DEPARTMENT OF THE INTERIOR

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Plays for oil and gas in the Raton basin, south-central Colorado and northeastern New Mexico

by

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CONTENTS

ILLUSTRATIONS

TABLES

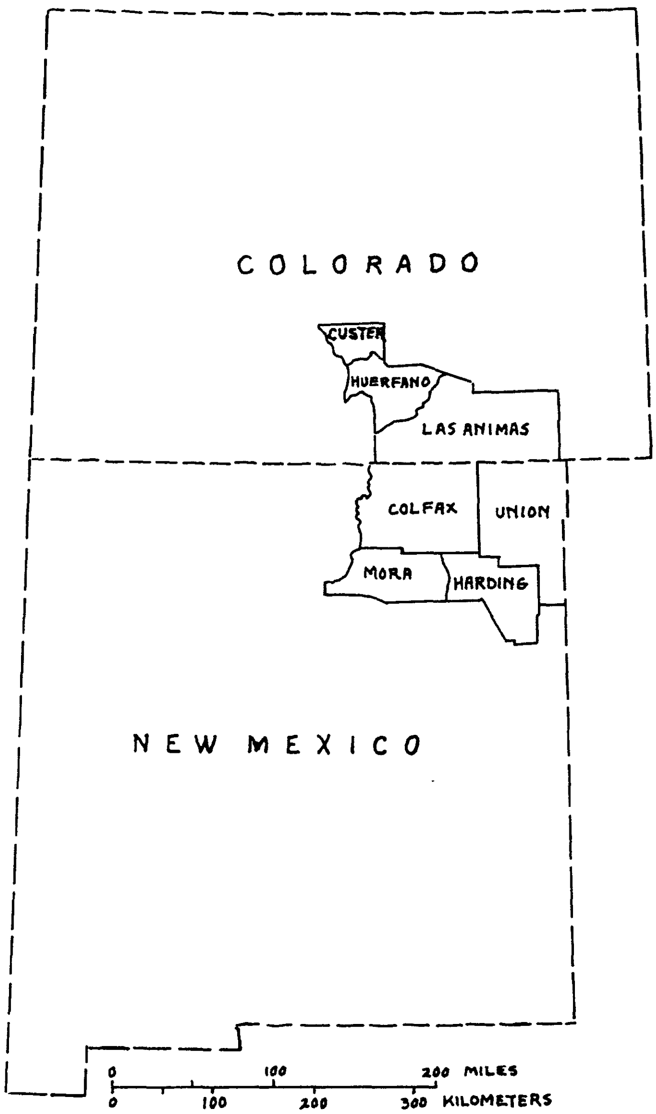

Figure 1.--Counties in the region of the Raton basin

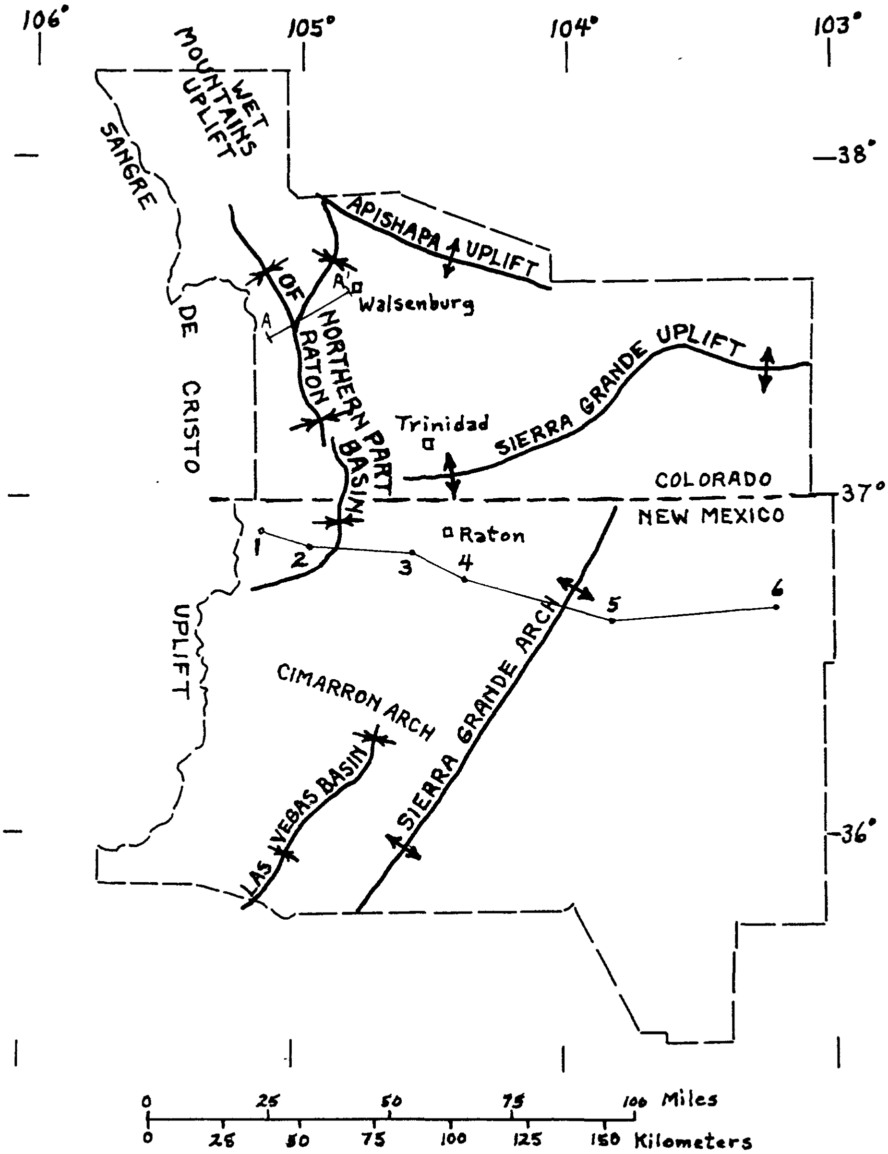

Figure 2.--Map showing structural features (Baltz, 1965/Tweto, 1979/Scanlon, 1983) and location of cross sections (figs. 3 and 4) in the region of the Raton basin, Colorado and New Mexico

