**U.S. Department of the Interior**
Bureau of Land Management
Casper Field Office, Wyoming

January 2004

Casper Field Office Planning Area

# Mineral Occurrence and Development Potential Report

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| % | percent |
| > | greater than |
| < | less than |
| ACEC | Area of Critical Environmental Concern |
| CAAA | Clean Air Act Amendments |
| NOAA | National Oceanic and Atmospheric Administration |
| PAW | Petroleum Association of Wyoming |
| 3D | three dimensional |
| AEO | Annual Energy Outlook |
| AML | Abandoned Mine Lands |
| APD | permit to drill |
| ASTM | American Society for Testing Materials |
| AU | assessment unit |
| BCFG | billion cubic feet of gas |
| BHA | bottom-hole assembly |
| BLM | Bureau of Land Management |
| BOP | blowout preventer |
| BTU | British Thermal Unit |
| CBM | coalbed methane |
| CDP | Coal Development Potential |
| CFR | Code of Federal Regulations |
| $CO_2$ | carbon dioxide |
| CSMG | Casper Solid Minerals Group |
| DEQ | Department of Environmental Quality |
| DOE | Department of Energy |
| DOI | Department of the Interior |
| DOT | Department of Transportation |
| DST | drill stem test |
| EA | Environmental Assessment |
| EIA | Energy Information Administration |
| EIS | Environmental Impact Statement |
| EPCA | Energy Policy and Conservation Act |
| FCLAA | Federal Coal Leasing Amendments Act |
| FO | Field Office |
| FUP | Free Use Permit |
| FWKO | free water knockout |
| FY | Fiscal Year |
| GIS | Geographical Information System |
| GSAM | Gas Systems Analysis Model |
| HAP | hazardous air pollutants |
| ISL | in-situ leaching |
| LBA | Lease By Application |
| MER | maximum economic recovery |
| mg/l | milligrams per liter |
| MMBNGL | million barrels of natural gas liquids |
| MMBO | million barrels of oil |
| MMS | Mineral Management Service |
| MSL | above mean sea level |
| MWD | measurement while drilling |
| N/A | not applicable |
| NAAQS | National Ambient Air Quality Standards |
| NEPA | National Environmental Policy Act |
| NETL | National Energy Technology Laboratory |
| NGL | natural gas liquids |
| NOI | Notice of Intent |
| NOS | Notice of Staking |
| $PM_{2.5}$ | particulate matter of 2.5 microns or less in diameter |
| ppm | parts per million |
| PRI | Power Resources Inc. |
| RAMC | Rio Algom Mining Corp. |
| RBCA | risk-based corrective active |
| RCT | Regional Coal Team |
| RFD | Reasonable Foreseeable Development |
| RMOTC | Rocky Mountain Oilfield Testing Center |
| RMP | Resource Management Plan |
| SMA | Surface Management Agency |
| $SO_2$ | sulfer dioxide |
| TDS | Total Dissolved Solids |
| TPS | Total Petroleum System |
| TPY | tons per year |
| U.S. | United States |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| UWYO | University of Wyoming |
| VOC | Volatile Organic Compounds |
| WOGCC | Wyoming Oil and Gas Conservation Commission |
| WSGS | Wyoming State Geological Survey |
| WYOSHRAB | Wyoming State Historical Records Advisory Board |

# MINERAL OCCURRENCE AND DEVELOPMENT POTENTIAL REPORT

## Casper Field Office Planning Area

**U.S. Department of the Interior**

**Bureau of Land Management**

**Casper Field Office, Wyoming**

**January 2004**

*It is the mission of the Bureau of Land Management to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.*

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# EXECUTIVE SUMMARY

This Mineral Occurrence and Development Potential Report has been prepared to support the process of amending the Resource Management Plan (RMP) for the Bureau of Land Management (BLM) Casper, Wyoming Field Office. The RMP encompasses Converse, Goshen, Natrona, and Platte counties, Wyoming. The Mineral Occurrence and Development Potential Report provides an intermediate level of detail for mineral assessments as prescribed in BLM Manual 3031. Information provided in the report will be incorporated into the RMP and the Environmental Impact Statement for the RMP revision.

In November 2000, Congress passed the Energy Policy and Conservation Act (EPCA) Amendments of 2000 that directed the Secretary of the Interior to conduct an inventory of oil and natural gas resources beneath federal lands. The inventory was to identify 1) United States Geological Survey (USGS) reserve estimates of oil and gas resources underlying these lands; and 2) the extent and nature of restrictions or impediments to the development of those resources (Department of the Interior et al. 2003). The report of the inventory reviewed federal oil and gas resources and constraints on their development in five basins in the Interior West, including the Powder River Basin, a portion of which lies within the Casper Planning Area. EPCA report results for the Powder River Basin were used in preparation of this mineral occurrence and development report.

The Casper Field Office manages 1.4 million acres of public land and 4.7 million acres of federal mineral estate. There are approximately 1,621,884 acres of BLM mineral ownership in Converse County, 255,623 acres in Goshen County, 2,373,523 acres in Natrona County, and 440,033 acres in Platte County. BLM mineral ownership by county minerals within the Casper Planning Area are classified into three major categories: leasable minerals (e.g. oil and gas, coal); locatable minerals (e.g. bentonite, metals, and gems); and salable minerals (e.g. common varieties of sand and gravel, building stone, limestone, scoria, and clay).

Future mineral development in the Casper Planning Area is influenced by the price of commodities, management, laws, and regulations. With all commodities, whether they are locatable, leasable, or salable, the level of resource potential can be difficult to predict, even with extensive geological studies. The potential demand and value of hydrocarbon resources is likely to stay above other leasable, locatable, or salable minerals. Other locatable and salable resources are likely to experience steady growth, which could mirror the growth rate of Wyoming's economy.

Mineral occurrence and development potential in the Casper Planning Area is associated with coal, oil and gas, coalbed methane (CBM), uranium, bentonite, limestone, building stone, and sand and gravel production. Natural gas production from unconventional sources, such as CBM, is projected to increase more rapidly than conventional production. Overall, oil and gas development in the eastern Wind River and southern Powder River basins, excluding CBM, is expected to decline slowly. The Powder River Basin contains several oil fields that are candidates for carbon dioxide injection. The use of carbon dioxide to enhance oil recovery in the planning area is expected to increase. Oil and gas potential for the Casper Arch have not been identified in the USGS assessments. Commercial interests suggest good potential for the development of some oil and gas reserves. The Denver Basin portion of the planning area shows little potential for oil and gas development.

Demand for Powder River Basin coal is expected to be affected by new environmental regulations expected to take effect in 2004 and 2008. New regulations for the control of mercury could eliminate much of the current advantage of the low sulfur western coal.

The Casper Planning Area is likely to continue with existing production levels of uranium. Bentonite production is expected to remain stable in the near future. Other locatable mineral commodities including gypsum, limestone, feldspar, flagstone, marble, metals, jade, emeralds, and diamonds are subject to market conditions that are not easily forecast. They could grow at a similar rate to the growth of Wyoming's economy.

Sand and gravel demand is likely to continue. Other salable minerals such as leonardite, clay, decorative stone, marble, and clinker are likely to see a growth rate similar to the growth of Wyoming's economy.

No recommendations or stipulations for minerals management have been developed at this time. Appropriate recommendations relating to management of the future mineral resource development within the Casper Planning Area will be developed during the resource management planning process.

# 1.0 INTRODUCTION

## 1.1 Purpose of Report

This Mineral Occurrence and Development Potential Report was prepared to support the process of amending the Resource Management Plan (RMP) for the Bureau of Land Management (BLM) Casper, Wyoming Field Office. The RMP will encompass the area described in this report as the Casper Planning Area. The Mineral Occurrence and Development Potential Report provides an intermediate level of detail for mineral assessments as prescribed in BLM Manual 3031. Information provided in the report will be incorporated into the RMP and the Environmental Impact Statement (EIS) for the RMP revision.

In November 2000, Congress passed the Energy Policy and Conservation Act (EPCA) Amendments of 2000 that directed the Secretary of the Interior, in consultation with the Secretaries of Agriculture and Energy, to conduct an inventory of oil and natural gas resources beneath federal lands. The inventory was to identify: 1) United States Geological Survey (USGS) reserve estimates of oil and gas resources underlying these lands; and 2) the extent and nature of restrictions or impediments to the development of those resources (Department of the Interior [DOI] et al. 2003). In late 2001, Congress indicated that the study should be considered a top priority for the DOI.

The EPCA report reviewed federal oil and gas resources and constraints on their development in five basins in the Interior West: the Montana Thrust Belt, the Powder River Basin, Southwestern Wyoming, the Uinta-Piceance Basin, and the San Juan Basin. A portion of the Powder River Basin lies within the Casper Planning Area. The five basins contain most of the onshore natural gas and much of the oil under federal ownership within the lower 48 states (DOI et al. 2003).

Since EPCA requires that all onshore federal lands be inventoried, the inventory will be expanded in the future to include additional areas of federal energy resources. For federal public-land managing agencies such as the BLM, this inventory is intended to serve primarily as a planning tool that provides land managers with additional information to help them develop management plans for the lands under their jurisdiction (DOI et al. 2003). It allows them to identify areas of high oil or gas potential and to evaluate the effectiveness of available stipulations in balancing the responsible development of those resources with the protection of other valuable resources in the area. It also allows resource managers to identify areas of low oil and gas potential but high potential for other resources or uses (e.g., wildlife or recreation). The report is a critical step in evaluating whether existing rules are appropriate, or need to be changed, either to provide greater protection to the environment or to promote appropriate resource development (DOI et al. 2003). EPCA report results for the Powder River Basin were used in preparation of this mineral occurrence and development report.

The mineral occurrence and development potential report for the Casper Planning Area is organized into six chapters and two appendices. Chapter 2.0 summarizes geological resources as they relate to the development and use of leasable, locatable, and salable minerals in the planning area. Subsections include physiography, stratigraphy, and structural geology and tectonics. Chapter 3.0 describes the leasable, locatable, and salable mineral resources of the planning area. Chapter 4.0 discusses the mineral resource potential of the Casper Planning Area. Chapter 5.0 provides recommendations developed by BLM staff regarding future development of leasable, locatable, and salable minerals for the planning period. Chapter 6.0 lists references used in development of the report. Appendix A provides a description of oil and gas operations procedures. Appendix B contains a list of data sources used in preparing the report figures.

## 1.2 Lands Involved and Record Data

The Casper Planning Area is located in east-central Wyoming, encompassing Converse, Goshen, Platte counties, and all but the southwestern corner of Natrona County. The Casper Field Office manages 1.4 million surface acres of public land and 4.7 million acres of federal mineral estate. There are approximately 1,621,884 acres of BLM mineral ownership in Converse County, 255,623 acres in Goshen County, 2,373,523 acres in Natrona County, and 440,033 acres in Platte County. Within the planning area, lands are also managed by the Bureau of Reclamation, the U.S. Forest Service (USFS), the U.S. Fish & Wildlife Service, the Department of Energy (DOE), the National Park Service, the State of Wyoming and county governments, and by private landowners. Figure 1-1 is a map of the Casper Planning Area.

