Commercial coal beds of the Raton coal field, Colfax County, New Mexico

Charles L. Pillmore

1976, pp. 227-247. https://doi.org/10.56577/FFC-27.227

in:

Vermejo Park, Ewing, R. C.; Kues, B. S.; [eds.], New Mexico Geological Society 27 th Annual Fall Field Conference Guidebook, 306 p. https://doi.org/10.56577/FFC-27

This page is intentionally left blank to maintain order of facing pages.

COMMERCIAL COAL BEDS OF THE RATON COAL FIELD, COLFAX COUNTY, NEW MEXICO

CHARLES L. PILLMORE
U.S. Geological Survey
Denver, Colorado 80225

INTRODUCTION

The Raton coal field occupies the New Mexico portion of the Raton Mesa coal region, the southernmost part of the Northern Great Plains Coal Province (Trumbull, 1960). The coal field (Fig. 1) covers an area of 900-1,000 mi^2 (2,300-2,600 km^2) in northeastern New Mexico and contains large reserves of high-quality coking coal in Upper Cretaceous and Paleocene rocks. An early estimate tabulated 4.27 billion metric tons of coal in beds 14 in. (36 cm) thick or greater beneath less than 3,000 ft (900 m) of cover (Read and others, 1950).

The Raton coal field is defined as the area of the Raton Basin in New Mexico that is underlain by Upper Cretaceous and Paleocene coal-bearing rocks. The Raton Basin is a large, arcuate structural and depositional trough that extends roughly from Huerfano Park, Colo., to Cimarron, N.M. (Fig. 1). The basin is bounded on the west by the Sangre de Cristo Mountains and on the east by the Apishapa arch in Colorado and by the Sierra Grande-Las Animas arch in New Mexico and Colorado (Johnson and Wood, 1956). The Las Vegas sub-basin south of the coal field is a structural part of the Raton Basin (Baltz, 1965).

Coal was discovered in the coal field by the Long Expedition about 1821 (Lee, 1917) and has been mined commercially since about 1870. Locations of the principal coal mining camps show that mining was concentrated initially along the eastern margins of the field (Fig. 1). As the demand for coal diminished following World War II, these early mines—Dawson, Koehler, Brilliant and others—closed down. The last was the Koehler mine, which shut down in 1966. Aggregate production of coal from the field by 1955 was 71.2 million metric tons, about one-fourth of the total amount produced

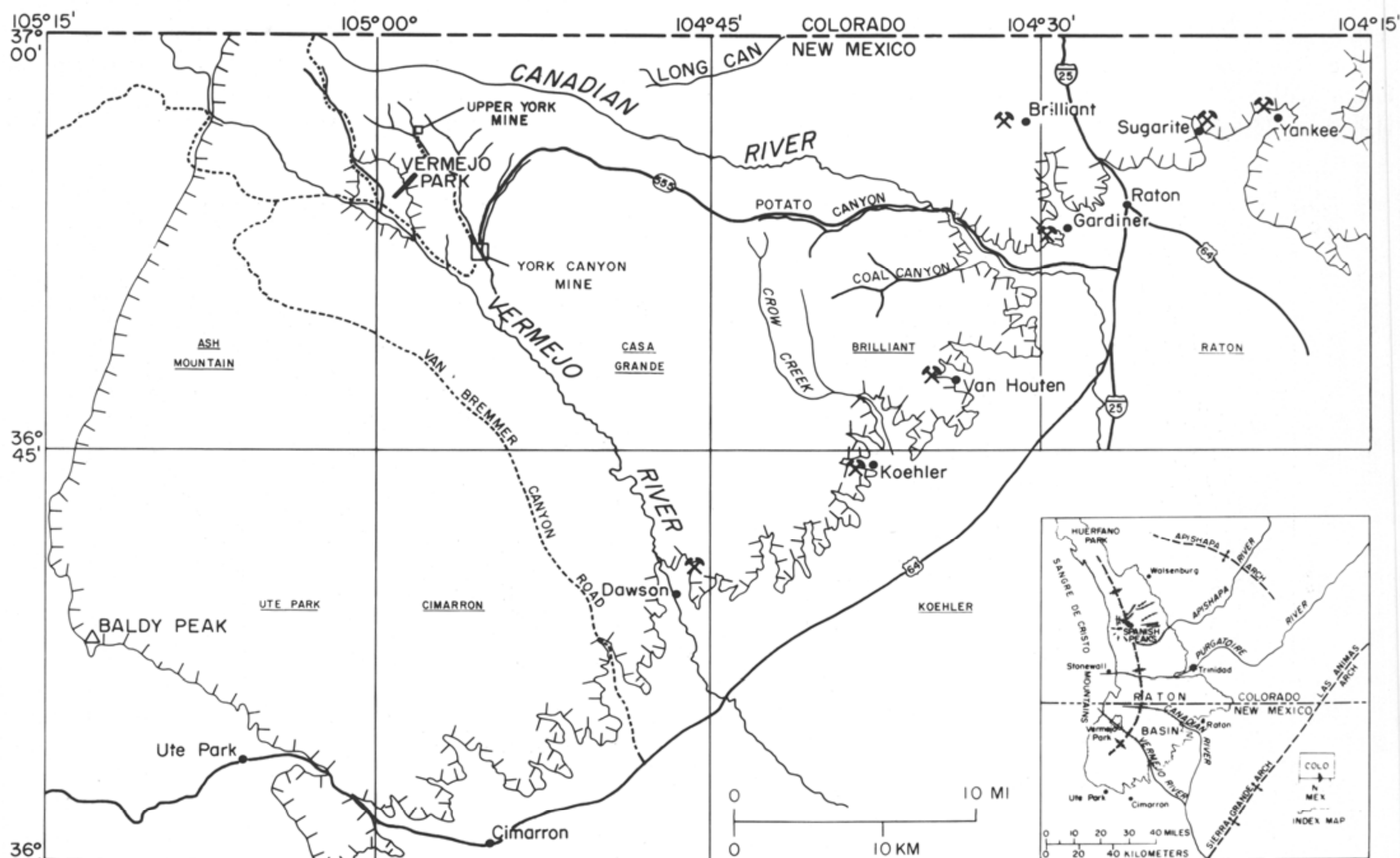

Figure 1. Map showing area of present and earlier studies in New Mexico part of Raton coal field. Hachured line is boundary of Raton coal field. Brilliant and Raton quadrangles (Lee, 1922); Ute Park, Cimarron and Koehler quadrangles (Wanek, 1963); Ash Mountain quadrangle (C. L. Pillmore and A. A. Wanek, unpub. data); Casa Grande quadrangle (Pillmore, 1964-66, 1969). Crossed picks show location of abandoned coal-mining camps.

from the coal fields of the Raton Basin in New Mexico and Colorado (Carter, 1956). The Koehler mine produced an additional 2.06 million metric tons from 1955 until it closed in 1966. The York Canyon mine (Fig. 1), which opened in October 1966, produced 7.13 million metric tons during its first 9 years of operation, from 1966-75 (E. D. Moore, Kaiser Steel Corp., oral commun., 1976). Thus, the total aggregate production from the field by 1975 was 80.3 million metric tons.

GEOGRAPHY

Surface land use is devoted to recreation, ranching, farming for stock feed and a small amount of logging. Much of the field is remote or closed to the public and has difficult access. Interstate 25, which crosses Raton Pass, and U.S. Highways 87 and 64, which skirt the eastern and southern margins of the field, are the only paved public highways in the area. A gravel road, N.M. 555, provides access to the York Canyon mine and Vermejo Park. The coal field is a highly dissected plateau, increasing gradually in elevation to the west and merging with the east flanks of the Sangre de Cristo Mountains. The southern and eastern margins of the field are characterized by bold escarpments that stand 500-1,000 ft (150-300 m) above the low plains, which are underlain by older rocks. The boundary between the Raton coal field and the Trinidad field to the north is the New Mexico-Colorado state line.

STRUCTURAL GEOLOGY

The Raton coal field occupies the southern part of the Raton Basin, a large structural depression about 4,000 mi^2 (10,400 km^2) that extends roughly from Huerfano Park, Colo., south to Cimarron, N.M. (Fig. 1). On the west side of the basin, sedimentary rocks are steeply tilted to overturned and faulted along the structurally complex east flank of the Sangre de Cristo Mountains. On the east side of the basin, strata are gently tilted and dip westward about 1° to 5°. In the Raton coal field, the gently dipping east limb of the basin is characterized by about 2,000 ft (600 m) of structural relief in 30 miles (50 km) and the more steeply dipping west limb, by more than 4,000 ft (1,200 m) in only 6 miles (10 km) (Fig. 2). The most prominent structural feature in the field is the Vermejo Park anticline, with more than 2,500 ft (760 m) of structural relief across a distance of only 4 miles (6.4 km) on its east flank and more than 500 ft (150 m) of closure. Records of drilling in 1926 (Union Oil Co., Bartlett Nos. 1 and 2) indicate that the folding was caused by a buried intrusive. Except for the Vermejo Park anticline, the structure of the Raton coal field is quite featureless; few faults have been found and prominent folds are rare. In the western margin of the region, Wanek (1963) mapped several en echelon faults that displace the Poison Canyon Formation about 1,500 ft (460 m); but, in general, the field is characterized mostly by gentle dips and few faults.

STRATIGRAPHY

The oldest map unit is the undifferentiated Pierre Shale and Trinidad Sandstone, both of Late Cretaceous age (Fig. 3). The coal-bearing Vermejo Formation, also of Late Cretaceous age, conformably overlies the Trinidad Sandstone but is locally absent beneath the base of the overlying coal-bearing Raton Formation of Late Cretaceous and Paleocene age (Brown, 1943; Robert H. Tschudy, written commun., 1967). The

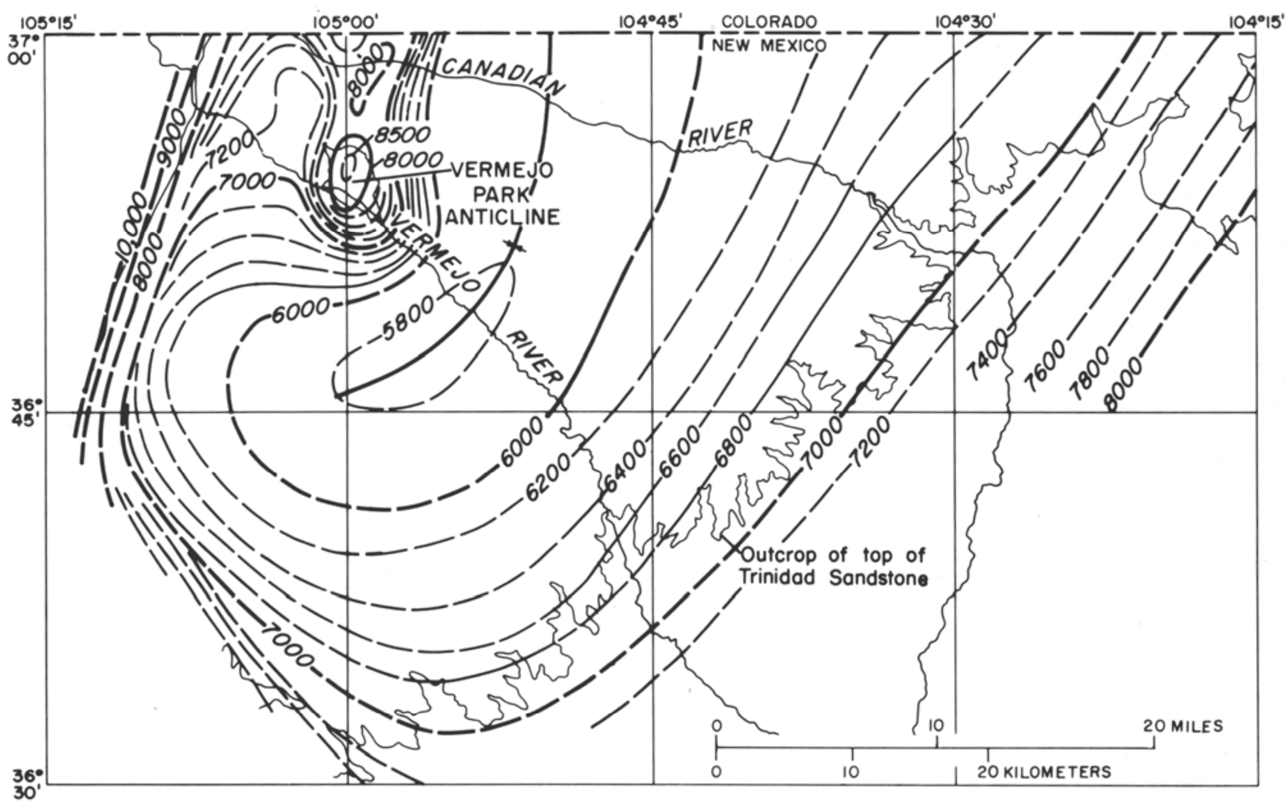

Figure 2. Map showing structure contours on top of Trinidad Sandstone, Raton coal field, Colfax County, New Mexico. Contour interval 200 ft; contours dashed where less certain or where Trinidad is eroded away.

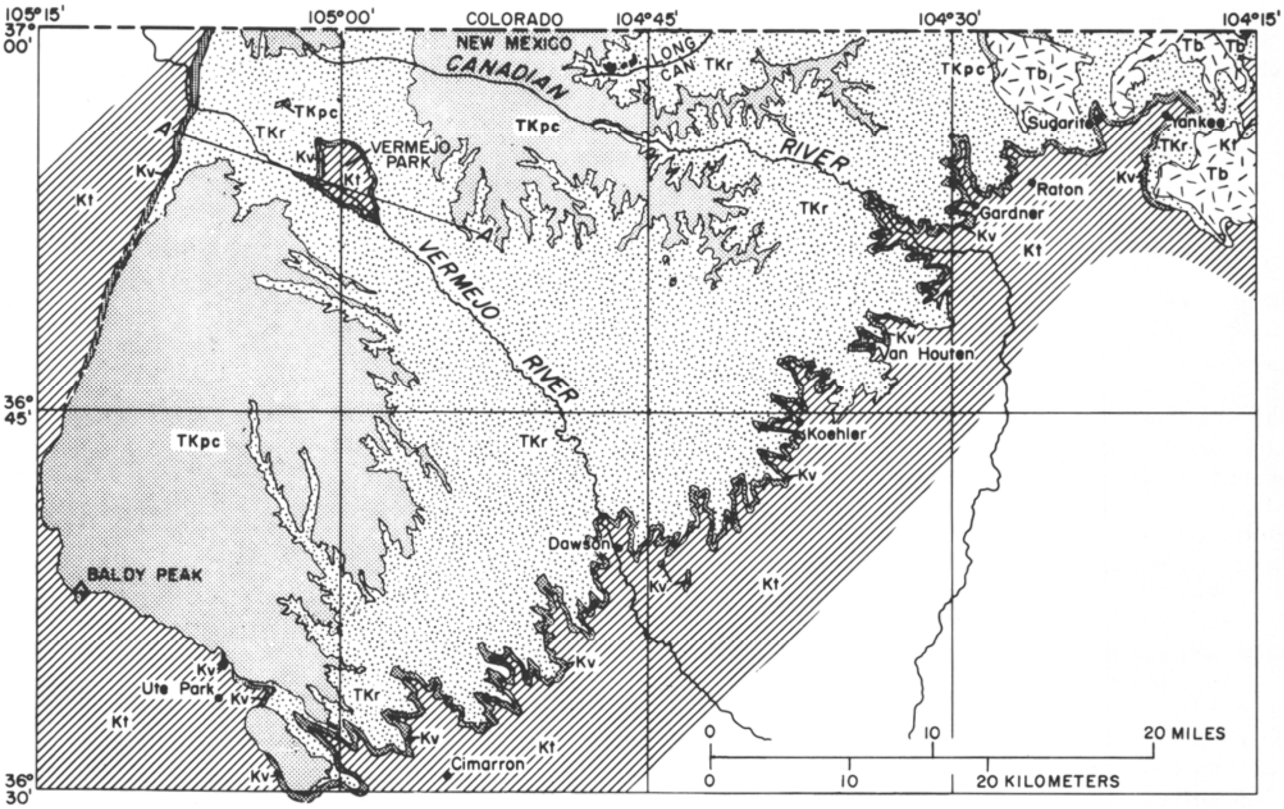

Figure 3. Generalized geologic map of Raton coal field; Kt, Trinidad Sandstone and older rocks; Kv, Vermejo Formation; TKr, Raton Formation; TKpc, Poison Canyon Formation; Tb, basalt lava flows. Small black areas in Long Canyon, syenodiorite intrusive.