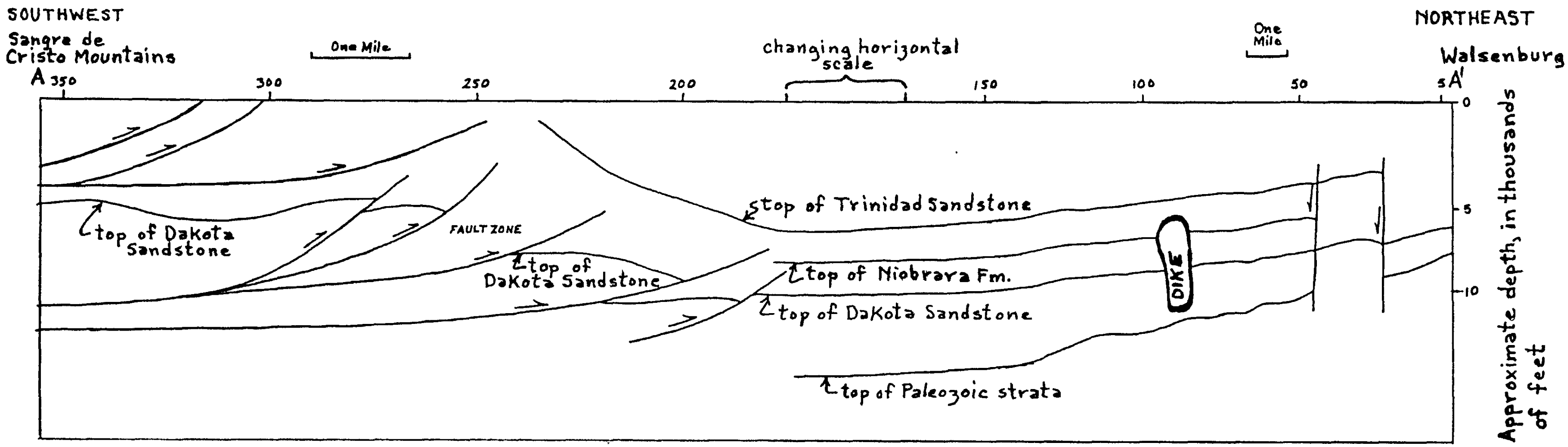

Figure 3.--Seismic cross section of the Raton basin (fig. 2) showing possible tops of stratigraphic units in Huerfano County, Colorado (Applegate and Rose, 1985)

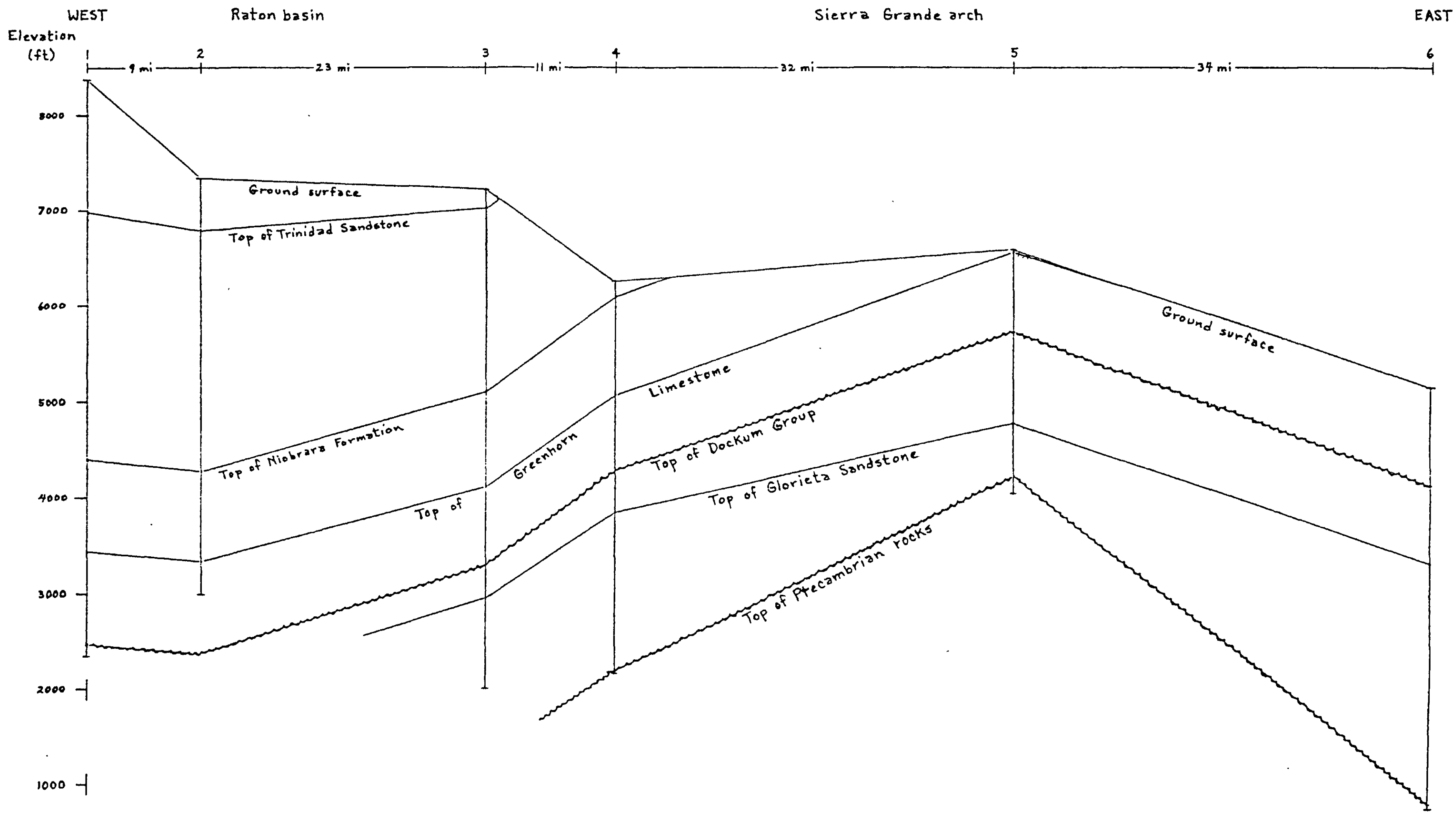

Figure 4.--Cross section of the Raton basin and the Sierra Grande arch, derived from logs of boreholes in Colfax and Union Counties, New Mexico. Locations of boreholes shown on figure 2 and table 1. Wavy lines represent unconformities.

siliciclastic and carbonate beds and is as much as 700 ft thick. Pennsylvanian and Permian strata unconformably overlie Precambrian rocks on the Apishapa and Sierra Grande uplifts and on the Sierra Grande arch (fig. 2).

Table 1.--Boreholes used for cross section (fig. 4) of Raton basin in northeastern New Mexico

Borehole	Operator	Name	County	Sec.	T.	R.
1	W. J. Gourley	Vermejo Park 1	Colfax	27	31N.	17E.
2	American Fuels Corp.	W.S. Ranch NM-B 1	-do-	6	30N.	19E.
3	Continental Oil Co.	St. Louis-Rocky Mountain and Pacific Rail-road Co. 1	-do-	13	30N.	22E.
4	Melvin Condron	Moore 1	-do-	10	29N.	24E.
5	Amoco Production Co.	State-EV1	Union	26	28N.	29E.
6	Skelly Oil Co.	N.M. Van Pelt 1	-do-	9	28N.	35E.

The Permian beds in the Raton basin are unconformably overlain by the Upper Triassic Dockum Group, a body of fluvial sandstone and shale as much as 1,200 ft thick (Baltz, 1965). The Upper Triassic rocks are unconformably overlain by Middle and Upper Jurassic strata, which consist of continental and shallow-marine siliciclastic and carbonate rocks, and are about 200-600 ft thick (Peterson, 1972; Berman and others, 1980). This Jurassic unit is unconformably overlain by a sequence of Lower and Upper Cretaceous beds that includes the Purgatoire Formation and the overlying Dakota Sandstone. These Cretaceous strata are composed mainly of continental and nearshore-marine sandstone and shale; their combined thicknesses are as much as 350 ft (Speer, 1976). Conformably overlying the Dakota is a succession of lower Upper Cretaceous formations (in ascending order, the Graneros, Greenhorn, Carlile, and Niobrara) which consist of open-marine shale, limestone, and minor sandstone, and are 1,100-1,300 ft thick (Baltz, 1965; Woodward, 1984). These rocks are conformably overlain by the Upper Cretaceous Pierre Shale, a body of open-marine shale as much as 2,900 ft thick. Shale and siltstone in the upper part of the Pierre grade into the overlying sandstone of the Upper Cretaceous Trinidad Sandstone. The Trinidad was deposited in delta-front and interdeltaic barrier-bar environments (Flores and others, 1985) and is commonly 100-250 ft thick (Matuszczak, 1969; Dolly and Meissner, 1977). Marine sandstone at the top of the Trinidad grades into nonmarine rocks of the overlying, Upper Cretaceous, Vermejo Formation (Pillmore, 1969). The Vermejo is composed of siliciclastic and coaly beds, which accumulated in fluvio-deltaic and coastal-plain environments (Flores and others, 1985); it is as much as 400 ft thick (Woodward, 1984). These beds are unconformably overlain, and conformably overlain locally, by the Raton Formation of Late Cretaceous and Paleocene age (Pillmore, 1969). The Raton Formation consists of

ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC NOMENCLATURE AND KNOWN PETROLIFEROUS ROCKS (*)	DOMINANT LITHOLOGY	THICKNESS (FEET)
CENOZOIC	QUATERNARY	Holocene		alluvium and eolian deposits	
		Pleistocene		alluvium, eolian deposits, and glacial drift	
	TERTIARY	Miocene	Ogallala Formation	sand and gravel	
		Oligocene		volcanic rocks	
		Eocene	Farisita Conglomerate	conglomerate and sandstone	0-1,200
			Huerfano Formation	sandstone and shale	0-2,000
			Cuchara Formation	sandstone and shale	0-5,000
		Paleocene	Poison Canyon Formation *	sandstone, siltstone, and mudstone	0-2,500
			Raton Formation *	sandstone, shale, and coal	1,100-more than 2,100
MESOZOIC	CRETACEOUS	Upper	Vermejo Formation *	sandstone, shale, and coal	0-400
			Trinidad Sandstone *	sandstone	0-300
			Pierre Shale *	shale	1,600-2,900
			Niobrara Formation *	shale and limestone	820-920
			Carlile Shale *	shale and siltstone	110-340
			Greenhorn Limestone *	limestone and shale	20-90
			Graneros Shale *	shale	110-400
			Dakota Sandstone *	sandstone and shale	30-200
		Lower	Purgatoire Formation	sandstone, shale, and coal	70-180
	JURASSIC	Upper	Morrison Formation	sandstone and shale	150-400
		Middle	Todilto Limestone	limestone and shale	50-100
			Entrada Sandstone	sandstone	20-120
	TRIASSIC	Upper	Dockum Group or Fm.	sandstone and shale	0-1,200
PALEOZOIC	PERMIAN	Guadalupian	Bernal Formation	shale, siltstone, and sandstone	0-150
		Leonardian	San Andres Limestone	limestone	0-150
			Glorieta Sandstone	sandstone	0-275
			Yeso Formation	shale, siltstone, and sandstone	0-500
		Wolfcampian	Sangre de Cristo Formation	shale, sandstone, and conglomerate	700-5,300
	PENNSYLVANIAN	Virgilian			
		Missourian			
		Desmoinesian	Magdalena Group	shale, sandstone, and limestone	0-6,000
		Atokan			
		Morrowan			
	MISSISSIPPIAN	Meramecian	Tererro Formation	conglomerate, limestone, and siltstone	0-130
		Osagean			
		Kinderhookian			
	DEVONIAN	Upper	Espiritu Santo Formation	sandstone and limestone	0-80
PRECAMBRIAN			metamorphic and igneous rocks		

Figure 5.--Stratigraphic units along the western flank of the Raton basin and known petroliferous rocks (*) in the basin, in Custer, Las Animas, and Huerfano Counties, Colorado, and Colfax, Harding, Mora, and Union Counties, New Mexico

siliciclastic and coaly rocks, which were deposited in fluvial environments, and it commonly ranges in thickness from about 1,100 ft to more than 2,100 ft.

The Poison Canyon Formation of Late Cretaceous and Paleocene age conformably overlies and intertongues with the Raton Formation in the basin but unconformably overlies the Raton, Vermejo, Trinidad, and Pierre Formations on the northwestern flank of the basin. The Poison Canyon is composed mostly of arkosic strata, which accumulated in fluvial environments (Flores and others, 1985), and is commonly 500-2,500 ft thick (Dolly and Meissner, 1977). Unconformably overlying the Poison Canyon in the northern part of the basin is a sequence of Tertiary (Eocene) formations composed mainly of varicolored, conglomeratic sandstone and interbedded variegated shale. Locally, this continental sequence is at least 5,000 ft thick (Dolly and Meissner, 1977).

Source rocks

In the Raton basin, marine shale in the Pennsylvanian Magdalena Group and marine limestone of Permian age could contain source beds for oil and gas (Volk, 1972; Woodward, 1984). Some of the marine shale and nonmarine carbonaceous beds of Early Cretaceous age as well as some of the marine shale and limestone of early Late Cretaceous age evidently are source rocks. Data from pyrolysis assays of 34 samples of cores and outcrops (using the procedure of Espitalie and others, 1977) indicate that the Dakota Sandstone, Greenhorn Limestone, Carlile Shale, and Niobrara Formation include source rocks of moderate to fair quality (tables 2 and 3). Marine shale units and nonmarine carbonaceous beds in other formations of Late Cretaceous age are also sources for oil and gas. Pyrolytic data from about 20 samples of these strata indicate that the Pierre Shale, Vermejo Formation, and Raton Formation contain source rocks of moderate to fair quality (tables 2 and 3). The coal in the Vermejo and Raton probably contains much methane (Dolly and Meissner, 1977). Continental mudstone beds in the Poison Canyon Formation of Paleocene age apparently are sources for oil and gas. Data from the pyrolytic analyses of two samples of core from the Poison Canyon indicate moderate to excellent source beds.

Burial history, thermal maturity, and timing of migration

The sedimentary rocks in the Raton basin were deposited and eroded intermittently during Phanerozoic time. These rocks formerly were at least 20,000 ft thick in the northern, deeper part of the basin; strata as much as 5,000 ft thick were eroded locally during the Cenozoic. Assuming that the generation of oil begins at about 212°F and that the geothermal gradient was 1.5-1.6°F/100 ft, the strata at depths of more than 10,000 ft could have generated oil. Lindsey, Andriessen, and Wardlaw (1986) report that more than 13,000 ft of sediment had been deposited near the western border of Custer County (fig. 1) by the end of Early Permian time. Consequently, petroleum generation could have begun in the northern part of the basin during the Permian. Nevertheless, analytical data from samples of outcrops and shallow cores in the western part of the region (tables 2 and 3) and from publications (Gautier and others, 1984; Bostick and Pawlewicz, 1984) indicate that strata of latest Cretaceous and Paleocene ages at the surface are mature to marginally mature (fig. 6). Dolly and Meissner (1977) obtained similar results from their study of the ranks of the shallow coal beds in the northern

Table 2.--Location and description of core and outcrop samples from the Raton basin, south-central Colorado and northeastern New Mexico

Core sample	County, State	Location (Sec.-T.-R.)	Borehole (company, lease)	Depth (ft)	Formation	Lithology
1	Huerfano, Colorado	11-29S.-67W.	Filon Expl. Co., Golden Cycle 1	661	Poison Canyon	carbonaceous mudstone
2	--do--	--do--	--do--	765	--do--	Do.
3	--do--	--do--	--do--	1,652	Raton	carbonaceous siltstone
4	--do--	--do--	--do--	1,714	--do--	mudstone
5	Las Animas, Colorado	15-33S.-63W.	Tom Vessels, McCarty 1	1,671	Niobrara	calcareous shale
6	--do--	--do--	--do--	1,683	--do--	Do.
7	--do--	--do--	--do--	2,034	--do--	Do.
8	--do--	--do--	--do--	2,035	--do--	Do.
9	--do--	10-34S.-62W.	Pecos Western Co., Hargrove Shadel 2	849	--do--	Do.
10	--do--	--do--	--do--	850	--do--	Do.
11	--do--	--do--	--do--	995	--do--	Do.
12	--do--	--do--	--do--	997	--do--	Do.
13	--do--	--do--	--do--	1,529	--do--	Do.
14	--do--	--do--	--do--	1,537	--do--	Do.
15	Colfax, New Mexico	24-28N.-20E.	Bennett Petroleum Co., Phelps-Dodge 1	2,020	--do--	Do.
16	--do--	--do--	--do--	2,036	--do--	Do.

