New Mexico's Energy Resources '75

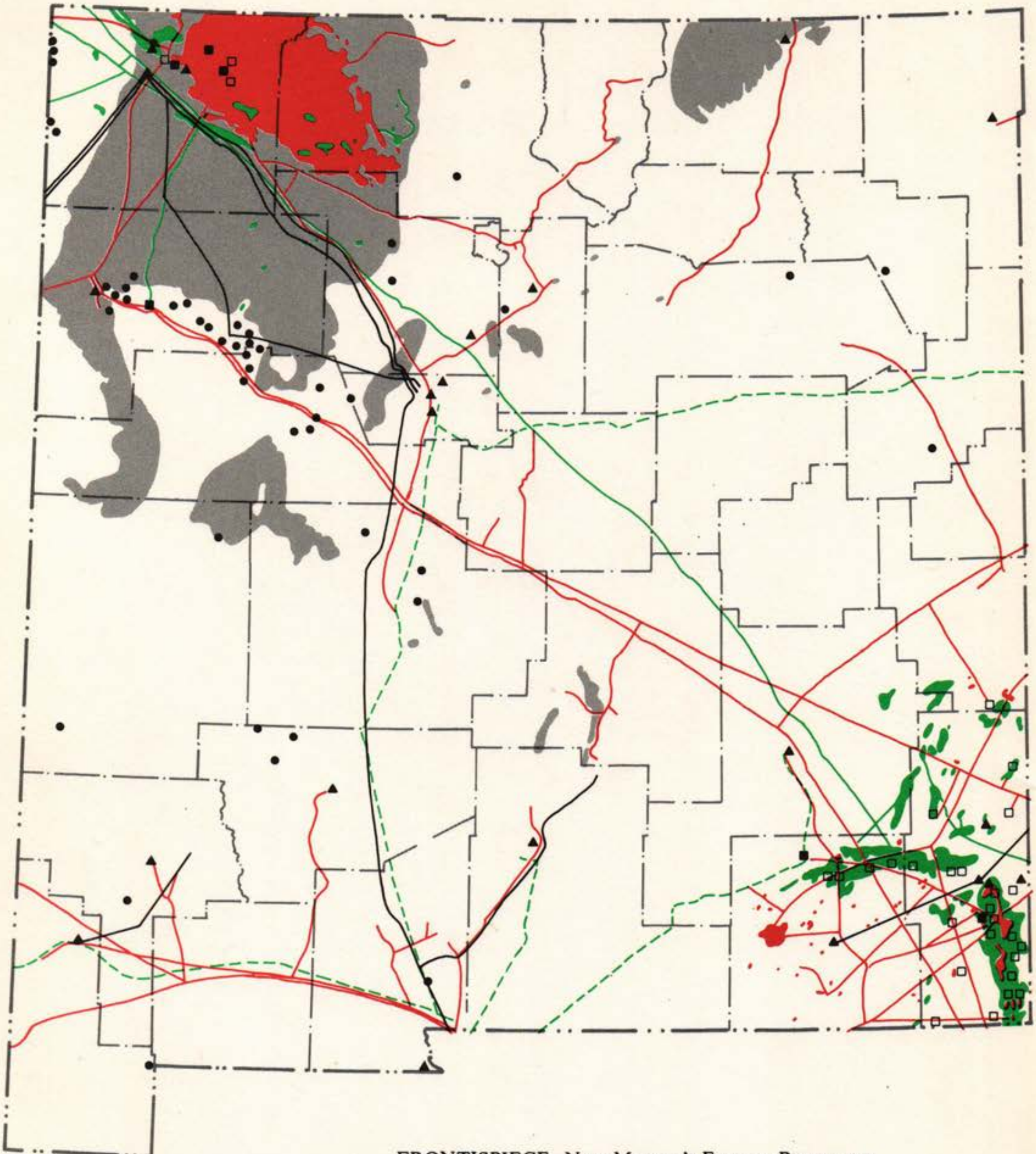
Prepared with the Office of State Geologist

Jerry Apodaca, Governor of New Mexico

BULLETIN 107 New Mexico Bureau of Mines & Mineral Resources 1976

A DIVISION OF

NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY



FRONTISPIECE—NEW MEXICO'S ENERGY RESOURCES

This map is a small-scale version of Resource Map 2 by the New Mexico Bureau of Mines & Mineral Resources, 1974. See legend inside back cover.

LEGEND

for map inside front cover

- Oil field
- Gas field
- Oil pipeline (6 to 16 inch)
- Petroleum products pipeline (6 to 12 inch)
- Gas pipeline (2 to 34 inch)
- Coal field
- Gas processing plant
- Oil refinery
- Generating station
- Major electric lines
- Uranium production

Arnold, et al.

ENERGY RESOURCES '75

New Mexico Bureau Mines

Bulletin 107

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New Mexico's Energy Resources '75

by

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SOCORRO 1976

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Preface

The Office of State Geologist is charged in part with the responsibility of conducting geological studies aimed at determining reserves of known supplies of energy resources, with compiling an inventory of such reserves, and of conducting studies of probable and potential supplies. The Office of State Geologist was established by Chapter 289 of the Laws of 1975. The State Geologist was appointed and the office opened on August 15, 1975. Permanent office space was secured at 2 Jefferson Place in Santa Fe, and the office was occupied January 1, 1976. The hiring of authorized staff is expected to be completed in the near future.

Time was not available to prepare a comprehensive energy resources inventory for the convening of the 1976 Legislature. Nevertheless, with the assistance of the New Mexico Bureau of Mines and Mineral Resources, we were able to prepare and publish this joint preliminary report. Nor would this report have been possible without the full cooperation as well of the New Mexico Oil Conservation Commission and the various individuals and companies who furnished information and opinions.

As indicated, this report is preliminary, and subject to change and refinement during the coming year as more thorough and detailed work is accomplished.

Emery C. Arnold
State Geologist
Office of State Geologist

Santa Fe,
January 12, 1976

Contents

ABSTRACT—Since 1969 production of crude oil in New Mexico has decreased each year to 98.6 million barrels in 1974. Oil discoveries have been low for the last 5 years, because exploration has been at a low rate. Exploration for, and discovery of, oil must increase substantially if large production decreases are to be averted. Oil prices probably must increase substantially to bring on increased exploration, .as well as to stimulate secondary and tertiary recovery projects. **Natural gas** production increased slightly from 1.123 trillion cubic feet in 1970 to 1.230 trillion cubic feet in 1974. In northwest New Mexico production of dry gas from producing wells is expected to decline slowly. In southeast New Mexico development of dry gas has been at record rates, but reserve/production ratios indicate these new gas reservoirs will be depleted more rapidly than fields in northwest New Mexico. Present development of new gas reserves should maintain current production in southeast New Mexico for several years. **Coal** resources are estimated at 283 billion tons, of which 6 billion are strippable. Current production is more than 9 million tons a year from the San Juan and Raton basins. If projects contemplating using coal are completed, more than 40 million tons will be mined by 1980 and nearly 60 million tons by 1985. New Mexico produces more than 50 percent of the nation's **uranium** from the Grants uranium region. The Energy Research and Development Administration estimates that New Mexico reserves ($8, $10, and $15 categories) are more than 255 million tons of ore with a U_3O_8 content ranging from 0.16 of one percent to 0.29 of one percent and totalling 516,000 tons. Potential **geothermal** energy areas occur along the Rio Grande valley and in southwest New Mexico. The most promising are Jemez Mountains, Socorro Peak, Radium Springs, Gila Hot Springs, and Lightning Dock.

Oil and Gas—
The most vital energy resource at present

Production of crude oil and natural gas is a major industry for New Mexico, providing a considerable part of the taxes that support the State. Preliminary figures for 1975 record 94.6 million barrels of crude oil valued at $770.6 million, 1.2 trillion cubic feet of natural gas worth $452.4 million, and 38.7 million barrels of natural gas liquids valued at $232.6 million (U.S. Bureau of Mines).

Reserves of natural gas (fig. 1) were about 23.5 trillion cubic feet in 1956, but in 1974 had dropped to 12 trillion cubic feet.

Reserves of crude oil have been declining (fig. 2) from the peak year of 1961, to a temporary low in 1965, to a secondary peak in 1966, and to the present low for 1974 of 625 million barrels.

Most of the oil is produced in southeast New Mexico; 55 percent of the natural gas is from that area. Exploration for oil and natural gas and discovery of these energy sources has declined since highs in the late 1950's, but picked up in recent years as prices have risen.

OIL PROJECTIONS

SOUTHEAST NEW MEXICO

The Permian basin of southeast New Mexico and west Texas has long been one of the major oil-producing provinces in the nation. Ninety-two percent of the state's oil production came from southeast New Mexico in 1974. The four producing counties in the area are Lea, Eddy, Chaves, and Roosevelt. Peak rate of production (fig. 3, page 8) was reached in 1969 when over 120 million barrels of oil and condensate were produced from 19,258 oil and gas wells. The Permian basin would have to be classed as a mature oil province. Therefore, the future discovery rate will be more modest than in the past. According to the American Petroleum Institute only 320 million barrels of new oil have been discovered and developed during the past 10 years in New Mexico. This discovery rate will not sustain the present production rate of just under 100 million barrels per year. Exploration drilling rates slowed perceptibly during the 1960's, primarily because of reduced incentives brought on by low oil prices, natural gas prices controlled at unrealistically low levels, and inflation-caused increases in drilling costs. Improved new oil prices in the 1970's have increased the exploration rate somewhat, but still far below levels of the 50's. Instability and uncertainty surrounding the price structure of oil and gas in the immediate future is currently having a depressing effect on both new exploration and development drilling.

Most of the early production in southeast New Mexico came from reservoirs in Permian strata. These reservoirs were relatively shallow, and production from many was prolific. Multipays were also encountered; in some areas oil was discovered in 4 or 5 pay zones in a single wellbore. Oil was later discovered in deep structures in Pennsylvanian, Mississippian, Devonian, Ordovician, and Silurian strata. Devonian beds particularly have been prolific oil producers. Characteristically, as exploration proceeds, the number of potential undiscovered oil reservoirs diminish. Even so, there are many areas, in older developed pools, where deeper horizons have not yet been tested. Possibly large pools have not yet been discovered. The hard fact is that several Class A (greater than 50 million barrels) discoveries must be made to replenish diminishing reserves.

Enhanced Recovery

One hope for slowing the decline in production rate and improving the situation with recoverable reserves is through improving "enhanced recovery" techniques. Most authorities estimate that primary recovery from a large number of pools in southeast New Mexico has not exceeded 15 percent. In other areas, where natural water drive is present, recoveries have run as high as 40 percent. The American Petroleum Institute estimates that the average recovery rate for all pools in southeast New Mexico has been 23 percent. Waterflood operations have been in effect in many of the older pools for a number of years and some have responded very well to waterflooding. In 1974, 35 percent of the total production from southeast New Mexico was classed as enhanced recovery production. Even so, recovery rates under enhanced recovery methods have seldom exceeded the amount produced under primary methods. Therefore, in a pool where 15 percent of the total oil in place has been recovered from primary production, the usual rule is to expect an additional 15 percent with secondary methods now in use. In many instances 70 percent of the original oil remains in place in the reservoir. The possibility of recovering a substantial portion of this huge potential reserve has caused the expenditure of many millions of dollars in research on improved recovery methods. These new procedures are commonly referred to as tertiary recovery methods. They entail such things as modifying the injection fluids used by adding various chemical compounds to improve sweep efficiencies in moving the oil out of the rock in which it is held. No oil is presently being produced in New Mexico under what can be defined as tertiary recovery processes. The New Mexico Bureau of Mines and the Petroleum Engineering Department of New Mexico Tech are researching tertiary recovery for the Loco Hills pool.

Several tertiary recovery processes have already been proved by industry for specific applications. Most tertiary recovery processes are expensive to apply; the breakthrough needed is to devise a process that is both effective and will produce oil at competitive prices. Chemical additives being used in tertiary processes cost from $6 to $8 per barrel; oil prices would have to be at least $13 per barrel to make such operations feasible.

Any prediction of the amount of secondary and tertiary oil that might be produced in southeast New Mexico in the next 10 years is speculative. Many pools that will respond to waterflooding have not yet been put under flood. A primary objective of the State Geologist's office and of the New Mexico Bureau of Mines and Mineral Resources is to conduct studies during the ensuing year aimed at defining the areas where secondary and tertiary recovery methods will be effective, enabling more accurate forecasts. Our present estimate is that an additional 200 million barrels of oil may be added to recoverable reserves in southeast New Mexico from enhanced recovery methods during the next 10 years in projects not yet under flood. If the economic climate improves and a tertiary recovery price breakthrough is accomplished, this figure may be substantially low.