Paleocene Poison Canyon Formation overlies the Raton and is the youngest sedimentary unit. In the west the Poison Canyon intertongues with the Raton and is partly of Late Cretaceous age (Table 1). Older rocks, ranging in age from Precambrian to Late Cretaceous, crop out in the Sangre de Cristo Mountains. North and east of Raton, basaltic and andesitic lava flows of late Miocene or Pliocene age (Stormer, 1972) form high mesas that stand 1,500 to 2,000 ft (460-610 m) above the High Plains.

Upper Cretaceous

Pierre Shale

The Pierre Shale is exposed on steep slopes beneath prominent cliffs of Trinidad Sandstone along the margins of the

Table 1.--*Generalized stratigraphic section of rocks in the Raton coal field*
(Position of Cretaceous-Tertiary Boundary from Pillmore, 1969)

AGE		FORMATION	GENERAL DESCRIPTION	APPROXIMATE THICKNESS IN FEET
TERTIARY	PALEOCENE	POISON CANYON FORMATION	Sandstone, coarse to conglomeratic, beds 5 to more than 50 feet thick, interbeds of soft yellow-weathering clayey sandstone; thickens to west at expense of underlying rocks	500+
		RATON FORMATION	Sandstone, very fine grained to fine grained with interbeds of claystone, siltstone, and coal; commercial coal beds in upper part. Lower few feet conglomeratic; intertongues with Poison Canyon to the west. Generally sharp erosional contact with underlying Vermejo Formation	0-2000
CRETACEOUS	LATE CRETACEOUS	VERMEJO FORMATION	Sandstone, very fine grained to medium grained, interbedded with mudstone, carbonaceous shale, and coal; extensive thick coals top and bottom	0-380
		TRINIDAD SANDSTONE	Sandstone, very fine grained to medium grained, contains casts of *Ophiomorpha* sp.	0-130
		PIERRE SHALE	Black shale, limestone concretions, silty in upper part, grades up to sandstone	2500+

coal field and at Vermejo Park (Fig. 4). The Pierre is an easily eroded, silty, black marine shale; it is limy in part and contains scattered, fossiliferous, oblate, gray to yellowish-brown septarian concretions. The Pierre is progressively sandier upward and locally intertongues with the Trinidad Sandstone through a transition zone 20-50 ft (6-15 m) thick (Johnson and Wood, 1956). The Pierre Shale is about 2,500 ft (760 m) thick, as measured in wells drilled in the field.

Trinidad Sandstone

The Trinidad Sandstone (Hills, 1899), included with the Pierre Shale on the geologic map (Fig. 3), forms steep, light gray cliffs above the dark slopes of the Pierre in Vermejo Park and along the margins of the field (Fig. 4). The Trinidad consists of clayey to clean, very fine- to medium-grained, calcareous marine feldspathic sandstone characterized by locally abundant *Ophiomorpha* burrows. The Trinidad is absent from the vicinity of Baldy Peak, where it is truncated below rocks mapped as Poison Canyon Formation (Lee, 1917; Wanek, 1963); it is as much as 130 ft (40 m) thick near Dawson and at Vermejo Park. The Trinidad Sandstone represents shallow-water beach deposits of the retreating Late Cretaceous sea (Fillmore and Maberry, this Guidebook). The Trinidad intertongues with the overlying Vermejo Formation along the southern boundary of the Raton field between Dawson and Cimarron (Lee, 1917; Wanek, 1963). The intertonguing between the Vermejo and Trinidad formations represents local transgressions during the overall retreat of the sea. These tongues probably are present in the subsurface and beneath the eastern high mesas elsewhere in the coal field.

Vermejo Formation

The coal-bearing Vermejo Formation (Lee, 1913) rests conformably on the Trinidad Sandstone; the contact, usually the base of the lowest carbonaceous zone, may be sharp to gradational. The Vermejo contains abundant plant fossils and consists of sandstone, siltstone, shale and beds of coal. It is absent near Ute Park and Baldy Peak (Wanek, 1963) and is as thick as 380 ft (120 m) at Vermejo Park. According to Lee (1922, 1924) it is also absent near Van Houten and Koehler, and it pinches out 2 miles (3.2 km) northeast of Raton, where it is truncated below an erosional unconformity at the base of the overlying Raton Formation (Fig. 5). This unconformity is not clearly defined in the eastern part of the basin, because the basal Raton sandstone is not consistently conglomeratic and in many places it resembles sandstones of the Vermejo Formation. The fine sediments suggest a low-energy flood-plain environment lying a considerable distance from the sediment source. Coarse-grained to conglomeratic sandstones occur at the base of the Raton to the west, suggesting a higher energy depositional environment. North of Ute Park, an angular unconformity separates the Vermejo from the overlying Poison Canyon Formation (Johnson and Wood, 1956; Wanek, 1963). In general, the Vermejo Formation crops out on steep slopes above Trinidad cliffs and below ledges and cliffs formed by the overlying conglomeratic sandstone at the base of the Raton Formation.

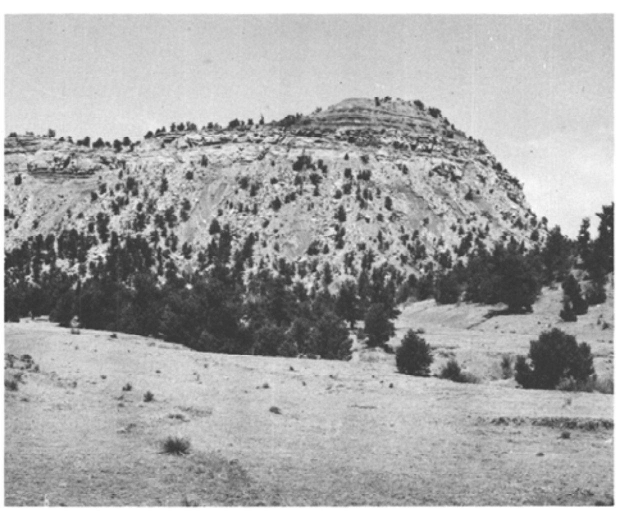

Figure 4. Cliffs formed by Trinidad Sandstone underlain by slope-forming Pierre Shale at mouth of Canadian River canyon near Raton, New Mexico.

Upper Cretaceous and Tertiary Rocks

Raton Formation

The Raton Formation, named by Hayden (1869) and restricted by Lee (1917), rests unconformably on the Vermejo Formation and is the thickest and most widely distributed of the coal-bearing units. It comprises three generally recognizable field divisions in New Mexico: a *basal sandstone,* conglomeratic throughout most of the western part of the field; a *lower zone,* predominantly sandstone and mudstone; and an upper *coal-bearing zone,* largely sandstone, siltstone and mudstone, with beds of coal. These zones vary in lithology and thickness throughout the Raton Basin.

The *basal sandstone* and overlying *lower zone* combine to form conspicuous cliffs along the margins of the coal field and around the rim of Vermejo Park. Conglomerate of the *basal sandstone* consists of pebbles and cobbles composed mostly of quartzite, chert and gneiss in a coarse-grained quartzose to arkosic sandstone matrix. The unit ranges in thickness from 0 to 50 ft (0-15 m) in the central part of the field, increasing to hundreds of feet in the western part where it is mapped as the Poison Canyon Formation—the western coarse-grained time-equivalent facies of the Raton Formation. In the eastern part of the field, the basal conglomerate is not everywhere present, and often the base of the Raton is difficult to trace.

The *lower zone* consists mostly of fine- to coarse-grained sandstone beds that form ledges and cliffs along the margin of the coal field, in the steep-walled canyons of the major streams and at Vermejo Park. Beds of siltstone and mudstone and thin impure coal beds also are common in this zone; coal beds are generally not of commercial thickness except east of Raton at Sugarite, where the Sugarite coal bed was mined for many years. The *lower zone* ranges in thickness from 200 or 300 ft (60-90 m) in the eastern part of the field (near Sugarite and Yankee) to 900 or 1,000 ft (270-300 m) in the central part near Vermejo Park. In the western and southern parts of the region, this zone grades into and intertongues with the coarser grained facies mapped as Poison Canyon Formation by Wanek (1963).

The *coal-bearing zone* consists of sandstone, siltstone, mudstone and shale in mostly slope-forming beds of variable resistance. Coal beds of minable thickness occur locally. This zone is present throughout most of the coal field, but in the western part it intertongues with and grades into the coarser

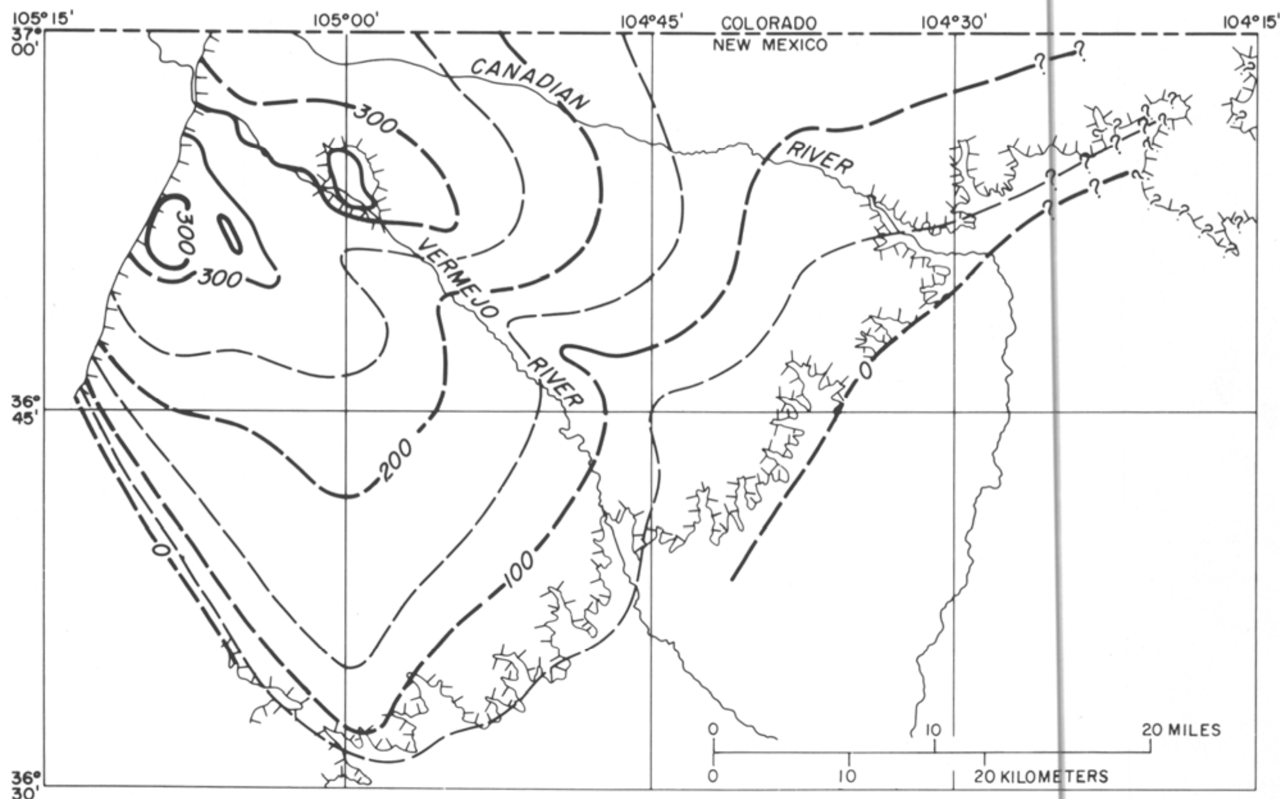

Figure 5. Isopach map of Vermejo Formation. Contour interval 50 ft. Hachured line shows limit of outcrop of the Vermejo Formation.

arkosic sandstones of the Poison Canyon Formation. The *coal-bearing zone* is the thickest of all zones in the Raton Formation throughout most of the field; however, it ranges in thickness from zero in the western part of the field to more than 1,000 ft (300 m) in the central part. All the commercial coal beds in the Raton Formation, except the Sugarite bed, are in this zone, including the lower beds at Yankee in the eastern part of the field (Lee, 1917).

Poison Canyon Formation

The Poison Canyon Formation (Hills, 1888) overlies the Raton Formation throughout most of the coal field, but to the west and southwest the Poison Canyon intertongues with and thickens at the expense of the Raton. Along the western margin of the field in the vicinity of Baldy Peak, Wanek (1963) mapped as Poison Canyon the coarse-grained to conglomeratic arkosic sandstones that overlie the Pierre Shale (Fig. 3). Seven miles to the southwest, at Idlewild, these rocks rest unconformably on the Dakota Sandstone (Clark, 1972). Throughout most of the coal field, the Poison Canyon consists of thick to massive, lenticular ledge-forming beds of coarse-grained to conglomeratic arkosic sandstone intercalated with beds of nonresistant, yellow weathering, sandy, micaceous mudstone. This sequence is about 1,000-1,500 ft (300-450 m) thick in the coal field. The contact with the underlying Raton Formation is indefinite and gradational through a transition zone as much as 150 ft (45 m) thick. (See Pillmore, measured section at mileage point 32.1, Second Day Road Log, this Guidebook.) The contact is mapped above the highest coal or carbonaceous zone and below the lowest persistent bed of arkosic granule sandstone.

IGNEOUS ROCKS

Igneous rocks of mid-Tertiary and younger age crop out at many places throughout the coal ¡field. Remnants of late Miocene and Pliocene basalt and an esite lava flows ranging in age from 7.2 to 3.5 m.y. B. P. are preserved on high mesas north and east of Raton (Stormer Kudo, this Guidebook). Dikes and sills, chiefly basalt with some andesite and lamprophyre, are found in almost all parts of the coal field but are not shown on the generalized geologic map (Fig. 3). Maps published by Lee (1922, 1924), Pr ore (1969) and Wanek (1963) show the outcrop distribution of these rocks throughout most of the coal field. In most cases, the dikes caused only limited alteration and metamorphic of the surrounding rocks and coal beds; but the sills, which were intruded along and into coal beds especially in the Ve mejo Formation, usually altered or completely assimilated nd destroyed the coal; locally forming prismatic coke. Potentially commercial graphite was formed during intrusio of this same bed into and contemporaneous with thermal metamorphism near Raton (Lee, 1924). In some localities, multiple sills were intruded nto the Trinidad, Vermejo and R ton formations. Tens, or perhaps even hundreds, of square of coal-bearing rocks were intruded, destroying hundreds of millions of tons of coal (Fig. 6). A recent K-Ar age determination on hornblende obtained from a core sample of h sill, intruded into the Vermejo Formation in the central part of the coal field, dates at 22.8±0.4 m.y. B.P. (J. D. Obradovich, written commun., 1976), about the same time as th Spanish Peaks emplacements (Stormer, 1972).