Information sources for this report were obtained from the BLM, the Wyoming State Geological Survey (WSGS), the Wyoming Oil and Gas Conservation Commission (WOGCC), the USGS, industry reports, internet reports, personal communication with resource specialists, and a variety of other sources listed in detail in the reference section. Appendix B lists data sources for report figures. Reasonable Foreseeable Development (RFD) scenarios for oil and gas are expected to be completed by the BLM later in 2004 and are not included in this report.

## Figure 1-1 Casper Field Office Planning Area

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# 2.0 GEOLOGY

## 2.1 Physiography

The Casper Planning Area lies within two major physiographic provinces: the Northern Great Plains Province, the Northern Rocky Mountain Province, and includes the Wyoming Basin region (Figure 2-1). The Great Plains Province is a vast region that spreads across the stable core or craton of North America. Precambrian metamorphic and igneous rocks form the basement of the Plains. With the exception of the Black Hills area, the region has low relief. Elevations range from 4,000 to 7,000 feet above mean sea level. The Rocky Mountain Province consists of high mountain ranges separated by synclinal basins that form broad valleys between the ranges, and includes the Wyoming Basins region. The Wyoming Basins region is an irregularly shaped area encompassing about 40,500 square miles (Law 1995). In the planning area, it includes portions of the Wind River and Shirley basins. A portion of the planning area also lies within the southern Powder River Basin, the richest coal province in the United States (U.S.) and one of the richest petroleum provinces in the Rocky Mountain area, and the Denver Basin in southeastern Wyoming. In Section 3.0 Figure 3-3 shows the locations of the basins within the planning area.

The Powder River Basin is a northwest-southeast trending structural basin bounded by the Bighorn Mountains to the west, the Laramie Mountains and Hartville Uplift to the south, and the Black Hills to the east (Macke 1993). The Wind River Basin is an east-west trending intermontane basin of the Rocky Mountain foreland. It is bounded on the north by the Owl Uplift, by the Washaki Mountains on the northwest, by the Wind River Mountains on the southwest, on the northeast by the Casper Arch, and on the southeast by the Sweetwater Uplift (Fox and Dolton 1995). The Denver Basin is a Laramide-age basin that occurs in the southeastern part of the planning area. It is bounded on the northwest by the Hartville Uplift. A small part of the northern edge of the Shirley Basin is also included in the planning area in southern Natrona County. Figure 2-2 depicts the bedrock geology of the planning area. Figure 2-3 depicts the surface geomorphology of the Casper Planning Area.

## 2.2 Stratigraphy

The Powder River Basin formed during the Laramide Orogeny (70 to 50 million years ago). It was shaped by folding and major faulting during the early Tertiary period, ending before the Oligocene White River formation was deposited (Glass and Blackstone 1996). Bedrock geologic formations exposed at the surface in the basin are (from youngest to oldest): the Oligocene White River formation; the Eocene Wasatch formation; and the Paleocene Fort Union formation. Upper Cretaceous formations such as the Lance are also exposed at the surface in the Basin. The basin contains a thick sequence of Phanerozoic strata that exceeds 18,000 feet in thickness at the basin axis (Dolton and Fox 1995). Basin sediments were derived from the Bighorn Mountains, the Laramie Mountains and Hartville Uplift, and the Black Hills. The early Tertiary basin fill sediments (Wasatch and Fort Union formations) reach a maximum thickness of more than 6,500 feet along the basin axis. Along drainages, Quaternary alluvial deposits overlie Tertiary geologic formations. The Cretaceous Lance formation, of continental origin, underlies the early Tertiary formations. Figure 2-4 presents the stratigraphic nomenclature of the Powder River Basin.

The Eocene Wasatch formation consists primarily of mudstone and sandstone, with minor amounts of conglomerate, carbonaceous shale, and coal. Sandstone makes up about one-third of the sequence (Molnia and Pierce 1992). The Paleocene Fort Union formation consists of sandstone,

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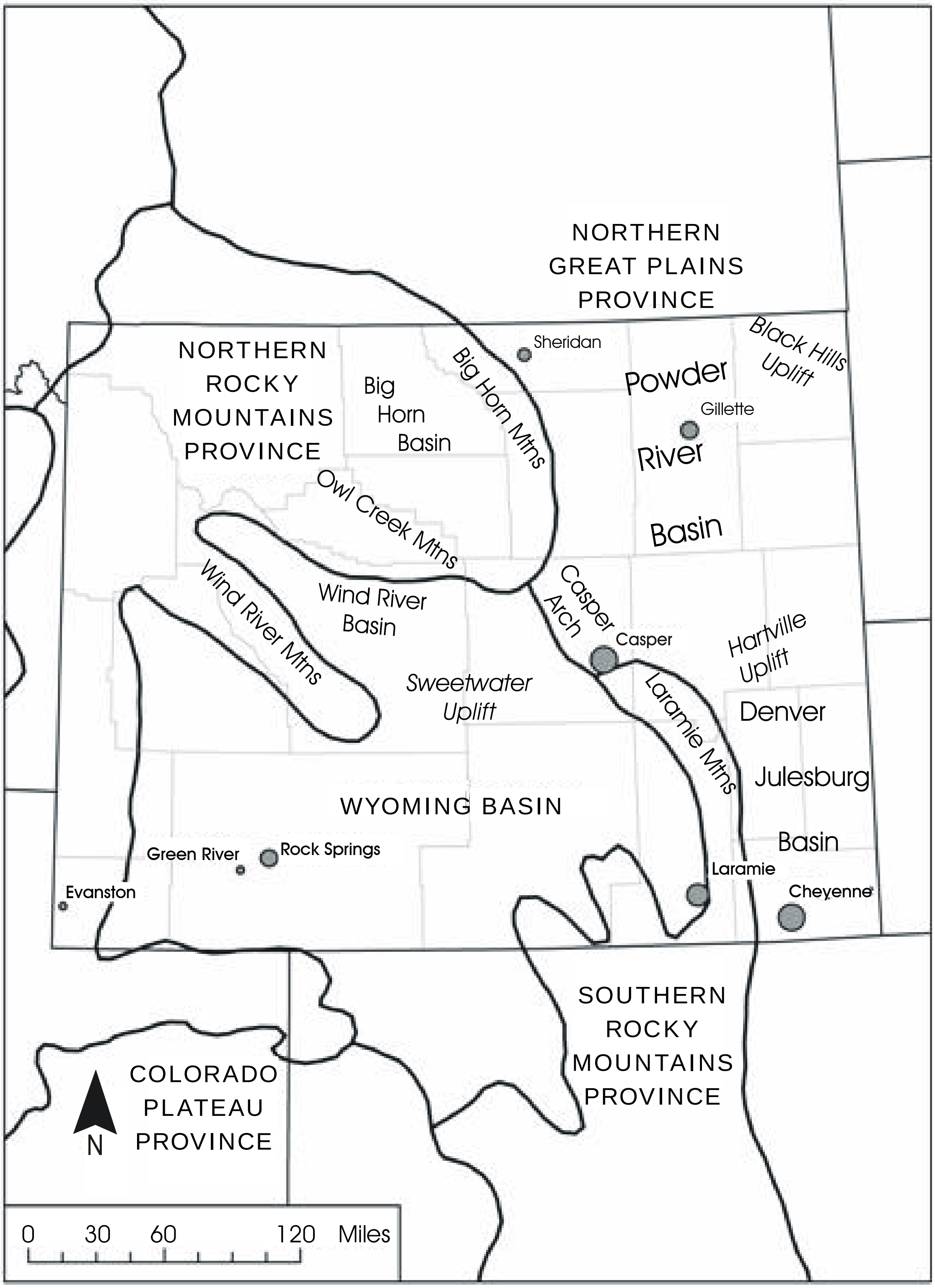


**Figure 2-1. Wyoming Physiographic Provinces**
(Map modified by SAIC, 2004)
(Source: Fenneman and Johnson 1946)

# Legend
# For Figure 2-2
# Bedrock Geology
## Casper Field Office Planning Area

- Chugwater and Goose Egg Formations
- Goose Egg Formation
- Chugwater Formation
- Chugwater and Dinwoody Formations
- Water
- Sundance Formation
- Sundance and Gypsum Spring Formations
- Cloverly and Morrison Formations
- Cloverly, Morrison, and Sundance Formations
- Cody Shale
- Frontier Formation
- Fox Hills Sandstone
- Fox Hills Sandstone and Lewis Shale
- Frontier Formation and Mowry and Thermopolis Shales
- Lance Formation
- Lewis Shale
- Lance Formation, Fox Hills Sandstone, Meteetse Formation, and Bearpaw and Lewis Shales
- Meeteetse Formation and Lewis Shale
- Mowry and Thermopolis Shales
- Mesaverde Group
- Niobrara Formation
- Steele Shale
- Guernsey Formation
- Madison Limestone or Group
- Mesozoic and Paleozoic Rocks
- Wells and Amsden Formations
- Casper Formation
- Hartville Formation
- TenSleep Sandstone and Amsden Formation
- Phosphoria Formation and Related Rocks
- Madison Limestone, Darby Formation, Bighorn Dolomite, Gallitin Limestone, Gros Ventre Formation and Flathead
- Conglomerate: Jacksone Hole; Med Bow
- Alluvium and Colluvium
- Alkalic Extrusive and Intrusive Igneous Rocks
- Landslide Deposits
- Dune Sand and Loess
- Gravel, Pediment, and Fan Deposits
- Fort Union Formation: Lebo Member
- Fort Union Formation: Tullock Member
- Fort Union Formation
- Dacite and Qartz Latite Intrusive and Extrusive Igneous Rocks
- Indian Meadows Formation
- Miocene Rocks
- Lower Miocene Rocks; Bighorn Mountains
- Lower Miocene and Upper Oligocene Rocks
- Upper Miocene Rocks
- Wasatch Formation, Main Body
- Wagon Bed Formation
- Wind River Formation (includes equivalent of Indian Meadows Formation)
- White River Formation
- White River Formation - Brule Member (includes Upper Conglomerate Member)
- White River Formation - Chadron Member
- White River Formation - Upper Conglomerate Member
- Oldest Gneiss Complex
- Metasedimentary and Metavolcanic Rocks
- Granitic Rocks of 2,600Ma Age Group
- Granite Gneiss
- Metamorphosed Mafic and Ultramafic Rocks
- Peridotite Intrusive Rocks
- Metasedimentary Rocks
- Granitic Rocks of 2,000Ma Age Group
- Granitic Rocks of 1,700Ma Age Group
- Quartz Diorite
- Anorthosite and Norite
- Pyroxene and Horneblende Syenite
- Sherman Granite
- Gallatin Limestone, Gros Ventre Formation and Flathead Sandstone

## Figure 2-2. Bedrock Geology, Casper Field Office Planning Area

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**Figure 2-3. Surface Geomorphology, Casper Field Office Planning Area**

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siltstone, mudstone, thick to thin coal beds, and minor conglomerates (Flores and Bader 1999). Fort Union sediments were deposited by north-flowing braided, meandering streams and swamps in the center of the basin, and by alluvial fans at the margin of the basin. Thick and widespread coalbeds, which may have been continuously deposited in a migrating depositional center, occur within the Fort Union formation (Finly and Goolsby 2000). The thickness of the Fort Union (Wyodak-Anderson) coal zone varies greatly. Along the southern margins of the basin, the Wyodak-Anderson coal zone (also known as Big George or Sussex) ranges from fewer than 2.5 feet to more than 200 feet thick where it splits in the Wyodak-Anderson coal zone merge beneath Pumpkin Buttes (Flores and Bader 1999). The Tongue River member of the formation consists of thick sandstone, fine-grained overbank deposits and coal beds (Pierce et al. 1990). The origin of the Lebo shale member is controversial. Ayres and Kaiser (1984) attribute a lake origin to the Lebo. Later authors (Whipkey et al. 1991, Flores and Bader 1999) attribute the high clay content in the Lebo to deposition of Cretaceous shales eroded off the rising Bighorn Mountains and Black Hills flanking the developing Powder River Basin. The Tullock member contains alluvial sediments deposited in a stream environment with sandstone, sandy siltstone, shale, thin limestone, and coal (Brown 1993).