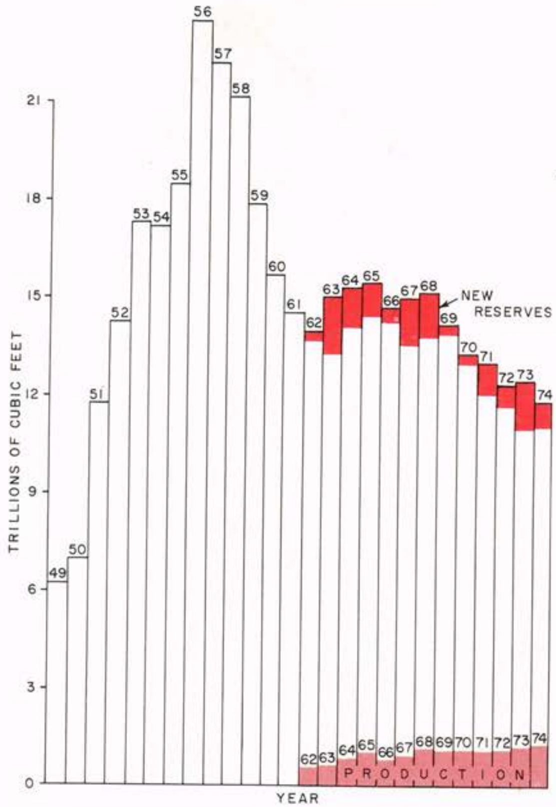

FIGURE 1—STATUS OF RESERVES OF NATURAL GAS IN NEW MEXICO 1949 TO 1974 (*Source: A.P.I.*).

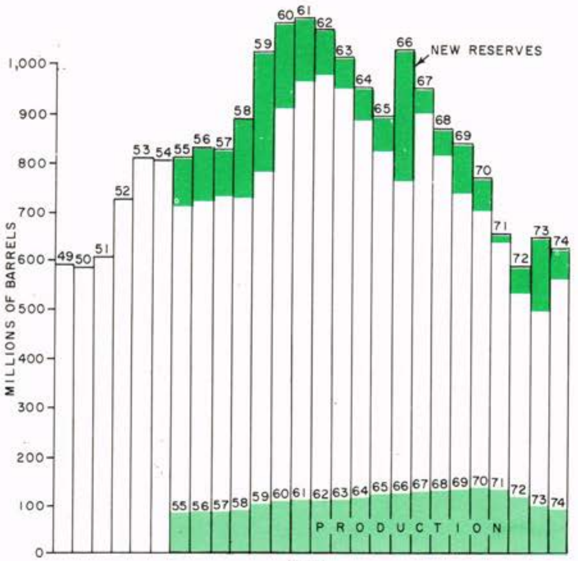

FIGURE 2—STATUS OF RESERVES OF CRUDE OIL IN NEW MEXICO 1949 TO 1974 (*Source: A.P.I.*).

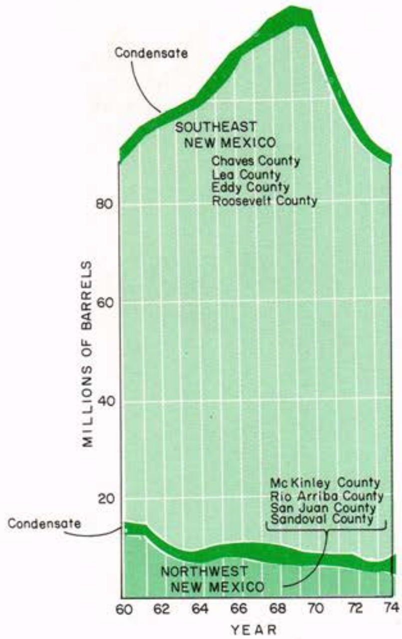

FIGURE 3—PRODUCTION OF CRUDE OIL AND CONDENSATE FOR SOUTHEAST AND NORTHWEST NEW MEXICO 1960 TO 1974 (*Source: N.M.O.C.C.*).

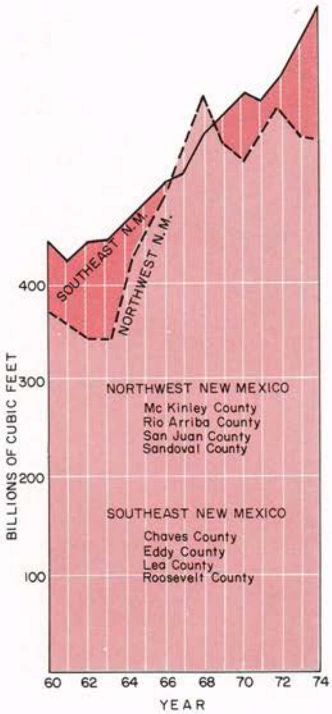

FIGURE 4—NATURAL GAS PRODUCTION FOR SOUTHEAST AND NORTHWEST NEW MEXICO 1960 TO 1974 (*Source: N.M.O.C.C.*).

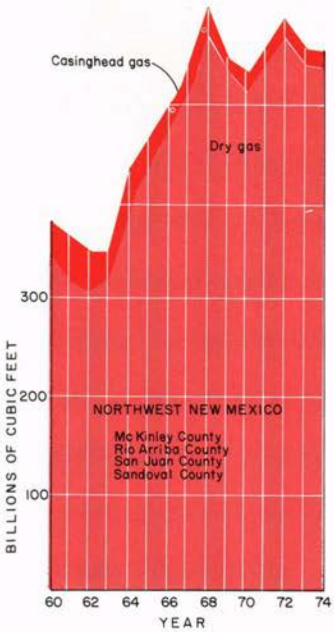

FIGURE 5—Casinghead and dry gas production for northwest New Mexico 1960 to 1974 (*Source: N.M.O.C.C.*).

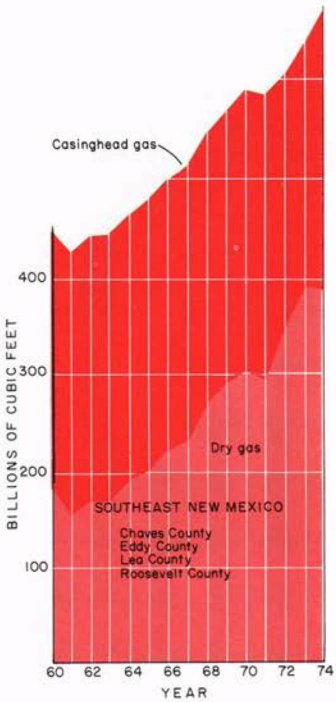

FIGURE 6—Casinghead and dry gas production for southeast New Mexico 1960 to 1974 (*Source: N.M.O.C.C.*).

NORTHWEST NEW MEXICO

Northwest New Mexico is primarily a natural-gas-producing province. Nevertheless, commercial oil was first discovered in New Mexico at the Hogback Dakota pool in San Juan County in 1922. This discovery brought on widespread leasing and exploration; some additional oil was discovered on the west side of the San Juan Basin at Rattlesnake and Table Mesa. However, the San Juan Basin has never emerged as a major oil-producing province. When drilling activity accelerated in the 1950's, resulting from natural gas development, a series of stratigraphic offshore bar oil reservoirs were discovered in the Gallup Sandstone. These pools occur in a relatively narrow band, usually not more than about 10 miles wide, extending from a point 15 miles northwest of Farmington, southeasterly 60 or 70 miles into Rio Arriba County. Sands are thin in these pools, usually not exceeding 20 ft; although production rates were respectable, reserves were low.

Oil was also discovered in fracture reservoirs in the Mancos Shale at the Verde pool on the extreme northwest edge of the San Juan Basin and in the Puerto Chiquito field on the extreme east edge. Primarily because of production from these Mancos and Gallup pools, annual production reached a peak of over 15 million barrels in 1961. Since that time, production has generally fluctuated downward. This decline was slowed by development of the Tocito Dome Pennsylvanian pool in western San Juan County in 1964. In 1974 crude oil production was only slightly over 6 million barrels, with gas well condensate production bringing the total to 8.8 million barrels.

Major new oil reservoirs are not likely to be discovered in Cretaceous strata in the San Juan Basin. Small structural traps may possibly be found along the edges and on the Chaco slope in the southern part of the San Juan Basin, where exploration is still continuing. Sporadic exploration is also being carried out in the Chama embayment on the northeast edge of the San Juan Basin. Oil reserves and production additions in northwest New Mexico from Cretaceous rocks will not exceed 25 percent during the next 10 years. The brightest hope for major oil development in northwest New Mexico is in the undeveloped 6,000-ft thick Paleozoic section below the Dakota Sandstone. The possibility of major strikes below the Dakota must, for the present, be classed as speculative. As in southeast New Mexico, the future of deep exploration in the San Juan Basin depends upon the oil and gas price structure in the future.

Secondary recovery operations have been in effect on most Gallup reservoirs in the San Juan Basin; many are nearing depletion, even under secondary efforts. Gallup sands are stratified and lenticular, with wide vertical variations in permeability causing low efficiency of recovery. Possibly tertiary methods might be used on these reservoirs in the future if the price of oil reaches a level high enough to make such efforts profitable. The price would probably have to be from $13 to $15 per barrel.

No separate projected production decline curve is shown in this report for crude oil for northwest New Mexico. Production from the area was only 5 percent of the state total in 1974. The crude oil production projection chart (fig. 7, page 15) is for the entire state; totals include projections from northwest as well as southeast New Mexico.

STATEWIDE

Projections of production and additions of recoverable reserves in the future are necessarily speculative. Political and economic factors will affect the outcome as much as geological factors. For this reason fig. 7 has three curves depicting results that might be expected between now and 1985 under varying conditions of success.

The 5-percent decline (table 1, p. 14) presumes a new oil rate from discoveries and extensions equal to the rate credited to the state during the period 1964 to 1975, approximately 320 million barrels. As the projection is made through 1985, an 11-year period, an additional 30 million barrels is added for 1985, totalling 350 million barrels. Also, an additional 200 million barrels of recoverable reserves must be added from new enhanced recovery projects during the period to maintain this rate of decline.

The American Petroleum Institute estimates the amount of recoverable oil as of January 1, 1975 to be 625 million barrels, bringing the total to 1,175 million barrels. The production through 1985, assuming a 5-percent decline, would be approximately 808 million barrels, leaving an unproduced balance of 367 million barrels at the end of 1985. The 5-percent decline curve is about equal to the decline for the 1970 to 1974 period: a high of 8.6 percent in 1973 and a low of 2.6 percent in 1974. The 1975 rate will be about 3.8 percent.

The 3-percent decline curve is admittedly very optimistic, but is added to show what production might be expected under very favorable economic conditions in the industry. To maintain the 3-percent decline rate, 100 million barrels of new recoverable reserves would probably have to be added above the amount added during the period 1964 to 1975; also another 100 million barrels of new oil would have to be recovered from enhanced recovery projects. The total recoverable reserve in this instance would be 1,375 million barrels (350 + 100 + 300 + 625). This curve presumes that the additional oil added above that amount needed to maintain the 5-percent decline curve would be added in approximately equal yearly increments, and that approximately half of the total reserve added would be produced during the 11-year period. Total production for the 11-year period would be approximately 909 million barrels; the amount remaining at the end of 1985 would be 466 million barrels (1,375 minus 909). Using the same method and making the same presumption, the 10-percent decline curve would result if new oil added from development and enhanced recovery totalled approximately 150 million barrels. The total recoverable reserve in this case would be 775 million barrels (625 + 150). Approximately 609 million barrels would be produced during the 11-year period; about 166 million barrels would remain unproduced at the end of 1985.

GAS PROJECTIONS

NORTHWEST NEW MEXICO

Natural gas development in the San Juan Basin did not begin on a large scale until 1951, when the first major market was developed in California. By 1960, actual production had reached 342 billion cubic feet from 4,800 dry gas wells (figs. 4 and 5). An additional 31.3 billion cubic feet was marketed in 1960 as casinghead from oil wells, making the total 373.4 billion cubic feet. Market restrictions dropped the total to 359.4 billion cubic feet in 1960, and 340.8 billion cubic feet in 1961. There was a steady increase to 1968, when the total reached 593.5 billion cubic feet, the peak year for gas production to date. Market restrictions again dropped the total to a low of 525.0 billion cubic feet in 1970. Production then increased rather slowly for 2 years to a high of 586.3 billion cubic feet in 1972. Since then market demand has been high. Very few wells have been under proration restriction. Even so, production has declined steadily to a total of 547.4 billion cubic feet in 1974. Production for 1974 came from 8,600 gas wells and 1,604 oil wells.

