Geology and Coal Resources of the Starkville-Weston Area Las Animas County Colorado

By GORDON H. WOOD, JR., ROSS B. JOHNSON, *and* GEORGE H. DIXON

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A study of the fuels resources in a 245 square-mile area in the southwestern part of Las Animas County, Colorado

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GEOLOGY AND COAL RESOURCES OF THE STARKVILLE-WESTON AREA, LAS ANIMAS COUNTY, COLORADO

By Gordon H. Wood, Jr., Ross B. Johnson and George H. Dixon

ABSTRACT

The part of the southern half of the Spanish Peaks quadrangle described in this report has an area of about 245 square miles. It is part of the Trinidad coalfield in the Raton Mesa region of southeastern Colorado, and extends from longitude 104°30′00″ on the east to longitude 104°52′30″ on the west and from the Colorado-New Mexico boundary line (approximately 37°00′00″) on the south to latitude 37°10′00″ on the north. Most of the area is in the Park Plateau subsection of the Raton section of the Great Plains physiographic province, the rest, near the town of Trinidad, is in the Chaquaqua Plateau subsection.

The area lies on the eastern limb of the Raton basin, a large, complex, and asymmetric structural depression that extends northward from the vicinity of Las Vegas, N. Mex., into Huerfano Park, southern Colorado, and lies between the north-trending Sangre de Cristo Mountains on the west and the northeasterly trending Sierra Grande arch on the east. The approximate axis of the basin lies a few miles to the west of the report area near the foot of the Sangre de Cristo Mountains and its general trace roughly parallels the axis of the range. The Raton basin was formed during the latter part of the Laramide revolution (Eocene epoch) by the same compressive forces which produced the eastward thrusting in the Sangre de Cristo Mountains. It is, in a regional sense, an overturned syncline, the western limb having been largely removed by erosion and the eastern limb having been irregularly downwarped into series of long, narrow, north-trending folds. Structural relief of these folds seldom exceeds 200 feet.

A prism of sedimentary rock in the Raton Mesa region may be 10,000 feet thick in the eastern part of the area of the report and may thicken gradually to as much as 25,000 feet in the western part. Cenozoic rocks average about 2,000 feet in thickness, and Mesozoic rocks, about 4,000 feet. The thickness of Paleozoic rocks is unknown, but it may range from 4,000 to 6,000 feet in the eastern part to 10,000 to 20,000 feet in the western part.

Cenozoic rocks exposed in the area consist of the upper part of the Raton formation, the Poison Canyon formation, bodies of igneous rocks, stream alluvium, upland cover, and soil mantle. The exposed Cretaceous strata from younger to older, consist, of the lower part of the Raton formation, Vermejo formation, Trinidad sandstone, and the upper beds of the Pierre shale.

Cretaceous rocks in the subsurface, from younger to older, are the lower beds of the Pierre shale, Niobrara formation, Carlile shale, Greenhorn limestone, Graneros shale, Dakota sandstone, and Purgatoire formation. The Jurassic strata

in the subsurface are assigned to the Morrison formation, Wanakah(?) formation, and Ocate sandstone. Triassic strata do not crop out in the region surrounding the area; however, a sequence of redbeds and limestone of possible Triassic or Permian age was entered by wells northeast and east of Trinidad and may extend into this area.

Paleozoic sediments accumulated during Pennsylvanian and Permian time as a geosynclinal sequence in the Rowe-Mora basin, a depositional basin, which trended approximately north-south between the Uncompaghre positive element to the west and the Sierra Grande positive element to the east. The deepest part of the basin appears to have been within the present limits of the Sangre de Cristo Mountains and the eastern margin apparently lay along the western flank of the present Sierra Grande arch. Thus, the Paleozoic sediments in the subsurface of the area were deposited east of the depositional axis of the basin and are a part of a prism of sedimentary rock that thickens rapidly westward. The difference in thickness of the wedge from east to west across the area is unknown, but Paleozoic rocks may be about 4,000–6,000 feet thick in the subsurface of the eastern part of the area and as much as 10,000–20,000 feet thick in the western part. The oldest Paleozoic rocks probably are an undivided sequence of Pennsylvanian age that may range in thickness from 2,000 feet in the east to 10,000 feet in the west. These sediments where exposed in the Sangre de Cristo Mountains appear to have been largely derived from the adjacent positive elements and deposited in a marine environment. There they consist of conglomerate, arkose, sandstone, dark shale, and limestone. The other Paleozoic rocks in the mountains are assigned to the Sangre de Cristo formation of late Pennsylvanian and early Permian(?) age. There they are a sequence of fine- to very coarse-grained continental redbeds. In the subsurface of the area, they may be about 2,000 feet thick beneath the eastern part and as much as 10,000 feet thick beneath the western part.

Beds of coal occur in the lower few feet of the Poison Canyon formation, and throughout the Vermejo and Raton formations. The coal is of high volatile *A* and *B* bituminous rank (A. S. T. M. classification). On an "as received" basis the heating value ranges from slightly more than 12,000 to slightly less than 14,000 British Thermal Units. The original reserves are estimated on a "bed-by-bed" basis and a "coal-zone" basis to have been about 5,244,490,000 short tons. The recoverable reserves based on the average percentage of recovery in coal mines of the western United States are about 2,567,500,000 short tons.

The beds of coal vary in thickness and in content of impurities. Those in the Raton and Poison Canyon formations are, in general, more lenticular and variable than those in the Vermejo formation. The Frederick and Primero beds in the lower member of the Raton formation are in places thick and have been two of the most valuable sources of coal in the area. The Ciruela bed in the middle member of the Raton has not been mined, is not as thick, is of lesser areal extent, and is, therefore, not as valuable. The Sopris, Cokedale, Upper Starkville, Lower Starkville, Morley, Piedmont, and Lower Piedmont beds of the Vermejo formation together with the Frederick and Primero beds, have yielded most of the coal produced in the area. At least 58,917,184 short tons have been mined by 1950. This is about 1 percent of the estimated total original reserves or about 2 percent of the estimated total recoverable reserves.

Future mining probably will be directed toward parts of beds outlined by systematic drilling, and probably will be chiefly in areas west of Cokedale, south of the present mined-out limits in the Purgatoire Valley, and west of the Morley mine workings. These beds probably will be developed by long inclined slopes or by vertical shafts.

Oil or gas have not as yet been discovered in south-central Colorado, and it is not possible to accurately evaluate the possibility of their occurrence in the area. The thick sequences of Pennsylvanian and Cretaceous rocks are suitable both as source and as reservoir rocks for the accumulation of petroleum. Because of the lenticular nature of the overlying upper-most Cretaceous and early Tertiary rocks it is not easy to determine from surface information the location of structural features in older rocks which are more than a few hundred feet below the datum plane for structure contouring. This difficulty is magnified greatly in determining structural features of rocks below the Ocate sandstone because the Sangre de Cristo formation and the underlying sequence of Pennsylvanian rocks probably form a thick wedge which thins rapidly eastward. Many of the deeper structural features probably can be found only by geophysical surveys and by stratigraphic drilling.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The area described in this report consists of 245 square miles in the southern half of the Spanish Peaks 30-minute quadrangle of southeastern Colorado. The southern and northern limits of the area are the Colorado–New Mexico boundary line and latitude 37°10′ N.; the eastern and western limits are longitude 104°30′00″ W. and 104°52′30″ W., respectively. The Colorado–New Mexico boundary line is from one-half to two-thirds of a mile south of latitude 37°. The area lies in the Trinidad coalfield, a part of the larger Raton Mesa region, and is largely drained by the Purgatoire River.

Plate 1 shows the location of the area covered by this report and of neighboring areas that have been mapped by the U. S. Geological Survey in southeastern Colorado and northeastern New Mexico. The geology of many of these areas has been described or shown by publications of the Geological Survey. These reports may be identified from the following list.

Reference no. on plate 1	*U. S. Geol. Survey publication**	*Author and date of publication*
1	Bull. 1051 (this report)	Wood, G. H., Johnson, R. B., and Dixon, G. H., 1957.
2	Geol. Atlas, folio 36	Gilbert, G. K., 1897.
3	Geol. Atlas, folio 58	Hills, R. C., 1899.
4	Geol. Atlas, folio 68	Hills, R. C., 1900.
5	Geol. Atlas, folio 71	Hills, R. C., 1901.
6	Geol. Atlas, folio 135	Fisher, C. A., 1906.
7	Bull. 381–C	Washburn, C. W., 1910.
8a	----do	Richardson, G. B., 1910.
8b	Prof. Paper 101	Lee, W. T., and Knowlton, F. H., 1917.
9	Geol. Atlas, folio 186	Stose, G. W., 1912.
10	Geol. Atlas, folio 214	Lee, W. T., 1922.
10	Bull. 752	Lee, W. T., 1924.

*See Literature cited for title.

Reference no. on plate 1	*U. S. Geol. Survey publication**	*Author and date of publication*
11	Prof. Paper 186–K	Dane, C. H., Pierce, W. G., and Reeside, J. B., Jr., 1937.
12	Oil and Gas Inv. Prelim. Map 68	Bass, N. W., 1947.
13	Coal Inv. Map C–4	Wood, G. H., Johnson, R. B., Eargle, D. H., Duffner, R. T., and Major, Harald, 1951.
14	Oil and Gas Inv. Map OM 141	Wood, G. H., Northrop, S. A., and Griggs, R. L., 1953.
15	Oil and Gas Inv. Map OM 137	Bachman, G. O., 1953.
16	Oil and Gas Inv. Map OM 146	Johnson, R. B., and Stephens, J. G., 1954.
17	Coal Inv. Map C–26	Wood, G. H., Johnson, R. B., and Dixon, G. H., 1956.
18	Oil and Gas Inv. Map OM 161	Johnson, R. B., and Stephens, J. G., 1956.
19	Oil and Gas Inv. Map OM 174	Harbour, R. L., and Dixon, G. H., 1956.

*See Literature cited for title.

PURPOSE AND SCOPE OF THE REPORT

The purpose of this report is to describe the geology and economic resources of a relatively small area in the coal-bearing Raton Mesa region. Interest in the occurrence, mining, and utilization of coal in the Raton Mesa region has been long and continued; interest in the possible occurrence of oil and gas has been sporadic but at times intense. Geologic work consisted of gathering and evaluating basic data on the stratigraphy of the coal-bearing rocks, and those that might contain accumulations of oil and gas, and on the general geology and structure of the area. The investigation also contributed to the knowledge of the regional geology and to the evaluation of the oil and gas possibilities in southeastern Colorado and northeastern New Mexico.

FIELD WORK

Field work by G. H. Wood and R. B. Johnson began in June 1949 and ended in November 1949. G. H. Dixon and K. W. Brett were geologic assistants from June to September. Because of the checkerboard pattern, the interdependence, and the overlap of work done by these individuals, it is not practical to indicate the portions of the area each mapped.

Single-lens aerial photographs at a scale of approximately 1:20,000 were used for mapping. The positions of geographic features, culture, geologic boundaries, and outcrop bands of coal beds were drawn on the aerial photographs by means of a stereoscope. A planimetric map of the area was made at a scale of 1:20,000 from the aerial photographs. It was made by means of metal-templet radial triangulation that was controlled by triangulation stations that were established by the Geological Survey, the U. S. Coast and Geodetic Survey, and the U. S. Forest Service. Geographic features, culture, geologic boundaries, and outcrop bands of coal beds were transferred from the aerial photographs by means of a Wernstedt-Mahan Plotter. Vertical control for the eastern part of the area was taken from a preliminary copy of a topographic map made from aerial photographs by the Geological Survey. Vertical control in the western part of the area was obtained by means of the K. E. K. Radial Plotter, and controlled by bench marks established by the U. S. Coast and Geodetic Survey and the Geological Survey. Land survey lines were located from section markers set by the U. S. General Land Office. Automobiles were used for travel over much of the area, but many localities near the Colorado-New Mexico boundary line could be reached only on foot or by horseback.

The methods used in mapping and correlating the individual coal beds differ somewhat from those usually employed. During the field season of 1948 it was found that tracing and mapping individual coal beds was difficult because the coal beds are poorly exposed. It was decided that the best method of locating and mapping the beds of coal was by mapping individual persistent beds or zones made up of lenticular beds of sandstone between the coal zones. Thus, the belts of outcrop of coal-bearing rocks shown on the geologic map contain many lines that mark the position of these zones of lenticular sandstone beds (pl. 2). These lines are also shown on the graphic sections (pl. 4) and were used as datums in correlating many of the coal beds (pls. 6–10).

GEOGRAPHY

SURFACE FEATURES

The part of the Spanish Peaks quadrangle described in this report lies in the south-central part of the Trinidad coalfield of the Raton Mesa region (pl. 1). The southern boundary of the area coincides approximately with the drainage divide between the Purgatoire and Canadian Rivers, which trends east-west nearly parallel to the Colorado-New Mexico boundary line. The divide crosses a once relatively flat but now intricately dissected upland surface that gradually rises westward from an altitude of 7,700 feet to about 8,200 feet. The Purgatoire River flows eastward across the area about eight miles north of the divide, and the intervening land slopes gently northward toward the river and is dissected by several major and many minor tributary canyons. The topography north of the river is similar, but the southward slope is gentler, because the drainage divide north of the Purgatoire River is generally lower.

The total relief in the area is about 2,300 feet. The altitude ranges from slightly less than 6,000 feet at Trinidad on the Purgatoire River to about 8,300 feet on the divide between Lorencito and Alamosa Canyons. Local relief may be as little as 300 or as much as 1,000 feet but commonly is 600–700 feet.

The Purgatoire River, master stream in the southern part of the Trinidad coal field and the only permanent stream in the area, flows through an open valley across the northern part of the area. Intermittent tributaries enter the Purgatoire Valley from flat-bottomed alluviated canyons, many of which are deep and narrow along their middle courses but are shallow and flat-bottomed along their upper courses; others, however, flow in narrow, deep canyons throughout most of their courses.

DRAINAGE AND WATER SUPPLY

The Purgatoire River drops from an altitude of about 6,810 feet at Weston to an altitude of about 5,970 at Trinidad, with an average gradient of 42 feet per mile in a distance of about 20 miles. The gaged flow of the river from June 21, 1949 to September 30, 1949 varied from 1,170 second feet to 24 second feet, and the average flow during the 37 years prior to 1949 was 93.1 second feet. The average flow for 1949 was 100 second feet and the total flow was 72,730 acre feet. In 1896 the river temporarily was dry, but 8 years later, in 1904, the record maximum flow of 45,400 second feet was measured.

South of the Purgatoire River the principal canyons are—from east to west—Raton, Long, Widow Woman, and Lorencito, all of which head in the high country near the Colorado-New Mexico boundary line. Long Canyon, the largest, heads in New Mexico and drains a considerable portion of the Brilliant quadrangle in the Raton coal field. North of the river the principal canyons are—from east to west—Colorado, Reilly, Burro, and Sarcillo. They head along the drainage divide between the Purgatoire and Apishapa Rivers and drain large regions north of the area.

Water for grazing, farming, and domestic purposes is pumped by windmills from shallow wells. During the late summer months and periods of prolonged drouth many of these wells decrease in yield and finally become dry.

Springs are few and most of them go dry late in the summer. Their rate of flow is seldom more than a gallon per minute. Many ranchers store well water, rain water, and melt water from snow in the small stock-watering reservoirs known as tanks.

ACCESSIBILITY AND ROUTES OF TRAVEL

The Starkville-Weston area is crossed by the main line of the Atchison, Topeka, and Santa Fe Railway, the Denver and Rio Grande Western Railroad, and the Colorado and Southern Railway. U. S. Highway 85 and 87 between Morley, Starkville, and Trinidad crosses the extreme eastern part of the area. U. S. highways 160 and 350 reach Trinidad from the north, northeast, and southeast. Colorado State Route 12 follows the Purgatoire valley from Trinidad to Weston across the northern part of the area and Colorado State Route 23 connects Starkville and Cokedale. The Federal highways and Colorado State Route 12 are paved; other State roads and the county roads are graded and generally are in good condition. Secondary roads extend from the main roads to most parts of the area. A few are maintained, but most are in need of repair. Ranch roads along the main canyons tributary to Purgatoire River give access to line camps, windmills, and coal-drillhole sites. A few poor roads climb some of the ridges and reach parts of the drainage divide between the Purgatoire and Canadian Rivers.

POPULATION

The population of the area is concentrated in the towns of Cokedale, Morley, Starkville, and Trinidad, and on ranches along the valley of Purgatoire River. In the 1950 census Trinidad had a population of 12,204; a decrease of 1,019 from the 1940 census figure. Las Animas County had a population of 25,902; a decrease of 6,467 from 1940 and 10,106 less than in 1930. The density of population in Las Animas County was 5.4 persons per square mile in 1950, but this part of the County may have a somewhat greater density figure because a part of the city of Trinidad is in it.

CLIMATE AND VEGETATION

The climate of the area ranges from that of a semiarid steppe to that of a semiarid forestland. Stations of the United States Weather Bureau at Trinidad (altitude 5,746 feet), Walsenburg (altitude 6,200 feet), Raton (altitude 6,600 feet) and North Lake (altitude 8,800 feet) have recorded average annual rainfall of 14.17 inches, 14.51 inches, 16.12 inches, and 22.39 inches, respectively (table 1).

Precipitation is greater in the western or higher parts of the area than in the eastern or lower parts, as shown by the records from North Lake in the foothills of the Sangre de Cristo Mountains, and by the presence of aspen and yellow pine in the higher parts of the area. Rainfall is greater during the summer months (table 1) and is

TABLE 1.—*Climatic data for the Starkville-Weston Area*

[From U. S. Weather Bureau reports]

Station	Length of record (years)	Mean monthly temperature (° F)												Mean annual temperature, (° F)
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Trinidad, Colo	40	31.2	33.2	40.2	48.8	57.5	66.9	71.6	70.6	63.3	52.6	41.5	31.7	48.3
Walsenburg, Colo	14	33.8	36.1	41.9	49.4	58.0	67.0	71.9	71.5	63.8	55.2	42.1	36.8	52.3

Station	Length of record (years)	Mean monthly precipitation (inches)												Mean annual precipitation (inches)
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Trinidad, Colo	42	0.38	0.63	0.81	1.85	1.75	1.25	2.12	1.83	1.28	0.99	0.56	0.72	14.17
Walsenburg, Colo	16	.50	.68	1.36	2.26	1.95	.92	1.57	1.49	1.38	1.04	.72	.64	14.51
North Lake, Colo	57	.85	1.42	1.87	2.49	2.10	1.69	3.67	3.17	1.61	1.40	.99	1.13	22.39
Raton, N. Mex	38	.34	.54	.70	1.29	1.96	1.90	2.89	2.36	1.96	1.12	.60	.46	16.12
Dawson, N. Mex	30	.31	.56	.64	1.15	1.97	1.99	2.87	2.60	1.40	1.45	.40	.37	15.71
Vermejo Park, N. Mex	21	.47	.60	.95	1.64	1.29	1.52	3.73	3.07	1.39	1.14	.52	.56	16.88

characterized by torrential thunderstorms or cloud-bursts, which usually fall on small areas and last only a few minutes. Because vegetation is sparse and gradients are steep, flash floods frequently result from these summer rains. The amount of snowfall varies considerably from year to year. Several feet of snow may cover most of the area during some winters, but snow may be absent except at high altitudes during others.

