buttes and locally basalt-capped mesas cut slightly below the Charette Mesa surface. Fourth stage basalts on one of these surfaces present near Wagon Mound were dated at 2.2 m.y.

By the time of the Maxon Crater eruption, 1.4 m.y. ago, the major drainages were well established.

The youngest flows in the field were erupted from several small vents on Charette Mesa, northwest of Wagon Mound. This youngest volcanic episode is characterized by hummocky flows of limited extent and surmounted by cinder cones.

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