Ninety-eight percent of the gas produced in the San Juan Basin comes from Upper Cretaceous rocks at depths from 1,000 ft to 8,500 ft. Some Pennsylvanian production has been significant, particularly from Barker Creek Dome, now nearing depletion and contributing little to the total. Cretaceous production has come in descending order from the Farmington Sandstone, Fruitland Formation, Pictured Cliffs Sandstone, Chacra Sandstone, Mesaverde Formation, Gallup Sandstone, and Dakota Sandstone. By far the most important of the zones have been the Pictured Cliffs Sandstone, Mesaverde Formation, and the Dakota Sandstone. The 3,600 wells producing from the Pictured Cliffs Sandstone contribute approximately 18 percent of the total production from the area. The Mesaverde Formation produces primarily from a huge stratigraphic reservoir approximately 70 miles long and 40 miles wide containing 2,164 wells. This pool contributes approximately 43 percent of the total gas. The Dakota Sandstone produces from a similar huge stratigraphic reservoir occupying much of the same geographic area as the Blanco Mesaverde pool. In addition, the reservoir extends from 10 to 18 miles southwest of the area occupied by the Blanco Mesaverde pool, and also extends 10 miles southeast of the southeastern extremity of the pool. The Basin Dakota pool contributes approximately 34 percent of the total production, and contained 2,359 producing wells as of September, 1975.

Cretaceous sandstone reservoirs in the San Juan Basin are all characterized by very low permeability and consequently relatively low productive capacities. Gas reserves are substantial, but return on investment is very slow on most wells. For this reason the development rate is price sensitive.

The Cretaceous section in the San Juan Basin has been extensively explored. Over 8,800 gas wells are now producing and some 2,000 oil wells are producing or have produced. Major discoveries of either oil or gas in the Cretaceous rocks are not likely in the future. Exploration has indicated the existence of many thin, marginal gas-producing zones adjacent to presently producing areas, in which commercial gas wells could be completed at higher gas prices. Perhaps 200 wells per year might be completed in such marginal zones over the next 5 years providing the wellhead price of gas reached levels of a minimum of $1.00 per thousand cubic feet. An additional 1,000 small-capacity Dakota gas wells might also be drilled providing gas prices reached $1.75 per thousand cubic feet. Drilling depths to the Dakota average 6,500 ft; wells located in low productive areas will not return drilling costs at present prices. However, significant reserves in the Dakota can be produced at prices substantially lower than prices now proposed for synthetic gas produced from coal gasification plants. In the fall of

1974 the New Mexico Oil Conservation Commission approved infill drilling to 160-acre density in the Blanco Mesaverde pool, that had been previously developed on 320-acre tracts. The denser drilling pattern will probably add 15 percent to 30 percent to Blanco Mesaverde pool reserves. If new gas prices are allowed for gas from these wells, and if prices improve to levels above $1.00 per thousand cubic feet, 200 new wells per year would probably be drilled in this pool in the next 10 years. In addition to adding to recoverable reserves, this development will also substantially increase deliverability from the pool; this additional capacity would go far in slowing the production decline rate for the area.

In summary, the most critical factor concerning future development of Cretaceous reservoirs in the San Juan Basin is the future price structure for natural gas. If all the development mentioned above is accomplished over the next 10 years, 4.5 to 5 trillion cubic feet of gas might be added to Cretaceous reserves in the San Juan Basin. If controls are continued at present levels, many of those reserves will not be developed, because the reserves would be uneconomical to produce.

A 6,000-ft thick sedimentary section of Paleozoic rocks is also present in the essentially unexplored inner area of the San Juan Basin. Pennsylvanian and Mississipian production has been encountered in structural pools on the north and west edges of the San Juan Basin. Not more than 25 basement tests have been drilled in the deeper part. With economic incentives, deep exploration will come; most authorities agree that discovery prospects are excellent. This development should be placed in the speculative category at the present time, however.

The projected future gas production curves for northwest New Mexico (fig. 8; table 2) show actual total natural gas production for the years 1966 through 1974. The 1975 production rate was estimated by projecting the 10-month total to 12 months. The 5-percent decline curve refers to the rate of decline that we estimate will be experienced if the future completion rate of gas wells in Cretaceous rocks equals the rate over the last several years. The curve does not anticipate any new deep discoveries nor does it allow for infill wells in the Blanco Mesaverde pool. At this rate of decline the production for the period 1975 through 1985 would be about 4.48 trillion cubic feet; the yearly rate of production in 1985 would be 311.36 billion cubic feet. With new natural gas prices now approaching $1.00 and with prospects of further improvement, sufficient marginal gas wells are likely to be completed to prevent the decline rate from exceeding 5 percent.

The upper curve shows a 5-percent decline in 1975, a 2-percent increase in 1976, 2-percent decline from 1977 through 1980, and a 3-percent decline from 1980 through 1985. This rate of production is based upon the addition of 200 Blanco Mesaverde infill wells yearly, in addition to normal development in other Cretaceous pay zones. Because more than 2,000 wells are in this pool, an additional 2,000 wells may be drilled in the pool during the next ten years if gas prices rise sufficiently. For this rate of decline, production for the period would be 5.30 trillion cubic feet; production in 1985 would be 430.13 billion cubic feet.

The 8-percent decline curve represents what production would be at a zero development rate. Decline in production might exceed 8 percent under these conditions, particularly toward the end of the 10-year period. For this rate of

TABLE 1—PROJECTED PRODUCTION OF CRUDE OIL AND CONDENSATE FOR NEW MEXICO 1975 TO 1985 BASED UPON VARIED RATES OF DECLINING PRODUCTION (*98,695,000 barrels produced in 1974*)

	Barrels of crude oil and condensate		
Year	*3% decline*	*5% decline*	*10% decline*
1975	95,734,000	93,760,000	88,825,000
1976	92,862,000	89,072,000	79,943,000
1977	90,076,000	84,619,000	71,949,000
1978	87,374,000	80,388,000	64,754,000
1979	84,753,000	76,368,000	58,278,000
1980	82,210,000	72,550,000	52,451,000
1981	79,744,000	68,922,000	47,206,000
1982	77,352,000	65,476,000	42,485,000
1983	75,031,000	62,202,000	38,236,000
1984	72,780,000	59,092,000	34,413,000
1985	70,597,000	56,138,000	30,972,000
totals	908,513,000	808,588,000	609,511,000

TABLE 2—PROJECTED PRODUCTION OF DRY GAS FOR NORTHWEST NEW MEXICO 1975 TO 1985 BASED UPON VARYING RATES OF DECLINING PRODUCTION (*547,392,000 thousand cubic feet produced in 1974*)

	Upper curve (fig. 8)		*Middle curve (fig. 8)*		*Lower curve (fig. 8)*	
Year	*% decline*[1]	*Thousand cu. ft. dry gas*	*% decline*	*Thousand cu. ft. dry gas*	*% decline*	*Thousand cu. ft. dry gas*
1975	– 5	520,023,000	– 5	520,023,000	– 5	520,023,000
1976	+ 2	530,423,000	– 5	494,022,000	– 8	478,421,000
1977	– 2	519,815,000	– 5	469,321,000	– 8	440,147,000
1978	– 2	509,418,000	– 5	445,855,000	– 8	404,935,000
1979	– 2	499,230,000	– 5	423,562,000	– 8	372,541,000
1980	– 2	489,245,000	– 5	402,384,000	– 8	342,738,000
1981	– 3	474,568,000	– 5	382,265,000	– 8	315,318,000
1982	– 3	460,331,000	– 5	363,151,000	– 8	290,093,000
1983	– 3	446,521,000	– 5	344,994,000	– 8	266,886,000
1984	– 3	433,126,000	– 5	327,744,000	– 8	245,535,000
1985	– 3	420,132,000	– 5	311,357,000	– 8	225,892,000
totals		5,303,000,000		4,485,000,000		3,903,000,000

1. Except for rise projected for 1976

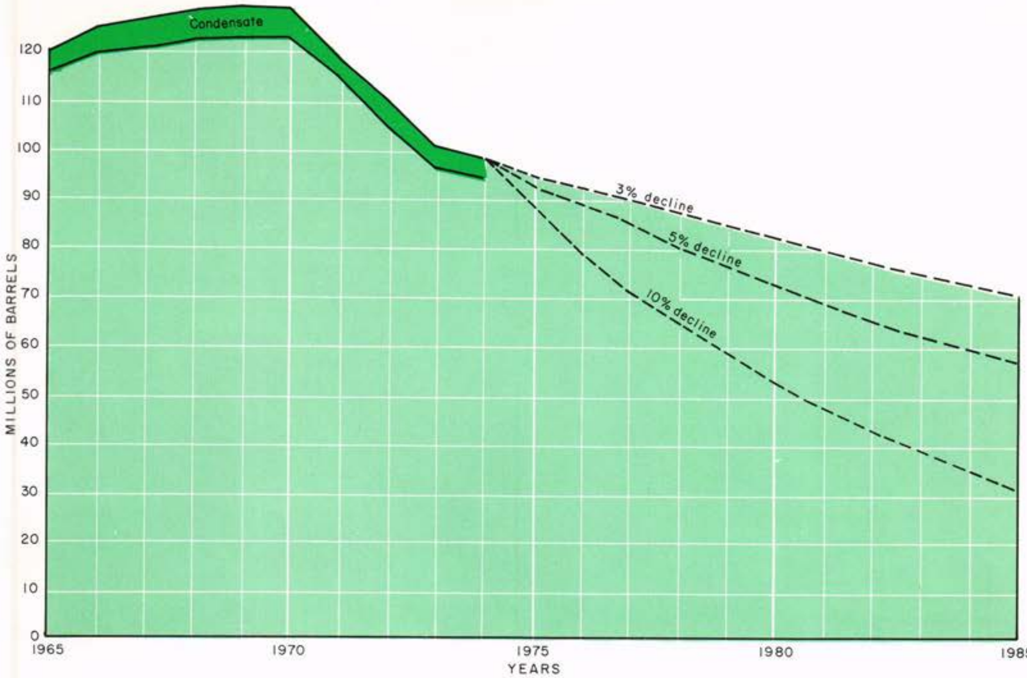

FIGURE 7—PRODUCTION OF CRUDE OIL AND CONDENSATE IN NEW MEXICO 1965 TO 1974, PROJECTED TO 1985 WITH VARIED RATES OF DECLINING PRODUCTION (*Source: N.M.O.C.C.*).

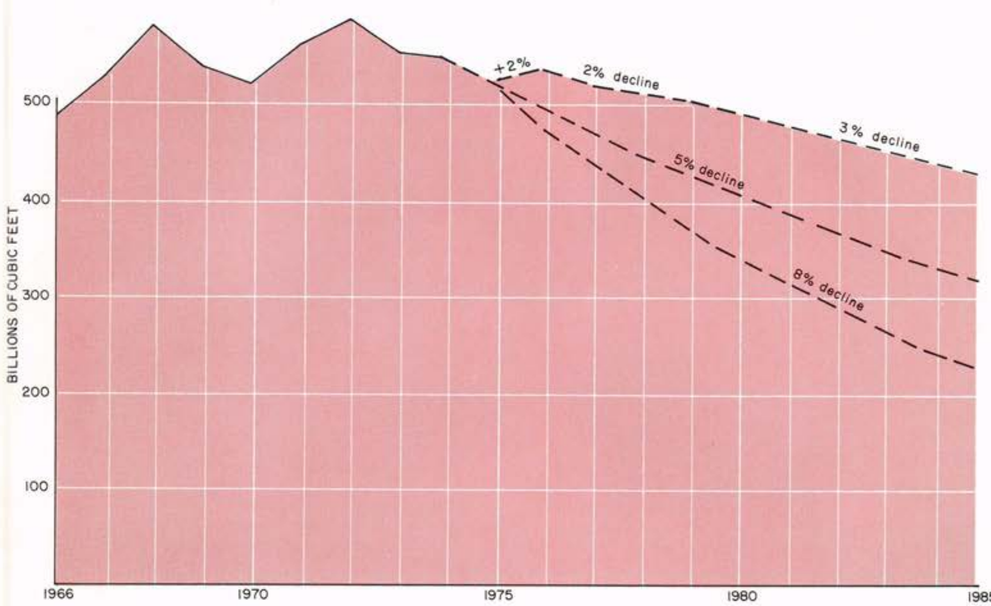

FIGURE 8—PRODUCTION OF DRY GAS IN NORTHWEST NEW MEXICO 1966 TO 1974, PROJECTED TO 1985 WITH VARYING RATES OF DECLINING PRODUCTION (*Source: N.M.O.C.C.*).