The vegetation is transitional between that of the Great Plains and that of the Southern Rocky Mountains. Groves of cottonwood are common in the lower valley bottoms. Juniper, pinyon pine, scrub oak, and mountain mahogany grow abundantly at slightly higher altitudes, and yellow pine and aspen are common in the highest parts of the area. Wild gooseberry, sotol, cholla, prickly pear, and barrel cactus are among the plants present at elevations below 7,000 feet. Several varieties of grass furnish grazing for considerable numbers of cattle.

PREVIOUS GEOLOGIC WORK

Some geologic features in the Starkville-Weston area were described in the reports of early exploring expeditions. Coal was noted in the Raton Mesa region in 1821 by members of the S. H. Long party (James, 1821; Long, 1823). Emory (1848) described coal near Trinidad and Walsenburg, and Abert (1848) collected fossil plants from the coal-bearing strata. Bailey (1848), who examined these plants, stated that they were younger than Carboniferous, and Hayden (1867, 1868a, 1868b, 1873, 1874a, 1876a, and 1876b) placed the coal-bearing strata of the region in the Tertiary system. Owen and Cox (1865), however, reassigned them to the Cretaceous system and Le Conte (1868) considered them to be middle Cretaceous in age. Lesquereux (1872, 1873, 1874a, 1878, and 1883) disagreed with Owen and Le Conte and maintained that the coal-bearing strata near Trinidad were Eocene in age. Stevenson (1879, 1881, and 1889) and Newberry (1874) reassigned them to the Cretaceous system, but St. John (1876) and Endlick (1877) followed Lesquereux and Hayden in assigning them to the Tertiary system.

During the next two decades few additions to geologic knowledge of the region were published. At about the turn of the century, however, Hills (1899, 1900, and 1901) published three important folios on the geology of the region, in which he assigned the coal-bearing strata to the Laramie formation of Cretaceous age. Richardson (1910) followed Hills in assigning the coal-bearing rocks to the Laramie formation. Lee (1909) divided the Laramie formation into the Upper Cretaceous Vermejo formation and the Eocene Raton formation. He interpreted the conglomerate at the base of the Raton formation to be evidence for an unconformity at the top of the

Vermejo formation. He also collected fossil plants which were identified by Knowlton (Lee and Knowlton, 1917) to be of Late Cretaceous and Eocene age. In later publications (1911, 1916, 1917, 1922, and 1924) Lee vigorously supported both the validity of the division and the existence of the unconformity.

Knopf in 1936 described the igneous rocks of the Spanish Peaks. In 1943 Brown revised the stratigraphic position of the Cretaceous-Tertiary boundary in the Trinidad coal field. He correlated the Vermejo formation and the lower several hundred feet of strata in the Raton formation with the Laramie formation and assigned the upper part of the Raton formation to the Paleocene. In 1951 Wood, Johnson and others described the geology, stratigraphy, and coal resources of a small part of the coal field. They followed the age assignments of Brown.

STRATIGRAPHY

About 3,000 feet of strata of Late Cretaceous and early Tertiary age are exposed in the area. They rest on an eastwardly thinning prism of early Mesozoic and late Paleozoic sedimentary rock. The prism may be 12,000 to 22,000 feet thick on the west and thin to 7,000 feet on the east. Older Paleozoic rocks are absent, thus the total thickness of sedimentary rock in the area probably ranged from 15,000–25,000 feet on the west to 10,000 feet on the east.

The formations exposed in the area, from younger to older, consist of the Poison Canyon formation (600± feet) of Paleocene age; the Raton formation (1,200–1,600 feet) of Paleocene and Upper Cretaceous age; the Vermejo formation (80–250 feet), Trinidad sandstone (45–200 feet), and the upper 300–500 feet of the Pierre shale, whose total thickness is 1,800–1,900 feet, all of Upper Cretaceous age. The Poison Canyon and Raton formations crop out over most of the area. The Vermejo formation, the Trinidad sandstone and the upper beds of the Pierre shale crop out in the eastern part of the area near Morley and in the valley of the Purgatoire river.

Several thousand feet of Mesozoic strata older than the upper beds of the Pierre shale, and late Paleozoic strata, underlie the area. The nearest exposures of older Mesozoic strata are in the foothills of the Sangre de Cristo Mountains west of the area and in the plains regions east, northeast, and southeast of the area. Paleozoic strata crop out over large areas in the Sangre de Cristo Mountains.

From youngest to oldest, the rocks of the Cretaceous system that are present in the subsurface are the lower beds of the Pierre shale, the Niobrara formation (775± feet), the Carlile shale (200± feet), the Greenhorn limestone (25± feet), the Graneros shale (190± feet), the Dakota sandstone (75± feet), and the Purgatoire formation (100± feet). Strata of Jurassic age crop out in the surrounding regions, and are believed to underlie the area. They consist of the Morrison formation (275± feet), the Wanakah(?) (30± feet) formation and the Ocate sandstone (60± feet). An unnamed sequence of red beds (as much as 180 feet), which may belong to either the Triassic or Permian systems, underlies the Ocate sandstone and rests on the Sangre de Cristo formation. This sequence has been reached by wells drilled in the eastern part of the area, but is absent in the foothills of the mountains to the west. The Sangre de Cristo formation (3,000(?)–10,000(?) feet) of strata of Permian(?) and Pennsylvanian age and an undivided sequence of chiefly marine strata (3,000(?)–10,000(?) feet) of Pennsylvanian age may underlie the area and if present are believed to thicken westward. In the Sangre de Cristo Mountains these undivided Pennsylvanian strata rest unconformably on igneous and metamorphic rocks of pre-Cambrian age.

PRE-CAMBRIAN ROCKS

Granite, gneiss, quartzite, pegmatite, and schist of pre-Cambrian age are exposed in the Sangre de Cristo Mountains a few miles to the west and southwest of the area. Such crystalline rocks undoubtedly underlie the area, although no wells in or near the area have reached them. The depth to these pre-Cambrian rocks is unknown but can be inferred from the thicknesses of sedimentary rocks as measured in the nearby mountains, from the depths of wells drilled to pre-Cambrian rocks on the Sierre Grande arch, and from the thicknesses of sections measured during the field work for this report. On the basis of these data, it is concluded that the depth to pre-Cambrian rocks may range from less than 10,000 feet in the eastern part of the area to between 15,000 and 25,000 feet in the western part.

PALEOZOIC ROCKS

Conclusions regarding the thickness and lithology of the buried Paleozoic rocks inferred to be present in the area are based on data gathered in the Sangre de Cristo Mountains and from wells drilled in localities east, northeast, and southeast of the area.

Strata of Paleozoic systems older than the Pennsylvanian are not believed to be present in the subsurface of the area. Formations assigned to some of these systems crop out in the northern part of the Sangre de Cristo Mountains in Colorado (Burbank, 1932, p. 19; Kirk, 1931, p. 220–240) and on the northeastern flank of the Wet Mountains, and wedge out southward in these ranges. They underlie the Great Plains to the northeast of the Apishapa arch (Maher,

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1950), but are absent throughout most of northeastern New Mexico. Hence they probably are not present beneath the intervening Spanish Peaks area.

PENNSYLVANIAN STRATA

Strata of Pennsylvanian age in the Sangre de Cristo Mountains of Huerfano and Las Animas Counties have not as yet been formally named in Geological Survey publications. In other publications they have been called the Lower Sangre de Cristo conglomerate, having the Veta Pass limestone member at its base (Melton, 1925, p. 807–815), and the Sandia formation and the Madera limestone of the Magdalena group (Brill, 1952, p. 809–880). Rocks having the lithology characteristic of the Magdalena group crop out in mountain ranges of central New Mexico. In the Sangre de Cristo Mountains, however, north of Cowels and Sapello, N. Mex., these rocks change rapidly in lithology and the contact between the Sandia and Madera formations becomes extremely difficult to trace (Read, C. B., 1948, oral communication). The lateral change in lithology and the attendent difficulty in mapping the Sandia-Madera contact indicate that Brill may have extended these formations too far northward as identifiable sedimentary units. Therefore, strata of Pennsylvanian age in the Sangre de Cristo Mountains of Las Animas and Huerfano Counties are considered in this report to be undivided. They probably are equivalent to the Hermosa formation of the San Juan Mountains of southwestern Colorado and are correlative with the lower part of the Magdalena group of central New Mexico.

Several sections of the Magdalena group, ranging from 8,000 to 10,000 feet in thickness, have been measured by C. B. Read (1949, oral communication) and associates in the Sangre de Cristo Mountains near Tres Ritos, N. Mex. Here the Magdalena strata consist of conglomeratic sandstone, arkose, graywacke, quartzose sandstone, dark shale, limestone, and arkosic limestone. Many beds of dark shale are bituminous, and the porosity and permeability of the coarser clastic rocks are relatively high.

Intensely faulted, and highly contorted strata of Pennsylvanian age are poorly exposed in several canyons of the Sangre de Cristo Mountains west of the area. The succession and thickness of these strata have not been determined, but preliminary estimates of their thickness range from 2,000 to 3,500 feet. Brill (1952, p. 859–864) measured 3,213 feet of strata in the vicinity of Whiskey Creek Pass. It is not known, however, whether the estimates and Brill's measured section include all or only a part of the sequence of Pennsylvanian rocks. The lithology of this sequence is similar to the lithology of the sequence exposed near Tres Ritos.

In Huerfano Park and in adjacent parts of the Sangre de Cristo Mountains determination of the sequence of Pennsylvanian rocks is complicated by thrust faulting and folding. The thickness of the Pennsylvanian rocks is known only approximately, as these rocks have not been separated from the Permian rocks. Burbank and Goddard (1937, p. 937–944), however, show about 4,000 feet of Pennsylvanian rocks in their graphic section.

Although locally variable in lithology and greatly variable in apparent thickness, rocks of Pennsylvanian age are consistent in their general characteristics in their outcrops in the Sangre de Cristo Mountains from Tres Ritos northward to Huerfano Park. The general magnitude of the thickness in the areas between these localities may be similar to that at Tres Ritos; however, the sequence at Tres Ritos may gradually thin to the apparent 2,000 to 4,000 feet estimated to the west of the area and in Huerfano Park.

The strata of Pennsylvanian age in the Sangre de Cristo Mountains were deposited under dominantly marine conditions in the Rowe-Mora basin, a geosyncline which existed from early Pennsylvanian time through a portion of Permian time. The sediments came chiefly from the Sierra Grande positive element to the east, and from the Uncompahgre positive element to the west. These structures existed during Pennsylvanian and Permian time. The Sierra Grande element was rejuvenated in Tertiary time when the Mesozoic strata that had been deposited across it were broadly flexed to form the Sierra Grande arch. Parts of the Uncompahgre element were irregularly uplifted at approximately the same time in what is now the western part of the Sangre de Cristo and San Juan Mountains.

Inasmuch as strata of Pennsylvanian age have not been recognized in samples from wells drilled on the Sierra Grande arch in eastern Colfax County, N. Mex., or in southern Las Animas County, Colo., Pennsylvanian strata in the Sangre de Cristo Mountains must wedge out eastward toward the arch. Thinning of strata within the basin probably is due to depositional overlap and to lensing. On the flanks of the Sierra Grande positive element, however, thinning may have been locally increased by uplift and erosion of some of the older Pennsylvanian strata before the deposition of the overlying Sangre de Cristo formation. Much of this eastward thinning may occur in the area of this report. For, although no wells have reached these strata here, geologic evidence indicates that they probably are present and range in thickness from 2,000 to 3,000 feet on the east to 10,000 feet on the west and in lithology resemble the Pennsylvanian strata exposed in the Sangre de Cristo Mountains to the west.

PERMIAN STRATA, SANGRE DE CRISTO FORMATION

The Sangre de Cristo formation of late Pennsylvanian and early Permian(?) age overlies and intertongues with the upper beds of the Magdalena group in the central part of the Rowe-Mora basin in New Mexico. At many places on the margins of the basin, however, it rests unconformably on the older strata of the Magdalena group or on pre-Cambrian rocks.

In the Sangre de Cristo Mountains the formation consists of red and gray conglomerate and arkose, buff quartzose sandstone, red siltstone, and shale, and gray to dark-gray nonmarine limestone. The formation thickens northward from about 5,000 feet in the vicinity of Eagle Nest, N. Mex., to approximately 10,000 feet at the southern boundary of Colorado (Read, C. B., 1949, oral communication). According to Brill (1952, p. 859), it is 9,549 feet thick at Whisky Creek, where there is intense thrust faulting, but it then thickens again to about 13,000 feet near Crestone (Melton, 1925, p. 805–815). A few hundred feet of strata assigned to the Sangre de Cristo and resting on pre-Cambrian rocks have been found in wells drilled on the Sierra Grande arch in eastern Colfax County, N. Mex., and Las Animas County, Colo.

The thick sequence of Sangre de Cristo strata exposed in the Sangre de Cristo Mountains accumulated in the Rowe-Mora basin. The thinner sequence in the vicinity of the modern Sierra Grande arch was deposited on the flanks and the top of the ancient Sierra Grande positive element. Thus a wedge of Sangre de Cristo strata, which thickens in a westerly and northwesterly direction, is present in the subsurface between the arch and the mountains. These strata probably accumulated as floodplain deposits in a basin between the positive elements and as piedmont deposits on the flanks of the positive elements. The thickness of the Sangre de Cristo formation in the map area is unknown but probably ranges from 2,000–3,000 feet on the east to 10,000 feet on the west. In lithology its rocks probably are similar to those exposed in the mountains.

PALEOZOIC AND MESOZOIC ROCKS, PERMIAN(?) AND TRIASSIC(?) STRATA

Permian rocks younger than the Sangre de Cristo formation and Triassic rocks have not been recognized in the Sangre de Cristo Mountains of Colorado. However, Jurassic strata unconformably overlie the Sangre de Cristo formation in the Sangre de Cristo Mountains from the vicinity of Cuervo Peak, which is about 10 miles south of the Colorado-New Mexico boundary line, to Huerfano Park. Several wells drilled east and northeast of Trinidad reach red sandstone, siltstone, shale, and limestone, either of Permian(?) age or

Triassic(?) age, or both. These strata, which range from less than 160 to more than 180 feet in thickness, overlie strata that are correlated with the Sangre de Cristo formation and underlie strata assigned to the Ocate sandstone. Thus, the absence of rocks of Permian(?) age that are younger than the Sangre de Cristo formation or of rocks of Triassic(?) age in the Sangre de Cristo Mountains in Colorado indicates that they wedge out in a westerly direction, perhaps in the area of this report.

North and east of the area the Lyons sandstone of Permian age, probably correlative with the upper part of the Sangre de Cristo formation, is overlain by the Lykins formation of Permian(?) and Triassic(?) age in the Front Range (Lovering and Goddard, 1950, p. 34 and 37), in the northern part of the Wet Mountains, and on the Model anticline (Bass, 1947). With the exception of the Lykins formation, no strata of Permian and Triassic age younger than the Lyons sandstone have been recognized in these localities. A few miles southeast of Raton, N. Mex., however, about 965 feet of strata of the Dockum group of Upper Triassic age were penetrated in the Cora B. Moore well, sec. 10, T. 29 N., R. 24 E. (Wood, Northrop, and Griggs, 1953). In this well the Dockum group is underlain by the Sangre de Cristo formation and overlain by the Ocate sandstone of Jurassic age.

Rocks of Permian(?) or Triassic(?) age in the subsurface near Trinidad may be correlative with either the Lykins formation or the Dockum group, or with both.

MESOZOIC ROCKS

Discontinuous exposures of Mesozoic rocks older than the upper part of the Pierre shale occur in the hogbacks and strike valleys that parallel the eastern front of the Sangre de Cristo Mountains and in the areas to the east, northeast, and southeast. Inferences as to the distribution, thickness and lithology of these older Mesozoic rocks in the area are based on studies of these outcrops and on samples from or on logs of wells reaching these rocks in the surrounding areas.

JURASSIC STRATA

OCATE SANDSTONE

The Ocate sandstone of Jurassic age was named by Bachman from exposures in the vicinity of Ocate, N. Mex. (Bachman, 1953). C. B. Read (1951, oral communication) and others have traced and correlated the formation northward along the foothills of the Sangre de Cristo Mountains to the Colorado-New Mexico boundary line, and we have traced it thence northward to the vicinity of Cucharas Camps, where it is cut out by the frontal thrust fault of the Sangre de Cristo Mountains. The Ocate sandstone reappears north of La Veta Pass and is well exposed in Huerfano Park.

In the foothills of the mountains the Ocate sandstone overlies the Sangre de Cristo formation conformably. However, the northwesterly wedging out of the Dockum group and the westerly wedging out of strata of Permian(?) or Triassic(?) age suggest that the base of the Ocate probably bevels these strata and also the upper beds of the Sangre de Cristo formation.

To the west of the area the Ocate consists of light-gray to buff, thick- to massive-bedded, fine- to medium-grained sandstone. Bedding generally is even and cross-lamination is uncommon. The grains of sand are dominantly quartz, although substantial quantities of weathered feldspar and chert are present. The larger sand grains are commonly well rounded and frosted. The cementing materials are calcium carbonate and clay. The porosity and permeability in the Ocate sandstone appears to vary locally from low to moderate. The lithology of the formation in the subsurface of the area is unknown but probably is similar to the lithology of the Ocate in outcrop.

The Ocate sandstone is 30 to 60 feet thick in the foothills of the Sangre de Cristo Mountains in Colorado, and it averages 60 to 65 feet thick in eastern Colfax County, New Mexico (Wood and others, 1953). Wells drilled east and northeast of Trinidad entered 50–65 feet of Ocate. Its thickness in the subsurface in the Starkville-Weston area is unknown, but probably is 30–65 feet.

WANAKAH(?) FORMATION

About 15 to 40 feet of strata tentatively assigned to the Wanakah formation crops out in the foothills of the Sangre de Cristo Mountains. These strata rest conformably on the Ocate sandstone and are overlain conformably by the Morrison formation. They consist of gray shale, siltstone, and fine-grained sandstone with occasional interbeds of light-red shale and siltstone. The cementing materials are clay, gypsum, and calcium carbonate. A few beds of sandy limestone or limy sandstone, 2 inches to 6 inches thick, occur in the lower part of the formation. One, perhaps more, beds of jasper 1 to 2 inches thick occur in the upper part. Irregular fragments and thin plates of jasper commonly mantle soil-covered slopes of the Wanakah(?) formation. These fragments and plates are an easy means of recognizing poorly exposed outcrops of the formation in the foothills of the Sangre de Cristo Mountains.

Relatively little is known of the regional extent, thickness, and variations in lithology of the Wanakah formation in northeastern New Mexico and southeastern Colorado. The average thickness beneath the Starkville-Weston area is probably less than 50 feet and the lithology probably is similar to that of the unit where it is exposed in the foothills of the Sangre de Cristo Mountains.