Mesozoic sediments in Wyoming predominantly consist of marine shales, marine sandstones, and near coastal freshwater deposits (Braun 2004). These units are deposited in a shallow transgressing and regressing sea infringing from the east. Limestones were deposited in the deeper portions of the sea, followed in the more shallow areas by shales, and then near-shore and beach deposited sands. Above sea level, fresh water deposits included muds, sands, and organic rich coastal swamps; portions of which would later become coal. A general description of the major formations deposited in the Mesozoic and Paleozoic follows. These formations, or their equivalents, characterize the lithologic units located within the planning area (Braun 2004).

The youngest unit is the Lance formation, which represents the upper lithologic unit within the Cretaceous. This unit contains sandstones with shales, volcanic water-laid tuffs, and coal beds. It can have thicknesses of greater than 400 feet. The Fox Hills sandstone, located below the Lance formation, is a fine grained sandstone commonly combined for mapping purposes with the Lewis shale. The Lewis shale is fine-grained marine shale with local concretion zones. The thickness of the two units can exceed 2,000 feet. The Mesaverde formation consists of a sequence of sandstones and shales having a thickness of between 1,000 and 1,500 feet. The Pine Ridge member, located near the top of the unit contains coal beds. The Mesaverde is underlain by the Steele shale, which is a thick shale sequence underlain by a persistent sandstone located near the base. The total thickness of the unit can be nearly 3,000 feet. Below this lies the Niobrara formation which is composed of calcareous shales with marlstone beds. It has a thickness of about 500 feet. The Frontier formation consists of a thin upper sandstone unit underlain by shales deposited as submergence of the underlying craton increased. The total thickness of the unit is less than 500 feet. The Mowry and Thremopolis shales underlay the Frontier. In areas, the Muddy sandstone separates the two formations. This sandstone has been an oil producer where conditions are favorable. The Cloverly and Morrison formations mark a regression of the sea to the east, and portions of these units were deposited above the existing seal level. The total thickness of the units can be up to about 450 feet. The Sundance formation is made up of upper sandstone and lower green shale. The unit can contain the mineral gloconite, and normally has a total thickness of less than 50 feet. The Sundance is Jurassic in age.

Triassic and Permian age sediments include the Chugwater, the Dinwoody, Goose Egg, and the Phosphoria formations. These formations vary across the area from shales and siltstones with gypsum partings, to dolomites. They all have a predominantly red or reddish color. The total thickness of the units can be a few hundred feet. The underlying Tensleep sandstone and Amsden formation are Pennsylvanian in age and composed of sandstones, shales, limestones and dolomites. The Darwin sandstone is located near the base of the unit at certain locales. The Mississippian Madison Limestone is a massive limestone and dolomite sequence with basal arkosic sand that can be locally developed. The Ordovician and Cambrian units are existent in places but have either not been deposited or eroded in others. The dominant units include the Ordovician Bighorn dolomite with its associate Whitewood dolomite found to the east. The Cambrian is recorded by the few locals where the Gros Ventre formation, the Gallatin formation, the Deadwood formation and the Flathead sandstone have been described. These units include limestones, shales, and sandstones. Due to their extreme depths within the basin areas, the character of these units has not been defined to the extent of the higher younger units.

The area has had multiple episodes of uplifting that have placed the depositional surface above sea level and thus subject to erosion. These events are known as unconformities since the erosion represents a break in the geologic record between the rock units. Major unconformities are present between the Mesozoic and the Tertiary, between the Jurassic and Triassic at the Sundance Chugwater contact, and over a portion of the area at the Chugwater-Tensleep contact. Additional unconformities are located between the Tensleep sandstone and the Madison limestone, between the Madison and the Ordovician units, between the Ordovician and the Cambrian units, and again between the Cambrian and Precambrian. The Cambrian/Precambrian unconformity in some locations represents hundreds of millions of years (Braun 2004).

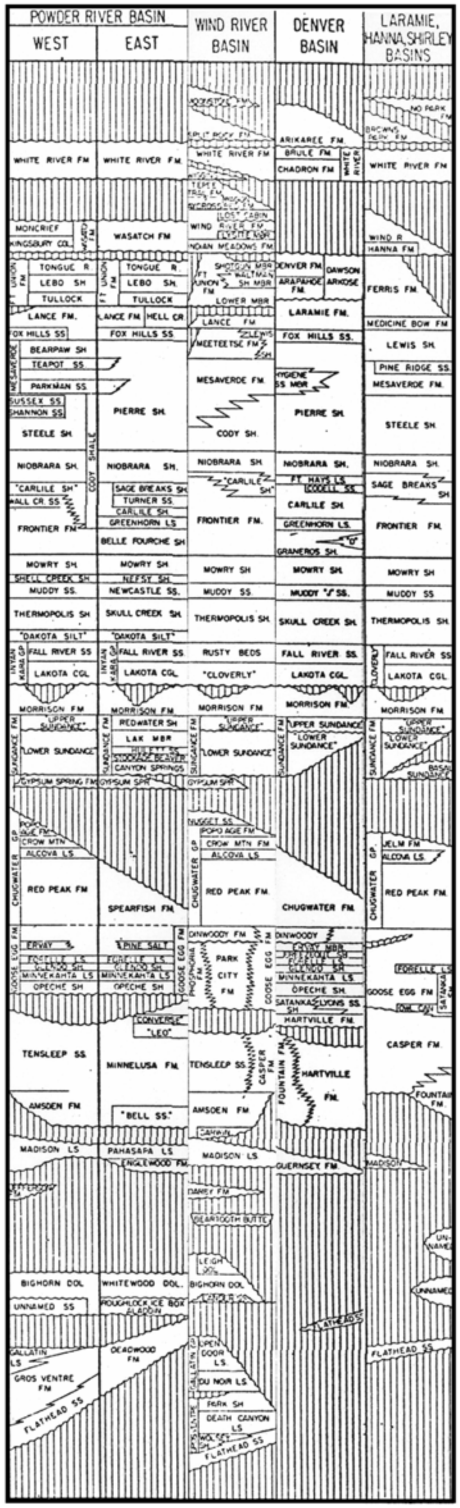
Wind River Basin tertiary system formations of the Cenozoic era, such as the Wind River formation (Eocene) and Fort Union formation (Paleocene), are gas-producing formations within the planning area. Other gas producing formations include the Lance and Meeteetse formations, of Upper Cretaceous age, and the Muddy Sandstone of Lower Cretaceous age. Refer to Figure 2-4 for the stratigraphic nomenclature of Wind River Basin. A portion of the steeply dipping western flank of the Denver Basin lies within the Casper Planning Area. Oil is found in the Niobrara formation which is commonly commingled with the underlying Codell Sandstone. Refer to Figure 2-4 for the stratigraphic nomenclature of the Denver Basin.

## 2.3 Structural Geology and Tectonics

The Casper Planning Area is in the Wyoming Foreland of the North American Craton, a complex structural zone where older rocks have been faulted up into mountains, and the trough areas are covered by younger rock units. They consist of Archean (older Precambrian) igneous and metasedimentary rocks, as well as younger Cambrian to Tertiary-aged sedimentary rocks (BLM 2003c). The uplift and basin systems in east-central Wyoming were formed by large-scale north-south striking block faulting, and thrusting from the west. The mountain and valley systems in east-central Wyoming are believed to have been formed by large-scale north-south striking block faulting, along with thrusting sourced from the west. The mountain ranges vary in elevation from 7,500 feet to 11,000 feet (Laramie Peak of the Laramie Range). Valley fills reach depths of several tens of thousands of feet. During the Laramide Orogeny, numerous episodes of igneous activity, in conjunction with thrust faulting, occurred in western Wyoming and in eastern Idaho. These events

**Figure 2-4. Stratigraphic Nomenclature, Powder River, Wind River, Denver, and Shirley Basins**

*(Source: Wyoming Geological Association 1969)*



are believed to have helped to create the major geologic features we see in the area today. This also set the stage for its diverse mineralogical occurrence and development potential (BLM 2003c).

The USGS and the WSGS monitor statewide earthquake events. Within the Casper Planning Area, 28 earthquakes of magnitude 2.5 or intensity III and above have been detected since the State of Wyoming started monitoring earthquakes in 1871 (BLM 2003c). Damaging earthquakes can occur anywhere in the state. Magnitude 7.5 events can occur in western Wyoming and magnitude 6.75 events can occur along the northern and southern margins of the Wind River Basin. Magnitude 6.25 to 6.5 events can occur anywhere in the rest of the state (BLM 2003c).

The most recent earthquake in the planning area (February 1, 2003) had an epicenter 15 miles northeast of Casper in Natrona County (BLM 2003c). This was the third quake to occur on or near that site. There have been 12 earthquakes in Converse County, four in Goshen County, 11 in Natrona County, and one in Platte County (BLM 2003c). Most earthquake activity has occurred on known active faults or along the north face of the Laramie Mountain Range. There has been no damage from these earthquakes on federal surface estate. Figure 2-5 depicts the location of earthquakes, faults, dikes, and landslides in the planning area as identified by the USGS and the University of Wyoming.

The Casper Sand Dunes are among the Wyoming Basin sand dunes present during the Pleistocene. From 13,000 to 8,100 years ago the dune fields were characterized by relatively slow eolian processes associated with soil formation. This was followed by alternating periods of erosion and stability, ending with a period of eolian formation about 700 years ago associated with increasing aridity during the Quaternary (Mayer and Mahan 2002). These dunes could become a hazard to due to overgrazing, dry weather, and human interference with dune vegetation, causing the dunes to migrate.

