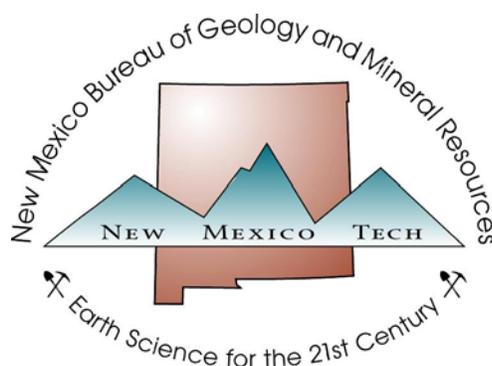


Oil, Natural Gas and Coal Potential Of McKinley County, New Mexico

by

Ronald F. Broadhead and Gretchen Hoffman



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**New Mexico Bureau of Geology and Mineral Resources
A division of New Mexico Tech
Socorro, NM 87801**

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Abstract

McKinley County New Mexico has been the site of oil, natural gas, and coal production during the last century. Oil and natural gas have been produced from 23 oil and gas pools on the Chaco Slope in the northeast part of the county. Four stratigraphic units have been productive: 1) sandstones in the Cretaceous-age Menefee Formation of the Mesaverde Group; 2) the Cretaceous-age Hospah sands of the Mancos Shale, sometimes erroneously referred to as Gallup sands; 3) the Cretaceous-age Dakota Sandstone; and 4) the Jurassic age Entrada Sandstone. Areas of highest potential for conventional oil and gas production lie along established trends of Cretaceous and Jurassic production on the Chaco Slope in the northeast part of the county. Other areas of high potential include sparsely drilled Navajo lands on the Chaco Slope in the northwest part of the county and the Zuni Basin in the southwest. Although coalbed methane has not been produced from McKinley County, there is significant potential. Principal targets include Menefee coals at depths exceeding 1,000 ft in the far northeastern part of the county. Other Cretaceous coals on the Chaco Slope and in the Zuni Basin also have noteworthy potential.

Coal has been produced from several stratigraphic intervals of Cretaceous age, including the Menefee Formation, the Crevasse Canyon Formation, and the Gallup Sandstone. Significant potential remains in the Crevasse Canyon, the Menefee, and also in the Cretaceous-age Fruitland Formation that has not been mined thus far within the county. Areas and strata of highest potential include: 1) the Fruitland Formation in the Star Lake area in the extreme northeast part of the county; 2) Menefee coals in the San Mateo and eastern Standing Rock coal fields northwest of Grants; 3) Crevasse Canyon coals in the Gallup coal field northeast and south of Gallup; and 4) Crevasse Canyon coals in the Crownpoint field.

Geologic setting

McKinley County has been the site of oil, natural gas, and coal production during the last century. The county is divided among several geologic and tectonic elements (Fig. 1) that control the location and depths of strata favorable to oil, natural gas, and coal. The Chaco Slope of the northeast and north-central parts of the county forms the southern flank of the San Juan Basin. Strata on the Chaco Slope dip gently northward into the San Juan Basin. With its thick sections of Cretaceous, Jurassic, Triassic, and Paleozoic strata (Fig. 2), this area has been the site of significant coal production from the Cretaceous section and oil and gas production from Cretaceous and Jurassic reservoirs. The Zuni Mountains in the south-central and southeast parts of the county are a geologically uplifted area on which the Cretaceous and Jurassic strata are not present and have seen no oil, gas, or coal production. The Zuni Basin lies to the west of the Zuni Mountains and contains a thick section of Cretaceous rocks with some historical coal-mining activity as well as underlying sections of Jurassic, Cretaceous, and Paleozoic rocks. To the southwest of the Zuni Basin is an uplifted area that includes the Pinon Springs anticline (Fig. 3W); Cretaceous strata have been removed by erosion from this area. The Defiance uplift in the very northwestern part of the county has seen no oil, gas or coal production; the Cretaceous has been eroded from the Defiance uplift and only Triassic and Paleozoic strata are present on top of the uplift.

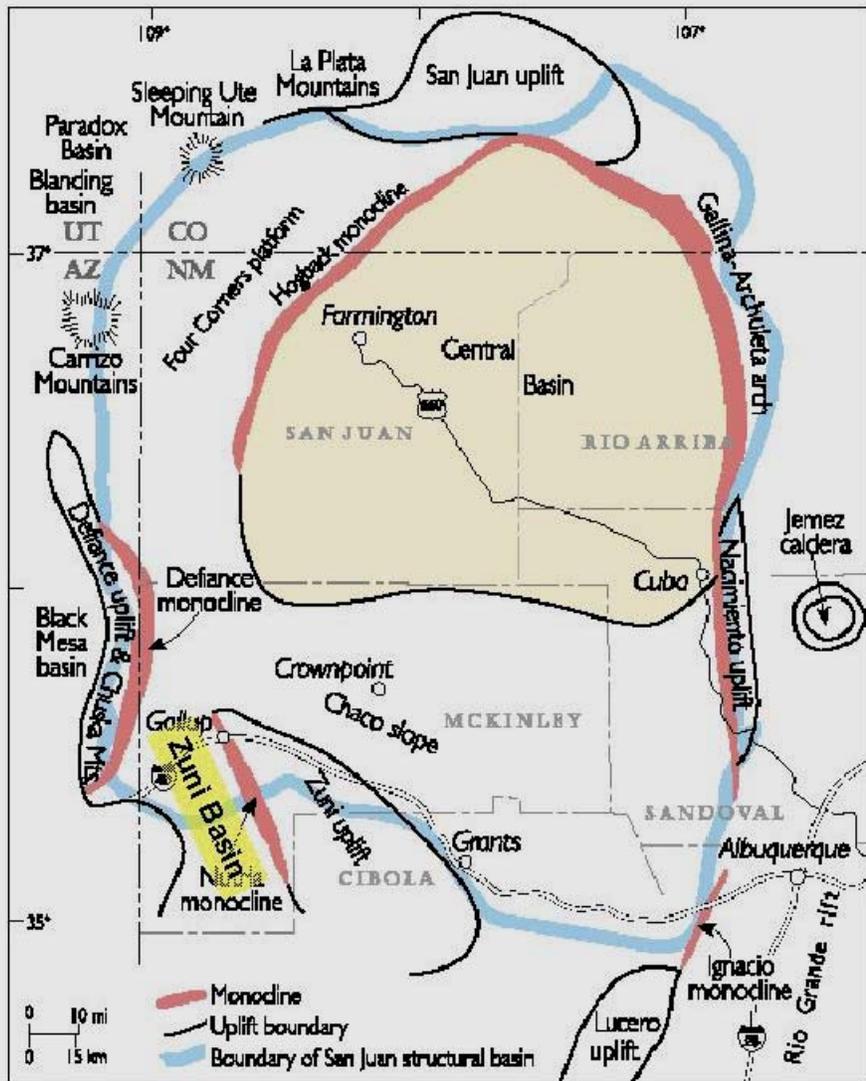


FIGURE 1 Structural features of the San Juan Basin and adjacent areas. From Craigg, 2001.

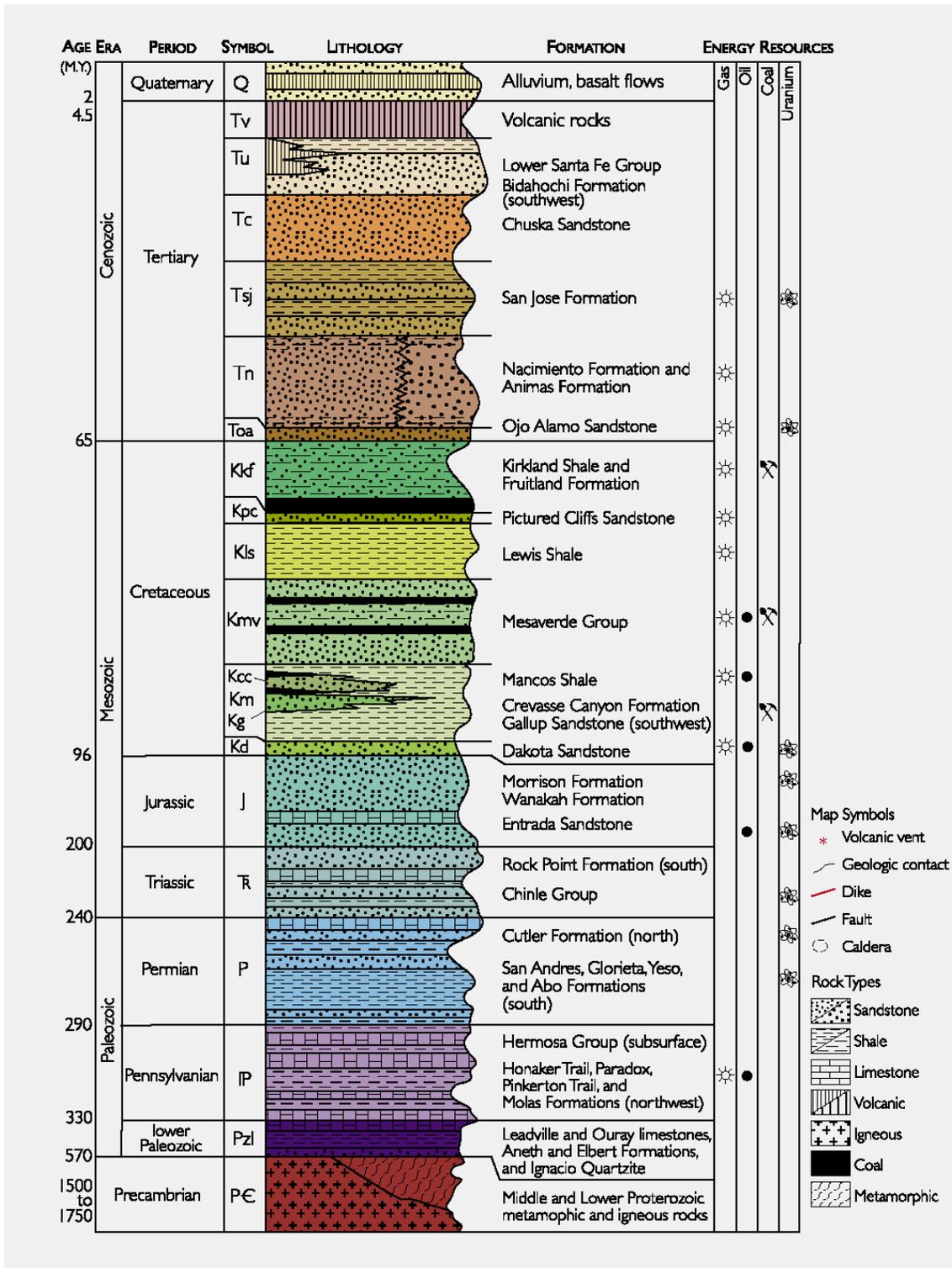


Figure 2. Stratigraphic column of rocks in McKinley County. From Brister and Price (2002).

Other data on this CD

An ArcView project for McKinley County is available on this CD (Mckinleyproject.apr). This project requires ArcView 3.2 be installed on your computer to run. An ArcExplorer file is also available and runs with ArcExplorer, a free program. ArcExplorer may be installed by running aep2setup.exe in the ArcExplorer folder. After installing ArcExplorer on your computer, run the project by clicking on the file named Mckinley.aep.

The McKinley project includes shapefiles clipped from files on Engler et al., 2001. This report was done for the BLM and is open-filed (New Mexico Bureau of Geology & Mineral Resources) available on CD with GIS maps upon request. Metadata from this source are included on the CD in the folder entitled "Metadata". Further explanation of files is in the text file entitled "explanation".

Oil and natural gas potential of McKinley County, New Mexico

Introduction

Oil and natural gas have been produced in McKinley County since 1927 when the Hospah field was discovered. A cumulative total of 27.5 million bbls oil and 6.9 billion ft³ gas have been produced from 23 oil and gas pools (Table 1). All production to date has been obtained from the Chaco Slope of the San Juan Basin in the northeast part of the county. The Chaco Slope forms the shallow, southernmost part of the San Juan Basin. Oil

and gas have been produced from strata of Cretaceous and Jurassic age. There is considerable oil and gas potential in McKinley County. Areas of highest potential for conventional oil and gas lie along established trends of Cretaceous and Jurassic production on the Chaco Slope in the northeast part of the county. Other areas of relatively high potential include the sparsely drilled Navajo lands in the northwest part of the county and the Zuni Basin in the southwest. There is also potential for coalbed methane where thick sections of Cretaceous-age coal-bearing strata are present. On the Chaco Slope and in the Zuni Basin. The area of highest coalbed methane potential is in the far northeastern part of the county where Menefee coals, matured to high volatile rank, are the principal target.

