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J. Michael O'Neill and Harold H. Mehnert, 1990, pp. 349-353

in:

Tectonic Development of the Southern Sangre de Cristo Mountains, New Mexico, Bauer, P. W.; Lucas, S. G.; Mawer, C. K.; McIntosh, W. C.; [eds.], New Mexico Geological Society 41st Annual Fall Field Conference Guidebook, 450 p.

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LATE CENOZOIC VOLCANISM, UPLIFT AND EROSION, SOUTHERN SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

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Abstract—The Ocate volcanic field in northeastern New Mexico lies abreast the structural transition zone between the Southern Rocky Mountains and the Great Plains physiographic provinces. The field consists of numerous basaltic flows and minor andesitic to dacitic differentiates. The flows are of limited extent and range in age from Miocene to Pleistocene. The physiographic expression of these flows reflects their ages. The oldest flows, between 8.1 and 5.6 Ma, cap the highest mesas. These flows are underlain by stream gravels and appear to rest on remnants of a single surface or a series of nearly equivalent surfaces cut into the mountain interior at elevations near 3000 m. Numerous accordant ridge tops, subsummits and parks in the adjacent Taos and Cimarron Ranges are also at elevations near 3000 m and suggest that this surface was widespread during late Miocene time. The 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 5 to 4 Ma, 3.3 to 3 Ma and 2.2 Ma. Of the four erosion surfaces, the two oldest are now warped and locally displaced where they cross 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 Ma, followed major stream valleys and are now perched nearly 125 m above present stream levels. Finally, basalts 0.8 Ma were erupted mainly onto older flows.

INTRODUCTION

Volcanic rocks in the vicinity of Ocate, New Mexico were first noted by Stevenson (1881), who described the physiography of the area and gave the name Ocate Mesa to the lava-capped surface that extends southward from the Cimarron Range. This region of lava-capped plateaus and mesas, referred to as the Ocate volcanic field (O'Neill and Mehnert, 1988; O'Neill, 1988), 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). Flows extend as far south as the Turkey Mountains but do not completely surround this uplift. Flows, vented on the southeast side of the Turkey Mountains, flowed eastward following the drainage of the Canadian and Mora Rivers.

The Ocate volcanic field occurs in the transition zone between the southern Rocky Mountains and the Great Plains physiographic provinces. This boundary is not clearly defined in north-central New Mexico. Lower Tertiary strata rise to more than 3000 m (10,000 ft) 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 these Cretaceous hogbacks; he continued this boundary southward, around the east side of the Cimarron Range and then directly west to the north-trending, 100 km long Mora-Moreno valley system (Fig. 1), thence southward toward Las Vegas (Figs. 1, 2).

The major frontal fault that bounds the east side of the Cimarron Range does, in fact, continue directly south, but takes on the character of a monoclinal flexure (Figs. 1, 2); this flexure trends south-southwest, is locally covered by the Ocate volcanic field, and merges with the high-angle reverse faults that mark the eastern boundary of the Sangre de Cristo Mountains directly north of Las Vegas (Baltz and O'Neill, 1983). This monoclinal flexure and fault on the east side of the Cimarron Range define a natural structural unit, the Cimarron block. Ray and Smith (1941) restricted the name Cimarron block to the Precambrian-cored northern part of this uplift; rocks in that part are separated from the southern, less strongly uplifted part, by a major northwest-trending high-angle fault. The Cimarron block is herein interpreted to mark the transition zone between the Rocky Mountain and Great Plains physiographic provinces. Much of the western part of the Ocate volcanic field lies within the southern part of the Cimarron block; the volcanic field crosses the eastern margin of the block and extends onto the Great Plains.