**Figure 2-5. Earthquakes, Faults, Landslide Areas and Dikes, Casper Field Office Planning Area**

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# 3.0 DESCRIPTION OF MINERAL RESOURCES

Minerals within the Casper Field Office Planning Area are classified into three major categories: leasable minerals (e.g. oil and gas and coal); locatable minerals (e.g. bentonite, metals, and gems); and salable minerals (e.g. common varieties of sand, stone, gravel, pumice, pumicite, cinders and clay). This categorization is based on several laws, beginning with the *General Mining Law of 1872,* which allowed the location of placer and lode mining claims as well as patents. This law declared "all valuable mineral deposits in lands belonging to the United States (U.S.)…to be free and open to exploration and purchase." Federal regulations further defined a "locatable mineral" or a "valuable mineral" as being whatever is recognized as a mineral by the standard authorities, and being found on public lands in quantity and quality sufficient to render the lands valuable. Whether or not a particular mineral deposit is locatable depends on such factors as quality, quantity, mineability, demand, and marketability. The law encourages mining companies to initiate exploration and development, stating that "all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, [are] to be free and open to exploration and purchase" (Legal Information Institute 2003).

In addition to the *General Mining Law of 1872*, a suite of laws govern mineral activity in the Casper Planning Area. They include:

- *Mineral Leasing Act of 1920* (as amended). Under this law, the BLM issues leases for development of oil and gas, deposits of coal, phosphate, potash, sodium, sulfur and other leasable minerals on public domain lands and on lands having federal reserved minerals University of New Mexico [UNM] 2004).

- *Materials Act of 1947* (as amended). Under this law, certain mineral and vegetative materials may be disposed of either through a contract of sale or a free-use permit. These minerals, commonly known as salable minerals, include common varieties of sand, stone, gravel, pumice, pumicite, cinders, clay, petrified wood and other mineral materials. The law also provides for free use of material by government agencies, municipalities or non-profit organizations, if the material is not to be used for commercial purposes.

- *Mineral Leasing Act for Acquired Lands of 1947* (as amended). This law authorizes and governs mineral leasing on acquired lands. It provides that minerals located on acquired federal lands are subject to the federal mineral leasing system.

- *Mining and Minerals Policy Act of 1970*. This law declares that it is the continuing policy of the federal government to foster and encourage private enterprise in the development of a stable domestic minerals industry and the orderly and economic development of domestic mineral resources.

- *Federal Coal Leasing Amendments Act of 1976* (FCLAA). This law amended Section 2 of the *Mineral Leasing Act of 1920* to require that all public lands available for coal leasing be offered competitively. Competitive leasing provides an opportunity for any interested party to competitively bid for a federal coal lease.

With the scattered land ownership pattern in the planning area, commercial industry has been unable to rely solely on use of public lands to meet their business needs. Mineral extraction interests have become accustomed to working with a mix of federal, state and private lands in order to secure the rights needed to extract, transport, and process raw mineral resources. The following sections provide a description of the leasable, locatable, and salable minerals in the Casper Planning Area.

## 3.1 Leasable Minerals

Under the *Mineral Leasing Act of 1920* (as amended), the BLM issues leases for the development of leasable minerals. Besides coal and oil and gas, leasable minerals include chlorides, sulfates, carbonates, borates, silicates or nitrates of potassium or sodium, sulfur in Louisiana and New Mexico, phosphates, asphalt, and gilsonite (43 Code of Federal Regulations (CFR) 3501.5). This law specifies, among other things, royalty rates, rental rates, lease size, and terms required for each kind of leasable mineral. The law also provides for the issuance of prospecting permits prior to lease issuance and competitive bidding for certain deposits.

The BLM issues leases for solid leasable minerals (other than coal and oil shale) in two different ways. Competitive leases are issued through a bidding process in areas where there is a known mineral deposit. Prospecting permits are issued in areas where there is not a known mineral deposit. If a prospecting permittee discovers a valuable mineral deposit, he/she can obtain a preference right lease without having to bid. Before any lease is issued, the BLM considers the comprehensive land use plan and environmental concerns of the proposed activity. The BLM can lease solid minerals on public and federal lands, and certain private lands, provided that the federal government owns the mineral rights.

The BLM manages coal leasing and other administrative duties relating to coal production on federal coal lands throughout the U.S. The BLM's Casper Solid Minerals Group (CSMG) is responsible for managing all coal-related activity within the Powder River Basin. Coal operations within the Casper and Buffalo Planning Areas are managed by the CSMG and not by the field offices themselves.

Leasing procedures for oil, non-coalbed methane (non-CBM) gas, and CBM are the same. Based on the *Federal Onshore Oil and Gas Leasing Reform Act of 1987*, all leases must be exposed to competitive interest. Lands that do not receive competitive interest are available for noncompetitive leasing for a period not to exceed two years. Competitive sales are held at least quarterly and by oral auction. Competitive leases are issued for a term of five years and noncompetitive leases are issued for a term of 10 years. If the lessee establishes hydrocarbon production, the competitive and noncompetitive leases can be held for as long as oil or gas are produced. The federal government receives yearly rental fees on non-producing leases. Royalty on production is received on producing leases, one-half of which is returned to the State of Wyoming.

The primary leasable minerals in the Casper Planning Area are oil, gas, and coal. Uranium has been leased in the past on acquired mineral estate in northern Converse County. Although natron has been leased historically it is not currently produced. The following section provides a detailed description of the leasable minerals in the Casper Planning Area. Figure 3-1 depicts the locations of solid leasables in the Casper Planning Area. Figure 3-2 depicts existing oil and gas leases.

**Figure 3-1. Solid Mineral Leases, Casper Field Office Planning Area**

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**Figure 3-2. Oil and Gas Leases, Casper Field Office Planning Area**

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### 3.1.1 Non-Coalbed Hydrocarbons

Wyoming has been explored for oil and gas for nearly 120 years. In 1884, the first oil well in Wyoming was drilled southeast of the present-day town of Lander. The Casper Planning Area contains portions of four oil and gas basins: the Powder River Basin (Converse and Natrona Counties), the Wind River Basin (Natrona County), the Denver Basin (Platte and Goshen Counties), and a very small portion of the Shirley Basin (Natrona County). Figure 3-3 depicts oil and gas basins in the Casper Planning Area. Figure 3-4 shows oil and gas fields. Figure 3-5 shows oil and gas wells.

The Casper Field Office is responsible for supervising and managing all exploration, development, and production operations on federal oil and gas leases in Converse, Goshen, and Platte counties, and all of Natrona County except the southwest corner. The oil and gas program falls into four functional areas: (1) lease operations, (2) inspection and enforcement of lease operations, (3) planning and policy related to oil and gas actions, and (4) geophysical exploration. Almost all of the oil and gas produced in the Casper Planning Area comes from Natrona and Converse counties. Based on production records from the WOGCC for 2002, 14 percent of the state's oil and 5 percent of the state's gas were produced from Natrona and Converse Counties (BLM 2003c). The federal mineral estate in the Casper Planning Area is about 4.7 million acres. The federal government owns 79 percent of the mineral estate in Natrona County and 50 percent of the mineral estate in Converse County (BLM 2003c). In November 2002, federal oil and gas leases covered 1,881,510 acres in the Casper Planning Area. Goshen and Platte counties have minimal oil and gas production (BLM 2003c).

The following section summarizes the origin and occurrence of non-coalbed hydrocarbons, and historical and current oil and gas production in the Casper Planning Area.

#### *3.1.1.1 Origin, Occurrence, and Trapping*

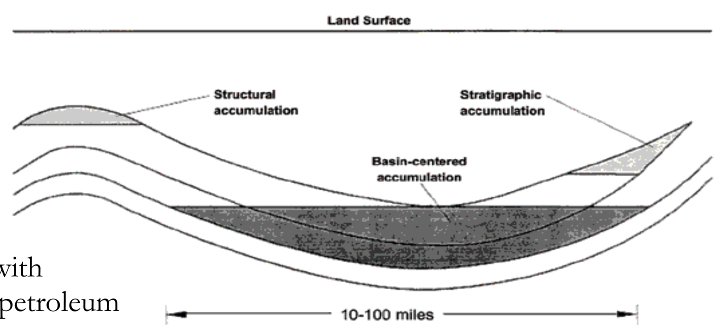


**Figure 3-0. Petroleum Traps**

*(Source: BLM 2003g)*

Crude oil and gas consist primarily of hydrocarbon compounds and are generally found in sedimentary rocks. The largest petroleum accumulations occur in sedimentary basins with widespread organic debris. Petroleum hydrocarbons are thought to derive from organic matter. This is supported by the common close association of the hydrocarbons with organic matter, and the occurrence of the largest petroleum deposits in sedimentary basins with widespread organic debris. When source rocks are subjected to increasing temperature and pressure and are thermally altered, they produce petroleum and natural gas. Hydrocarbons may mobilize and migrate away from the source rocks into more porous and permeable rocks called reservoir rocks where petroleum is held in traps (BLM 2003g). Examples of rock units within the planning area that commonly exhibit oil reservoir characteristics include the Minnelusa, the Phosphoria, and Frontier formations, the Tensleep sandstone, the Inyan Kara Group, and the Madison limestone. Examples of organic-rich source rocks include the Steele, Niobrara, Mowery, and Thermopolis shales.

There are three types of petroleum traps: structural, stratigraphic, and combination or unconventional traps (See Figure 3.0). Structural

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## Figure 3-3. Oil and Gas Basins, Casper Field Office Planning Area

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## Figure 3-4. Oil and Gas Fields, Casper Field Office Planning Area

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**Figure 3-5. Oil and Gas Wells, Casper Field Office Planning Area**

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traps can occur as a result of folding of reservoir strata. Hydrocarbons migrate into the reservoir and are held there by less permeable rock on top of the reservoir. Structural traps also form when a reservoir is sealed by movement of a fault that places less permeable strata opposite the reservoir or when the fault itself is the sealing agent (BLM 2003g). Stratigraphic traps form as a result of a lateral change in the physical characteristics of the reservoir or a change in the continuity of the rocks resulting in a change in permeability. A change in permeability may also result from later alteration (diagenesis) which causes a reduction in pore sizes decreasing the potential flow paths through the reservoir. This can form a barrier to petroleum migration. Combination and unconventional traps have elements common to both structural and stratigraphic traps. Unconventional traps include fractured reservoirs, coal seams, and basin-centered gas accumulations. In the basin-centered gas accumulation, there is no obvious seal or permeability barrier. Instead of a continuous seal, hydrocarbons are trapped in widespread low-permeability reservoirs (BLM 2003g).

Primary production is characterized by initial stages of reservoir production in which the hydrocarbons fairly easily moved to the well bore, either by the natural forces in the reservoir or through artificial lift (pumping). Primary recovery sometimes only recovers a fraction of the hydrocarbons originally in place in the reservoir. In order to more efficiently extract the oil as the reservoir energy is depleted, oil and gas operators conduct a variety of secondary recovery operations, including injection of water, gas, or steam to maintain pressure for production, or to flood the reservoirs and force the hydrocarbons to producing wells. There are also tertiary recovery methods that involve the injection of miscible fluids, or other procedures to decrease the oil viscosity or to try to move the oil to production wells (BLM 2003g).