TABLE 3—PRODUCTION OF CRUDE OIL AND NATURAL GAS IN NEW MEXICO 1960 TO 1974 (*Source: N.M.O.C.C.*)

Year and area	Barrels				Thousand cubic feet		
	Oil	Condensate	Total oil and condensate	Water	Casinghead gas	Dry gas	Total gas
NW	13,430,845	1,374,351	14,805,196	915,768	31,266,992	342,133,828	373,400,820
SE	91,149,978	1,409,974	92,559,952	84,017,567	262,155,625	186,358,171	448,513,796
1960, total	104,580,823	2,784,325	107,365,148	84,933,335	293,422,617	528,491,999	821,914,616
NW	14,210,632	1,525,358	15,735,990	1,862,902	39,954,895	319,541,175	359,496,070
SE	95,596,439	1,220,972	96,817,411	97,512,336	269,373,304	157,725,609	427,098,913
1961, total	109,807,071	2,746,330	112,553,401	99,375,238	309,328,199	477,266,784	786,594,983
NW	9,181,861	1,659,507	10,841,368	3,839,406	35,895,143	304,909,639	340,804,782
SE	97,225,296	1,261,389	98,486,685	113,139,221	275,932,682	170,015,467	445,948,149
1962, total	106,407,157	2,920,896	109,328,053	116,978,627	311,827,825	474,925,106	786,752,931
NW	7,942,818	1,874,934	9,817,752	4,470,887	27,183,166	321,553,533	348,736,699
SE	98,794,993	1,370,312	100,165,305	127,283,521	272,556,376	171,932,132	444,488,508
1963, total	106,737,811	3,245,246	109,983,057	131,754,408	299,739,542	493,485,665	793,225,207
NW	7,443,260	2,550,525	9,993,785	7,131,448	20,991,913	405,718,222	426,710,135
SE	102,508,438	1,361,185	103,869,623	138,760,709	270,538,055	195,430,490	465,968,545
1964, total	109,951,698	3,911,710	113,863,408	145,892,157	291,529,968	601,148,712	892,678,680
NW	8,776,902	2,804,888	11,581,790	10,600,522	18,467,730	441,561,504	460,029,234
SE	105,966,181	1,618,506	107,584,687	150,261,064	276,863,641	208,128,648	484,992,289
1965, total	114,743,083	4,423,394	119,166,477	160,861,586	295,331,371	649,690,152	945,021,523
NW	8,159,673	3,196,280	11,355,953	13,533,781	15,222,739	483,275,803	498,498,542
SE	111,015,456	1,819,342	112,834,798	158,177,814	286,076,861	228,035,560	514,112,421
1966, total	119,175,129	5,015,622	124,190,751	171,711,595	301,299,600	711,311,363	1,012,610,963
NW	7,533,818	3,528,057	11,061,875	16,198,320	13,928,329	523,356,226	537,284,555
SE	113,060,912	1,879,664	114,940,576	167,575,219	281,722,938	236,644,443	518,367,381
1967, total	120,594,730	5,407,721	126,002,451	183,773,539	295,651,267	760,000,669	1,055,651,936
NW	6,732,250	3,673,081	10,405,331	17,020,379	13,140,201	580,374,026	593,514,227
SE	115,700,459	2,505,535	118,205,994	195,073,824	279,612,600	277,239,086	556,851,686
1968, total	122,432,709	6,178,616	128,611,325	212,094,203	292,752,801	857,613,112	1,150,365,913
NW	6,011,237	3,035,489	9,048,726	16,929,938	12,964,592	538,010,671	550,975,263
SE	117,722,236	2,455,899	120,178,135	210,505,804	282,222,689	280,642,531	562,865,220
1969, total	123,735,473	5,491,388	129,226,861	227,435,742	295,187,281	818,653,202	1,113,840,483
NW	5,780,167	2,905,943	8,686,110	18,593,311	11,066,422	513,961,890	525,028,312
SE	117,181,123	2,280,664	119,461,787	226,808,233	292,907,627	305,519,255	598,426,882
1970, total	122,961,290	5,186,607	128,147,897	245,401,544	303,974,049	819,481,145	1,123,455,194
NW	6,012,907	2,801,992	8,814,899	18,860,437	11,573,567	546,546,676	558,120,243
SE	107,708,035	1,887,036	109,595,071	206,386,656	291,253,975	298,056,323	589,310,298
1971, total	113,720,942	4,689,028	118,409,970	225,247,093	302,827,542	844,602,999	1,147,430,541
NW	5,730,714	2,874,298	8,605,012	20,415,149	12,314,515	574,019,873	586,334,388
SE	99,665,888	2,254,324	101,920,212	196,174,211	259,535,532	351,899,738	611,435,270
1972, total	105,396,602	5,128,622	110,525,224	216,589,360	271,850,047	925,919,611	1,197,769,658
NW	5,175,343	2,394,207	7,569,550	20,659,128	12,932,204	537,186,284	550,118,488
SE	91,233,655	2,182,481	93,416,136	199,979,510	250,718,587	398,702,355	649,420,942
1973, total	96,408,998	4,576,688	100,985,686	220,638,638	263,650,791	935,888,639	1,199,539,430
NW	5,599,465	2,401,954	8,001,419	26,544,506	14,612,336	532,780,048	547,392,384
SE	88,483,452	2,210,094	90,693,546	204,598,067	289,089,197	393,191,355	682,280,552
1974, total	94,082,917	4,612,048	98,694,965	231,142,573	303,701,533	925,971,403	1,229,672,936

decline, the production for the period would be 3.903 trillion cubic feet; production for 1985 would be 225.89 billion cubic feet.

The decline in production rates shown are estimated on the basis of opinions solicited from gas purchasers and oil and gas operators in the area, as well as from independent studies conducted by the Office of State Geologist. Although opinions differ, fig. 8 represents a consensus of expert opinion on future production rates.

SOUTHEAST NEW MEXICO

Production of natural gas for southeast New Mexico from 1960 through 1974 is shown in table 3 and fig. 6. Dry gas production increased from 200 billion cubic feet in 1960 to about 400 billion cubic feet in 1974 (from 1,700 gas wells). While the dry gas rate has doubled during the period, casinghead gas production has maintained stable rates of between 250 and 300 billion cubic feet yearly.

A projection curve for natural gas in southeast New Mexico is not included in this report. The variability of future development is so uncertain that such a curve would have little meaning. The canvass (by the Office of State Geologist) of purchasers and operators in southeast New Mexico regarding future production trends indicates considerable optimism concerning the discovery and development of new dry gas reserves, particularly in the Atoka and Morrow strata of Pennsylvanian age. Estimates of possible additional new reserves run as high as 7 trillion cubic feet. This gas is relatively deep and expensive to develop; again, the future gas price schedule will greatly influence the development rate. In 1974, 250 dry gas wells were drilled in southeast New Mexico, a large increase over any previous year. Gas completions for 1975 will probably total about 210. Average production rates for Pennsylvanian wells in the area average 1.5 to 5 million cubic feet per day for the first year, with the production rates declining from 15 percent to 25 percent during the first 3 or 4 years, leveling off at 12 percent or 13 percent thereafter. The successful completion and production of 200 or 300 wells of this type per year will significantly increase yearly production of dry gas from the area over the period of development, even though the individual well reserve depletion rate is relatively steep compared to wells in northwest New Mexico. The production decline rate for southeast New Mexico dry gas may be 15 percent to 20 percent per year, excluding new development.

The situation with regard to future production rates for casinghead gas in southeast New Mexico is similar. Casinghead gas production was 262 billion cubic feet in 1960, and increased slowly over the years, with a high of 292 billion cubic feet in 1970. In 1972 production dropped to 259 billion cubic feet, and to 250 billion cubic feet in 1973. The curve reflects an apparent increase in 1974. An examination of the records, however, indicates that this increase was caused by the consolidation (New Mexico Oil Conservation Commission Order R-1670-M, January 1, 1974) of the Blinebry Oil and Gas pools into the Blinebry Oil pool and the redefinition of all gas produced as casinghead gas. This redefinition is also reflected as a decrease in dry gas production in 1974 (fig. 6). A large portion of the casinghead gas being produced in the area is coming from pools that have been producing for many years and are nearing depletion on primary production. Expert opinion is that the zero development casinghead gas depletion rate would

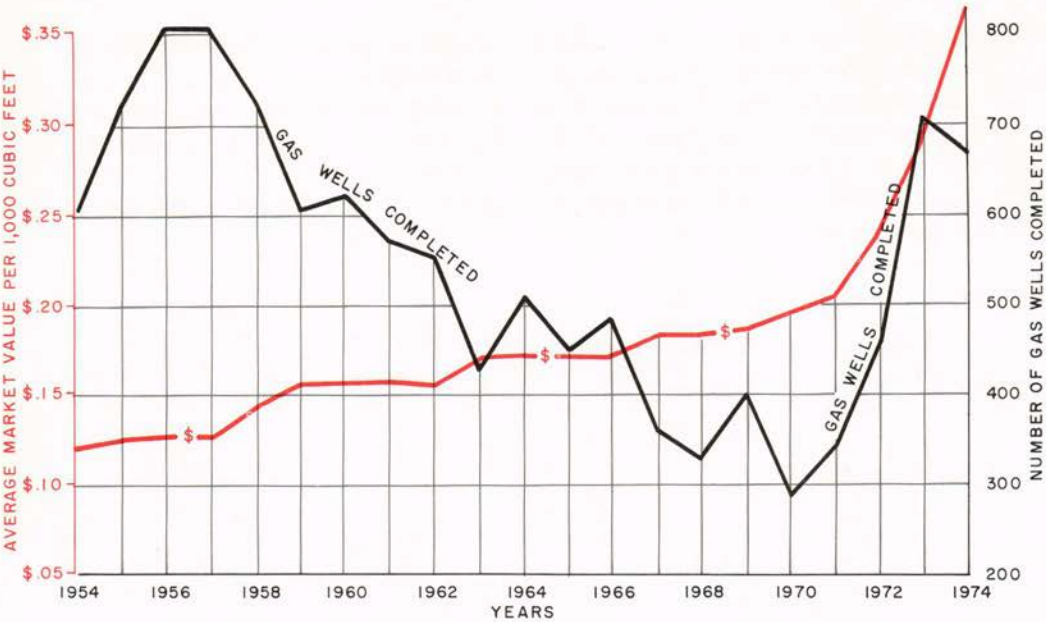

FIGURE 9—Average market value of natural gas and the number of gas wells completed in New Mexico 1954 to 1974 (*Source: N.M.O.C.C.*).

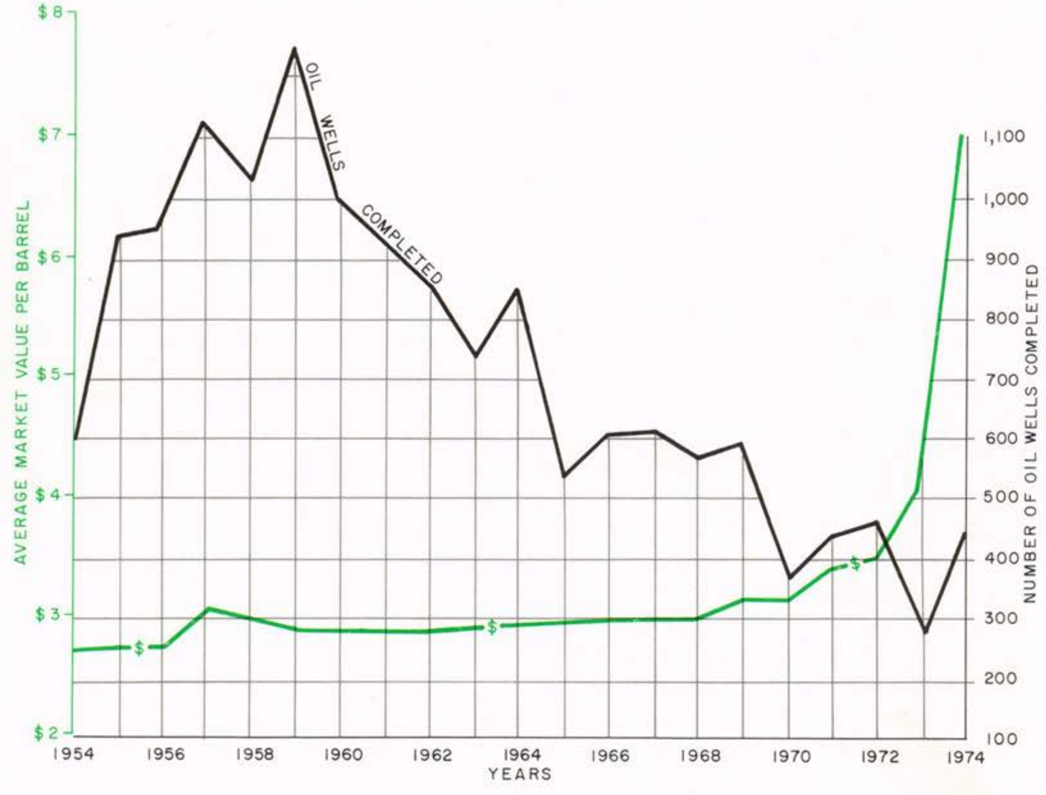

FIGURE 10—Average market value of crude oil, and the number of oil wells completed in New Mexico 1954 to 1974 (*Source: N.M.O.C.C.*).

be between 15 percent and 20 percent per year. This rate of decline can only be lessened by the discovery and development of new oil pools in the area. The rate of development of new oil reserves depends largely on the future price of crude oil. The new rolled back price of $7 or $8 per barrel will hardly attract the exploration investment necessary to improve the discovery rate.