Some of the dikes and sills may b older, as suggested by an age of 28.1±0.4 m.y. B.P. determi d by K-Ar methods on

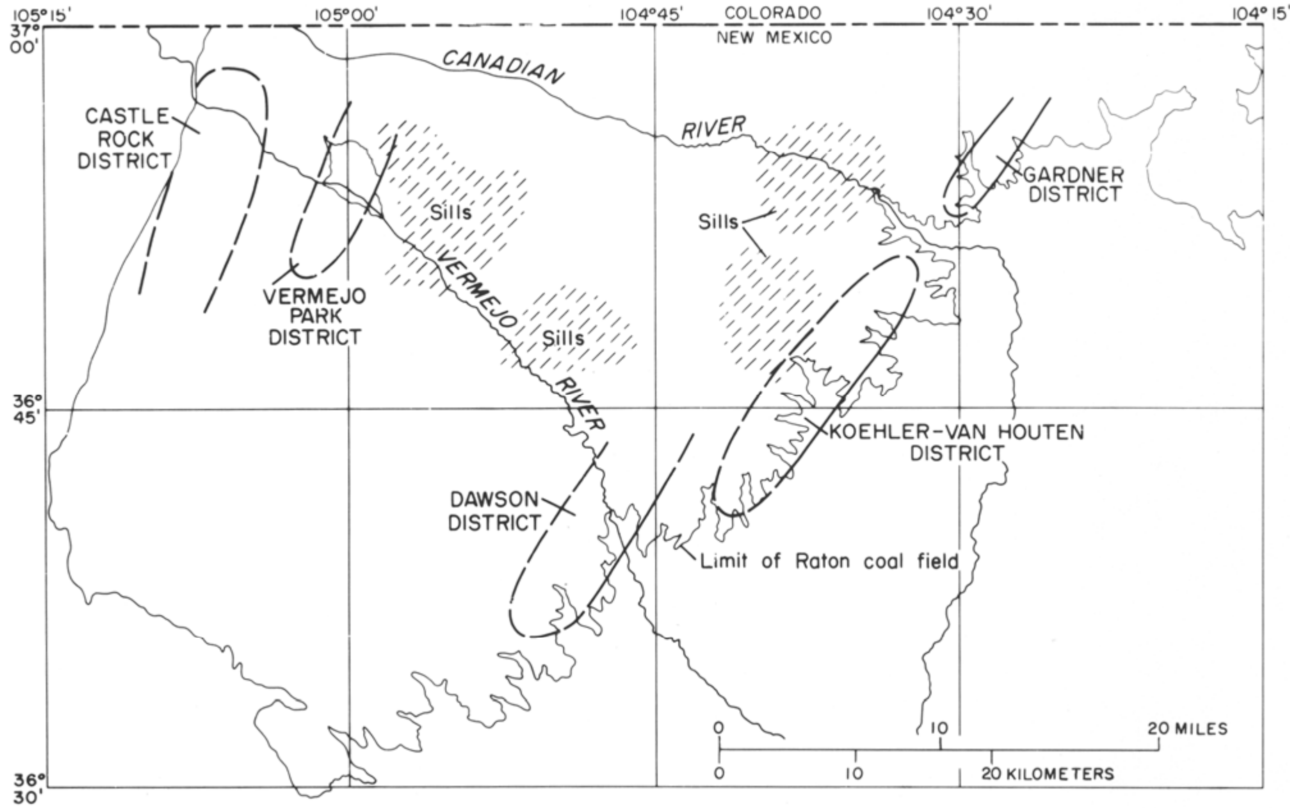

Figure 6. Map showing location, approximate outline and orientation of thick pod-shaped deposits of coal in the Raton coal bed.

biotite obtained from a lamprophyre intruded into the Pierre Shale at the western margin of the coal field, northwest of the Castle Rock district (J. D. Obradovich, written commun., 1976) (Fig. 5). In either case, these age determinations show that the emplacement of dikes and sills in the coal field occurred in late Oligocene to early Miocene time.

Near the Colorado-New Mexico state line, in Long Canyon, a fine- to medium-grained syenodiorite forms an irregularly shaped plug or laccolith that intrudes the Raton and Poison Canyon Formations (Fig. 3). A K-Ar age determination by J. D. Obradovich (written commun., 1976) on biotite from this rock is 10.4±0.2 m.y. B.P., surprisingly young considering the known ages of other intrusive rocks in the region. A corroborative fission-track determination of 12.9±3.7 m.y. B.P. was made on sphene graines from this rock by C. W. Naeser (written commun., 1976). These data suggest that the Vermejo Park anticline, which may have formed as a result of the emplacement of a similar pluton, may be the same age. The presence of a "dike" of coal that flowed under pressure during folding and cut a sill near the base of the Vermejo Formation indicate that the folding occurred at least after emplacement of the sill (Fig. 7).

COAL RESOURCES

The Raton Basin contains modest coal resources compared to some coal fields now being prospected and developed elsewhere in the western United States; however, the coal from the Raton field is of high rank, yields a high-quality coke, and may be of greater economic importance than coal from other larger fields. Average heating values of coals from the Raton field are nearly twice those of lower rank coals from the Fort Union region and nearly 1.5 times those from the Powder River region. Coal from the Allen mine in the Trinidad coal field near Stonewall, Colo., is used in the Colorado Fuel and Iron Corp. steel plant at Pueblo, Colo., and the coal soon to be produced from the new Maxwell mine will also be used there. Most coal from the York Canyon and Upper York Canyon mines near Vermejo Park is shipped 1,100 miles (1,770 km) by rail to the Kaiser Steel Corp. plant at Fontana, Calif. (Coal Age, 1967). Some, the middling coal, is burned locally as steam coal. At the present rate of production, estimated resources in the Raton field will last for several thousand years.

Almost the entire Raton field is underlain by coal beds of minable thickness, but in some parts of the coal field, thick

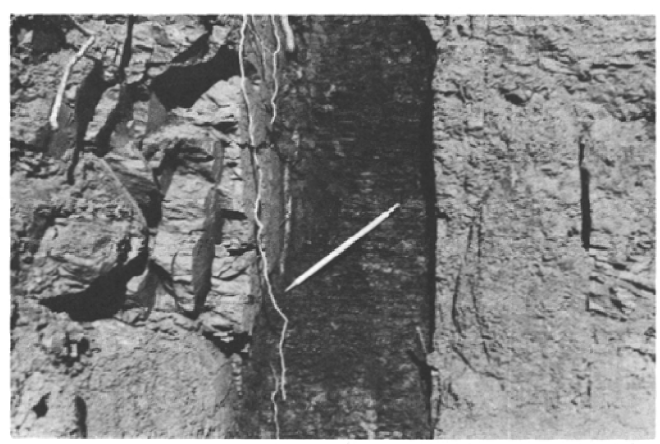

Figure 7. Closeup view of coal "dike" cutting the sill, showing cleat formed perpendicular to walls of the "dike."

overburden precludes any possibility of mining. Only the southwesternmost part, totaling perhaps 80 to 100 mi² (210-260 km²), is barren. The coal is all high-volatile A to B bituminous rank; some representative coal analyses are given in Table 2 and additional analyses, with trace element and other geochemical data, are included in the Appendix. Values included in these analyses result from particular field sampling techniques and routine laboratory procedures (U.S. Bureau of Mines Bull. 638, 1967). Table 2 shows values obtained from mostly single samples where partings greater than 0.37 in. (0.9 cm) were routinely excluded. Values in the Appendix were obtained by sampling and analyzing individual splits within particular coal beds.

Data showing ranges in volatile matter and sulfur for 164 samples of the most important coal beds in the coal field (Table 3) represent whole-bed core samples washed in a heavy liquid (S.G. about 1.5). Partings and coal splits are included in the samples, and so aggregate values that represent the character of the coal resulting from a beneficiation process are obtained. Departures from these ranges (Table 2 and Appendix) are mainly samples of coal splits lying above or below the major seams and may not represent the coal bed as a whole or significant tonnages of coal.

COAL BEDS IN THE VERMEJO FORMATION

Coal beds occur in the Vermejo Formation throughout the coal field. The most persistent and widely mined bed is the Raton coal bed, which occurs generally within a few feet of the base of the Vermejo, but which may also occur tens of feet above the base. Although the Vermejo coal bed occurs near the top of the Vermejo Formation, this name should be restricted to the western part of the coal field, where the bed is thick and the formation is more than 250 ft (75 m) thick. In the eastern part of the field, a bed about 85 ft (26 m) above the Trinidad Sandstone, called the Sugarite coal bed, was included in the "lower coal zone" of the overlying Raton Formation by Lee (1917, 1922, 1924), but was mapped in the Vermejo Formation by Zeuss (1967). R. H. Tschudy (written commun., 1969) stated that the Sugarite is part of the Raton Formation, on the basis of pollen assemblages similar to those found in thin, impure coal beds in the Upper Cretaceous part of the *lower zone* of the Raton Formation near Vermejo Park.

Table 2.--Representative proximate analyses of selected coal beds in the Raton coal field

Mine or location	Coal bed	Volatile matter (percent)	Fixed carbon (percent)	Ash (percent)	Sulfur (percent)	Btu
		Raton Formation				
York Canyon-----	York Canyon-----	35.7	54.9	8.8	0.6	14,340*
Chimney Divide--	Chimney Divide--	38.4	47.6	13.4	.5	13,980*
Ancho Canyon----	Ancho Canyon----	36.3	54.0	8.6	.5	13,835*
Brilliant-------	Tin Pan---------	37.0	46.5	16.5	.6	12,470***
Mine No. 3------	Yankee----------	38.7	48.7	12.6	.6	12,700***
		Vermejo Formation				
Vermejo Park----	Vermejo---------	28.2	53.7	18.0	0.5	10,030**
	Raton-----------	25.4	60.5	14.1	.5	11,440**
Dawson No. 3----	---do-----------	38.2	49.3	12.5	.8	13,230***
Koehler No. 1---	---do-----------	37.5	50.0	12.5	.7	13,100***
Van Houten No. 4.	---do-----------	37.1	51.6	11.3	.9	13,220***

*Bulk core sample data courtesy of Kaiser Steel Corp.; Btu results obtained from washed coal (1.4 sp. gr.).

**Weathered outcrop sample analysis courtesy of U.S. Bureau of Mines (generally higher ash and lower calorific values); low-volatile content probably caused by intrusive rocks.

***Mine analyses, moisture free, selected from Ellis (1936, p. 44-48).

Table 3.--Ranges in volatile matter and sulfur (moisture- and ash-free) for 164 core samples of the major coal beds in the Raton coal field

[Data courtesy of Kaiser Steel Corp., 1976]

Sample locality and coal bed	Number of samples	Volatile matter (moisture- and ash-free)	Sulfur
York Canyon area:			
York Canyon main bed	8	39.1-41.4	0.40-0.59
Upper Left Fork bed	17	35.6-40.1	.44- .56
Lower Left Fork bed	10	37.4-41.0	.48- .57
Castle Rock Park:			
Raton bed	41	29.2-42.5	.60- .90
Vermejo bed	34	32.4-41.9	.63- .93
Central area:			
Ancho bed	21	43.1-46.1	.50- .65
Green bed	18	40.6-45.4	.46- .69
Brown bed	9	37.2-39.8	.45- .55
Potato Canyon bed	6	39.6-44.0	.51- .74
	164		

Raton Bed

The Raton coal bed is as thick as 14.5 ft (4.4 m) (Lee, 1924) and is the most extensive and valuable bed in the Raton field. The Raton bed is commonly applied to commercial coal beds found at or near the base of the Vermejo Formation throughout the Raton coal field, regardless of whether the beds can be traced back to the Raton area. Where two or more beds are present, the thickest bed is usually called the Raton bed. The coal may rest directly on the Trinidad Sandstone or occur 30 ft (9 m) or more above it.

During retreat of the Cretaceous sea eastward, large elongate swamps formed behind and generally parallel to a northeast-trending strand. The regional trend of the strand is northwest in southern Colorado (Gill and Cobban, 1969), but thick coal trends indicate a north to northeast direction in New Mexico. These swamps were loci for the accumulation of large amounts of vegetal material that later formed the pod-shaped deposits of the Raton coal field (Fig. 6). These thick pods accumulated during stable periods in the progradation of the shoreline, where subsidence kept pace with sedimentation. These pods may lie behind thicker sequences of the Trinidad Sandstone or underlie limited transgressive tongues of the Trinidad. Similar depositional environments of the Fruitland Formation in the San Juan Basin, New Mexico, have been described by Fassett and Hinds (1971).

Early mining of the Raton bed was concentrated along the Dawson, Koehler-Van Houten and Gardiner trends at the eastern margin of the coal field, where the convenience of side-hill entry and rail transportation could be utilized (Fig. 6). The beds (or pods) probably are not continuous, even though they lie at or near the base of the Vermejo Formation. Because they are related to stable periods during regression of the sea, the coal beds in the pods are progressively older to the west. Other areas in the coal field possibly contain similar deposits of coal, but subsurface information is not available.

Vermejo Coal Bed

The Vermejo bed, also called the Spring Canyon or Bartlett bed at Vermejo Park, is as thick as 15 ft (4.5 m) at the western edge of the Castle Rock district and 10 ft (3 m) at Vermejo Park. The Vermejo coal formed in large swamps on the broad floodplain of a mature stream system; compared to the Raton bed, it is more irregular in thickness and distribution.

Whereas the Raton bed thins and splits in the eastern part of Vermejo Park (Fig. 8; line A-A', Fig. 3) and is intruded by sills there and in the vicinity of York Canyon, the Vermejo bed consists of two beds at places in Vermejo Park, but is absent to the east, apparently truncated below the erosional unconformity at the base of the Raton Formation. The Vermejo bed is restricted to areas where the Vermejo Formation is thicker than about 250 ft (75 m) (Fig. 5).

COAL BEDS IN THE RATON FORMATION

Coal beds are common in the Raton Formation but are less extensive and not as widely distributed as coal beds in the Vermejo Formation. The upper Left Fork and York Canyon beds, in the central part of the field in the *coal-bearing zone* of the Raton Formation, are the only coal beds now being mined. Though many coal beds occur in the *lower zone,* they are, with the exception of the Sugarite bed, mostly lenticular, impure, bony and less than 2 ft (0.6 m) thick. In a drill hole near Dawson, Wanek (1963) reported a 4.5 ft (1.4 m) thick coal bed, of unknown purity and lateral extent, about 90 ft (27 m) above the base of the formation; possibly this is an equivalent of the Sugarite bed to the northeast.

EASTERN PART OF THE FIELD

Lee (1924) discussed the coal beds in the Raton Formation in the Brilliant and Raton quadrangles and described the thickness, stratigraphic position and mines in each bed. Several beds of commercial value as thick as 8 ft (2.4 m) occur in the eastern part of the field, but most are less than 4 ft (1.2 m) thick, are limited areally, contain partings of shale or bone and were considered by Lee as less desirable for manufacture of coke.

Two recently explored beds, called the "Brown" and the "Green" coal beds (Kaiser Steel Corp., written commun., 1976), and the Tin Pan and Potato Canyon coal beds underlie large areas west of Raton (Fig. 9); and the Sugarite and Yankee beds occur east of town.