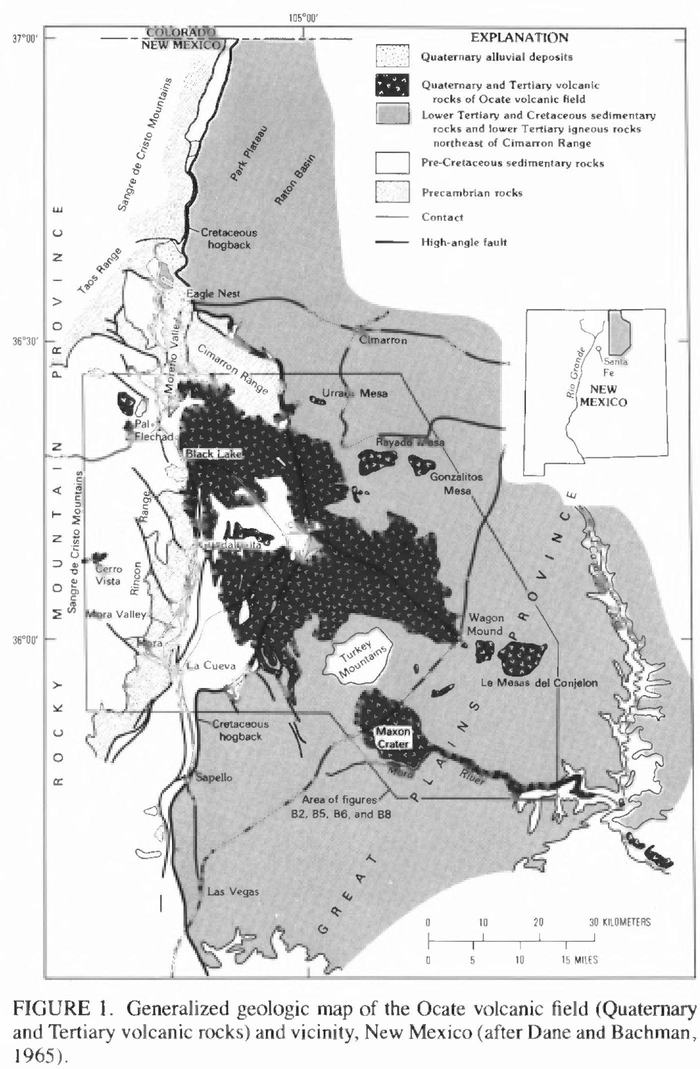

FIGURE 1. Generalized geologic map of the Ocate volcanic field (Quaternary and Tertiary volcanic rocks) and vicinity, New Mexico (after Dane and Bachman, 1965).