In summary, the declining rate of production of dry gas from older gas pools, and the declining rate of production of casinghead gas may be offset over the next several years by the development of new Pennsylvanian dry gas reserves in the area. This production could maintain total gas production at present levels, perhaps even increase the total gas produced if a normal oil discovery rate is maintained. The low reserve/production ratio on most of the new pools being discovered, however, indicates that such production rates cannot be maintained if the new gas development rate drops far below present levels. Without new gas development, the dry gas production decline rate would probably also be between 15 percent and 20 percent per year.

Comparisons of prices of oil and of natural gas with exploration drilling and with completions show similar trends. While the price of natural gas crept slowly upward from 12 cents per thousand cubic feet in 1954 to about 20 cents in 1971, gas well completions dropped from highs in the late 1950's to a low in 1970. Then, as prices rose to over 35 cents in 1974, completions rose to about 700 per year (fig. 9).

The trend for crude oil is similar. Prices per barrel were at or below $3 until 1969; completions of oil wells dropped from a high of more than 1,200 in 1959 to less than 400 in 1970 (fig. 10). Recent price increases to over $7 per barrel stimulated an upswing in oil well completions.

FUTURE PETROLEUM PROVINCES

(Map and text follow on pages 20 and 21)

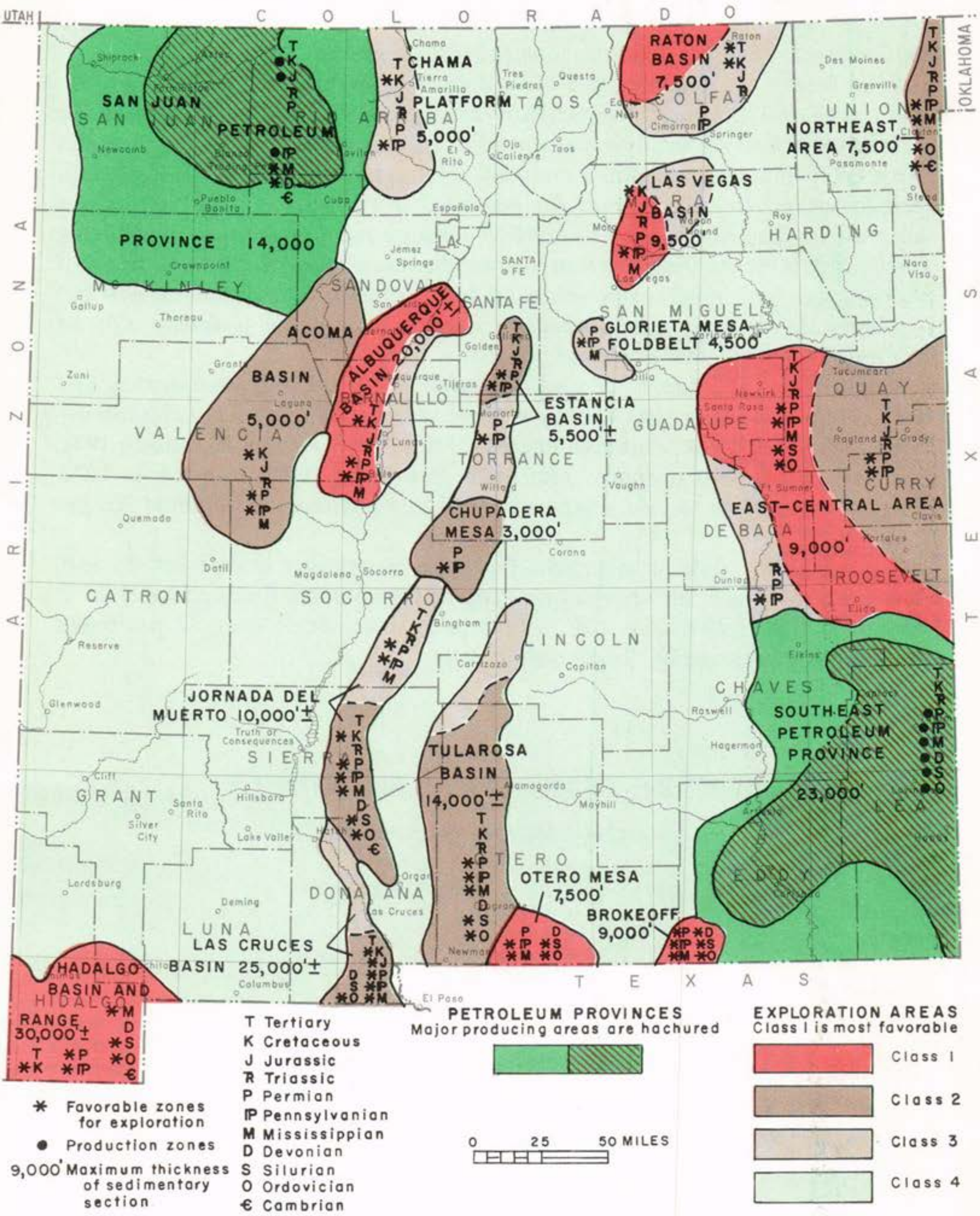

FIGURE 11—PETROLEUM PROVINCES AND EXPLORATION AREAS IN NEW MEXICO (*Source: New Mexico Bureau Mines Mineral Resources, Resource Map 3*).

FUTURE PETROLEUM PROVINCES

Fig. 11 depicts the major producing areas as well as other areas with varying degrees of potential for the discovery of oil and/or gas. For each of these areas, except Class 4, the stratigraphic sequence is indicated along with the more favorable zones for exploration and the maximum thickness of sedimentary rocks overlying the Precambrian basement.

The potential for each area is based on the size of the area, depositional environments, thickness of sedimentary rocks, structural conditions, and the presence of suitable petroleum reservoir and source rocks. Any given area may have localities of greater or lesser potential depending mostly on structural conditions. Similarly, a Class 4 area having the least potential may have spots that justify exploration.

Since the preparation of this map last year some gas discoveries have been drilled in the southern part of the east-central area and in the Las Vegas Basin. Although small, these discoveries demonstrate that hydrocarbons occur outside the producing areas, and tend to encourage exploration in other parts of the state.

The currently nonproductive areas have little likelihood of containing the amount of petroleum known in the southeast and northwest areas. This statement does not rule out the possibility of significant discoveries; the basic limitation is the volume of rock present and the conditions under which these rocks were deposited.

The discovery of large reserves that could have a significant long-range impact on the future of New Mexico's oil and gas industry must come from the current producing areas. In studying a map showing all the wells drilled in these areas, little room appears to be left for major discoveries. However, when the shallower tests are removed large unexplored areas begin to appear. Examples of largely untested zones within the producing provinces are 1) the Pennsylvanian rocks of the San Juan Basin where large oil reserves should be present, and 2) Ordovician, Silurian, and Devonian strata in the eastern part of the Delaware Basin with excellent gas potential. The limits of many pools have not yet been established, and considerable shallow oil exists behind pipe awaiting depletion of deeper zones. These sources represent future development programs that, along with secondary and tertiary recovery, can make sizeable contributions to our reserves.

In addition to the price structure for oil and gas, other factors also contribute to more active exploration and development: an expansion of our basic knowledge of the results of past drilling, a better understanding of the depositional and structural framework controlling accumulations of petroleum, new or improved completion and recovery techniques, and probably most important of all, the change in economic philosophy brought about by new discoveries.

ANTICIPATED DEMANDS 1975 TO 2000

At present two large electric generating plants, the San Juan plant and the Four Corners plant, near Farmington, consume over 8 million tons of coal yearly. Near Gallup, the McKinley mine of Pittsburg & Midway Coal Mining Company ships 380,000 tons a year to the Cholla Generating plant near Joseph City, Arizona. The Kaiser Steel Corporation York Canyon mine ships about 1 million tons of coking coal a year to the Los Angeles area for use in its Fontana steel mills.

These operations account for most of New Mexico's coal consumption, which was 9,392,000 tons in 1974 according to the U.S. Bureau of Mines.

The Coronado Generating plant at St. Johns, Arizona, now under construction by the Salt River Project Authority, may require over 3 million tons yearly, with production planned from coal beds northeast of Gallup, New Mexico, near Star Lake.

Farther in the future are the planned coal gasification plants near Burnham that will utilize 40 million tons of coal a year.

Referring to table 4, 1975 production of coal in New Mexico will have required nearly ten million tons of coal for electrical generation and steel coking—nearly all the coal produced in the state.

Assuming that the Coronado plant at St. Johns, Arizona comes on line in 1978, coupled with the additional units of the San Juan complex (Units #1, #3, and

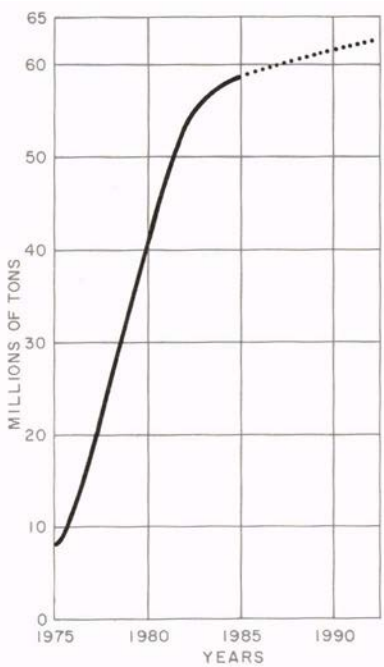

FIGURE 12—YEARLY REQUIREMENTS FOR COAL 1975 TO 1990 (*based on data in table 4*).

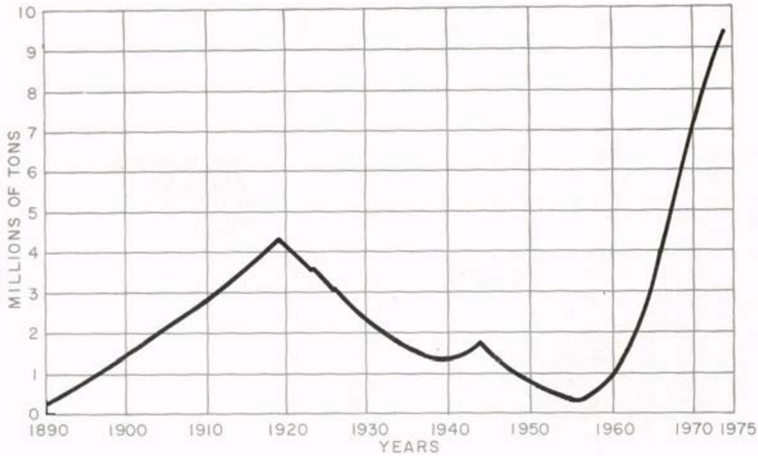

FIGURE 13—AMOUNTS OF COAL MINED ANNUALLY IN NEW MEXICO 1890 TO 1975.

#4) programmed for online status between 1976 and 1980, and the completion of the Wesco and El Paso gasification complexes by 1980, apparently more than 40 million tons of coal will be needed per year by 1980 (fig. 12). The yearly requirement will rise to approximately 59 million tons by 1985, if the El Paso and Wesco gasification plants are completed.

PRODUCTION

The Spanish used small amounts of coal from the early 1600's. Anthracite was mined in the Cerrillos area in 1835. Army troops mined coal in the Carthage area in 1861. First records of coal production were for 1882.

In 1918 a peak production of over 4 million tons was reached, much of this for use by the railroads and lead and copper smelters. Production began to diminish as the railroads began to use diesel fuel and as the use of natural gas increased. Production decreased to less than a million tons in 1950, and to 116,656 tons in 1958. Annual production has ranged from 116,656 tons in 1958 to 8,308,000 in 1972, 9,300,000 in 1973 and 9,392,000 tons in 1974. In 1960 the opening of the York Canyon mine by Kaiser Steel Corporation initiated an upsurge accelerated by the opening of the Navajo and San Juan coal-burning electric generating plants in the Farmington region. Production in 1972 consisted of over 8 million tons of subbituminous coal, surface mined, and over a million tons from underground mines.

Projection of current demands indicate that production may be as much as 10 million tons for the year 1975 (fig. 13).