"Brown" Coal Bed

The "Brown" coal is the lowest bed in the eastern part of the coal field, other than the Sugarite and reaches a thickness of about 7 ft (2.1 m). In the vicinity of Crow Creek, Coal and Potato Canyons, it underlies an unspecified area of several

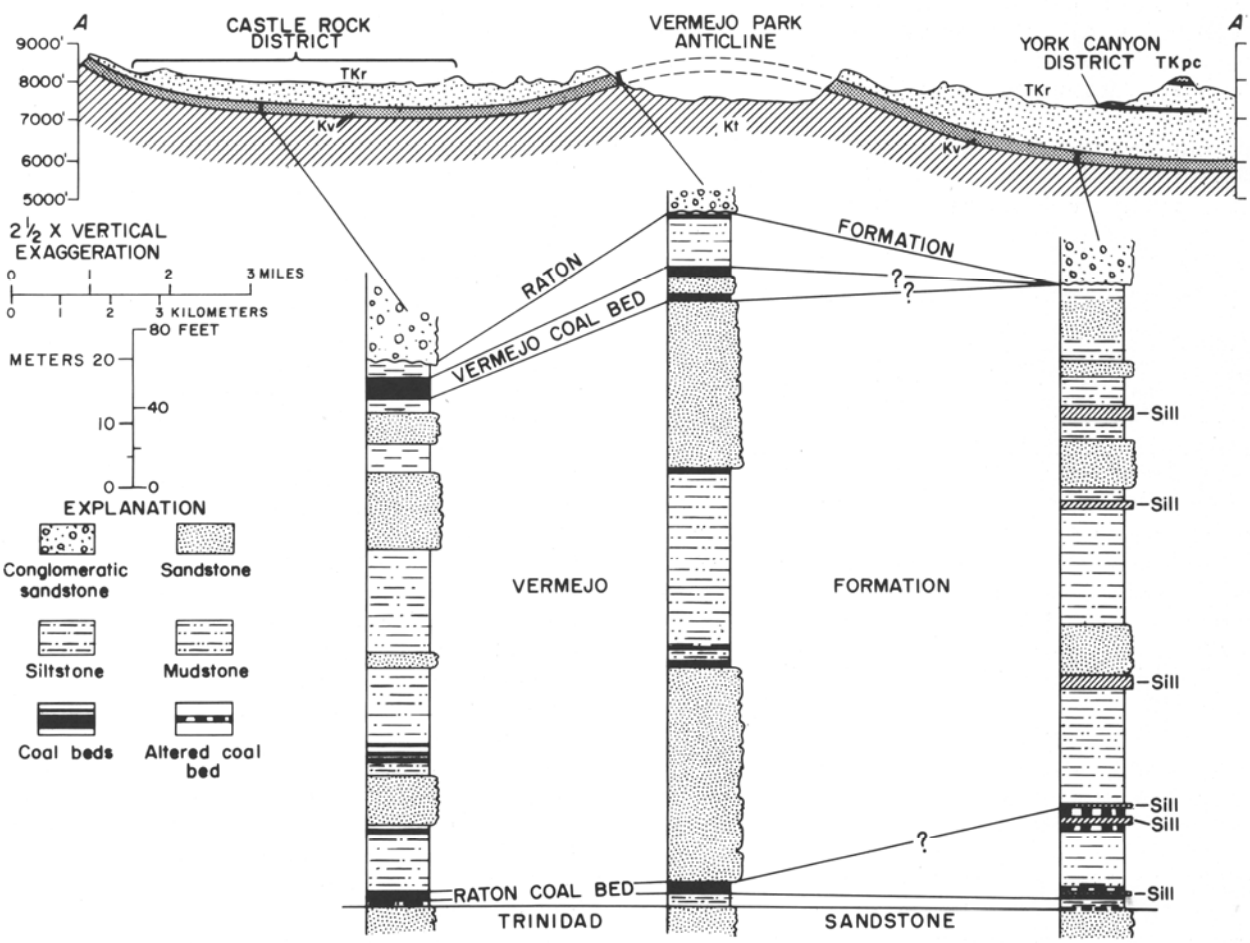

Figure 8. Cross section and columnar sections showing Vermejo Park anticline and lithologic changes in the Vermejo Formation across the northwestern part of the Raton coal field. Trace of cross section on Figure 3. TKr, Raton Formation; Kv, Vermejo Formation; Kt, Trinidad Sandstone.

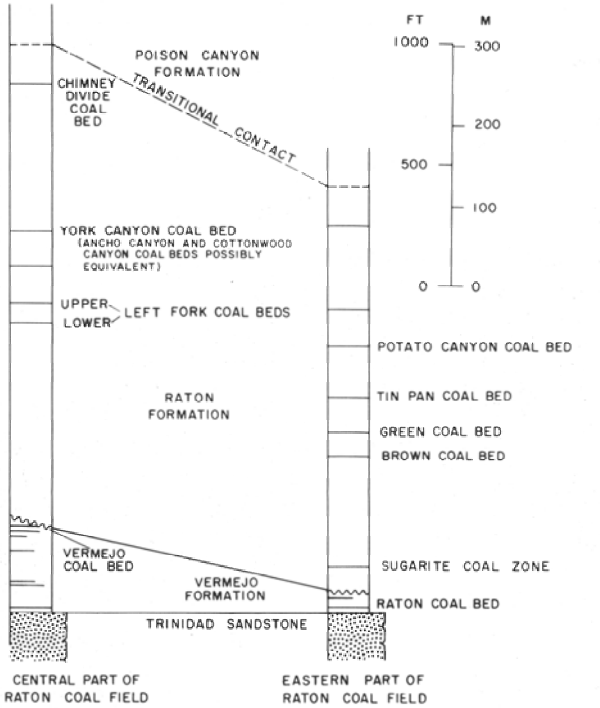

Figure 9. Diagrammatic stratigraphic section showing relations of coal beds in central and eastern parts of Raton coal field, New Mexico.

square miles, presumed similar to the area underlain by the "Green" coal bed. The "Brown" bed lies about 600-650 ft (183-198 m) above the Trinidad Sandstone (Kaiser Steel Corp., written commun., 1976); and may be correlative to one or both of the Left Fork coal beds to the west.

"Green" Coal Bed

The "Green" bed crops out in the bottom of Crow Creek and has been traced in the subsurface throughout an area of several square miles. The bed occurs as a zone as thick as 16 ft (4.8 m) composed of alternating thin coal and carbonaceous shale partings mostly less than 1 ft (0.3 m) thick. It lies approximately 700-750 ft (213-228 m) above the Trinidad Sandstone. Lee (1924) described what may be this bed at a location where it consists of a zone of 12.9 ft (3.9 m) thick containing 9.5 ft (2.9 m) of coal. Lee reported a second zone 12.5 ft (3.8 m) thick that lies 125 ft (38 m) stratigraphically above the "Green" coal bed, but it contains only 3.1 ft (0.94 m) of coal and is not considered economic.

Tin Pan Coal Bed

The Tin Pan coal bed underlies an area of about 40 mi^2 (104 km^2), mostly north of the Canadian River and beginning about 4 miles (6.4 km) west of Raton (Lee, 1924). The coal lies 850-900 ft (259-274 m) above the Trinidad Sandstone (Kaiser Steel Corp., written commun., 1976). Near Brilliant, it reaches a maximum thickness of 13.3 ft (4 m), with a total coal thickness of 9.45 ft (2.8 m) (Lee, 1924); but, individual coal beds in the zone rarely reach thicknesses greater than 5 ft (1.5 m), and the bed generally contains one or more shale partings. It crops out in many canyons adjacent to and along the Canadian River. Coal was produced from the Tin Pan bed for several years at Brilliant, but, according to Lee (1924), the coal is softer than the older coal of the Raton bed and produces a weak and "in some ways inferior" coke. When mixed with coal from the Raton bed a satisfactory grade is obtained.

Potato Canyon Coal Bed

The Potato Canyon bed underlies an area of several square miles along and north of the Canadian River, and it extends south into the head of Crow Creek and Coal Canyons. The bed lies about 950-1,050 ft (290-320 m) above the Trinidad Sandstone. In Potato Canyon the bed is as thick as 8.45 ft (2.5 m), with a total coal thickness of 7.25 ft (2.2 m), but individual beds within the zone rarely reach 3 ft (0.9 m) in thickness (Lee, 1924). The coal bed is characterized by several shale partings. It has been prospected extensively but not mined; an entry was driven into the bed on the south wall of Potato Canyon (Bohor and Pillmore, this Guidebook).

Sugarite Coal Bed

The lowest coal bed of commercial thickness in the Raton Formation occurs in the Sugarite zone, which lies 80 to 200+ ft (25-60 m) above the base of the Raton Formation and extends throughout an area of about 100 mi^2 (260 km^2) in the eastern part of the coal field (Lee, 1924). Recent subsurface investigations reveal that in the Blossburg district, west of Raton, a zone equivalent to the Sugarite is 40-50 ft (12-15 m) thick and lies 140-190 ft (43-58 m) above the base of the Raton Formation (Kaiser Steel Corp., written commun., 1976). The coal bed was up to 5.5 ft (1.6 m) thick in the mine at Sugarite; in most other localities, it is thinner and contains several shale partings. Although the coal is noncoking in character, it has high heating value and was popular as domestic fuel because it burns freely, without notable clinker, due to its high resin content.

Yankee Coal Bed

The Yankee coal bed occurs near the eastern limit of the coal field and is thinner and less extensive than the other beds in the area. Like most of the others, it is characterized by shale partings. Though preliminary tests indicated that it was of coking quality, the coal rarely occurred in beds thicker than 2.5-3 ft (0.7-0.9 m), and comparatively little coal has been mined from this bed. The Yankee bed underlies a number of other coal beds scattered through the *coal-bearing zone* of the Raton; presumably these are more lenticular and of less commercial value. The Yankee bed is only 300-400 ft (90-120 m) above the top of the Trinidad Sandstone, indicating either that the *lower zone* thins significantly a short distance from the Tin Pan area in the east (Lee, 1924), or that coal beds occur lower in the Raton Formation here than they do farther to the west. The Yankee coal bed lies at the base of the *coal-bearing zone.* It is possibly stratigraphically equivalent to one of the other beds, but most outcrops are obscured and tracing of the beds on the ground is nearly impossible. Palynological and trace-element studies may aid in correlating these beds.

CENTRAL PART OF THE FIELD

The major beds in the central part of the field are the upper and lower Left Fork, Cottonwood Canyon, Ancho Canyon, York Canyon and Chimney Divide (or Ridge) coal beds (Fig. 10).

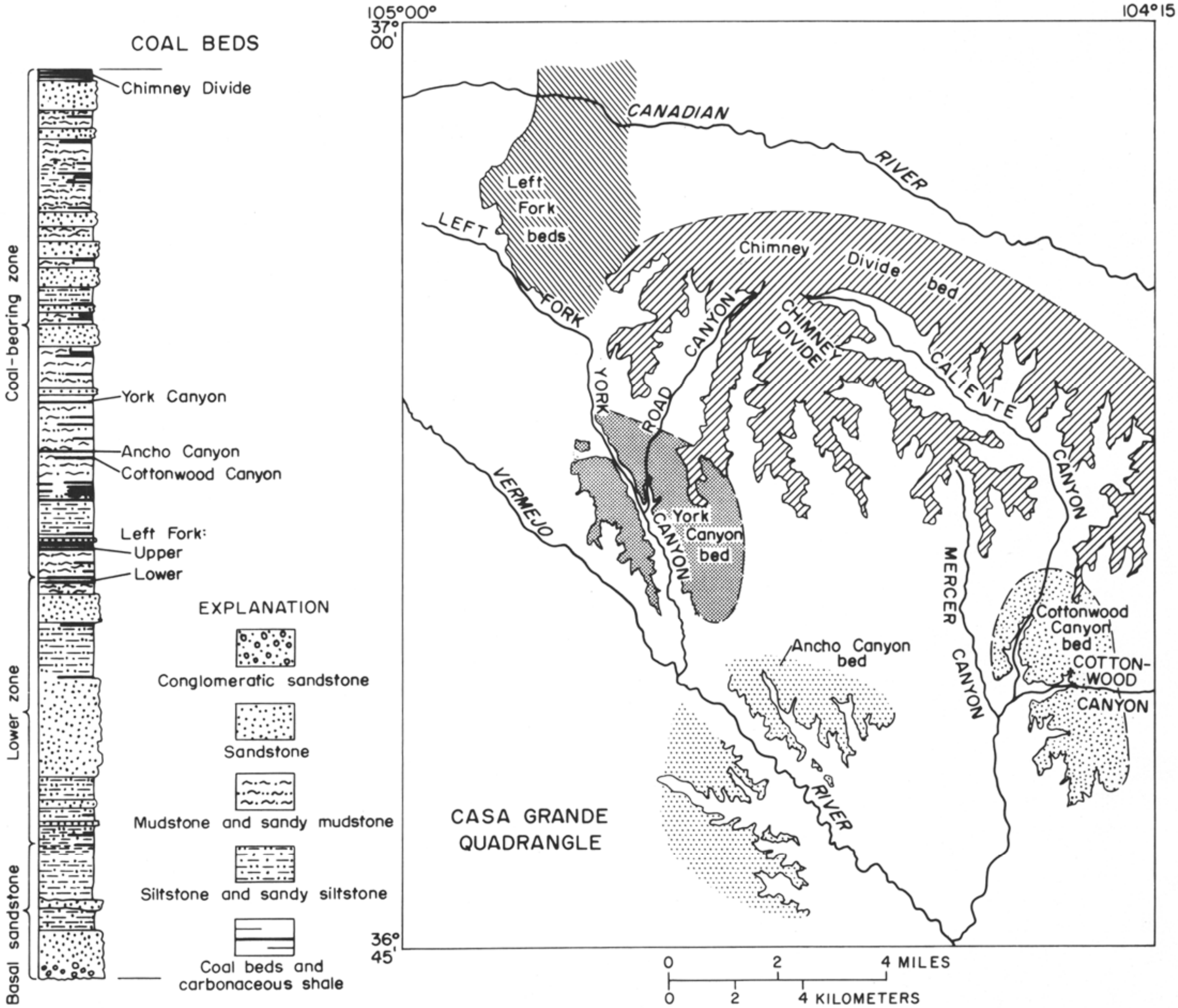

Figure 10. Stratigraphic relations and generalized bed maps of some major coal beds in the Raton Formation in the central part of the Raton coal field, showing areas for which coal resources have been calculated.

Left Fork Coal Beds

The Left Fork coal beds are two beds about 70-80 ft (21-24 m) apart that crop out near the base of the *coal-bearing zone* and are exposed on the steeply dipping east flank of the Vermejo Park anticline in the Left Fork of York Canyon northeast of Vermejo Park and in the Canadian River canyon. The dip flattens rapidly and much of the area underlain by the Left Fork beds is relatively flat lying. The coal is of excellent quality (Tables 2 and 3 and Appendix). The lower bed is about 1,200-1,250 ft (365-380 m) above the Trinidad Sandstone and about 900-950 ft (274-290 m) above the base of the Raton. It becomes as thick as 10 ft (3 m) throughout several square miles, but splits and thins to the south toward the Vermejo River.

The upper bed is also 10 ft (3 m) thick and is more consistent and extensive. It thins to the south but appears to persist for several miles; to the north, near the state line, it splits and contains many shale partings. The Upper York, the newest mine in the coal field, was opened on this upper bed in August, 1976; both beds will eventually be mined.

Cottonwood Canyon Coal Zone

The Cottonwood Canyon coal zone crops out in Cottonwood and Caliente Canyons and underlies an area of about 10 mi^2 (26 km^2) near the east boundary of the Casa Grande quadrangle. It occurs at about the same elevation and stratigraphic position as the Ancho Canyon bed, and is possibly correlative with the York Canyon, but exact stratigraphic relations have not been established. The Cottonwood Canyon bed ranges in thickness from a few inches to 7 aggregate ft (2.1 m) of coal in a 9 ft (2.7 m) zone, but the bed is characterized by

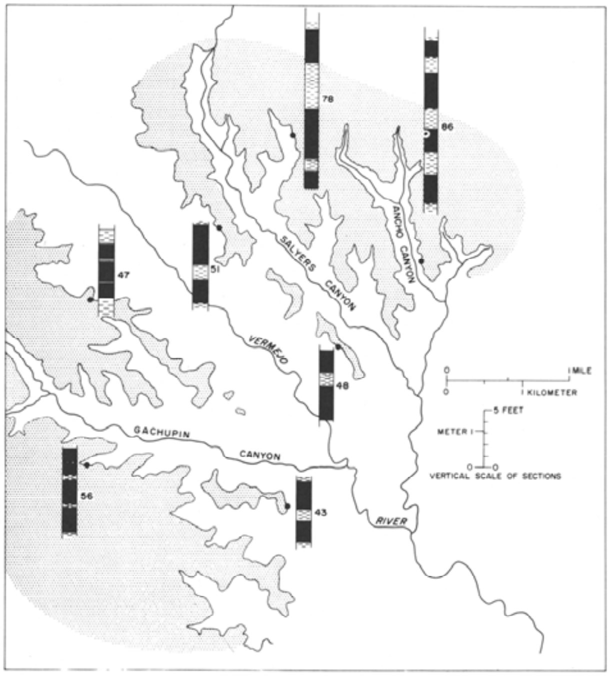

Figure 11. Coal sections and bed map of the Ancho Canyon coal bed. Number is aggregate thickness of coal in inches; line shows outcrop of the bed.

several shale partings and has less commercial potential than many other beds in the field.