#### 3.1.1.2 Historical Production

The first oil drilling in Natrona County was recorded in 1888 about 3 miles north of Casper and the first refinery was built in Casper in 1894/1895 (Natrona County 2003). Industry growth began with the arrival of the railroad in 1888. The first crude oil pipeline was constructed in 1911 (Petroleum Association of Wyoming [PAW] 2003). The Salt Creek Oil Field, north of Casper, is one of the best known oil-producing fields in the U.S. It has produced crude oil since 1889, and changed Casper from a sheep and cattle center to an oil town. In 1923, the Salt Creek Oil Field produced 1/5 of the total crude oil in the U.S. (Wyoming State Historical Records Advisory Board [WYOSHRAB] 2003). The Salt Creek Oil District remains one of the major oil fields of the U.S., containing some 2.7 billion barrels of recoverable crude within its reservoir (WYOSHRAB 2003).

The Salt Creek Oil District was at the center of a major scandal in the 1920s involving Salt Creek Naval Oil Reserve No. 3, popularly known as Teapot Dome. Salt Creek Naval Oil Reserve No. 3 was one of several tracts of public land reserved by the U.S. government in the early 20$^{th}$ century to serve as emergency underground oil supplies for use by the Navy when regular oil supplies diminished (Wyoming Tales and Trails 2003). Politicians and private oil interests opposed the restrictions placed on the oil fields claiming that the reserves were unnecessary and that American oil companies could provide for the Navy. Albert B. Fall, who became Warren Harding's Secretary of the Interior in 1921, convinced the Secretary of the Navy, Edwin Denby, to turn the control of the oil fields over to him. Fall leased the Teapot Dome to Harry Sinclair's Mammoth Oil Company. In return for leasing this and another oil field, Fall received gifts totaling about $400,000. The scandal was made public in 1924 after findings by the U. S. Senate. A series of civil and criminal suits related to the scandal lasted throughout the 1920s. In 1927, the Supreme Court ruled that the oil leases had been corruptly obtained, invalidated the Teapot Dome lease, and the Navy regained control of the Teapot Dome reserves (Wyoming Tales and Trails 2003). The Teapot Dome field is managed by the DOE as a testing center (the Rocky Mountain Oilfield Testing Center) for enhanced recovery and other technologies that might improve oil and gas production in the Casper Planning Area and other areas.

#### 3.1.1.3 Current Production

The majority of current oil and gas production in the Casper Planning Area occurs within Natrona County (Wind River and Powder River basins), and Converse County (Powder River Basin). Goshen and Platte counties, in the Denver Basin portion of the planning area, show little activity. A detailed discussion of oil and gas operations methods and procedures is presented in Appendix A.

As of 2003, there were 48 oil and gas fields in Natrona County and 73 oil and gas fields in Converse County (BLM 2003c). In 1985, oil production averaged 754,000 barrels per month in Natrona County and about 818,000 barrels per month in Converse County. By 2002, oil production in Natrona County had dropped to about 288,245 barrels per month, and in Converse County to about 185,800 barrels per month (BLM 2003c). In 1985, gas production averaged 1.3 million cubic feet per month in Natrona County and 2.5 million cubic feet per month in Converse County. Gas production in 2002 was 3.2 million cubic feet per month in Natrona County and 2.0 million cubic feet per month in Converse County. The increase in gas production in Natrona County is primarily attributed to the development of Waltman Field between 1995 and 1997 (BLM 2003c). It is the 11$^{th}$ largest gas-producing field in Wyoming. Salt Creek Field is the leading oil producing field in Natrona County with about 2.1 million barrels of oil in 2001. Salt Creek Field is the third largest oil-producing field in Wyoming. Lost Dome Field, discovered in 1998, is the second leading oil-producing field in Natrona County with 306,504 barrels of oil in 2001 (BLM 2003c). Scott Field is the leading oil-producing field in Converse County, with 770,320 barrels in 2001. Approximately 250 federal wells have been plugged in the Casper Planning Area since 1997, an average of about 40 wells per year (BLM 2003c). The number of wells to be plugged in the future is expected to increase as fields reach their economic limits.

Table 3-1 lists federal permits to drill in the counties within the Casper Planning Area as of 2003. Table 3-2 lists the oil and gas industry's share of 2002 property taxes for each of the counties.

**Table 3-1. Casper Planning Area Well Status (as of November 2003)**

| | Natrona County | Converse County | Goshen County | Platte County |
|---|---|---|---|---|
| Plugged/abandoned wells | 4,280 | 969 | 39 | 12 |
| Dormant Wells | 104 | 29 | 0 | 0 |
| Completed Wells | 2,343 | 585 | 1 | 0 |
| Monitoring Wells | 3 | 0 | 0 | 0 |
| Notice of Intent to Abandon | 79 | 15 | 0 | 0 |
| Spuds | 130 | 9 | 0 | 0 |
| Expired Permits | 156 | 87 | 0 | 0 |
| Permits to Drill | 57 | 8 | 0 | 0 |
| **Total Permits Issued** | **7,152** | **1702** | **40** | **12** |
| Awaiting Approval | 28 | 40 | 0 | 0 |
| **Grand Total** | **7,180** | **1,742** | **40** | **12** |

*Source: WOGCC 2003*

**Table 3-2. Oil and Gas Industry Property Tax Share, 2002**

| County | Oil/Gas Share of County Property Tax |
|---|---|
| Natrona | 47.92% |
| Converse | 40.62% |
| Platte | 10.20% |
| Goshen | 3.35% |

*Source: PAW 2003*

### 3.1.2 Coalbed Methane

The presence of methane in coal seams was historically recognized as a potential hazard in coal mining (BLM 2003g). Methane was originally extracted from coal in order to provide a margin of safety for underground coal mining by removing as much methane as possible prior to mining. Concentrations of methane gas between 5 and 15 percent are an explosion hazard. Methane released by surface mining methods is not generally considered hazardous because, in the absence of an enclosed space, it can seldom build to an explosive concentration. Methane is a greenhouse gas harmful to the environment when vented to the atmosphere during the mining process. When captured and marketed through coalbed natural gas development, it is an economically valuable resource. In the early 1980s, Congress considered CBM as an unconventional gas resource and enacted tax incentives for the production of gas from coal seams. As a result of improved economic and technological factors (e.g. prices, costs, completion procedures) most CBM can presently be economically produced without tax or other incentives.

#### *3.1.2.1 Origin and Occurrence*

CBM is a byproduct of the process of turning plant materials into coal. During coalification, methane is formed by chemical reaction in carbonaceous material. Methane formation is accelerated by high temperatures and is most plentiful in higher-rank coals. Although much of the methane generated by the coalification process escapes to the surface or migrates into adjacent rocks, some is trapped within the coal itself (DeBruin et al. 2001). The methane is stored as free gas in pores and fractures in the coal, as dissolved gas in water within the coal, or as adsorbed gas on the surface of the coal (DeBruin et al. 2001). Because most coals have microfractures, or cleat, there is a great deal of surface area on which gas can be adsorbed, allowing for the storage of a much higher volume of gas than in conventional gas reservoirs (BLM 2003g).

Biogenic methane, related to bacterial activity, forms first. Thermogenic methane forms when the temperature exceeds that at which bacteria can live. Generation of thermogenic methane begins in the higher ranks of the high volatile bituminous coals. Maximum generation of methane from coal occurs at about 300 degrees Farenheit (°F ). At higher temperatures and in higher rank coals, methane is still generated, but at lower volumes (DeBruin et al. 2001).

Methane gas is extracted when the hydrostatic pressure in the coal is lowered by pumping out the water that is in the coal. Gas extraction often involves pumping of large amounts of water in the initial stages of development. As much as 6,000 barrels of water per day have initially been produced from a single well. Once wells reach economic production, water production rates can be substantially lower (BLM 2003g). Water quality can range from less than 200 milligrams per liter (mg/l) of total dissolved solids (TDS), to over 90,000 mg/l. A typical range of TDS for the Powder River Basin is approximately 500 to 3,500 mg/l.

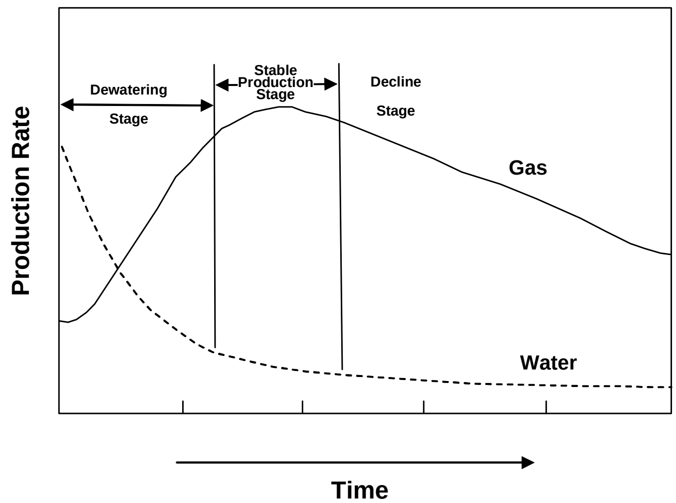



**Figure 3-5a. CBM Well Production Profile**
*(Source: BLM 2003g)*

Gas storage in coal beds is more complex than in most conventional reservoirs because coal beds are both the source rocks and the reservoir rocks. Water flow, rock porosity, and fissures allow gas migration outside the coal seam. The process of CBM extraction would be expected to draw some portion of the methane outside of the coal seam back to be extracted.

CBM is stored in four ways (DeBruin et al. 2001):

1) as free gas within the micropores and cleats in the coal;
2) as dissolved gas in water within the coal;
3) as adsorbed gas held by molecular attraction on surfaces of macerals (organic constituents that comprise the coal mass), micropores, and cleats in the coal; and
4) as absorbed gas within the molecular structure of the coal.

Wyoming's coal beds are Cretaceous and Tertiary in age. Although Cretaceous coals may attain a rank of high volatile type A bituminous coal, many are lower in rank and have not attained the thermal maturity to generate large amounts of thermogenic CBM. However, they may contain biogenic CBM (DeBruin et al. 2001). Deeply buried Cretaceous coals in the Wind River Basin have probably reached ranks that could result in significant thermogenic methane generation (DeBruin et al. 2001). Tertiary coal beds in Wyoming are generally lignite to sub-bituminous in rank. Some may be high volatile bituminous in rank when they have been deeply buried and have reached sufficient maturity for thermal generation of methane. These coalbeds are located in the deeper parts of the Wind River and other coalfields.