Table 2.--Location and description of core and outcrop samples from the Raton basin, south-central Colorado and northeastern New Mexico--continued

Outcrop sample	County, State	Location (Sec.-T.-R.)	Formation	Member	Lithology
17	Huerfano, Colorado	4-27S.-68W.	Carlile Shale	Juana Lopez	calcareous shale
18	--do--	5-27S.-68W.	Greenhorn Limestone	Hartland Shale	Do.
19	--do--	26-30S.-69W.	Niobrara	Smoky Hill Shale	Do.
20	Las Animas, Colorado	34-28S.-53W.	Dakota Sandstone		shale
21	--do--	16-30S.-64W.	Niobrara	Smoky Hill Shale	calcareous shale
22	--do--	35-31S.-69W.	Pierre Shale		shale
23	--do--	--do--	Vermejo		carbonaceous shale
24	--do--	30-32S.-63W.	Pierre Shale		shale
25	--do--	--do--	--do--		Do.
26	--do--	18-32S.-68W.	--do--		Do.
27	--do--	19-32S.-68W.	--do--		Do.
28	--do--	--do--	--do--	Tepee zone	limestone
29	--do--	8-33S.-60W.	Niobrara	Fort Hays Limestone	calcareous shale
30	--do--	--do--	Carlile Shale	Juana Lopez	Do.
31	--do--	23-33S.-68W.	Vermejo		coaly mudstone
32	--do--	29-33S.-68W.	Pierre Shale		shale
33	--do--	1-34S.-64W.	Vermejo		carbonaceous shale
34	--do--	17-34S -68W.	Pierre Shale		shale
35	--do--	25-34S.-69W.	--do--		Do.
36	--do--	7-35S.-63W.	Raton		carbonaceous shale
37	Colfax, New Mexico	24-31N.-23E.	Pierre Shale		shale
38	--do--	6-30N.-23E.	--do--		Do.
39	--do--	35-30N.-23E.	--do--	Sharon Springs	Do.

Table 2.--Location and description of core and outcrop samples from the Raton basin, south-central Colorado and northeastern New Mexico--continued

Outcrop sample	County, State	Location (Sec.-T.-R.)	Formation	Member	Lithology
40	--do--	2-28N.-26E.	Niobrara	Smoky Hill Shale	calcareous shale
41	--do--	36-27N.-18E.	Pierre Shale		shale
42	--do--	31-27N.-23E.	Niobrara	Smoky Hill Shale	calcareous shale
43	--do--	32-26N.-19E.	Pierre Shale	Sharon Springs	septarian concretion
44	--do--	--do--	--do--	--do--	shale
45	--do--	28-25N.-19E.	Niobrara	Smoky Hill Shale	calcareous shale
46	--do--	33-25N.-22E.	--do--	--do--	Do.
47	--do--	--do--	--do--	Fort Hays Limestone	Do.
48	--do--	2-24N.-19E.	--do--	Smoky Hill Shale	Do.
49	--do--	9-24N.-23E.	Greenhorn Limestone	Hartland Shale	Do.
50	Harding, New Mexico	3-22N.-25E.	--do--	--do--	Do.
51	Mora, New Mexico	27-21N.-22E.	Niobrara	Smoky Hill Shale	Do.
52	--do--	7-21N.-23E.	Carlile Shale	Juana Lopez	Do.
53	--do--	35-20N.-24E.	Dakota Sandstone		shale
54	Union, New Mexico	31-31N.-28E.	Niobrara	Fort Hays Limestone	calcareous shale
55	--do--	4-30N.-28E.	Greenhorn Limestone	Hartland Shale	Do.
56	--do--	11-27N.-34E.	Dakota Sandstone		shale
57	--do--	16-23N.-29E.	--do--		Do.

Table 3.--Organic composition, hydrocarbon-source potential, and thermal maturity of sampled rocks from the Raton basin, south-central Colorado and northeastern New Mexico

Sample (Described on Table 2)	Organic carbon (wt%)	S_1 (mg/g)	S_2 (mg/g)	S_3 (mg/g)	$T(S_2)$ (°C)	Genetic potential (ppm)	HI (mgHC /gC)	OI ($mgCO_2$ /gC)	Transformation ratio (S_1/S_1+S_2)	Hydrocarbon-source potential	R_o, percent (median)	Thermal maturity
1	3.31	0.08	4.07	0.44	430	4,150	122	13	0.02	moderate to fair	0.62	marginally mature
2	3.40	0.16	7.91	0.44	437	8,070	232	12	0.02	good to excellent		Do.
3	1.73	0.28	1.68	0.71	438	1,960	97	41	0.14	marginal		mature
4	0.50	0.08	0.26	0.24	431	340	52	48	0.24	poor		Do.
5	1.20	0.39	0.86	0.13	462	1,250	71	10	0.31	marginal	1.30?	Do.
6	1.53	0.40	1.02	0.11	463	1,420	66	7	0.28	--do--		Do.
7	2.53	1.19	1.55	0.23	472	2,740	61	9	0.43	moderate to fair		Do.
8	2.83	1.32	1.67	0.23	463	2,990	59	8	0.44	--do--		Do.
9	1.84	1.50	3.04	0.35	441	4,540	165	19	0.33	--do--	1.04?	Do.
10	1.60	1.32	3.03	0.23	445	4,350	189	14	0.30	--do--		Do.
11	1.80	1.28	2.16	0.42	444	3,440	120	23	0.37	--do--	0.89	Do.
12	1.59	1.11	3.21	0.31	445	4,320	201	19	0.26	--do--	0.81?	Do.
13	2.02	0.43	2.00	0.21	451	2,430	99	10	0.18	--do--		Do.
14	0.88	0.16	0.63	0.20	446	790	71	22	0.21	poor		Do.
15	2.17	1.59	3.74	0.25	450	5,330	172	11	0.30	moderate to fair		Do.
16	1.53	1.20	2.31	0.20	447	3,510	150	13	0.34	--do--		Do.
17	0.30	0.00	0.04	0.52	---	40	13	173	0.00	poor		unknown
18	0.99	0.01	0.18	1.19	441	190	18	120	0.06	--do--		probably mature
19	2.82	0.14	3.43	.097	442	3,570	121	34	0.04	moderate to fair		Do.