Ancho Canyon Coal Bed

The Ancho Canyon coal bed crops out in nearly flat strata throughout an area of 16 mi^2 (42 km^2) in the vicinity of Ancho, Salyers, Gachupin, Bracketts and Vermejo River Canyons (Fig. 11). In much of this area, it consists typically of two beds of coal, each about 2 ft (0.6 m) thick, separated by a hard, dense, carbonaceous shale bed 0.5-2 ft (0.15-0.6 m) thick. The coal underlies long, flat-topped ridges in dissected ridge-and-valley terrain. In Ancho Canyon the total coal thickness ranges from thin streaks to 9 ft (2.7 m) of coal in a composite zone 15 ft (4.6 m) thick. The zone is made up of coal beds that are as much as 5 ft (1.5 m) thick but are commonly less than 3 ft (0.9 m), separated by shale partings as thick as 3.5 ft (1 m). The Ancho Canyon bed is about 1,350 ft (410 m) above the Trinidad Sandstone and 1,150-1,200 ft (350-366 m) above the base of the Raton Formation, about the same position stratigraphically as the York Canyon. Recent investigations indicate that the beds are probably equivalent.

York Canyon Coal Bed

The York Canyon coal bed underlies a dissected area of 12 mi^2 (31 km^2) in York and Road Canyons in the central part of the Casa Grande quadrangle (Fig. 12). It ranges from a bed containing many partings and only a few inches of coal in the southeast part of the outcrop area to a single bed of coal more than 10 ft (3 m) thick near the York Canyon mine. The coal is consistently at least 6 ft (2 m) thick throughout the bed area (Fig. 12) northeast of the mine site. A major parting that rapidly thickens westward to about 30 ft (9 m) divides the bed into upper and lower benches along the western margin of the bed outcrop area. East of York Canyon, the rocks are nearly flat, but to the west the beds are tilted as steeply as 15° on the east limb of the Vermejo Park anticline.

Stratigraphically, the York Canyon coal bed is about 300 ft (91 m) above the Left Fork beds, about 1,500 ft (460 m) above the Trinidad Sandstone, and 1,200-1,280 ft (366-390 m) above the base of the Raton. Measured coal resources in the York Canyon bed in the area east of York Canyon totaled 30 million metric tons in beds 4 ft (1.2 m) thick or greater (1969). Production of clean coal shipped from the York Canyon mine to January, 1975, was 7,133,834 metric tons (Fig. 13). The York Canyon mine, the only producer in the field, was opened by Kaiser Steel Corp. in 1966, and the present daily production is 3,180-3,630 metric tons.

Chimney Divide (or Ridge) Coal Bed

The Chimney Divide coal bed crops out below crests of long fingerlike ridges and underlies high drainage divides throughout an area of more than 50 mi^2 (130 km^2) across the north-central portion of the Casa Grande quadrangle (Fig. 10). The coal bed commonly consists of two benches, each about 2 ft (0.6 m) thick, separated by a carbonaceous shale parting about 6 in. (15 cm) to 1 ft (0.3 m) thick. The outcrops commonly are obscured by brush and the bed is difficult to trace on the surface. The coal bed may be made up of a series of lenses at approximately the same stratigraphic position rather than of a single continuous bed. The bed extends northward to the Canadian River, where the coal becomes dirty and splits into several beds. This bed is the most extensive commercial Raton Formation coal bed or composite zone in the Raton field.

The Chimney Divide bed is near the top of the *coal-bearing zone* and generally is the highest coal bed in the sequence. It is about 1,880 ft (570 m) above the base of the Raton Formation and about 2,200 ft (670 m) above the Trinidad Sandstone in the vicinity of York Canyon.

SUMMARY

Coal beds in the Raton Formation may prove to be the most economically significant in the coal field. As noted in the production records, in only 9 years, the York Canyon coal bed has produced about one-tenth as much coal as the entire field produced for the first 100 years, mainly from beds in the Vermejo Formation. Special circumstances control the accumulation of thick coal deposits in continental environments: amount and kind of vegetation, water depth, climate and tectonic stability are all important factors in controlling accumulation of sufficient vegetal material to eventually form coal beds of commercial thickness. Because these conditions are of a regional nature, occurrence of a thick coal at a particular stratigraphic position in one area should provide a clue to the position of a similar coal deposit elsewhere in the basin. Thinning or thickening of strata below the coal interval across the basin must be considered in coal exploration. For instance, the York Canyon bed, lying 1,500 ft (460 m) above the Trinidad Sandstone in the central part of the depositional basin may be correlative with either the Tin Pan or the Potato Canyon coal beds lying 900 to 1,050 ft (274-320 m) above the Trinidad Sandstone in the eastern part. Of course, thinning of the Vermejo Formation must also be taken into consideration.

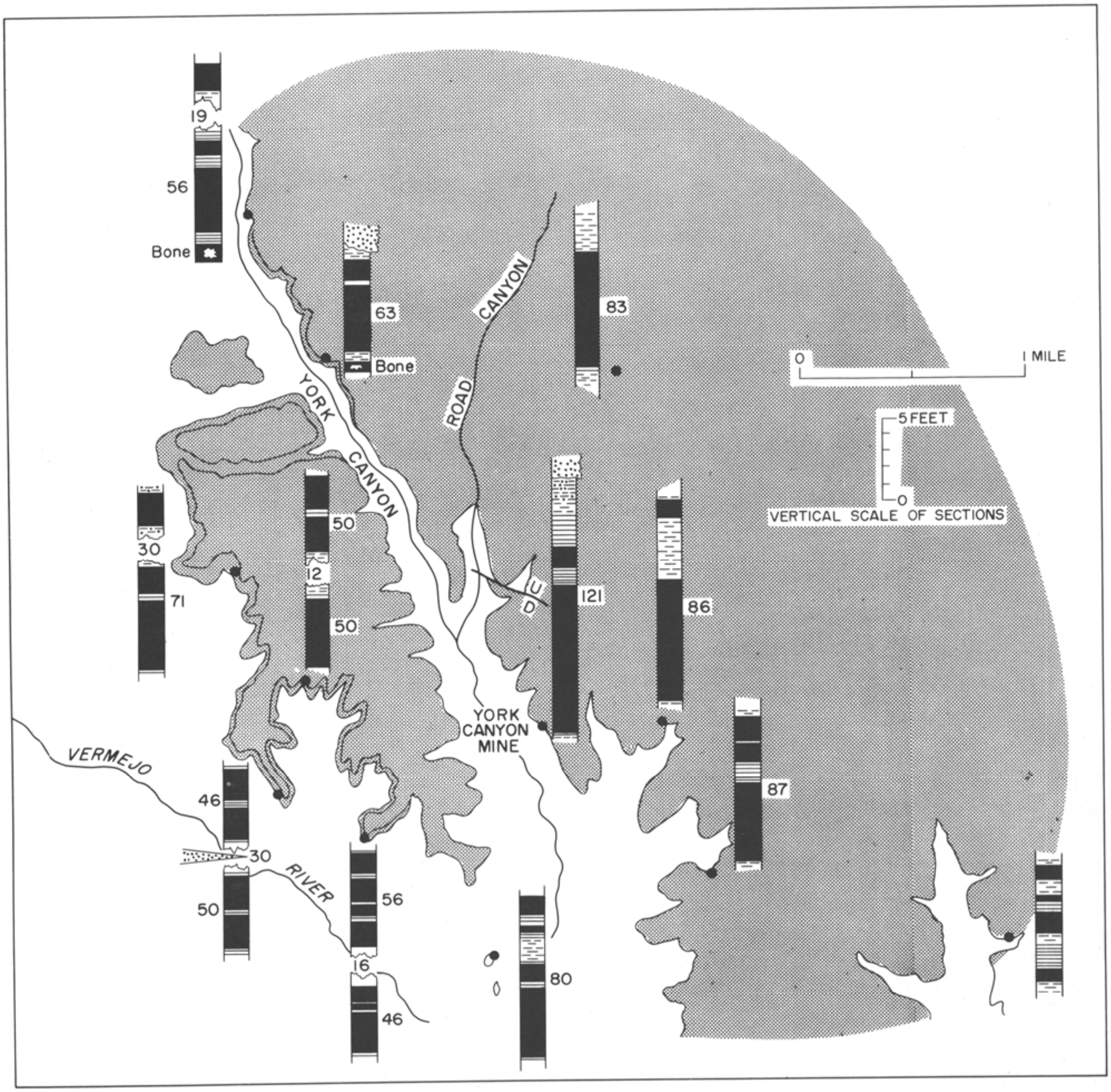

Figure 12. Coal sections and bed map of the York Canyon coal bed. Number in column is thickness of coal in inches; line shows outcrop of the bed.

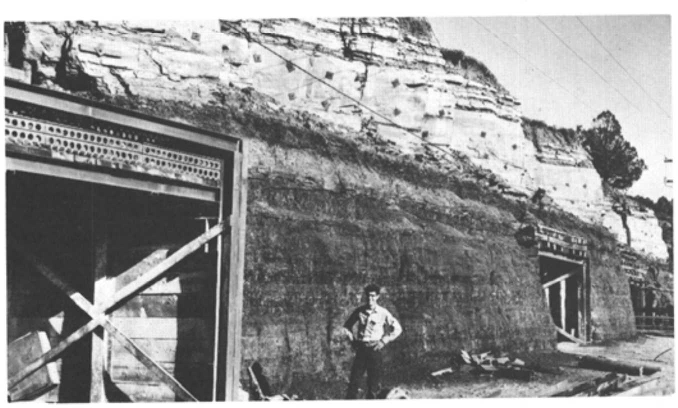

Figure 13. Close-up of York Canyon coal bed at main entry to York Canyon mine.

Future coal exploration programs should consider the concept of stratigraphic position as a guide to location of thick coal deposits.

REFERENCES

Averitt, Paul, 1966, Coking-coal deposits of the Western United States: U.S. Geol. Survey Bull. 1222-G, p. G1-G48.

Baltz, E. H., 1965, Stratigraphy and history of the Raton basin and notes on San Luis basin, Colorado-New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 2041-2075.

Brown, R. W., 1943, Cretaceous-Tertiary boundary of the Denver Basin, Colorado: Geol. Soc. America Bull., v. 54, p. 65-86.

Carter, D. A., 1956, Coal deposits of the Raton Basin (Colo.-N. Mex.), *in* Rocky Mtn. Assoc. Geologists Guidebook, Guidebook to the geology of the Raton basin, Colorado, 1956: p. 89-92.

Clark, K. F., and Read, C. B., 1972, Geology and ore deposits of Eagle Nest, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Bull. 94, 152 p.

Coal Age, 1967, 1,100 mi from mine to coke ovens: Coal Age, v. 72, no. 4, p. 94-100.

Ellis, R. W., 1936, Analyses of New Mexico coals: U.S. Bur. Mines Tech. Paper 569, 108 p.

Fassett, J. E., and Hinds, J. S., 1971, Geology and fuel resources of the Fruitland Formation and Kirtland Shale of the San Juan basin, New Mexico and Colorado: U.S. Geol. Survey Prof. Paper 676, 76 p.

Gill, J. R., and Cobban, W. A., 1969, Paleogeographic maps of Telegraph Creek, Eagle, Claggett, Judith River, Bearpaw, and Fox Hills times of late Cretaceous Epoch in the western interior region: U.S. Geol. Survey open-file report, 6 sheets.

Hayden, F. V., 1869, Preliminary field report (third annual) of the United States Geological Survey of Colorado and New Mexico: Washington, U.S. Govt. Printing Office, 155 p.

Hills, R. C., 1888, The recently discovered Tertiary beds of the Huerfano River basin, Colorado: Colorado Sci. Soc. Proc., v. 3, pt. 1, p. 148-164.

---- 1899, Description of the Elmoro quadrangle, Colorado: U.S. Geol. Survey Geol. Atlas, Folio 58, 6 p.

Hoyt, J. H., and Weimer, R. J., 1965, The origin and significance of *Ophiomorpha (Halymenites)* in the Cretaceous of the Western Interior, *in* Wyoming Geol. Assoc. Guidebook 19th Ann. Field Conf., Sedimentation of Late Cretaceous and Tertiary outcrops, Rock Springs uplift: 1965, p. 203-207.

Johnson, R. B., 1969, Geologic map of the Trinidad quadrangle, south-central Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map 1-558.

---- and Wood, G. H., Jr., 1956, Stratigraphy of Upper Cretaceous and Tertiary rocks of Raton basin, Colorado and New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 707-721.

Lee, W. T., 1913, Recent discovery of dinosaurs in the Tertiary: Am. Jour. Sci., 4th ser., v. 35, p. 531-534.

---- 1917, Geology of the Raton Mesa and other regions in Colorado and New Mexico, p. 9-221 *in* Lee, W. T., and Knowlton, F. H., Geology and paleontology of Raton Mesa and other regions in Colorado and New Mexico: U.S. Geol. Survey Prof. Paper 101, 450 p. (1918).

---- 1922, Description of the Raton, Brilliant, and Koehler quadrangles, New Mexico: U.S. Geol. Survey Geol. Atlas, Folio 214, 17 p.

---- 1924, Coal resources of the Raton coal fields Colfax County, New Mexico: U.S. Geol. Survey Bull. 752, 254 p.

Pillmore, C. L., 1964-1966, Geologic maps of the Catskill SW, SE, NE and NW quadrangles, Las Animas County, Colorado, and Colfax County, New Mexico: U.S. Geol. Survey open-file reports.

---- 1969a, Geologic map of the Casa Grande (formerly Catskill) quadrangle, Colfax County and Las Animas County, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-823.

Pillmore, C. L., 1969b, Geology and coal deposits of Raton coal field, Colfax County, New Mexico: Mtn. Geologist, v. 6, p. 125-142.

Read, C. B., Duffner, R. T., Wood, G. H., Jr., and Zapp, A. D., 1950, Coal resources of New Mexico: U.S. Geol. Survey Circ. 89, 24 p.

Stormer, J. C., Jr., 1972, Ages and nature of volcanic activity on southern High Plains, New Mexico and Colorado: Geol. Soc. America Bull., v. 83, p. 2443-2448.

Trumbull, J., 1960, Coal fields of the United States. U.S. Geol. Survey Map, 2 sheets, 1:500,000.

Wanek, A. A., 1963, Geology and fuel resources of the southwestern part of the Raton coal field, Colfax County, New Mexico: U.S. Geol. Survey Coal Inv. Map C-45, 2 sheets (1964).

Wood, G. H., Jr., Johnson, R. B., and Dixon, G. H., 1957, Geology and coal resources of the Starkville-Weston area, Las Animas County, Colorado: U.S. Geol. Survey Bull. 1051, 68 p.

Zeuss, Hilario, 1967, Geology of the Raton area, Colfax County, Raton quadrangle, New Mexico [M.S. thesis] : Golden, Colorado School Mines, 108 p.

APPENDIX: GEOCHEMICAL DATA ON YORK CANYON, UPPER LEFT FORK, POTATO CANYON AND RATON COAL BEDS OF RATON COAL FIELD, COLFAX COUNTY, NEW MEXICO

Introduction

This appendix (from U.S. Geological Survey Open-File Report 76-542 by C. L. Pillmore and J. R. Hatch) presents analytical data on 16 coal samples and 10 shale samples from underground and open-pit mines, outcrops and a core hole in the Raton coal field, Colfax County, New Mexico. The samples were collected from coal beds in rocks of the Vermejo Formation and the Raton Formation. Proximate, ultimate, Btu and forms-of-sulfur analyses are given on 10 selected coal samples; major and minor oxides and trace-element compositions of these and 6 additional coal samples, and of shale beds related to the York Canyon mine and the outcrop of Vermejo Park were also determined.