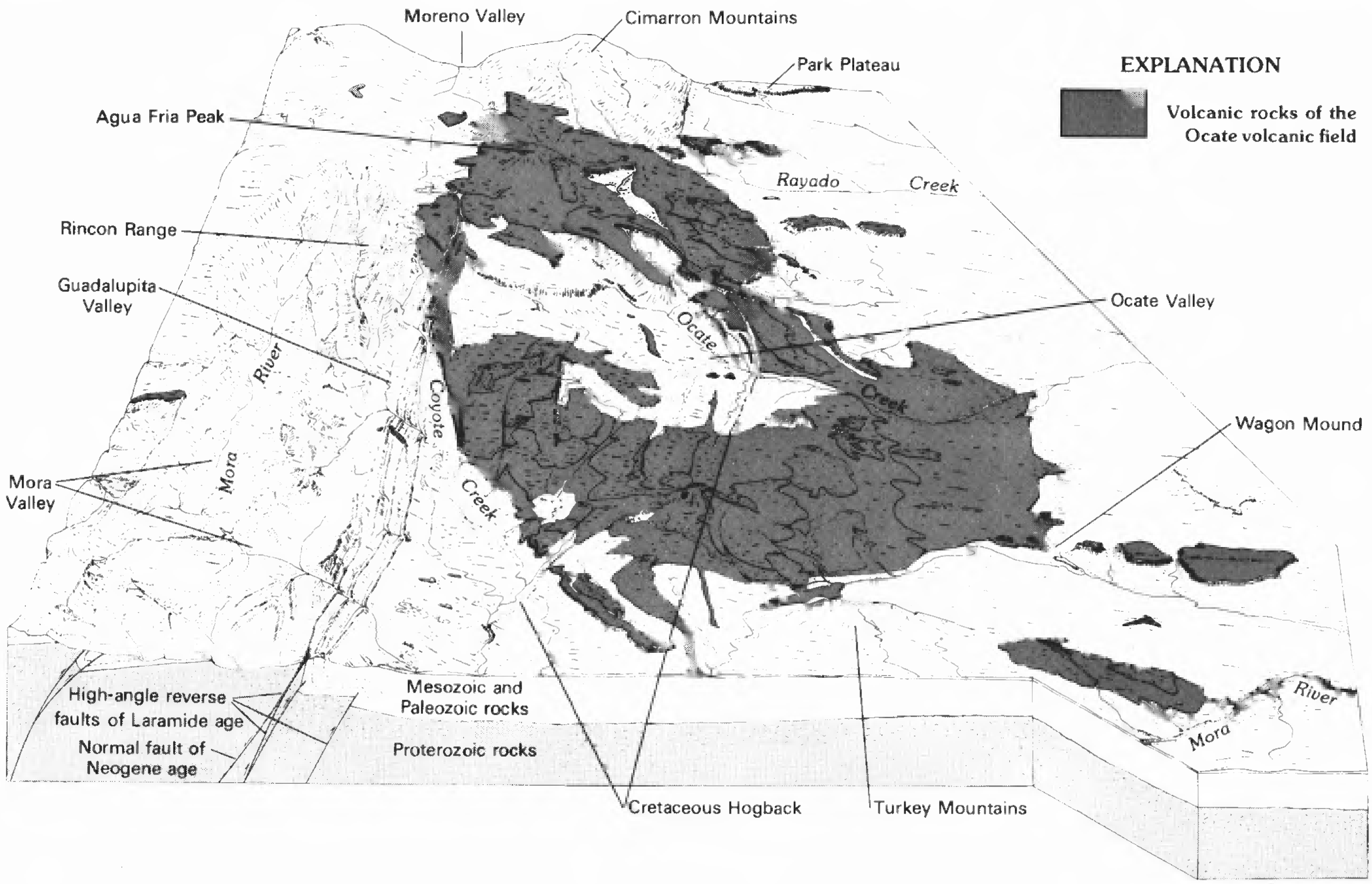

FIGURE 2. Block diagram of the Ocate volcanic field showing major geographical features. View is to the north. Area shown in diagram is indicated on Figure 1.

VOLCANIC STRATIGRAPHY AND GEOMORPHIC EVOLUTION

The Ocate volcanic field consists of numerous volcanic flows ranging in age from late Miocene to Pleistocene (O'Neill and Mehnert, 1988). The field ranges in elevation from over 3000 m in the Sangre de Cristo Mountains to less than 1800 m on the Great Plains. The physiographic expression of these flows reflects their relative ages (Fig. 3); the flows that cap the highest mesas are oldest and were erupted prior to 5 million years ago. The intermediate-level basalts were erupted between 4 and 5 million years ago. Flows, 3.3 and 2.2 Ma, cap the lowest mesa levels in the area. The youngest flows, dated at 1.4 and 0.8 Ma, flowed onto surfaces that have since been little eroded.

High-level surfaces and their volcanic caprock

The highest gravel-covered surfaces in this area underlie basalts that are older than 5 Ma. The oldest basalts, dated at 8.3 Ma, are present in the northwestern part of the field (Fig. 2) where elongate mesas capped by basalt reach altitudes in excess of 3000 m (Figs. 1, 2). Well-rounded stream pebbles, cobbles and boulders of Precambrian granite, gneiss and pegmatite are exposed at the base of these flows.

Basalts exposed along the west-central side of the volcanic field and dated at 5.7 Ma consist of a northeast-trending, flow-capped ridge. The base of the basalts ranges in elevation from about 3020 m on the northeast to near 2895 m at the southwest. The flows occupy a south-westerly inclined paleovalley, and locally pebbles and cobbles of well-rounded Precambrian igneous and metamorphic rocks are present at the contact with the underlying bedrock. These gravels are separated from the nearest Precambrian outcrops in the Rincon Range to the east by the Mora River valley (Fig. 2); this valley floor is nearly 600 m below the base of the basalts and the underlying gravels.

Basalt flows in the northeastern part of the volcanic field (Fig. 1), west of the Moreno Valley (Peterson, 1969), are described as thin local flows resting on lag gravels of the Miocene Carson Conglomerate (Just, 1937). Their geomorphic expression is similar to that of the 5.7 Ma basalts located directly to the south.