OCCURRENCES

The general location of coal in New Mexico is depicted in fig. 14. The rank of coal, heating value, and reserves are given in table 5. About one-fifth (25,000 square miles) of the area of New Mexico is underlain by coal beds at various depths. Due to the lenticular shape of the beds, estimation of coal resources with reasonable accuracy is difficult. Many minable beds extend for only several miles

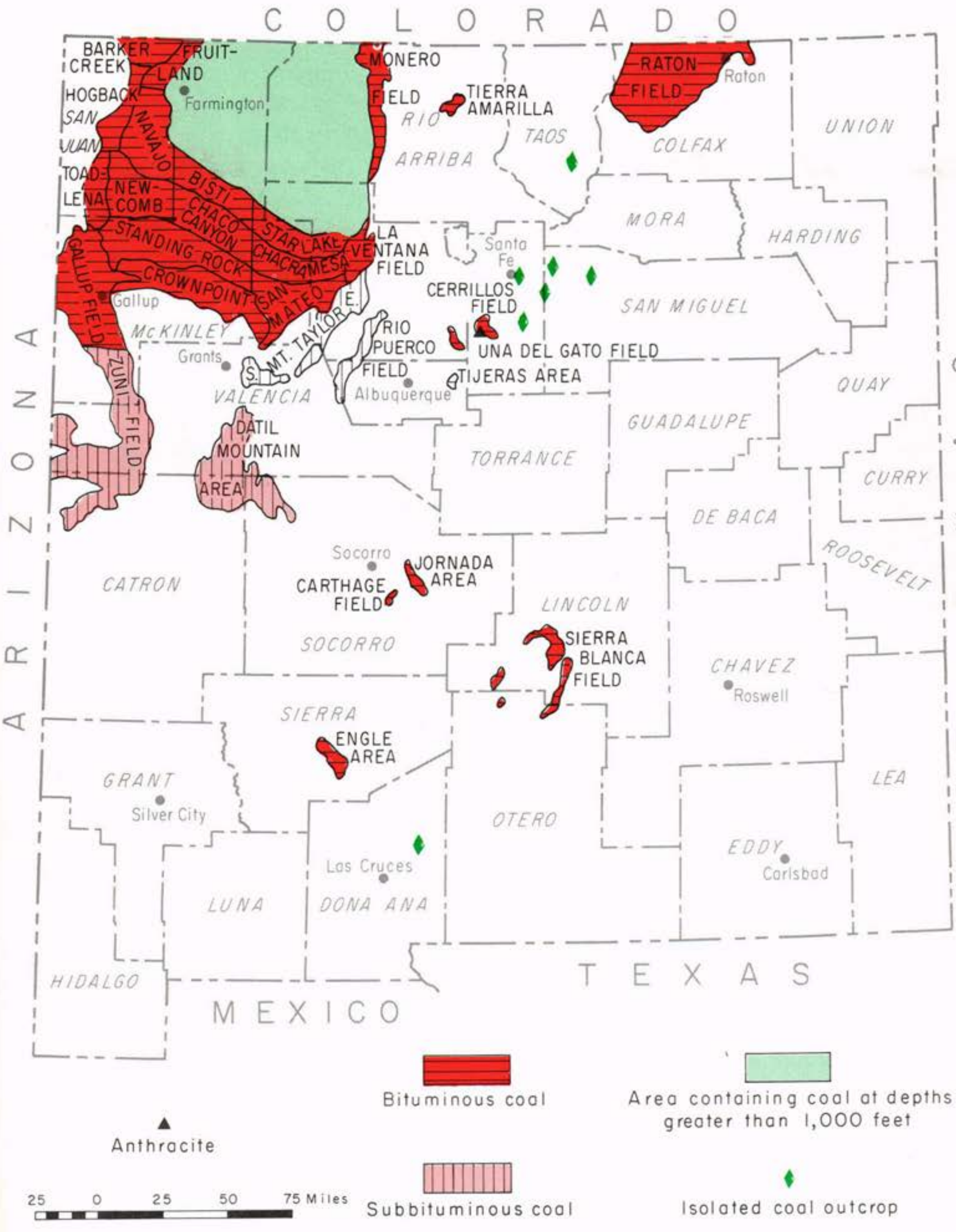

FIGURE 14–Coal in New Mexico (*Source:* Kottlowski, Shomaker, and Beaumont, 1975).

(rarely more than 6) and then thin to uneconomic thickness. Some of the coals are at depths of 5,000 ft or more, particularly in the northeastern part of the San Juan Basin, where the Cretaceous strata dip steeply into the basin.

San Juan Basin coals occur in the Fruitland and Mesaverde Formations (Upper Cretaceous). Coals in both formations were deposited during retreats and transgressions of seas across the area, evidenced by sedimentational cycles within the Cretaceous of the San Juan Basin. Shorelines migrated from southwest to northeast across the basin during regressions of the sea, creating extensive swamp environments that also moved successively northeastward as the shoreline retreated. During relatively stable periods, thick deposits of organic material accumulated, resulting in the accumulation of thick coal deposits paralleling shorelines trending generally northwest-southeast. At other times the seas retreated more rapidly, resulting in areas that contain thin coal seams, or none at all. Coal beds, therefore, tend to be continuous in a northwest-southeast direction, and lenticular and discontinuous in a southwest-northeast direction.

Succeeding transgressions of seas across the area repeated the cycle, extensive swamp environments forming landward from the transgressing sea. These depositional cycles resulted in a widespread distribution of coal across the entire San Juan Basin. By far the largest volume of strippable coal occurs in the Fruitland Formation because the Fruitland outcrop occupies a structural position farther from the steeply dipping strata bordering the basin than does the Mesaverde outcrop. Dips on the Fruitland beds are very gentle. As a result large areas of Fruitland coal have a thin overburden that makes strip mining economically feasible. Even so, 98 percent of Fruitland coal lies at a depth more than 250 ft below the surface (Kottlowski, Beaumont, and Shomaker, 1975).

At the present, strip mining below 225 ft is generally noneconomic (Atwood, 1975). Improved technology of excavation or rising prices of coal could make surface mining at greater depths possible. This general condition may vary, depending on the thickness of coal beds exposed at a given site.

Tables 6 and 7 indicate coal resources available for possible development in New Mexico. Wherever possible a distinction is made between strippable and deep resources. Strippable coals are defined as those beds covered by 250 ft or less of overburden.

Improved technology of burning deep-seated coal in situ (in place) to obtain gas, or deep underground mining, may be found to be economically feasible to utilize the deep deposits in the future.

About 5,711.6 million short tons, or 2 percent of the total coal resources in New Mexico, are available in strippable quantities in the San Juan Basin (Kottlowski, Beaumont, and Shomaker, 1975).

SAN JUAN BASIN

In table 6, columns 1 and 2 include beds of coal 3 ft or greater in thickness overlain by overburden less than 150 ft in thickness. columns 3 and 4 include beds 5 ft or thicker and covered by overburden between 150 and 250 ft in thickness.

Where possible reserves are identified as "measured" or "inferred." Measured reserves were based on observations of outcrops or drillhole data at sites a mile or less apart. Inferred reserves were based on similar data from sites more than a

TABLE 6—ORIGINAL STRIPPABLE COAL RESERVES IN NEW MEXICO, MILLIONS OF SHORT TONS (*Source: New Mexico Bureau Mines Mineral Resources, Memoir 25*)

	Overburden less than 150 ft			*Overburden 150 ft to 250 ft*			
Coal field or area	*Measured (column 1)*	*Combined*[1]	*Inferred (column 2)*	*Measured (column 3)*	*Combined*[1]	*Inferred (column 4)*	*Totals*
Gallup	–	270.0	–	–	88.0	–	358.0
Durango and Mesaverde	–		–	–		–	
Barker Creek	–		–	–		–	
Hogback	–		–	–		–	
Toadlena	–		–	–		–	
Newcomb	–		78.5	–		6.3	84.8
Chaco Canyon	–		31.0	–		–	31.0
Chacra Mesa	–		–	–		–	
San Mateo	–		21.2	–		–	21.2
Standing Rock	–		63.5	–		75.0[2]	138.5
Zuni	–		6.2	–		–	6.2
Crownpoint	–		15.0	–		–	15.0
South Mount Taylor	–		1.4	–		–	1.4
East Mount Taylor	–		–	–		–	
Rio Puerco	–		–	–		–	
La Ventana	–		15.0	–		–	15.0
Tierra Amarilla	–		–	–		–	
Monero	–		–	–		–	
Pagosa Springs	–		–	–		–	
Durango	–		–	–		–	
Fruitland	93.0		–	65.0		–	158.0
Navajo	–	1,024.7	–	–	1,352.8	–	2,377.5
Bisti	–		958.0	–		912.0	1,870.0
Star Lake	–		365.0	–		270.0[2]	635.0
Totals		2,942.5[3]			2,769.1[3]		5,711.6

1. Some portion limited by stripping ratio; figures for measured and inferred reserves not released by companies
2. Estimates for Standing Rock and Star Lake in column 4 are being revised; new estimates are not now known
3. Includes measured, inferred, and combined

TABLE 7—ESTIMATED REMAINING COAL RESOURCES OF NEW MEXICO OUTSIDE SAN JUAN BASIN, MILLIONS OF SHORT TONS (*Source: Kottlowski, Beaumont, and Shomaker, 1975*)

	Strippable[1] *resources*	*Strippable and deep resources combined*	*Deep resources*
Raton basin		4,709	
Cerrillos field	–		59
Una del Gato field		17	
Tijeras area	–		2
Datil Mountain area		1,320	
Carthage field		39	
Jornada del Muerto area			
Sierra Blanca field		1,644	
Engle area		unknown	
Total		7,790	61

1. Beneath 250 ft or less of overburden

mile apart and involved extensive extrapolation of data and projection of geologic evidence. The term "original" denotes that tonnage mined prior to the report time during which the report was in preparation was ignored because tonnages were relatively insignificant. Mining leases were not included to avoid the problem of determining what a reasonable recovery factor would be.

In summary, in the San Juan Basin about 2,942 million tons of coal may occur with less than 150 ft of overburden. Another 2,769 million tons probably occur beneath an overburden ranging in thickness between 150 ft and 250 ft. Beneath 250 ft or less of overburden, therefore, about 6 billion tons of coal may occur. Below 250 ft, doubtless enormous quantities of coal await new techniques of burning coal in situ to obtain gas, or solution mining.

Fassett and Hinds (1971) estimated that the Fruitland Formation alone, probably embodying about 90 percent of the strippable coals in the San Juan Basin, contains approximately 200 billion tons in beds greater than 2 ft thick, as deep as 4,500 ft.

Another 7,790 million tons are available in strippable and deep resources combined in 9 other subordinate coal fields (table 7). The Raton field with an estimated resource of both categories of 4,709 million tons is the largest of the smaller fields.

Adding reserve tonnages calculated for the San Juan Basin (table 6) to the estimates for other outlying fields (table 7) obtains an overall total as given in table 8.

Nearly 3 billion tons of readily exploited resource (strippable down to 150 ft) are available to meet the anticipated 1980-85 requirement of 40 million tons a year by users of San Juan Basin coal. Below 150 ft to 250 ft of overburden are an additional 2.7 billion tons of coal (see table 2).

The estimate of future annual requirements of 55 million tons (table 1) may be too conservative. Some authorities (Shomaker, 1975) have conjectured that nearly 73 million tons per year may be needed by 1983, and that a figure of 110 million tons might be reached by that year if all the developments being considered were realized.

Of the 4 major mines presently in operation, 3 are strip mines: Navajo, San Juan, and McKinley, all in the San Juan Basin. York Canyon, an underground and strip mine, is located near Raton.

Over 1,200 people are employed in the mines and at mine-mouth generating plants with an annual payroll of approximately 14 million dollars. This figure may rise to over 133 million dollars if the proposed coal gasification complexes become operative.

CAPACITY

In table 9 the ranking of eastern and western states relative to additional coal capacity is compared. The Coal Advisory Committee of the Federal Energy Administration estimated that additional capacity under construction, announced or planned, would, by the end of 1975, add 577.8 million tons to existing capacity, a total of over one billion tons.

Of the additional capacity of 578 million tons, 302.4 million tons will come from mines in western states with 275.0 million tons from mines in eastern states.