Sample distribution

Three coal beds in the Raton Formation were sampled. Several samples from the York Canyon coal bed were taken from Kaiser Steel's York Canyon underground (Sample Nos. D169000, 001 and D176216, 217) and surface (Sample Nos. D169004, 005, 006, 007, and 008) mines. Samples of the middling (D169002) and washed (D169003) coal from the wash plant were also analyzed. The Upper Left Fork coal bed (D169801, 802) was sampled in Kaiser Steel's development entries in the Left Fork of York Canyon. The Potato Canyon coal bed (D168803), in the eastern part of the field, was sampled at a test entry at Potato Canyon near the road to the York Canyon mine.

Two samples of the Raton coal bed of the Vermejo Formation were taken: an outcrop of the bed (D169012) was sampled near the Bartlett mine at the northwest entrance to Vermejo Park; and a core sample of the Raton bed (D169013), from a deep hole in the eastern part of the field, about 12 miles (20 km) southwest of Raton, was furnished by Kaiser Steel Corporation.

The cooperation of Kaiser Steel in granting access to the sample sites and supplying the core of the Raton bed is gratefully acknowledged. We also thank the New Mexico Bureau of Mines & Mineral Resources for permission to include data on D176216 and D176217.

Analytical Data

Analytical data for the 16 coal samples and 10 rock samples from the Raton coal field are tabulated in Tables 1-5. Statistical summaries of these data for the 16 coal samples are listed in Tables 6-8. For comparison, statistical summaries for 295 Rocky Mountain province coal samples are listed in Tables 6a-8a.

Using the analytical data, comparison between individual coals in the same and in different formations is possible. The whole-coal data (Tables 3, 4), summarized below, show that the core sample of the Raton coal bed (D169013) contains considerably more of certain elements than the outcrop sample of the same bed (D169012), which is about 22 miles (35 km) away:

Table 1.--Proximate, ultimate, Btu, and forms-of-sulfur analyses of 10 samples from selected sites in the Raton coal field, New Mexico

[All analyses except Btu are in percent. Original moisture content may be slightly more than shown, because samples were collected and transported in plastic bags to avoid metal contamination. Form of analyses: 1, as received; 2, moisture free; 3, moisture and ash free. A. D. Loss is air-dried loss]

		PROXIMATE ANALYSIS				ULTIMATE ANALYSIS				
SAMPLE	FORM OF ANALYSIS	MOISTURE	VOL.MTR.	FIXED C	ASH	HYDROGEN	CARBON	NITROGEN	OXYGEN	SULFUR
D168801	1	1.5	36.6	54.4	7.5	5.2	76.7	1.7	8.4	0.5
	2	-	37.2	55.1	7.7	5.1	77.9	1.8	7.0	.5
	3	-	40.3	59.7	-	5.6	84.3	1.9	7.7	.5
D168802	1	2.1	36.7	50.8	10.4	5.3	71.6	1.8	10.4	.5
	2	-	37.5	51.9	10.6	5.1	73.1	1.8	8.9	.5
	3	-	41.9	58.1	-	5.8	81.7	2.0	10.0	.5
D168803	1	1.5	35.1	53.6	9.8	5.0	74.8	1.6	8.3	.5
	2	-	35.6	54.4	10.0	4.9	75.9	1.7	7.0	.5
	3	-	39.5	60.5	-	5.4	84.3	1.8	7.9	.6
D169000	1	2.2	33.3	45.3	19.2	4.7	65.7	1.5	8.4	.5
	2	-	34.0	46.4	19.6	4.5	67.2	1.6	6.6	.5
	3	-	42.3	57.7	-	5.6	83.6	2.0	8.2	.6
D169001	1	1.9	36.1	54.0	8.0	5.2	75.9	1.7	8.8	.4
	2	-	36.8	55.1	8.1	5.1	77.3	1.8	7.2	.5
	3	-	40.0	60.0	-	5.5	84.1	1.9	8.0	.5
D169004	1	1.4	38.2	51.9	8.5	5.2	75.9	1.7	8.3	.4
	2	-	38.7	52.7	8.6	5.1	77.0	1.8	7.1	.4
	3	-	42.4	57.6	-	5.6	84.3	1.9	7.7	.5
D169005	1	1.3	42.3	50.6	5.8	6.0	77.8	2.0	7.8	.6
	2	-	42.8	51.3	5.9	5.9	78.8	2.0	6.8	.6
	3	-	45.5	54.5	-	6.3	83.8	2.1	7.1	.7
D169006	1	1.8	37.1	53.4	7.7	5.4	76.4	1.7	8.4	.4
	2	-	37.8	54.4	7.8	5.3	77.8	1.8	6.9	.4
	3	-	41.0	59.0	-	5.7	84.4	1.9	7.5	.5
D169013	1	2.5	31.2	43.5	22.8	4.7	61.8	1.2	8.9	.6
	2	-	32.0	44.6	23.4	4.6	63.4	1.3	6.7	.6
	3	-	41.7	58.3	-	6.0	82.7	1.7	8.8	.8
D176216*	1	1.7	34.2	49.6	14.5	5.0	70.2	1.6	8.2	.5
	2	-	34.8	50.4	14.8	4.9	71.4	1.6	6.7	.6
	3	-	40.8	59.2	-	5.7	83.8	1.9	7.9	.7

				FORMS OF SULFUR		
SAMPLE	FORM OF ANALYSIS	BTU	A.D.LOSS	SULFATE	PYRITIC	ORGANIC
D168801	1	13740	.00	0.01	0.05	0.40
	2	13950	-	.01	.05	.41
	3	15110	-	.01	.05	.44
D168802	1	12830	.00	.00	.04	.44
	2	13110	-	.00	.04	.45
	3	14660	-	.00	.05	.50
D168803	1	13410	.00	.02	.04	.43
	2	13610	-	.02	.04	.44
	3	15110	-	.02	.05	.48
D169000	1	11810	.40	.01	.07	.42
	2	12070	-	.01	.07	.43
	3	15020	-	.01	.09	.53
D169001	1	13550	.50	.01	.07	.37
	2	13810	-	.01	.07	.38
	3	15030	-	.01	.08	.41
D169004	1	13620	.00	.00	.06	.38
	2	13810	-	.00	.06	.39
	3	15110	-	.00	.07	.42
D169005	1	14230	.00	.00	.05	.56
	2	14410	-	.00	.05	.57
	3	15320	-	.00	.05	.60
D169006	1	13660	.20	.00	.11	.30
	2	13910	-	.00	.11	.30
	3	15090	-	.00	.12	.33
D169013	1	11620	.50	.00	.08	.49
	2	11910	-	.00	.08	.50
	3	15550	-	.00	.11	.65
D176216*	1	12520	.55	.01	.02	.52
	2	12740	-	.01	.02	.53
	3	14950	-	.01	.02	.62

Table 2.--Major and minor oxide and trace-element composition of the laboratory ash of 16 coal samples from selected sites in the Raton coal field, New Mexico

[Values are in either percent or parts per million. The coals were ashed at 525°C. L after a value means less than the value shown, N means not detected. S after the element title means that the values listed were determined by semiquantitative spectrographic analysis. The spectrographic results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., but are reported arbitrarily as mid-points of those brackets, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of the spectrographic data is approximately one bracket at 68 percent, or two brackets at 95 percent confidence]

SAMPLE	ASH %	SIO2 %	AL2O3 %	CAO %	MGO %	NA2O %	K2O %	FE2O3 %	MNO %	TIO2 %
D168801	6.4	48.	28.	3 8	1.83	0.70	0.34	7.7	0.020L	1.3
D168802	9.8	48.	28.	3 4	1.91	.67	.46	7.5	.020L	1.3
D168803	11.7	48.	27.	3.2	1.10	.26	.66	6.5	.020L	1.0
D169000	18.6	57.	27.	1.8	1.39	.81	1.2	4.6	.020L	1.0
D169001	8.3	33.	22.	16.	1.81	.95	.075	8.0	.030	1.2
D169002	38.2	50.	20.	11.	1.44	.49	1.2	3.0	.020L	.91
D169003	9.1	42.	25.	7.8	1.96	.95	.41	6.9	.020L	1.2
D169004	10.0	39.	23.	13.	2.01	.58	.27	5.3	.020L	1.2
D169005	6.3	40.	27.	5.8	2.16	.49	.30	11.	.020	.81
D169006	10.0	32.	21.	17.	2.49	1.24	.19	6.2	.028	.86
D169007	11.4	41.	25.	12.	2.41	.36	.16	5.0	.020L	1.2
D169008	6.2	44.	26.	6.6	1.58	.51	.42	11.	.020L	.86
D169012	16.2	60.	17.	4.3	1.08	.49	2.3	4.3	.024	.73
D169013	31.6	60.	30.	.36	.53	.54	.33	2.8	.020L	.88
D176216	9.5	37.	21.	13.	1.99	1.53	.52	5.5	.015	1.3
D176217	20.6	47.	22.	6.8	1.44	.57	1.3	4.3	.017	.90

SAMPLE	P2O5 %	SO3 %	CL %	CD PPM	CU PPM	LI PPM	PB PPM	ZN PPM	B PPM-S	BA PPM-S
D168801	1.5	3 0	0.10 L	1.0L	196.	78.	35.	43	150	7000
D168802	1.7	2.6	.10 L	1.0L	146.	80.	45.	46.	150	5000
D168803	.45	.10 L	.10 L	1.0L	130.	78.	55.	86	150	1000
D169000	.10 L	.62	.10 L	1.0L	204.	72.	50.	62.	70	1500
D169001	1.7	4.3	.10 L	1.0L	130.	90.	45.	46.	150	5000
D169002	.10 L	.93	.10 L	1.0L	94.	58.	35.	84.	50	1000
D169003	1.0	3.7	.10 L	1.0L	208.	100.	65.	73.	150	3000
D169004	.71	3.5	.10 L	1.0L	178.	90.	60.	39.	150	5000
D169005	.35	6.4	.10 L	1.0L	170.	78.	70.	80.	150	3000
D169006	.97	4 6	.10 L	1.0L	172.	86.	60.	46	150	5000
D169007	.77	4.3	.10 L	1.0L	100.	136.	60.	101.	70	2000
D169008	.10 L	5.4	.10 L	1.0L	130.	68.	60.	102.	150	3000
D169012	.10 L	5.7	.10 L	1.0L	50.	40.	40.	31.	70	500
D169013	.10 L	.10 L	.10 L	1.0L	46.	118.	195.	34.	70	500
D176216	1.0 L	5.5	.20 L	1.0L	190.	80.	50.	31.	200	3000
D176217	1.0 L	2.0	.20 L	1.0L	92.	67.	40.	40.	100	2000

SAMPLE	BE PPM-S	CE PPM-S	CO PPM-S	CR PPM-S	GA PPM-S	GE PPM-S	LA PPM-S	MO PPM-S	NB PPM-S	ND PPM-S
D168801	10	N	30	70	30	N	70	10	20	N
D168802	3	N	15	50	30	N	70	7	20	N
D168803	15	N	30	50	50	N	70	7	20	N
D169000	7	N	15	50	30	N	70	7	20 L	N
D169001	3	N	15	30	30	N	100	7	20 L	N
D169002	3	N	10	70	30	N	70	N	20	N
D169003	7	N	20	50	30	N	100	10	20	N
D169004	7	N	15	70	30	N	70	10	20	N
D169005	20	500 L	70	70	30	N	150	15	20	150
D169006	3	N	15	30	30	N	70	7	20 L	N
D169007	5	N	20	50	30	N	100	7	20	N
D169008	20	500 L	70	50	30	20 L	150	15	20	150
D169012	5	N	10 L	15	30	N	70	10	20 L	N
D169013	3	N	10	10	30	N	70	10	30	N
D176216	7	500 L	15	30	30	N	100 L	7	30	N
D176217	5	500 L	15	50	30	N	100 L	7	30	N

SAMPLE	NI PPM-S	SC PPM-S	SR PPM-S	V PPM-S	Y PPM-S	YB PPM-S	ZR PPM-S
D168801	50	30	2000	200	70	7	300
D168802	30	20	1500	150	30	3	200
D168803	30	20	700	150	70	7	200
D169000	15	20	500	150	30	3	150
D169001	30	20	3000	100	50	5	200
D169002	10	15	1500	150	30	3	150
D169003	30	30	2000	200	70	7	200
D169004	30	20	2000	200	70	7	200
D169005	150	30	1500	200	200	20	200
D169006	30	15	3000	150	50	5	150
D169007	50	20	1500	150	70	7	150
D169008	150	30	1500	150	150	15	150
D169012	10 L	10	1500	70	50	5	150
D169013	10 L	10	200	70	30	3	200
D176216	30	15	2000	150	70	5	200
D176217	50	15	1500	150	50	3	70

		D169013	D169012
Whole coal:			
(ppm)	Pb	61.6	6.5
	Li	37.3	6.5
	P	140	71
	Se	1.6	.7
	Th	15.5	3.0
	U	4.1	1.5
	Cu	14.5	8.1
	Mo	3	1.5
	Nb	10	3
Percent ash:		31.6	16.2
Ppm in ash:	Pb	195	40
	L	118	40

The analyses of the ash of these samples (Table 2) show appreciable differences of about the same magnitude as noted above; Pb values for D169013 are about five times those of D169012, and Li values are about three times higher.

Differences in composition between the Raton coal bed of the Vermejo Formation and the composition of coal beds in the Raton Formation are that the coal in the Raton bed has lower volatile-matter and fixed-carbon values; generally higher ash content; lower H, 0, N and Btu values; and somewhat higher S contents (Table 1). Other elemental analyses display the following differences: (1) U and Th contents in the whole-coal analyses of the Raton bed core sample (D169013) are generally two to five times higher than in other coal samples, (2) Cu content of the ash of samples of the Raton coal bed are one-half to one-fourth those of the Raton Formation coal beds (Table 2), and (3) average value for P in the whole coal (Table 4) is about one-fourth to one-third that of the Raton Formation coal beds.

The average (arithmetic mean) ash content of the coal samples from the Raton field is 11.4 percent; N, 1.7 percent; S, 0.5 percent; Btu/lb, 13,000 (Table 6). For comparison, the average value in 86 Rocky Mountain province coal samples (Table 6a) is 9.1 percent ash, 1.2 percent N, 0.6 percent S and 10,480 Btu/lb. The coals typical of the Raton coal field are higher in Btu and lower in sulfur content than representative coals of the Rocky Mountain province.

A comparison of average concentrations of oxides in the laboratory ash of the 16 Raton field coal samples with those determined for the laboratory ash of 295 Rocky Mountain province coal samples (Tables 7, 7a) shows that P_2O_5 concentration is higher by more than 50 percent in the ash of Raton field coals, while Na_2O, MnO and SO_3 concentrations are lower by more than 50 percent. Average values for the other nine oxides reported in the ash are about the same in both sets of samples.

Data for 37 elements calculated to, or reported on, a whole-coal basis are summarized for the Raton field coal samples on Table 8 and for the 295 Rocky Mountain province coal samples on Table 8a. For comparative purposes, the average element concentrations in shale (Turekian and Wedepohl, 1961, Table 2) are listed on both tables. A comparison of the average amounts of 37 elements in Raton field coal with those in the average shale (Turekian and Wedepohl, 1961) (Table 8, 8a) shows that the concentrations of Al, Fe, Ti, F, Hg, Li, B, Co, Sc, V and Zr are less by more than a factor of five in the coal; Mg, Na, K, Zn, Cr and Ni are less by more than a factor of ten. The concentrations of the other 20 elements reported are similar to those of the average shale. Na, As, Cd, B, Mo and Nb concentrations in Raton field coal are less by a factor of two or more than those in Rocky Mountain coal. Cu values are about 50 percent higher, and Sr about two times higher than those of the Rocky Mountain coal. The average concentrations of the other 29 elements in the Raton field coal samples do not differ significantly from their average amounts in Rocky Mountain coal.