MORRISON FORMATION

The Morrison formation crops out on the eastern flank of the Sangre de Cristo Mountains, where it consists of thick beds of gray-green, gray, red, brown, and variegated claystone and siltstone and thinner beds of gray, buff, and light-red fine-grained sandstone. The proportion of claystone and siltstone appears to exceed that of sandstone. In the subsurface to the east and northeast of Trinidad the formation also consists of claystone, siltstone and sandstone, but also contains some limestone. The presence of limestone beds indicates that the Morrison formation grades westwardly in this area from a limestone-clastic sequence to a clastic sequence. Some beds of limestone may grade or thin out in the area.

The thin Wanakah(?) formation, which underlies the Morrison, maintains a fairly uniform thickness from the Colorado-New Mexico boundary line northward to Cucharas Camps. This suggests that the Morrison rests conformably on the Wanakah(?) formation. Stratigraphic relations between the Morrison formation and the overlying Purgatoire formation were not finally determined because of heavy timber and talus covered slopes. It is believed, however, that the depositional relations are parallel but that the formations are regionally disconformable.

The Morrison formation ranges in thickness from 250 to 300 feet in the foothills of the Sangre de Cristo Mountains. In eastern Colfax County, N. Mex., it averages 345 feet in thickness (Wood, Northrup, and Griggs, 1953). Wells drilled east and northeast of Trinidad penetrated 235 to 300 feet of Morrison strata. Beneath the southern half of the Spanish Peaks quadrangle the thickness is not known, but it probably ranges from 250 to 300 feet.

CRETACEOUS STRATA

PURGATOIRE FORMATION

The Purgatoire formation crops out in the hogback that constitutes the eastern front of the Sangre de Cristo Mountains. The basal unit of the formation is commonly a bed of cross-stratified, fine- to coarse-grained, yellowish-brown conglomeratic and quartzitic sandstone that ranges from slightly less than 50 feet to about 75 feet in thickness. At several localities the bed splits into two or three massive sandstone beds separated by gray, gray-green, and dark-gray silty shale. The bedding is usually parallel but occasionally lenticular. The sandstone is composed largely of frosted grains of quartz that are cemented by calcium carbonate, silica, and clay. The porosity and permeability appear to range from high to low. The upper unit of the formation is a gray to dark-gray bituminous shale that ranges from slightly less than 10 feet to about 30 feet in thickness.

In the type area in the Apishapa quadrangle (Stanton, 1905, p. 662), in the vicinity of Tucumcari, N. Mex. (Dobrovolny, Summerson, and Bates, 1946, sheet 2), and in the southern foothills of the Front Range (Richardson, 1915, p. 6), the Purgatoire formation contains an Early Cretaceous marine faunal assemblage.

The Purgatoire formation ranges from about 60 to 100 feet in thickness in the foothills of the Sangre de Cristo Mountains. It is 75 to 135 feet thick in wells drilled east and northeast of Trinidad, and it averages about 65 feet in eastern Colfax County, N. Mex. (Wood, and others, 1953).

The thickness of the Purgatoire formation in the subsurface of the area, although unknown, probably is between 75 and 125 feet. The lithology of the formation in the subsurface probably is similar to the lithology of the outcrops.

DAKOTA SANDSTONE

The Dakota sandstone of Early Cretaceous age rests disconformably on the Purgatoire formation and is conformably overlain by the Graneros shale. The formation is well exposed in the hogback at the eastern foot of the Sangre de Cristo Mountains, where it crops out as a vertical or nearly vertical ledge 50–200 feet thick, consisting of several white to buff, massive, and conspicuously cross-stratified beds. The bedding is chiefly parallel, but locally it is lenticular. The rock generally is fine to medium grained, but may be coarse grained to conglomeratic. Cementing materials are silica and calcium carbonate. Many beds are quartzitic, and all are well cemented. Porosity and permeability usually are low. Many irregular intersecting fractures and joints are filled with veinlets of silica.

In the subsurface to the east and northeast of Trinidad the Dakota sandstone is from 100 to 125 feet thick. In some wells it is apparently one thick bed of sandstone, but in others it consists of several thick beds of sandstone, separated by beds of gray to dark-gray shale.

The thickness of the Dakota sandstone in the Starkville-Weston area is not known, but it probably is between 50 and 200 feet. The lithology probably is intermediate between the lithologies of the Dakota rocks exposed in the foothills of the Sangre de Cristo Mountains and those reached by wells northeast of Trinidad.

GRANEROS SHALE

The Graneros shale rests conformably on the Dakota sandstone and intertongues with the overlying Greenhorn limestone. Near Tercio the Maxwell Grant well 1 in sec. 27, T. 34 S., R. 68 W. entered about 185 feet of dark-gray to black, noncalcareous shale that is correlated with the Graneros shale. The formation is about 200–210 feet thick where exposed about 10 miles to the northwest of Vermejo Park, near the Colorado-New Mexico boundary line (Dane and others, 1937, p. 210). A zone of calcareous concretions lies about 30 to 40 feet above the base and a thin calcareous sandstone or sandy limestone occurs about 45–50 feet below the top. Wells drilled in the area east and northeast of Trinidad entered dark-gray to nearly black shale, with an average thickness of 185 feet, which is correlated with the Graneros shale. In eastern Colfax County, N. Mex., the average thickness of the Graneros is about 160 feet and, except for the presence of several bentonite beds, the lithology is similar to the lithology of Graneros rocks exposed near Vermejo Park (Wood and others, 1953).

Therefore, the Graneros shale in the area probably is from 170 to 200 feet thick and consists of dark-gray to black noncalcareous shale with occasional zones of concretionary, bentonitic, and limy shale.

GREENHORN LIMESTONE

The Greenhorn limestone intertongues with the underlying Graneros shale and is conformably overlain by the Carlile shale. Near the Colorado-New Mexico boundary line northwest of Vermejo Park, the Greenhorn limestone is approximately 50 feet thick (Dane and others, 1937, p. 213). It contains a lower interval of hard gray limy shale 25 feet thick. The driller's log for the Maxwell Grant well 1, indicates that the lower interval is at least 20 feet thick, but does not furnish adequate data to identify the top of the limy shale interval. Drillers' logs for most of the wells that have been drilled east and northeast of Trinidad are poor, and it is difficult or impossible to distinguish the limy shale, limestone, and shale belonging to the Greenhorn. The logs suggest, however, that the Greenhorn is 20–30 feet thick and consists of interbedded thin dark-gray limestone and limy shale which probably are equivalent to the entire Greenhorn sequence of the Vermejo Park area, although possibly they may be equivalent to only the lower limestone and shale beds of that area.

In the map area the Greenhorn probably consists of 20–30 feet of dark-gray limestone and limy shale beds.

CARLILE SHALE

In much of eastern Colorado the Carlile shale is divided into three members which, from the oldest to the youngest, are the Fairport chalky shale member, the Blue Hill shale member, and the Codell sandstone member. The Codell sandstone member is the only one recognized in the region immediately to the east and northeast of the area.

The Carlile shale is 170–200 feet thick in the Elmoro quadrangle, the eastern part of the Spanish Peaks quadrangle, and the Walsenburg quadrangle (Hills, 1899, p. 1; 1901, p. 1; 1900, p. 1). It consists of a dark-gray shale overlain successively by a 10- to 15-foot bed of sandstone and a thin dark limestone. These sandstone and limestone beds are believed to be correlative with the Codell sandstone member. To the west of the area about 225 feet of dark-gray Carlile shale was entered by the Maxwell Grant well 1. A 10-foot bed of sandy shale or shaly sandstone, which here lies approximately 60 feet below the top of the formation, is believed to be generally correlative with the Codell sandstone member. In eastern Colfax County, N. Mex., the Carlile shale has an average thickness of 210 feet and consists of dark-gray calcareous and silty shale and fossiliferous dark-gray limestone. Numerous septarian concretions occur in the upper part of the formation. No lithologic correlative with the Codell sandstone member has been recognized in Colfax County, N. Mex. (Wood and others, 1953).

In the subsurface of the area the Carlile shale probably ranges from 190 to 210 feet in thickness and consists of dark-gray shale overlain by a sandstone-limestone sequence which is correlative with the Codell sandstone member.

NIOBRARA FORMATION

The Niobrara formation in southeastern Colorado and northeastern New Mexico is usually divided into the Fort Hays limestone member and the Smoky Hill marl member. The Fort Hays limestone member rests conformably on the Carlile shale and grades upward into the Smoky Hill marl member. Johnson (1930, p. 789–794) concluded that the top of the Carlile shale in eastern Colorado is an unconformity. The persistent occurrence of strata that are probably equivalent to the Codell sandstone member a few feet below the base of the Fort Hays limestone member suggest, however, that the Carlile-Niobrara contact is not an unconformity in the region immediately surrounding the map area. On Gold Creek near the Colorado-New Mexico boundary line, about 10 miles northwest of Vermejo Park, the Fort Hays consists of approximately 20 feet of interbedded gray limestone, shale, and bentonite (Dane, Pierce, and Reeside, 1937, p. 223). Drillers' logs of wells adjacent to the area show the Fort Hays member to consist of 15 to 35 feet of interbedded gray limestone and shale. The Fort Hays limestone member in the subsurface of the area probably is of like thickness and lithology.

North and east of the Spanish Peaks quadrangle the Smoky Hill marl member consists of 500–700 feet of yellowish-orange chalk with some dark-tan and bluish shale, and white limestone. White calcareous flecks in the chalk give it a mottled appearance. To the south, in Colfax County, N. Mex., the lithology is quite different; the member consists of 750 feet (Dane, Pierce, and Reeside, 1937, p. 223) to 1000 feet (Wood, Northrup, and Griggs, 1953) of gray arenaceous and calcareous white mottled shale in which the calcareous content decreases upward. This change in lithology southward is gradual, and at least part of it may occur in the subsurface of the area.

PIERRE SHALE

The oldest strata exposed in the southern half of the Spanish Peaks quadrangle are the upper beds of the Pierre shale. They crop out in the vicinity of Trinidad in the northeastern part of the area and near Morley in the southeastern part. These beds are 100–200 feet thick and consist of buff to medium-gray very fine- to fine-grained thin-bedded, silty and shaly sandstone beds alternating with gray to nearly black thin-bedded, silty and sandy shale beds. The uppermost 100 feet of the Pierre shale and the lowest 10–20 feet of the Trinidad sandstone intertongue between Trinidad and a point about 1 mile west of Jansen. The lower part of the Trinidad sandstone becomes shaly eastward and grades into the Pierre shale, whereas the tongue of Pierre shale above the lower part of Trinidad sandstone wedges out west of Jansen. The base of the Pierre shale is gradational with the underlying Smoky Hill marl member of the Niobrara formation.

In the foothills of the Sangre de Cristo Mountains the formation consists of dark-gray to black, noncalcareous, fissile shale; several thin zones of limestone and iron carbonate concretions; and an upper sequence of interbedded gray to black shale beds and buff to gray sandstone beds. The upper sequence is correlative with the upper beds of the Pierre shale in the area and those described hereafter in eastern Colfax County.

The formation in eastern Colfax County, New Mexico, is composed of dark-gray to black, fissile, noncalcareous, gypsiferous shale that contains several zones of limestone and iron carbonate concretions (Wood, Northrup, and Griggs, 1953). The upper beds are similar to those exposed in the area and foothills of the Sangre de Cristo Mountains.

The Pierre shale thickens northwestward from about 1,600–1,700 feet in eastern Colfax County to about 2,000–2,300 feet near the Spanish Peaks and Walsenburg. Within the mapped area, the Morley well 1, sec. 7, T. 35 S., R. 63 W., on the Morley dome entered about 1,800 feet of Pierre shale. The thickness of the formation in the area probably ranges from 1,800 to 1,900 feet, and the lithology probably is similar to that of the Pierre where that formation is exposed in the foothills of the Sangre de Cristo Mountains and in eastern Colfax County.

TRINIDAD SANDSTONE

In his report on the Elmoro quadrangle, Hills (1899, p. 2) described about 150 feet of strata under the name Trinidad formation and divided the formation into two parts: the lower Trinidad, about 75 feet thick, and the upper Trinidad, from 70 to 80 feet thick. Subsequently, he changed the name to the Trinidad sandstone (Hills, 1901, p. 1), but retained the same formational boundaries. Lee (1917, p. 48) redefined the formation by assigning the lower Trinidad to the Pierre shale and restricting the name Trinidad sandstone to upper Trinidad (see pl. 2).

In general, this report follows Lee's definition of the Trinidad sandstone.

North of the Purgatoire River the Trinidad sandstone crops out as a massive cliff or a series of ledges, but south of the river it is largely covered except near Morley. The formation intertongues with and grades into the underlying Pierre shale and is conformably overlain by the Vermejo formation.

The Trinidad sandstone consists of light-gray, gray, and buff slightly arkosic sandstone beds with occasional thin interbeds of light-tan, light-gray, and gray silty shale. The bedding is medium to massive and is most commonly tabular, less commonly, irregular, and infrequently lenticular. Some beds have parallel stratification, and others are cross-stratified with variably concave-inclined- and continuous-inclined-laminae. Most of the grains are quartz but there are some of weathered feldspar, mica or ferromagnesium minerals. The grain size is predominantly fine, but ranges from very fine to medium. Cementing materials are calcium carbonate, clay, and silica, and cementation varies from good to poor. Casts and molds of *Halymenites major* Lesquereux are abundant.

In the eastern part of the area the Trinidad sandstone ranges from 45 to 120 feet in thickness. It probably thickens gradually westward in the subsurface to 260 feet near Stonewall (Wood and others, 1951, sheet 1).

VERMEJO FORMATION

The Vermejo formation crops out as slopes and ledges in the northeastern part of the area and in the vicinity of Morley. It rests conformably on the Trinidad sandstone and is overlain conformably by the Raton formation. Near Cokedale the upper beds of the Vermejo intertongue with beds of conglomeratic sandstone at the base of the Raton.

The lower few feet of the Vermejo formation are shale at most localities, but east of the longitude of Jansen and on the northern flank of the Morley dome yellow-buff, yellow-gray, olive-gray, and rusty cross-stratified lenticular sandstone, as much as 30 feet thick, lies below the shale. Hills (1901, p. 1) apparently placed this unit in the upper Trinidad and Lee (1917, p. 122–128) included it in the upper part of the Trinidad sandstone. Although the lithology of this sandstone is somewhat similar to that of the Trinidad, it differs in having a coarser texture, carbonaceous fragments, abundant silicified plant leaves, and the absence of *Halymenites major* Lesquereux. It apparently was deposited on and behind beaches where deposition was influenced both by wind and water. The sandstone consists largely of a sand that was probably derived by reworking of the underlying Trinidad sandstone (Harbour, R. L., 1953, oral communication).

Typical Vermejo rocks are buff, gray, gray-green slightly arkosic sandstone; buff, gray and dark-gray, and nearly black carbonaceous, coaly, and silty shale; and coal beds. The bedding is thin to massive. The thinner beds are usually parallel stratified and parallel laminated, and the thicker beds are irregularly and lenticularly stratified, and invariably are crosslaminated. The grains are principally quartz with a variable proportion of grains of weathered feldspar, mica, and ferromagnesium minerals. The grain size ranges from very fine to medium with very fine and fine grains predominating. The cementing materials are clay and calcium carbonate. The siltstone and shale beds, which are a few inches to many feet thick, are at most places nonfissile, but locally are laminated or fissile. Coal beds, many of which have been mined, are interbedded with the shale and siltstone.

Along the eastern margin of the area the Vermejo formation is 80 to 140 feet thick. West of the longitude of Jansen in the Piedmont, Sopris, and Cokedale mines, it thickens rapidly to 200–220 feet. It probably thickens gradually in the subsurface to between 220 and 380 feet on the western edge of the coal field (Wood and others, 1951, sheet 1).

MESOZOIC AND CENOZOIC ROCKS

CRETACEOUS AND TERTIARY STRATA, RATON FORMATION

The Raton formation, 1,200 to 1,600 feet thick, is the bed rock for much of the area. The basal Raton strata locally lie unconformably on the Vermejo formation in the foothills of the Sangre de Cristo Mountains of New Mexico, but in the Starkville–Weston area, they intertongue with and generally are concordant on the underlying Vermejo strata (see pl. 3). An indefinite thickness of the lower part of the formation is of Late Cretaceous age and the rest is of Paleocene age (Brown, 1943, p. 83). The bases of persistent sandstone zones, each composed of many lenticular sandstone beds, are shown on the map by lines within the band of outcrop of the formation. In the Stonewall-Tercio area (Wood, Johnson, and others, 1951, sheet 1) the Raton formation was divided into three members. The rocks that make up any member of the Raton are neither individually nor collectively distinguishable from other rocks in the formation. (See pl. 4.) The members may be recognized only by their relative position in the formation and not by distinctive lithologies. The members were mapped and correlated throughout the entire area of this report.

The lower member consists of a basal buff, gray, purple-gray, and dark-gray granule and pebble conglomeratic sandstone overlain by interbedded buff, gray, and olive-gray very fine- to medium-grained arkose, graywacks, and quartzose sandstone beds; gray to dark-gray siltstone and carbonaceous and noncarbonaceous silty shale beds; and thin to thick lenticular coal beds. The sandstone beds crop out as cliffs and ledges, and the coal, siltstone, and shale beds form slopes. The member is 1,000–1,200 feet thick.

The basal conglomeratic sandstone ranges in thickness from less than 2 inches to more than 20 feet. It consists of one or, in places, two thin to massive, conspicuous, cliff- or ledge-forming beds, the lower of which locally intertongues with the upper beds of the Vermejo formation. Bedding commonly is obscure, but at some localities continuous inclined-crosslamination is well developed. The matrix consists of fine to very coarse sand grains. Fresh and weathered feldspar granules are scattered throughout the conglomerate. Pebbles of granite, gneiss, and quartzite are generally less numerous than feldspar granules and are absent in the vicinity of Sopris and the Starkville mine. The grains and granules are angular to subrounded and the pebbles are subangular to rounded. Cementing materials are quartz and other forms of silica, and clay. The clastics apparently were eroded from pre-Cambrian, Pennsylvanian, and Permian terranes to the west.

The arkose, graywacke, and quartzose sandstone beds of the lower member are thin- to massive-bedded. The thicker beds are usually crosslaminated. They are either lenticular-, irregular-, or tabular-bedded and commonly form conspicuous cliffs and ledges. The grain size is very fine to medium; and locally it is coarse. The degree of rounding varies from subangular to subrounded. Calcium carbonate and clay are the principal cements. The beds of siltstone and shale are in most places thicker than the beds of sandstone and have a carbonaceous content that decreases upward.

The lowest 250 to 300 feet of the member includes several coal beds that are less than 1 foot 2 inches thick, whereas the upper 700 to 900 feet contain several coal beds of commercial thickness, the most important of which are the Frederick and Primero. These beds have been worked by the Frederick, Quinto, Primero, and Sexto mines.

Local intraformational disconformities and angular unconformities are common in the lower member of the Raton formation and are especially numerous in the valley of the Purgatoire River. Dip and strike measurements near these features generally do not represent the regional inclination.