TABLE 8—TOTAL COAL RESOURCES IN NEW MEXICO, MILLIONS OF SHORT TONS (*Source: Kottlowski, Beaumont, and Shomaker, 1975*)

	Strippable[1] resources (column 1)	Strippable and deep resources combined (column 2)	Deep resources (column 3)	Total
San Juan Basin	5,711		269,177	274,888
Other coal fields	–	7,790	61	7,851
Total	5,711	7,790	269,238	282,739

1. Beneath 250 ft or less of overburden

TABLE 9—COMPARISON OF ADDITIONAL CAPACITY OF EASTERN STATES VS WESTERN STATES (*Source: Federal Energy Administration*)

Region and state	*Additional capacity (millions/tons)*	*Regional rank*	*National rank*
Eastern states			
West Virginia	71.00	1	2
Kentucky	69.00	2	3
Illinois	40.60	3	5
Pennsylvania	31.50	4	7
Alabama	19.55	5	10
Ohio	14.20	6	12
Virginia	13.70	7	13
Indiana	11.00	8	15
Tennessee	4.85	9	16
Total Eastern	275.00		
Western states			
Wyoming	123.00	1	1
Montana	57.30	2	4
Utah	36.60	3	6
Arizona	27.00	4	8
North Dakota	21.90	5	9
Texas	16.70	6	11
New Mexico	13.60	7	14
Washington	3.00	8	17
Colorado	2.90	9	18
Total Western	302.40		
Total United States	577.80		

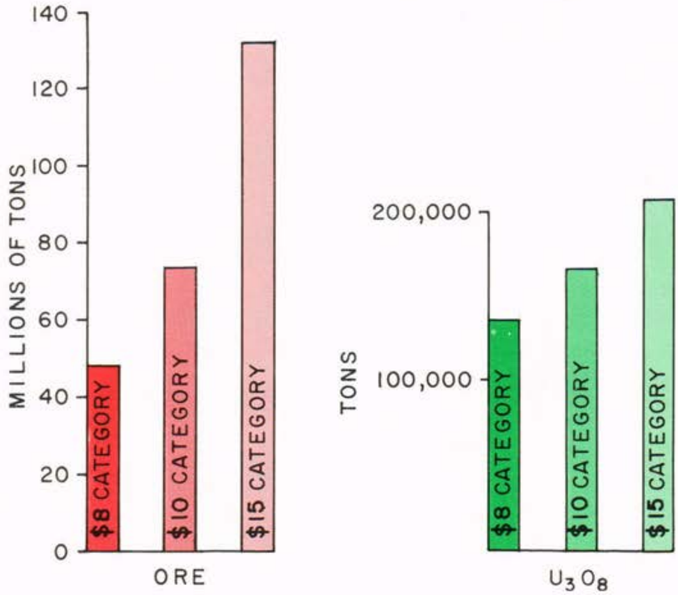

FIGURE 15—Reserves of uranium in New Mexico 1975 in terms of production cost category.

Uranium–significant for the long term

OCCURRENCE

Most of the uranium mined in New Mexico is in the Grants uranium region, a strip about 110 miles long extending from Gallup eastward to the Rio Puerco. Minable deposits are not continuous throughout the region but occur in several districts where special stratigraphy or structure caused large accumulations of uranium ore. Within the region are 6 principal mining districts, Gallup, Church Rock, Smith Lake, Ambrosia Lake, Grants, and Jackpile-Paguate.

Early mining of uranium began in 1951 from the Todilto Limestone deposits and from the sandstone in Anaconda's Jackpile open-pit mine. The original discovery (although yellow carnotite ore had been recognized earlier) was a tyuyamunite sample from the Todilto Limestone outcrop at the base of Haystack Butte. Uranium ore also has been found in commercial quantities in the Dakota Sandstone, and the Brushy Basin and Westwater Canyon Members of the Morrison Formation (Kelley, 1963).

The sedimentary rocks containing minable uranium deposits in the area are of Jurassic and Cretaceous ages. The ore-bearing and adjacent beds, in ascending order, are the Entrada Sandstone, Todilto Limestone, Summerville Formation, Bluff Sandstone, and Morrison Formation, all of Late Jurassic age, and the Dakota Sandstone of Early and Late Cretaceous age (Hilpert, 1963). This sequence, resting on the Wingate Sandstone or the Chinle Formation of Triassic age, ranges from 1,000 to 1,500 ft in thickness.

Uranium has been found outside of the Grants mineral region but not as yet in commercially important quantity. Carnotite deposits were discovered west of Shiprock in San Juan County in 1918 and uraniferous minerals were found in the White Signal and Black Hawk districts of Grant County in 1920 (Hilpert, 1965).

The mined deposits are in flat-lying beds and range from local masses that contain less than a ton of material to large masses that contain as much as several million tons. Average grade of the ore is approximately 0.25 percent U_30_8. Ore is surface mined in the Laguna district and in underground mines as deep as 3,000 ft in other districts.

Vein deposits have not been an important source of uranium in New Mexico; only 15,000 tons of ore from this source have been mined.

PRODUCTION AND RESERVES

New Mexico's production of uranium has led the nation except for 1973 when Wyoming mined about one percent more than our state. For the 5 years from 1970 through 1974, New Mexico's production ranged from a low of 9,968,000 pounds of U_30_8 in 1973 to a high of 12,112,000 in 1970, with the value of production rising from $69.97 million in 1970 to $104.7 million in 1974. Production for 1975 was 9.9 million pounds of U_30_8 valued at $215.8 million (U.S. Bureau of Mines preliminary data).

Reserves of uranium ore in New Mexico as estimated by Energy Research and Development Administration (report of January 1, 1975) and related to the cost of producing the various ores are:

Reserve category	Tons ore	U_3O_8 %	U_3O_8 Tons	% Total U.S. tons U_3O_8	Number of deposits
$8	47,905,000	0.29	137,100	69	66
$10	74,730,000	0.22	168,100	53	87
$15	132,913,000	0.16	210,800	50	103

These amounts are shown graphically in fig. 15. Most of these ore reserves are in the Grants uranium region and 95 percent of the ores are in the sandstone beds of the Morrison Formation.

Exploration drilling continues on the south side of the San Juan Basin, as well as in other parts of northern New Mexico where the Morrison Formation occurs; other reserves of uranium ore probably await discovery. For example, in mid-December 1975 Phillips Petroleum Company announced their drilling near Seven Lakes, 48 miles northeast of Gallup, had found at least 25 million pounds of U_3O_8 in 7 million tons of ore at depths of 3,000 to 3,500 ft.

Staatz and Olson (1973) investigated thorium resources in New Mexico and listed 24 deposits of which 9 are of the fossil placer or placer variety. At the present time these deposits in New Mexico are minor in importance because of the larger and more economically attractive thorium ores in Idaho, Montana, and Colorado. All may be used in the future to provide nuclear fuel.

MINES

McKinley County

Ann Lee Mine, United Nuclear Corporation
Johnny M Mine, Ranchers Exploration and Houston Natural Gas Joint Venture
Kerr-McGee Section 17 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 19 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 22 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 24 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 30 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 30 West Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 33 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 35 Church Rock Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 35-14-9 Mine, Kerr-McGee Nuclear Corporation
Kerr-McGee Section 36 Mine, Kerr-McGee Nuclear Corporation
Smith Lake, Western Nuclear
San Mateo, Gulf Energy Minerals
Northeast Church Rock Mine, United Nuclear Corporation
Sandstone Mine, United Nuclear Corporation
Section 27 East Mine, United Nuclear Corporation
UN-HP Section 15 Mine, United Nuclear-Homestake Partners
UN-HP Section 23 and General Mine, United Nuclear-Homestake Partners
UN-HP Section 25 Mine, United Nuclear-Homestake Partners
UN-HP Section 29 and 32 Mine, United Nuclear-Homestake Partners
Western 21 Mine, Western Nuclear, Inc.

Valencia County

F-33 Mine, Homestake Mining Company
H-1 Laguna, The Anaconda Company
Jackpile-Paguate Mine, The Anaconda Company
L-Bar Ranch Mine, Sohio Petroleum Company
Laguna P-9-2 Mine, The Anaconda Company
P-10 Mine, Kop-Ran Development Corporation
Marquez, Sohio Petroleum Corporation

MILLS

Operator	Location	Date began operations	Capacity tons per day
Anaconda	Grants	Sept., 1953	3,000
United Nuclear-Homestake	Grants	Sept., 1958	3,000
Kerr-McGee Corporation	Grants	Dec., 1958	3,300

U.S. RESOURCES AND DEMAND

The January 1, 1975 estimates of potential uranium ore resources in the United States made by the Energy Research and Development Administration are:

Forward costs (cumulative[1])	Tons U_3O_8		
	Probable	Possible	Speculative
$ 8	300,000	200,000	30,000
$10	460,000	390,000	110,000
$15	680,000	640,000	210,000
$30	1,140,000	1,340,000	410,000

1. Each cost category includes all lower cost resources.

Reserves are ores in known deposits; estimates are based on detailed sample data. Potential resources are based on knowledge of known favorable geologic environment.

Peneconcordant deposits in which uranium is deposited, closely associated with carbonaceous organic material, in lake, river, and nearshore marine-deposited sandstones provide the most abundant source of the ore. The sandstone type deposits found in the San Juan Basin (New Mexico), Shirley Basin (Wyoming), and the Texas Coastal Plain constitute 95 percent of the known deposits in the United States. Phosphatic rocks and marine black shales enriched with uranium are a possible source, but the percentage of U_30_8 is very low, and technological problems exist relative to removal of the uranium.

The total cumulative purchases of U_30_8 from 1949 through the year 1962 (given by ERDA) are 11,373 tons or slightly over 3.6 million tons of ore. The annual projected requirement for U_30_8 between 1975 and the year 2000 is estimated to rise from 11,700 short tons in 1975 to 153,600 short tons in the year 2000 (Brookins, 1975). Obviously, all of New Mexico's uranium will be needed.

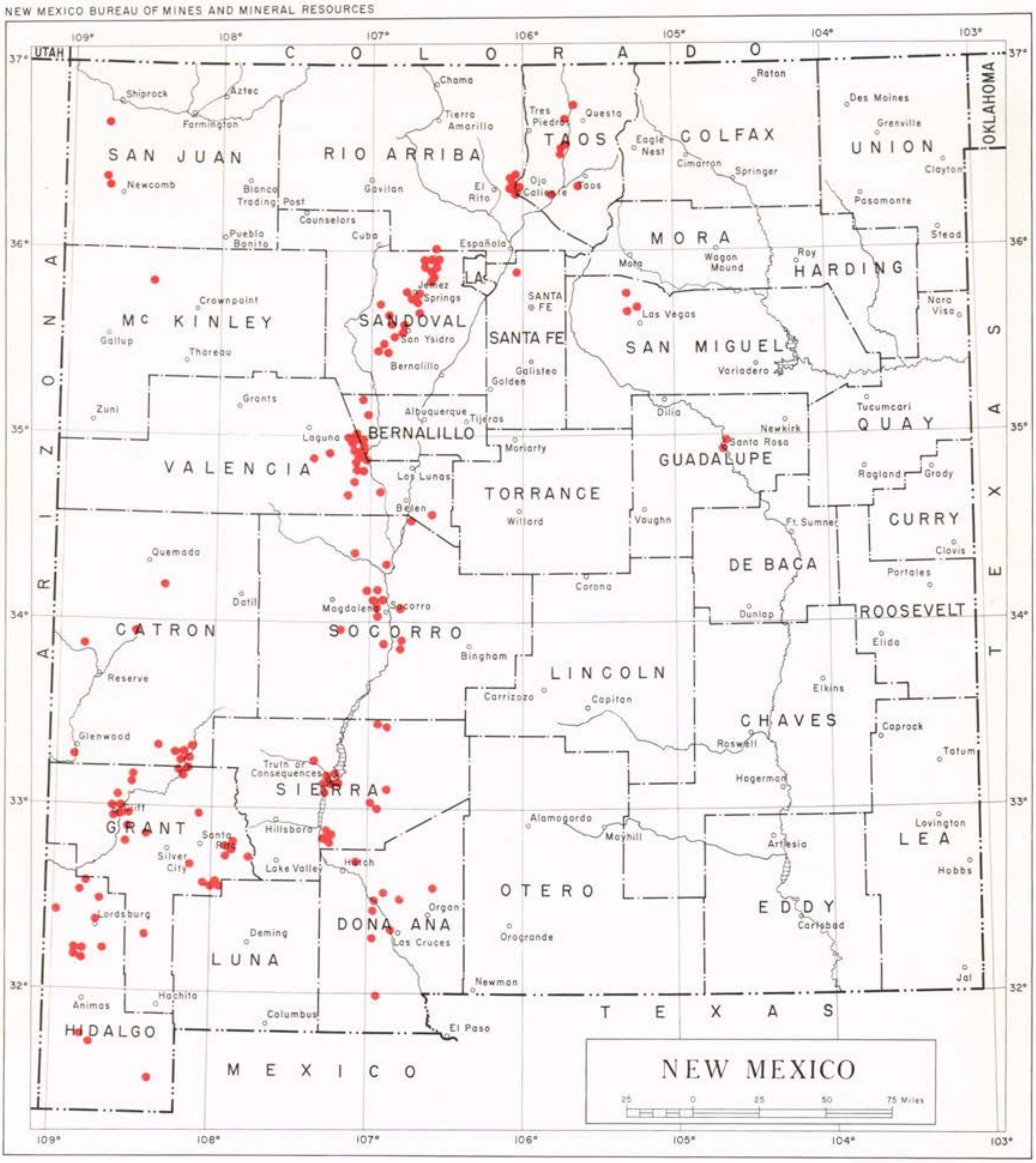

FIGURE 16—Location of thermal springs and wells having temperatures greater than 65°F.