Table 3.--Organic composition, hydrocarbon-source potential, and thermal maturity of sampled rocks from the Raton basin, south-central Colorado and northeastern New Mexico--(continued)

Sample (Described on Table 2)	Organic carbon (wt%)	S_1 (mg/g)	S_2 (mg/g)	S_3 (mg/g)	$T(S_2)$ (°C)	Genetic potential (ppm)	HI (mgHC /gC)	OI ($mgCO_2$ /gC)	Transformation ratio (S_1/S_1+S_2)	Hydrocarbon-source potential	R_o, percent (median)	Thermal maturity
20	1.99	0.02	2.04	0.61	430	2,060	102	30	0.01	--do--	0.49-0.53	immature
21	1.33	0.03	0.74	1.40	436	770	55	105	0.04	poor		possibly mature
22	0.89	0.05	0.47	0.55	441	520	52	61	0.10	--do--		mature
23	10.89	0.62	34.30	0.76	441	34,920	314	6	0.02	good to excellent	0.65	Do.
24	1.07	0.05	0.52	0.22	444	570	48	20	0.09	poor		mature
25	1.21	0.08	0.58	0.03	445	660	47	2	0.12	--do--		Do.
26	0.78	0.04	0.40	0.60	442	440	51	76	0.09	--do--		Do.
27	1.07	0.09	0.44	0.64	449	530	41	59	0.17	--do--		Do.
28	0.16	0.04	0.14	0.16	436	180	87	100	0.22	--do--		Do.
29	0.41	0.00	0.07	0.56	437	70	17	136	0.00	--do--		possibly mature
30	1.69	0.06	2.12	0.89	438	2,180	125	52	0.03	moderate to fair		Do.
31	42.68	0.26	42.28	17.11	445	42,540	99	40	0.01	good to excellent	0.48	Do.
32	0.59	0.01	0.03	0.70	---	40	5	118	0.25	poor		Do.
33	1.23	0.02	0.31	0.17	446	330	25	13	0.06	--do--	1.06	mature
34	0.72	0.01	0.26	0.55	447	270	36	76	0.04	--do--		Do.
35	3.03	0.26	3.03	0.51	445	3,290	100	16	0.08	moderate to fair		Do.
36	0.81	0.02	0.19	0.00	454	210	23	0	0.10	poor	0.92-0.97	Do.
37	0.81	0.02	0.28	0.26	440	300	34	32	0.07	--do--		marginally mature
38	1.22	0.03	0.64	0.56	442	670	52	45	0.05	--do--		Do.
39	2.11	0.61	3.37	0.37	437	3,980	159	17	0.15	moderate to fair		mature
40	0.84	0.07	0.64	0.15	434	710	76	17	0.10	poor		marginally mature
41	0.57	0.03	0.21	0.35	456	240	36	61	0.12	--do--		mature
42	2.35	0.64	3.23	1.00	438	3,870	137	45	0.17	moderate to fair		marginally mature

Table 3.--Organic composition, hydrocarbon-source potential, and thermal maturity of sampled rocks from the Raton basin, south-central Colorsdo and northeastern New Mexico--(continued)

Sample (Described on Table 2)	Organic carbon (wt%)	S_1 (mg/g)	S_2 (mg/g)	S_3 (mg/g)	$T(S_2)$ (°C)	Genetic potential (ppm)	HI (mgHC /gC)	OI ($mgCO_2$ /gC)	Trans-formation ratio (S_1/S_1+S_2)	Hydro-carbon-source potential	R_o, percent (median)	Thermal maturity
43	0.39	0.15	0.22	0.29	441	370	56	74	0.42	poor		mature
44	0.74	0.16	0.90	0.10	437	1,060	121	13	0.15	marginal		Do.
45	1.27	0.04	0.56	0.54	443	600	44	42	0.07	poor		Do.
46	0.62	0.05	0.21	0.07	447	260	33	11	0.19	--do--		Do.
47	1.49	0.03	0.56	0.79	445	590	37	53	0.05	--do--		Do.
48	1.22	0.06	0.64	0.78	442	700	52	63	0.09	--do--		Do.
49	3.06	1.24	5.92	0.35	440	7,160	193	11	0.17	good to excellent		Do.
50	1.91	0.14	2.77	0.97	429	2,910	145	50	0.05	moderate to fair		immature
51	3.08	1.37	5.06	0.35	442	6,430	164	11	0.21	good to excellent		mature
52	2.16	0.61	3.06	0.33	442	3,670	141	15	0.17	moderate to fair		Do.
53	0.39	0.00	0.07	0.33	446	70	17	84	0.00	poor		probably mature
54	1.09	0.01	0.49	0.67	434	500	44	61	0.02	--do--		marginally mature
55	0.15	0.01	0.09	0.36	453	100	60	240	0.10	--do--		mature
56	0.91	0.01	0.14	0.47	436	150	15	51	0.07	--do--	0.69?	possibly mature
57	3.30	0.04	4.73	0.34	429	4,770	143	10	0.01	moderate to fair	0.51	immature

part of the basin. The generation and migration of oil could have begun in the Permian and apparently occurred during the Eocene. However, MacMillan (1980) concluded that the Mississippian and Pennsylvanian formations in southeastern Colorado "reached generative maturity in early Paleocene" time, just prior to probably "maximum burial beneath Eocene rocks." In the northern part of the Sangre de Cristo Mountains, along the western border of Custer County (fig. 1), Paleozoic sedimentary rocks were heated probably in response to: burial during Laramide (Late Cretaceous to middle Eocene) folding and thrusting; and high heat flow during Rio Grande rifting (late Oligocene to early Miocene) (Lindsey and others, 1986). C. W. Spencer of the U.S. Geological Survey has proposed (1987, written commun.) that the geothermal flux in the Raton basin was unusually high during the Tertiary. The intrusive igneous rocks in the region, which might reflect a higher heat flow and might have affected the generation and migration of hydrocarbons, are of Oligocene and Miocene age.

Hydrocarbon occurrence

Small amounts of methane were produced during the late 1970's at the Wagon Mound field in Mora County, New Mexico (Woodward, 1984; fig. 7). The reservoir for this field is in the Dakota Sandstone and is restricted to a small anticline. At the Chalfont Kaiser 1-Y well in Colfax County, New Mexico (fig. 7), a significant volume of flammable gas (1.5 million cubic feet of gas per day) was recently discovered in the Dakota at a depth of 3,320 ft. Methane was formerly produced from fractures in the Greenhorn, Carlile, and Niobrara Formations at the Garcia field (fig. 7) in Las Animas County, Colorado (Clair and Bradish, 1956). The cumulative production (as of 1/1/85) for the Garcia field is about 1.6 billion cubic feet (Colorado Oil and Gas Conservation Commission, 1986). In northwestern Colfax County, New Mexico, at the Pennzoil Vermejo Ranch 2, the Pierre Shale reportedly yielded 691,000 cubic feet of gas (Broadhead, 1982). At the Gardner field in western Huerfano County, Colorado (fig. 7), the Carlile Shale has produced (as of 1/1/85) about 3,700 barrels of oil and about 2.9 million cubic feet of gas (Colorado Oil and Gas Conservation Commission, 1986). In other boreholes and at outcrops in the basin, minor amounts of hydrocarbons have been found in the Dakota, Graneros, Greenhorn, Carlile, Niobrara, Pierre, Trinidad, Vermejo, Raton, and Poison Canyon Formations (Matuszczak, 1969; Dolly and Meissner, 1977; Woodward, 1984). Most of these occurrences of oil and gas are apparently associated with fracture systems.