The middle member of the Raton formation is conformable with the other members. Its lower and upper contacts are on the bases of sandstone zones that are composed of several of lenticular beds. The middle member does not have a basal conglomerate, but otherwise its lithology is nearly identical to that of the lower member. Two rather persistent coal beds in the member locally are of commercial thickness in the area. Erosional and angular unconformities are fewer than in the lower member. The middle member, which is 80 to 160 feet thick, is the most convenient datum for structure contouring in the area. Contours drawn on the base of the member, however, do not represent the regional inclination of deeply buried strata, inasmuch as there is irregular lenticular thickening of many of the beds in the Vermejo, Raton, and Poison Canyon formations.

The upper member is from 100 to 200 feet thick and averages about 150 feet in thickness. It is conformably overlain by the lower arkosic sandstone beds of the Poison Canyon formation. Its lithology is generally similar to that of the lower and middle members, except that the sandstone beds are somewhat more arkosic and coarser-grained, and the siltstone and shale intervals are commonly tan or light-gray rather than gray and dark-gray in color. Coal beds at most localities are impure, very lenticular, and of small areal extent. Erosional and angular unconformities are fewer than in the other members.

CENOZOIC ROCKS

TERTIARY STRATA, POISON CANYON FORMATION

The Paleocene Poison Canyon formation conformably overlies the upper member of the Raton formation. Although, in the vicinity of the Spanish Peaks the formation is 2,100 to 2,500 feet thick, only about 600 feet of the formation remain in the area of this report. Poison Canyon strata consist of massive cliff-forming beds of medium- to very coarse-grained arkosic sandstone, granule and pebble conglomerate beds, thin coal beds, and thick shale units. The coarser clastic rocks are buff, gray, and olive, with weathered outcrops stained light-red. Some beds of sandstone and conglomerate are lenticular and crosslaminated, others are even-bedded, and parallel-laminated. Granite, gneiss, and quartzite pebbles range up to 3 or 4 inches in diameter. Most of the feldspar granules are unweathered.

The shale is buff, light-gray, and tan. Internal bedding structures in the shale units generally are obscure and many appear to be a single bed. The shale is commonly silty and locally is carbonaceous, especially in the lower part of the formation. The Poison Canyon generally is barren of coal, but in the upper reaches of Lorencito and Alamosa Canyons thin lenticular beds of impure coal occur near the base of the formation.

QUATERNARY STRATA, QUATERNARY DEPOSITS

Deposits of Quaternary alluvium fill the bottoms of the larger valleys and many of their tributaries. These deposits are shown on the geologic map only where they cover large areas. Upland cover and soil mantle which blanket many slopes and much of the higher parts of the area are not shown on the map.

IGNEOUS ROCKS

Sills of early Tertiary(?) age that intrude the Vermejo and Raton formations are well exposed in the valley of the Purgatoire River, where they are especially numerous. They are fine grained, dark in color, and have been classified as basalt and lamprophyre (Hills, 1901). They range in thickness from a few inches to 20 or 30 feet. The exteriors of the sills commonly are finer grained than the interiors and the adjacent sedimentary rocks are usually baked for a variable distance from the contact. Locally, coal where near or adjacent to the sills is changed to coke.

In the lower part of Long Canyon, in Frisco Canyon, and on the southwestern flank of Morley dome several thin dikes intrude the Vermejo formation and the basal beds of the Raton formation. The rocks of these dikes are similar in texture and composition to that of the sills.

The dikes and sills were probably emplaced during the Eocene epoch, soon after the eastward thrusting of the Sangre de Cristo Mountains. It is possible, however, that they are contemporaneous with the late Tertiary(?) and Quaternary basalt flows of Raton Mesa.

STRUCTURE

The structure of the Starkville-Weston area is relatively simple, the principal structural feature being the eastern limb of the Raton basin, a part of which is in the area. The basin is a broad complex asymmetric syncline whose major axis trends northward, approximately along the western edge of the Raton Mesa region, and parallels the strike valleys and hogbacks of the adjacent fault-bounded Sangre de Cristo Mountains. It was formed during the closing phases of the Laramide revolution when the Sangre de Cristo Mountains were thrust eastward. A complex overturned anticline that lies on a complex overturned syncline developed on the eastern side of the mountains, as a result of the compression which accompanied the thrusting. The anticline and much of the western limb of the syncline have been largely destroyed by erosion; only parts of them are preserved in the mountains and in the foothills. Most of the Raton basin is underlain by the gentle eastern limb, part of which is preserved in the Raton Mesa region. This eastern limb was downwarped and a number of long narrow north-trending irregular low folds were superimposed on it by the same forces that formed the basin. The region of deepest downwarping is 5–12 miles wide and lies 8–20 miles east of the major axis of the basin. Structural relief of few of the folds in the basin exceeds 200 feet.

East of Morley and beyond the limits of the area the Raton formation is intruded by a large basalt plug that has a diameter of one-half to two-thirds of a mile and has arched the strata for several miles around it into an irregular dome, the Morley dome. Raton Creek, which flows across the western flank of the dome, has breached the Raton Vermejo and Trinidad formations and exposed the upper beds of the Pierre shale. The structural relief of the dome was not determined, because much of it lies outside the mapped area.

Several vertical or nearly vertical normal faults occur between Sarcillo and Wet Canyons, and in Frisco Canyon. Displacements are usually less than 25 feet and are seldom as great as 50 feet. The faulting probably was contemporaneous with the folding and, therefore, probably took place in the closing phases of the Laramide revolution.

GEOMORPHOLOGY

The Starkville-Weston area is situated in the western half of the Raton section of the Great Plains physiographic province. This section lies between the Southern Rocky Mountain province on the west and the High Plains section of the Great Plains province on the east. The western edge of the area is 7 to 10 miles east of the foothills of the Sangre de Cristo Mountains, which here are the front range of the Southern Rocky Mountain province. The Raton section has been described as a trenched peneplain surmounted by lava-capped plateaus and buttes (Fenneman, 1930). This description, however, is somewhat misleading, because there is no general trenched peneplain and the lava-capped plateaus and buttes are found only in the east-central portion of the section. Four geomorphic units, or sub-sections, are usually recognized. These are the Raton Mesa group, the Park Plateau, the Chaquaqua Plateau, and the Las Vegas Plateau (Fenneman, 1931, p. 37–38). The Raton Mesa group consists of high lava-capped mesas that lie south and southeast of Trinidad and east of Raton. The Park Plateau is somewhat lower than the mesas of the Raton group but is considerably higher than the Chaquaqua and Las Vegas Plateaus. It lies west of Raton, Trinidad, and Walsenburg and east of the foothills of the Sangre de Cristo Mountains. The Chaquaqua Plateau lies north of the Raton Mesa group and east of the Park Plateau, and the Las Vegas Plateau lies south of the Raton Mesa group and southeast of the Park Plateau.

Most of the area of this report is situated in the intricately and deeply dissected Park Plateau; the rest is part of the Chaquaqua Plateau. In the higher parts of the Park Plateau the Raton and Poison Canyon formations are beveled by the Park Plateau erosion surface, part of which forms the drainage divide that closely parallels the Colorado-New Mexico boundary line and separates the drainage basins of the Canadian and Purgatoire Rivers. It is also on the summits of many of the ridges which extend northward from the drainage divide. Hills of Poison Canyon strata rise above the general level of the surface in many places along the divide. Just south of the Purgatoire River the Park Plateau surface has been almost completely destroyed by erosion, and north of the river no remnants of the surface are preserved.

The southwesternmost portion of the Chaquaqua Plateau is in the vicinity of Trinidad. Many miles east of the area the surface of the plateau is a stratum plain which cuts at a low angle across beds of the Dakota sandstone. Nearer the area, stripping was not complete and the erosion surface gradually rises across beveled westward-dipping and stratigraphically higher Cretaceous formations. Near Trinidad the erosion surface bevels the upper part of the Pierre shale.

Several levels of stream terraces are preserved in Purgatoire Valley and some extend as prominent benches into the lower parts of the major tributary valleys and canyons. In Purgatoire Valley, the stream terraces are capped by gravel derived from rocks ranging in age from pre-Cambrian to early Tertiary. The terrace gravels in the tributaries, however, were derived only from Upper Cretaceous and early Tertiary rocks.

GEOLOGIC HISTORY

During the pre-Cambrian, thousands of feet of sediments were deposited in northeastern New Mexico and southeastern Colorado. Later in the pre-Cambrian these sediments were strongly deformed during several orogenic episodes; intruded by many large igneous bodies; and metamorphosed into gneiss, quartzite, and schist. It appears that one or more periods of deformation occurred after intrusion because the igneous rocks are foliated. Later, the region was subjected to a cycle of erosion the beginning and duration of which is uncertain; however, the cycle appears to have persisted until latest Mississippian or earliest Pennsylvanian time. If early Paleozoic sediments accumulated, they were removed from most if not all the surrounding region by latest Mississippian or earliest Pennsylvanian time.

Early in the Pennsylvanian period the sea advanced across the region contemporaneous with orogenic movements that produced the Ancestral Rocky Mountains. The Sierra Grande and Uncompahgre positive elements were outlined and intermittently uplifted, and the intervening geosyncline, the Rowe-Mora basin, was gradually depressed. Detritus from the positive elements was deposited in the sea in the early part of the period. During the middle part of the period, however, the quantity of detritus gradually exceeded the capacity of the subsiding geosyncline and the sea slowly and intermittently withdrew as additional sediments accumulated alternately in marine and continental environments. These sediments which consist predominantly of a lower marine sequence, and an upper continental and marine sequence, were indurated to form the undivided strata of Pennsylvanian age. During late Pennsylvanian time and into Permian time, the positive elements continued to supply large quantities of sediments that accumulated in the geosyncline as a continental sequence of piedmont and floodplain deposits. By the middle of Permian time, however, the positive elements were reduced to near-base-level and were no longer capable of supplying the geosyncline with large quantities of detritus. The sediments that were deposited in late Pennsylvanian and in part of Permian time became the Sangre de Cristo formation.

The history of the rest of the Permian period and all the Triassic period is uncertain, because Triassic strata are absent in the foothills of the Sangre de Cristo Mountains, and Permian(?) or Triassic(?) strata are present in the subsurface northeast of Trinidad.

These Permian(?) or Triassic(?) rocks near Trinidad may correlate with either the Dockum group or the Lykins formation, or with both. If they correlate with the Dockum group (Triassic), the geologic history is as follows: during the late Permian and Early Triassic epochs the region was near base-level. Some of the upper beds of the Sangre de Cristo formation may have been eroded locally. Subsequently, in the Late Triassic epoch, mud, silt, and sand accumulated on floodplains to form the rocks of the Dockum group. Near the end of the Late Triassic epoch or in the Early Jurassic epoch the region was gently tilted southeastward by epeirogenic movements, and erosion removed the strata of Dockum age in the vicinity of the Sangre de Cristo and Wet Mountains.

If the beds near Trinidad correlate with the Lykins formation (Permian and Triassic) rather than with the Dockum group, the geologic history is somewhat different. Some time during the late Permian and Early Triassic epochs the sea advanced across the region from the east and Lykins sediments were deposited. The sea later withdrew, and the mud, silt, and sand comprising the beds of the Upper Triassic Dockum group may have been laid down on floodplains. Subsequently, the region was tilted southeastward by epeirogenic movements, and the Lykins strata were partially removed and the Dockum sediments were wholly removed by erosion in the vicinity of the Sangre de Cristo and Wet Mountains. If the beds near Trinidad correlate with both the Lykins formation and the Dockum group, they accumulated in an environment which was first marine and then continental. The geologic history, if this correlation is correct, is similar to that outlined for the Dockum, except that marine deposition began in late Permian time followed by continental deposition in Late Triassic time.

After epeirogenic movement and erosion the region subsided, and a shallow sea is believed to have transgressed, probably from the west. Although the sea could have transgressed from the east or south, there is no data to support this concept in the immediate area. The Ocate sandstone of Jurassic age probably was laid down in and along the margins of this sea as offshore-bar and beach deposits that may have been locally modified by the wind. In central and northern New Mexico, sediments making up the succeeding Wanakah formation were deposited in an environment whose waters were characterized by varying concentrations of calcium sulfate and calcium carbonate. In southeastern Colorado these equivalent rocks appear to have been deposited on floodplains and in lakes as the sea withdrew. Subsequently, strata of the overlying Morrison formation were laid down on floodplains, in large lakes, and on deltas of rivers emptying into the lakes.

After deposition of the Morrison, the region remained slightly above base-level and some of the newly deposited sediments may have been eroded. During the later part of the Early Cretaceous epoch, however, the sea transgressed the area from the southeast and east. The strand line appears to have been west of the foothills of the Sangre de Cristo Mountains. Near the area the sands incorporated in the lower part of the Purgatoire formation probably were deposited as offshore bars and on beaches, and the muds accumulated in estuaries, coastal swamps, and on deltas and floodplains. Subsequently, the sea withdrew and some of the Purgatoire strata may have been removed by erosion.

Late in the Early Cretaceous epoch the region subsided and was covered by a shallow broad sea. The sand and mud of the Dakota sandstone were laid down along the advancing margin of the sea. After the deposition of the Dakota sandstone several thousand feet of mud, silt, fine sand, and calcium carbonate were deposited below the level of wave and current agitation. These sediments have been indurated into the Graneros shale, Greenhorn limestone, Carlile shale, Niobrara formation, and Pierre shale. Epeirogenic movements that preceded or accompanied the beginnings of the Laramide revolution apparently commenced late in the time of deposition of the Pierre shale. The fine sand and clay in the upper beds of the Pierre are the record of these movements. The sea then withdrew slowly eastward and the Trinidad sandstone accumulated as regressive offshore, bar, and beach deposits. As the sea continued to retreat, mud, silt, sand, and carbonaceous material of the Vermejo formation was laid down on floodplains, deltas, and in swamps.

In latest Cretaceous time during deposition of the upper part of the Vermejo formation, movements of the Laramide revolution began in the vicinity of the present day Rio Grande Valley, west of the area. A large region was gradually uplifted and sediments derived from it were deposited in a subsiding basin, the ancestral Raton basin, which lay to the east. These sediments consisted of gravel, sand, silt, mud, and carbonaceous material. They probably accumulated as piedmont deposits near to the uplifted area and, at a greater distance from the uplift, as floodplain, delta, and swamp deposits that are preserved in the Raton Mesa region as the Raton formation of latest Cretaceous and Paleocene age. The piedmont deposits, however, have been eroded away or are concealed beneath thrust plates in the Sangre de Cristo Mountains.

The area which was first uplifted in latest Cretaceous time was rejuvenated in Paleocene time during deposition of the upper part of the Raton formation. Gravel, coarse sand, and finer clastics were eroded from this uplifted area or highland and deposited on adjacent piedmonts and on floodplains in the basin. These sediments form the lower beds of the Paleocene Poison Canyon formation, which were deposited along the western margin of the basin concurrently with deposition of the upper beds of the Ration formation farther to the east in the central part of the basin. North of the area the middle and upper parts of the Poison Canyon formation consist of beds of boulders and cobbles, coarse-grained sandstone and shale. The boulder and cobble beds record several climatic changes or additional orogenic episodes in the Paleocene highland which may have resulted in mountains.

After deposition of Poison Canyon sediments, and still in Paleocene time the mountains were rejuvenated and the basin was compressed. Several large open folds which formed in the basin were subsequently beveled by erosion. Next, gravel, sand, silt, and mud of the Eocene Cuchara formation were laid down in the basin in an environment similar to that of Poison Canyon deposition. After the deposition of the Cuchara sediments, the mountains were again uplifted and eroded, and the basin sediments were folded and eroded. Later, the clastic sediments of the Eocene Huerfano formation were deposited on piedmonts and floodplains. Near the end of Huerfano deposition, the present structure of the eastern part of the Sangre de Cristo Mountains was outlined by orogenic movements that culminated the Laramide revolution. Before, during, and after this orogeny, numerous sills and dikes of acidic to basic igneous rocks were intruded into the sedimentary rocks of the Spanish Peaks region and adjacent areas of Colorado and New Mexico. Also during the orogeny, the Raton basin was downwarped, the structural relief of the ancient Sierra Grande positive element was increased, and the modern Sierra Grande arch was developed.

Geologic events that occurred during much of later Tertiary time are not recorded in the immediate vicinity of the area. It is likely, however, that during the Oligocene epoch and the early part of the Miocene epoch the region was being eroded. Late in Tertiary time the Ogallala formation probably was deposited, only to be later eroded away.

In early Quaternary time several erosion surfaces were developed. Remnants of these are preserved on Raton Mesa and the higher parts of the area mapped. The present topography developed during late Quaternary time.

COAL

STRATIGRAPHIC POSITION AND CHARACTER OF COAL BEDS

Bituminous coal beds of commercial thickness occur in the Vermejo formation, in the three members of the Raton formation, and locally in the lower several hundred feet of the Poison Canyon formation. The Vermejo coal beds are usually somewhat thicker and somewhat more extensive than coal beds in the Raton and Poison Canyon formations.

Correlations of coal beds in the Vermejo (pl. 5) and Raton (pls. 6–10) formations in this report differ from the correlations advanced by Hills (1901, p. 5), Richardson (1910, p. 102–108), and Lee (1917, p. 115–127). In this report the Vermejo and Raton formations are viewed as being conformable in a regional sense and are known to locally intertongue. Lee, however, postulated that the Vermejo is separated from the Raton by a regional erosional unconformity and by local angularities. Hills and Richardson did not correlate the coal beds throughout much of the area.

In this report coal beds near the top of the Vermejo formation are considered to wedge or pinch out westward by intertonguing with the basal strata of the Raton formation (pls. 1 and 5). In contrast, Lee, believed that these coal beds were truncated eastward by the regional erosional unconformity. His belief was based largely on eastward thinning of the Vermejo formation and to a lesser extent on the occurrence of a conglomerate at the base of the Raton formation. The eastward thinning of the Vermejo, however, appears to be depositional rather than erosional.

COAL BEDS OF THE VERMEJO FORMATION

The coal beds of the Vermejo formation have been mined extensively in the northeastern part of the area near Cokedale, Sopris, Starkville, and Trinidad and in the southeastern part of the area near Morley. The stratigraphic relations of these beds and of the Vermejo formation to the underlying Trinidad sandstone and the overlying Raton formation are illustrated on plate 3. The lateral extent, character, and correlation of the coal beds are shown on plate 5. The coal sections shown on plate 5 were measured at localities 1–25.

Fourteen coal beds of the Vermejo formation having thicknesses of 1 foot 2 inches or more are correlated within the area. Eight of these coal beds are of sufficient importance to be named on plate 5, and their tonnages individually estimated in table 3. These coal beds are known to underlie areas of 20 to 30 square miles and several may underlie areas as great as 35 square miles. Other important beds may underlie the western part of the area, but are not exposed in or near the area.

The roofs of coal beds of the Vermejo are at most places carbonaceous shale or siltstone, but locally they are sandstone. The floors are generally either carbonaceous shale or siltstone, but in several places they are siliceous shale and sandstone. Root impressions are imperfectly preserved at many localities in carbonaceous shale or siltstone beds that underlie the coal beds.