Statistical Methods

The estimate of the most probable concentration, as used in this report is the geometric mean, Gm, the antilog of the mean of the logarithms of concentration. The measure of scatter about the mode is the geometric deviation, GD, which is the antilog of the standard deviation of the logarithms of concentration. These statistics are used because of the common tendency for trace element concentration in natural materials to exhibit positively skewed frequency distributions. The distributions can be normalized by analyzing and summarizing trace element data on a logarithmic basis.

If the underlying frequency distributions are lognormal, the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to Gm-GD. The estimated range of the central 95 percent of the observed distribution has a lower limit equal to $GM/(GD)^2$ and an upper limit equal to $GM \bullet (GD)^2$ (Connor and others, 1976).

Although the geometric mean is generally an adequate estimate of the most common concentration, it is a biased

Table 3.--Amounts of seven trace elements in 16 coal samples from selected sites in the Raton coal field, New Mexico

[Analyses on air-dried (32°C) coal. All values are in parts per million. L after a value means less than the value shown]

SAMPLE	AS PPM	F PPM	HG PPM	SB PPM	SE PPM	TH PPM	U PPM
D168801	1.	20.L	0.05	0.5	1.4	2.9	1.2
D168802	1.	40.	.01	.3	1.9	3.4	1.2
D168803	5.	90.	.04	.7	1.3	7.6	1.8
D169000	1.	160	.05	.5	1.8	8.0	2.3
D169001	1.	90.	.06	.2	1.2	4.5	.7
D169002	2.	195.	.08	.4	1.8	7.7	3.2
D169003	1.	65.	.05	.3	1.4	5.0	1.2
D169004	1.	40.	.10	.2	1.6	3.7	1.5
D169005	1.	95.	.06	.3	1.2	4.1	1.0
D169006	1	65.	.09	.2	1.5	4.9	1.3
D169007	1	120.	.04	.2	1.1	3.4	1.4
D169008	1.	80.	.04	.2	1.0	3.9	.7
D169012	1.L	95.	.02	.2	.7	3.0L	1.5
D169013	2.	90.	.05	.5	1.6	15.5	4.1
D176216	2	50.	.13	.3	2.1	4.4	1.0
D176217	2.	180.	.04	.4	2.1	10.3	1.5

Table 4.--Major, minor, and trace-element composition of 16 coal samples from selected sites in the Raton coal field, New Mexico, reported on whole-coal basis

[Values are in either percent or parts per million. Si, Al, Ca, Mg, Na, K, Fe, Mn, Ti, P, Cl, Cd, Cu, Li, Pb, and Zn values were calculated from analysis of ash. As, F, Hg, Sb, Se, Th, and U values are from direct determinations on air-dried (32°C) coal. The remaining analyses were calculated from spectrographic determinations on ash. L after a value means less than the value shown and N means not detected]

SAMPLE	SI %	AL %	CA %	MG %	NA %	K %	FE %	MN PPM	TI %	P PPM
D168801	1.4	0.94	0.17	0.070	0.033	0.018	0.34	9.9 L	0.050	430.
D168802	2.2	1.5	.24	.113	.049	.037	.51	15. L	.077	750.
D168803	2.6	1.7	.26	.077	.022	.065	.53	18. L	.073	230.
D169000	5.0	2.6	.25	.156	.112	.19	.60	29. L	.11	81. L
D169001	1.3	.95	.92	.091	.058	.005	.47	19.	.058	630.
D169002	8.9	4.0	3.1	.332	.138	.37	.81	59. L	.21	170. L
D169003	1.8	1.2	.50	.107	.063	.031	.43	14. L	.064	410.
D169004	1.8	1.2	.89	.121	.043	.023	.37	15. L	.072	310.
D169005	1.2	.91	.26	.082	.023	.016	.47	9.8	.031	97.
D169006	1.5	1.1	1.2	.150	.092	.016	.44	22.	.052	430.
D169007	2.2	1.5	.95	.165	.031	.015	.40	18. L	.080	380.
D169008	1.3	.84	.29	.059	.024	.022	.46	9.6 L	.032	27. L
D169012	4.5	1.5	.50	.105	.058	.31	.49	30.	.071	71. L
D169013	8.9	5.1	.082	.101	.126	.087	.61	49. L	.17	140. L
D176216	1.7	1.0	.88	.114	.107	.041	.36	11.	.072	410. L
D176217	4.6	2.4	1.0	.179	.087	.22	.62	27.	.11	900. L

SAMPLE	CL %	AS PPM	CD PPM	CU PPM	F PPM	HG PPM	LI PPM	PB PPM	SB PPM	SE PPM
D168801	0.006L	1.	0.06L	12.5	20.L	0.05	5.0	2.2	0.5	1.4
D168802	.010L	1.	.10L	14.4	40.	.01	7.9	4.4	.3	1.9
D168803	.012L	5.	.12L	15.2	90.	.04	9.1	6.4	.7	1.3
D169000	.019L	1.	.19L	37.9	160.	.05	13.4	9.3	.5	1.8
D169001	.008L	1.	.08L	10.8	90.	.06	7.5	3.8	.2	1.2
D169002	.038L	2.	.38L	35.9	195.	.08	22.2	13.4	.4	1.8
D169003	.009L	1.	.09L	18.8	65.	.05	9.1	5.9	.3	1.4
D169004	.010L	1.	.10L	17.8	40.	.10	9.0	6.0	.2	1.6
D169005	.006L	1.	.06L	10.8	95.	.06	4.9	4.4	.3	1.2
D169006	.010L	1.	.10L	17.2	65.	.09	8.6	6.0	.2	1.5
D169007	.011L	1.	.11L	11.4	120.	.04	15.5	6.8	.2	1.1
D169008	.006L	1.	.06L	8.1	80.	.04	4.2	3.7	.2	1.0
D169012	.016L	1.L	.16L	8.1	95.	.02	6.5	6.5	.2	.7
D169013	.032L	2.	.32L	14.5	90.	.05	37.3	61.6	.5	1.6
D176216	.019L	2.	.09L	18.0	50.	.13	7.6	4.8	.3	2.1
D176217	.041L	2.	.21L	19.0	180.	.04	13.8	8.2	.4	2.1

SAMPLE	TH PPM	U PPM	ZN PPM	B PPM-S	BA PPM-S	BE PPM-S	CE PPM-S	CO PPM-S	CR PPM-S	GA PPM-S
D168801	2.9	1.2	2.7	10	500	0.7	N	2	5	2
D168802	3.4	1.2	4.5	15	500	.3	N	1.5	5	3
D168803	7.6	1.8	10.1	15	100	1.5	N	3	7	7
D169000	8.0	2.3	11.5	15	300	1.5	N	3	10	5
D169001	4.5	.7	3.8	15	500	.2	N	1.5	2	2
D169002	7.7	3.2	32.1	20	500	1	N	5	30	10
D169003	5.0	1.2	6.6	15	300	.7	N	2	5	3
D169004	3.7	1.5	3.9	15	500	.7	N	1.5	7	3
D169005	4.1	1.0	5.1	10	200	1.5	30 L	5	5	2
D169006	4.9	1.3	4.6	15	500	.3	N	1.5	3	3
D169007	3.4	1.4	11.5	7	200	.7	N	2	7	3
D169008	3.9	.7	6.3	10	200	1.5	30 L	5	3	2
D169012	3.0L	1.5	5.0	10	70	.7	N	1.5 L	2	5
D169013	15.5	4.1	10.7	20	150	1	N	3	3	10
D176216	4.4	1.0	2.9	20	300	.7	50 L	1.5	3	3
D176217	10.3	1.5	8.2	20	500	1	100 L	3	10	7

SAMPLE	GE PPM-S	LA PPM-S	MO PPM-S	NB PPM-S	ND PPM-S	NI PPM-S	SC PPM-S	SR PPM-S	V PPM-S	Y PPM-S	YB PPM-S	ZR PPM-S
D168801	N	5	0.7	1.5	N	3	2	150	15	5	0.5	20
D168802	N	7	.7	2	N	3	2	150	15	3	.3	20
D168803	N	7	.7	2	N	3	2	70	15	7	.7	20
D169000	N	15	1.5	3 L	N	3	3	100	30	5	.5	30
D169001	N	7	.7	1.5 L	N	2	1.5	200	7	5	.5	15
D169002	N	30	N	7	N	5	7	700	70	10	1	70
D169003	N	10	1	2	N	3	3	200	20	7	.7	20
D169004	N	7	1	2	N	3	2	200	20	7	.7	20
D169005	N	10	1	1.5	10	10	2	100	15	15	1.5	15
D169006	N	7	.7	2 L	N	3	1.5	300	15	5	.5	15
D169007	N	10	.7	2	N	7	2	150	15	7	.7	15
D169008	1.5 L	10	1	1.5	10	10	2	100	10	10	1	10
D169012	N	10	1.5	3 L	N	1.5 L	1.5	200	10	7	.7	20
D169013	N	20	3	10	N	3 L	3	70	20	10	1	70
D176216	N	10 L	.7	3	N	3	1.5	200	15	7	.5	20
D176217	N	20 L	1.5	7	N	10	3	300	30	10	.7	15

Table 5.--Major, minor, and trace-element composition of 10 rock samples from selected sites in the Raton coal field, New Mexico, reported on a whole-rock basis

[Values are in either percent or parts per million. SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, Fe_2O_3, MnO, TiO_2, P_2O_5, Cl, Cd, Cu, Li, Pb, and Zn values were calculated from analyses of rock ash. As, F, Hg, Sb, Se, Th, U, total carbon, organic carbon, carbonate carbon, and total sulfur values are from direct determinations on air-dried (32°C) rock. The remaining analyses, indicated by an S after the element title, were calculated from spectrographic determinations on ash. These spectrographic results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc. but are reported arbitrarily as mid-points of those brackets, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of the spectrographic data is approximately one bracket at 68 percent, or two brackets at 95 percent confidence. L after a value means less than the value shown and N means not detected]

SAMPLE	SIO2 %	AL2O3 %	CAO %	MGO %	NA2O %	K2O %	FE2O3 %	MNO %	TIO2 %	P2O5 %
D169014	60.	21.	0.15	0.89	0.79	2.0	2.2	0.018L	0.85	0.091L
D169015	18.	7.0	4.4	.46	.18	.42	1.1	.007L	.28	.037L
D169016	56.	21.	.46	1.05	.13	2.2	2.3	.018L	.70	.088L
D169017	48.	18.	4.1	1.12	.08	1.6	3.6	.032	.65	.084L
D169018	52.	18.	.27	1.07	.76	1.9	3.0	.016L	.72	.080L
D169019	48.	20.	.20	.91	.13	1.6	2.0	.015L	.65	.077L
D169020	52.	21.	.25	.94	.22	1.2	1.9	.016L	.73	.082L
D169021	51.	19.	.51	1.24	.30	1.2	3.8	.017L	.73	.083L
D169022	54.	20.	.20	1.09	.80	1.7	2.9	.017L	.80	.085L
D169027	42.	14.	.34	.47	.05	2.6	1.9	.013L	.58	.064L

SAMPLE	CL %	AS PPM	CD PPM	CU PPM	F PPM	HG PPM	LI PPM	PB PPM	SB PPM	SE PPM
D169014	0.091L	2.	0.9L	42.	716.	0.04	38.	27.	0.6	1.0
D169015	.037L	5.	.4L	20.	176.	.05	17.	13.	.6	2.1
D169016	.088L	3.	.9L	44.	764.	.06	37.	22.	.7	2.0
D169017	.084L	5.	.8L	65.	488.	.12	35.	25.	.6	2.6
D169018	.080L	4.	.8L	50.	552.	.20	53.	20.L	.4	1.5
D169019	.077L	8.	.8L	65.	680.	.18	38.	27.	.9	3.2
D169020	.082L	4.	.8L	49.	476.	.07	42.	20.	.6	2.1
D169021	.083L	5.	.8L	56.	604.	.09	41.	25.	.8	2.0
D169022	.085L	3.	.9L	53.	632.	.17	66.	21.L	.5	2.0
D169027	.064L	1.	.6L	26.	440.	.05	6.	16.L	.4	.9

SAMPLE	TH PPM	U PPM	ZN PPM	B PPM-S	BA PPM-S	BE PPM-S	CO PPM-S	CR PPM-S	GA PPM-S	LA PPM-S	TOTAL S%
D169014	16.2	6.6	75.	50	700	N	N	50	30	70	0.06
D169015	6.0	2.8	17.	20	200	N	3 L	20	10	N	.32
D169016	13.6	4.6	32.	50 L	700	3	N	50	30	70	.22
D169017	13.4	5.9	62.	50 L	700	N	15	20	20	70	.33
D169018	11.6	5.0	156.	50 L	700	N	15	70	20	N	.54
D169019	14.6	6.7	35.	50 L	500	N	10	50	20	50	.44
D169020	15.1	5.6	168.	50	700	N	N	70	20	70	.17
D169021	14.0	5.5	77.	50 L	700	N	15	50	20	70	.23
D169022	10.7	5.5	191.	50 L	700	2	15	70	20	70	.28
D169027	8.2	4.2	39.	50	500	N	N	10	20	N	.23

SAMPLE	NB PPM-S	NI PPM-S	SC PPM-S	SN PPM-S	SR PPM-S	V PPM-S	Y PPM-S	YB PPM-S	ZR PPM-S	TOTAL C%	ORGNC C%	CRBNT C%
D169014	30	10 L	15	N	300	150	30	3	200	2.83	2.8	0.02
D169015	7	3 L	5	N	700	50	7	1	50	52.2	51.	.96
D169016	15	10 L	15	15	150	150	15	3	150	3.49	3.5	.01L
D169017	15	15	15	N	150	150	15	2	150	8.22	7.4	.83
D169018	15	20	15	N	150	150	20	2	200	12.0	12.	.01L
D169019	15	15	10	N	200	100	15	2	100	13.4	13.	.01L
D169020	15	7 L	15	N	200	150	15	1.5	150	9.45	9.4	.01L
D169021	15	15	15	N	200	150	15	1.5	150	8.99	8.5	.50
D169022	15	20	15	20	150	70	20	2	150	8.03	8.0	.01L
D169027	15 L	N	7 L	N	100	50	15	1.5	100	24.4	24.	.01L

Table 6.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate, ultimate, Btu, and forms-of-sulfur analyses for 10 Raton field coal samples

[All values except Btu are in percent and are reported on the as-received basis]

	Arithmetic mean (abundance)	Observed range		Geometric mean (expected value)	Geometric deviation
		Minimum	Maximum		
Proximate and ultimate analyses					
Moisture	1.8	1.3	2.5	1.8	1.2
Volatile matter	36.1	31.2	42.3	36	1.1
Fixed carbon	50.7	43.5	54.4	50.6	1.1
Ash	11.4	5.8	22.8	10.4	1.6
Hydrogen	5.2	4.7	6	5.2	1.1
Carbon	72.7	61.8	77.8	72.5	1.1
Nitrogen	1.7	1.2	2	1.6	1.1
Oxygen	8.6	7.8	10.4	8.6	1.1
Sulfur	.5	.4	.6	.5	1.2
Btu	13,100	11,620	14,230	13,070	1.1
Forms of sulfur					
Sulfate	0.01	0.00	0.02	0.01	1.4
Pyritic	.06	.02	.11	.05	1.6
Organic	.43	.30	.56	.42	1.2

Table 7.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 17 major and minor oxides and trace elements in the ash of 16 Raton field coal samples

[All samples were ashed at 525°C. L after a value means less than the value shown]

Element or oxide	Arithmetic mean (abundance)	Range		Geometric mean (expected value)	Geometric deviation
		Minimum	Maximum		
Ash %	13.9	6.2	38.2	12.0	1.7
SiO_2 %	45	32	60	45	1.2
Al_2O_3 %	24	17	30	24	1.2
CaO %	9.1	.36	17	5.7	2.7
MgO %	1.72	.53	2.49	1.60	1.5
Na_2O %	.70	.26	1.53	.63	1.6
K_2O %	.65	.08	2.3	.45	2.4
Fe_2O_3 %	6.2	2.8	11	5.8	1.5
MnO %	.023	.015	.029	.022	1.3
TiO_2 %	1	.73	1.3	1	1.2
P_2O_5 %	1	.1 L	1.7	.28	5.4
SO_3 %	5.4	.62	6.4	1.9	4.4
Cd ppm	1 L	------	1 L	-------	---
Cu ppm	143	46	208	128	1.6
Li ppm	83	40	136	80	1.3
Pb ppm	59	35	195	55	1.5
Zn ppm	59	31	102	54	1.5

Table 6a.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate, ultimate, and forms-of-sulfur analyses for 86 Rocky Mountain province coal samples

[All values except Btu are in percent and are reported on the as-received basis]

	Arithmetic mean (abundance)	Observed range		Geometric mean (expected value)	Geometric deviation
		Minimum	Maximum		
Proximate and ultimate analyses					
Moisture	12.9	1.6	35.0	10.5	2.0
Volatile matter	36.0	22.7	46.7	35.7	1.1
Fixed carbon	42.0	17.1	52.5	41.5	1.2
Ash	9.1	2.1	32.2	7.7	1.8
Hydrogen	5.6	4.4	6.7	5.6	1.1
Carbon	59.7	27.1	75.2	58.9	1.2
Nitrogen	1.2	.5	1.6	1.1	1.3
Oxygen	23.8	8.2	47.9	22.4	1.4
Sulfur	.6	.2	5.1	.5	1.8
Btu	10,480	4,660	13,370	11,110	1.5
Forms of sulfur					
Sulfate	0.05	0.01L	1.59	0.02	2.4
Pyritic	.19	.02	2.64	.11	2.9
Organic	.32	.06	1.11	.22	3.0

Table 7a.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 17 major and minor oxides and trace elements in the ash of 295 Rocky Mountain province coal samples

[All samples were ashed at 525°C; L after a value means less than the value shown]

Oxide or element	Arithmetic mean (abundance)	Observed range		Geometric mean (expected value)	Geometric deviation
		Minimum	Maximum		
Ash %	13.3	1.76	88.2	10.9	1.9
SiO_2 %	46	15	79	44	1.4
Al_2O_3 %	21	4.3	35	19	1.4
CaO %	8.9	.21	35	6.2	2.4
MgO %	1.63	.22	7.10	1.4	1.8
Na_2O %	1.39	.08	8.56	.68	3.3
K_2O %	.65	.05	3.0	.45	2.3
Fe_2O_3 %	7.6	1.1	26	4.5	2.8
MnO %	.049	.004	.55	.029	2.8
TiO_2 %	.89	.02L	1.8	.81	1.6
P_2O_5 %	.41	.056	3.6	.14	4.2
SO_3 %	8.4	.10L	29	5.1	2.7
Cd ppm	.7	.5 L	4.0	.59	1.9
Cu ppm	87	22	1,260	77	1.6
Li ppm	88	10 L	328	73	1.9
Pb ppm	45	20 L	195	41	1.5
Zn ppm	77	13	1,820	62	1.9

Table 8.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 37 elements in 16 Raton field coal samples (whole-coal basis). For comparison, average shale values are listed (Turekian and Wedepohl, 1961)

[As, F, Sb, Th, and U values used to calculate the statistics were determined directly on whole coal. All other values used were calculated from determinations made on coal ash. L after a value means less than the value shown. Statistical values for Mn and Cd could not be calculated owing to variability of the lower limits]

Element or oxide	Arithmetic mean (abundance)	Range Minimum	Range Maximum	Geometric mean (expected value)	Geometric deviation	Average shale
Si %	3.1	1.2	8.9	2.5	2.0	7.3
Al %	1.8	.84	5.1	1.5	1.7	8.0
Ca %	.74	.08	3.1	.49	2.5	2.21
Mg %	.126	.059	.33	.115	1.5	1.55
Na %	.068	.022	.14	.056	1.9	.96
K %	.09	.005	.37	.04	3.5	2.66
Fe %	.49	.34	.81	.48	1.3	4.72
Mn ppm	---	9.6 L	30	---	---	850
Ti %	.08	.03	.21	.07	1.7	.46
P ppm	310	27 L	750	220	2.3	700
As ppm	1	1 L	5	1	1.6	13
Cd ppm	---	.1 L	.4 L	---	---	.3
Cu ppm	16.9	8.1	37.9	15.3	1.6	45
F ppm	95	20 L	195	78	1.9	740
Hg ppm	.06	.01	.13	.05	1.8	.4
Li ppm	11.1	4.2	37.3	9.5	1.8	66
Pb ppm	8.5	2.2	61.6	6.5	2.1	20
Sb ppm	.3	.2	.7	.3	1.5	1.5
Se ppm	1.5	.7	2.1	1.4	1.3	.6
Th ppm	5.7	2.9	15.5	5	1.7	12
U ppm	1.6	.7	4.1	1.4	1.6	3.7
Zn ppm	7.9	2.7	32.1	6.5	1.9	95
B ppm	15	7	20	15	1.4	100
Ba ppm	300	70	500	300	1.9	580
Be ppm	1	.2	1.5	.7	1.8	3
Co ppm	3	1.5 L	5	2	1.6	19
Cr ppm	7	2	30	5	2.0	90
Ga ppm	5	2	10	3	1.8	19
Mo ppm	1	.7	3	1	1.6	2.6
Nb ppm	3	1.5 L	10	3	2.0	11
Ni ppm	5	1.5 L	10	3	2.0	68
Sc ppm	2	1.5	7	2	1.5	13
Sr ppm	200	70	700	150	1.8	300
V ppm	20	7	70	15	1.7	130
Y ppm	7	3	15	7	1.5	26
Yb ppm	.7	.3	1.5	.7	1.5	2.6
Zr ppm	20	10	70	20	1.7	160

estimate of elemental abundance. In Tables 6-8 and 6a-8a, the estimates of arithmetic means (abundance) are Sichel's *t* statistic (Miesch, 1967).

A common problem in statistical summaries of trace-element data arises when the element concentration in one or more of the samples lies below the limit of analytical detection, resulting in a "censored" distribution. Procedures developed by Cohen (1959) are used here to compute unbiased estimates of the geometric mean, geometric deviation and arithmetic mean for cases in which the concentration data are censored.

Acknowledgments

The analytical results for this paper were compiled with the assistance of Scott D. Woodruff and Ricky T. Hildebrand, U.S. Geological Survey. The proximate, ultimate, Btu and forms-of-sulfur analyses of the coal samples in Table 1 were made by the Coal Analysis Section of the U.S. Bureau of Mines, Pittsburgh, Pa., under the direction of Forrest E. Walker, chemist-in-charge. The major- and minor-oxide and trace element analyses in Tables 2, 3, 4 and 5 were made by A. J. Bartel, J. W. Brown, G. T. Burrow, E. J. Fennelly, J. Gardner, P. Guest, J. C. Hamilton, R. J. Knight, R. E. McGregor, V. M. Merritt, H. T. Millard, Jr., D. R. Norton, V. E. Shaw, G. D. Shipley, J. A. Thomas, J. S. Wahlberg and T. L. Yager of the U.S. Geological Survey, under the direction of Claude Huffman, Jr., chemist-in-charge.

Table 8a.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 37 elements in 295 Rocky Mountain province coal samples (whole-coal basis). For comparison average shale values are listed (Turekian and Wedepohl, 1961)

[As, F, Sb, Se, Th, and U values used to calculate the statistics were determined directly on whole-coal. All other values used were calculated from determinations made on coal ash. L means less than the value shown]

Element	Arithmetic mean (abundance)	Observed range Minimum	Observed range Maximum	Geometric mean (expected value)	Geometric deviation	Average shale
Si %	3.2	0.9	23	2.3	2.3	7.3
Al %	1.6	.14	13	1.1	2.3	8.0
Ca %	.61	.05	3.7	.48	2.0	2.21
Mg %	.107	.015	.76	.089	1.8	1.55
Na %	.155	.002	.76	.055	4.2	.96
K %	.092	.003	1.7	.041	3.6	2.66
Fe %	.64	.10	4.2	.34	3.1	4.72
Mn ppm	33	2.7	492	20	2.6	850
Ti %	.062	.001L	.54	.047	2.1	.46
P ppm	280	8.2	1800	120	3.7	700
As ppm	2	1 L	50	2	2.5	13
Cd ppm	.8	.021	.50	.5	2.7	.3
Cu ppm	10.8	1.3	100	8.4	2.0	45
F ppm	95	20 L	920	69	2.2	740
Hg ppm	.08	.01	1.48	.05	2.4	.4
Li ppm	13	.44 L	82.9	8.0	2.7	66
Pb ppm	6.5	.95	62	4.7	2.2	20
Sb ppm	.4	.05 L	5.2	.3	2.2	1.5
Se ppm	1.6	.10L	5.7	1.2	2.1	.6
Th ppm	4.2	1.7	34.8	2.9	2.5	12
U ppm	1.9	.1	23.8	1.1	2.8	3.7
Zn ppm	10.7	1.0	380	6.8	2.6	95
B ppm	70	7	300	70	2.2	100
Ba ppm	300	3	1,500	150	2.6	580
Be ppm	.7	.05	3	.5	2.3	3
Co ppm	2	.3	10	1.5	2.0	19
Cr ppm	5	.5	70	5	2.2	90
Ga ppm	5	.3	30	3	2.3	19
Mo ppm	2	.2	15	1.5	2.3	2.6
Nb ppm	7	.3	30	5	2.6	11
Ni ppm	3	.7	20	2	2.1	68
Sc ppm	2	.3	15	1.5	2.0	13
Sr ppm	100	5	700	100	2.1	300
V ppm	15	1.5	100	100	2.1	130
Y ppm	7	.5	30	5	2.1	26
Yb ppm	.7	.03	3	.5	2.2	2.6
Zr ppm	30	3	100	20	2.3	160

Sample Information

Description of 10 analyzed samples on Table 1

Samples D168801 and D168802

Underground mine face channel samples (D168801) and (D168802), Left Fork coal bed, Raton Formation, Paleocene age; sample D168801 is 108 inches thick, a 6 in. parting is excluded; sample D168802 is 84 in. thick, a basal split and parting are excluded, Left Fork prospect, Colfax County, New Mexico, lat. 36°56′21″ N, long. 105°58′ W.

Sample D168803

Outcrop channel sample, Potato Canyon bed, 72 in. thick, partings excluded, Raton Formation, Paleocene age, Potato Canyon prospect, Colfax County, New Mexico, lat. 36°52′27″ N, long. 104°40′36″ W.

Samples D169000 and D169001

Face bench samples, lower (D169000) and main (D169001) benches of the York Canyon bed, 27 and 48 in. thick, respectively, Raton Formation, Paleocene age, York Canyon mine, long wall panel, 7th right, Colfax County, New Mexico, lat. 36°52′13″ N, long. 104°53′37″ W.

Samples D169004 and D169005

Face bench samples, main (D169004) and upper (D169005) benches of the York Canyon bed, 106 and 16 in. thick, respectively, Raton Formation, Paleocene age, Kaiser Steel strip mine (south end), Colfax County, New Mexico, lat. 36°52′13″ N, long. 104°55′14″ W.

Sample D169006

Face bench sample, main bench of the York Canyon bed, 87 in. thick, Raton Formation, Paleocene age, Kaiser Steel strip mine (north end), Colfax County, New Mexico, lat. 36°52′38″ N, long. 104°55′17″ W.

Sample D169013

Core sample, 60 in. thick, Raton bed, Vermejo Formation, Early

Cretaceous age, depth 1,189-1,194 feet, lat. 36°48'55" N, long. 104°37'13" W.

Sample D176216

Underground mine face channel sample, York Canyon bed, lower bench 60 in. thick (composited with D176217 for this analysis), partings excluded, Raton Formation, Paleocene age, York Canyon mine, Colfax County, New Mexico, lat. 36°53' N, long. 104°54'46" W. (Collected by George S. Austin, New Mexico Bureau of Mines & Mineral Resources.)

Description of 6 additional coal samples not on Table 1 but included on Tables 2, 3 and 4

Samples D169007 and D169008

Upper bench samples, 18 in. second bench (D169007), and 14 in. top bench (D169008) of the York Canyon bed, Raton Formation, Paleocene age Kaiser Steel strip mine (north end), Colfax County, New Mexico, lat. 36°52'38" N, long. 104°55'17" W.

Sample D169072

Outcrop face channel sample, Raton bed, 60 in. thick, Vermejo Formation, Late Cretaceous age, tributary to Spring Canyon, Vermejo Park, Colfax County, New Mexico, lat. 36°55'30" N, long. 105°01'10" W.

Sample D769002

Tipple sample (middling coal), York Canyon mine wash plant, York Canyon bed, Raton Formation, Paleocene age, Colfax County, New Mexico, lat. 36°52'1 3" N, long, 104°53'37" W.

Sample D169003

Tipple sample (clean-coal pile), York Canyon mine wash plant, York Canyon bed, Raton Formation, Paleocene age, Colfax County, New Mexico, lat. 36°52'13" N, long. 104°53'37" W.

Sample D776217

Underground mine face channel sample, York Canyon bed, upper bench 69 inches thick, Raton Formation, Paleocene age, York Canyon mine, Colfax County, New Mexico, lat. 36°53' N, long. 104°54'46" W. (Collected by George S. Austin, New Mexico Bureau of Mines & Mineral Resources.)

Descriptions of rock samples on Table 5

Samples D169014 and D169015

York Canyon bed, Raton Formation, Paleocene age, York Canyon mine, long wall panel, 7th right, Colfax County, New Mexico, lat. 36°52'13" N, long. 104°53'37" W.

D169015—channel sample, carbonaceous shale 3 in. thick
(D169001—main coal bed sample, 48 in. thick)
D169014—channel sample, silty carbonaceous shale 3 in. thick at base of coal
(D169000—lower coal bench sample, 27 in. thick)

Samples D169076, D169017, and D169018

York Canyon bed, Raton Formation, Paleocene age, Kaiser Steel strip mine (south end), Colfax County, New Mexico, lat. 36°52'13" N, long. 104°55'14" W.

D169018—channel sample, carbonaceous shale and mudstone (roof) 4 in. thick
D169017—channel sample, carbonaceous shale 10 in. thick
(D169005—upper coal bench 16 in. thick) D169016—channel sample, basal carbonaceous shale and mudstone 4 in. thick
(D169004—main coal seam 106 in. thick)

Samples D169019, D769020, D169021, and D169022

York Canyon bed, Raton Formation, Paleocene age, Kaiser Steel strip mine (north end), Colfax County, New Mexico, lat. 36°52'38" N, long. 104°55'17" W.

D169022—channel sample, carbonaceous mudstone (roof) 6 in. thick
D169021—channel sample, carbonaceous shale 7 in. thick
(D169008—top bench of coal, 14 in. thick) D169020—channel sample, coaly shale and shaly coal split 10 in. thick
(D169007—second bench of coal, 18 in. thick) D169019—channel sample, carbonaceous shale and mudstone 4 in. thick at base of coal

Sample D169027

Outcrop sample (3 in.) at base of coal, Raton bed, Vermejo Formation, Late Cretaceous age, tributary to Spring Canyon, Vermejo Park, Colfax County, New Mexico, lat. 36°55'30", long. 105°01'10" W.

References

Cohen, A. C., 1959, Simplified estimators for the normal distribution when samples are singly censored or truncated: Technometrics, v. 1, p. 217-237.

Connor, J. J., Keith, J. R., and Anderson, B. M., 1976, Trace-metal variation in soils and sagebrush in the Powder River Basin, Wyoming and Montana: U.S. Geol. Survey Jour. Research, v. 4, p. 49-59.

Miesch, A. T., 1967, Methods of computation for estimating geochemical abundance: U.S. Geol. Survey Prof. Paper 574-B, 15 p.

Pillmore, C. L., 1969, Geology and coal deposits of the Raton coal field, Colfax County, New Mexico: Mtn. Geologist, v. 6, p. 125-142.

Turekian, K. K., and Wedepohl, K. H., 1961, Distribution of the elements in some major units of the Earth's crust: Geol. Soc. America Bull., v. 72, p. 175-192.