The plays in the Raton basin are defined by the areal extent, in the subsurface, of two stratigraphic units that contain potential reservoir beds and are associated with potential source rocks. These units are the combined Purgatoire and Dakota Formations of Early and Late Cretaceous age, and the combined Trinidad, Vermejo, and Raton Formations of Late Cretaceous and early Tertiary age. Both units consist mainly of siliciclastic rocks which were deposited in marine and continental environments.

Other prospective stratigraphic units, which could contain reservoir beds and might be associated with source rocks for oil and gas, are the Pennsylvanian Magdalena Group, the Permian Glorieta Sandstone, the Jurassic Entrada Sandstone, the Cretaceous Carlile Shale, and the Upper Cretaceous and Paleocene Poison Canyon Formation. However, the Magdalena Group presumably is thermally overmature for oil and the constituent hydrocarbons could have migrated into younger formations. Furthermore, the potential reservoir beds in the Glorieta and Entrada have not been found in proximity to source

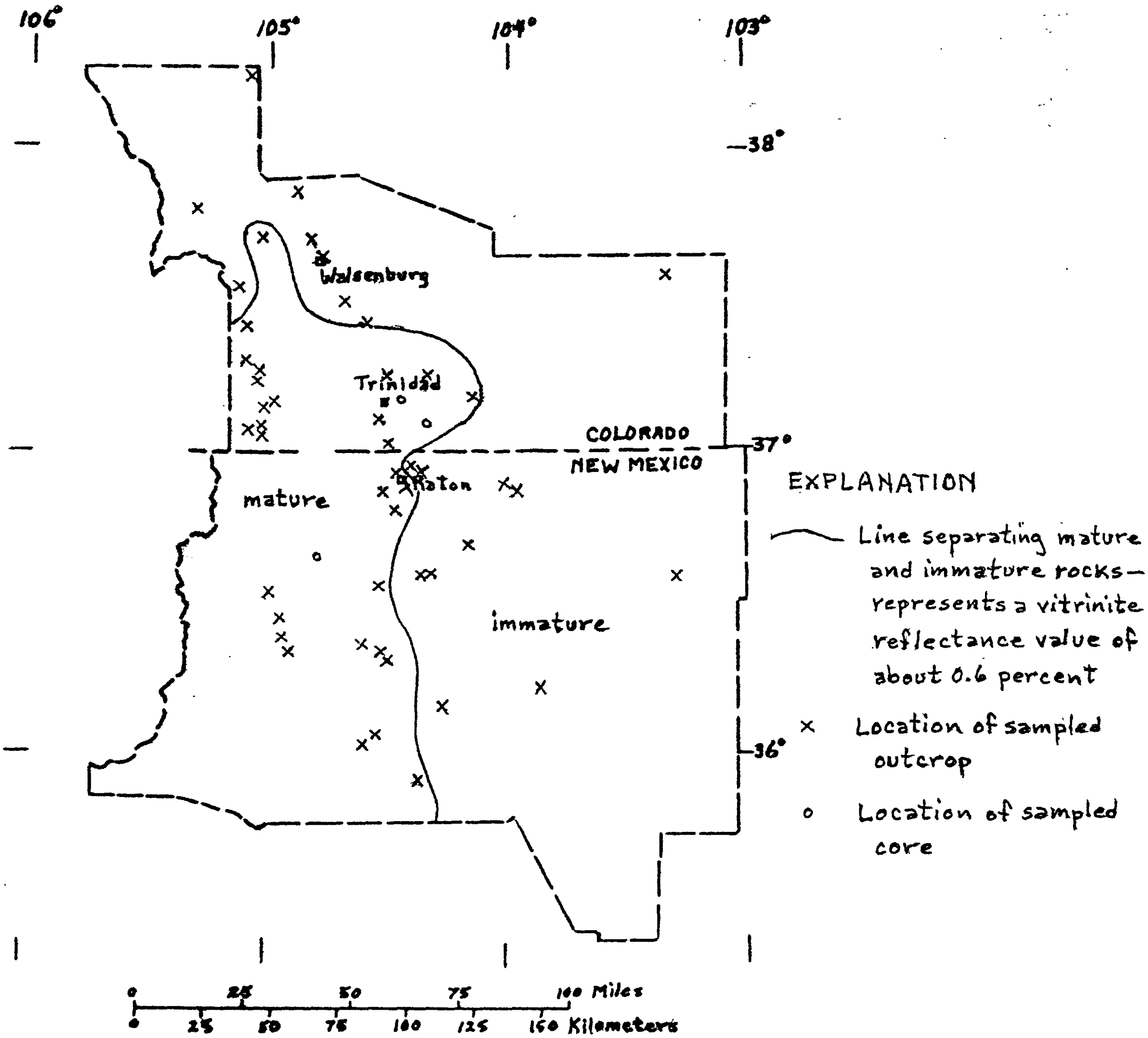

Figure 6.--Map showing sample localities and the thermal maturity of outcropping rocks in the region of the Raton basin, Colorado and New Mexico