COAL BEDS OF THE RATON FORMATION

Coal beds in the Raton formation have not been mined as extensively as those in the Vermejo formation; although the largest mine in the area, at Valdez, mines the Frederick bed in the Raton formation. The stratigraphic relations of strata in the Raton formation to those in the overlying Poison Canyon formation are shown on plate 5. The lateral extent and character of individual coal beds and their correlation within coal zones are illustrated on plates 6–10.

The lower member of the Raton formation contains 25 coal beds thicker than 1 foot 2 inches that are in 16 coal zones and have appreciable areal extent. The coal zones are arbitrarily considered to be delimited by the enclosing zones of sandstone beds, the lower boundaries of which are shown on the geologic map. They are designated, from oldest to youngest, as coal zones *A–P*. Sections of coal in zones *A–P* were measured at localities 26 to 247 and are illustrated on plates 6–9. Only two coal beds, the Frederick bed in coal zone *C* (pl. 6), and the Primro bed in coal zone *I* (pl. 7) are of sufficient importance to warrant individual estimates of tonnage (table 3). These two coal beds underlie areas that may be as much as 75 square miles in extent. Few other coal beds in the member underlie areas larger than 10 square miles.

Two coal zones and three coal beds thicker than 1 foot 2 inches are recognized in the middle member of the Raton formation. The coal zones are separated by a zone of sandstone beds whose lower boundary is shown on the geologic map (pl. 2). They are named coal zones *Q* (pl. 9) and *R* (pl. 10). Sections of these coal zones were measured at localities 248 to 273 (pls. 9 and 10). One coal bed, the Ciruela (pl. 10, coal zone *R*), is sufficiently thick to warrant use of an individual name and a separate estimation of tonnage (table 3). It was recognized in the Stonewall–Tercio area (Wood and others, 1951). Within the area of this report it appears to be quite lenticular and locally it may be absent. However, a coal bed occupies the stratigraphic position of the Ciruela bed throughout much of the area south of the Purgatoire River and west of Long Canyon. Compared to the Frederick and Primero beds, the Ciruela bed is not of great economic importance; but locally it appears to be sufficiently thick to have possible future value. Other coal beds in the middle member may thicken locally, but none is known to be so extensive as the Ciruela.

The upper member of the Raton formation contains two coal zones in which five coal beds have thicknesses of 1 foot 2 inches or more and have sufficient areal extent to be considered potentially important. These coal zones, *S* and *T* (pl. 10), are separated by a zone of sandstone beds whose lower boundary is shown on the geologic map (pl. 2). Coal sections of these zones were measured at localities 274 to 294 (pl. 10). None of the coal beds in these zones are of sufficient areal extent to warrant naming, or separate treatment in calculation of tonnage (table 3). Because of this and because they are usually very lenticular and in most places are impure, they are of doubtful future economic importance.

The roof and floor rocks of the coal beds in the Raton formation generally are carbonaceous shale or siltstone. However, at many localities the roof rock is a thick sandstone bed. Root impressions and carbonized root fillings are quite common beneath many coal beds in the Raton.

CORRELATION OF COAL BEDS IN THE VERMEJO AND RATON FORMATIONS WITH BEDS IN ADJACENT AREAS

Correlation of individual coal beds in the Vermejo formation between the exposures described in this report and the exposures in the Stonewall-Tercio area on the western margin of the Raton Mesa region is uncertain without subsurface data. In the absence of such data, no attempt is made in this report to correlate the coal beds of this area with coal beds already recognized in the Stonewall-Tercio area (Wood, and others, 1951). Several coal beds in the Raton formation described in this report, however, can be correlated with coal beds previously recognized in the Stonewall-Tercio area. The more important of these are the Ciruela bed, which was measured at localities 73 to 128 (pl. 9) and the Primero bed which was measured at localities 23 to 41 (pl. 7) (Wood, and others, 1951).

COAL BEDS OF THE POISON CANYON FORMATION

Coal has not been mined commercially from the Poison Canyon formation. Individual coal beds are not only thin but are lenticular and small in areal extent. Coal beds in this formation crop out principally near the headwaters of Lorencito Canyon in the southwestern part of the area. The stratigraphic relations of the lower strata of the Poison Canyon formation and the upper strata of the underlying Raton formation are shown on plate 5. Sections of coal beds of the Poison Canyon were measured at localities 295–300 (pl. 10). Most of these coal beds are less than 1 foot 2 inches, which is the minimum mineable thickness. Tonnages for coal beds of the Poison Canyon, therefore, have not been estimated and summarized in table 3.

The coal beds of the Poison Canyon usually lie in sequences of thick buff claystone or siltstone. The claystone and siltstone exhibit little bedding structure and at most places appear to have been leached by ground water.

PHYSICAL AND CHEMICAL PROPERTIES OF THE COAL

The coal in the southeastern part of the Trinidad field is classified as high volatile *A* and *B* bituminous coal. Analyses indicate that most of the coal within the area of this report and in all the region to the south of the Apishapa River in the Trinidad and Raton coal fields is of coking quality; however, it is likely that coal of some beds not analyzed will not coke and, therefore, is of domestic quality. Table 2 shows a series of representative analyses of mine samples from coal beds in the area. These analyses are on an "as received" basis.

TABLE 2.—*Representative analyses of mine samples of coals of the Starkville-Weston area, Las Animas County, Colo.*

[Analyses (made on an "as received" basis) are selected from "Analyses of Colorado Coals:" U. S. Bur. Mines Tech. Paper 574, p. 94-100, 1937]

Mine	Sample No.	Formation	Bed	Proximate analysis, in percent				Ultimate analysis					Heating value	
				Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units
Cokedale	6321	Vermejo	Cokedale	2.7	25.8	57.3	14.2	0.6	4.6	71.1	1.1	8.4	7,139	12,850
Morley	A59282	do	Morley	2.0	30.4	51.9	15.7	1.7	----	----	----	----	6,967	12,540
Do	A59287	do	do	1.9	31.9	53.1	13.1	1.6	5.3	72.5	1.3	7.2	7,217	12,990
Primero	14060	Raton	Primero	1.5	30.8	54.4	13.3	1.5	5.0	73.1	1.7	6.4	7,222	13,000
Do	34098	do	do	2.1	31.4	55.6	10.9	1.5	5.0	74.7	1.7	7.2	7,389	13,300
Do	14059	do	do	1.4	32.3	53.4	12.9	1.5	5.0	73.5	1.7	6.4	7,267	13,080
Piedmont	10218	Vermejo	Piedmont	5.8	26.2	53.8	14.2	.6	5.2	69.5	1.2	9.3	6,917	12,450
Sopris	6310	do	Sopris	1.9	28.2	56.9	13.0	.7	4.6	72.2	1.1	8.4	7,283	13,110
Do	31949	do	do	2.1	28.3	51.9	17.7	.7	4.8	69.3	1.3	6.2	6,867	12,360
Starkville	11134	do	Lower Starkville	2.1	29.2	55.5	13.2	.6	4.6	71.8	1.2	8.6	7,139	12,850
Do	11135	do	do	1.8	28.7	55.3	14.2	.6	4.7	71.8	1.2	7.5	7,072	12,730
Frederick	A58382	Raton	Frederick	2.0	30.3	58.3	9.4	.6	5.4	76.3	1.7	6.6	7,661	13,790

Coal in the Vermejo formation and in the lower member of the Raton formation is brittle and friable, and usually has a bright luster, platy cleavage, and either a prismatic or cubic cleat. It occasionally breaks with a conchoidal fracture. The composition of the coal appears to be largely vitrain and durain with a lesser amount of fusain. The coal is usually pure. Impurities, if present, commonly are quartz grains, pyrite, melonterite, and occasional lenticular partings of claystone and siltstone.

Coal in the middle and upper members of the Raton formation has a bright to dull luster, is friable, brittle, and in some localities soft. It has cubic or prismatic cleat and platy cleavage. Conchoidal fracture is common. The composition of the coal may be approximately equal parts of vitrain and durain with subordinate quantities of fusain, or it may be largely durain with lesser amounts of vitrain and fusain. The coal is clean at most places and elsewhere impurities consist chiefly of pyrite, quartz grains, sulfur, and limonite.

Coal in the Poison Canyon formation usually has a dull luster, is friable, and soft, and has a cubic cleat. Conchoidal or irregular fracture is common. The coal, which is commonly dirty, appears to be composed largely of durain with subordinate quantities of fusain and vitrain.

COAL RESERVES

Measured sections of coal beds in the Vermejo, Raton, and Poison Canyon formations throughout the area are shown on plates 5–10. These plates also show the thinning or thickening between the various localities where the coal sections were measured.

The original reserves of the area, which are summarized in tables 3 and 4, are estimated to have been 5,244,490,000 tons. Approximately 1 percent of the original reserves had been mined by the end of 1950. The estimate of original reserves is based upon thicknesses of coal beds measured at many places along the outcrops during the field work. These measured thicknesses of coal beds are shown in the accompanying coal sections on plates 5–10, and their locations are shown on the geologic map (pl. 2).

CLASSES OF RESERVES

The total estimate of original coal reserves combines estimates made on a bed-by-bed basis and additional estimates made on a coal-zone basis. In table 3 the original reserves as estimated on a bed-by-bed basis are divided into categories based on thickness of bed, and on reliability of the data on which the estimate was based and presented by township, geologic formation and member.

TABLE 3.—*Estimated original reserves (in thousands of short tons), on a coal-bed basis, in the Starkville-Weston area, Las Animas County, Colo.*

[All coal is of bituminous rank and beneath 0–1,000 feet of overburden, except where footnote references indicate two exceptions in which a minor amount of coal beneath 1,000–2,000 feet of overburden is included in the estimate]

Formation and coal beds	Reserves of coal in beds of thickness shown: Measured and indicated: 14 to 28 inches	Measured and indicated: 28 to 42 inches	Measured and indicated: More than 42 inches	Measured and indicated: Total (measured and indicated)	Inferred: 14 to 28 inches	Inferred: 28 to 42 inches	Inferred: More than 42 inches	Inferred: Total (inferred)	Total reserves: 14 to 28 inches	Total reserves: 28 to 42 inches	Total reserves: More than 42 inches	Grand total
T. 33 S., Rs. 63 (fractional) and 64 W. (fractional)												
Raton formation:												
Lower member, all beds	910	790	0	1,700	240	3,120	0	3,360	1,150	3,910	0	5,060
Vermejo formation:												
Coal beds:												
Sopris	750	11,520	2,460	14,730	20	100	0	120	770	11,620	2,460	14,850
Cokedale	1,140	8,500	6,200	15,840	1,490	2,350	530	4,370	2,630	10,850	6,730	20,210
Lower Starkville	450	2,040	6,160	8,650	0	0	0	0	450	2,040	6,160	8,650
Other beds	14,920	19,630	33,680	68,230	5,210	7,200	5,060	17,470	20,130	26,830	38,740	85,700
Total (T. 33 S., Rs. 63 (fr.) and 64 W. (fr.)	18,170	42,480	48,500	109,150	6,960	12,770	5,590	25,320	25,130	55,250	54,090	134,470
T. 33 S., R. 65 W. (fractional)												
Raton formation:												
Lower member, coal beds:												
Primero	1,370	1,510	280	3,160	150	3,080	0	3,230	1,520	4,590	280	6,390
Frederick	720	3,210	4,740	8,670	410	220	2,650	3,280	1,130	3,430	7,390	11,950
Other beds	3,480	50	6,710	10,240	5,180	2,850	8,450	16,480	8,660	2,900	15,160	26,720
Vermejo formation:												
Coal beds:												
Cokedale	1,350	1,970	7,780	11,100	1,950	2,080	60	4,090	3,300	4,050	7,840	15,190
Piedmont	0	90	4,980	5,070	4,390	7,620	1,630	13,640	4,390	7,710	6,610	18,710
Lower Piedmont	910	2,300	0	3,210	2,780	230	0	3,010	3,690	2,530	0	6,220
Other beds	1,080	2,070	0	3,150	1,480	0	0	1,480	2,560	2,070	0	4,630
Total, T. 33 S., R. 65 W. (fr.)	8,910	11,200	24,490	44,600	16,340	16,080	12,790	45,210	25,250	27,280	37,280	89,810

T. 33 S., Rs. 66 (fractional) and 67 W. (fractional)

Raton formation:												
Middle member, Ciruela bed	1,470	0	0	1,470	0	0	0	0	1,470	0	0	1,470
Lower member, coal beds:												
Primero	810	3,940	37,490	42,240	350	3,150	33,220	36,720	1,160	7,090	70,710	78,960
Frederick	290	750	0	1,040	0	0	0	0	290	750	0	1,040
Other beds	18,400	1,930	20	20,350	13,080	0	0	13,080	31,480	1,930	20	33,430
Total, T. 33 S., Rs. 66 (fr.) and 67 W. (fr.)	20,970	6,620	37,510	65,100	13,430	3,150	33,220	49,800	34,400	9,770	70,730	114,900

T. 34 S., Rs. 63 (projected, fractional) and 64 W.

Raton formation:												
Lower member, coal beds:												
Primero	1,680	0	0	1,680	1,560	0	0	1,560	3,240	0	0	3,240
Other beds	9,050	280	0	9,330	13,950	40	0	13,990	23,000	320	0	23,320
Vermejo formation:												
Coal beds:												
Sopris	3,750	7,650	1,900	13,300	[a] 19,010	23,050	0	[a] 42,060	[a] 22,760	30,700	1,900	[a] 55,360
Lower Sopris	1,390	100	0	1,490	1,600	0	0	1,600	2,990	100	0	3,090
Upper Starkville	360	420	50	830	760	520	970	2,250	1,120	940	1,020	3,080
Lower Starkville	220	1,140	1,620	2,980	4,910	2,780	1,050	8,740	5,130	3,920	2,670	11,720
Morley	1,830	2,750	1,960	6,540	2,960	1,360	0	4,320	4,790	4,110	1,960	10,860
Piedmont	420	1,040	9,520	10,980	6,700	12,300	17,460	36,460	7,120	13,340	26,980	47,440
Lower Piedmont	490	290	0	780	12,060	2,120	0	14,180	12,550	2,410	0	14,960
Cokedale	1,430	1,800	70	3,300	3,630	1,100	0	4,730	5,060	2,900	70	8,030
Other beds	90	100	0	190	1,450	220	0	1,670	1,540	320	0	1,860
Total, T. 34 S., Rs. 63 (pr., fr.) and 64 W.	20,710	15,570	15,120	51,400	[a] 68,590	43,490	19,480	[a] 131,560	[a] 89,300	59,060	34,600	[a] 182,960

[a] Includes 1,590,000 short tons of coal in Sopris bed beneath 1,000–2,000 feet of overburden.

T. 34 S., R. 65 W.

Raton formation:												
Lower member, coal beds:												
Primero	710	0	0	710	[b] 1,450	0	0	[b] 1,450	[b] 2,160	0	0	[b] 2,160
Frederick	10,100	24,930	37,930	72,960	7,890	1,130	0	9,020	17,990	26,060	37,930	81,980
Other beds	9,190	4,720	1,480	15,390	18,620	3,860	230	22,710	27,810	8,580	1,710	38,100
Vermejo formation:												
Coal beds:												
Cokedale	0	510	260	770	1,840	1,020	20	2,880	1,840	1,530	280	3,650
Piedmont	0	0	0	0	3,230	3,850	1,280	8,360	3,230	3,850	1,280	8,360
Lower Piedmont	0	0	0	0	2,810	160	0	2,970	2,810	160	0	2,970
Other beds	0	0	0	0	170	0	0	170	170	0	0	170
Total, T. 34 S., R. 65 W.	20,000	30,160	39,670	89,830	[b] 36,010	10,020	1,530	[b] 47,560	[b] 56,010	40,180	41,200	[b] 137,390

[b] Includes 270,000 short tons in the Frederick coal bed beneath 1,000–2,000 feet of overburden.

TABLE 3.—*Estimated original reserves (in thousands of short tons), on a coal-bed basis, in the Starkville-Weston area, Las Animas County, Colo.*—Continued

Formation and coal beds	Reserves of coal in beds of thickness shown								Total reserves			Grand total
	Measured and indicated				Inferred							
	14 to 28 inches	28 to 42 inches	More than 42 inches	Total (measured and indicated)	14 to 28 inches	28 to 42 inches	More than 42 inches	Total (inferred)	14 to 28 inches	28 to 42 inches	More than 42 inches	
T. 34 S., R. 66 W.												
Raton formation:												
Upper member, all beds	110	0	0	110	680	0	0	680	790	0	0	790
Middle member, Ciruela bed	8, 610	1, 780	0	10, 390	3, 260	50	0	3, 310	11, 870	1, 830	0	13, 700
Lower member, coal beds:												
Primero	2, 360	90	0	2, 450	5, 350	2, 790	0	8, 140	7, 710	2, 880	0	10, 590
Frederick	530	2, 260	220	3, 010	12, 030	3, 490	0	15, 520	12, 560	5, 750	220	18, 530
Other beds	3, 630	570	0	4, 200	21, 450	0	0	21, 450	25, 080	570	0	25, 650
Total, T. 34 S., R. 66 W	15, 240	4, 700	220	20, 160	42, 770	6, 330	0	49, 100	58, 010	11, 030	220	69, 260
T. 34 S., R. 67 W. (fractional)												
Raton formation:												
Upper member, all beds	6, 430	1, 130	0	7, 560	450	0	0	450	6, 880	1, 130	0	8, 010
Middle member, coal beds:												
Ciruela	0	2, 390	0	2, 390	17, 380	450	0	17, 830	17, 380	2, 840	0	20, 220
Other beds	2, 570	30	0	2, 600	500	0	0	500	3, 070	30	0	3, 100
Lower member, coal beds:												
Primero	40	1, 500	520	2, 060	2, 340	3, 870	0	6, 210	2, 380	5, 370	520	8, 270
Other beds	3. 870	210	0	4, 080	3, 020	0	0	3, 020	6, 890	210	0	7, 100
Total, T. 34 S., R. 67 W (fr.)	12, 910	5, 260	520	18, 690	23, 690	4, 320	0	28, 010	36, 600	9, 580	520	46, 700

T. 35 S., Rs. 63 (projected, fractional) and 64 W. (projected)

Raton formation:												
Lower member, all beds	420	7,420	0	7,840	13,580	310	0	13,890	14,000	7,730	0	21,730
Vermejo formation, coal beds:												
Sopris	980	230	10	1,220	0	0	0	0	980	230	10	1,220
Lower Sopris	0	0	0	0	60	0	0	60	60	0	0	60
Morley	470	2,080	15,520	18,070	10,430	12,970	970	24,370	10,900	15,050	16,490	42,440
Other beds	4,630	750	2,100	7,480	2,570	0	0	2,570	7,200	750	2,100	10,050
Total, T. 35 S., Rs. 63 (pr., fr.) and 64 W. (pr)	6,500	10,480	17,630	34,610	26,640	13,280	970	40,890	33,140	23,760	18,600	75,500

T. 35 S., R. 65 W. (projected)

Raton formation:												
Lower member, coal beds:												
Primero	510	0	0	510	350	0	0	350	860	0	0	860
Other beds	2,970	370	0	3,340	2,020	0	0	2,020	4,990	370	0	5,360
Vermejo formation, all beds	380	0	0	380	310	0	0	310	690	0	0	690
Total, 35 S., R. 65 W. (pr.)	3,860	370	0	4,230	2,680	0	0	2,680	6,540	370	0	6,910

T. 35 S., R. 66 W. (projected)

Raton formation:												
Upper member, all beds	3,050	0	0	3,050	4,420	0	0	4,420	7,470	0	0	7,470
Middle member, Ciruela bed	1,620	0	0	1,620	4,460	0	0	4,460	6,080	0	0	6,080
Lower member, all beds	0	0	0	0	70	0	0	70	70	0	0	70
Total, T. 35 S., R. 66 W. (pr.)	4,670	0	0	4,670	8,950	0	0	8,950	13,620	0	0	13,620

T. 35 S., R. 67 W. (projected, fractional)

Raton formation:												
Upper member, all beds	100	0	0	100	60	0	0	60	160	0	0	160
Middle member, coal beds:												
Ciruela	0	0	0	0	4,840	0	0	4,840	4,840	0	0	4,840
Other beds	3,000	530	0	3,530	270	0	0	270	3,270	530	0	3,800
Total, T. 35 S., R. 67 W. (pr., fr.)	3,100	530	0	3,630	5,170	0	0	5,170	8,270	530	0	8,800
Grand total	135,040	127,370	183,660	446,070	[c] 257,230	109,440	73,580	[c] 432,390	[c] 386,270	236,810	257,240	[c] 880,320

[c] Includes 1,860,000 short tons in Sopris and Frederick coal beds beneath 1,000–2,000 feet of overburden.