Less thermally mature Tertiary coal beds in the Wasatch and Fort Union formations of the Powder River coalfield contain biogenic CBM (DeBruin et al. 2001). A significant quantity of biogenic methane is present in the shallow, thick Tertiary coal beds of the Powder River coalfield (DeBruin et al. 2001). While methane content is relatively low (estimated at 30 to 40 standard cubic feet of methane per ton of coal), the coal seams are so massive that even this low amount of methane per ton adds up to a large amount of resource.

### 3.1.2.2 Historical and Current Production

The Powder River Basin is one of the most important CBM producing regions in the U.S. (BLM 2003c). Some historic ranches, using coal beds as water sources, encountered CBM as early as 1916 (DeBruin et al. 2001). The first economic production of CBM in the basin occurred in 1989. From 1976 to 1996, 1,169 CBM wells were drilled (Flores et al. 2001). CBM drilling from 1997 to 1999 increased to 4,379 wells; in 2000, 3,831 wells were drilled. About 4,000 CBM wells were producing by October 2000 (Flores et al. 2001). From January 1994 through May 2001, CBM production increased at a rate of 65 percent per year. During 2000, a total of 150.7 billion thousand cubic feet of methane was produced from basin coalbeds in Wyoming (WOGCC 2001). By the end of 2001, about 12,024 CBM wells were drilled or permitted for drilling. As of November of 2000, an estimated 4,093 CBM wells were producing (BLM 2003a).

In 2001, the Powder River coalfield was the most active new production gas field in the U.S. (DeBruin et al. 2001), producing more than 250 million cubic feet of methane. However, no CBM has been realized to date in the portion of the basin that extends into Converse County and the Casper Planning Area (BLM 2003c). Refer to Figure 3-4 for the location of CBM fields in the planning area.

At the time CBM development accelerated in the Powder River Basin, Western's MIGC pipeline was the only pipeline out of the basin. Three major pipelines (large diameter, high pressure gathering lines) were built in the basin during 1999 and 2000: Bighorn Gas Gathering, Fort Union, and Thunder Creek. CBM flows south out of the basin on three interstate pipelines, and to the north on one interstate pipeline. As of early 2001, nearly 0.5 billion cubic feet of gas per day were being transported out of the basin (De Bruin et al. 2001).

There was a large decline in applications for permits to drill for CBM in Wyoming during 2002, perhaps awaiting the approval of the Powder River Basin Oil and Gas Project Final EIS, approved in January 2003. In addition, low prices, which fell to levels of about $2.00 or less for most of the year, following unprecedented high prices in early 2001 may have contributed to the decline in applications. Production of methane through December 2002 was up 28.7 percent from the previous year to 327.1 billion cubic feet (Mining Engineering 2003). Figure 3-5b shows CBM production in Wyoming from 1978 to 2003.

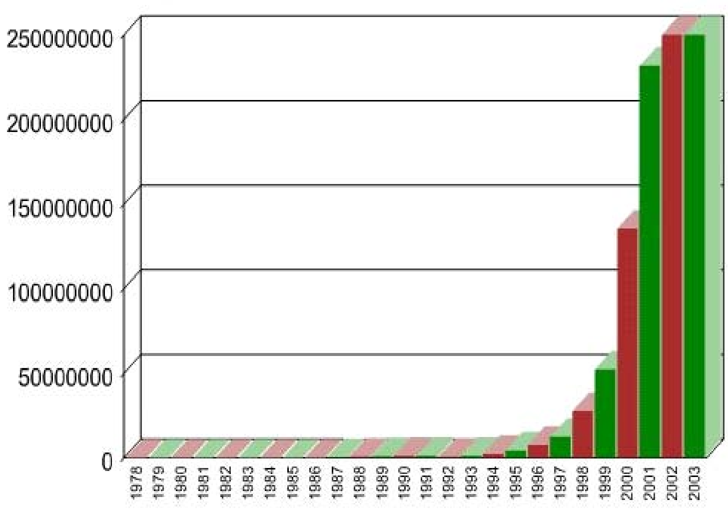



**Figure 3-5b. Wyoming CBM Production (Million Cubic Feet)**
*(Source: WOGCC 2004)*

## 3.1.3 Coal

The BLM manages coal leasing and other administrative duties relating to coal production on federal coal lands throughout the U.S. The CSMG is responsible for managing all coal related activity within the Wyoming Powder River Basin. Coal operations within the Casper and Buffalo Planning Areas are managed by the

CSMG and not by the field offices themselves. The CSMG is composed of geologists, mining engineers, and environmental and Geographical Information System (GIS) specialists. Its primary responsibilities are threefold: to manage coal exploration, existing coal leases, and new coal leases.

Prior to leasing a party might be interested in exploring for coal deposits. The entire Casper and Buffalo Planning Areas are open to coal exploration through the coal exploration license process. The CSMG conducts an environmental assessment (abbreviated version of a full EIS) of the proposed exploration activities to verify its suitability for exploration. In addition, the CSMG coordinates with either the Casper or Buffalo Field Offices to ensure the exploration activity will not significantly affect environmental (e.g., threatened or endangered species) or paleontological (e.g., fossils) resources. Although an exploratory application has never been fully denied, certain stipulations are commonly made to protect resources. The reclamation of the exploratory drilling is handled by the CSMG.

The CSMG also manages all new lease applications in the Powder River Basin. An average of 3.5 years is required from the time an application is submitted to the actual lease decision. During that time the CSMG develops mine plans, geologic models, mine costs, and a full EIS. Economists and appraisers are used to develop the fair market value of the lease, which is held confidential. If the lease is granted, the lessee will need to pay right to sign the lease, which sometimes can reach $380,000,000.

The CSMG dedicates most of its time managing and inspecting current leases. For existing leaseholders, a 12.5 percent royalty is paid to the Mineral Management Service (MMS) (federal government agency that manages royalty payments to the U.S.). In addition, the lessee must pay $3 per acre per year to rent the land. The CSMG conducts two types of inspections for existing lease holders – product verification, and a maximum economic recovery (MER). The product verification audit compares what the MMS received in royalties against what the company said it mined. If the numbers are different, the CSMG ensues an investigation. The MER is an inspection to ensure that the maximum amount of coal is being extracted from the area and compares to what the company originally said it would mine. If there is a discrepancy, the loss must be justified or royalties could be assessed. The Wyoming Department of Environmental Quality (DEQ) manages mine reclamation under the authority of the *Surface Mining Control and Reclamation Act*.

Wyoming has the largest federal coal program in the BLM and is the nation's largest producer of coal, with about 34 percent of the nation's coal production. Most Wyoming coal is used for steam generation in the electrical utility industry. Coal production in Wyoming occurs in four areas, including the Powder River Basin, the southernmost portion of which is within the Casper Planning Area. The Casper Planning Area also includes portions of two other coal fields that are presently not producing coal: the Wind River Coal Field and the Goshen Hole Coal Field. Figure 3-6 depicts coal fields within the planning area.

Coal is classified by rank according to the Standards of the American Society for Testing Materials (ASTM). Most Wyoming coals are ranked as bituminous or sub-bituminous. Detailed information regarding coal classification is provided in ASTM D-388. The classification system may be summarized as follows:

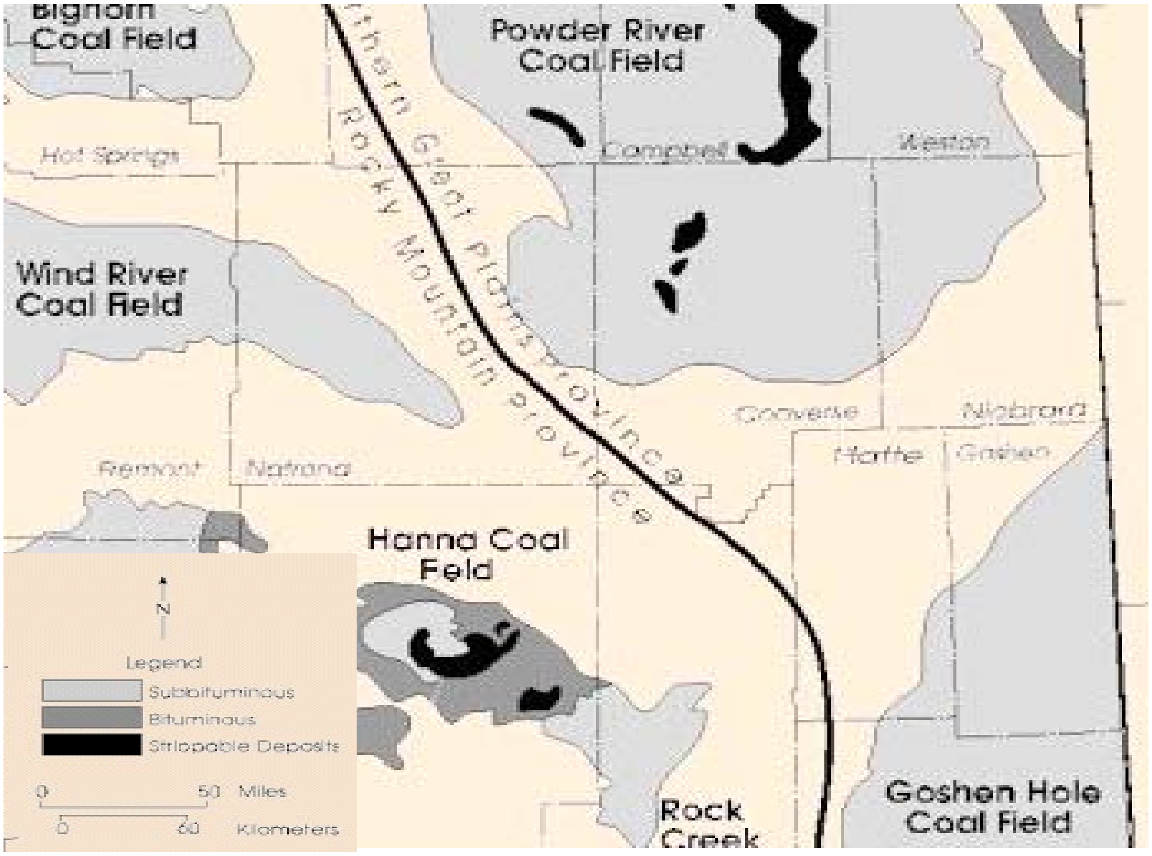



**Figure 3-6. Casper Planning Area Coal Fields**

*(Source: WSGS 2003k)*

I. Anthracitic
- Meta-anthracite
- Anthracite
- Semi-anthracite

II. Bituminous
- Low volatile bituminous
- Medium volatile bituminous
- High volatile "A" bituminous
- High volatile "B" bituminous
- High volatile "C" bituminous

III. Sub-bituminous
- Sub-bituminous "A"
- Sub-bituminous "B"
- Sub-bituminous "C"

The following sections briefly describe the Casper Planning Area coal fields. Figure 3-7 depicts primary coal-bearing formations in Wyoming.