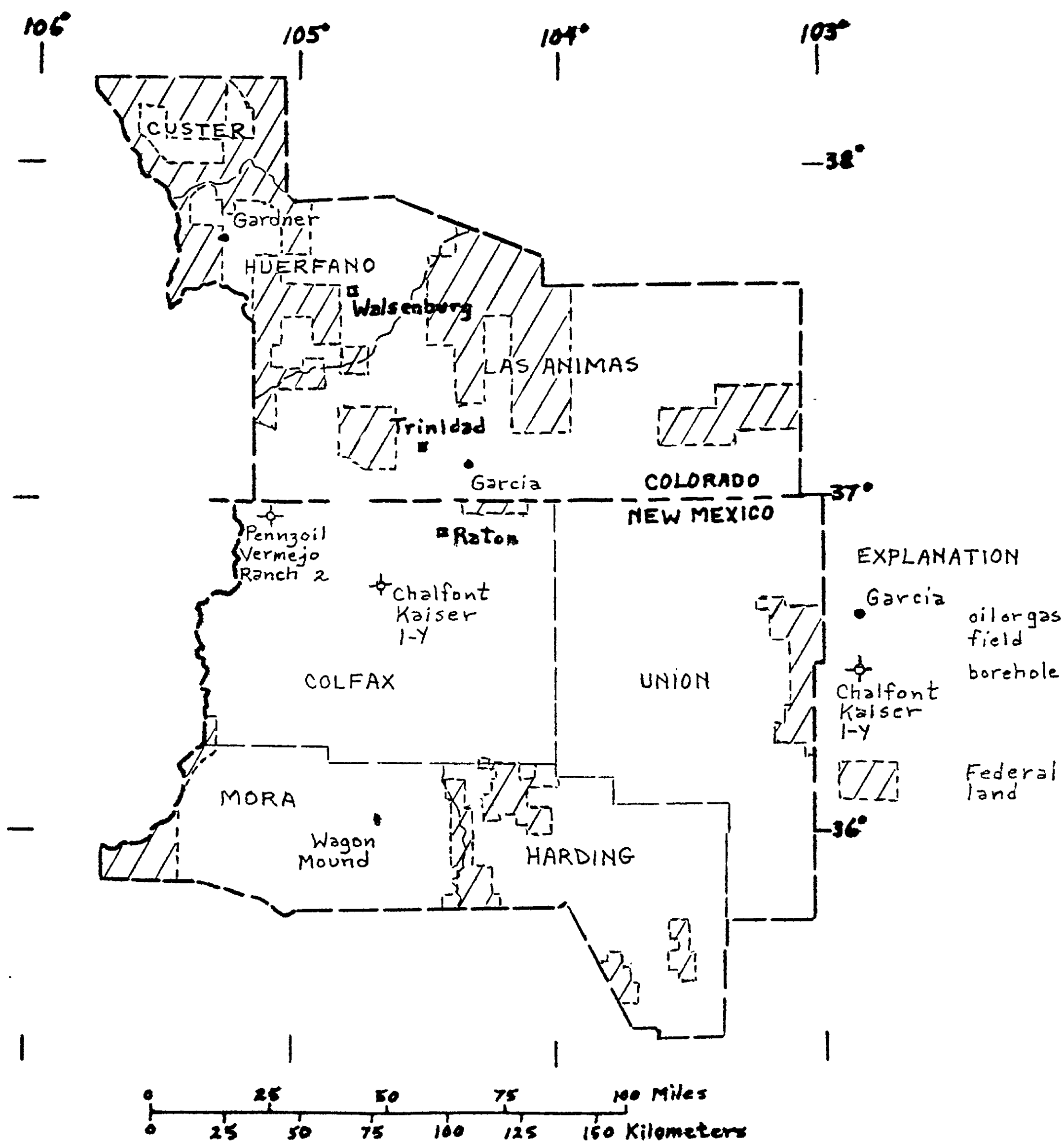

Figure 7.--Map showing Federal land, oil and gas fields, and boreholes in the region of the Raton basin, Colorado and New Mexico

rocks. The porous sandstone units in the Carlile and Poison Canyon have little areal extent, although they commonly are near source beds for hydrocarbons.

PRINCIPAL PLAYS

The most promising plays for oil and gas in the Raton basin are a large area underlain by the Cretaceous Purgatoire Formation and Dakota Sandstone, and a smaller area underlain by the Cretaceous Trinidad Sandstone and Vermejo Formation and the Cretaceous and Paleocene Raton Formation.

Purgatoire-Dakota

The Purgatoire-Dakota play, which comprises most of the western half of the Raton basin region (fig. 8), contains siliciclastic strata of Early and Late Cretaceous age which were deposited in nearshore-marine and continental environments. This play is demonstrated and the northern part of the play underlies several areas of Federal land.

Potential reservoirs in the play are about 30 ft thick and are composed of porous and permeable sandstone (Volk, 1972). In two cores from the northwestern part of the basin, sandstone units of the Dakota have porosities of 8-15 percent and permeabilities of 7-8 millidarcies. Sandstone units in the Purgatoire-Dakota throughout the basin commonly yield moderate amounts of water (Speer, 1976).

Gas was structurally entrapped in the Purgatoire-Dakota in an anticline at the abandoned Wagon Mound field in Mora County, New Mexico (fig. 7). However, no gas or oil has been found in these strata at other anticlines in the Raton basin. The Purgatoire-Dakota in the region probably includes lenticular bodies of sandstone which could form stratigraphic traps for oil and gas. Nevertheless, hydrocarbon-bearing, stratigraphic traps in these formations have not been reported. The sandstone units of the Purgatoire-Dakota also could contain hydrodynamic traps (Baltz, 1965), although none have been identified in the basin. Most reservoir beds in the formations would probably be sealed by units of shale.

The shale and coal within the Purgatoire-Dakota sequence and the overlying shale include source beds for oil and gas. Data from the pyrolytic analysis of four samples, from outcrops in the eastern part of the region, indicate moderate to fair source rocks in the formations (tables 2 and 3). Presumably, the Purgatoire-Dakota in the northern part of the basin generated hydrocarbons in early Tertiary (Eocene) time, when overlying strata were more than 10,000 ft thick. Migration of the hydrocarbons probably began in the Eocene and continued intermittently thereafter.

The Purgatoire-Dakota unit crops out on the flanks of the Raton basin and occurs at depths of 5,000-10,000 ft near the troughline of the basin (Clark, 1976; Applegate and Rose, 1985). These strata are virtually unexplored in the deeper parts of the basin and are lightly explored elsewhere in the region. In the mid-1950's, Continental Oil Company found significant shows of oil or gas in these rocks, in seven boreholes in the east-central part of the basin (Speer, 1976). Minor amounts of methane were produced during the late 1970's from the Purgatoire-Dakota at the Wagon Mound field (fig. 7) in Mora County, New Mexico (Woodward, 1984). In 1984, Chalfont Oil and Gas Company discovered methane (1.5 million cubic feet per day) in these formations in Colfax County, New Mexico. The Purgatoire-Dakota has also produced large amounts of carbon

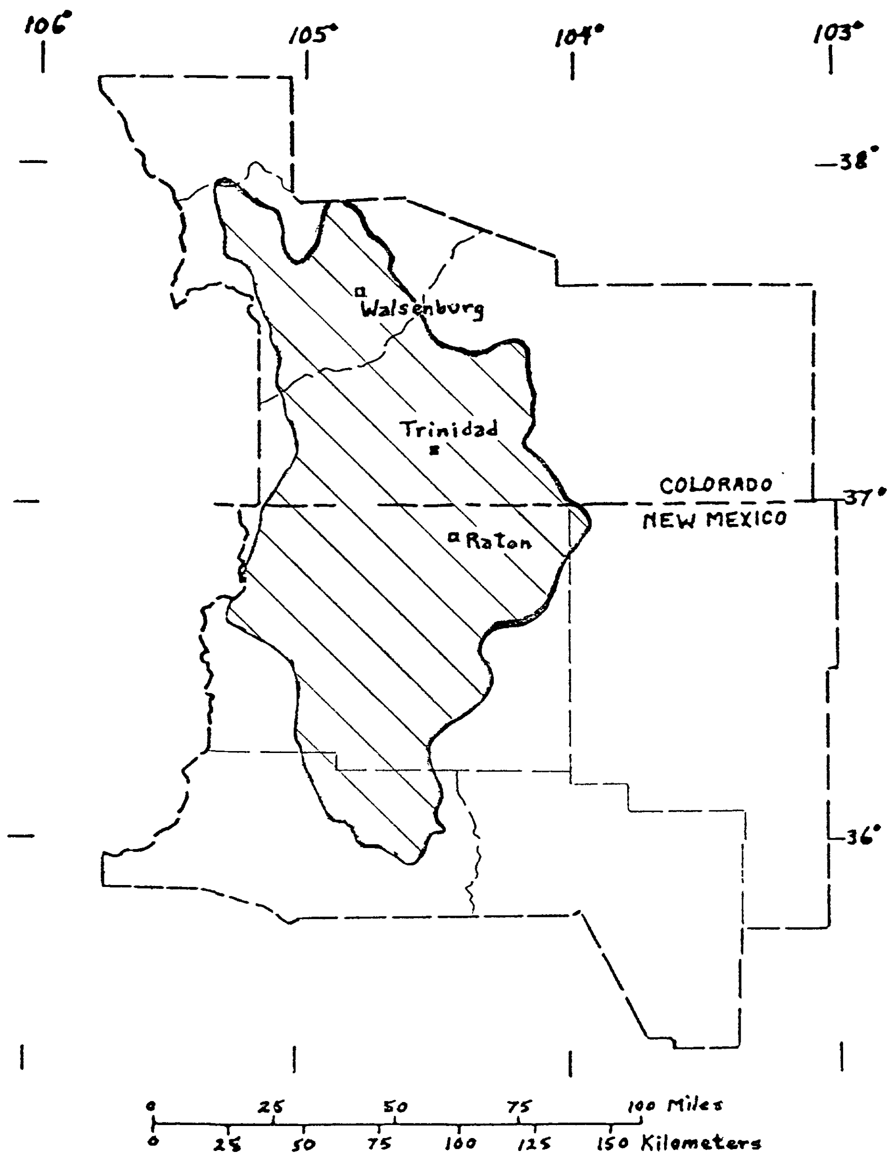

Figure 8.--Map showing play (lined) in the Purgatoire Formation and Dakota Sandstone of the Raton basin, Colorado and New Mexico

dioxide, at the Sheep Mountain field in western Huerfano County, Colorado Colorado Oil and Gas Conservation Commission, 1986). Units of sandstone in this body of rocks generally contain water; the basal sandstone commonly is an aquifer. In the deeper parts of the basin, the permeability of the sandstone is probably low. However, these formations have not been thoroughly explored.