TABLE 4.—*Total estimated original coal reserves (in thousands of short tons) in the Starkville-Weston area, Las Animas County, Colo.*

[All coal is of bituminous rank]

Township and range	Reserves estimated to be in coal beds				Other estimated reserves, inferred to be in coal zones	Grand total
	In beds 14 to 28 inches thick	In beds 28 to 42 inches thick	In beds more than 42 inches thick	Total		
T33S, R63W	130	1, 600	2, 600	4, 330	2, 640	6, 970
T33S, R64W	25, 000	53, 650	51, 490	130, 140	55, 050	185, 190
T33S, R65W	25, 250	27, 280	37, 280	89, 810	361, 790	451, 600
T33S, R66W	24, 100	6, 340	61, 360	91, 800	383, 290	475, 090
T33S, R67W	10, 300	3, 430	9, 370	23, 100	64, 280	87, 380
T34S, R63W	5, 050	1, 300	1, 620	7, 970	18, 600	26, 570
T34S, R64W	84, 250	57, 760	32, 980	174, 990	602, 130	777, 120
T34S, R65W	56, 010	40, 180	41, 200	137, 390	889, 870	1, 027, 260
T34S, R66W	58, 010	11, 030	220	69, 260	765, 000	834, 260
T34S, R67W	36, 600	9, 580	520	46, 700	277, 380	324, 080
T35S, R63W	380	850	1, 700	2, 930	6, 550	9, 480
T35S, R64W	32, 760	22, 910	16, 900	72, 570	176, 120	248, 690
T35S, R65W	6, 540	370		6, 910	303, 120	310, 890
T35S, R66W	13, 620			13, 620	327, 920	341, 540
T35S, R67W	8, 270	530		8, 800	129, 570	138, 370
Total all townships	386, 270	236, 810	257, 240	880, 320	4, 364, 170	5, 244, 490

The reserves estimated on a bed-by-bed basis (table 3) are placed in three categories, which are based on the following bed thicknesses: 14 to 28 inches, 28 to 42 inches, and more than 42 inches. The tonnage estimate for each of these thickness categories was obtained by constructing isopachous maps for each coal bed. The areal extent (acreage) and the average thickness of coal for each isopach interval were then determined and from this information the estimated tonnage was computed.

In addition to classification on the basis of thickness, the reserves are also placed in measured and indicated reserves or in inferred reserves. These divisions indicate the reliability of data regarding the occurrence of coal at various distances from the points of measurement. These classifications were derived from an original division into measured, indicated, and inferred reserves. Measured reserves were computed from thicknesses in outcrops, trenches, and mines, and arbitrarily were limited to areas not more than one-quarter mile from the points of measurement. Indicated reserves were computed by projection and interpolation based on geologic evidence from known data for a distance not to exceed one mile from the points of measurement. Inferred reserves were computed by evaluating geologic evidence gained during field work which showed whether coal beds were continuous or wedged out. All areas of coal included in the inferred reserves lie beyond those of indicated reserves and are, in general, more than one mile from the outcrop or other point of measurement.

Measured reserves in the area are quite small in proportion to the total reserves, owing largely to the fact that almost all data concerning coal beds were obtained at the outcrop. They were therefore combined with indicated reserves in table 3 to include all coal less than one mile from the outcrop.

Reserves of coal have been further divided by the U. S. Geological Survey in recent years on the basis of the thickness of the overburden. Classifications based on overburden are commonly of two types: (1) coal beneath overburden usually less than 120 feet in thickness and that can be strip mined, and (2) coal beneath overburden that is one thousand feet or more in thickness. During our field work, the Starkville-Weston area was examined for strippable coal beds. Because the terrain is steep, probably there are no localities where large-scale strip-mining methods could be used. Therefore, reserves are classified in this report only in the 0–1,000 foot category. Most of the coal reserves, estimated on a bed-by-bed basis (table 3), are less than 1,000 feet deep, as also are most of the additional coal reserves estimated on a coal-zone basis (table 4). Overburden, therefore, was not considered in the coal-zone reserves.

MINING

Few mines are now being operated in the area. The two most important are the Frederick mine and the Morley mine, which are owned by the Colorado Fuel and Iron Corp. Several other mines in the vicinities of Starkville and Sopris, most of which produce between 500 and 2,000 short tons per year, are worked intermittently.

Mining activity in the past was considerably greater than it is at the present. Large mines no longer operated include the Cokedale, Piedmont, Primero, Sopris, and Starkville; smaller important mines include the La Belle, Francisco-Frisco, Quinto, Jeffries, and Viola.

Statistics for coal production in southern Colorado date back to 1873, but in these early production statistics Las Animas County was grouped with other counties to the north. Separate production figures for Las Animas County (and the report area) are obtainable from 1884 to date, except for the years 1889 and 1890. Coal production before 1884 probably was not large; and it is likely that Table 5, which shows coal production for the period from 1884–1950, exclusive of 1889–90, shows most of the coal produced. During this period, at least 58,917,184 short tons was mined. Greatest mining activity was in the two decades from 1900 to 1920, when approximately one-half of the coal, or 29,818,367 short tons, was mined. Almost half of all the coal (26,887,196 tons) has been mined at the Frederick and Morley mines.

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TABLE 5.—*Production of coal (in short tons) from the Starkville-Weston Area, Las Animas County, Colo.*

[Data from published reports of the Colorado State Mine Inspector; all coal of bituminous rank]

Year	Mine													
	Stark-ville	Sopris	La Belle	Frederick	Morley	Primero	Piedmont	Francisco-Frisco	Coke-dale	Quinto	Jeffries	Viola	Others	Total
1884-88*	852, 130	134, 557	0	0	0	0	0	0	0	0	0	0	91, 650	1, 078, 337
1891-1900	3, 096, 164	2, 523, 790	30, 500	0	0	0	0	0	0	0	0	0	0	5, 650, 454
1901-10	3, 053. 458	1, 429, 050	329, 373	722, 860	1, 167, 274	4. 252, 940	887, 117	179, 020	1, 095, 968	169, 903	0	0	90, 983	13. 377, 946
1911-20	1, 690, 159	2, 431, 683	67, 108	3, 186, 809	2, 427, 157	3, 149, 524	1, 001, 115	0	1, 862, 509	0	228, 732	48, 173	337, 452	16, 430, 421
1921-30	26, 686	1, 559, 563	87, 691	3, 586, 907	3, 496, 656	781, 539	8, 009	0	0	0	74, 092	0	174, 505	9, 795, 648
1931-40	14, 174	141, 837	3, 711	3, 524, 709	1, 173, 691	0	0	14, 596	0	0	30, 029	0	13, 809	4, 916, 556
1941	5, 969	0	0	657, 043	175, 832	0	0	0	0	0	867	0	1, 975	841, 686
1942	0	0	0	630, 933	202, 439	0	0	48	0	0	695	0	4, 981	839, 096
1943	0	0	0	649, 148	242, 615	0	0	0	0	0	475	0	7, 438	899, 676
1944	0	0	0	619, 847	224, 707	0	0	883	0	0	81	0	4, 084	849, 602
1945	0	0	0	578, 950	197, 330	0	0	972	0	0	25	0	2, 658	779, 935
1946	0	0	0	416, 339	153, 830	0	0	822	0	0	830	0	4, 341	576, 162
1947	0	0	0	613, 348	219, 469	0	0	463	0	0	0	0	4, 555	837, 835
1948	0	0	0	543, 301	187, 060	0	952	620	0	0	619	0	5, 969	738, 521
1949	0	0	0	461, 042	162, 100	0	2, 146	0	0	0	2, 733	0	5, 172	633, 193
1950	0	0	0	490, 023	175, 777	0	1, 041	0	0	0	0	0	5, 275	672, 116
Grand total	8, 738, 740	8, 220, 480	518, 383	16, 681, 259	10, 205, 937	8, 184, 003	1, 900, 380	197, 424	2, 958, 477	169, 903	339, 178	48, 173	754, 847	58, 917, 184

*Production figures for years 1889–90 not available.

RECOVERABLE RESERVES

Few data are available concerning the ratio of coal produced to that lost during mining operations in the Raton and Trinidad coal fields of the Raton Mesa region. Throughout the western United States, however, the amount of coal recovered in mining averages about one-half of the coal originally present. If this proportion is valid for the area of this report, about 108,000,000 short tons of coal either has been mined or has been lost during mining operations. The remaining original reserves in the area estimated on a bed-by-bed basis are approximately 770 million short tons; and the remaining original reserves in beds more than 28 inches thick are about 386 million short tons. When remaining reserves estimated on a coal-zone basis are added to the bed-by-bed reserves, the total remaining original reserves in the area are about 5,135 million short tons. Applying the 1: 1 ratio, the recoverable reserves on a bed-by-bed basis are estimated to be about 385 million short tons, and the recoverable reserves in beds more than 28 inches thick are about 193 million short tons. When the recoverable reserves on coal-zone basis are added, the total recoverable reserves of coal in the area are 2,567,500,000 short tons.

FUTURE DEVELOPMENT

A part of the future success of the mining of coal in the part of the Raton Mesa region surrounding the Starkville-Weston area may depend in part upon the correlation of coal beds in the Vermejo (pl. 5) and Raton (pls. 6–10) formations (see also Stratigraphic position and character of coal beds and pl. 3). The results of the field work for this report indicate that in this area the two formations are conformable and that locally they intertongue. Coal beds of the Vermejo formation pinch out to the west, owing to intertonguing witb the basal beds of the Raton formation or to local nondeposition. These relations are not valid to the north in the region between the Apishapa and Huerfano Rivers, where these formations are separated by a widespread unconformity. The interpretation advocated by Lee (1917) differs from the preceding interpretation, in that he believed that this widespread unconformity to the north extends southward into the Starkville-Weston area. Lee's interpretation has been widely accepted, and if mining in the vicinity of Trinidad and Morley has been guided by it, large blocks of coal reserves may have been overlooked. It is possible that considerable tonnages of minable coal may be found, if mine maps are reexamined, data are evaluated, and future exploration guided by the stratigraphic relations advanced in this report.

In the Purgatoire River Valley between Cokedale and Trinidad and near Morley, the coal beds of the Vermejo formation have been intensely mined. At these localities the Vermejo is 80–220 feet thick.

Near Trinidad and Morley most of the mining has been in the lower coal beds of the Vermejo formation. Efficient recovery of any overlying unmined coal may now be difficult owing to actual or potential slumping. West of Sopris and Cokedale only the upper beds have been mined, and the lower beds probably could be mined from shafts 200–500 feet deep.

The estimated coal reserves remaining in the area suggest that large-scale mining of coal beds in the Vermejo formation for an extended period of time appears to be feasible probably by deep shafts or slopes. A program of drilling to outline the areal extent of individual coal beds would be advisable.

Although the reserves in the Raton formation are large, most of the coal is in lenticular coal beds that are, in general, too small in areal extent for large-scale, long-continued mining. North of the Purgatoire River the Frederick bed may contain sufficient reserves for mining on a moderate scale and locally the Primero bed may contain large reserves.

DESCRIPTION BY TOWNSHIPS

In the following pages the coal deposits in each township are described in order from east to west in each tier of townships, beginning with the northern most tier. Where all the township is not included in the area, the word 'fractional' in the heading to the township description indicates that only a portion of the township is being described. Detailed data on the coal not given elsewhere in this report are presented. Localities at which coal sections were measured are numbered consecutively beginning with the Vermejo formation and ending with the Poison Canyon formation. The measured sections are shown graphically in plates 5 to 10, and are identified by the same numbers in the text and on the geologic map (pl. 2).

T. 33 S., R. 63 W. (FRACTIONAL)

The upper strata of the Pierre shale are exposed beneath the Trinidad sandstone in the northern part of the township. Intertonguing relations between these formations are shown on the geologic map (pl. 2). The Trinidad sandstone is overlain by about 100 feet of the Vermejo formation, which, in turn, is overlain by about 600 feet of the Raton formation.

Coal beds in the Vermejo formation.—The Lower Starkville coal bed, the lowest bed in the coal section measured at locality 25 (pl. 5), here consists of the following units from the base upward: coal, 4 feet 1 inch; shale, 2 inches; coal, ¾ inch; shale, 7 inches; and coal, 10 inches. The bed was measured in the portal of a small mine. A few feet stratigraphically higher in the Vermejo formation the Upper Starkville bed, which consists of 4 feet 5 inches coal, was also measured in the portal of another small mine. Still higher, the Sopris bed consists, from the base upward, of coal, 1 foot 4 inches; shale, ½ inch; and coal, 1 foot 11 inches. The beds at locality 25 are intermittently traceable southeastward to locality 24 in T. 33 S., R. 64 W.

Coal beds in the Raton formation.—The only coal bed in the Raton formation exposed in the portion of the township that is in the area is at locality 78. It is shown on plate 6, which illustrates the lateral and vertical relations of the coal beds in coal zone *F* of the lower member of the Raton formation. At locality 78 the coal bed lies 18 feet above a massive-sandstone bed and 24 feet below second bed of sandstone (pl. 1). The coal bed consists of coal, 1 foot 5 inches; shale, ¼ inch; coal, 8 inch; shale, ¼ inches; and coal, 7 inches.

T. 33 S., R. 64 W. (FRACTIONAL)

The Purgatoire River flows northeastwardly across the portion of the township included in the area. The upper strata of the Pierre shale, exposed in the valley of the Purgatoire River, are overlain by about 100 feet of the Trinidad sandstone. Intertonguing relations between these formations are shown on the geologic map (pl. 2) and in the graphic sections (pl. 3). The Vermejo formation ranges from about 100 to 220 feet in thickness in the township and rests conformably on the Trinidad sandstone. It is overlain by basal conglomeratic sandstone beds of the Raton formation with which it intertongues. About 700 feet of the lower member of the Raton formation is preserved in the township.

Much of the mining activity of the area has been concentrated in this township. The portals of the Sopris and Starkville mines were in the township, but the main workings were in T. 33 S., R. 63 W.; T. 34 S., R. 63 W.; and T. 34 S., R. 64W. Other important mines were the Francisco-Frisco, Jeffries, La Belle, McLaughlin, Piedmont, and Williams.

Coal beds in the Vermejo formation.—The Lower Piedmont bed ranges in thickness from 1 foot to 2 feet 3 inches in the coal sections measured at localities 6, 23, and 24 (pl. 5), and in the diamond-drill hole near Sopris (Hills, 1901). Coal from the Lower Piedmont bed is generally clean and relatively free from partings.

The Piedmont bed, which was extensively mined at the Piedmont and the Francisco-Frisco mines, was measured at localities 6, 7, 8, 9, 23, and 24 (pl. 5), and was entered by the drill hole near Sopris (Hills, 1901). The bed is variable in thickness and consists characteristically of a lower bench of coal, a middle parting of shale, and an upper bench of coal. The combined thickness of coal ranges from 9 inches at locality 9 to 8 feet 5 inches in the drill hole near Sopris (Hills, 1901). Coal from the Piedmont bed is clean, but the bed locally contains several shale partings.

Above the Piedmont bed and below the Lower Starkville bed are several thin coal beds (pl. 5). These coal beds were recognized in the coal sections measured at localities 6, 8, 11, 22, 23, and 24. Several were also reached by the drill hole near Sopris (Hills, 1901). Most of them, however, are less than 1 foot 2 inches thick and all are less than 2 feet 4 inches thick.

The Lower Starkville bed was measured at localities 6, 8, 23, and 24 and was recognized in the drill hole near Sopris (Hills, 1901). This bed has been extensively mined at the Starkville mine. West and north of the Starkville mine it appears to thin rather rapidly. It contains 4 feet 4 inches of coal at locality 24 near the Starkville mine but is only 3 inches thick in the drill hole near Sopris (Hills, 1901). The Lower Starkville bed usually contains several partings, otherwise the coal generally is clean.

Between the Lower Starkville bed and the Cokedale bed are several thin to thick coal beds. These beds were measured at localities 6, 8, 10, 11, and 17 and are correlated into the drill hole near Sopris (Hills, 1901). They are intruded by basic sills at locality 8 and are altered to natural coke at locality 10.

Some of the haulageways and rooms of the Cokedale mine were driven along the Cokedale bed. This bed also was worked at the Viola mine, the portal of which was in this township, although the main workings were in sec. 36, T. 33, S., R. 65 W. The Cokedale bed was worked at several "wagon" mines having portals east and south of the Viola mine. The bed was measured at localities 5, 11, 16, 17, 18, 19, and 21, and was correlated with a bed reached by the drill hole near Sopris (Hills, 1901). It is thickest, about 4 feet 7 inches, near the mouth of Reilly Canyon, and it thins rather rapidly and irregularly to the east and southeast. The Cokedale bed contains considerable bony coal and several shale partings at the localities where it is thick (pl. 5) and it is considered a dirty coal.

West of Carpios Canyon the Cokedale bed is directly beneath or is within a few feet of the base of the lower tongue of the basal conglomeratic sandstone in the Raton formation. The relations of the Cokedale bed to this tongue are shown on the geologic map (pl. 2) and on plate 5. East of the mouth of Long Canyon this lower tongue loses its conglomeratic character and is similar to the stratigraphically lower sandstone beds of the Vermejo formation. The upper tongue, however, retains all the characteristics of the basal conglomeratic sandstone and becomes even more conglomeratic eastward.

The Upper Starkville bed where it was measured at locality 23 is less than 1 foot 2 inches thick.

Above the lower tongue of the basal conglomeratic sandstone of the Raton formation and below the Sopris bed are several beds of coal, each generally less than 1 foot 2 inches thick. In the drill hole near Sopris (Hills, 1901), however, one of these beds is 3 feet 10 inches thick. These beds were also measured at localities 19, 20, and 23.