Areas of highest oil, gas, and coalbed methane potential contain large tracts of federal and private land and substantial amounts of interspersed state trust lands. In addition, natural gas pipelines that serve the San Juan Basin run through this area. Elsewhere, lands favorable for oil and gas are dominated by Navajo, Zuni, and a mix of private, federal and state lands. The Navajo and Zuni lands have been sparsely tested with exploratory wells.

Methodology for evaluation of oil and natural gas potential

Six levels of oil and natural gas potential were used in this assessment of the oil and natural gas resources of McKinley County (Table 2). These ratings apply to conventional oil and gas; coalbed methane potential was evaluated separately. Assigned

Table 1. Summary of petroleum geology of productive strata in McKinley County.

Stratigraphic unit (formation)	Oil & gas pools productive from stratigraphic unit and discovery year	Cumulative oil production barrels	Cumulative gas production Thousand ft³ (MCF)	Cumulative water production barrels	Depth to production	Comments
Menefee Formation of Mesaverde Group (Cretaceous)	Red Mountain (1934) Chaco Wash (1961) Blackeye (1972) Pot Mesa (1987) Franciscan Lake (1975) Star (1974) Papers Wash (1976) Blue Mesa (1983)	980233	1134719	5230987	300-2200 ft	Fluvial sandstone reservoirs.
Hospah sand (Cretaceous)	Nose Rock (1986) Hospah (1927) Hospah South upper sand (1965) Hospah South lower sand (1965) Miguel Creek (1978) Miguel Creek North (1978)	21954144	52926	391047029	1100-2300 ft	Beach and offshore sandstone reservoirs.
Dakota Sandstone (Cretaceous)	Blackeye (1972) Hospah (1967) Marcelina (1975) Lone Pine Dakota A (1970) Lone Pine Dakota D (1970) Walker Dome (1945)	2849508	5673964	2515644	2500-3800 ft	Delta-margin and shallow-marine sandstone reservoirs. Walker Dome pool has never been produced.
Entrada Sandstone (Jurassic)	Arena Blanca (1985) Ojo Encino (1976) Papers Wash (1976) Papers Wash South (1976)	1750237	5946	59261619	5100-5900 ft	Aeolian dune reservoirs have excellent reservoir quality and yields but high vertical permeability can lead to water coning.

TABLE 2. Criteria used to rate oil and gas potential in McKinley County

Level of oil & gas potential	Are strata with favorable source and reservoir facies present?	Has production been established along trends of favorable reservoir facies?	If production is established, what is relative amount for McKinley County?	Have exploratory wells encountered shows of oil and/or gas?	Comments
6 (highest)	Multiple favorable formations present.	Yes	Relatively high volumes of oil and/or gas have been produced from favorable strata.	Yes (production established)	High potential from reservoirs characterized by high volumes of production plus additional possible potential from other reservoirs.
5	Multiple favorable formations present.	Yes	More modest volumes of oil and/or gas have been produced from favorable strata.	Yes (production established)	High potential from reservoirs characterized by more modest volumes of production plus additional possible potential from other reservoirs.
4	Multiple favorable formations present.	No	No production established to date.	Yes	Highest rating possible for a nonproductive trend or area.
3	At least one formation present at adequate depths.	No	No production established to date.	Yes, if area has several test wells. Not necessarily if area has no wells or is only sparsely drilled.	A rating of 3 indicates a modest possibility for the occurrence of oil or gas. These areas may not have an adequate number of test wells.
2	At least one formation present but perhaps at very shallow depth. Deeper favorable formations not present or have questionable potential.	No	No production established to date.	No	A rating of 2 indicates a low possibility for the occurrence of oil or gas.
1 (lowest)	No strata with favorable facies present.	No	No production established to date.	No	A rating of 1 indicates a very low or zero possibility for the occurrence of oil or gas.

Oil and gas pools and geologic elements of eastern McKinley County

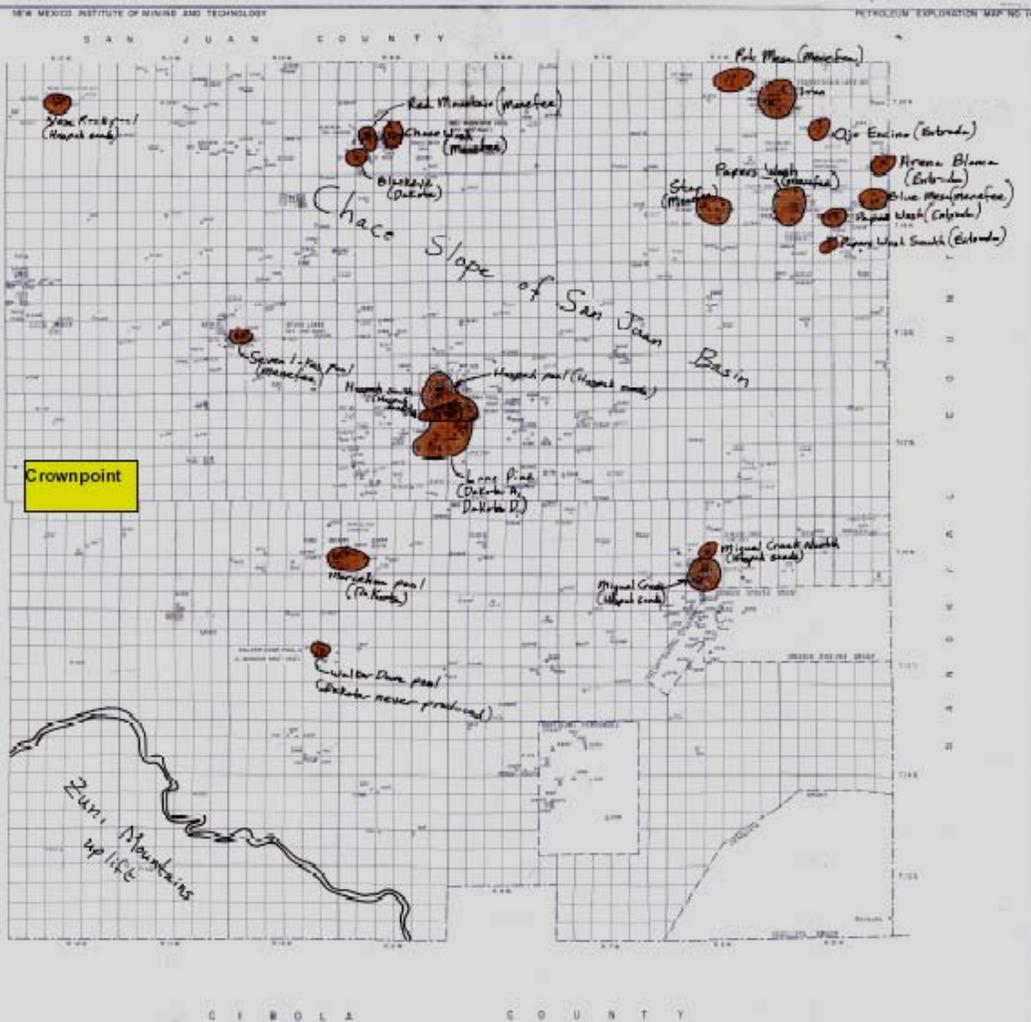


Figure 3E. Oil and gas pools and geologic elements of eastern McKinley County.

Oil and gas pools and geologic elements of western McKinley County

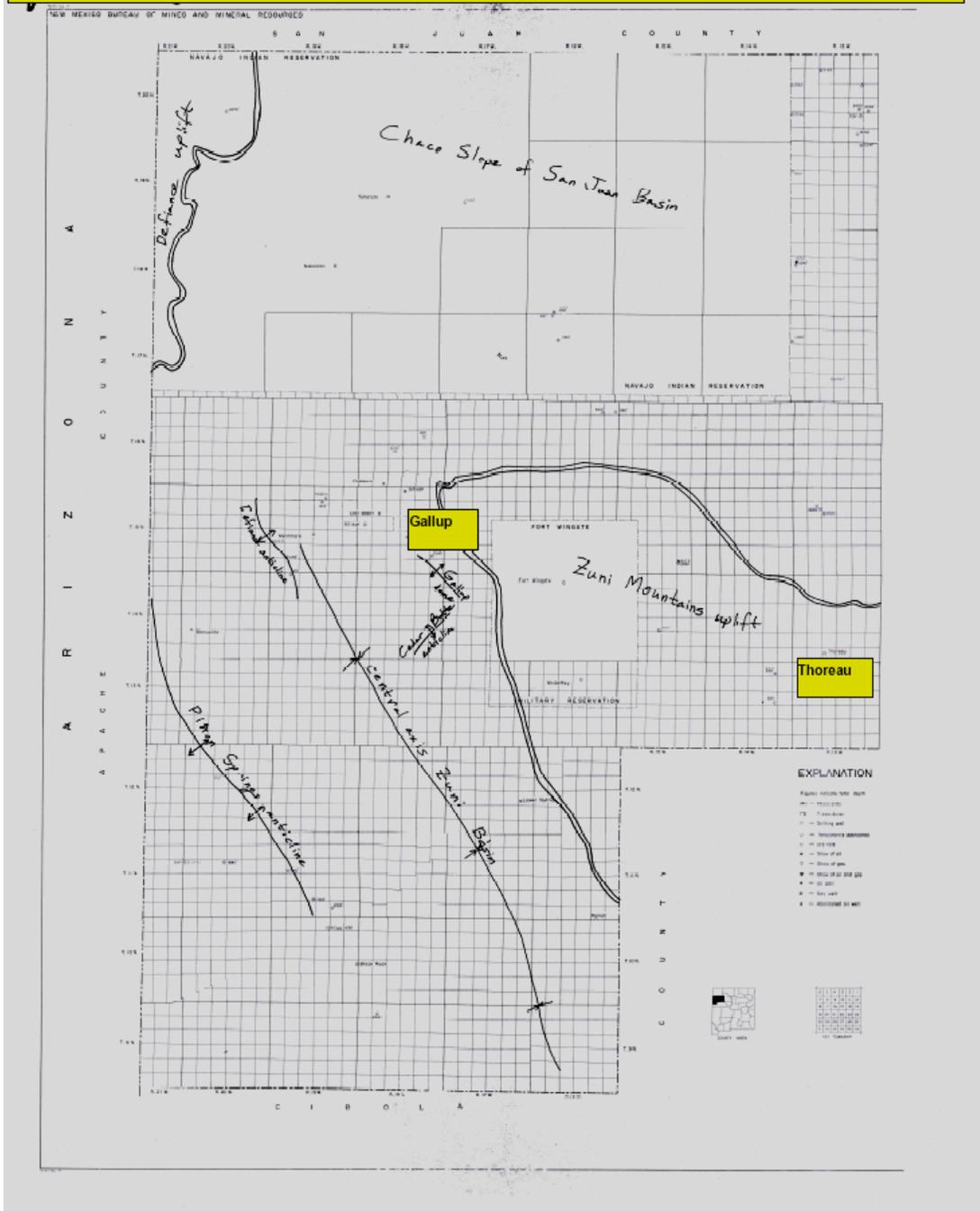


Figure 3W. Oil and gas fields and geologic elements of western McKinley County.

levels of oil and natural gas potential were based on the evaluation of four geologic factors discussed below.

The presence of strata that contain favorable oil and gas source rocks and reservoir rocks is the first, and perhaps foremost factor. Without these favorable strata, the potential for the occurrence of commercial volumes of oil or natural gas is essentially nil. If only either source strata or reservoir strata are known to be present, but not both, then the potential is somewhat lower. The presence of multiple stratigraphic units that contain favorable source and reservoir rocks results in the assignment of a higher oil and gas potential than if just one stratigraphic unit with favorable facies is present.

The occurrence of oil and/or gas production in favorable strata identified above is the second factor that was evaluated. The production must occur either in McKinley County or an adjacent area. If commercial levels of production have occurred, then a higher level of potential is assigned than if commercial production has not occurred. The presence of commercial production decreases the uncertainty in the assignment of a high level of potential. For this report, a potential level of 5 or 6 (the highest levels) are assigned only if commercial production has been obtained from an area. A potential level of 4 is the highest ranking possible for a nonproductive area or trend. The presence of multiple stratal units with commercial production results in assignment of a higher potential than if only a single stratal unit with commercial production is present.

The third geologic factor concerns the volume of oil or gas that has been obtained from a productive stratigraphic unit. Reservoirs in some formations produce relatively modest volumes of oil or gas. Reservoirs in other formations produce oil and gas in higher volumes. An example of the former in McKinley County is the Menefee Formation of the Mesaverde Group (Cretaceous) that has produced relatively low volumes of oil and associated natural gas from shallow reservoirs. Examples of the latter are the Hospah sands (Cretaceous) which have produced most of the oil that McKinley County has yielded. There are several reasons why a reservoir may yield low volumes of oil and gas. Factors that may contribute to low production rates include limited porosity and permeability of the reservoir, thin reservoir beds, laterally discontinuous reservoir beds, and a paucity of natural reservoir energy. Low reservoir energy can result from shallow depths (< 1,000 to 2,000 ft) and accompanying low reservoir pressures or low levels of dissolved gas in a solution-gas drive reservoir. From an economic viewpoint, the shallow depth of low-volume, low-pressure reservoirs and resultant low drilling costs may compensate for lower production when compared to deeper, higher pressure, higher volume reservoirs that are more expensive to drill.

The results of exploratory drilling in an area are the fourth factor used to evaluate oil and natural gas potential. If unsuccessful exploratory wells have encountered noncommercial oil and/or gas shows, then potential is ranked higher than if no show have been encountered. The presence of oil or gas shows indicates that at least some reservoirs have been at least partially charged by hydrocarbons.

Data used in oil and gas evaluation in this report were obtained from files at the New Mexico Bureau of Geology and Mineral Resources and published surface geologic maps (Chapman et al., 1977; Beaumont, 1998). The geologic maps were used to construct the geologic framework of the county. The New Mexico Bureau of Geology and Mineral Resources Petroleum Exploration map of McKinley County was the base for most of the oil and gas information. This was supplemented by well records, well logs, and published scientific papers cited in this report.

Methodology for evaluation of coalbed methane potential

Five levels of coalbed methane potential were used in this assessment of oil and gas resources of McKinley County (Table 3). Coalbed methane is natural gas that occurs in coal beds. Coalbed methane was assessed separately from conventional oil and gas because its occurrence in the reservoir is different from conventional gas, is restricted to coal beds, and must be produced differently than conventional gas in most cases. In most coalbed methane reservoirs, the natural fractures (sometimes called cleats) in the coal are naturally filled with water. Unlike conventional gas reservoirs, the coal gas does not occur as free gas in pore spaces but is instead adsorbed onto the coal itself. The pressure that the water exerts on the fracture surface normally holds the adsorbed gas in place. In order to produce gas from the coal, the water must be pumped out of the fractures and therefore is produced by coalbed methane wells at the ground surface. When the water is removed by pumping, the pressure exerted by the water on the surface of the fractures is decreased and gas is desorbed from the coal. It moves into the fractures where it may be produced.

Assigned levels of coalbed methane potential were based on several geologic factors. Foremost among these factors is the presence of coal-bearing strata in the subsurface. Areas without coal beds in the subsurface have zero coalbed methane potential. This essentially confines areas of coalbed methane potential to those parts of McKinley County where the Dilco Coal member of the Crevasse Canyon Formation is present in the subsurface and is overlain by younger strata.

TABLE 3. Criteria used to rate coalbed methane potential in McKinley County.

Level of coalbed methane potential	Are coal-bearing strata present?	Depth of coal-bearing strata	Thermal maturity (rank) of coal	Known thickness of individual coal beds	Thickness of coal-bearing strata	Gas-in-place estimated	Comments
5 (highest)	Yes	As deep as 2,000-2,500 ft.	High volatile coal rank.	Known coals may be more than 10 ft thick.	Relatively large thickness of coal-bearing strata.	Available resource calculations indicate more than 5 BCF/mi ² .	Thermogenic gas possible; relatively high production rates possible.
4	Yes	Greater than 1,000 ft.	High volatile coal rank.	Known coals may be more than 10 ft thick.	Relatively large thickness of coal-bearing strata.	Available resource calculations indicate less than 5 BCF/mi ² .	Thermogenic gas possible; relatively high production rates possible.
3	Yes	Shallow coal-bearing strata overlain by other formations.	Rank less than high volatile.	Most known coal beds less than 10 ft thick.	Intermediate thickness of coal-bearing strata.	Resource estimates not available.	Biogenic gas possible; relatively low production rates possible.
2	Yes	Coal-bearing strata crop out or are very shallow.	Rank less than high volatile.	Most known coal beds less than 10 ft thick.	Relatively low thickness of coal-bearing strata.	Resource estimates not available.	Biogenic gas possible; relatively low production rates possible.
1 (lowest)	No	No coal-bearing strata present.	No coal-bearing strata present.	No coal beds present.	No coal-bearing strata present.	No coal gas.	No coalbed methane expected.

A second factor concerns the depth of burial of coal-bearing sequences that contain potential coalbed methane reservoirs. Coals at greater burial depths are naturally subjected to greater pressures and may therefore have retained greater volumes of adsorbed gas per unit volume of coal.

A third factor concerns the thermal maturity (or rank) of the coal. Very thermally mature coals have been subjected to higher temperatures throughout geologic time and have a high-volatile rank. And generally have been buried more deeply than coals with a low-volatile rank. The thermally mature coals have generated methane by inorganic thermal processes and will generally yield higher volumes of gas per unit volume of coal than thermally immature coals. Gas in thermally immature coals is generally thought to have been generated biogenically by bacteria. Gas yields from wells that produce from biogenic coalbed methane reservoirs are generally low. However, the shallower depths of biogenic coalbed methane reservoirs results in shallower wells that are less expensive to drill, presenting an economic advantage for these shallower sources of gas.

A fourth factor relevant to coalbed methane potential concerns the thickness of coalbeds present within favorable strata. Generally areas with thicker coal beds are more favorable than areas with thinner coal beds because the thicker coalbeds may contain larger volumes of gas. Shallow coals in southeast Oklahoma with thickness of 6 ft are productive of economically viable volumes of coal gas (Dr. Charles Mankin, State Geologist of Oklahoma, personal communication July 2002). However, those Oklahoma coals are very thermally mature and very "gassy" and have in the past been buried to very great depths, properties unlikely to exist in McKinley County. There is no hard and fast rule, but generally coal thickness of more than 10 ft appears necessary for viable production. It may be possible to produce from several thinner beds that occur vertically close to one another, but production from several thin coals has not always been successful. The task of simultaneously dewatering several coals from a single wellbore is difficult. Also, thinner beds are more likely to be laterally discontinuous and therefore may have very limited drainage area and reserves.

A fifth geologic factor relevant to coalbed methane potential concerns the number of coal beds present within a favorable stratigraphic unit. The greater the number of coalbeds, the more likely it is that at least one thicker bed will yield economic levels of production. Also, commingled completions that involve multiple thin coals, although not always successful, have the potential to yield sustained economic production where a single thin coal may yield insufficient volumes of gas. Therefore, coalbed methane potential is generally higher where thicker sequences of coal-bearing

strata have been both deposited and preserved. In general in McKinley County, this also corresponds to areas of greater burial depth so that potential is enhanced by thicker sections of coal in the subsurface, greater thermal maturity, and greater pressures that can hold more gas in place.

A sixth factor relevant to coalbed methane potential is the occurrence of current or historical coal mining. Mined coals are not available as coalbed methane reservoirs and the presence of coal mines therefore reduces the coalbed methane potential. Areas that contain coal leases that have never been mined may or may not be available for coalbed methane production.

Data used for the coalbed methane evaluation in this report were obtained from files at the New Mexico Bureau of Geology and Mineral Resources and published surface geologic maps (Beaumont, 1998; Chapman et al., 1977) and coal data (Hoffman, 1996b). These sources were supplemented by well records, well logs, and published scientific papers cited in this report.

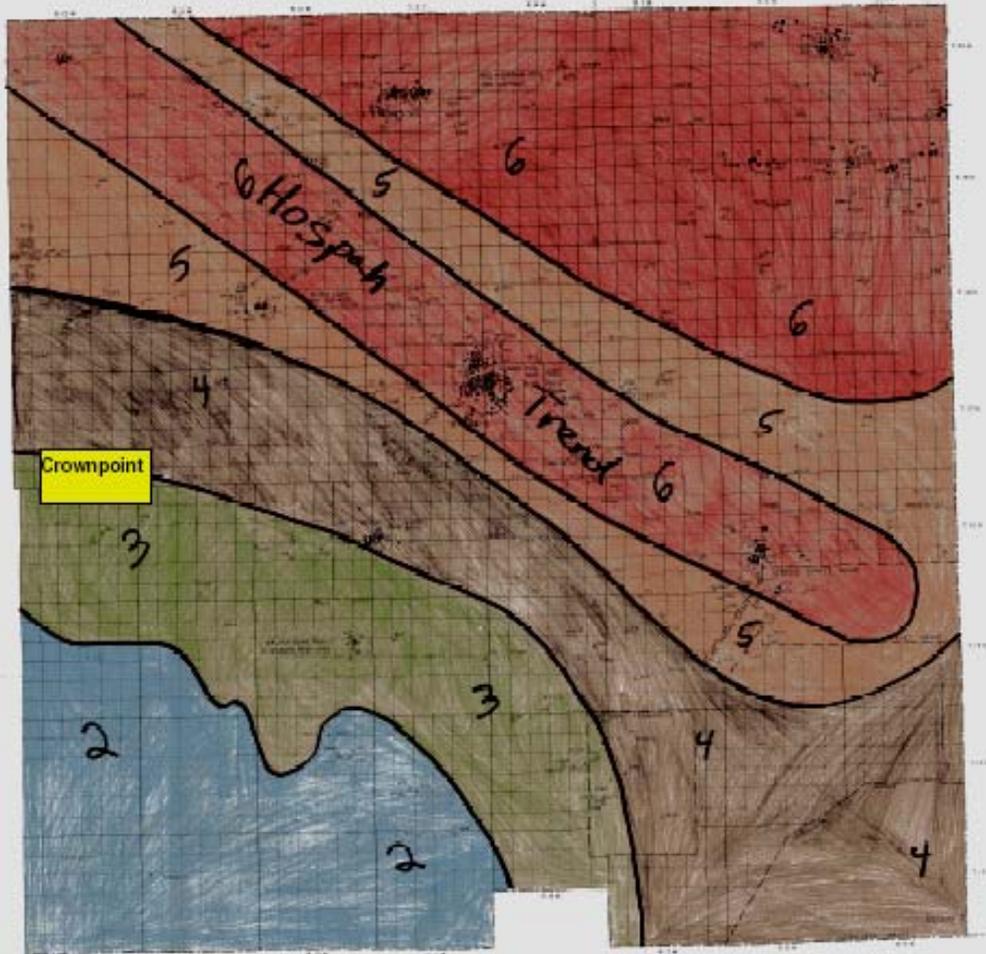
Oil and gas potential of McKinley County

Oil and natural gas have been produced from reservoirs of Cretaceous age on the Chaco Slope. All production has been of conventional oil and gas; no coalbed methane has been produced. All production has been historically limited to the northeastern part of the Chaco Slope. Production has not been established elsewhere in the county but, in general, exploration has been limited and exploratory wells are few and far between in areas of the county outside of the Chaco Slope. As discussed below, portion of the Chaco Slope have a high potential. Other presently nonproductive areas have oil and gas potential ranging from low to high.

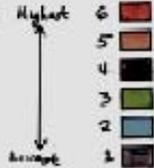
Exploration on the Chaco Slope was undertaken in an attempt to extend the prolific production in the central San Juan Basin southward to its southern fringe in McKinley County. Production of the Chaco Slope has been obtained from the Menefee Formation of the Mesaverde Group (Cretaceous), the Hospah sands (Cretaceous; sometimes erroneously referred to as Gallup sands), the Dakota Sandstone (Cretaceous), and the Entrada Sandstone (Jurassic; Figs 2, 3E, 3W; Table 3). By far, most oil production in the county has been obtained from the Hospah sands and most gas production has been obtained from the Dakota Sandstone. Maximum depth to production is approximately 6000 ft from Entrada reservoirs in the northeasternmost part of the county.

Deeper Pennsylvanian and Permian strata have potential on the Chaco Slope but have been penetrated by only a very few wells as exploration has been concentrated on shallower strata that are

Oil and gas potential of eastern McKinley County



OIL GAS POTENTIAL



PETROLEUM EXPLORATION MAP OF MCKINLEY COUNTY, NEW MEXICO

Figure 4E. Oil and natural gas potential of eastern McKinley County.

easier and less expensive to drill for. Although gas shows have been encountered in some of the deep wells drilled to the Pennsylvanian section, the oil and natural gas geology and potential of the strata is poorly documented and understood. Maximum depth to potential Pennsylvanian reservoirs is approximately 10,000 ft in the northeastern part of McKinley County and becomes progressively shallower to the southwest until these strata are exposed at the surface in the Zuni Mountains. Where exposed at the surface, the Pennsylvanian and Permian strata have no seals, have been flushed by influent groundwaters, and have essentially zero oil and gas potential.

Menefee pools produce from fluvial, continental reservoirs of the Menefee Formation (Cretaceous; Table 1). This is the shallowest stratigraphic unit that has been productive in McKinley County. The Menefee has produced 980 thousand bbls oil and 1135 million ft³ (MCF) gas within the county. Reservoirs are typical lenticular fluvial sands that produce from depths of 300 to 2200 ft. Most production from the Menefee is obtained from very northeastern McKinley County (Fig. 3E) where both the upper and lower parts of the Menefee are productive. Menefee potential decreases to the southwest because the Menefee becomes shallower and also thinner. Southwestward thinning is partly depositional and partly due to erosional thinning because of exposure at the ground surface.

Hospah pools produce from strand line "Hospah" sandstones in the lower part of the Mancos Shale (Upper Cretaceous; Table 1, Figs. 2, 3E). These sandstones lie along a northwest-southeast trend in northeastern McKinley County that is parallel to the ancient late Cretaceous shoreline. Hospah pools have yielded more oil than pools productive from other strata in McKinley County. Hospah reservoirs have produced almost 22 million bbls oil and 53 million ft³ (MMCF) gas in McKinley County. The Hospah trend delineates an area of highest potential (potential level 6; Fig. 4E) where there is significant potential from the Hospah as well as shallower Menefee reservoirs and deeper Dakota reservoirs. Prospective Hospah sands are 100 ft deep along the southeast part of the trend and 2300 ft deep along the northwest part of the trend where they dip into the deep subsurface of the San Juan Basin.

Dakota reservoirs produce from delta margin and shallow-marine sandstone reservoirs of the Dakota Sandstone (Upper Cretaceous; Berg, 1979). The Dakota forms the most prolific natural gas reservoirs in McKinley County (Table 1). Dakota reservoirs have produced 2.8 million bbls oil and 5674 million ft³ (MMCF) gas in McKinley County. Depth to production ranges from 2500 to 3800 ft. Areas of high potential (potential levels 5 and 6) are defined by the presence of Dakota reservoirs as well as additional potential from Menefee reservoirs (Figs. 4E, 4W).

Entrada pools produce from eolian dune sandstone reservoirs of the Entrada Formation (Jurassic) in the extreme northeastern part of McKinley County (Fig. 3E). Entrada reservoirs have produced 1.8 million bbls oil and only 5.9 million ft³ (MMCF) gas from McKinley County. Depth to production ranges from 5100 to 5900 ft. Potential for Entrada production increases to the north as the Entrada dips into the subsurface of the San Juan Basin. Influent water recharged from outcrops on the flanks of the Zuni Mountains appears to have flushed oil out of the Entrada in the southeastern part of the Chaco Slope between the Zuni Mountains and the deeper, northeastern areas where the Entrada is productive (see Vincelette and Chittum, 1981). An area of highest potential (potential level 6) in extreme northeastern McKinley County (Fig. 4E) is partially defined by productive Entrada reservoirs.

Other areas of McKinley County have no established oil and gas production and have potential levels from 1 (essentially no potential) to 4 (the highest potential rating possible in a nonproductive area or trend). From the area of high potential in northeastern McKinley County, the potential for oil and gas decreases steadily to the south and southwest across the Chaco Slope as the sedimentary section thins onto the flanks of the Zuni Mountains and reservoir-bearing strata that are productive to the north were either never deposited or have been removed by erosion. The potential level decreases from 4 to 3 to 2. The area on the Chaco Slope with a potential level of 4 has possibilities of production from the Dakota Sandstone as well as the lowermost part of the Menefee Formation and unknown potential in the deeper Pennsylvanian section. The area of the Chaco Slope with a potential level of 3 has the possibility of production from the Dakota as well as the Pennsylvanian, but no commercial production has been obtained from this area. The Dakota crops out at the surface over much of this area and oil and gas has probably either leaked out and escaped or has been flushed out by influent surface waters. The area with a potential level of 2 along the north flank of the Zuni Mountains may have some oil and gas possibilities in the Pennsylvanian section, but younger possible Cretaceous and Jurassic reservoirs are not present, either having never been deposited or having been removed by erosion.

The central core of the Zuni Mountains has a potential level of 1. In this region, either Precambrian basement rocks with no reservoir and source potential are exposed at the surface or a shallow section of Paleozoic, Triassic, and Jurassic is present that appears to have been flushed by recharged waters. Strata in this area are more likely to be sources of fresh water than oil and gas.

The Zuni Basin (or Gallup-Zuni Basin) lies to the west of the Zuni Mountains uplift (Fig. 1). Oil and gas production has not been established in this area and exploratory drilling has been very

sparse. The central axial part of the basin has been assigned a potential level of 4, the highest potential rating allowable in a nonproductive area. As much as 2100 ft of Upper Cretaceous strata contain possible source rocks of oil and gas along the basin axis. Black, organic-rich Cretaceous shales are source facies of oil and gas and Cretaceous coals are source facies of gas that may have migrated into adjacent reservoir sandstones.

Principal reservoir targets are sandstones in both the Dakota and Gallup (Upper Cretaceous) intervals. An oil show was encountered in the Dakota Sandstone at depths of 1911 to 1943 ft in the Marshall Drilling No. 1 Beal-Miller well, located in Sec. 3 T15N R19W. A gas show was also reported from the Beal-Miller well in the Morrison Formation (Jurassic). With no source facies present in either the Morrison Formation or in underlying Triassic sandstones and red shales, the source of the gas is enigmatic but is most likely the overlying Cretaceous shales. The Cretaceous in the southern part of the Zuni Basin remains undrilled and therefore untested.

Paleozoic reservoirs, although exhibiting signs of freshwater flushing to the east (Zuni Mountains) and west may be buried sufficiently deep along the axis of the basin to be protected from freshwater flushing. It is also possible that the Zuni Basin has a late Paleozoic ancestry as do other similar features in New Mexico. If so then the central axis of the Zuni Basin may be underlain by a late Paleozoic elevator basin that has significant oil and gas potential. Triassic shales provide an extensive vertical seal to the Paleozoic section.

The southwesternmost part of McKinley County (Pinon Springs anticline area) has been assigned an oil and gas potential of 3. Cretaceous strata have been removed by erosion from this area. Possible reservoirs are present in the San Andres Formation (Permian), the Abo Formation (Permian), and the Pennsylvanian section. Oil shows have been reported from the San Andres and Yeso Formations in the Burr Oil and Gas No. 1 Zuni well, located in Sec. 28 T11N R19W. To the west the High Plains No. 1Y State well, located in Sec. 18 T11N R20W was converted to a water well in Permian strata, indicating that a significant portion of the Permian section in the basin may have been flushed by groundwater. The San Andres and Glorieta serve as major aquifers in the region; water in these strata is recharged at outcrops in the Zuni Mountains and moves downdip in a radial pattern away from the outcrop (White and Kelley, 1989). This recharge may flushed most or all of the reservoirs in the San Andreas and Glorieta in the Zuni Basin.

There is limited oil and gas potential in the Yeso Formation in this area southwest of the central Zuni Basin axis. In the Cities Service No. 1 Zuni A well, located in Sec. 5 T9N R18W, marginal oil source rocks have been identified in Yeso dolostones (Bayliss and Schwarzer, 1988).

These source rocks may have generated relatively small volumes of hydrocarbons. The complex internal stratigraphy of the Yeso, with its interbedded and interfingering sandstones, limestones, dolostones, and evaporites, may provide numerous internal seals that have offered protection from freshwater flushing by fresh waters entering at the outcrop belt in the Zuni Mountains.

The Defiance uplift of northwestern McKinley County (Fig. 1) has an oil and gas potential of 3. Only a single well has been drilled in this part of the county. The Cretaceous section, so prolific to the east and northeast within the San Juan basin, has been removed by erosion from this uplifted area. Principal targets are Pennsylvanian and Mississippian limestones which are sparsely productive to the north in westernmost San Juan County. Very little is known about the petroleum geology of this area, partly because so little drilling has been done.

Coalbed methane potential of McKinley County

Coalbed methane potential of McKinley County ranges from a level of 1 (no possibility of coalbed methane) to 5 (a very high possibility of coalbed methane; Table 3, Figs. 5E, 5W). Large parts of the county have no coalbed methane potential (rating of 1). In these areas, coal-bearing strata of Cretaceous age are not present or crop out at the surface.

Areas with the highest ratings (levels 4 and 5) are present at depth and occupy a relatively small part of the county, approximately 250 mi². Principal targets are coals in the Menefee Formation at depths of 1500 to 2000 ft. Menefee coals are relatively deeply buried in this area and have been matured to a high volatile rank (Crist et al., 1990). Therefore, they may be capable of producing thermally-generated methane. The area identified as having the highest potential (level 5) has been calculated to have more than 5 BCF/mi² gas-in-place within the Menefee. The area having a potential of 4 has an estimated gas-in-place of less than 5 BCF/mi² but generally greater than 2.5 BCF/mi².

Coalbed methane potential of eastern McKinley County

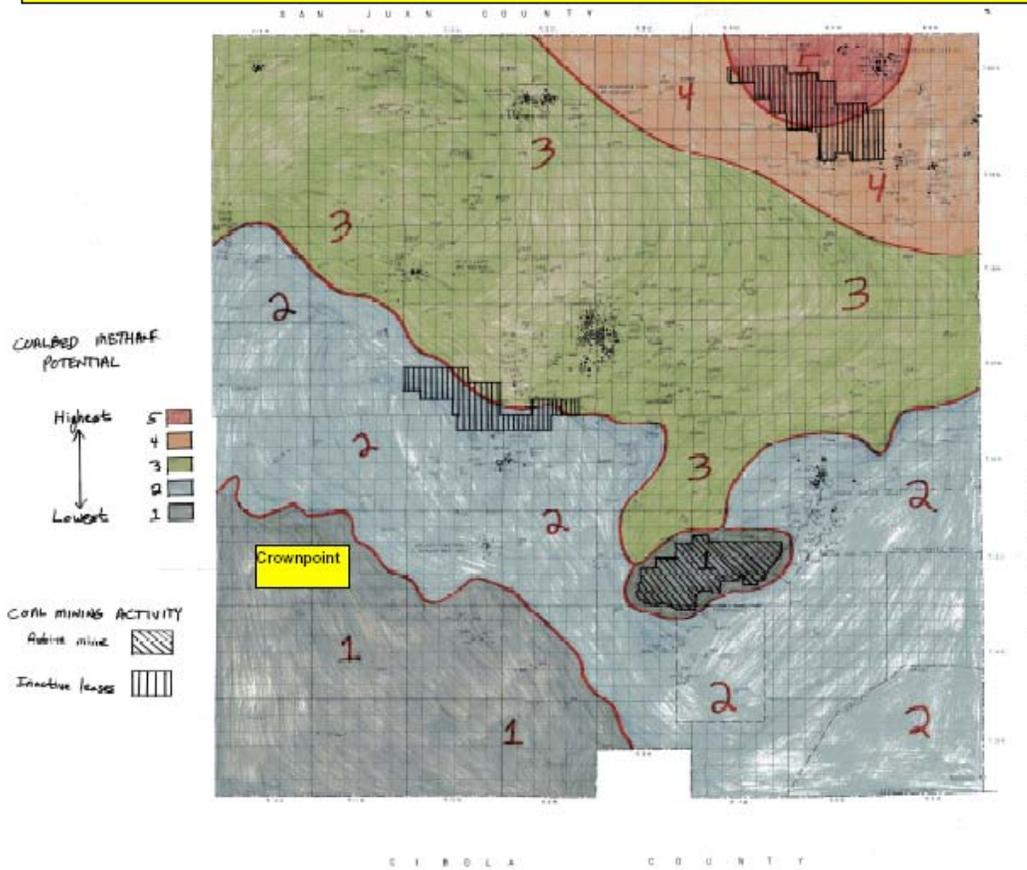


Figure 5E. Coalbed methane potential of eastern McKinley County.

Coalbed methane potential of western McKinley County

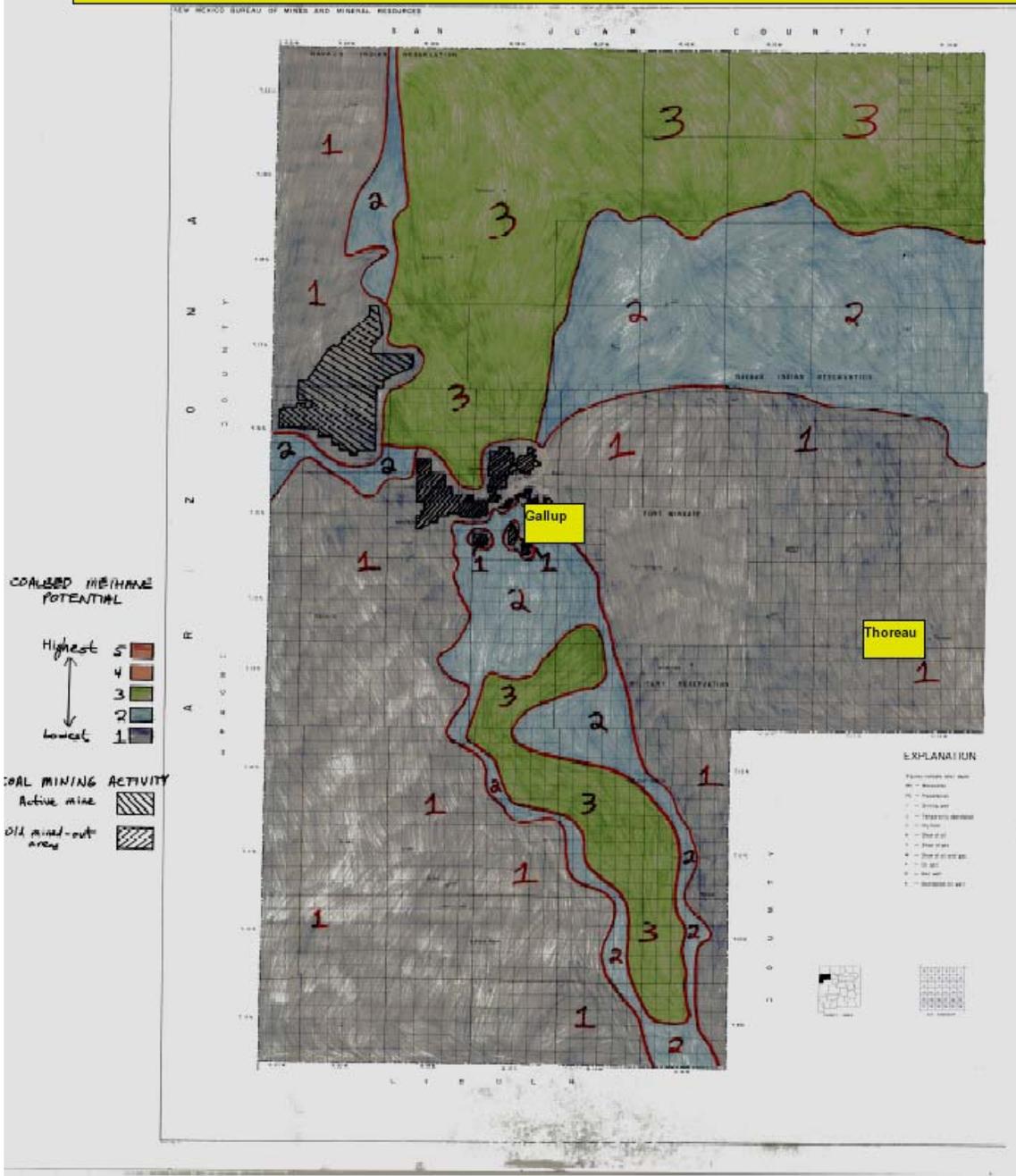


Figure 5W. Coalbed methane potential of western McKinley County.

Coalbeds in the Menefee Formation of the Mesaverde Group are generally thinner and less laterally continuous than coalbeds in the younger Fruitland Formation, which is the prolific coalbed methane reservoir in the central and northern parts of the San Juan Basin (see Crist et al., 1990; Shomaker and Whyte, 1977). Therefore, the Menefee coals may be expected to yield less gas than the most productive of the Fruitland coals.

Southwest of the area of high potential, the potential for coalbed methane gradually decreases from level 3 to level 2. In this region, coal rank is probably less than high-volatile and any gas that can be produced from the coals has most likely been generated biogenically. Menefee coals are probably the main coalbed methane targets although there may be some deeper Crevasse Canyon and Gallup coals as well. Coalbeds are less than 10 ft thick over much of the area, but a few beds may be thicker than 10 ft (Hoffman, 1996b). The thin and discontinuous nature of the coals limits coalbed methane potential.

The area of potential level 2 to the southwest has fewer target opportunities. Although sufficient data on coal rank, coal thickness and coal quality are not available to fully define potential, the shallow depth of burial of the Cretaceous coal-bearing section strongly indicates that thermal maturity of the coals is low and that only biogenic processes may have contributed to gas generation. Principal targets are coals in the Crevasse Canyon and Gallup intervals. Menefee coals have been removed by erosion from most of the area on the Chaco Slope with a potential rating of 2. In addition, coals from the upper part of the Crevasse Canyon crop out over most of the area. Coalbeds are less than 10 ft thick over much of the area, but a few beds may be thicker than 10 ft (Hoffman, 1996b). The thin and discontinuous nature of the coals also limits coalbed methane potential.

The coalbed methane potential of the Zuni Basin ranges from 1 to 3 (Fig. 5W). Coals are present only within the Cretaceous section. Potential is 2 along the margins of the basin where coal-bearing strata in the lowermost Cretaceous either crop out or are very shallow. Potential is higher along the central axis of the basin where the Cretaceous section is thicker and has been more deeply buried. Coalbeds are known to be present at depths from 700 to 1000 ft and may be even deeper along the central axis where drilling has not penetrated the entire Cretaceous section. Coal rank has not been documented in the Zuni Basin, but relatively shallow depths of burial indicate a rank less than high volatile in most places. It is possible that coals in the lower part of the section (Gallup interval) may have been buried sufficiently deep along the central axis to be more mature and have reached the high volatile stage. If so, there is a possibility of thermogenic gas.

Most Cretaceous coals in the upper part of the Cretaceous section appear to be less than 2.5 ft thick with a maximum thickness of 6.6 ft in the Zuni Basin (Roybal, 1989; Hoffman, 1996b). Coal thickness appears to decrease to the south (Lease and Shomaker, 1971; Tabet, 1981; Roybal, 1989). These coals may be too thin to yield economic levels of coalbed methane unless completions in multiple beds are attempted. However, coals in the deeper Gallup interval have been noted to be as thick as 7 ft in places (Anderson and Stricker, 1987) which elevates the potential of the lower part of the Cretaceous section within the Zuni Basin.

Conventional wisdom would assign a low potential to areas in the northern Zuni Basin where historical mining has resulted in removal of coals. However, many of the older mines in the Gallup and Gamerco areas were underground mines (Nickelson, 1988). It is possible that old mine workings became filled with methane gas after abandonment of the mines and therefore may act as gas reservoirs. Essentially, the mine tunnels would act as large cavity completions with access to large cross sections of incompletely mined coals. Coalbed methane has not been normally produced in this manner, but there are a few examples of this type of production in Ohio. Among other factors, viability depends on the composition of gas that fills the mine workings; if the gas contains too much air or other non-hydrocarbon components then the gas can not be transported through pipelines unless it is first process to remove non-hydrocarbon components, an expensive process. If this type of production method is contemplated, then the areas with a potential of 1 in the northern part of the Zuni Basin could be reclassified to a potential of 3 or possibly even 4.

Land status and pipelines

Private and federal lands dominate the areas of highest oil and natural gas potential in northeast McKinley County (Fig. 6). There are significant amounts of state trust land in this region also. Navajo lands dominate areas with high potential in northwest McKinley County. Areas with highest potential in southwest McKinley County are in the Zuni Basin. Most of the Zuni basin is dominated by Zuni lands. There are significant blocks of private and federal lands as well as some state trust lands in the northernmost parts of this basin.

A number of major natural gas pipelines cut through McKinley County (Fig. 7). These include both interstate and intrastate pipelines that serve the San Juan Basin as well as the gas-producing areas of southeast New Mexico and west Texas. Pipelines are present in areas of high oil and gas potential in northeast McKinley County.

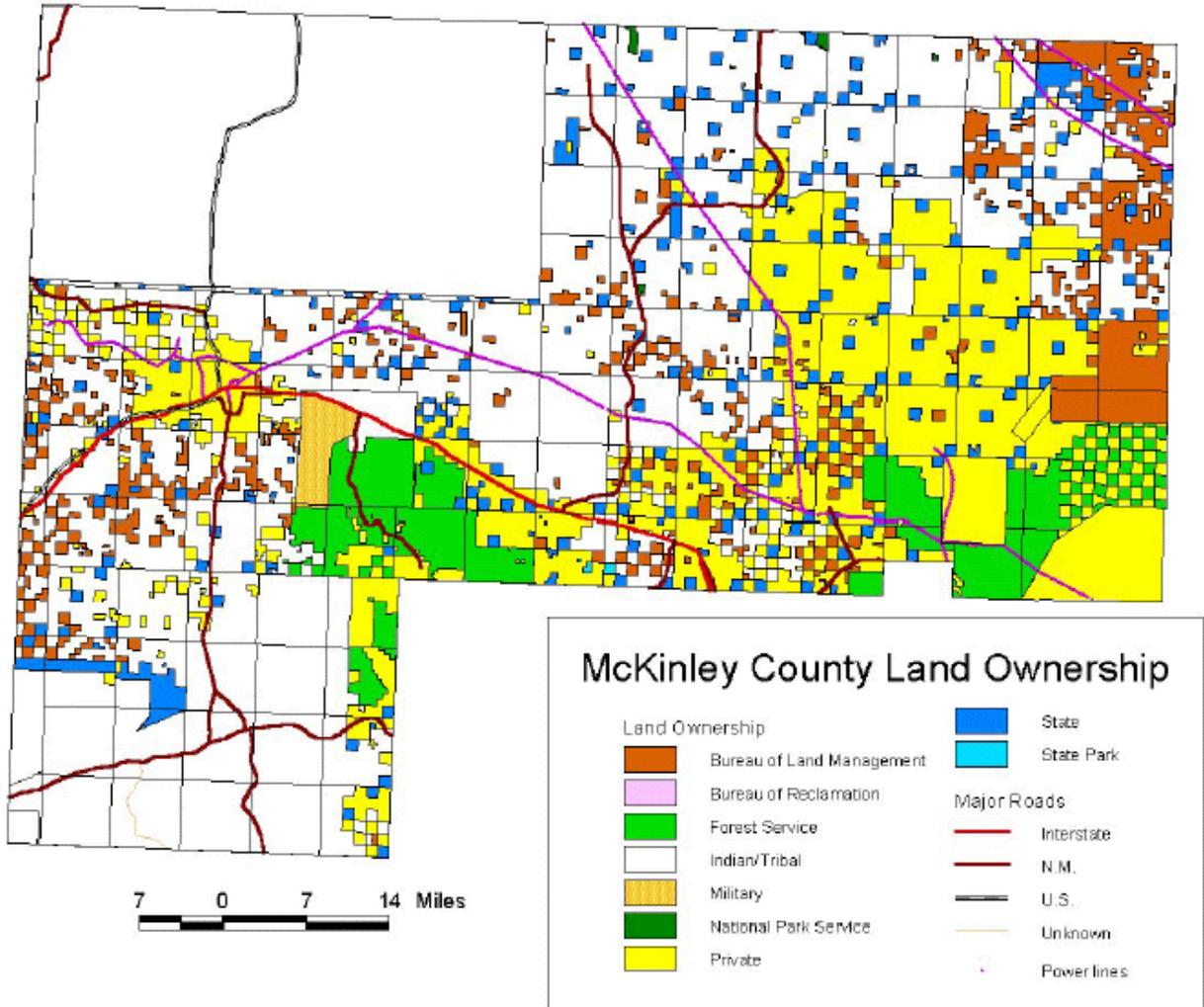


Figure 6. Land ownership in McKinley County.

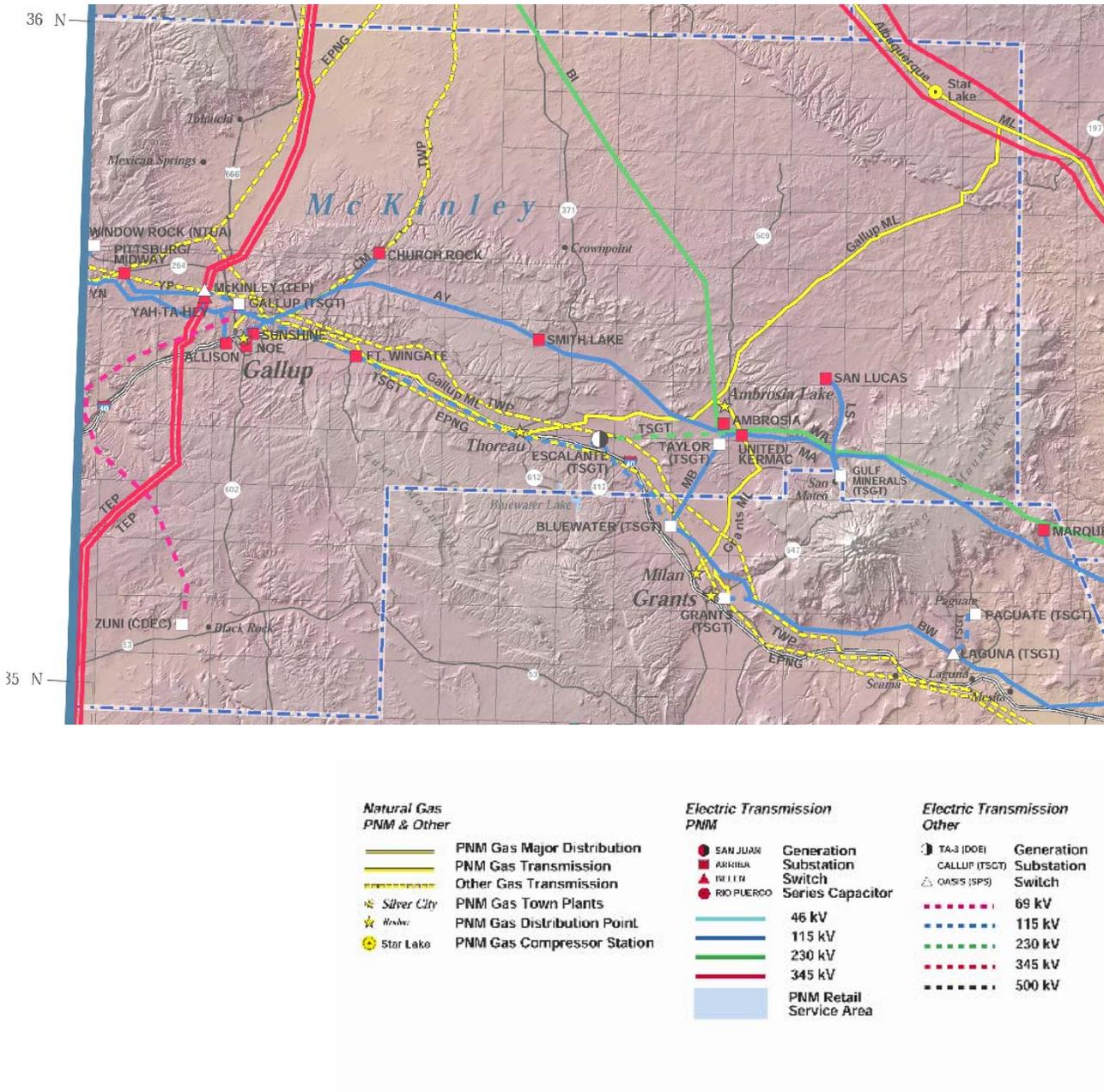


Figure 7. Natural gas pipelines and electric transmission lines in McKinley County. From PNM Major Transmission System Map. Pipeline are in yellow. Electric transmission lines in blue, green and red.

Coal potential of McKinley County, New Mexico

Introduction

This resource evaluation for McKinley County is a compilation of previous studies for the Department of Energy (DOE), Bureau of Land Management (BLM), and ongoing U. S. Geological Survey (USGS) investigations. The DOE study completed in 1994, is the basis for this evaluation with updates in production and depletion figures. New Mexico Bureau of Geology and Mineral Resources (NMBGMR) Resource Map 20, by E. C. Beaumont (1998) is the basis for accompanying maps illustrating areas of surface minable resources. Although underground reserve figures are given, the resource and development potential evaluations are primarily for surface minable coal. Underground reserves have greater potential for coalbed methane development. The following is a brief overview of the methodology used for the DOE project (Hoffman, 1996a).

Assumptions and methodology

Use of existing data

Existing data for this study consists of point source data in the NMBGMR computerized database for the San Juan Basin (SJB). For McKinley County, 1150 data points were used in calculations. These data are from published sources, NMBGMR Oil and Gas Library geophysical logs, data provided by companies, Bureau of Land Management (BLM) data from inactive federal coal leases and tract delineation studies, and NMBGMR coal studies. Collection and entry of these data into the National Coal Resource Data System (NCRDS) is part of a cooperative grant with the USGS. Point source data plotted on 7.5-minute quadrangle maps and hand-planimetered resource area measurements of these data were reexamined for the DOE study. Areas of exposure of coal-bearing rock units derived from the latest geologic mapping were transferred onto these data-point maps to define resource areas. Determination of coal **rank**, sulfur, Btu, and ash categories used all available data in the NMBGMR **quality** database for the SJB. Production figures used for **depletion of original resources** were calculated from the following sources:

- 1) Percentages of total tonnage by depth and thickness for mining before 1962 are from individual mine data from Nickelson (1988)
- 2) NMBGMR mine and resource databases, and Territorial and State Mine inspector reports
- 3) Data from the New Mexico Energy Minerals and Natural Resources Department (NMEMNRD) annual reports for production from 1970 through 2001

Total coal production tonnages by county for the DOE study are derived by averaging the totals from the Territorial and State reports and data supplied from the DOE-EIA for this study. The DOE-EIA and State figures are comparable, although differences do occur. The average total tonnage figures for the years up to and including 2001 were multiplied by the standard **recovery factors**, 80% for surface and 50% for underground, to calculate production and mining losses. Recent mine production and losses during mining (1970–2001) were directly subtracted from the original demonstrated resources.

Both surface and underground deposits in the SJB are addressed in the DOE study. The SJB includes several coal fields defined by formational and political boundaries. Table 5 lists the coal fields in McKinley County and these fields are shown in Fig. 8. Table 5 lists the **remaining demonstrated reserve base** (DRB) for each field by formation. Major land-use restrictions influencing the coal areas are listed in Table 5.

Reliability criteria

Estimates within the demonstrated category (**measured plus indicated resources**) are based on USGS Circular 891 (Wood et al., 1983). Demonstrated resources encompass an area within a 0.75 mi radius from a known coal occurrence. This area is multiplied by the thickness of the coal (Acre ft) then multiplied by the density factor (st/acre ft) resulting in tons of coal. All chemical analyses used to find quality parameters are on an as-received basis with less than 33% ash yield and weighted on total bed thickness. Clustering of resource and quality data occurs in exploration or mine areas, but many areas have sparse data coverage.

Mapping and physical criteria

This demonstrated reserve base used the USGS criteria for subbituminous and bituminous coals. Subbituminous coals are assigned a density factor of 1770 st/acre ft, and bituminous coal is assigned a density factor of 1800 st/acre ft (Wood et al., 1983). Subbituminous demonstrated resources include coal 2.5 ft or greater in thickness; bituminous demonstrated resources include coal 28 inches or greater in thickness. Table 4 lists the thickness and depth intervals used for the resource estimates. Coal with less than 20 ft of overburden is excluded from the original resource estimate and these figures were used for the remaining DRB analyses. Coal resources with less than 20 ft of overburden were eliminated because SJB coal within this interval is generally weathered

and not useful for energy production. Most operating mines in the SJB use the greater-than-20-ft depth criterion for calculating mine reserves.

Table 4. Basic Resource Criteria. Modified from Wood et al., 1983.

Coal Seam Thickness		Overburden Thickness	
		depth from surface	underground or surface mining
<u>Bituminous</u>	<u>Subbituminous</u>		
28-42 inches	2.5-5 ft	20 to 200 ft	Surface
> 42 inches	5-10 ft	200 to 500 ft	Underground
	> 10 ft	500 to 1000 ft	Underground

Selection and integration of coal quality data

All available coal quality data for the SJB at the NMBGMR were used to calculate rank and other coal quality parameters. Most of these analyses are from cores or mine samples totaling 339 individual analyses for McKinley County coal areas. Individual sample analyses were weighted by percent of total seam thickness and statistically averaged by township to decide quality categories for the DRB. Average weighted analyses for each field are given in Hoffman (1996a,b).

To meet current standards of the Clean Air Act and amendments, generating stations may not discharge gaseous effluent containing more than 1.2 lb of sulfur dioxide (SO₂) per million Btu, which translates to about 0.6% lb sulfur per million Btu. Resources with sulfur content of with less than 0.6% lbs sulfur/MMBtu meet compliance coal standards, above this level, the power plants burning this coal must have combustion gas scrubbers to remove sulfur from power plant emissions. On Table 5 under "Coal Quality" sulfur content is listed as low, moderate or high; Low sulfur is less than 0.6%, moderate sulfur is 0.6-0.83% and high sulfur is 0.84-1.24%lbs sulfur/MMBtu.

Use of judgment and/or extrapolation

Many of the fields have very little quality data. This is particularly true for the smaller Menefee, Crevasse Canyon, and Gallup Sandstone fields where there has been very little

exploration. The author examined the data available in these fields and data from adjacent areas to decide the quality parameters to assign to the DRB. The extent to which data from adjacent fields was used depended on the amount of data available within the field; reliance on outside data ranged from 10 to 50%. Although specific coal quality parameters vary from sample to sample, the rank of the coal is generally constant within a formational unit, unless there are local changes in the geothermal gradient.

Classification of Coal-Resource and Development Potential

Resource Potential

The resource and development potential ranking is based on a subjective classification. The potential is classified according to the availability of geologic data and the geologic probability of occurrence of coal in an area. A **high resource potential** is assigned to areas where known mines or leased areas occur or where the geologic and quality data indicate an excellent probability that coal occurs in significant amounts. **Moderate resource potential** exists where data suggests reasonable probability of economic coal deposits, but data coverage is inadequate for a higher rank. A **low to moderate resource potential** exists in areas where data suggests there are coal resources, but they are not as great as moderate and data indicates a lower possibility of economic coal occurrence, either through the reserve estimate and/or the thickness of the coals. **Low resource potential** indicates the data available for the area shows existence of a coal deposit, but it is of low economic potential because of thin beds or lack of extent of the deposit.

Development Potential

The presence of coal in an area does not guarantee that mining will take place. The geology of a coal deposit is the first factor in determining whether a coal deposit has economic potential. Other factors include 1) the technology available for extraction, 2) distance to a market and competition within the market, and 3) available transportation network. Land ownership issues including checkerboard areas where there are multiple landowners can also limit putting together a minable unit (see Hiles, 2002). Except for geology, some of these factors will change depending on the end use and economics at any point in time

The geology of an area determines whether coal is present or absent, and if the coal beds are thick enough to be considered minable with the available mining techniques. The structure of an area, whether the rock units are flat lying, have significant dips or are faulted, also determines

whether a coal bed can be mined with the techniques available. Coal quality is important as well, and often dependent on the end use. Currently the sulfur content with respect to the heating values (Btu/lb) of the coal is one of the significant quality characteristics.

The development potential is based on the resource potential and the economic potential of an area. **High development potential** indicates an area is currently being mined, has active coal leases, or the resource in the area and economic conditions are favorable for the area. **High to moderate development potential** occurs in areas where the resource potential is high, but because of restrictions in the area, such as lack of transportation, checkerboard land ownership, or significant coal removed by past mining, this area is given a lower rating. **Moderate development potential** indicates the area has a high to moderate resource potential for development, but there are economic conditions, such as land ownership, that may hinder development. Moderate potential can also be applied to an area that has moderate resource potential and lower economic promise than a higher ranking. **Low to moderate development potential** applies to areas with a lower resource potential that also have barriers to economic development, lessening the chances for development. **Low development potential** indicates only a slight possibility, if any for production of the deposit, primarily because of the low resource potential, geologic structure of the area, and land use restrictions.

Coal Potential in McKinley County

The San Juan Basin is a roughly asymmetric, circular, structural depression, which is deeper in the northeastern part of the basin. The coal-bearing Late Cretaceous strata dip steeply into the basin on the northwest along the Hogback monocline, and on the east along the Archuleta arch and Nacimiento uplift (Fig. 1). Gentle dips prevail in the south and southwest sections (Chaco slope). The deepest part of the basin is about 30 mi west of the Monero, in Rio Arriba County (Fig. 1) on the northeast edge, where the Cretaceous coal beds are as much as 9,000 ft below the surface. Along the southern edge of the San Juan Basin, several structural features and faults influence the Cretaceous coal-bearing units (Fig. 1). In McKinley County, most of the outcrops of coal-bearing sequences are within the Chaco Slope, however near Gallup the Defiance monocline, the Nutria monocline and the Zuni uplift influence coal beds.

Coal-bearing rocks in the San Juan Basin are of Late Cretaceous age (45-60 million years ago) and were developed in peat swamps or mires in nearshore or coastal environments. Most San Juan Basin coals thick enough to have economic potential developed as the seas slowly retreated to

the northeast because of increased sediment supply from the continental highlands to the southwest. The slow and uneven retreat allowed for greater buildup of organic material in the peat mires (swamps) and for preservation of the coal in the rock record. The coals that developed from these Late Cretaceous peat mires in the San Juan Basin do not have great lateral extent, but there are multiple seams within a coal-bearing rock formation. Coals vary in thickness, pinch out, or can be cut by channel sands that were deposited by streams entering the mires.

There are three major coal-bearing rock sequences in the San Juan Basin: the Crevasse Canyon, Menefee and Fruitland formations (Fig. 8). The Crevasse Canyon is the oldest unit, but coals in this formation are not being mined at this time. The Menefee Formation has two coal-bearing sequences and is the oldest coal-bearing unit actively mined in the San Juan Basin (Stratigraphic Column). The Cleary Coal Member is at the base and the Upper Coal Member at the top of this unit. Coals in both the Cleary and Upper Coal members are thin, averaging 3–5 ft but some seams can be up to 25 ft thick. These coals have limited lateral extent and there are multiple seams within the coal-bearing sequence at any one location. Surface minable coal in the Cleary Coal Member is present along the southern edge of the basin and is near the surface on the western and eastern limbs where the rock units dip steeply. The Upper Coal Member is near the surface along the southern edge of Chacra Mesa, a prominent topographic feature extending from Torreon towards Chaco Canyon. Capping Chacra Mesa is the thick, resistant Cliff House Sandstone overlying the Menefee Formation (Fig. 2). The Fruitland Formation is the youngest coal-bearing unit and outcrops along the western, southern and part of the eastern edges of the basin (Fig. 8). Some of the thickest coals are near the base of the Fruitland, above shoreline-developed sandstones of the Pictured Cliffs Sandstone. Coal seams in the Fruitland Formation can reach thicknesses of 30 ft, but 5–10 ft seams are more common. The lateral extent of these coals is limited but they tend to have greater continuity than coals in the Menefee Formation.

McKinley County contains all the major coal-bearing sequences found in the San Juan Basin. Development of coal resources for mining is greatest for coal resources within 200 ft of the surface. Underground mining is not as economic as surface mining and any deep coal reserves should be examined for coalbed methane potential instead of conventional mining methods. Based on resource calculations, thickness of seams, structure, and presence of coal mining or mining leases, the areas of greatest potential for coal mining in McKinley County are:

- Fruitland Formation Star Lake area, northeast corner of McKinley County. The coals in the Fruitland Formation are relatively thick and have greater continuity than any of the other coal-

bearing sequences in the San Juan Basin. The thickness and continuity of the coals constitute a considerable resource base in the Star Lake area. Being on the Chaco Slope, the beds dip gently to the north-northeast and the gentle topography of the area is conducive to surface mining.

Although there has been little or no mining in the area, a coal lease held by Peabody Coal (Fig. 9E) covers a large section of the Fruitland outcrop within McKinley County. The major drawback to this area is a lack

of rail transportation. The best option for development of this coal area is concurrent development of a coal-fired generation station in the area to use the coal. Powerlines are present in this area.

- The Cleary Coal Member, Menefee Formation, in the San Mateo and eastern Standing Rock fields, northwest of Grants have a high potential for development. Coals in this sequence average 5 ft thick and there are multiple seams within the coal-bearing section. Although there is some structure in the area, the topography and general dip of the coal beds is conducive to surface mining. Active mining at the Lee Ranch mine and the South Hospah coal lease indicate this area has good potential for further coal development. A rail spur exists to the South Hospah lease and Lee Ranch is one of two mines in the San Juan Basin that transport their coal by rail. This area of the Basin has significant private land holdings (Figs. 6, 9E).
- The Gibson-Cleary Member, Crevasse Canyon Formation, in the Gallup field, northeast and south of the town of Gallup has moderate-high development potential. The coal in this sequence has some of the best quality characteristics of any of the coal-bearing sequences in the San Juan Basin. Coal quality and coal thickness (avg. 4.5 ft) with multiple coal seams is a positive factor. However, not all areas in the Gallup field are conducive to surface mining because of the significant dips related to the structure of the area. Coal mining began in this field in the 1880s and continues at the McKinley mine; therefore, many areas are mined out, reducing the coal resource and areas for development (see Fig. 9W). Land ownership in the Gallup area may also be a factor for development because of the checkerboard ownership (Fig. 9W).
- The Gibson Member, Crevasse Canyon Formation, in the Crownpoint field has significant coal resource potential and a moderate development potential. The reserves in this area are great, although the coal seam thickness (avg. 3.6 ft) is relatively thin. The topography and structure of the area are conducive to surface mining, however there is no rail into the area and much of the land ownership is Indian or checkerboard Indian allotted (Figs. 6, 8, 9E). There has been no significant mining or development of coal in the past however there was considerable

exploration for uranium in the area. The geophysical logs from this exploration indicate a significant coal resource.

The accompanying map (Figs. 9E, 9W) illustrates the rankings for all coal areas in McKinley County and the factors influencing development potential rankings are summarized in Table 5. The outlines of the areas are from Beaumont, (1998) which follow the outcrop of the geologic unit and a projected 200-ft depth line for surface mining. In some cases, a coal field may have several rankings of development potential shown on the map, but Table 5 has only the predominant ranking. Table 5 has a data for the Gallup Sandstone, but the outline of this unit is not on the map. The Gallup Sandstone outcrop is not on Beaumont's map (1998) and has a very low potential for coal mining development.

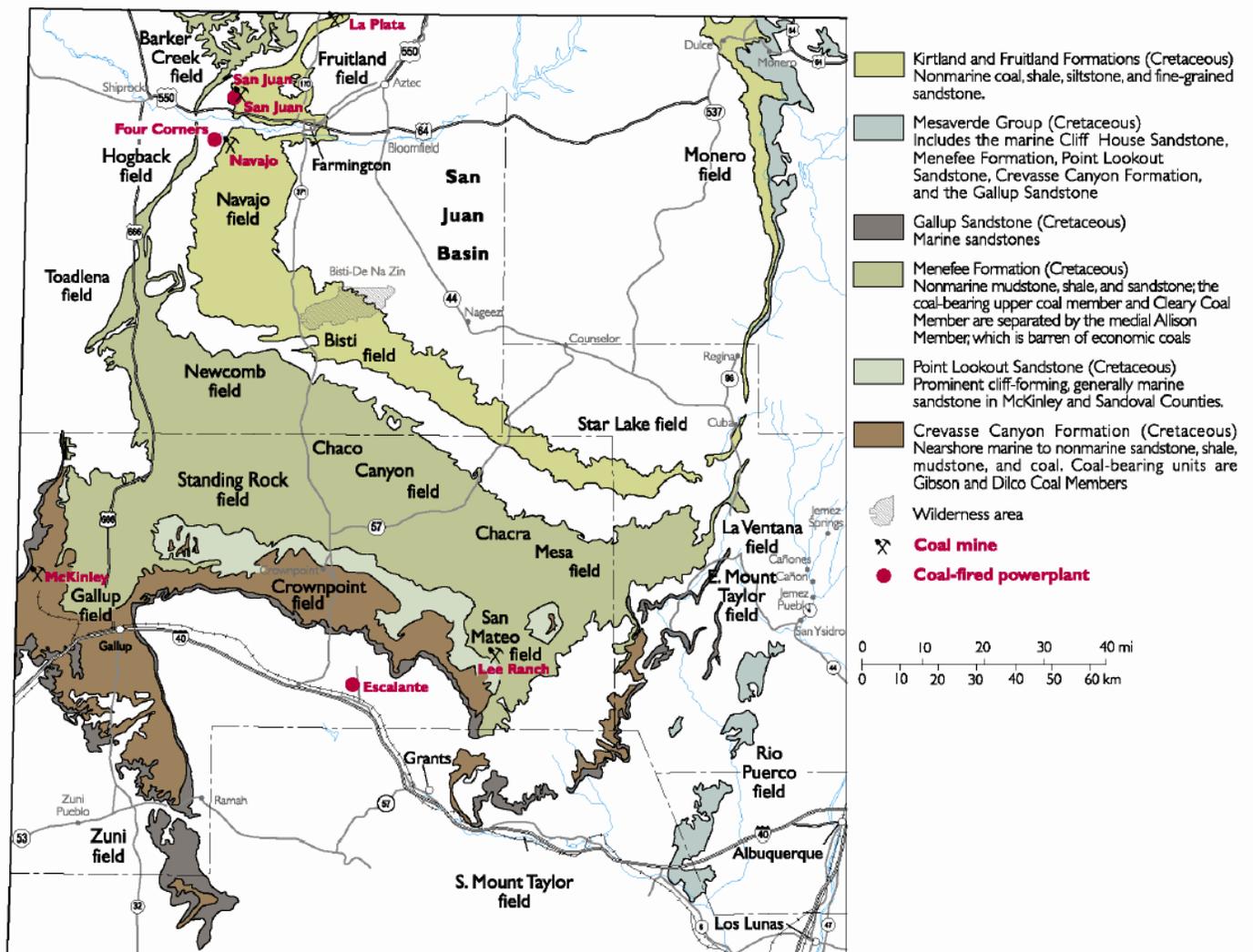


Figure 8. Coal fields and coal-bearing rock units within the San Juan Basin. From Hoffman, 2002.

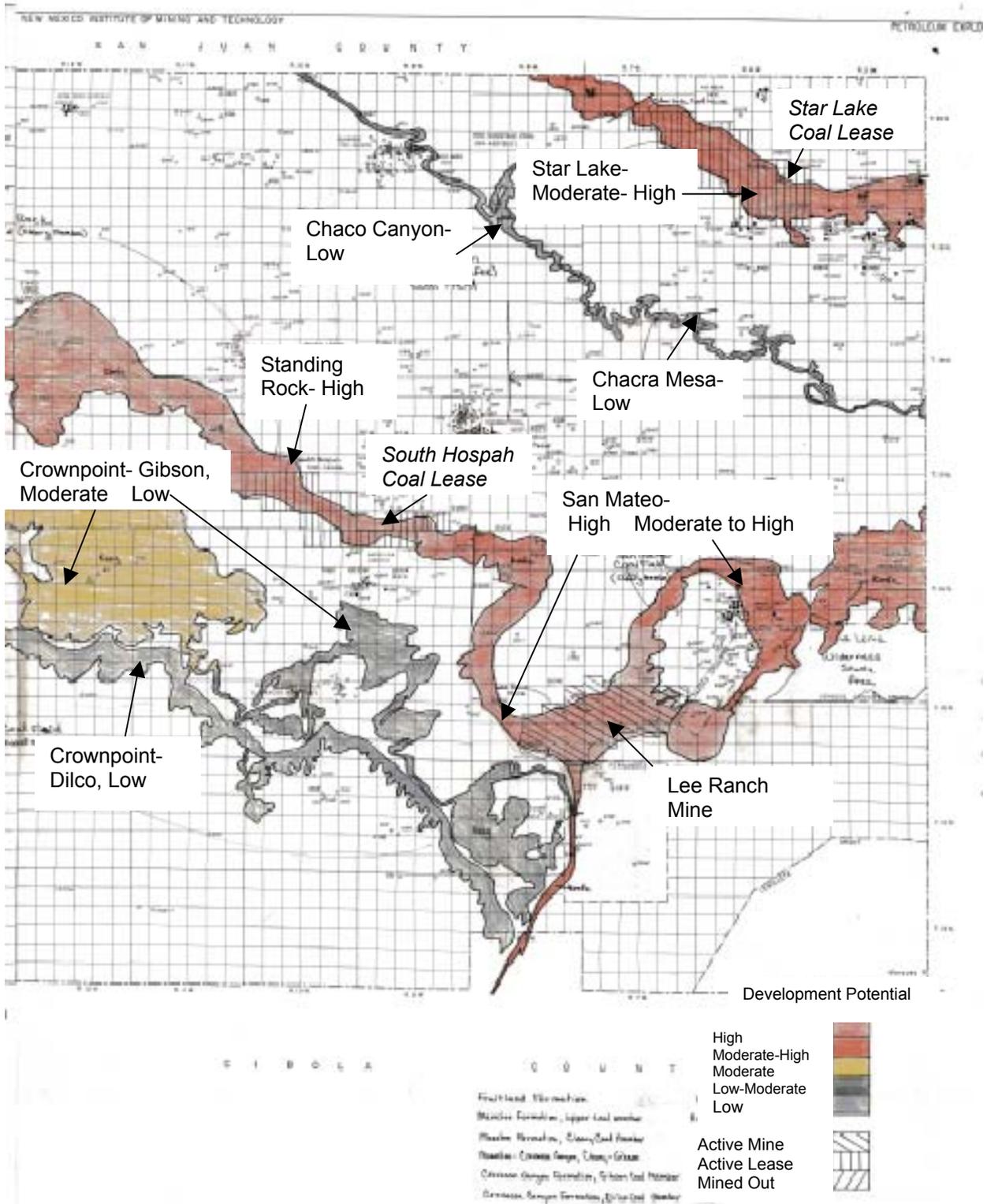
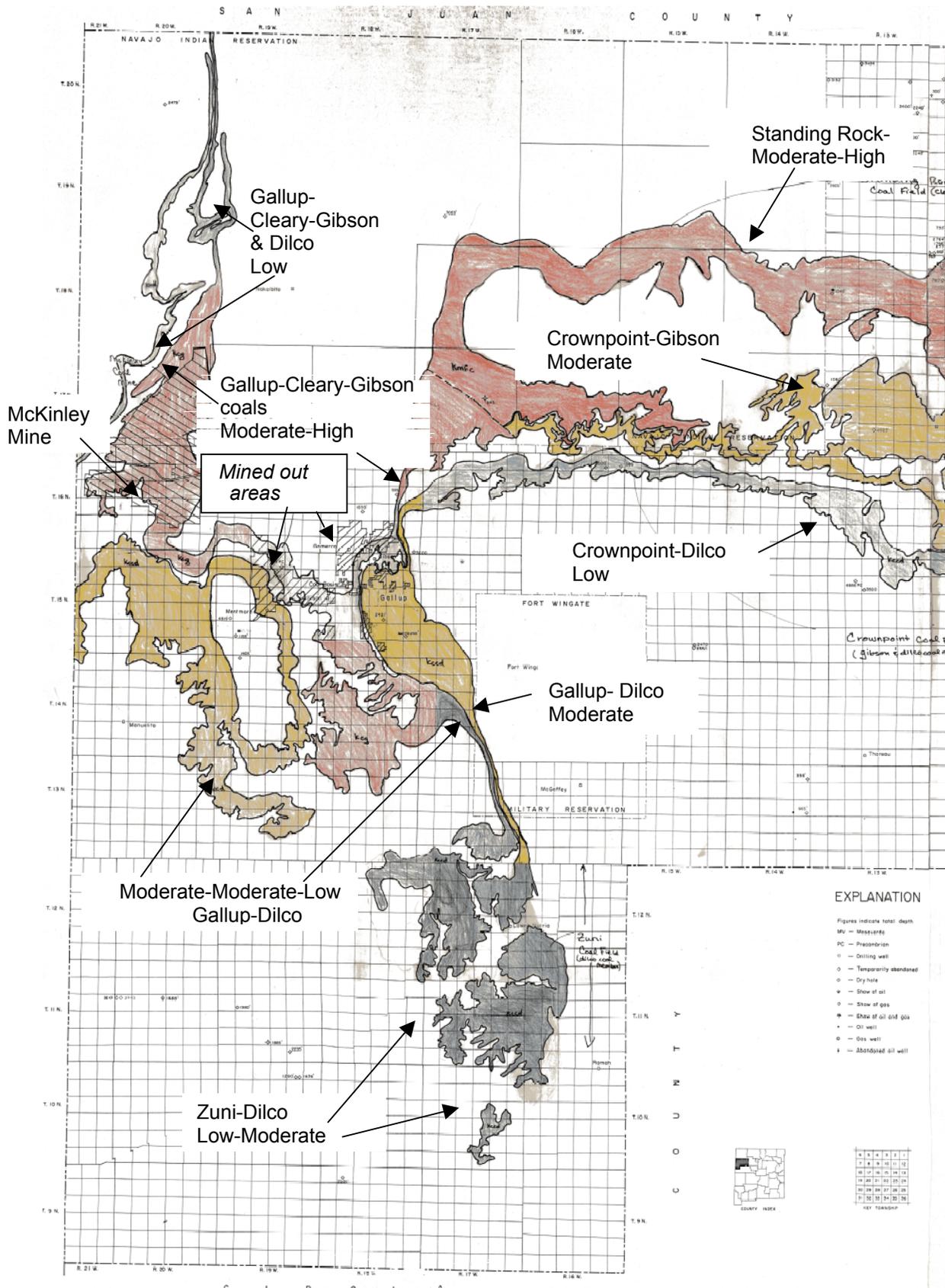


Figure 9E. Coal Development Potential, East Half McKinley County. **DRAFT**



□ Figure 9W. Coal Development Potential, West Half McKinley County. **DRAFT**

Table 5. Fruitland and Menefee Coal Resource Potential in McKinley County¹

Formation	Fruitland	Menefee	Menefee	Menefee	Menefee
Coal Member		Upper	Upper	Cleary	Cleary
Field	Star Lake	Chaco Canyon	Chacra Mesa	San Mateo	Standing Rock
Description (within McKinley County)	Northeast corner, Fruitland outcrop	Northeast corner, Upper Menefee outcrop	Northeast corner, from R8W east, upper Menefee outcrop	Northwest of Mount Taylor, south of Chacra Mesa	Northwest of San Mateo area from R9W, west along Cleary Coal outcrop
Coal Geology	Coals average 6.6 ft, lenticular, multiple seams	Thin coals- average economic coal 2.8 ft, highly lenticular	Avg. economic coal 3.2 ft., average at least 2 seams in section, lenticular	Avg. economic coal 4.8 ft, average 2 seams in section, lenticular	Avg. economic coal 5.0 ft, average 2 seams in section, lenticular
Coal Quality	Subbituminous A-High Volatile C Bituminous high ash content, low (<1%) sulfur	Subbituminous A, low ash, moderate sulfur	Subbituminous A, moderate ash, low sulfur	Subbituminous A, moderate ash, variable sulfur, from low to high	Subbituminous A, moderate ash, moderate sulfur
Economic Activity	No major mining, active Star Lake Coal lease (Peabody)	Small drifts, no major mining activity	Small drifts, no major mining activity	Lee Ranch Mine	No significant past mining, active South Hospah Coal lease (Peabody)
Estimated Remaining Reserves (DRB) Surface Underground (million st)	483.89 127.09	5.82 50.74	26.63 148.34	412.54 317.59	392.20 448.49
Resource Potential	High	Low	Low	High	High (particularly in the eastern half)
Restrictions	Outlier of Chaco National Historic Monument, pipelines, pumping station,	Chaco River. Thick sandstone beds overlying coals are prohibitive to surface mining	Few small oil and gas fields. Thick sandstone beds overlying coals are prohibitive to surface mining	La Lena Wilderness area, Mount Taylor covers large area of underground resources, Cibola National Forest, Land Grants	Outlier of Chaco National Monument, small oil and gas fields, particularly in underground resource area, pipelines, state highways 509,371,
Economic restrictions	Lack of rail transportation, land access				Checkerboard ownership. Positive-rail spur
Development Potential	Moderate-High	Low	Low	High	High

¹Data in table summarizes discussions in Hoffman (1996a, 1996b)

Table 5. cont'd. Crevasse Canyon and Gallup Coal Resource Potential in McKinley County¹

Formation	Crevasse Canyon	Crevasse Canyon	Crevasse Canyon	Crevasse Canyon	Crevasse Canyon	Gallup Sandstone
Coal Member	Gibson-Cleary	Gibson	Dilco	Dilco	Dilco	Gallup
Field	Gallup	Crownpoint	Gallup	Zuni	Crownpoint	Zuni, Crownpoint areas
Description (within McKinley County)	Gallup area, all outcrops of the Gibson-Cleary to southern edge of T12N-	From R8W-R17W, Gibson member outcrop	Gallup area, all outcrops of the Dilco to southern edge of T12N	South of Gallup area, outcrops of Dilco coal member	From R8W-R17W, Dilco member outcrop	
Coal Geology	Four economical seams, average 4.5 ft thick, generally 3 seams in section - Beds dip into Gallup Sag, from the Nutria Monocline (E) and Defiance uplift (W)	Average thickness 3.6 ft with two seams in a section. Lenticular coal beds.	Five economic coals reported avg. thickness 4.2, generally 2 seams in section. Beds dip into Gallup Sag, from the Nutria Monocline (E) and Defiance uplift (W)	Average coal seam 3.9 ft with 2 seams in section. Beds dip into the Gallup Sag from the Nutria Monocline (E) and Defiance uplift (W)	Coal beds are thin and lenticular. Average seam thickness is 3.7 ft, averaging two seams in a section.	Very thin seams in all areas-
Coal Quality	Subbituminous A to High Volatile C Bituminous, low ash, low sulfur	Subbituminous A, Moderate ash, high sulfur	Subbituminous A to High Volatile C Bituminous, low ash, low to moderate sulfur	Subbituminous A, moderate to high ash, moderate sulfur	Subbituminous A-B, moderate ash, high sulfur (>1%)	Subbituminous A
Economic Activity	Coal mining since the 1880's After 1960s began large surface mines. McKinley Mine active	Minimal mine activity in the early 1900s.	Coal has been mined from the Dilco but not active mining at present	Minimal mining activity	No mining	Some mining in Zuni area
Estimated. Remaining Reserves (DRB): Surface— Underground— (million st)	393.58 356	647 317	161.00 196.00	23.34 30.61	15 113	35.91, 29.16 11.28 1.2
Resource Potential	High	High	Moderate	Low-Moderate	Low	Low
Restrictions	Mined out areas north of the town of Gallup in the surface resource area, in populated area. Navajo Indian Reservation	Small oil fields, village of Crownpoint, several state roads.	Mined out areas, Near town of Gallup, a populated area	Zuni Indian Reservation,	Several state roads. Overlain by thick Sandstones	Mined out areas, Near town of Gallup, a populated area
Economic restrictions	Checkerboard land ownership- Plus is railroad	Checkerboard land ownership, lack of transportation	Checkerboard land ownership- Plus is railroad	Land ownership	Checkerboard land ownership	Checkerboard land ownership- Plus is railroad
Development Potential	Moderate-High	Moderate	Moderate	Low-Moderate	Low	Low

Glossary for Coal Resources

accessibility—See accessible reserves

accessible reserves—That part of the demonstrated reserve base that can be accessed, excluding areas that are restricted by manmade or natural obstructions or environmental and other legal restrictions (EIA, February 1993).

demonstrated reserve base (DRB)—A collective term for the sum of coal in both measured and indicated resource categories of reliability. The DRB represent 100 percent of coal in place as of a certain date. Includes beds of bituminous coal and anthracite 28 inches or more thick and beds of subbituminous coal 60 inches or more thick that can be surfaced mined. Includes also thinner and/or deeper beds that presently are being mined or for which there is evidence that they could be mined commercially at this time. The DRB represents that portion of the in-place identified resources of coal from which reserves are calculated (EIA, February 1993).

depletion—The subtraction of both the tonnage produced and the tonnage lost to mining from the demonstrated reserve base and identified resources to determine the remaining tonnage as of a certain time. Term defined by EIA for use in coal resource and reserve reports (EIA, February 1993).

depletion factor—The multiplier of the tonnage produced that takes into account both the tonnage recovered and the tonnage lost due to mining. The depletion factor is the reciprocal of the **recovery factor** in relation to a given quantity of production. Term defined by EIA for use in coal resource and reserve reports (EIA, February 1993).

estimate—A determination as to the amount or tonnage of coal in an area. The term estimate indicates that the quantities of resources are known imprecisely. An estimate differs from an assessment, which is an analysis of all data concerning an area's coal resources and reserves with the objective of reaching a judgment about the geologic nature and economic potential of the coal resources and reserves of the area. (Wood et al., 1983)

indicated resources—Coal for which estimates of the rank, quality, and quantity have been computed partly from sample analyses and measurements and partly from reasonable geologic projections. Indicated resources are computed partly from specified measurements and partly from projection of visible data for a reasonable distance based on geologic evidence. Indicated coal is projected to extend as a 0.5-mile wide belt that lies more than 0.25 miles from the outcrop or points of observation or measurement (EIA, February 1993).

measured resources—Coal for which estimates of the rank, quality, and quantity have been computed partly from sample analyses and measurements and partly from reasonable geologic projections. Measured resources are computed from dimensions revealed in outcrops, trenches, drill holes and mine workings. Measured coal is projected to extend as a 0.25-mile wide belt from the outcrop or points of observation or measurement (EIA, February 1993).

original resources—The amount of coal in-place before production. Where mining has occurred, the total of *original resources* is the sum of the identified resources, undiscovered resources, coal produced, and coal lost-in-mining (Wood et al., 1983).

quality or grade—Refers to individual measurements such as heat value, fixed carbon, moisture, ash, sulfur, phosphorous, major, minor, and trace elements, coking properties, petrologic properties, and particular organic constituents. The individual quality elements may be aggregated in various ways to classify coal for such special purposes as metallurgical, gas, petrochemical, and blending usages (EIA, February 1993).

rank—The classification of coal relative to other coals, according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite (Standard Classification of Coal by Rank, 1992 draft) American Society for Testing Materials, ASTM Designation D-388-91a (EIA, February 1993).

recoverability—That part of the reserve that can be recovered by present mining methods. See recovery factor, reserves

recovery factor—The percentage of total tons of coal estimated to be recoverable from a given area in relation to the total tonnage estimated to be in the demonstrated reserve base. For calculating depletion factors only, the estimated recovery factors for the demonstrated reserve base, generally are 50% for underground mining methods and 80% for surface mining methods. More precise recovery factors can be computed by determining the total coal in place and the total recoverable in any specific locale (EIA, February 1993).

reserves—That portion of demonstrated resources that can be recovered economically with the application of extraction technology available currently or in the foreseeable future. Reserves include only recoverable coal; thus terms such as "minable reserves," "recoverable reserves," or "economic reserves" is redundant. Although

"**recoverable reserves**" is considered redundant and implies recoverability in both words, the EIA prefers to use the term selectively, in contexts where it is essential to distinguish recoverable from in-ground resources (EIA, February 1993) .

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