Three high mesas east and south of Ocate are capped by basalts interpreted to be older than about 5 Ma based on their physiographic expression and on the age of basalts capping adjacent, intermediate-level mesas. At least one flow, the Apache Mesa (west) flow (Fig. 3), is underlain by a thin veneer of gravel composed mainly of Precambrian pebbles and cobbles. These flows are widely separated, and lie very

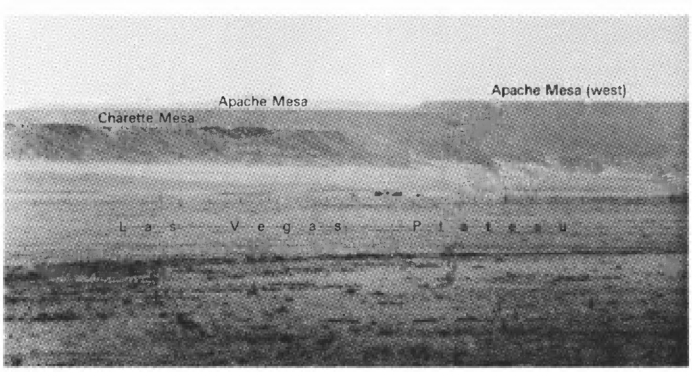

FIGURE 3. Part of Ocate volcanic field in Great Plain province, north-central New Mexico. View to southwest; snow-capped Sangre de Cristo Mountains in background. Three major physiographic levels of basalt-capped mesas are shown. They are, from highest to lowest: Apache Mesa (west), Apache Mesa and Charette Mesa.

close to the eastern margin of the Cimarron block. The basalts appear to be about the same age and to have been confined to broad, southeasterly inclined stream valleys.

High-level basalts at Wagon Mound stand as a series of east-trending buttes and mesas that represent both volcanic necks and basalt-capped mesas (Fig. 2). The basaltic flows are separated from the underlying bedrock 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 (Figs. 1, 2). These basalts yielded a K-Ar age of 5.9 Ma.

The nearly equivalent elevations, near 3000 m, of the highest basalts in the west and northwest parts of the volcanic field (Fig. 2), 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 what are now major topographic depressions, as indicated by the probable 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 (Fig. 1) are probable remnants of this widespread surface.

The surface beneath the basalts on Apache Mesa (west) and Las Mesas del Conjelon appears to represent the eastward extension of the surface beneath the physiographically highest basalts to the west. The surface beneath Las Mesas del Conjelon rises 9.5 m/km to Apache Mesa (west), then increases to 32 m/km to the base of the basalts dated at 8.3 Ma. The change in gradient occurs at the monoclinal flexure that marks 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 without tectonic activity. This surface is probably coextensive with the widespread late Miocene erosion surface in the front ranges of Colorado and Wyoming (Knight, 1953; Moore, 1959; Scott, 1963, 1975), and probably represents the upland erosional area which supplied sediment for the Miocene Ogallala Formation (Frye and Leonard, 1957, 1959; Scott, 1975).

Intermediate-level surfaces and their volcanic caprock

Basalts and minor andesites and dacites of the intermediate-level flows are most abundant in the northern part of the volcanic field (Fig. 1); these rocks cap gravel-covered surfaces that are about 60 m below the highest basalt-capped surfaces. These rocks have been dated at 4.3 Ma (Hussey, 1971) and 4.7 Ma from exposures located directly southeast of the Cimarron Range. Rocks of this age group apparently constitute the majority of the flows in and around the Agua Fria Peak area and interfinger with 4.5 Ma volcanic rocks in the southern part of the Moreno Valley. Flows erupted south of Agua Fria Peak (4.7 Ma and 4.2 Ma) flooded flat, gravel-covered surfaces to the south (Fig. 2). Four-to-five-million-year-old basalts are present along Coyote Creek (4.7 Ma: Stormer, 1972), in the central part of the Mora-Moreno valley system (4.3 Ma) and cap mesas directly west of the valley (4.1 Ma) (Fig. 2).

Basalts in the northwestern part of the volcanic field (Figs. 1, 2) rest on a southeasterly inclined surface covered by gravels composed largely of Precambrian metamorphic and igneous rocks. These gravels are now separated from their probable source area to the west by the Mora-Moreno valley system. This surface, an extension of the Urraca surface of Smith and Ray (1943), was defined from mesas east of the frontal faults bounding the Cimarron Range (Figs. 1, 2), and from the larger mesas directly south of the Cimarron Range. They tentatively correlated this surface with the erosional surface of the Park Plateau to the north. The Urraca surface formed at some time between 4.8 million years ago (the age of the oldest basalts that preserve beneath their cover the intermediate-level gravel-capped surfaces) and 4.3 million years ago (the age of the youngest basalts on mesas directly east of the Cimarron Mountains).