The Sopris bed was mined at the Sopris and La Belle mines. It was measured at localities 4, 5, 19, 20, 23, and 24, and was correlated with a bed reached by the drill hole near Sopris (Hills, 1901). It is intruded by a basic sill and either is altered to natural coke or is almost obliterated at localities 8, 10, 11, and 20. The bed usually contains several shale partings and locally contains bony coal near the top

Coal beds in the Raton formation.—Only the thin coal beds in the lower member of the Raton formation remain in the township. They are shown in plate 6, which illustrates the relations of coal beds in coal zones *A* and *B*. The coal beds at localities 27 and 30 are thin and unimportant, but the one at locality 29 is 2 feet 8 inches thick, underlain by 7 inches of shale and 3½ inches of coal, and is overlain by ½ inch of shale and 2 inches of bony coal.

T. 33 S., R. 65 W. (FRACTIONAL)

The Purgatoire River flows from west to east across the southern half of this township. Near the mouth of Burro Canyon Raton strata overly the Vermejo. The latter formation is believed to average about 220 feet in thickness in the subsurface and is overlain by a variable thickness of the Raton formation that ranges up to 1,200 feet. The middle and upper members of the Raton crop out in the northwestern part of the township.

The main workings of the Frederick mine are in T. 34 S., R. 65 W., but the portal is in this township. In the area between Reilly and Burro Canyons the Cokedale and Viola mines mined the Cokedale coal bed.

Coal beds in the Vermejo formation.—The upper coal beds of the Vermejo formation crop out in T. 33 S., R. 65 W., and several of the lower coal beds may be correlated into the subsurface by means of data from the drill hole near the mouth of Reilly Canyon (Lee, 1917, p. 125). In this drill hole, the Lower Piedmont bed is 3 feet 6 inches thick (pl. 5). The overlying Piedmont bed contains, from bottom to top, 6 inches of coal, 1 foot of shale, 5 feet of coal, 3 feet of shale, and 2 feet of coal. A 4 foot 2 inch bed of coal which lies 13 feet 10 inches above the Piedmont bed was not recognized at outcrops to the east and apparently either is a thick lenticular local bed or is a bed which wedges out eastward. The Lower Starkville bed is 9 inches thick. It has above it a 1 foot 6 inch bed of coal, a 1 foot 3 inch bed of coal, and the Cokedale bed.

The Cokedale bed has been intensively mined in the township by the Cokedale and Viola mines and by several "wagon" mines whose portals are west of the Viola portal. The Cokedale bed was measured at localities 12, 13, 14, and 15, and was correlated with a bed reached by the drill hole near the mouth of Reilly Canyon (Lee, 1917, p. 125). The bed is somewhat irregular in thickness and ranges from 1 foot 4 inches of coal at locality 12 to 5 feet of coal in the drill hole. Locally it contains several shale and bony-coal partings, and coal from the bed is reported to be quite dirty.

Coal beds in the Raton formation.—Most of the coal beds near the base of the Raton formation are discontinuous and less than 1 foot 2 inches thick. Sections were measured at localities 26 (pl. 6, coal zone *A*), 28 (pl. 6, coal zone *B*), and 35 (pl. 6, coal zone *D*). A lenticular bed of coal in coal zone *C* (pl. 6) is 4 inches thick at locality 31, 1 foot 6 inches thick at locality 32, and 1 foot 9 inches thick at locality 33.

The Frederick bed in coal zone *E* (pl. 6) was measured at localities 40, 41, 42, 46, 48, 58, 59, 60, and 62. It is only 1 foot 8 inches thick at locality 41 and is 4 feet 8 inches thick at locality 60. There has been little mining north of the Purgatoire River on this bed, where considerable reserves remain. Locally the bed is lenticular and contains several shale partings. Except for impurities due to adjacent shale partings, individual seams of coal are generally clean.

A thin but seemingly persistent coal bed was measured in coal zone *E* (pl. 6) beneath the Frederick bed at localities 47 and 58. A slightly lower coal bed was measured at localities 44 and 45.

The coal beds of coal zone *F* (pl. 6) vary from thin to thick. Two coal beds that are usually slightly thicker than 1 foot 2 inches appear to underlie appreciable areas and were measured at localities 65, 66, 67, 68, and 73. A 4-inch bed of bony coal near the top of the coal zone was measured at locality 75.

A number of coal beds less than 1 foot 2 inches thick were measured at localities 79 and 80 in coal zone *G* (pl. 6) and locality 88 in coal zone *H* (pl. 6). The upper coal bed, which is 2 inches thick, at locality 80, thickens gradually southward to 1 foot 10 inches at locality 81 in T. 34 S., R. 65 W.

The Primero bed in coal zone *I* (pl. 7) was measured at two localities in the township. It contains 1 foot 6 inches of clean coal at locality 114 and 1 foot 9 inches of dirty coal at locality 115. At these localities the Primero bed is underlain by other coal beds slightly thicker than 1 foot 2 inches.

Several discontinuous coal beds less than 1 foot 2 inches thick were measured at locality 152 in coal zone *J* (pl. 7), and localities 160 and 161 in coal zone *K* (pl. 8). Thin lenticular beds of bony coal occur at locality 180 in coal zone *L* (pl. 8) and at locality 216 in coal zone *N* (pl. 8).

T. 33 S., R. 66 W. (FRACTIONAL)

The Purgatoire River flows across the township from west to east. The upper part of the lower member, the middle member, and the upper member of the Raton formation crop out north of the river and are overlain by the basal strata of the Poison Canyon formation west of Molino Canyon.

Coal beds in the Vermejo formation.—The Vermejo formation does not crop out in the township; therefore, the number of coal beds and their relations and lateral extent are unknown.

Coal beds in the Raton formation.—The lower strata of the lower member of the Raton formation do not crop out in the township, and the number of coal beds, their thicknesses, and their relations and lateral extent are unknown. The oldest coal beds exposed in the township are in coal zone *H* (pl. 6). They are 6 inches thick and were measured at localities 95 and 96.

All workings of the Primero mine in the Primero bed, one of the largest mines in the area, were entirely within the township. The Primero bed is in coal zone *I* (pl. 7). It was measured at localities 100, 101, 102, 103, 104, 105, 111, 130, 132, 133, 135, and 136, and was found to range in thickness from 10 inches at locality 135, to 6 feet 2 inches at locality 111. It is lenticular and locally contains a variable number of shale partings, but the coal is generally clean and the principal impurity is pyrite. Several thin beds of coal lie a few feet below or above the Primero bed, where it was measured at localities 105, 112, 131, 134, and 136.

The 3 foot 7 inch coal bed measured at locality 141 in coal zone *J* (pl. 7) thins northwestwardly to 7 inches at locality 140. Several stratigraphically higher thin beds of coal and coaly shale were also measured at locality 140. The 6-inch bed of coaly shale near the top of the section grades laterally into 11 inches of coal at locality 142.

Two beds of coal less than 1 foot 2 inches thick were measured near the middle of coal zone *K* (pl. 8) at locality 168. Three isolated and apparently lenticular beds of coal that are less than 1 foot 2 inches thick were measured in coal zone *L* (pl. 8) at localities 178 and 179.

At locality 193 the lower coal bed in coal zone *M* (pl. 8) is 1 foot thick. Several miles to the east at locality 195 it is 1 foot 10 inches thick. The upper coal bed at locality 193 is 1 foot 6 inches thick and at locality 194, which is less than two miles away, this same bed is 1 foot 1 inch thick.

A coal bed that crops out over a considerable part of the township and three underlying lenticular coal beds in coal zone *N*, all locally thicker than 1 foot 2 inches, were measured at localities 204, 205, 206, 211, and 212 (pl. 8).

The coal beds of coal zone *O* (pl. 9) were measured at localities 228 and 229. At locality 228 a lenticular coal bed 2 feet thick, occurs near the middle of the zone. At locality 229 the coal beds are less than 1 foot 2 inches thick and lie near the top of the zone.

Two coal beds were measured in coal zone *P* at locality 234 (pl. 4). The lower is 1 foot 10 inches thick and the upper is 2 feet 3 inches thick. The lower bed thins to 7 inches of coaly shale and the upper bed appears to be absent at locality 235, about 2½ miles to the northeast. A thin lenticular bed of coal occurs near the top of the zone at localities 245 and 246.

The Ciruela bed in coal zone *R* in the middle member of the Raton formation (pl. 10) is not present at locality 272. A lower bed of coal in the zone consists of coal, 2 inches; shale, 1 inch; coal, 4 inches; shale, ½ inch; coal, 9 inches; shale, ½ inch; and coal, 11 inches.

T. 33 S., R. 67 W. (FRACTIONAL)

Only a small part of the township is included in the area. Strata of the Vermejo formation and the lower strata of the lower member of the Raton formation do not crop out but are in the subsurface; the upper strata of the lower member of the Raton crop out but only in the valley of the Purgatoire River. The middle and upper members of the Raton formation and the lower strata of the Poison Canyon formation crop out north of the river. The portal and some workings of the Quinto Mine are in the township.

Coal beds in the Vermejo formation.—The number, relations, and thicknesses of these beds are unknown.

Coal beds in the Raton formation.—The lower part of the lower member of the Raton formation is in the subsurface of the township. The oldest coal beds exposed in the township were measured in coal zone *H* (pl. 6) at locality 94, where the lower bed is 1 foot 2 inches thick and the upper bed consists of coal, 3½ inches; shale, ½ inch; coal, 5½ inches; shale, ⅛ inch; and coal, 10 inches.

Near the portal of the Quinto Mine in coal zone *I* (pl. 7) at locality 128, the Primero bed consists of coal, 1 foot 1 inch; bony coal, 1 inch; coal, 1 foot 2½ inches; shale, 1 inch; coal, 1 foot; coaly shale, 8 inches; and coal, 11 inches. About ¾ of a mile to the northwest at locality 129, the bed has thinned to 9½ inches of bony coal, 8 inches of coal, 5 inches of shale, and 11 inches of coal. Several higher seams of coal were not included in the Primero bed, because the intervening shale partings are thicker than the coal seams. At locality 128 the coal is clean and at locality 129 it has been locally altered to natural coke.

The upper coal bed at locality 177 in coal zone *L* (pl. 8) is 11 inches thick. It grades laterally eastward into bony coal at locality 178 in

T. 33 S., R. 66 W. The 2-foot coal bed at locality 192 in coal zone *M* (pl. 8) thins eastward to 1 foot 6 inches at locality 193 in T. 33 S., R. 66 W., and the 1 foot 9 inch coal bed at locality 202 in coal zone *N* (pl. 8) apparently maintains nearly constant thickness between localities 202 and 204 in T. 33 S., R. 66 W.

At locality 226, in coal zone O (pl. 9), a coal bed 3 feet thick crops out, and at locality 227 a slightly lower coal bed is 1 foot 4 inches thick. A 1 foot 2 inch coal bed occurs near the middle of coal zone P (pl. 9) at locality 242.

T. 34 S., R. 63 W. (PROJECTED, FRACTIONAL)

The upper strata of the Pierre shale, the Trinidad sandstone, the Vermejo formation, and the lower member of the Raton formation crop out in the portion of the township that lies in the area. These strata are exposed on the western slopes of Fishers Peak Mesa and in the tributaries of Raton Creek.

Coal beds in the Vermejo formation.—Coal beds in the Vermejo formation are exposed only at locality 1 (pl. 5), where the coal-bearing sequence commences with a 1-foot bed of bony coal which lies 9 feet above the Trinidad sandstone and 16 feet 6 inches below the Morley bed. The Morley bed consists of coal, 6½ inches; shale, ½ inch; coal, 6 inches; shale, 1 inch; coal, 1 foot 8 inches; shale, 2 inches; and coal, 2 feet 4 inches. In the township the bed has been mined by some of the eastern workings of the Morley Mine.

A 2-foot bed of coaly shale that correlates with the Upper Morley bed lies 24 feet 6 inches above the Morley bed. It grades northward into 1 foot 4 inches of coal at locality 2, in T. 34 S., R. 64 W.

The Lower Sopris bed, 28 feet 9 inches higher in the section, consists of 1 foot 1 inch of natural coke. It is overlain by 3 inches of shale and a sill of basic igneous rock 1 foot 9 inches thick. The Sopris bed lies 9 feet 2 inches above the sill and consists of 1 foot 9 inches of coal, 5 inches of shale, and 1 foot 9 inches of coal. It, in turn, is overlain by 2 inches of natural coke, 3 inches of shale, and 8 inches of natural coke, which is 2 feet 6 inches below another sill of basic igneous rock.

Coal beds in the Raton formation.—Coal beds of the Raton formation are nowhere exposed in the township. Their normal outcrops on Fishers Peak Mesa are covered by landslide debris and talus from lava flows.

T. 34 S., R. 64 W.

Raton Creek flows northward across the eastern part of the township, and Saruche Canyon drains northwestwardly across the western part of the township to its junction with Long Canyon. About three quarters of the township is in the Maxwell Grant and is not formally divided into sections. The upper strata of the Pierre shale are exposed near Morley, and the Trinidad sandstone, the Vermejo formation, and the basal strata of the Raton formation crop out near Starkville and Morley. The highest strata of the lower member and those of the middle and upper members of the Raton are exposed over most of the rest of the township. Strata of the Poison Canyon formation, however, cap the ridge between Raton Creek and Saruche Canyon.

The portal and part of the mine workings of the Morley mine as well as the southernmost workings of the Sopris and Starkville mines are in the township.

Coal beds in the Vermejo formation.—Coal beds of the Vermejo formation underlie the township and were measured at localities 2 and 3. About one mile north of Morley at locality 2 (pl. 5) the lower coal bed is 1 foot thick. It lies 17 feet above the Trinidad sandstone and 5 feet below the Morley bed. The Morley bed consists of coal, 11 inches; shale, 2½ inches; and coal, 1 foot 2 inches. It is overlain by 1 foot 10 inches of shale, 10½ inches of coal, 12 feet 1 inch of shale, siltstone, and sandstone, and by the Upper Morley bed. This latter bed consists of 4 inches of bony coal and 1 foot 4 inches of coal. It is overlain by several 1- to 2-inch beds of bony coal in the next 21 feet. The overlying Lower Sopris bed consists of coal, 11½ inches; shale, 1½ inches; coal, 3 inches; shale, ½ inch; coal, 6½ inches; shale, ½ inch; and coal, 1 foot ½ inch. The Sopris bed, which is 12 feet 7 inches above the Lower Sopris bed, is only 1 foot 3 inches thick. At locality 2 the Morley and Sopris beds are thinner than at locality 1 or at the Morley Mine.

The upper strata of the Vermejo formation are poorly exposed at locality 3 (pl. 5) near Starkville. The Cokedale bed contains 1 foot 1½ inches of coal. A few feet higher the Upper Starkville bed or its correlative, the Upper Morley bed, is only 5½ inches thick, and is overlain by the lower strata in the basal conglomeratic sandstone of the Raton formation.

Coal beds in the Raton formation.—Several thin beds of coal occur in the lower member of the Raton formation below the Primero bed. These were measured at locality 30 in coal zone *B* (pl. 6) and localities 85 and 87 in coal zone *G* (pl. 6). At localities 92 and 93 in coal zone *H* (pl. 6), most of the coal beds are thin, but at locality 93 the upper bed reaches a thickness of 1 foot 9 inches.

The Primero bed in coal zone *I* (pl. 7) was measured at localities 122, 123, 124, 125, and 139. It ranges in thickness from 8 inches at locality 139 to 2 feet 3 inches at locality 123. It is somewhat thinner in this township than in the township to the northwest, and the coal is dirtier.

Several coal beds more than 1 foot 2 inches thick and other thinner coal beds were measured at localities 156, 157, and 158 in coal zone *J* (pl. 7); at localities 175 and 176 in coal zone *K* (pl. 8), and at locality 191 in coal zone *L* (pl. 8). The coal in most of these beds is relatively clean.

T. 34 S., R. 65 W.

Most of the township is drained by Long Canyon which trends northeastwardly across it. Major tributaries to Long Canyon are Colorow and Martinez Canyons. Other large drainage systems are Widow Woman and Madrid Canyons. The members of the Raton formation crop out in the canyons and on the lower divides and the Poison Canyon formation is exposed on the higher divides. Most of the workings, the air-blower shaft, the electrical shaft, and the inclined ventilating and escape slopes of the Frederick Mine are in the township.

Coal beds in the Vermejo formation.—The coal-bearing beds of the Vermejo formation underlie the township, but their number, thickness, and lateral relations in the sequence are not known.

Coal beds in the Raton formation.—Several beds of coal less than 1 foot 2 inches thick lie below the Frederick bed in coal zone *C* at locality 34 (pl. 6), and in coal zone *D* at localities 36, 37, and 38 (pl. 6). These beds are lenticular and have small areal extent.

The Frederick bed in coal zone *E* (pl. 6) was measured at localities 43, 49, 50, 51, 52, 53, 54, 55, 56, 57, 61, 63, and 64. It ranges in thickness from 6 inches at locality 54 to 10 feet 1 inch at locality 61. It is generally underlain by a relatively continuous but thinner and less important coal bed. This thinner bed commonly is less than 1 foot 2 inches thick, but at locality 43 it reaches a thickness of 2 feet 2 inches. Both beds are relatively free from impurities although they contain a number of shale partings.

Several coal beds in coal zone *F* (pl. 6) were measured at localities 69, 70, 71, 72, 74, 76, and 77. Some of these are more than 1 foot 2 inches in thickness. The thickest bed, generally near the base of the coal zone, is 1 foot 1 inch thick at locality 74, and contains 1 foot 8 inches of coal at locality 69. A bed 1 foot 10 inches thick at locality 81 and 1 foot 8 inches thick at locality 82 occurs in coal zone *G* (pl. 6). Several higher beds of coal and coaly shale in the same zone are less than 1 foot 2 inches thick and were measured at localities 83 and 84.

Several thin coal beds in coal zone *H*, two of which are locally thicker than 1 foot 2 inches, were measured at localities 89, 90, 91, 98, and 99 (pl. 6). At locality 90 a coal bed 28 feet below the top of the coal zone is 1 foot 5 inches thick, and at locality 98, a slightly higher bed has the same thickness.

The coal beds in coal zone *I* (pl. 7) were measured at localities 116, 117, 118, 119, 120, 121, 126, 137, and 138. The Primero bed is relatively thin in the township, ranging in thickness from 1 foot 11½ inches of coal, at locality 120, to 6 inches of coal, at locality 118. A 3 foot 8 inch bed of coal, which is believed to underlie a rather large area, lies above the Primero bed at locality 119. Coal beds in zone *I*, other than in the Primero bed, are usually clean, whereas the Primero bed commonly contains shale partings and interstitial clay.

One bed which locally exceeds 1 foot 2 inches in thickness was measured at locality 151 in coal zone *J* (pl. 7). Other thinner beds were measured at localities 145, 146, 147, 149, 150, 153, 154, and 155. In general, the coal in these beds is clean, but the beds are too thin to be of economic importance.

At locality 165 a coal bed in coal zone *K* (pl. 8) reaches 1 foot 7 inches in thickness. It and thinner coal beds were also measured at localities 162, 163, 164, 166, and 173. The coal beds have few shale partings and most of the coal is clean.