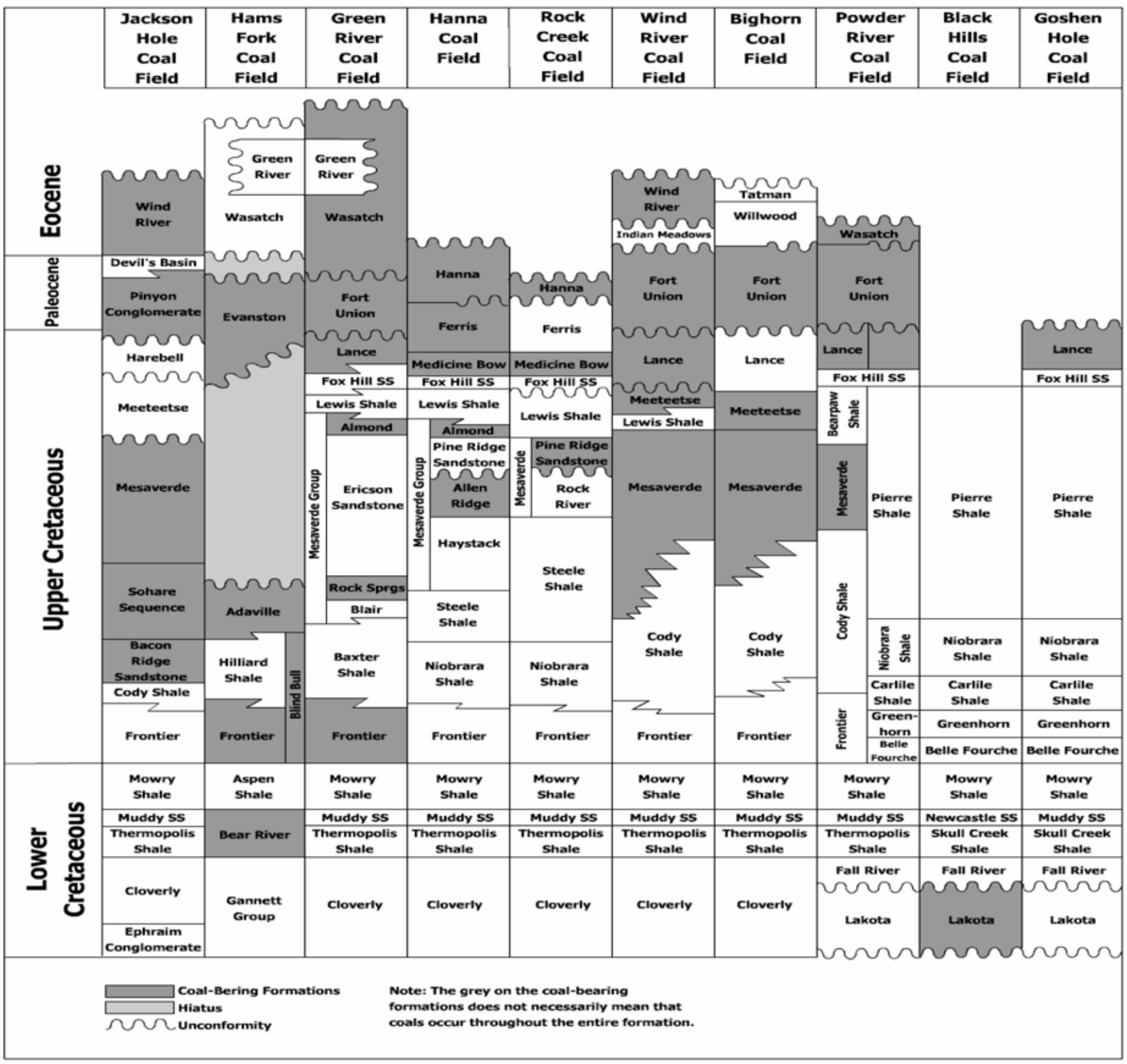



**Figure 3-7. Wyoming Coal-Bearing Formations**

*(Source: UWYO 2003b)*

### *POWDER RIVER COAL FIELD*

The Casper Planning Area overlaps the southern Powder River Basin, which contains some of the thickest and most extensive deposits of low-sulfur coal in the world (MWH 2003). Many of the largest production coal mines in the U.S. are located in the Powder River Basin. All of these mines are surface mines. All of the currently-producing mines, except for one, are located in Campbell County outside of the Casper Planning Area. A part of one large mine, the Antelope Mine, is located within Converse County.

The Wyodak-Anderson coal zone, mined in the eastern Powder River Basin (Flores and Bader 1999) includes the Canyon, Anderson, Wyodak, and Big George splits. At the North Antelope/Rochelle Mine, the Wyodak-Anderson zone is one bed. Moving south, the zone splits into two separate beds which are both mined at the Antelope Mine. The upper split is the Anderson, the lower split is the Canyon. The quality of the coal improves toward the south of the basin enabling the mines near the Converse/Campbell County line to produce a better quality product with more market demand. Production capacity currently exceeds demand (BLM 2003e).

### *GOSHEN HOLE COAL FIELD*

The Goshen Hole Coal Field (Denver Basin) is about 75 miles southeast of the Powder River Basin where coal-bearing rocks are exposed in a topographic basin. Goshen Hole coal is Upper Cretaceous in age from the Lance formation. No coal more than 2.5 feet thick is known to occur in the field, although a gas well in southern Goshen County is said to have penetrated a coal bed 4 to 5 feet thick within 1,000 feet of the surface (BLM 2003g). Because of the thin coal beds at the surface, resource/reserve data are not available from this coal field. The coal is thought to be sub-bituminous (BLM 2003g). No areas of coal development potential have been identified in the Goshen Coal Field in the Casper Planning Area, no current mining is occurring in this area, and no future mining is expected in the time frame of this planning effort.

### *WIND RIVER COAL FIELD*

The Casper Planning Area overlaps the eastern portion of the Wind River Coal Field. Coal in the Wind River Basin of Wyoming is mainly found in the Fort Union formation and subordinately in the Wind River formation. These deposits have low importance in the National Coal Resource Assessment because it is improbable they will be utilized in the next 20 to 30 years (Flores and Keighin 1999). The Fort Union formation is considered a minor coal-bearing formation. Exposed coal is uncommon and thin, seldom reaching 3 feet in thickness, although some beds may reach 5 to 15 feet in thickness and extend for more than 2 miles laterally (Flores and Keighin 1999). Fort Union outcrops occur along the edge of the Wind River Basin in the western part of the planning area in Natrona County. Tertiary coal in the Wind River Basin is generally considered to be sub-bituminous, but analyses are not available to verify its rank or quality (Flores and Keighin 1999). Coal development potential has not been identified in this portion of the Casper Planning Area.

## *3.1.3.1 Historical and Current Production*

Historically, production in the Casper Planning Area has occurred in two locations: the Ross area (north of Glenrock) at the Dave Johnston Mine and at the Antelope Mine in northern Converse County. The first recorded coal production in the Powder River Basin was in 1883 near Glenrock and Douglas, Wyoming. Converse County was producing 31,000 tons of coal from the Inez and Deer Creek mines by 1888 (Flores and Bader 1999). In 1898, the Glenrock Mine, owned by the Glenrock Coal Company, produced 46,270 tons of coal, most of which was shipped out of state (Young 1898). By 1907, coal was the principal mineral product of Wyoming and production was increasing in volume as new railroads reached new fields. In the mid-1950s, geologists identified extensive coal seams a few miles from the town of Glenrock, and a coal-fired power plant was completed there by Pacific Power and Light Company in 1958. From 1960 to 1972, three more power plant units were completed. Glenrock Coal Company's Dave Johnston Mine produced more than 2.9 million tons of coal from the School Seam (University of Wyoming [UWYO] 2003). In 1998, Glenrock Coal Company announced the shut down of the Dave Johnston mine. Coal production ended in 1999 and final reclamation began (UWYO 2003).

The 5,800 acre Antelope property is the southernmost mine in the Powder River coal field. The 18-year-old Antelope Mine was purchased from a PacifiCorp subsidiary by Kennecott Energy Company in 1993. Production increased from 5.7 million tons per year (TPY) in 1992 to 13.6 million TPY in 1997 due to demand for Antelope's high-British Thermal Units (high-BTU) Southern Powder River Basin sub-bituminous coal (Carter 1998). At Antelope, coal from the Anderson and Canyon seams averages about 8,800 BTU/pound with 0.25 percent sulfur, 26 percent moisture, and 5 percent ash. Its Hardgrove grindability index is in the 50 to 65 range. As of 1998, approximately 30 percent of production came from the Anderson seam, which averaged about 25 feet thick. The remainder came from the 30 to 45 foot-thick Canyon seam (Carter 1998). The Antelope Mine was originally conceived as a 12 million TPY mine in the early 1980s, but produced 19 million tons in 1998. The 2001 permitted production capacity at the Antelope Mine was 30 million TPY (BLM 2003d). Table 3-3 lists coal production at the Antelope Mine from 1998 through 2002.

**Table 3-3. Antelope Mine Coal Production, 1998 – 2002**

| Year | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|
| Coal Produced (million tons) | 19.4 | 22.7 | 23.0 | 24.6 | 26.8 |

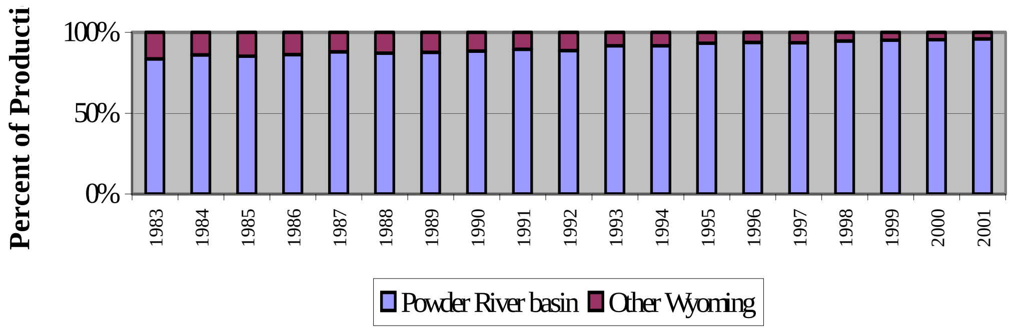
*Source: BLM 2003d*

Antelope Coal Company has applied for the West Antelope Lease By Application (LBA) Tract, which includes approximately 3,542 acres containing approximately 294 million tons of federal coal. The majority of this tract is in Converse County and the Casper Planning Area. Antelope Coal Company operates the adjacent Antelope Mine and proposes to mine the West Antelope LBA Tract as a maintenance tract for the existing mine, if a lease sale is held and they acquire the lease (BLM 2003b).

Powder River Coal Company has applied for the NARO North and NARO South LBA Tracts in Campbell and Converse counties, including a total of approximately 4,503 acres containing approximately 564 million tons of federal coal adjacent to the North Antelope/Rochelle Mine Complex. A small portion of the NARO South LBA extends into Converse County and the Casper Planning Area. The company proposes to mine NARO North and NARO South LBA Tracts as maintenance tracts for the existing mine complex, if a lease sale is held and they acquire the lease (BLM 2003b).

In 2000, 11 surface coal mines in Campbell County, together with one surface coal mine in Converse County produced 323 million tons of coal from the Wyodak coal zone (BLM 2003a). In

2002, Powder River Basin coal production was 354.1 million short tons. Converse County produced 26.2 million short tons, which was 2.2 million short tons more than in 2001 (Mining Engineering 2003). Figure 3-8 compares Powder River Basin coal production to other Wyoming coal production levels from 1983 through 2001.




*Source: BLM 2003a*

**Figure 3-8. Powder River Basin Coal Production Comparison**

Coal mining in the Wind River Basin started in approximately 1870, but Tertiary coal appears to have mined only from one field in about 1900 (Flores and Keighin 1999). There is apparently no record of the amount of coal produced, but the quantity was probably very limited and for local use only (Flores and Keighin 1999).

### 3.1.4 Natron

Natron ($Na_2CO_310H_2O$) is a sodium carbonate mineral related to trona ($Na_3CO_2HCO_3$). It is deposited in saline lake beds in arid environments and is mined near the surface, unlike trona which is mined underground. Natrona County was named for the natron or soda deposits in the county. In the past, natron was mined occasionally in the Casper Planning Area when trona from southwestern Wyoming was not available. Known natron reserves in the planning area occur on private land and sometimes beneath lakes, and natron extraction is difficult (Specht 2003). Currently, there is no natron production from federal minerals in the Casper Planning Area (Specht 2003).

## 3.2 Locatable Minerals

Base and precious locatable minerals in the Casper Planning Area include metals (such as gold, silver, platinum, copper, and chromite), as well as talc, jade, white marble, chemical-grade limestone, bentonite, diamonds, and uranium (BLM 2003c). Uranium was discovered in the Powder River and Wind River Basins during the 1950s. The Casper Planning Area contains sedimentary uranium deposits in the Wind River and Powder River Basins area. Commercial development of the sedimentary deposits of uranium, bentonite, white marble, jade, and chemical-grade limestone deposits has occurred over the past 50 years. Converse, Goshen, Natrona, and Platte Counties contain approximately 4,983 mining claims (BLM 2003c). Figure 3-9 depicts the locations of mining claims within the Casper Planning Area in 2002. It includes locatable minerals such as uranium,

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## Figure 3-9. 2002 Mining Claims within the Casper Field Office Planning Area

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bentonite, jade, feldspar, and limestone. Figure 3-10 shows locatable mineral locations in the planning area.

The *1872 Mining Law* (as amended) governs locatable minerals and other mineral activity in the Casper Planning Area. The BLM must approve any plan of operations or Notice of Intent (NOI) to explore on all public land. Except for areas withdrawn or otherwise segregated from mineral location, all BLM-administered mineral estate remains open for prospecting and development of locatable minerals. Development is subject to the regulations contained in 43 CFR 3809. The following locations in the Casper Planning Area are not open for prospecting or development:

- North Platte River protective withdrawal;
- Federal Aviation Administration Air Navigation Site;
- Pathfinder National Wildlife Refuge;
- Naval Petroleum Reserve No. 3;
- Camp Guernsey;
- Fort Laramie National Historic site;
- Bureau of Reclamation project lands;
- Lands classified under the *Recreation and Public Purposes Act*;
- Lands at Table Mountain, Muddy Mountain, and Fremont canyon (classified under the *Classification and Multiple Use Act*;
- Lands acquired by exchange where mineral rights were acquired; and
- Lands disposed of by sale, pending promulgation of regulations.

Some minerals, such as limestone or building stone, can be classified as either locatable (uncommon variety) or salable (common variety), depending on the characteristics of the deposit. To classify a mineral as locatable (uncommon variety), the 1968 ruling from *U.S. Minerals Development Corp.,* 75 ID 127 (1968) stated that the mineral must meet the following characteristics (Maley 1985):

In 1969, *McClarty V. Secretary of the Interior* (408 F.2d 907, 908) set the following standards to distinguish locatable minerals from salable minerals (Maley 1990):

> "There must be a comparison of the mineral deposit in question with other deposits of such minerals generally.
>
> 1. the mineral deposit in question must have unique property;
> 2. the unique property must give the deposit a distinct and special value;
> 3. if the special value is for uses to which ordinary varieties of the mineral are put, the deposit must have some distinct and special value for such use; and
> 4. the distinct and special value must be reflected by the higher price which the material commands in the market place (or by reduced cost or overhead so that the profit to the claimant would be substantially more)."

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**Figure 3-10. Locatable Minerals and Non-Hydrocarbon Leasable Minerals, Casper Field Office Planning Area**

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Locatable mineral deposits in the Planning Area are summarized in Table 3-4. Mine locations are listed in Table 3-5.

**Table 3-4. Locatable Mineral Deposits, Casper Planning Area**

| Location | Commodity |
|---|---|
| Highland Flats District, Converse County | Uranium |
| East Gas Hills District, Natrona County | Uranium |
| Sweetwater Arch, Natrona County | Jade |
| South Salt Creek and 33 Mile Road, Natrona County | Bentonite |
| Laramie Range, Platte Country | White Marble |
| Hartville Anticline, Platte County | Limestone (chemical grade) |

*Source: BLM 2003b.*

**Table 3-5. Locatable Mineral Mines, Casper Planning Area**

| Permit Number | Operator | Site | Mineral |
|---|---|---|---|
| WYW141460 | Divide Construction | Bass Quarry | Limestone |
| WYW153810 | Imery Marble Inc. | White Marble Quarry | Marble |
| WYW154741 | Imery Marble Inc. | Silvergreen Quarry | Building stone |
| WYW118966 | Power Resources | Highland Mine Sec 24 | Uranium |
| WYW124668 | Power Resources | Highland Mine | Uranium |
| WYW119890 | Power Resources | Smith Ranch Facility | Uranium |
| WYW147770 | Power Resources | Smith Ranch In-situ | Uranium |
| WYW132586 | Black Hills Bentonite | South Salt Creek | Bentonite |
| WYW151023 | Black Hills Bentonite | South Salt Creek | Bentonite |
| WYW150617 | Slate Rock | Brush Creek | Dolomite limestone |
| WYW156504 | John F. Snook | Lone Tree Mine | Jade |
| WYW140590 | Power Resources | East Gas Hills In-situ | Uranium |

*Source: BLM 2003b.*

### 3.2.1 Uranium

Uranium is considered to be the most significant locatable mineral produced in the Casper Planning Area (BLM 2003c). It is mined using surface mining, underground mining, or in-situ leaching (ISL) techniques. The uranium ore, or yellowcake, is shipped to an enrichment facility to improve the concentration of fissionable uranium to a useful level for the application. Uranium is commonly used to provide electricity in the U.S. and abroad, and to power U.S. Navy vessels. The uranium industry is facing stiff competition from foreign sources. The U.S. government's decision to greatly reduce its stockpile has also contributed to a glut of uranium on the market. Only in-situ plants are currently producing in Wyoming, due to the challenging commercial environment (BLM 2003c).

The significant uranium deposits in the Powder River Basin are in Tertiary strata (Stover 1997). Host sandstones for uranium mineralization are the arkosic sandstone units of the upper Paleocene Fort Union formation and lower sandstone units of the Eocene Wasatch formation (Stover 1997). The Wasatch formation is the youngest bedrock unit, with a thickness of as much as 1,400 feet (Molnia and Pierce 1992). Flores and Bader (1999) report a thickness of 1 mile for the Fort Union Formation.

Uranium was first mined in Niobrara County, Wyoming in 1920 for its radium content (WSGS 2002a). Within the Casper Planning Area, uranium was discovered in the Powder River and Wind River basins during the 1950s. Continued exploration for uranium resulted in discovery of additional sedimentary uranium deposits in the major basins of central and southern Wyoming. Uranium production declined in the mid-1960s, but picked up again in the late 1960s and 1970s with the discovery of major uranium deposits in the Powder River Basin, including Christensen Ranch, Smith Ranch, Morton Ranch, and the Highland Mine (Paydirt 1999). Conventional mine production peaked in 1980, then decreased in the early 1980s through the early 1990s when many in-situ mines were developed (Paydirt 1999). Production from conventional mine/mill operations in Wyoming ended in 1992 (Paydirt 1999).

During the 1980s, ISL emerged as an economically and environmentally preferred means for extracting uranium ores in the U.S. (Stover 1997). ISL consists of pumping an environmentally-benign solution of water and sodium bicarbonate down an injection well where it flows through the deposit and dissolves the uranium (WSGS 2002a). In 1996, Rio Algom Mining Corp. (RAMC) began developing a commercial ISL mine at Smith Ranch with a planned annual capacity of 907 tons of uranium (Stover 1997). Development began at Reynolds Ranch, north of the Smith Ranch area, in 1997 to confirm and expand resources of 3,720 tons of U308. In late 2001, two in-situ mining operations were producing uranium in Wyoming, including CAMECO's Highland/Morton Ranch and Smith Ranch operations (WSGS 2002a). In 2002, Power Resources Inc. (PRI) (a subsidiary of CAMECO) was the sole uranium producer in the planning area. PRI's Highlands Flat operation produced 878,069 pounds of uranium that year (State Inspector of Mines 2002).

Wyoming has been the leading producer of uranium in the nation since 1995 (WSGS 2002a). Table 3-6 summarizes the Casper Planning Area's uranium production statistics for 2002. Table 3-7 lists Wyoming in-situ uranium production and operators since1986.

**Table 3-6. Uranium Production By Mine in 2002, Casper Planning Area**

| Operator | Mine | County | Facility | Production (Pounds) |
|---|---|---|---|---|
| PRI | Highland – Smith Ranch Project | Converse | In-situ mine | 878,069 |
| RAMC | Smith Ranch Project (sold to PRI in 2002) | Converse | In-situ mine | 494,000 |
| UMETCO Minerals | Gas Hills Operation | Natrona | Open-pit mine | Final reclamation |

*Source: State Inspector of Mines 2002*

**Table 3-7. Wyoming In-Situ Uranium Production Since 1986**

| Year | Total Production (pounds of yellowcake) | Number of Operations | Operators |
|---|---|---|---|
| 1986 | 59,950 | 2 | Rocky Mountain Energy, Western Nuclear |
| 1987 | Test production only | 3 | Altair Resources, Malapai Resources (Irigary and Christiansen Ranches), Pathfinder Mines |
| 1988 | 923,000 | 1 | Everest Minerals (Highland) |
| 1989 | 1,065,281 | 2 | Malapai Resources, Power Resources (Highland) |
| 1990 | 1,047,813 | 3 | Power Resources, RAMC (S. Powder River Basin), Total Minerals (Irigary and Christiansen Ranches) |
| 1991 | 1,038,559 | 2 | PRI (Highland and Morton Ranch), Total Minerals |
| 1992 | 1,164,080 | 2 | PRI, Total Minerals |
| 1993 | 1,175,000 | 3 | PRI, