The Raton basin of northeastern New Mexico and southeastern Colorado is a Laramide structural basin bounded on the west by the Sangre de Cristo uplift, on the north by the Wet Mountains uplift and Apishapa arch, and on the east by the Sierra Grande arch. The basin is asymmetrical and the northerly trending axis generally is near the Sangre de Cristo uplift. The intrabasinal Cimarron arch separates the structurally deeper northern part of the Raton basin from the shallower, southern, Las Vegas sub-basin.

During most of Paleozoic time the Raton basin and its bounding uplifts were part of the relatively stable "continental backbone." The oldest known sedimentary rocks in the basin are marine beds of Devonian (?) and Mississippian age. In Early Pennsylvanian time the Rowe-Mora and Central Colorado geosynclinal basins were formed in the area of the present Sangre de Cristo uplift and the western half of the present Raton basin. The basins were bounded on the west by the intermittently rising San Luis uplift, and on the east and north by the ancestral Sierra Grande, Apishapa, and Wet Mountains uplifts. A mainly marine unstable shelf facies of the Magdalena Group of Pennsylvanian age in the Las Vegas sub-basin is 1,500-2,500 feet thick. These rocks grade abruptly northward into a marine geosynclinal facies which is as much as 6,000 feet thick in the Las Vegas sub-basin. The Magdalena Group is absent from the Cimarron arch, but it probably is present in the western half of the northern Raton basin where it may be 4,000 feet thick. Orogenic debris of the Sangre de Cristo Formation of Pennsylvanian and Early Permian age was derived mainly from the San Luis uplift, filled the Rowe-Mora and Central Colorado basins, and lapped onto Precambrian rocks of the other bounding uplifts. The Sangre de Cristo Formation is 700-1,500 feet thick at the south, and 6,000-9,500 feet thick at the north.

Higher Permian rocks, and Upper Triassic and Upper Jurassic rocks have average aggregate thicknesses ranging from 2,500 feet at the south to 1,100 feet at the north. These deposits blanketed the region of the present Raton basin and buried the late Paleozoic, Sierra Grande, and Apishapa uplifts. Cretaceous marine shale interbedded with some sandstone blanketed the entire region. The Cretaceous rocks are about 4,500 feet thick at the north, and remnants in the Las Vegas sub-basin are 900-1,000 feet thick.

The terrestrial latest Cretaceous and early Tertiary rocks, which are about 12,000 feet in aggregate maximum thickness in the northern part of the Raton basin, were derived mainly from the rejuvenated San Luis uplift. During early and middle Tertiary time, the San Luis uplift and the western parts of the Paleozoic Rowe-Mora and Central Colorado basins were elevated to form the Sangre de Cristo uplift. The present Raton basin, Wet Mountains uplift, and the Apishapa, Las Vegas, and Sierra Grande arches were formed in early Tertiary time.

The Raton basin has been a basinal area for most of its history since Early Pennsylvanian time. Thick marine sediments of Pennsylvanian and Cretaceous ages probably were sources of petroleum. Potential traps, both stratigraphic and structural, are known to exist in many parts of the basin, although these traps are mainly untested. Encouraging "shows" of oil and gas have been found in Pennsylvanian rocks in the Las Vegas sub-basin, and in Cretaceous rocks in several parts of the basin, but there has been no commercial production.

San Luis Basin.—In middle and late Tertiary time the ancient San Luis uplift was tilted eastward and its eastern part founded to form the San Luis basin, which is the northern part of the complex Rio Grande trough. The northwestern part of the San Luis basin merges into the eastern flank of the San Juan Mountains uplift. The southwestern part of the basin is bounded by the east-titled Brazos uplift. The eastern and northern boundaries of the basin are a complex fault zone along the western margin of the Sangre de Cristo uplift which merges, around the northern end of the basin, with the Sawatch and Gunnison uplifts.

Much of the San Luis basin is filled with middle to upper Tertiary and Quaternary terrestrial sediments and interbedded andesite and basalt that are at least 5,000 feet thick locally. This basin fills rests on lower and middle Tertiary volcanics that are related to the volcanics of the San Juan Mountains. Because the region of the San Luis basin was a part of the Paleozoic and Mesozoic San Luis uplift, it is probable that extensive areas of Paleozoic or Mesozoic rocks are preserved beneath the lower to middle Tertiary volcanics. The stratigraphy and geologic history of the San Luis basin are not encouraging for petroleum possibilities.
INTRODUCTION

The Raton and San Luis basins of Colorado and New Mexico have attracted only slight attention from the petroleum industry, even though the first wildcat test in the Raton basin region was drilled almost 65 years ago. There has been no commercial production of petroleum in either basin, but encouraging "shows" of oil and gas have been found in several rock units at widely scattered points in the Raton basin.

The subsurface geology of both basins is poorly known because of the scarcity of deep test wells. However, a general reconstruction of the distribution of rock units in the basins can be obtained by comparing subsurface data with the somewhat better-known surface geology of the basins and their bounding uplifts. This approach is not without its problems, because Cenozoic structural complications on the margins of the basins and in the uplifts cause considerable doubt about the distribution and thickness of some stratigraphic units. The reconstructions derived from combining surface and subsurface geology indicate considerable stratigraphic complexity in the Raton and San Luis basins. In the Raton basin this complexity probably favors the occurrence of petroleum deposits; in the San Luis basin, the complexity appears to be unfavorable.

RATON BASIN

GENERAL TECTONIC DESCRIPTION

The Raton basin of southeastern Colorado and northeastern New Mexico is the southernmost of the Laramide intracratonic folded basins at the eastern margin of the Rocky Mountains (Fig. 1). The northernmost part—the Huerfano Park region—is intermontane, but most of the basin lies in the western part of the Great Plains. Throughout its length the Raton basin is bordered at the west by the Sangre de Cristo uplift. At the east the basin is bordered by the broad, low, and locally ill-defined Sierra Grande arch. The northern part of the basin is considered to be the Las Vegas basin. However, more recently (Johnson and Wood, 1959, p. 2) the term Raton basin has been applied in the broader sense to the entire region between the Sangre de Cristo uplift and the Sierra Grande and Apishapa arches, and the northern part of the basin is considered to merge, along the Cimarron intrabasinal arch, into the southern basin. It is in this broader sense that the term Raton basin is used in the present report. The term Las Vegas sub-basin is applied to the part of the Raton basin south of the Cimarron intrabasinal arch. The main part of the basin that lies north of the arch is called simply the northern Raton basin.

Most of the Sangre de Cristo uplift west of the Raton basin is composed of crystalline rocks of Precambrian age and sedimentary rocks that range in age from Ordovician to Early Permian. These rocks were uplifted and crowded eastward by Laramide orogenic forces. The western limit of the basin northward from Las Vegas is, most places, vertical or overturned, and generally is broken by west-dipping high-angle reverse faults and thrusts (Northrop and others, 1945; Baltz and Bachman, 1956, p. 101-107; Bachman, 1953; Wane and others, 1964; Dane and Bachman, 1962; Johnson, Wood, and Harbour, 1959; Bolyard, 1959). In Huerfano Park low-angle imbricate thrust plates extend well into the western part of the basin (Burkam and Goddard, 1951; Johnson, 1959, p. 107-111). Igneous rocks of Tertiary age occur as sills, dikes, and stocks along the western margin of the basin in the vicinity of Ute Park and Eagle Nest, and west and southwest of Huerfano Park.

The Raton basin is an asymmetrical downwarp complementary to the Sangre de Cristo uplift and, except in the vicinity of the Cimarron arch, the axis of the structural trough lies in the western part of the basin. North of the Spanish Peaks the axis of the basin bifurcates around a southerly trending Cimarron arch, named for the Cimarron River, which lies on or near the arch between the vicinity of Ute Park and Springer, New Mexico. East of Springer the intrabasinal arch merges with the Sierra Grande arch. In older reports (Darton, 1928, p. 314) the terms Raton basin and Raton coal basin were applied only to the later and structurally deeper part of the basin north of the Cimarron arch, whereas the shallower southern part was called the Las Vegas basin. However, more recently (Johnson and Wood, 1959, p. 2) the term Raton basin has been applied in the broader sense to the entire region between the Sangre de Cristo uplift and the Sierra Grande and Apishapa arches, and the northern part of the basin is considered to merge, along the Cimarron intrabasinal arch, into the southern basin. It is in this broader sense that the term Raton basin is used in the present report. The term Las Vegas sub-basin is applied to the part of the Raton basin south of the Cimarron intrabasinal arch. The main part of the basin that lies north of the arch is called simply the northern Raton basin.
plunging spur (Greenhorn anticline) of the Wet Mountains uplift. The western axis has been called the La Veta syncline, whereas the eastern axis is the Delcarron syncline (Johnson and Stephens, 1954). The Tertiary igneous stocks of the Spanish Peaks were intruded in the trough of the northern part of the basin, and are accompanied by a swarm of large dikes that occur in a broad east-west hand which extends nearly across the basin north of Trinidad, Colorado (Johnson, 1961).

The eastern axis of the Raton basin is very broad and dips very gently west from the Sierra Grande arch and south and west from the Apishapa arch. For convenience, in Figure 1 the flanks of the arches are included in the basin, although it could be debated at great length where the eastern limb of the basin ends and the western limbs of the arches begin. The Huerfano Park segment of the basin is separated from the Wet Mountains uplift by a swarm of large dikes that occur in a broad east-west hand which extends nearly across the basin north of Trinidad, Colorado (Johnson, 1961).

The Sierra Grande arch is a broad, flat saddle on the northeastern margin of the Raton basin (section C-C', Fig. 2), as in the Las Vegas sub-basin. Similar relations obtain also in the Huerfano Park area (Johnson, 1959, especially pl. 6).

The general configurations of the troughs of the Las Vegas sub-basin and the northern part of the Raton basin are shown in Figure 2. In most of the Las Vegas sub-basin and on the Cimarron arch the surface rocks are Cretaceous. Rocks of Jurassic, Triassic, and Permian ages are exposed at the western margin of the basin and in the central parts of Ocate anticline and Turkey Mountains dome. The maximum aggregate thickness of sedimentary rocks in the Las Vegas sub-basin is of the order of 12,700 feet (section B-B', Fig. 2). The Magdalena Group of Pennsylvania age, and the Sangre de Cristo Formation of Pennsylvanian and Early Permian age are as much as 8,800 feet thick in the trough of the basin, but these rocks thin eastward toward the Sierra Grande arch, and the central parts of the basin, the Magdalena Group is absent. There are too deep wells for accurate delineation of these formations. The wedge-edges of various stratigraphic units, however, are in general of the order of 25,000 feet. However, the aggregate maximum thickness of sedimentary rocks in the trough of the northern part of the basin is of the order of 25,000 feet. Howevt, this figure is misleading because of angular unconformities and overlies within the Tertiary rocks and because Quaternary erosion has removed large amounts of rocks from parts of the basin. Perhaps more than 16,000-20,000 feet of sedimentary rocks are preserved at any place in the trough. No wells have reached the Precambrian in the trough of the northern part of the Raton basin. However, Pennsylvanian and Lower Permian rocks are known to be 13,000-14,000 feet thick in the Sangre de Cristo uplift, and this or absent on the eastern flank of most of the basin (section C-C', Fig. 2), as in the Las Vegas sub-basin. Similar relations obtain also in the Huerfano Park area (Johnson, 1959, especially pl. 6).

### PALEOTECTONICS

The latest Cretaceous and Tertiary tectonic elements of the Raton basin region are related to major structural features that were formed mainly in Pennsylvania and Permian time. These elements are shown in generalized form on Figure 3. The San Luis uplift at the west was on the northeastern margin of a large Paleozoic and early Mesozoic positive area that extended northwest across southwestern Colorado. This positive area, in its entirety, is generally called the Colorado uplift or geanticline (see King, 1934, p. 104-105). The eastern margin of the San Luis uplift seems to have been mainly in the area that is now the downfaulted San Luis basin, which is the northern segment of the present Rio Grande trough. The southwestern and central parts of the ancient San Luis uplift are in the Laramide Baja Ross uplift and beneath the San Juan Mountains volcanic field (see Fig. 1) (seal Read and others, 1949; Dane, 1948).

The area of the present southern Sangre de Cristo uplift and the Las Vegas sub-basin are the site of a geosynclinal basin—the Rowe-Mora basin (Read and Wood, 1947, p. 225-227)—which

by between the ancient San Louis uplift and the ancestral Sierra Grande uplift (so called to distinguish it from the present Sierra Grande arch). The Rowe-Mora basin was connected at the south by a low, folded saddle with the ancestral To-urncari basin. The area of the northern Sangre de Cristo uplift and probably most of the northern Raton basin were parts of the Central Colorado basin that was enclosed between the San Luis uplift and the ancestral Wet Mountains-Appishapa uplift. The Central Colorado basin probably was connected with the Rowe-Mora basin in Early and Middle Pennsylvania time. However, scanty and problematic stratigraphic evidence seems to indicate that the ancestral Chimarron arch arose as part of the Sierra Grande uplift in Middle and Late Pennsylvania time to separate, at least partly, the two geosynclinal basins.

### ROCKS OF DEVONIAN(?), MISSISSIPPIAN, AND PENNSYLVANIAN AGES

The oldest sedimentary rocks known to be present in the Raton basin are marine sandstone and dolomitic limestone of the Espiritu Santo Formation of Devonian (?) age (Fig. 4). This unit ranges from a few feet to 80 feet thick in the southern Sangre de Cristo Mountains (Baltz and Read, 1960, p. 1754-1756), and is about 35 feet thick at the Continental No. 1 Leatherwood-Reed well (no. 1, Fig. 4) in the Las Vegas sub-basin. The Espiritu Santo probably correlates with the Chaffee Formation of Late Devonian age in the northern Sangre de Cristo Mountains.

The Terero Formation of Mississippian age rests unconformably on the Espiritu Santo and is composed of limestone, breccia and marine conglomerate, argillaceous, and crystalline limestone, and siltstone. The Terero ranges in thickness from a few feet to 130 feet in the southern Sangre de Cristo Mountains (Baltz and Read, 1960, p. 1760) and from 50 to possibly more than 100 feet in the Las Vegas sub-basin. The breccia and conglomerate units of the Terero are porous at some outcrops, and were a loss-circulation zone in the Continental No. 1 Mares-Duran well on Ocate anticline, indicating some porosity and permeability in the subsurface also. Although the Terero is below possible source rocks, it might be a petroleum reservoir under favorable structural conditions on the flanks of the Las Vegas sub-basin or near faults in the basin.

Rocks of Ordovician, Devonian, and Mississippian ages crop out in the northern Sangre de Cristo Mountains (Litsey, 1956), but these rocks wedge out southward at outcrops and may not be presented in the subsurface of the northern Raton basin.

During much of Paleozoic time the region including the present Sierra Grande and Apishapa uplifts, Raton basin, and much of the Sangre de Cristo uplift seems to have been part of the broad, southwest-trending, shelf-like "continental backbone" (King, 1951, p. 30), on which sedimentary rocks older than Devonian are not present. Whether pre-Devonian sedimentary rocks were deposited on and later eroded from this shelf is a matter of conjecture. Maher and Collins (1949) indicate that the thick pre-Pennsylvanian, Paleozoic sequence of Kansas, Oklahoma, and eastern Colorado thins toward the Sierra Grande uplift in a manner suggesting that it has a long history as a positive area.

### ROCKS OF PENNSYLVANIAN AGE

The first recorded stage of formation of the Raton basin was in Early Pennsylvanian time when the erogenic forces that produced the ancestral Rockies began to downwarp the Rowe-Mora and Central Colorado basins. The Magdalena Group and the Minturn Formation, both of Pennsylvania age, and the Sangre de Cristo Formation of Pennsylvanian and Permian age (Fig. 4) are complex suites of sediments whose vertical and lateral variations reflect several stages of formation and eventual filling of the geosynclinal basins.

### Magdalena Group and Minturn Formation

The Magdalena Group in New Mexico consists of the Sandia Formation and the overlying Madera Limestone. The Sandia Formation (Atoka age), the lower unit of the Magdalena in the southern Sangre de Cristo uplift and the Las Vegas sub-basin, is a suite of coarse-grained to conglomeratic sandstone, dark gray shale, and subordinate thin limestone beds deposited in a mixed marine-terrestrial environment during a general transgression of the Pennsylvanian seas. The Sandia is about 400-600 feet thick in the Las Vegas sub-basin. The Deer Creek Formation of Bolyard (1959, p. 1904-1910) in the northern Sangre de Cristo Mountains is a similar sequence of rocks that contains red shale and correlates generally with the Sandia. The Deer Creek may correlate with the lower part of the Minturn that lies at
Spanish Peaks (north of section)

The Huerfano and Cuchoro Fms.
Poison Canyon and Raton Fms.
Sangre de Cristo Fm.

Bernal, San Andres, Glorieta, and Yeso Fms.

List of wells

Colorado
1. Shell Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 29, T. 34S., R. 68 W.
2. Continental Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 29, T. 34S., R. 68 W.
3. Continental Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 30, T. 34S., R. 68 W.

New Mexico
4. Continental Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 14, T. 34N., R. 17 E.
5. Continental Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 15, T. 34N., R. 17 E.
6. Continental Oil Co. no. 1 Colorado Fuel and Iron Co., sec. 16, T. 34N., R. 17 E.

Lines of cross sections shown on Fig. 1.

Fig. 2.—Diagrammatic cross sections of Raton basin.
The Deer Creek ranges from 300 to 1,100 feet thick. The Madera Limestone (Atoka through Virgil age) in the southern Sangre de Cristo uplift (Read and others, 1944; Read and Wood, 1947, Fig. 1) and the Las Vegas sub-basin consists of a lower, gray limestone member and an upper, arkosic limestone member. The gray limestone member is composed of interbedded crystalline fossiliferous limestone, dark gray shale, and sandstone, and is 700-1,200 feet thick. The arkosic limestone member consists of interbedded crystalline and clastic limestone, red, green, and gray shale, and conglomeratic arkosic sandstone, and is 450-2,770 feet thick. The gray limestone member was deposited in a predominantly marine environment, whereas the arkosic limestone member was deposited in a mixed marine-terrestrial environment and records strongly accelerated orogeny in the geosynclinal area and its bounding uplifts.

Rocks of Des Moines age in the Colorado part of the Sangre de Cristo uplift have been called the Madera Formation by Brill (1952, Pl. 1 and p. 816-820) and Bolyard (1959, p. 1910-1918). These writers applied the terms "gray limestone member" and "arkosic limestone member" to rocks which are lithologically somewhat similar to the members of the Madera in New Mexico, although the arkosic limestone member of Brill and Bolyard is, for the most part, older than the arkosic limestone member of New Mexico. The Madera of these writers is 2,200-2,400 feet thick. Brill applied the name Whiskey Creek Pass Limestone Member to a thin unit which is the upper part of his Madera Formation in Colorado, and he extended the term also into New Mexico. However, the Whiskey Creek Pass Limestone in Colorado is said to be Des Moines in age, whereas the youngest rocks of the Madera in northern New Mexico contain fusulinids of Virgil age.

The Deer Creek and Madera Formations of Bolyard and Brill grade northward, in the Sangre de Cristo uplift northwest of Huerfano Park, into a thick sequence of interbedded, brown, gray, and yellow conglomerate, arkosic sandstone, shale, and thin limestone of the Minturn Formation (Atoka?) through Des Moines age; Bolyard, 1959, p. 1919-1922). These rocks contain a few thin marine beds, but were deposited as a dominantly fluviatile facies in a part of the Central Colorado basin that must have been near mountainous highlands. The Minturn is more than 5,500 feet thick.

The total thickness of the Magdalena Group of New Mexico and its general equivalents in Colorado is shown in Figure 5. This map relies heavily on surface data from the Sangre de Cristo uplift because so few wells have been drilled to the Precambrian basement in this region. Most of the basement tests on the eastern flank of the Raton basin and on the Sierra Grande uplift were drilled on surface anticlines. Possibly some of these anticlines are rejuvenated Paleozoic folds; or, they might have resulted partly from differential compaction and "draping" of the sedimentary rocks across old highs. If this is the case, northwesterly aligned synclinal basins containing Pennsylvanian rocks might be present and undetected at places on the eastern limb of the basin and on the uplift.

The interpretation of the distribution of the Magdalena Group along the northern and southern flanks of the Cimarron arch is complicated, not only by a lack of subsurface control, but also by structural complications in the eastern side of the Sangre de Cristo uplift. West of Eagle Nest faulted slices of the Magdalena are several thousand feet thick. However, Wanek and others (1964) indicate that the Sangre de Cristo Formation lies on Precambrian rocks at outcrops south and west of Ute Park, and Triassic rocks lie on Precambrian rocks near the dam at Eagle Nest. Wanek and Read (1956, p. 92) interpret this contact at Eagle Nest to be a relatively flat, west-dipping fault downthrown on the west. C. B. Read (oral communication, 1965) indicates that the contact of the Sangre de Cristo and Precambrian rocks east of Eagle Nest also may be faulted. The eastern margin of the Sangre de Cristo uplift south of Ute Park is bounded by a large fault downthrown on the east (Wanek and others, 1964). Thus, according to C. B. Read, the bulge in the eastern front of the Sangre de Cristo uplift southeast of Eagle Nest may have been a result of Laramide upward movement of a mass of Precambrian granite which was completely bounded by faults, and which pierced and shoved aside part of the overlying sedimentary rocks. A possible alternate explanation is that the Laramide deformation postulated by Read may have occurred on a Paleozoic positive area, as depicted in Figures 3 and 5.

North of Eagle Nest along the eastern margin
FIG. 4.—Diagram showing relations of Paleozoic rocks.

Sources of data:
1. Continental Oil Co no. 1 Eastwood-Need well, sec. 15, T 16 N, R 17 E.
2. Hercules Exploration Co no. 1 Sopapita well, sec. 20, T 17 N, R 16 E.
3. Surface stratigraphic section, measured by E. H. Baltz west of Sopapita, projected to line of diagram.
4. Continental Oil Co no. 1 Moses-Odum well, Odum anticline, sec. 14, T 23 N, R 17 E.
5. Outcrops near Eagle Nest (Wanek and Reed, 1956, p. 90-92), outcrops in Cimarron Creek Canyon north of Clean Creek store (Wanek and Reed, 1964).
6. Surface stratigraphic section (A A. Moore, personal communication), Vermilion River, T 32 N, R 17 E.
These wells have been interpreted as possibly being in fault contact with the Sangre de Cristo Formation at least as far north as the State line (A. A. Wanek, oral communication, 1958). Here, and in the adjacent part of the Raton basin, it is impossible to say whether the Magdalena Group is present. The Union Oil Co. Nos. 1 and 2 Bartlett wells drilled on Vermejo Park anticline (Fig. 1) reached total depth in igneous rocks that occur in the lower part of the Cretaceous section. These wells have been interpreted as possibly having reached the Precambrian (Foster and Stipp, 1961). However, this seems unlikely because the Sangre de Cristo Formation and overlying Permian, Triassic, and Jurassic rocks are present below the Cretaceous at outcrops west of Vermejo Park dome (loc. 7, Fig. 6) and in all the other deep wells in this region, although farther east the Sangre de Cristo is very thin. Bates (1942, p. 145) suggests that the core of Vermejo Park dome is occupied by an igneous intrusion, presumably related to other Tertiary intrusives on the western margin of the basin. Thus, the possibility that the Magdalena may be present in the subsurface is not eliminated. Recent drilling shows that domal or laccolithic intrusions of Tertiary age occur in the Magdalena Group at Turkey Mountain dome in the Las Vegas sub-basin. Outcrops indicate Tertiary laccolithic intrusives also at Capulin and Rancho Grande anticlines on the Sierra Grande uplift (Wood et al., 1953).

In the Colorado part of the basin the isopachous lines are inferred only from thicknesses at outcrops west of the basin and from the few wells on the eastern limb of the basin that indicate the Magdalena is not present there (cross section C-C', Fig. 2). Wells at a few places on the Apishapa arch have found "shows" of oil in a thin sequence of red shale, arkose, and thin limestone that has been called the "lower carbonate zone" of the Sangre de Cristo or the Fountain Formation, and has also been assigned to the arkosic limestone member of the Madera Formation (Clair and Bradish, 1956a, b; Oborne, 1956). These rocks may lie east of the crest of the ancestral Wet Mountain-Apishapa uplift (Oborne, 1956, p. 63-64), and their relation to the Magdalena Group or Sangre de Cristo Formation of the Sangre de Cristo uplift has not been established with certainty. Along the western flank of the Wet Mountains uplift the Sangre de Cristo Formation is known to thin and lap onto Precambrian rocks (Johnson, 1959, p. 93), but a very thick section of rocks referable to the Magdalena and the Minturn underlies the Sangre de Cristo in the western part of Huerfano Park.

Facies.—At the southern end of the ancient Rowe-Mora basin (Fig. 3) the Sandia and Madera Formations accumulated on an unstable, mainly marine shelf (stippled on Fig. 5). The Sandia Formation on the shelf contains numerous thick, fairly clean sandstone beds. The Madera contains many relatively thick biothermal limestones, some clastic limestones, and some relatively clean sandstones interbedded in shale. The shelf facies is characterized by local inter- and intraformational angular unconformities, and secondary porosity was developed on some of them. Three large anticlines were formed on the shelf in Pennsylvanian and Early Permian time.

The shelf facies can be projected eastward from the mountains into the subsurface of the Las Vegas sub-basin, although its northern edge can not be located accurately from existing subsurface data. Asphaltic residues occur in faulted outcrops of the Madera and Sangre de Cristo Formations northwest of Las Vegas (Northrop and others, 1946), and the Starr Adams No. 3 and Hancock No. 1 Sedberry wells on the Graham anticline north of Las Vegas encountered strong "shows" of gas in the shelf facies of the Madera. "Shows" of oil also have been reported from the shelf facies of the Madera near the southern end of the Sangre de Cristo uplift. To date there has been no commercial production of oil or gas.

The shelf facies of the Magdalena Group thickens northward rather abruptly and grades laterally into a mainly marine geosynclinal facies (unpatterned on Fig. 5) in which thick gray and black shale predominates over sandstone and limestone. Although the thick shale might have been a source of petroleum, the sandstone and limestone are generally argillaceous and impermeable. The Continental No. 1 Mares-Duran well on Ocate anticline penetrated about 5,500 feet of rocks of the geosynclinal facies without "shows" of oil or gas. The facies of the Deer Creek and Madera Formations in the northern Sangre de Cristo uplift is similar to the geosynclinal facies of the Las Vegas sub-basin. The fluvialite sandstones of the Minturn Formation might offer better possibilities for reservoirs.
ROCKS OF PENNSylvANIAN AND PERMian

AGE

Sangre de Cristo Formation.—The Sangre de Cristo Formation is composed of thick red and green shale with interbedded arkose and conglomerate and a few thin beds of limestone. Most of the formation is terrestrial, but the lower third contains a few thin tongues of marine limestone (Zeller and Baltz, 1954, p. 3) in the southern Sangre de Cristo uplift and Las Vegas sub-basin. Thin non-marine limestone beds also occur at several positions in the formation. Surface work northwest of Las Vegas determined that the upper (Missouri and Virgil) part of the arkosic limestone member of the Madera grades northward into the lower part of the Sangre de Cristo Formation. This lower part, at least, of the Sangre de Cristo seems to have been derived from the north, probably from the ancestral Cimarron arch. Similarly, the overlying Yeso Formation of Permian (Leonard) age grades northward into the upper part of the Sangre de Cristo (Bachman, 1953). Thus, the Sangre de Cristo, which is as much as 3,500 feet thick in the Las Vegas sub-basin, contains rocks ranging in age from Late Pennsylvanian through Early Permian.

In the northern Sangre de Cristo uplift and western part of the northern Raton basin the Sangre de Cristo Formation ranges from 6,500 to at least 9,500 feet thick (Brill, 1952, p. 821). Early Permian vertebrates have been found in the Sangre de Cristo Formation, but it has not been established whether the formation also contains rocks of Pennsylvanian age in Colorado. Thin marine limestone was reported at one locality by Bolyard (1959, p. 1924). The lithologic character of the Sangre de Cristo in Colorado is generally similar to that in New Mexico, but northwest of Huerfano Park the Crestone Conglomerate Member of Bolyard (1959, p. 1924) is 6,000 feet thick and consists predominantly of massive boulder and cobble conglomerate that probably was derived from a nearby mountainous terrane in the San Luis uplift.

The Sangre de Cristo Formation is thickest in the troughs of the ancient Rowe-Mora and Central Colorado basins. The formation thins eastward onto the Wet Mountains-Apishapa, Sierra Grande, and Cimarron uplifts where it overlaps the Magdalena Group and rests on Precambrian rocks. On the Apishapa uplift Permian rocks rest locally on pre-Pennsylvanian Paleozoic rocks. At places on the uplifts the Sangre de Cristo is only a few hundred feet thick and, locally on the Sierra Grande uplift, Triassic rocks rest on monoclinal rocks of Precambrian age (Wood et al., 1953).

The influx into the geosynclinal basins of large amounts of arkose and conglomerate of the upper part of the Madera and lower part of the Sangre de Cristo Formation in Late Pennsylvanian time indicates a period of strong orogeny which continued through Early Permian (Wolfcamp) time. The Sierra Grande uplift, Cimarron arch, and Wet Mountains uplift must have supplied a large amount of the first-cycle detritus, but they were mostly buried by the Sangre de Cristo Formation in Early Permian time. The influence of the ancient San Luis uplift is difficult to evaluate because much of the uplift is now downfaulted into the Rio Grande trough, and much of the uplift is concealed beneath the San Juan Mountains volcanic field. In the western part of the San Luis uplift in New Mexico the present Brazos uplift, Permian rocks rest on the Precambrian and are overlapped by Triassic rocks. The San Luis uplift seems to have supplied a huge amount of the detritus which finally forced the sea out of the geosynclinal basins, filling them, and lapping onto the eastern uplands. The orogeny that culminated in Late Pennsylvanian and Early Permian time was the eastern portion of the geologic event recorded for the Raton basin region from Precambrian time to latest Cretaceous time. The tectonic elements that were established in the late Paleozoic influenced later sedimentation and geologic structure.

Although the Sangre de Cristo Formation does not contain rocks that are likely sources of petroleum, some of the arkoses might be suitable reservoirs in areas where they overlap Pennsylvanian marine rocks on the margins of the Las Vegas sub-basin and Cimarron arch and on the eastern limb of the northern Raton basin. To date these subsurface areas of overlap have not been located or tested anywhere in the basin. "Shows" of oil and gas in the Sangre de Cristo were reported on the Graham anticline in New Mexico, and asphaltic residues occur in the Sangre de Cristo at outcrops northwest of Las Vegas (Northrop and others, 1946).

Rocks of Permian Age

In the waning phases of Early Permian orogeny, the sea returned, covering part of the Raton basin region, and the Yeso Formation and Glorieta Sandstone of Leonard age, San Andres Limestone of Leonard and Guadalupian age, and Bernal Formation of Guadalupian age were deposited in the region of the southern Sangre de Cristo uplift, the Las Vegas sub-basin, and the southwestern Sierra Grande arch (Fig. 6). Similar rocks are present also in part of the northern Raton basin, and at places on the Apishapa arch.

Yeso Formation.—The Yeso Formation in the Las Vegas sub-basin and southern Sangre de Cristo uplift consists of orange to brick-red siltstone and shale, fine-grained sandstone, and local dolomite and gypsum. The Yeso is about 500 feet thick at the south but thins northward and disappears south of the Cimarron arch (Brill, 1952, p. 821-828). Bachman (1953) pointed out that the Sangre de Cristo and Yeso interfinger and the Yeso is replaced laterally northward by the upper part of the Sangre de Cristo Formation. This may indicate that the Cimarron arch was supplying some detritus in Leonard time.

Glorieta Sandstone.—The Glorieta Sandstone consists of gray, fine- to medium-grained, well-sorted, well-cemented, marine sandstone that is as much as 275 feet thick. The Glorieta becomes coarser-grained north of Ocate anticline and is absent from outcrops at the southwestern margin of the Cimarron arch (Brill, 1952, p. 821; Bachmnan, 1956, p. 101). Southward-inclined imbricate bedding in the vicinity of Ocate anticline seems to indicate that the sediments of the Glorieta in this area were derived from the north, possibly from the Cimarron arch. Oil stains occur at places in the Glorieta, but these rocks have not yielded oil in the Raton basin. The Lyons Sandstone of Colorado (probably equivalent in age to the Glorieta) yielded helium and commercial amounts of natural gas at Model dome on the Apishapa arch.

San Andres Limestone.—The San Andres Limestone is composed of dense, dark gray, earthy, marine limestone that contains a few sandy layers. The San Andres is about 150 feet thick in the southern part of the Las Vegas sub-basin, but thins northward and wedges out a few miles north of Las Vegas. The San Andres commonly is slightly feldspar at outcrops and in the subsurface, but has not yielded oil in the Raton basin.

Bernal Formation.—The Bernal Formation consists of pink, orange, and red siltstone, shale, fine- to coarse-grained sandstone, and some thin beds of limestone and gypsum. The Bernal is lithologically similar to the Yeso Formation. The Bernal locally is as thick as 150 feet in the Las Vegas sub-basin but is thinnest at most places, and is absent locally because of an erosion surface at its top. The Bernal overlaps the San Andres Limestone and has been traced north of the Ocate anticline. However, the Bernal is absent from the outcrops at the eastern margin of the Sangre de Cristos in the vicinity of the Cimarron arch. The Bernal is considered to be probably of Guadalupian age (Bachman, 1953), but the stratigraphy of the Bernal has not been studied carefully, and its age is not substantiated yet by fossils. Possibly, some of the rocks included in the Bernal are Triassic.

Regional correlations.—At some outcrops on the eastern margin of the Sangre de Cristo uplift north of Eagle Nest and in southernmost Colorado, the Sangre de Cristo Formation is overlain by a poorly exposed sequence of orange, pink, and red arkosic sandstone, siltstone, and shale containing a few thin beds of limestone and some white sandstone (unnamed unit, Fig. 6). These rocks are a maximum of 100-200 feet thick and are similar to rocks cropping out from Purgatoire River northward that were assigned to the Lykins Formation of Permian (?) and Triassic(? ) age by Johnson and Baltz (1960, p. 1899-1902). These rocks also can be identified in the subsurface of the northern Raton basin in both New Mexico and Colorado. Part of the sequence in the subsurface in southernmost Colorado has been correlated with the Yeso Formation and Glorieta Sandstone by Shaw (1956, p. 14-18), who postulates that the Yeso and Glorieta are present throughout much of the Raton basin, but wedge out westward in the subsurface just east of the Sangre de Cristo Mountains. Shaw's correlation is based on stratigraphic position and lithology; however, rocks correlated with the Yeso are similar also to parts of the Bernal Formation, the unnamed unit, and the Lykins(? ) Formation (see Johnson and Baltz, 1960). The pink and orange, fine- to coarse-grained sandstone and shale correlated by Shaw with the Glorieta
SOUTH

Southern Raton basin (Las Vegas sub-basin)

Eagle Nest arch (Cimarron arch)

Raton and San Luis Basins

NORTH

Northern Sangre de Cristo Mts.

Wet Mtns.

Graneros

Dakota

Purgatoire

Morrison

Raton Creek (?) Formation

Grande de Cristo Formation

Precambrian crystalline rocks

Sources of data:
1. Continental Oil Co. No. 1 Leatherwood-Red well, sec. 16, T. 16 N., R. 76 E., E. H. Baltz
2. Surface stratigraphic section, vicinity of Sangre de Cristo, T. 16 N., R. 66 E., E. H. Baltz
4. Surface stratigraphic section, nearby, T. 16 N., R. 66 E., E. H. Baltz
5. Composite surface stratigraphic sections, vicinity of Eagle Nest (Mason and Reed, 1955, p. 155-156, 159-161).

Fig. 6 — Diagram showing correlation of Precambrian rocks and part of Mesozoic rocks.
do not resemble the gray, well-cemented, well-sorted Glorieta Sandstone of the Las Vegas sub-basin, but they do resemble some of the exposed rocks of the unnamed unit and the Lykins (?) unit.

The unnamed unit and its subsurface equivalents seem to correlate, at least partly, with the Leonard and Guadalupe rocks that are 400-500 feet thick in the subsurface of the eastern limb of the northern Raton basin and the Apishapa arch (Shaw, 1956, p. 15; Norman, 1956; Osborne, 1956, p. 59-60). These rocks wedge out toward the Wet Mountains and are not present at outcrops on the margins of this uplift.

Probably the Leonard and Guadalupe rocks were deposited as a thin but widespread blanket over most of the Raton basin region. These rocks are mainly marine in the Las Vegas sub-basin, but their possible equivalents, including the unnamed unit and all or part of the Lykins (?) unit in the western part of the northern Raton basin, seem to be terrestrial. In the eastern part of the northern Raton basin, and on the Apishapa uplift and eastern limb of the Sierra Grande uplift, the Leonard and Guadalupe rocks seem to be marine. The absence of these rocks from parts of the Sierra Grande uplift (Wood et al., 1953), Cimarron arch, and Wet Mountains-Apishapa arches is mainly the result of Late Permian or Triassic uplift and erosion, although it may be partly the result of non-deposition.

**Rocks of Triassic Age**

After a long period of non-deposition and slight erosion, terrestrial rocks of Late Triassic age were laid down as a blanket of fluvialite sandstone and shale over much of the Raton basin region. Triassic rocks are absent from the northwestern part of the Apishapa arch and the Wet Mountains uplift, and are present only locally in the northern part of the northern Raton basin.

**Dockum Group.**—In most of the Raton basin region the rocks of Late Triassic age are referred to the Dockum Group. In the subsurface the Dockum is 1,000-1,200 feet thick in the Las Vegas sub-basin and 500-800 feet thick on the Sierra Grande arch, generally being thinnest near the crest of the arch. The Dockum is 300-400 feet thick in the subsurface on the eastern limb of the northern Raton basin, but thins northward and westward toward the Apishapa arch and Wet Mountains and the northern Sangre de Cristo uplift (Oriel and Mudge, 1956, Pl. 1), and finally wedges out in the subsurface.

In the Las Vegas sub-basin and southern Sangre de Cristo uplift the Dockum Group consists of the Santa Rosa Sandstone overlain by the Chinle Formation (Fig. 6). The Santa Rosa ranges in thickness from about 250-350 feet and consists of thin to thick brown, gray, and red sandstone and interbedded thin to thick red shale. The thickness changes because of the lenticularity of the upper sandstone beds. At most places the lower part is a massive unit of sandstone, as much as 150 feet thick, that contains pebbles of quartz, limestone, chert, and other sedimentary rocks. Nodular limestone and pebbles of limestone and chert also are common at places in the shale interbeds and some of the higher sandstones.

The thickness of the Chinle Formation ranges from 600 to 900 feet in the Las Vegas sub-basin. The Chinle consists mainly of red, purple, and greenish shale but contains varied proportions of interbedded red, brown, and gray sandstone, especially near the middle. Some of the shales are calcareous, and thin limestone beds occur at places. Lithologically, the sandstone and thin shales of the middle member of the Chinle (Northrop and others, 1946) are similar to the Santa Rosa, although the middle member is generally thinner than the Santa Rosa, ranging from 30 to 180 feet thick.

In the subsurface of much of the northern Raton basin the Dockum Group consists of a basal unit of conglomeratic sandstone, 75-100 feet thick, containing limestone and chert pebbles, that has been called the "unnamed unit" of the Dockum Group by Oriel and Mudge (1956, p. 20-21). This unit probably correlates with the Santa Rosa Sandstone, but the correlation has not been established firmly. The unnamed unit is overlain by red, purple, and green sand and interbedded sandstone and local thin cherty limestone, together as much as 275 feet thick, that have been correlated with the Sloan Canyon Formation by Oriel and Mudge (1956, p. 21). These rocks probably are equivalent also to part of the Chinle Formation.

Traces of asphaltic residues occur in well samples from the lower part of the Santa Rosa Sandstone at places in the Las Vegas sub-basin. The source of this asphalt probably was the San Andres Limestone. Some oil might have been introduced into the Santa Rosa from uplifted, faulted, or eroded Paleozoic oil fields in the area of the present Sangre de Cristo uplift on several occasions since Triassic time. However, the Santa Rosa contains large amounts of "fresh" asphaltic water and probably is mainly flushed now. Traces of asphaltic residue also occur in the Triassic rocks of the northern Raton basin. Although some of the Triassic sandstones are moderately porous and permeable, they are not favorably situated with respect to source beds in most of the Raton basin to be considered as probable, large petroleum reservoirs.

**Johnson Gap Formation.**—In the western part of the northern Raton basin and the Sangre de Cristo uplift from the Cimarron arch northward, Triassic rocks range from a few feet to 700 feet thick, with the thickness decreasing irregularly, but generally northward (Johnson and Baltz, 1950; Robinson and others, 1964, Fig. 8b). The Johnson Gap Formation (Fig. 6), which consists of siliceous limestone conglomerate, gray and red sandstone, siltstone and shale, and gray and red sandstone (Johnson and Baltz, 1960, p. 1897-1899), is 80-120 feet thick and may be equivalent to part of the Santa Rosa Sandstone. However, these rocks are similar also to the middle and upper members of the Chinle Formation in the Las Vegas sub-basin, and the correlations are not established firmly. The Johnson Gap Formation is equivalent (Johnson and Baltz, 1960) to part of the Dockum Group (Oriel and Mudge, 1956, loc. 19, 20, Pl. 1) in the subsurface of the northern Raton basin, and on the Sierra Grande and Apishapa arches. At least part of the Lykins (?) Formation of the southwestern part of the Raton basin seems to be Triassic (Johnson and Baltz, 1960, p. 1900-1901), but its relation to the Triassic units has not been established.

**Source areas.**—The Upper Triassic sediments of the Raton basin region were derived in part from reworking of underlying Permian rocks. Local monadnocks of Precambrian rocks supplied some of the detritus. The only obvious source of large amounts of limestone and chert pebbles is the Magdalena Group of the western parts of the Raton-Mora and Central Colorado basins; thus, it is possible that these rocks had begun to be deformed and uplifted slightly in Triassic time.

**The general northward thinning of the Triassic seems to have been mainly the result of very gentle warping and erosion in Jurassic time, although part of the thinning might be intraformational. The Dockum is folded into broad, low (pre-Late Jurassic) anticlines which can be observed clearly at the southern end of the present Ocate anticline, in the canyon of the Dry Cimarron River near the northeastern corner of New Mexico, and at other places in the region.**

**Rocks of Jurassic Age**

In Late Jurassic time a widespread blanket of shallow-marine and overlying terrestrial deposits were laid down across the entire Raton basin region. The total thickness of these rocks ranges from about 100 to 600 feet, the differences in thickness being attributable mainly to an erosion surface at the top of the Jurassic rocks.

**Entrada Sandstone.**—The basal Upper Jurassic unit in almost the entire region is the Entrada Sandstone (Fig. 6). This sandstone has been called the Exeter, Wingate, or Ocate Sandstone in various reports, but is now (McLaughlin, 1954, p. 88-91; Johnson, 1959, p. 95) generally correlated with the Entrada Sandstone of Utah. The Entrada ranges in thickness from 20 feet to 120 feet with considerable local variation. In Colorado the thickness varies, but the Entrada thins generally northward toward the Wet Mountains, and is absent from the eastern flank of the uplift.

The Entrada is a white to pink and red, fine-
coarse-grained, moderately well-sorted sandstone. Most of the sand grains are rounded and frosted quartz, but grains of red and green chert and weathered feldspar also are present. The cement generally is calcareous and, locally, slightly gyspiferous.

An eolian origin of the Entrada has been postulated because of the sweeping tangential cross-beds that are common at many places. However, much of the bedding is parallel and even, and the Entrada intertongues with overlying deposits of limestone, fine clastics, and evaporites. It seems likely that the Entrada was deposited on and near beaches and in near-shore marine environments during the transgression of a shallow sea.

The Entrada lies unconformably on Triassic rocks in the subsurface of most of the region, but overlaps the Triassic in the northern Raton basin and Apishapa arch and rests on the Sangre de Cristo Formation in the subsurface and at outcrops in the northern Sangre de Cristo uplift and Wet Mountains uplift. At Williams Creek on the southwestern side of the Wet Mountains (loc. 12, Fig. 6) the Entrada is arkosic, and it seems to have been derived from a nearby Precambrian terrane. However, the contact of the Entrada and the Precambrian is faulted (Johnson, 1959, Pl. 4). The Entrada laps onto Precambrian rocks in the present Brazos uplift in New Mexico and in the San Juan Mountains and Gunnison uplifts in Colorado, indicating that the ancient San Luis uplift was a positive area at the time of deposition of the Entrada. At places in the Las Vegas sub-basin and on the Sierra Grande uplift the Entrada rests on red and white sandstones which have been correlated tentatively with the Glen Canyon Group of Late Triassic and Jurassic age.

The stratigraphy and correlations of these rocks are not known well. Rocks near Mora River south of Ocate anticline that are similar to the Naranjo Formation of Bachman (1953) consist of reworked red Chine sediments that grade southward into the lower part of the Entrada. Similar relations seem to indicate slight folding, reworking, and sorting of Triassic sediments on some anticlines during deposition of the Entrada.

**Tolitto Limestone and Ralston Creek (?) Formation.**—The Entrada Sandstone is overlain by intertongues with a unit of evenly bedded, probably mainly marine, rocks that consists of varied facies of limestone, green and red shale, gypsum, and thin sandstone (the "middle unit of Jurassic age" of Oriel and Mudge, 1956). These rocks are present throughout the Raton basin region where they range in thickness from 50 to 100 feet. In the southern Sangre de Cristo uplift west of Las Vegas the unit consists mainly of gray, finely laminated, fettal limestone correlated with the Tolitto Limestone of western New Mexico (Northrop and others, 1946; Baltz and Bachman, 1956). The Tolitto tectonics out northward and eastward into a sequence of locally gyspiferous, reddish to waxy-green shale that contains interbedded thin, fine- to medium-grained sandstone, and red chalcedony beds. This sequence was correlated with the Wanakah Formation of southwest Colorado (Bachman, 1953; Wood et al., 1953; Johnson, 1962, p. C40-C54) assigned these rocks in the Colorado portion of the Raton basin to the Ralston Creek (?) Formation. They are generally equivalent to the Ralston Formation of Frederickson et al. (1956) at the eastern edge of the Front Range and the Canon City embayment in Colorado.

**Morrison Formation.**—The Ralston Creek (?) Formation is overlain by fluvialite deposits of the Morrison Formation throughout the Raton basin region. The thickness of the Morrison ranges from about 150 to 400 feet, with considerable local variation because of regional warping, local gentle folding, and erosion of upper beds prior to deposition of the overlying Purgatoire Formation of Early Cretaceous age. The Morrison generally is thickest in the western parts of the Raton basin, and thins irregularly eastward onto the Sierra Grande and Apishapa arches and the Wet Mountains uplift.

The Morrison consists of varied proportions of red, gray, and brown sandstone and conglomerate, and interbedded red, gray, and green shale and thin local limestone beds. The regional stratigraphy of the Morrison in the Raton basin has not been studied in detail, and little is known of the distribution of units of less-than-formational rank. The greenish to reddish sandstone and shale and interbedded coarser-grained and conglomeratic sandstone of the upper part of the Morrison are similar to the Brushy Basin Member of the Morrison of the Colorado Plateau. Some of the sandstone and conglomerate in the upper part of the Morrison is similar to the overlying Purgatoire Formation, causing local confusion in determining the top of the Morrison.

**Source areas and petroleum possibilities.**—Part of the sediments of the Entrada in the Raton basin are reworked Triassic sediments. However, much of the sediment of the Entrada, Ralston Creek (?), and part of the Morrison was derived from the central New Mexico highland south of the Raton basin, as shown by facies changes and southward thickening of sandstone units in east-central and west-central New Mexico. Some of the sediment probably was derived also from sources in Oklahoma and Kansas. The clast-porphyritic conglomerate of the upper part of the Morrison may have been derived from the west, and the ancient San Luis and Wet Mountains uplifts must have contributed some of the clastics.

Although some of the Jurassic rocks, especially of the Entrada Sandstone, are porous and permeable, they are not generally in favorable stratigraphic positions with respect to possible source beds to be likely petroleum reservoirs and have not yielded oil or gas where they have been tested in the Raton basin. The thin Tolitto Limestone in the southern part of the Las Vegas sub-basin is fetid, and trace oil stains in the Entrada can be attributed to it. Dead oil stains occur in the Entrada and Ralston Creek (?) at Tercio anticline in the northern Raton basin.

**ROCKS OF CRETACEOUS AGE**

In Early Cretaceous time the Raton basin region and the ancient positive areas became parts of the extensive Rocky Mountain geosyncline. More than 3,500 feet of sediments, largely marine, accumulated in the Raton basin region before the end of Cretaceous time.

**Purgatoire Formation.**—The Purgatoire Formation of Early Cretaceous age rests unconformably on the Morrison Formation and is present throughout much of the Raton basin and in the Sierra Grande and Apishapa arches. Throughout much of this region the Purgatoire Formation consists of a lower conglomeratic sandstone member and an upper member composed of varied proportions of gray carbonaceous to coaly shale and interbedded thin sandstone. These members generally are equivalent to the Lytle Sandstone and Glencairn Shale Members of the Purgatoire in the Front Range of Colorado (Waage, 1953). Recently, T. G. McLaughlin (U.S. Geol. Survey Water-Supply Paper 1805, in preparation) has designated the lower unit the Cheyenne Sandstone Member, and the upper unit the Kiowa Shale Member of the Purgatoire Formation in the subsurface of the Apishapa arch. Rocks equivalent to the Cheyenne differ considerably in thickness, but are generally 100-150 feet thick in the northern Raton basin, and rocks tentatively correlated with the Cheyenne are 30-40 feet thick in the Las Vegas sub-basin. Rocks equivalent to the Kiowa in the northern Raton basin are 15-45 feet thick, and the shaly rocks tentatively correlated with the Kiowa in the Las Vegas sub-basin generally are only 20-40 feet thick, and locally are absent from the western edge of the basin.

The Kiowa contains marine fossils in southeastern Colorado and probably is mainly a shallow-water marine deposit throughout most of its extent, although it may have accumulated in lagoons or swamps at the west. At places along the western margin of the Raton basin the Purgatoire and the overlying Dakota Sandstone can not be differentiated with assurance, and they have been mapped together as the Dakota Sandstone by some authors. The Cheyenne Sandstone Member is porous and permeable and generally yields large amounts of water in wells. At a few places in the northern part of the basin the Cheyenne has produced "shows" of oil, but these were floured out by water.

**Dakota Sandstone.**—The Purgatoire Formation is overlain throughout the Raton basin and the arches at the east by gray to buff sandstone and interbedded gray shale of the Dakota Sandstone of Early Cretaceous age. In New Mexico the Dakota commonly is only 30-60 feet thick. In Colorado the Dakota thickens northward to 100-150 feet. At the southeastern side of the Wet Mountains the Dakota and Purgatoire together are as much as 650 feet thick and are said to be a deltilian deposit there (Waage, 1953, p. 19-20). In the subsurface of much of the northern Raton basin the Dakota is about 100 feet thick. In general, the Dakota seems to thicken slightly from east to west.

At places, especially in the outcrop areas at the western margin of the Raton basin, the Dakota is nearly all sandstone and contains lenses of conglomerate. However, at most places the Dakota...
consists of several thin to thick, even-bedded sandstones that are separated by thin gray shales. Some of the sandstones are fine-grained to finely conglomeratic, whereas other beds consist of clean, well-sorted, loosely cemented sandstone. In general, the sandstone beds thin slightly eastward and the proportion of shale increases slightly eastward.

Much of the Dakota is marine, but in the western part of the basin it contains stream-channel sandstones and at places may be mainly terrestrial. The upper part of the Dakota grades into the marine rocks of the overlying Graneros Shale. "Shows" and stains of oil have been found in the Dakota at a few places in the Las Vegas sub-basin and at many places where it has been tested in the northern Raton basin.

**Graneros Shale, Greenhorn Limestone, and Carlile Shale.**—The Graneros Shale, Greenhorn Limestone, and Carlile Shale are marine rocks that are present throughout a large region of the Great Plains including the Raton basin and its bounding arches at the east. The Early Cretaceous-Late Cretaceous time boundary is within the Graneros Shale.

The Graneros rests conformably on the Dakota Sandstone and consists of dark gray shale that contains thin beds of bentonite, a few thin beds of limestone, and locally a minor amount of fine-grained sandstone. The Graneros is 185-380 feet thick in the northern Raton basin, and 215-250 feet thick in the southern part of the basin. In the trough of the northern Raton basin near Raton to about 550 feet along the western margin of the basin, some of this sand might have been derived from areas far at the west. On the other hand, it is possible also that some of this sand might have been derived from areas far at the west. 

**Niobrara Formation.**—The Niobrara Formation lies on the Carlile Shale throughout most of the Raton basin and on the Apishapa and South Grande arches. The Niobrara is about 500 feet thick at outcrops on the flanks of the Wet Mountains (Johnson and Stephens, 1954), and is much as 630 feet thick in the subsurface of the northern Raton basin. In the southern part of the Las Vegas sub-basin the Niobrara is absent because of Quaternary erosion, but as much as 90 feet of rocks probably equivalent to the Niobrara are preserved in the trough of the basin a few miles northwest of Las Vegas.

The Niobrara Formation is marine. The lower part of the formation consists of thin limestone and interbedded shale, the Fort Hays Limestone Member, that ranges in thickness from 25-55 feet in the northern Raton basin (Colban, 1956) to 10-20 feet in the Las Vegas sub-basin. The upper part, the Smoky Hill Member, consists of marly shale with interbedded thin limestone and sandy shale. Locally the middle part of the Smoky Hill contains distinct beds of fine grained sandstone that are as much as 10-30 feet thick. "Shows" of oil and gas have been reported from fractured Niobrara Shale in the northern Raton basin.

**Pierre Shale.**—The Pierre Shale lies on the Niobrara Formation in much of the Raton basin but has been eroded from parts of the eastern flanks of the basin and from the southern part of the Las Vegas sub-basin. The Pierre is as much as 2,300 feet thick (Johnson and Wood, 1955, p. 710). At wells near the Colorado-New Mexico border the Pierre is about 1,230 feet thick, and near the southern margin of the northern Raton basin the Pierre is about 1,100 feet thick (Johnson and Wood). South of here much of the Pierre has been removed by Quaternary erosion and only the lower part is preserved.

The Pierre is marine and consists of mainly dark gray non-calcareous shale, but contains a few thin beds of limestone, sandy shale, and sandstone. A zone about 100 feet thick that consists of the Apache Creek Sandstone Member (Scott and Colban, 1956, p. 890) and other beds of calcareous sandstone and silts occurs about 500 feet above the base of the Pierre and in the subsurface of the northern Raton basin. The upper 200-300 feet of the Pierre consists of interbedded shale and thin sandstone that grade into and intertongue with the overlying Trinidad Sandstone. "Shows" of oil and gas have been encountered in fractured Pierre Shale in the northern Raton basin.

**Trinidad Sandstone and Vermejo Formation.**—The Trinidad Sandstone and the overlying Vermejo Formation are present in the northern Raton basin in the roughly triangular region between Ute Park, a point about 13 miles east of Raton, New Mexico, and the southern part of San Luis basin. The Trinidad and Vermejo are absent from the westemmost part of the basin in New Mexico between Ute Park and a point west of Vermejo Park anticline, also because of angular unconformity with the Poison Canyon Formation (Fig. 7).

The Trinidad Sandstone is 0-300 feet thick. It thins thickest near the axis of the northern Raton basin where it ranges from 140 feet thick at the south to about 300 feet thick northward from Purgatoire River (Johnson and Wood, 1956, Fig. 1 and p. 712). Along the western margin of the basin the Trinidad is 80-220 feet thick and, on the eastern limb of the basin, 80-100 feet thick (Johnson and Wood). The Trinidad consists of slightly arkosic, fine-to medium-grained sandstone with some interbedded thin shale. These sediments were deposited in beach and near-shore environments during the closing phases of marine transgression. The Trinidad intertongues with the overlying Vermejo Formation (Johnson and Wood) and with the underlying Pierre Shale (Harbour and Dixon, 1956).

Excellent "shows" of oil have been reported from wells that penetrate the Trinidad in Colorado, and asphaltic residues and oil seeps occur in the Trinidad in the Cimarron River canyon in New Mexico, and also on Alamo dome (Johnson and Stephens, 1954; Creely and Saterdal, 1956). In Colorado, the Trinidad is an attractive drilling objective in the northern Raton basin because it is in the shallows of the Cretaceous marine sandstones in much of the region.

The Vermejo Formation thickens westward from a wedge near Raton to about 550 feet in the trough of the northern Raton basin near the Spanish Peaks in Colorado (Johnson and Wood, 1956, Fig. 5). The Vermejo thins westward from the trough and averages about 250 feet in thickness along the western margin of the basin (Johnson and Wood). The Vermejo Formation is composed of varied proportions of buff to gray shale, carbonateous shale, coal, and slightly arkosic fine-to medium-grained sandstone that were deposited in swamps and on flood-plains near the coast of the eastward-retreating Cretaceous sea.

**Source areas.**—Before Cenozoic orogeny and erosion, the Cretaceous rocks probably formed a thick blanket across the entire Raton basin region, the ancient positive areas on the east, and most of the region on the west. However, regional variations in thickness and lithology indicate that this blanket was not uniform, and that the ancient tectonic elements influenced sedimentation to some degree.

Part of the Purgatoire Formation consists of reworked sediments of the underlying Morrison, but part probably was derived from the Precambrian of the Wet Mountains uplift, as shown by onlap near the southeastern edge of that uplift (R. B. Johnson, oral communication, 1965) and by the deltaic sediments of the Purgatoire and Dakota in that area (Waage, 1953). The Dakota Sandstone in the present Brazos uplift in New Mexico contains coarse Precambrian detritus, and laps onto the Precambrian at places, indicating that the ancient San Luis uplift supplied at least some of the Early Cretaceous sediment.

During most of Late Cretaceous time the thick, shaly sediments that accumulated in the Raton basin region probably were derived mainly from orogenic areas in southwestern New Mexico, Arizona, and central Utah that supplied the detritus of the Mesaverde Group and related rocks. However, the differences of thickness of the various shale units indicate that the northern Raton basin, the Cimarron arch, and the Las Vegas sub-basin underwent slightly different amounts of subsidence. Possibly, the thin but widespread sandy units such as the Codell Sandstone in the northern part of the Carlile Shale, the sandy beds of the Smoky Hill Marl Member of the Niobrara, and the Apache Creek Sandstone Member of the Pierre were derived from areas far at the west. On the other hand, it is possible also that some of this sand might have been derived from island areas on the San Luis uplift. Such sources might be indicated by the northeastern thinning of the Mancos Shale of Late Cretaceous age in
The thin sandstone beds in the upper part of the Pierre Shale are the first direct evidence of Laramide orogeny in the Raton basin region (Johnson and Wood, 1956, p. 712). The intertonguing relations of the Pierre, Trinidad, and Vermejo Formations (Fig. 7) indicate that the Cretaceous sea retreated eastward or northeastward across the Raton basin region, and that sediments were derived from the west. Parts of the Pictured Cliffs Sandstone and the Fruitland Formation (homogenetic equivalents of the Trinidad and Vermejo), both of Late Cretaceous age in the San Juan basin, were derived from the east or northeast (Baltz, in preparation). This indicates that at least the southern part of the ancient San Luis uplift was rising in late Montana time and was a source of sediments supplied to the Cretaceous sea in both regions.

**Rocks of Latest Cretaceous and Tertiary Ages**

The major orogenic events that produced the present Raton basin and its bounding uplifts began in latest Cretaceous time and continued episodically through Oligocene time. The terrestrial rocks that record the stages of orogeny are preserved only in the northern Raton basin and Huerfano Park. Most of the Tertiary history of the Las Vegas sub-basin and the Sierra Grande and Apishapa arches can be inferred only by analogy with events in the northern part of the basin.

The details of the latest Cretaceous and Tertiary stratigraphy and history are discussed by Johnson and Wood (1956) and Johnson (1959). The following discussion is summarized largely from these papers.

**Raton Formation and Poison Canyon Formation.**—The Raton Formation of Late Cretaceous and Paleocene age lies on the Vermejo Formation and consists of fine- to coarse-grained arkosic sandstone, gray shale, and numerous beds of coal. At most places the basal part of the Raton is a pebble-bearing conglomerate. The Raton Formation is a swamp and flood-plain facies, as much as 1,700 feet thick in the trough of the basin, that grades westward into and intertongues with a piedmont facies of the lower part of the overlying Poison Canyon Formation of Paleocene age (Fig. 7). This lower part of the Poison Canyon consists of coarse, arkosic sandstone, conglomerate, and thin yellow shale which were derived mainly from Precambrian terranes on the west. The Poison Canyon is as much as 2,500 feet thick in the trough of the basin. The angular unconformity between the Poison Canyon and the Cretaceous rocks in the western part of the basin (Fig. 7) shows that by Paleocene time the Sangre de Cristo uplift had begun to form in the western parts of the ancient Rowe-Mora and Central Colorado geosynclines. The ancient San Luis uplift was elevated, as shown by the facies of Paleocene rocks in the San Juan basin (Baltz, in preparation), and was a hinterland west of the crumpled and rising troughs of the ancient geosynclines. The Raton and the Poison Canyon are conformable in much of the basin, but on the eastern and western margins of Huerfano Park the Poison Canyon truncates and overlaps the Raton, Vermejo, and Trinidad, and locally truncates the Pierre Shale to rest on the Niobrara Formation. Coarse conglomerates of the northern part of the Poison Canyon must have been derived mainly from the rising Sangre de Cristo uplift, but part of the formation probably was derived from the newly rising Wet Mountains uplift.

"Shows" of oil and gas were found in the Poison Canyon Formation at Alamo dome (Creely and Saterdal, 1956, p. 71) in the vicinity of the overlap of the Trinidad Sandstone.

**Cuchara Formation.**—The Cuchara Formation of early Eocene age consists of varicolored conglomeratic sandstone and interbedded variegated shale. The Cuchara rests unconformably on the Poison Canyon, overlies it, and extends into the northern part of Huerfano Park where it rests on the Pierre Shale. The Cuchara locally is absent from the eastern part of Huerfano Park, but is at least 5,000 feet thick in the trough of the basin near the Spanish Peaks. The sediments of the Cuchara probably were derived from rocks ranging from Precambrian through Paleocene. The red sediments of the Cuchara probably were derived mainly from red beds of the Sangre de Cristo Formation in the strongly uplifted region west of the basin, and also from the Wet Mountains.

**Huerfano Formation.**—After deposition of the
Cuchara, another episode of uplift occurred in the regions west and north of the Raton basin. During and after this orogenic episode the Huerfano Formation of Eocene age was deposited unconformably on the Cuchara Formation. The Huerfano is composed of variegated shale and interbedded conglomeratic sandstone. An outlier of the Huerfano Formation occurs in the western part of the Spanish Peaks, but most of the formation is in Huerfano Park where it is as much as 2,000 feet thick, and where it rests with angular unconformity on rocks as old as the Pierre Shale.

In latest Eocene or in Oligocene time the present Raton basin and its bounding uplifts were delineated in essentially their present structural form largely because of strong thrusting and uplift of the Sangre de Cristo region and downwarp of the basin. The western part of the Sangre de Cristo uplift probably still merged with the ancient San Luis uplift prior to the late Miocene and Pliocene formation of the Rio Grande trough. Sills, dikes, and strata of the Cretaceous Sandstone interbedded with sillie composition were intruded at places along the western margin of the northern Raton basin and in the area of the present Spanish Peaks in latest Eocene or Oligocene time. The laccolithic intrusions at Turkey Mountain dome and in the Tempie dome-Capulin anticline area of the Sierra Grande arch also may be of early Tertiary age.

Farisita Conglomeratic.—After the final major Laramide orogenic episode the pebbles, cobbles, and boulders of the Farisita Conglomerate of Oligocene (?) age were deposited on eroded rocks ranging in age from Eocene to Precambrian. The Farisita is preserved only in Huerfano Park where it is as much as 1,200 feet thick. Probably most of the sediments of the Farisita were derived from the west, but the Farisita laps onto Precambrian rocks at the western margin of the Wet Mountains uplift which probably also was a source of the sediments of the Farisita.

Devises Hole Formation.—The Devils Hole Formation of Miocene (?) age rests unconformably on the Farisita Conglomerate. The Devils Hole is preserved only in the Huerfano Park area and is 25-1,300 feet thick. The formation consists of a western facies of red conglomeratic sandstone derived from the Sangre de Cristo uplift, and an eastern facies of water-laid tuff and volcanic conglomerate that contains fragments of Precambrian rocks and was derived from the Wet Mountains area. The Devils Hole overlaps the overthrust plates in the western part of Huerfano Park. These relations provide evidence of the pre-Miocene (?) age of the major episode of thrusting in the Sangre de Cristo uplift. The Wet Mountains fault cuts the Devils Hole at the eastern edge of Huerfano Park and indicates some uplift of the Wet Mountains, or depression of the Huerfano Park segment of the Raton basin since middle Tertiary time.

SEDIMENTS AND ROCKS OF LATE TERTIARY AND QUATERNARY AGES

The late Tertiary and Quaternary history of the Raton basin has not been studied in detail. However, it appears that much of the region, including the Sangre de Cristo uplift, was reduced by erosion to an eroded, sloping compound surface of low relief prior to deposition of the Ogallala Formation of Pliocene age. The Ogallala is preserved mainly east of the crests of the Sierra Grande and Apishapa arches.

Epeirogenic uplift of the entire region occurred in late Tertiary time, at the time the Rio Grande trough was being formed. Andesitic and basaltic dikes, plugs, and volcanic flows of late Tertiary and Quaternary age in many parts of the Raton basin are associated with this period of regional deformation and large-scale erosion. Extensive basaltic flows of probable late Tertiary age are thought to have extended eastward for at least 100 miles from Raton along the Colorado-New Mexico line. Basalt flows were extruded from centers near the axis of the Sierra Grande arch in New Mexico, along the western margin of the basin south of the Cimarron arch, and in the central and northeastern parts of the Las Vegas sub-basin.

Oil was found in fractures in a thick igneous sill at Ojo anticline (Creely and Saterdal, 1934a, p. 68-70) in the northern part of the Raton basin, indicating that the petroleum possibilities of areas of igneous intrusion should not be discounted merely because of the presence of igneous rocks.

CONCLUSIONS

The study of the stratigraphy of the Raton basin indicates that this region has been a basin area for most of its history since Early Pennsylvanian time. The thick marine geosynclinal sediments of the Magdalena Group, especially the gray and black shale, seem to be likely sources of hydrocarbons. The shelf facies of the Magdalena in the southern part of the Las Vegas sub-basin, and the clastics of the Minturn Formation in the Huerfano Park region, are potential reservoir rocks which were formed at the time when coarse clastics were being expelled from the geosynclinal facies because of compaction. The deposition of the Rowe-Mora and Central Colorado basins relative to the Wet Mountains, Apishapa, and Sierra Grande uplifts and the Cimarron arch in Late Pennsylvanian and Early Permian time may have resulted in the formation of combination stratigraphic-structural traps because of updip truncation of the Magdalena Group by the Sangre de Cristo Formation. This event occurred also during the time when coarse clastics probably were being expelled from the geosynclinal areas. The subsequent history of the region indicates that the Paleozoic basinal areas of the present-day Raton basin remained intact or were accentuated during later tectonic events. Therefore, it is probable that traps in the areas of truncation of the Magdalena Group may have remained more or less intact.

Although Permain, Triassic, and Jurassic rocks contain porous, permeable sandstones that might be suitable reservoirs, these rocks are not generally in favorable positions with respect to possible source rocks to be considered as likely sources of petroleum. It is possible that in some places faulting may have placed these rocks in favorable positions for influx of petrolierous fluids, especially along the western margin of the Raton basin.

The Cretaceous rocks are the most attractive objectives for oil and gas exploration in much of the Raton basin, especially the northern part, because of their widespread extent, relatively shallow depth, and lithologic types. The thick shales are likely sources of hydrocarbons, and some of the confined sandstones are suitable reservoir rocks. The relatively thin and shallow Cretaceous sequence in the Las Vegas sub-basin is less attractive because it is mainly strongly flushed, although "shoals" of gas have been reported from the Greenhorn and Cretaceous strata. The trace of oil has been found along the Dakota.

Nearly all the major anticlines in the Raton basin that involve Cretaceous rocks have been largely tested by drilling. No really commercial accumulations of hydrocarbons have been found yet in the Cretaceous rocks, although a few wells in the northern part of the basin produced small amounts of oil or gas at the Ojo, Escondido, and Garcia anticlines. However, encouraging multiple "shows" have been found not only in sandstone but also in fractured shale in some of the structures in the northern part of the basin. Overthrust structures along the western margin of the basin (Johnson et al., 1958; Johnson, 1959) offer mainly untested possibilities of both fault traps and anticlinal accumulations in the Purgatoire and Dakota, and of fractured-shale reservoirs as well. The overlaps of the Trinidad and Vermejo and part of the Pierre by the Poison Canyon and higher Tertiary rocks offer possibilities of stratigraphic-structural traps south of Huerfano Park. Hydrodynamic traps also might occur in the Cretaceous sandstone units on monocline, antithetic ridges or faults on both the eastern and western limbs of the Raton basin.

Several kinds of stratigraphic traps probably exist in the Cretaceous rocks, especially on the eastern limbs of the basin. The slight eastward thinning of the Dakota seems to be accompanied by a general eastward diminution in grain size, and local sand-line or bar accumulations of clean, well-sorted sandstone might be present. If the differences in thickness of the Graneros, Carli,, Niobrara, and Pierre Shales in the Las Vegas sub-basin, the Cimarron arch, and the northern Raton basin are the results of local or regional unconformities, offshore bar accumulations of winnowed sandstones might be present. Outcrop data indicate that tongues of the Trinidad Sandstone wedge out eastward into the Pierre Shale, and such updip wedge-outs also must be present in the subsurface of the eastern limb of the northern Raton basin. Not enough is known of the details of Cretaceous stratigraphy in the Raton basin to evaluate the probability of occurrence or the locations of any of these kinds of stratigraphic traps, but what is known about the regional stratigraphy indicates that such traps are possible.

NOTES ON SAN LUIS BASIN

GENERAL TECTONIC DESCRIPTION

The San Luis basin in south-central Colorado and north-central New Mexico is an intermontane structural depression between the San Juan Mountains volcanic field and Brazos uplift at the west and the Sangre de Cristo uplift at the east (Fig. 8). This structural basin includes the phys-
graphic feature in Colorado that was described the San Luis Valley by Sidleenthal (1910, p. 109), who indicated that the valley also extends southward over 15 miles into New Mexico (see map of physiographic divisions on Fig. 8). Upson (1939) extended the term San Luis Valley to include areas farther south in New Mexico. Upson (1939, p. 722 and Fig. 2) named and described Alamosa Basin, San Luis Hills, Taos Plateau, Costilla Plains, and Culebra Reentrant as physiographic subdivisions of the valley. The structural 

Scanty well data indicate that the volcanic rocks of the San Juan Mountains (Potosi Volcanic Group) dip east beneath Miocene and Pliocene sediments and lie more than 5,000 feet below the surface northwest of Alamosa, whereas these volcanic rocks crop out and form parts of the San Luis Hills in the vicinity of the Rio Grande south and southeast of Alamosa (U.S. Geol. Survey, 1935). This may indicate that the Alamosa segment of the basin is bounded, north of the San Luis Hills, by concealed northeast-trending faults that are downthrown toward the northwest (Upson, 1939, p. 727-728).

The Alamosa segment is a topographically, nearly flat drainage basin whose deepest parts are northeast and east of Alamosa where several lakes and playas are present. In this area sediments of Pliocene or Pleistocene age are more than 2,000 feet thick (Powell, 1958, p. 22-24), but these sediments thin toward the west and southwest, indicating that part of the tilting and depression of the basin occurred as late as Pleistocene time. This part of the basin may have subsided 12,000-15,000 feet, relative to the Sangre de Cristo uplift, since middle Tertiary time.

In New Mexico the San Luis basin is bounded on the east by the gently east-tilted Brazos uplift. The boundary is obscured by volcanic rocks and sediments of late Tertiary and Quaternary ages, but at the north, the western boundary of the basin is marked by large normal faults downthrown to the east (Kelley, 1956, p. 109: 1954). This southern part of the basin west of Taos is a graben. The southern boundary of the San Luis basin was defined by Kelley (1956, p. 109) as the Embudo structural constriction southwest of Taos. These relations seem to indicate that the Santa Fe Group is unconformably overlying the volcanic rocks of the Sangre de Cristo uplift. In the vicinity of Taos, Pennsylvanian rocks of the uplift are adjacent to the eastern faulted border of the San Luis basin. On the north, Precambrian rocks of the uplift are adjacent to the basin for most of its length. A major fault zone, downthrown on the west, extends north from the western spur of the Sangre de Cristo in New Mexico, into the basin along the western side of San Pedro Mesa, to a point north of San Luis, Colorado (U.S. Geol. Survey, 1935). The Culebra Reentrant is a graben (Upson, 1939, p. 734).

In most of the San Luis basin south of Alamosa, the surface rocks are volcanic. The youngest of these rocks are the thick basalt flows that cap the Taos Plateau west of the Rio Grande and occur at places east of the river. These basalt flows have been tilted east slightly and are overlain, in the Costilla Plains east of the Rio Grande, by Quaternary alluvial deposits, derived from the east, that mainly mask the faulted eastern boundary of the basin. This is generally known about the subsurface stratigraphy of the San Luis basin. Most of the basin is filled by sediments and basaltic to andesitic volcanics of the Santa Fe Group of Miocene to Pleistocene (?) age that were deposited during the downfaulting of the basin. Outcrops in the bounding uplifts and at places on the margins of the basin indicate that the Santa Fe Group is underlain at many places by volcanic rocks and conglomeratic red beds of early to middle Tertiary age.

ROCKS OF EARLY TO MIDDLE TERTIARY AGE

In the southern part of the Brazos uplift Precambrian rocks are overlain by the El Rito Formation of Smith (1938) of Eocene (?) age. These rocks consist of pebbly to boulder conglomerate, red shale, and sandstone, and they are similar to their probable correlative, the Blanco Basin Formation of Oligocene(?), and possibly Eocene, age (Larsen and Cross, 1956, p. 60-61) which rests on rocks of Cretaceous age at outcrops in the northern part of the Brazos uplift and the southernmost part of the San Juan Mountains volcanic field. The El Rito is as much as 200 feet thick, and the Blanco Basin is about 500 feet thick.

The El Rito and Blanco Basin Formations are overlain by thick series of rhyolitic to latitic flow rocks, volcanic conglomerate, and tuff. At the north the volcanic rocks are assigned to the Eaquita Formation of Smith (1938) and the Caran Conglomerate of Just (1937), both of Miocene age.
Volcanic rocks, related intrusives and, at the base, variegated conglomerate, sandstone, and shale. Includes the Vollejo Formation of Upson (1941) and overlying pre-Hinsdale volcanics in Colorado.

Geologic map compiled mainly from:
- U.S. Geol. Survey, 1935
- Dane and Bachman, 1957
- Dane and Bachman, 1962
- Larsen and Cross, 1956

Fig. 8 - Geologic map of the Raton and San Luis basins and adjacent regions.
an rocks are present beneath the early Tertiary rocks in the vicinity of Taos.

In the northern part of the basin volcanic rocks, including the Potosi Volcanic Group and some pre-Potosi volcanic rocks dip east from the San Juan Mountains and pass beneath Quaternary sediments and the Santa Fe Group in the basin. The Orrin Tucker No. 1 Thomas well in sec. 13, T. 41 N., R. 8 E., about 24 miles north of Alamosa, encountered a sequence of mainly volcanic conglomerates and breccias and some flow rocks between the depth of 5,210 feet and the total depth of 8,023 feet. These rocks probably are mainly the Potosi Volcanic Group, but the lower 173 feet contain much red, purple, and green clay similar to the Blanco Basin Formation (see log in Powell, 1958, p. 275-280).

In most of the northern part of the San Luis basin it is impossible to say what lies beneath the volcanic rocks which may be 3,000-4,000 feet thick at places (Larsen and Cross, 1956, Pl. 2). Perhaps Mesozoic rocks are present beneath the volcanics west and northwest of Alamosa (Larsen and Cross, 1956, Pl. 2, cross sections B-B' to E-E') as they are in the southern part of the San Juan Mountains, but there are no outcrops or well data to well the distribution of the Mesozoic rocks. Near the northern end of the basin the volcanics rest on uplifted and faulted Precambrian crystalline rocks and Paleozoic sedimentary rocks. The sedimentary rocks probably are on the southwestern margin of the ancient Central Colorado basin, and would not be expected to be present farther south in the area of the ancient San Luis uplift, the distribution of the Mesozoic rocks. Near the northern end of the basin the volcanics rest on uplifted and faulted Precambrian crystalline rocks and Paleozoic sedimentary rocks. The sedimentary rocks probably are on the southwestern margin of the ancient Central Colorado basin, and would not be expected to be present farther south in the area of the ancient San Luis uplift, the distribution of the Mesozoic rocks.

The eastern part of the San Luis basin was, in Paleozoic time, part of the Central Colorado basin. However, the Precambrian rocks at the western side of the Sangre de Cristo uplift rose from the ancient basin during Laramide orogeny. It seems almost certain that, prior to the downfaulting of the Rio Grande trough, the area of much of the eastern San Luis basin was part of the generally mountainous region that constituted the hinterland of the Laramide orogenic belt. Therefore, it is unlikely that any extensive areas of Paleozoic or Mesozoic sedimentary rocks are preserved in the subsurface of the eastern San Luis basin except possibly in fault slices.

Contents of late Tertiary and Quaternary Age

The Alamosa Formation is overlain by a sequence of late Tertiary and Quaternary sediments that are mainly equivalent to the Tesuque Formation of middle Miocene to Recent age. The Tesuque Formation is overlain by a sequence of late Tertiary and Quaternary sediments that are mainly equivalent to the Tesuque Formation of middle Miocene to Recent age. The Tesuque Formation consists of successive intergradations of units of sediments, volcanic detritus, and basaltic and andesitic flow rocks. The lowest unit is composed of pinkish basalt and gray sand, silt, local gravel, local tuffaceous sediments, and a few basalt flow rocks. These deposits were named the Tesuque Formation of middle (?) Miocene to early Pliocene age by Spiegel and Baldwin (1963, p. 39-45). In the San Luis basin the Tesuque Formation is exposed in the gorge of the Rio Grande southwest of Taos and along the southeastern margin of the Brazos uplift.

The Tesuque Formation is overlain by a sequence of basalt and andesite flows and interbedded thin sediments of Pliocene and Pleistocene (?) age that extend across the Taos Plateau in the southern part of the basin and are at least 500 feet thick northwest of Taos. The basalt and andesite flows of the Tesuque Formation were erupted from centers that rise as hills above the plains on both sides of the Rio Grande. At the western margin of the basin in New Mexico the flows lap across the Tesuque Formation onto the Carbon Conglomerate. In southern Colorado the basalt and andesite flows are referred to the Hinsdale Formation (Larsen and Cross, 1956) and they lap onto the Potosi Volcanic Group which crops out in the northeastern San Luis Hills west of the Rio Grande for about 20 miles north of the State line. The flows also lap onto the Potosi at the western margin of the Alamosa basin and are present in the subsurface southwest of Alamosa where they dip northeast in the Alamosa Basin beneath the Quaternary sediments (Powell, 1975, p. 19) and wedge out or become thin and discontinuous farther northwest.

In the Alamosa basin north of Alamosa, sediments that are mainly equivalent to the Tesuque Formation and basaltic or andesitic flow rocks that are equivalent to the Hinsdale Formation have been penetrated in deep wells. These sediments are predominantly pinkish-buff but contain gray, red, and bluish beds. The Tesuque consists of clay, arkosic sand, and gravel that are slightly calcareous, and the formations contains some beds of fusiferous material and volcanic conglomerate. The sediments were derived from the granitic terrane of the Sangre de Cristo uplift and also from the San Juan Mountains volcanic field. The Orrin Tucker No. 1 Thomas well penetrated about 885 feet of Quaternary sediments and about 4,325 feet of sediments which are referable mainly to the Tesuque Formation. An undetermined amount, perhaps 600 feet, of the upper part of the Tesuque probably is laterally equivalent to the basalt and andesite flows (the Hinsdale Formation) of the upper part of the Santa Fe Group south of Alamosa. "Shoals" of gas were reported at depths of 3,801 feet and 4,006 feet in the Tesuque Formation at the Rush and Calvert well in sec. 27, T. 41 N., R. 10 E., about 25 miles north of Alamosa. It's gas may have been volcanically generated, or it may have been "swamp gas" from buried carbonaceous sediments. The fluvialitic and playa-type sediments of the Tesuque Formation are not likely sources of petroleum.

SEEDMENTS OF LATE TERTIARY AND QUATERNARY AGE

The Alamosa Formation of Pliocene or Pleistocene age (Siebenthal, 1910, p. 40-47; Powell, 1918, p. 20-24) overlies the Santa Fe Group in Colorado and consists of unconsolidated gravel, sand, silt, and clay. These sediments are confined mainly to the Alamosa Basin, but thinner equivalents are present in the Costilla Plains in New Mexico, also. The coarser materials were deposited near the margins of the Alamosa Basin as fans, and finer material was deposited, probably in a lacustrine environment, in the eastern part of the basin in the "sump" area where the present lakes and playas occur. Records from deep water wells indicate that the Alamosa Formation ranges in thickness from a feather edge at the western side of the basin to more than 2,000 feet in the central part of the basin north of Alamosa.

Because the region of much of the San Luis basin was part of the ancient San Luis uplift and was a source for a tremendous amount of sediment shed both east and west in late Paleozoic time, part of Mesozoic time, and latest Cretaceous and early Tertiary time, it is doubtful that extensive areas of Paleozoic or Mesozoic rocks are preserved in the basin beneath the Tertiary volcanics and basin fill. This conclusion is indicated also by outcrops in northern New Mexico where Tertiary sediments and volcanics rest on the Precambrian west of the basin, at places within the basin, and in the western part of the Sangre de Cristo uplift. Possibly, Pennsylvanian rocks are present beneath the eastern Tertiary rocks in the basin near Taos. Although small amounts of "swamp gas" occur in Pliocene and Pleistocene sediments, the stratigraphy and geologic history of the San Luis basin are not encouraging for possibilities of petroleum occurrence.

ELMER H. BALTZ

RATON AND SAN LUIS BASINS

CONCLUSIONS

In middle Tertiary time, after the extrusion of large amounts of volcanic material of mainly intermediate composition in Laramide orogenic areas of north-central New Mexico and south-central Colorado, the Laramide geanticline that included the eastern part of the ancient San Luis uplift and the hinterland of the Sangre de Cristo uplift was tilted eastward. Its eastern part faulted along high-angle faults to form the complex faulted blocks of the San Luis basin. This east-tilting and downfaulting continued episodically through the late Tertiary and was accompanied by deposition of the Tesuque Formation and extrusion of basalts and andesites. Some of the deformation and basin filling continued into the Quaternary period.

Because the region of much of the San Luis basin was part of the ancient San Luis uplift and was a source for a tremendous amount of sediment shed both east and west in late Paleozoic time, part of Mesozoic time, and latest Cretaceous and early Tertiary time, it is doubtful that extensive areas of Paleozoic or Mesozoic rocks are preserved in the basin beneath the Tertiary volcanics and basin fill.