Figure 4 depicts, in a general way, the early Pliocene topography of this surface. The Park Plateau is marked by a gentle southeast slope with a concave upward profile; the gradient is steepest nearer the Sangre de Cristo Mountains. To the south, around Ocate, this surface contains

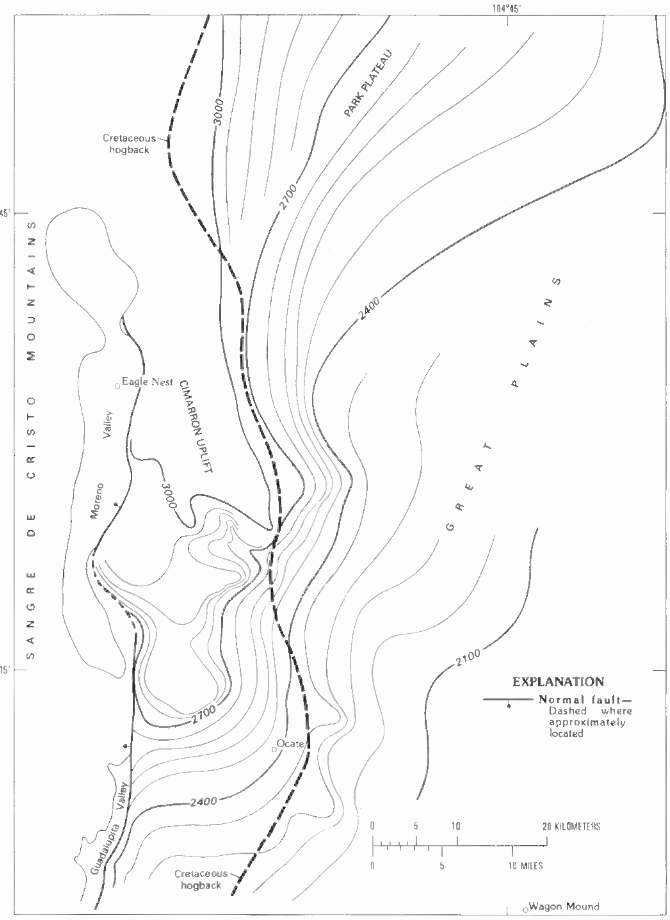

FIGURE 4. Contour map drawn on the 4- to 5-million-year-old Urraca surface (projected across present valleys) in the Ocate volcanic field and in the Park Plateau in the Raton basin. Contour interval is 200 ft (60 m) (datum mean sea level). Contour lines are approximately located. Heavy line marks the approximate boundary between Southern Rocky Mountain and Great Plains provinces.

areas of variable slope and profiles are both concave upward and downward (O'Neill, 1988). From the Moreno Valley on the west to the topographically highest basalts near Agua Fria Peak, the elevation of the Urraca surface decreases from nearly 3000 m to about 2850 m. East of Agua Fria Peak, the surface becomes more steeply inclined before again assuming a gentle southeast-dipping gradient. The surface cuts evenly across highly resistant Permian sandstone, across easily eroded Pennsylvanian shales and truncates the monoclinal flexure upturned along the east side of the Cimarron block. The convex upward aspect of this surface east of Agua Fria Peak cannot be considered to have been present when this surface was formed. Rather, this must represent warping of that surface by differential uplift between the Cimarron block and the Great Plains.

Basalts erupted onto the Urraca surface in the Agua Fria Peak area are continuous with the basalts in the southern part of the Moreno Valley; however, the Moreno Valley flows lie some 100 m below this surface. The youngest flows, which have not been dated, cascaded over an arcuate west-facing scarp held up by steeply dipping Paleozoic sedimentary rocks (Fig. 2). The basalts on both levels appear to be coeval; radiometric ages from their lateral equivalents range between 4.8 and 4.1 m.y.

The ancestral Rayado Creek (Fig. 2) was a major drainage system in early Pliocene time, and cut a large, east-southeast-sloping plain on predominantly gently folded Permian Glorieta Sandstone and older sandstone and shale prior to 4.8 Ma. This drainage appears to have been captured by the south-flowing Coyote Creek that followed the less resistant Laramide structural zone, parallel to the mountain front (Fig. 2). With the capture of its headwaters by Coyote Creek, pediplanation by the ancestral Rayado Creek was arrested. Erosion along Coyote Creek reduced the westernmost part of the Urraca surface several tens of meters before volcanism occurred. This slightly lower pediplain cut by Coyote Creek apparently extended over much of the area west and southwest of Ocate, and probably extended across the area now occupied by 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 mesas directly east of the Mora-Moreno Valley system in the west-central part of the volcanic field. Coplanar pediments, not capped by basalts in this area, appear to be remnants of this surface.

Down-to-the-west normal faulting may have initiated the Coyote Creek erosion cycle. This is reflected in the lower level of flows in the southern part of the Moreno Valley that cascaded over the fault scarp. North-trending, down-to-the-west normal faults are present directly north of the basalt cascade and mark the eastern boundary of the Neogene Moreno Valley (Ray and Smith, 1941; Clark and Read, 1972) and offset some of the Agua Fria flows (Fig. 1). To the south, basalt-capped mesas adjacent to the Mora-Moreno valley system and dated at 4.1 Ma, end abruptly at the valley on the west. Nearly 300 m below, in the valley and directly west of the basalts, are flows interpreted to be their downfaulted equivalents. Farther south, faults are seen to cut alluvium on the east side of the Mora Valley (Baltz and O'Neill, 1983, 1986). Geophysical data of Mercer and Lapalla (1970) indicate an eastward-thickening wedge of valley fill in the Mora Valley. The Mora-Moreno Valley system appears to be a half-graben, bounded on the east by normal faults, that began to form during the 4- to 5-million-year-old volcanic episode.

Low-level surfaces and their volcanic caprock

Basalts of the youngest age group comprise most of the flows in the Great Plains Province, and also cover a large part of the southern Cimarron block. Age relations among these basalts are known from superposition and physiographic expression and from 5 K-Ar age dates; flows range in age from 3.3 to 0.8 Ma. Flows that cap Charette Mesa are the oldest dated flows in this group and are 60 m below the 4- to 5-million-year-old flows that cap the Urraca surface.

The oldest volcanic rocks on Charette Mesa are basalt flows at Wagon Mound, dated at 3.3 Ma (Stormer, 1972) and 3.1 Ma. Westward, these flood basalts are overlain by successively younger, less voluminous flows erupted from small cones that stand as rounded knobs and mounds 30 to 100 m high. Basalts on Charette Mesa are underlain by coarse stream gravels composed of Precambrian metasedimentary and igneous rocks, Paleozoic sedimentary rocks and minor Tertiary basaltic rocks. These gravels and the flat surface on which they rest appear to represent a broad surface formed by the ancestral Ocate Creek which coalesced with streams flowing south and southeast from the Cimarron Range.

The basalts within the Ocate Valley were not dated; hence, the minimum age of the underlying fluviatile Las Feveras Formation (Bachman, 1953) is not known. That this valley began to form after the 4- to 5-million-year-old volcanic episode and before the beginning of volcanism, 3.3 to 3.1 Ma, is indicated by: (1) the north and west sides of Ocate valley are marked by high mesas capped by 4–5 Ma basalts that do not spill into the depression; (2) the flows on Charette Mesa rest on a beveled bedrock surface that broadens to the east toward Wagon Mound (Figs. 1, 2). Ocate Creek within Ocate Valley is graded to this gravel-covered surface preserved beneath basaltic rocks as old as 3.3 Ma; and (3) the Las Feveras Formation is a fine-grained fluvial valley fill that covers much of the floor of Ocate Valley. In contrast to the pervasive 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), these rocks record a period of deposition. Infilling of the valley must have been produced by blockage of the Ocate drainage system. That the Las Feveras Formation is restricted to the Ocate Valley (Bachman, 1953) suggests that this blockage occurred very near the monoclinal flexure that marks the present stream outlet to the valley. The cause of the blockage is unknown, but either damming of the drainage by lava or by faulting prior to volcanism is a reasonable possibility. Flows lacking distinct flow morphology and belonging to the third period of volcanism rest directly on the Las Feveras Formation, indicating that this valley was present by latest Pliocene, and that the Las Feveras Formation is late Pliocene to early Pleistocene in age.

One or two periods of incipient pediplanation after the Charette Mesa period of volcanism are recorded by scattered erosional remnants in the form of small buttes and mesas (Fig. 1). Most of these are capped by gravel, but a small mesa, located 4.5 km north of Wagon Mound, is capped by basalt. The basalt cap lies 20 m below the Charette Mesa flows and about 15 m above the adjacent lowlands; basalts on this mesa were dated at 2.2 Ma. Gravel-covered surfaces similar in their physiographic expression to the 2.2-Ma-basalt-capped mesa are preserved as isolated buttes adjacent to and south of Rayado Creek and along the course of Coyote Creek (Fig. 1). These small buttes define the lowest widespread surface preserved in this area.

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 Maxon Crater flowed about 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. Basalt collected from these flows exposed in the roadcut along I-25 gave a K-Ar date of 1.4 Ma.

The youngest volcanic rocks in the area were erupted from the central part of Charette Mesa. The basalts consist of a youthful-looking series of flows showing well preserved flow morphology that are associated with moderately eroded cinder cones. Most of these flows were erupted from Cerro del Oro, the major cinder cone in this area. A specimen collected from basalt interlayered in the cinder cone was dated at 0.8 Ma.

SUMMARY

Volcanic flows older than 5 Ma 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 Ma. The flows appear to rest on a surface or series of nearly equivalent surfaces that mainly slope gently southeast from a drainage divide that in this part of the Sangre de Cristo Mountains was located east of the present divide, probably near the Rincon Range (Fig. 1). This paleosurface cuts across diverse rock types and sharp structural breaks, suggesting that late Miocene time was marked by erosion and pediplanation without tectonic activity.

About 5.5 Ma, 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 development of a younger, lower surface. This younger surface, cut several tens of meters lower and which wraps around the mesas capped by the older basalts and around the Cimarron Range, is equivalent to the Urraca surface of Smith and Ray (1943) and is continuous with the vast, continuous surface of the Park Plateau in the Raton basin. In the Ocate volcanic field, this regional feature is represented by a southeast-sloping erosion surface, largely carved by the ancestral Rayado and Coyote Creeks. Much of the upper reaches of this surface was covered by intermediate-level volcanic rocks erupted between 4 and 5 Ma.

Structure contours drawn on this surface and the older surface nearly parallel to it are both concave upward and downward, indicating that they have been warped. The concave downward aspect of the surfaces is roughly coincident with the eastern margin of the Cimarron block. Warping is due to uplift of the Cimarron block with respect to the adjacent Great Plains. This surface is also cut by significant down-to-the-west normal faults on the west side of the volcanic field. These faults extend from the Moreno Valley 100 km south to the Mora Valley; displacement is as great as 275 m.

After this period of broad uplift and volcanism, major erosion was confined to established drainages in the western part of the area, and the central and southeast parts of the volcanic field. The ancestral Ocate Creek eroded the Ocate Valley to about its present size and altitude, as the present floor of the valley is graded to the surface beneath the low-level basalts, 3.3 to 3.1 Ma, that cap Charette Mesa. These flows or contemporaneous faulting apparently dammed Ocate Creek and raised the base level causing deposition of the fluvial Las Feveras Formation in Ocate Valley.

This volcanism was followed by continued uplift; associated denudation is marked by the formation of still lower paleoerosion surfaces and overlying gravels in the area, now preserved as isolated gravel-capped buttes and locally, basalt-capped mesas standing slightly below the Charette Mesa surface. Basalt on one of these surfaces near Wagon Mound was dated at 2.2 Ma.

By the time of the Maxon Crater eruption, 1.4 Ma, the major drainages were well established; downcutting along the lower reaches of the Mora River since 1.4 Ma exceeds 100 m. 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.

ACKNOWLEDGMENTS

This description of the Ocate volcanic field is largely excerpted from Gustafson, T., ed., Quaternary non-glacial geology of the southern Great Plains: Geological Society of America Centennial Decade of North American Geology, v. K-2. We gratefully acknowledge GSA for permission to publish this paper in this New Mexico Geological Society Field Conference Guidebook.

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Charles B. Read, USGS, field trip leader of NMGS 7th Annual Fall Field Conference speaking at Stop 1 of first day (19 October 1956) in Dalton Campground, 5 mi north of Pecos, New Mexico. Precambrian, Devonian, Mississippian and Pennsylvanian rocks were discussed at this stop. Photo by Sam Thompson III.