The beds of coal in the zones above coal zone *K* are mostly thin and lenticular, and the coal is rather clean. These beds were measured at localities 186 and 187 in coal zone *L* (pl. 8); at localities 196 and 197 in coal zone *M* (pl. 8), where the lower coal bed is 1 foot 10½ inches thick; at locality 213 in coal zone *N* (pl. 8); at locality 221 in coal zone *O* (pl. 9) where the upper coal bed is 1 foot 5 inches thick, and at locality 271 in coal zone *R* (pl. 10), where the Ciruela bed is 7 inches thick.

T. 34 S., R. 66 W.

This township is drained by the Lorencito Canyon, the West Fork of Widow Woman Canyon, and Little Martinez Canyon. The Poison Canyon formation crops out on the high divides, whereas, the various members of the Raton formation cap the lower divides and crop out in the canyons. The coal reserves are relatively large, but little coal has been mined in the township.

Coal beds in the Vermejo formation.—The Vermejo formation occurs in the subsurface of the township, but the number of coal beds, their relations, and their lateral extent are unknown.

Coal beds in the Raton formation.—The lower strata of the Raton formation do not crop out in the township, and the number of coal beds in this sequence, their relations, and their lateral extent are unknown.

Higher in the Raton formation a thick lenticular bed of coal was measured at locality 86 in coal zone *G* (pl. 6). It consists, from the base upward, of coal, 11 inches; coaly shale, 5 inches; coal, 1 foot, 1 inch; shale, 5 inches; and coal, 8 inches. Except for the shale partings, the coal is clean. A 1 foot 6 inch bed of coaly shale was measured near the top of coal zone *H* (pl. 6) at locality 97.

The Primero and associated coal beds in coal zone *I* (pl. 7) were measured at localities 106, 107, 108, 109, 110, and 113. The thickness of the Primero bed ranges from 5 inches at locality 113 to 2 feet 6 inches at locality 109. The coal contains fewer shale partings and less clay here than in T. 34 S., R. 65 W., however, the coal bed at most localities is not thick enough to mine profitably at the present.

A thin relatively persistent coal bed was measured at localities 143 and 144 in coal zone *J* (pl. 7). Several coal beds a few feet higher in the coal zone *K* (pl. 8) were measured at localities 169, 170, 171, and 172. A coal bed near the base of the zone at locality 170 is 1 foot 3 inches thick, and another bed near the top of the section measured at locality 171 is 2 feet 6 inches thick.

Several thin coal beds in coal zone *L* (pl. 8) were measured at localities 181, 182, 183, 184, and 185. The middle coal bed at locality 184 is 1 foot 7 inches thick and the upper coal bed at locality 183 consists of coal, 7½ inches; shale, 1½ inches; coal, 3½ inches; shale, ⅜ inch; bony coal, 1 inch; shale, ½ inch; and coal, 6 inches.

The coal beds of coal zone *N* (pl. 8) were measured at localities 203, 207, 208, 209, and 210. Except at locality 203, they are less than 1 foot 2 inches thick. The lower coal bed at this locality is 2 feet 6 inches thick, and the coal is clean and free from impurities.

Most of the coal beds of coal zone *O* (pl. 9) are less than 1 foot 2 inches thick. They were measured at localities 220, 222, 230, 231, and 232. The coal bed at locality 220 is 1 foot 4 inches thick and consists of clean coal. This bed is rather widespread to the west of the locality, but in general it appears to be too thin to mine at the present time. A similar coal bed in coal zone *P* (pl. 9) was measured at localities 243 and 244. It is 2 inches thick at locality 243 and 1 foot 7 inches thick at locality 244. It appears to underlie a considerable area to the southeast of locality 244. A thin bed of coal lower in the coal zone was measured at locality 247.

The coal beds of coal zone *Q* (pl. 9) were measured at localities 250, 251, 252, 253, 254, 255, 256, 257, 258, and 259. Two of these beds locally become thicker than 1 foot 2 inches. At locality 252 one of the upper beds in the coal zone is 1 foot 6 inches thick and at locality 259, one of the lower beds consists of 4 inches coal, ½ inch shale, 5 inches coal, ½ inch shale, and 11 inches coal.

The Ciruela and associated beds in coal zone *R* (pl. 10) were measured at localities 264, 265, 266, 267, 268, 269, 270, and 273. The thickness of the Ciruela bed ranges from 3 inches at locality 270 to 2 feet 6 inches at locality 267. The average thickness of the bed probably is about 1 foot 3 inches. A somewhat lower coal bed at locality 268 is 2 feet 8 inches thick.

The coal beds above the Ciruela bed are thin and are at the present time of no great economic importance. These beds were measured at localities 280 and 281 in coal zone *S* (pl. 10), and at localities 293 and 294 in coal zone *T* (pl. 10).

T. 34 S., R. 67 W. (FRACTIONAL)

Only the eastern part of this township is in the area. The South Fork of Purgatoire River flows northeastwardly, draining the central part of the township. Cow Canyon drains the northeast part, and Alamosa and Little Alamosa Canyons, the southeast. The basal part of the lower member of the Raton formation is in the subsurface of the township. The upper part of the lower member and the middle and upper members crop out in the canyons and on the lower divides. The Poison Canyon formation is exposed on the higher divides and in the upper reaches of the larger canyons.

Coal beds in the Vermejo formation.—The Vermejo formation underlies the township, but the number of coal beds, their relations, and their lateral extent are not known.

Coal beds in the Raton formation.—Coal beds in the lower part of the lower member are not exposed in the township, and their number, relations, and lateral extent are unknown. The oldest coal beds exposed in the township are in coal zone *O* (pl. 9) and were measured at localities 218 and 219. The coal bed at locality 218 is 1 foot 4 inches thick and apparently underlies a considerable area to the east.

Several coal beds less than 1 foot 2 inches thick were measured at locality 233 in coal zone *P* (pl. 9). A 2 foot 8 inch coal bed stratigraphically higher in coal zone *Q* (pl. 9) was measured at locality 249, but it was absent at locality 248.

Several coal beds, which exceed 1 foot 2 inches in thickness were measured at localities 274, 275, and 282 in coal zone *S* (pl. 10). The lower coal bed at locality 274 is 1 foot 6 inches thick and the upper coal bed, which is 3 feet 6 inches above it, is 2 feet 4 inches thick. At locality 275 a slightly higher coal bed consists of 2 feet 2¼ inches of coal, 1½ inches of shale, and 6½ inches of coal.

Three coal beds exceed the minimum thickness of 1 foot 2 inches in coal zone *T* (pl. 10). At locality 291 the exposed coal bed is 1 foot 6 inches thick; and at locality 292 the lower coal bed is 2 feet 4 inches thick and the upper coal bed is 1 foot 3 inches thick.

T. 35 S., R. 63 W. (PROJECTED, FRACTIONAL)

A small part of this fractional land unsurveyed township is in the area. It is drained by tributaries of Raton Creek. Most of the town of Morley is in the northwestern corner of the township, as are some of the workings of the Morley mine. The Trinidad sandstone, the Vermejo formation, and the lower strata of the Raton formation crop out near Morley. The middle and upper members of the Raton formation and the Poison Canyon formation are exposed in the upper reaches of the canyons and on the ridges to the south of Morley near the Colorado-New Mexico boundary line.

Coal beds in the Vermejo formation.—The Vermejo formation crops out in the canyon of Raton Creek in the northwestern corner of the township; elsewhere, however, the number of coal beds in the Vermejo, their lateral relations, and their thicknesses are unknown. A section of coals in the Vermejo formation was measured, just north of the township line at locality 1. Many of the coal beds of the Vermejo in the northern part of the township probably are similar to those measured at locality 1 (pl. 5).

Coal beds in the Raton formation.—Few coal beds of the Raton formation occur in the part of the township that is in the area. The only measured coal section is at locality 39 (pl. 6) where the lower coal bed consists of 1 foot 4 inches of clean coal and the upper coal bed is 3¼ inches thick.

A short distance east of the eastern boundary of the area the Savage, or Turner, coal bed was mined at the Red Robin and Turner mines. The bed was not identified within the area, but it may be present in the subsurface. At the Red Robin and Turner mines the bed, which is in coal zone *M*, ranges from 4 to 5 feet in thickness. It is unlikely that a bed so thick could be everywhere concealed within the area, but it is possible that it is much thinner or is absent.

T. 35 S., R. 64 W. (PROJECTED)

This township is largely drained by Gallinas Creek and Saruche Canyon, although parts of it are drained by tributaries of Raton Creek and by Railroad Canyon which has been eroded into New Mexico. The Trinidad sandstone and the Vermejo formation crop out near Morley and the Raton and Poison Canyon formations are exposed in canyons and on divides elsewhere in the township. Many entries, haulageways, and rooms of the Morley mine underlie the township.

Coal beds in the Vermejo formation.—No coal beds of the Vermejo formation were measured in the township, but tonnage estimates for coal in the Vermejo were calculated from sections measured in adjacent townships and from coal-thickness data published by the U. S. Bureau of Mines (Technical Paper 574, 1937, Analyses of Colorado coals). These data indicate that the Morley bed varies in thickness from about 5 feet to almost 7 feet 6 inches in the Morley mine. The character, thickness, and lateral relations of other coal beds within the township are unknown, but these beds probably are similar to the coal beds measured at locality 1, T. 34 S., R. 63 W., and at locality 2, T. 34 S., R. 64 W. (pl. 5).

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Coal beds in the Raton formation.—The lower strata in the lower member of the Raton formation apparently contain little coal. The oldest coal beds in the member were measured at locality 159 in coal zone *J* (pl. 7), where they are less than 1 foot 2 inches thick and are of little economic importance.

In coal zone *M* at locality 201 (pl. 8) the lower coal bed is 1 foot 4 inches thick. It is overlain by 4 inches of carbonaceous shale, 12 feet of shale and sandstone, and a lenticular 11-inch coal bed. At locality 225 an 8-inch coal bed lies 1 foot below the mappable sandstone at the top of coal zone *O* (pl. 9).

A coal bed at locality 241 in coal zone *P* (pl. 9) consists of coal, 1 foot 2 inches; shale, 8½ inches; coal, 5 inches; shale, ¼ inch; coal, 2 inches; shale, ¼ inch; and coal, 1 foot. It lies 5 feet 6 inches below the mappable sandstone at the top of the coal zone, and it thins westward to coal, 2½ inches; shale, ½ inch; coal, 1 inch; shale, 1/16 inch; coal, ¾ inch; shale, 1/16 inch; coal, 2 inches; shale, 1¼ inch; and coal, 2¾ inches at locality 240 in T. 35 S., R. 65 W.

T. 35 S., R. 65 W. (PROJECTED)

The eastern part of this township is drained by Colorow Canyon and the western part by Long and Martinez Canyons. The Vermejo formation and the lower strata of the lower member of the Raton formation are in the subsurface and the upper strata of the lower member and the middle and upper members of the Raton formation crop out in the canyons and on the lower divides. Strata of the Poison Canyon formation are exposed on the higher divides.

Coal beds in the Vermejo formation.—Although the Vermejo formation underlies the township, the number of coal beds, their relations, and their thicknesses are unknown.

Coal beds in the Raton formation.—The oldest coal beds of the Raton formation exposed in the township were measured in Colorow Canyon in coal zone *I* (pl. 7) at locality 127. These coal beds consist of a 3-inch bed correlative with the Primero bed and a 5-inch bed 5 feet below it. Buried strata of the lower member may contain additional beds of coal.

Several thin and discontinuous coal beds were measured at locality 148, in coal zone *J* (pl. 7) and at localities 167 and 174, coal zone *K* (pl. 8). A coal bed that contains 1 foot 7 inches of coal was measured at locality 188 in coal zone *L* (pl. 8). A 10-inch coal bed lies 8 feet below and a 9-inch coal bed lies 16 feet 3 inches below the base of the 1-foot 7-inch coal bed. The upper coal bed at locality 188 was not identified in the coal section measured at locality 190, but, somewhat higher in the coal section a 9-inch bed of coal lies 3 feet below the top of the coal zone. A 5-inch coal bed is immediately below the top of the coal zone at locality 189.

The coal beds in coal zone *M* (pl. 8) were measured at localities 198, 199, and 200, where some locally are thicker than 1 foot 2 inches. The upper coal bed in coal zone *N* (pl. 8) was measured at localities 214, 215, and 217. It contains 5 inches of coal at localities 214 and 217 and 2 feet of coal at locality 215.

Several thin to moderately thick coal beds occur at locality 224 in coal zone *O* (pl. 9). The thickest bed contains 2 feet 6 inches of clean coal. The upper coal bed at locality 238 in coal zone *P* (pl. 9) is 1 foot 2 inches thick, and about 4 miles to the east at locality 239 a correlative coal bed is 3 inches thick. A slightly higher coal bed at locality 240 contains 9 inches of coal.

The coal beds above coal zone *P* (pl. 9) are thin and unimportant. Sections of coal in zone *Q* were measured at localities 261 and 262 (pl. 9), and sections in zone *T* were measured at locality 288 (pl. 10).

T. 35 S., R. 66 W. (PROJECTED)

The western part of this township is drained by Lorencito Canyon and the principal tributary, Oso Canyon. The eastern part is drained by Martinez and Little Martinez Canyons. The lower member of the Raton formation crops out in the canyons and the middle and upper members are exposed on the valley slopes and on the lower divides. Strata of the Poison Canyon formation crop out on the higher divides and in the uppermost reaches of the canyons.

Coal beds in the Vermejo formation.—The township is underlain by strata of the Vermejo formation. The thickness of these strata and the number of intercalated coal beds, their relations, and their lateral extent are unknown.

Coal beds in the Raton formation.—The lower strata of the lower member of the Raton formation do not crop out in the township, and the number of coal beds in these strata is unknown. The oldest exposed coal beds are in Martinez Canyon at locality 223 in coal zone *O* (pl. 9), where they are less than 1 foot 2 inches thick and are of small economic importance. The coal beds in coal zone *P* (pl. 9) were measured at localities 236 and 237, where no coal bed is as much as 1 foot 2 inches thick. The middle coal bed thickens eastward within a distance of about 2 miles from 2 inches at locality 237 to 1 foot 2 inches at locality 238, T. 35 S., R. 65 W. The lower coal bed thicknes from 7 inches at locality 237 to 1 foot 1 inch at locality 238.

Most of the coal beds at locality 260 in coal zone *Q* (pl. 9) and at locality 263 in coal zone *R* (pl. 10) are thin, but two of the beds are 1 foot 2 inches thick or slightly thicker.

The coal beds in coal zones *S* (pl. 10) and *T* (pl. 10) are thin and discontinuous. They were measured at localities 277, 278, 279, 285, 286, and 287. The coal bed at locality 286 contains 1 foot 6 inches of clean coal.

T. 35 S., R. 67 W. (PROJECTED, FRACTIONAL)

Most of this township is drained by Lorencito Canyon, Spring Creek Canyon, and the southern tributaries of Pancho Canyon. The Vermejo formation and the lower member of the Raton formation do not crop out in the township. The middle and upper members of the Raton formation are exposed in the canyons and the Poison Canyon formation crops out on the divides.

Coal beds in the Vermejo formation.—The township is underlain by an unknown thickness of the Vermejo formation. No coal beds of the Vermejo are exposed and the number of coal beds, their lateral extent, and their relations are unknown.

Coal beds in the Raton formation.—No coal beds of the lower and middle members of the Raton formation were measured in the township, and the presence of these beds is inferred by interpolating from coal sections measured in T. 34 S., R. 66 W., T. 34 S., R. 67 W., and T. 35 S., R. 66 W.

Coal beds in the upper member of the Raton formation are generally thin and discontinuous. They were measured at locality 276 in coal zone *S* (pl. 10) and at localities 283, 284, 289, and 290 in coal zone *T* (pl. 10). The coal bed at locality 289 is 1 foot 3 inches thick and consists of coal stained by limonite and melanterite.

Coal beds in the Poison Canyon formation.—All the coal beds of the Poison Canyon formation occur in this township. Most are less than 1 foot 2 inches thick and most of the coal is dirty or impure. Coal beds of the formation were measured at localities 295, 296, 297, 298, 299, and 300 (pl. 10). The thickest of the coal beds in the Poison Canyon is at locality 298, where there is 1 foot 8 inches of impure coal.

The lower strata of the Poison Canyon formation may intertongue laterally with the upper strata of the upper member of the Raton formation. The coal beds of the Poison Canyon formation may, therefore, grade laterally into coal beds in coal zone *T* of the upper member of the Raton formation.

OIL AND GAS POSSIBILITIES

The Raton basin, including the Starkville-Weston area, may contain accumulations of oil and gas of economic importance in structural and stratigraphic traps. Such deposits, if present, probably occur in the undivided Pennsylvanian strata and in the Cretaceous formations.

The Pennsylvanian Magdalena group in the Sangre de Cristo Mountains of New Mexico includes a number of thick bituminous-shale units that are potential source rocks. This group and the lower part of the Sangre de Cristo formation contain highly porous and permeable sandstone and conglomerate beds that are potential reservoirs. If the equivalent strata in the Colorado part of the mountains are as thick as these formations are near Tres Ritos, N. Mex., at least part of the Raton basin has a thick section of Pennsylvanian strata that wedges out eastward towards the Sierra Grande arch. The presence of potential source beds and of potential reservoir rocks in the Sangre de Cristo Mountains suggests that this wedging out of Pennsylvanian strata and their overlap may have been favorable to the formation, migration, and accumulation of oil and gas beneath the basin. Just where such accumulations may occur is not known; some may well be in the subsurface of the Starkville-Weston area.

Accumulations of oil and gas may occur in the Purgatoire formation and the Dakota sandstone. If so, their entrapment probably is due to a combination of structural and stratigraphic features: folding or tilting of strata would provide the structural control, and variations in porosity and permeability the stratigraphic control.

The limestone and shale strata of Upper Cretaceous age between the Dakota sandstone and the Trinidad sandstone may contain accumulations of petroleum in stratigraphic traps similar to those in the Florence and Canon City fields. In these fields oil and gas were found in closely spaced connecting joints and fissures. In the Starkville-Weston area such traps are most likely to occur near the axes of folds.

The Trinidad sandstone is similar in lithology to the gas-producing Pictured Cliffs sandstone of the San Juan basin. Both intertongue with generally equivalent underlying marine-shale bodies and are overlain by generally equivalent coal-bearing rocks. The similarity of lithology and stratigraphic relations suggest that the Trinidad sandstone also may contain commercial accumulations of gas. Accumulations of oil and gas may have been controlled by changes in porosity and permeability, by intertonguing, or by folding and tilting.

Exploration for oil and gas in the Raton basin should be guided by a knowledge of the probable stratigraphic succession, such as is suggested in this report and by the probable depth to the strata that are to be tested, which may be tentatively determined from the stratigraphic data included herein. Such assumptions should then be checked by stratigraphic drilling and by geophysical means as the first phase of an exploration program. The possibility that accumulations of oil and gas occur in previously untested Pennsylvanian and Cretaceous rocks of this area should encourage exploration.

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