Trinidad-Vermejo-Raton

The play for the Trinidad, Vermejo, and Raton Formations is in the northern part of the Raton basin, in southern Huerfano and western Las Animas Counties, Colorado, and northwestern Colfax County, New Mexico (fig. 9). In Colorado, this play encloses several areas of Federal land. Most of the play is speculative. The formations consist mainly of sandstone, siltstone, shale, and coal, which were deposited in nearshore-marine and fluviodeltaic environments (Flores and others, 1985).

The units of sandstone in these formations are potential reservoirs for oil and gas. In the Trinidad, potential reservoirs are laterally extensive and can be as much as 80 ft thick. At outcrops, these strata reportedly have porosities and permeabilities of as much as 18 percent and 5 millidarcies, respectively (Dolly and Meissner, 1977). In the subsurface, sandstone in the upper part of the Trinidad can have porosities of 10-11 percent and be at least 47 ft thick (Rose and others, 1986). Potential reservoirs in the Vermejo and Raton Formations are lenticular and as much as 40 ft thick. Outcrop samples of these beds have porosities and permeabilities of as much as 15 percent and 29 mililidarcies, respectively. Cores of sandstone and conglomerate from the Raton Formation have average porosities of 10-20 percent and average permeabilities of 0.2-2.0 millidarcies (Dolly and Meissner, 1977).

Potential accumulations of hydrocarbons in the Trinidad, Vermejo, and Raton Formations could be entrapped by impermeable rocks and possibly by hydrodynamic pressure. Traps for hydrocarbons in the Trinidad Sandstone would be mainly structural but might also be hydrodynamic in the deepest parts of the basin. Traps in the Vermejo and Raton Formations would be mostly stratigraphic.

The source rocks for oil and gas associated with the Trinidad, Vermejo, and Raton Formations are shale in the upper part of the Pierre Shale and carbonaceous beds within the Vermejo, Raton, and Poison Canyon Formations. Pyrolytic analyses of samples of the Pierre indicate some marginal to fair source rocks (tables 2 and 3). Analytical data for the Vermejo, Raton, and Poison Canyon Formations indicate marginal to excellent source rocks. In this play, outcropping strata of Late Cretaceous and Paleocene ages are thermally mature to marginally mature (tables 2 and 3); their maturity is appropriate for oil generation. The generation and migration of hydrocarbons in strata of the Trinidad-Vermejo-Raton apparently began no earlier than Eocene time.

The base of the Trinidad Sandstone crops out and is as much as 6,000 ft deep in the Raton basin (Applegate and Rose, 1985). Strata of the Trinidad, Vermejo, and Raton Formations are lightly explored in the basin and are almost unexplored near the troughline of the basin in Colorado. Only traces of oil and gas have been found in these formations and most of the shows are in boreholes on the eastern flank of the basin (Matuszczak, 1969; Dolly and Meissner, 1977). The potential resources in these strata are probably conventional and could include both oil and gas. The probability of discovering a producible amount of methane in this sequence is intermediate.

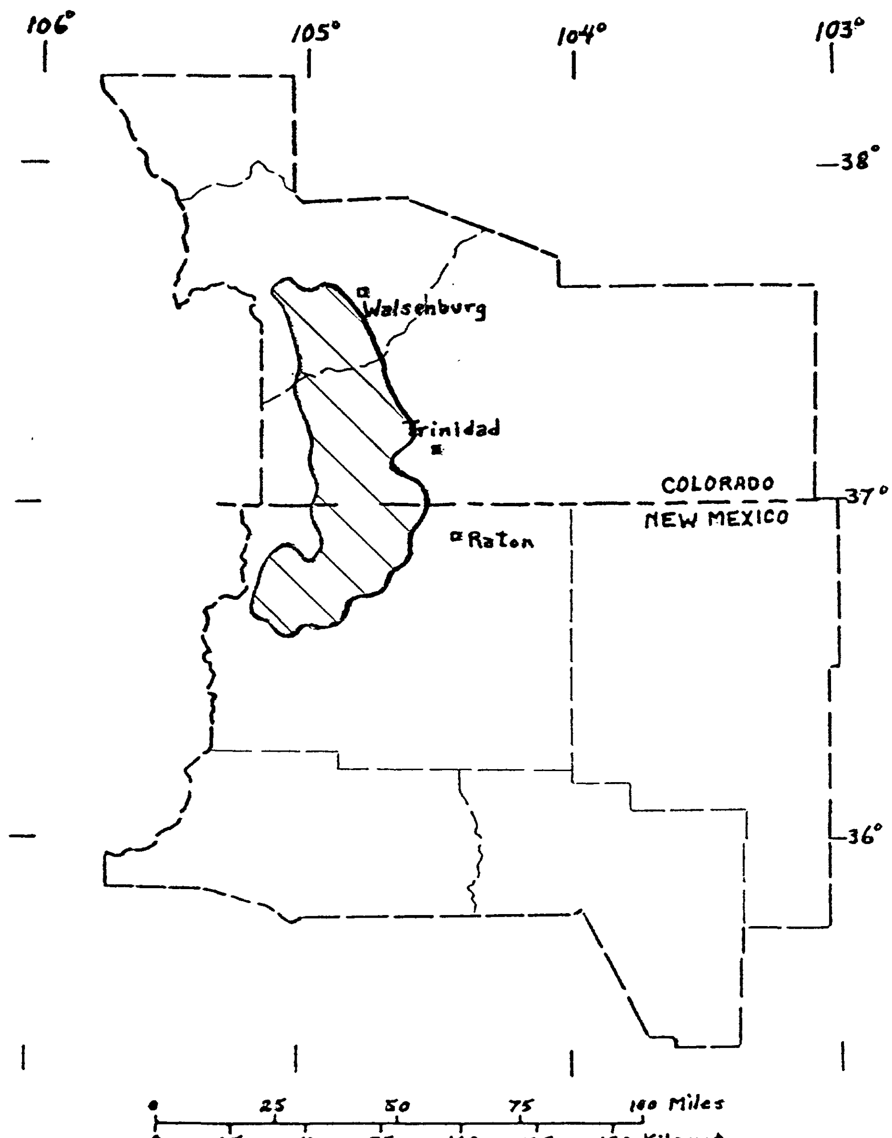

Figure 9.--Map showing play (lined) in the Trinidad, Vermejo, and Raton Formations of the Raton basin, Colorado and New Mexico

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