Geothermal—

A little known resource having interesting potential

OCCURRENCES

Geothermal reservoirs are complex and difficult to evaluate. Furthermore, they are local phenomena, therefore difficult to find. Based on recent studies, two regions in New Mexico have geothermal potential: the region encompassing the Rio Grande valley and adjoining mountains, and the region encompassing the west-central and southwest part of the state.

The Rio Grande region is characterized by: mountain masses bordering, and uplifted above, the valley floor; with numerous hot springs having temperatures greater than 65°F (fig. 16, Summers, 1965b); with heat flow values approximately twice that of normal values for geologically stable areas (fig. 17, Reiter, and others, 1975); with intense tectonic and volcanic activity (Chapin, 1971); and with locally intense seismic activity (Sanford, 1963).

The west-central and southwest region is characterized by local areas of hot springs, by sites of approximately twice normal heat flow, by large ancient volcanoes (Elston and others, 1975), and by immense masses of volcanic rocks.

Chemical analysis of thermal spring waters, determination of terrestrial heat flow, monitoring of seismicity, measurement of earth resistivity, and geologic analysis of volcanic provinces are the major methods for evaluating regional and local geothermal potential. Numerous hot springs suggest the presence of significant geothermal waters. Chemical analyses of waters in hot springs may provide possible geothermal reservoir temperatures and may be used to locate areas of high geothermal potential (Swanberg, 1975). Heat-flow values of twice normal suggest areas of regional geothermal potential, whereas heat-flow values of 5 to 10 times normal suggest areas of significant local geothermal potential. Regions of high seismicity may relate to major tectonic and volcanic activity. High seismicity may be related in some areas to geothermal phenomena. The passage of electrical currents through the earth's near-surface crust is enhanced (resistivity is reduced) in hot rock (Jiracek, 1974). Recent large-scale volcanism is often correlated with high subsurface temperatures.

UTILIZATION

NEW MEXICO

Presently the only use of New Mexico's geothermal energy is associated with hot springs, many of which have been developed as small mineral baths or spas. The most significant industrial activity is that being conducted by Union Oil Company in the Valles Caldera, an ancient volcano in the Jemez Mountains. The wells drilled by Union Oil Company's Geothermal Division range in depth from 6,000 to 9,000 ft, and cost from $500,000 to $1,000,000 per well. Of the 16 tests drilled, 6 are reported to have produced hot water and/or wet steam, with temperatures around 200°F. The water has a brine content of about one-quarter that of sea water, including much silica as well as carbonates and sulfates. To

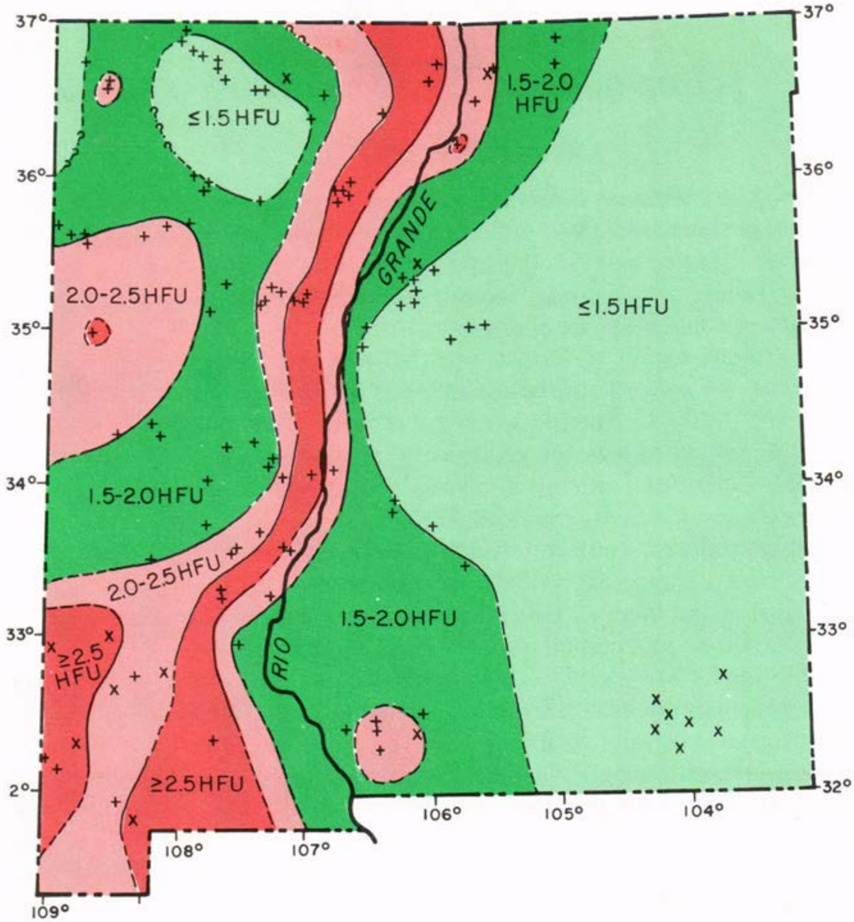

FIGURE 17—TERRESTRIAL HEAT-FLOW CONTOUR MAP. Contour interval, 0.5 HFU: +, sites measured by New Mexico Institute of Mining and Technology; X, sites of other investigators. (*Source: Reiter and others, 1975*).

attract a 55-megawatt electric generating complex, Union would need to prove a 30-year energy resource capacity from their wells *(Enchantment*, 1975). Experimental stimulation of a geothermal reservoir is being carried out by Los Alamos Scientific Laboratory on the west margin of Valles Caldera.

Other interests in geothermal energy in New Mexico are reflected by the active leasing program. The valuable land areas are shown on fig. 18. Specific locations of state geothermal leases may be obtained from the Commissioner of Public Lands in Santa Fe, and of federal leases from the U.S. Bureau of Land Management in Santa Fe.

The greatest geothermal potential in New Mexico appears to be along the Rio Grande valley, coinciding with a geologic structure called the Rio Grande rift. Areas of high heat flow and/or hot waters near or above 100°F are the Valles Caldera, Socorro Mountain, Radium Springs, and Ojo Caliente. The greatest density of population also occurs along the Rio Grande valley. The future electrical and heating needs of some of this population might be served by

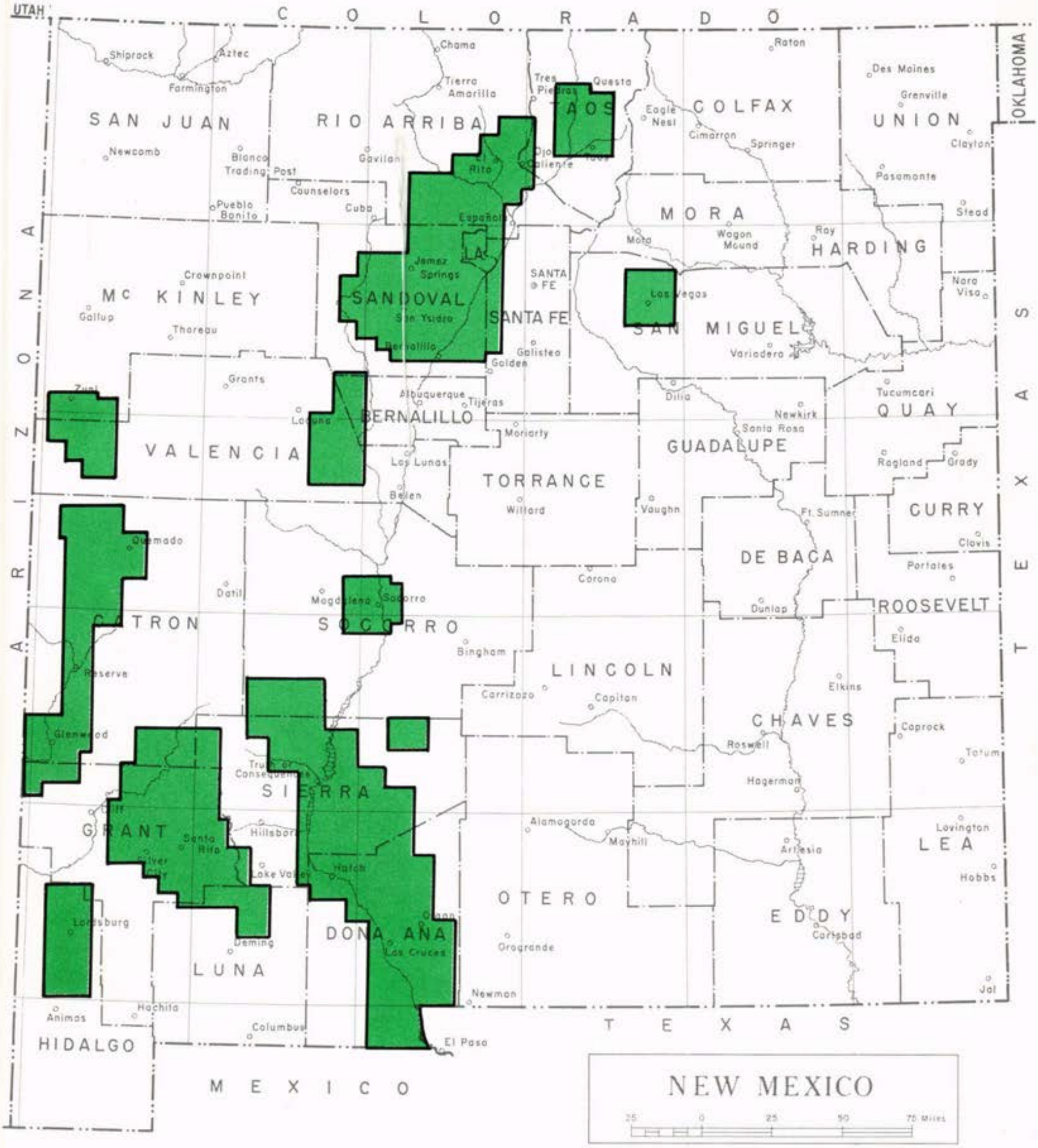

FIGURE 18—LOCATION OF GEOTHERMAL-RESOURCE LANDS (*Source:* State Land Office).

geothermal energy. Other areas of very hot waters are located in southwest New Mexico at Gila Hot Springs, Mimbres, and the Animas "Hot Spot" (Lightning Dock area) southwest of Lordsburg.

Much work is needed before such energy resources can be accurately located and developed. State, industrial, and federal groups working cooperatively on regional studies as well as local detailed investigations to obtain hydrogeologic, geophysical, and geochemical data could determine likely geothermal targets. The environmental impact of exploitation and development for each area requires careful evaluation. The results of present studies in the Valles Caldera region will be useful in forecasting development of geothermal energy for generation of electric power in New Mexico. Use of thermal waters for space heating in the near future should also be evaluated. Some of the many scientific publications on geothermal energy in New Mexico are listed among the selected references at the back of this bulletin.

OTHER AREAS

The use of geothermal energy to power energy plants is fairly recent in the United States. The first commercial geothermal power plant (now developed to 500 megawatts) was built in 1960 in The Geysers area in California, north of San Francisco. The first large geothermal power plant (now 340 megawatts) was constructed at Larderello, Italy in 1904. In the 1950's the geothermal fields of New Zealand were initially developed. Japan, Mexico, and Russia have built and are operating power plants using geothermal energy.

The three types of geothermal fields are hot water, dry steam, and dry rock. The hot water fields may be further divided into superheated water (wet steam) and those of lower temperatures (Berman, 1975):

Area	*Type*
Larderello, Italy	Dry steam
The Geysers, California	Dry steam
Wairakei, New Zealand	Wet steam
Cerro-Prieto, Mexico	(Superheated water)
Patho, Mexico	(Superheated water)

The use of natural steam or superheated water that flashes to steam provides a low-cost source where the steam is passed through a screen to remove instream particles, then introduced into a turbine. A plant using this source requires no boiler plant, fueling facilities, or smokestack. The discharged waters, however, may possibly introduce pollution problems. The Valles Caldera area being explored by Union Oil Company in New Mexico produces wet steam, only about 25 percent as efficient as the dry steam produced at The Geysers.

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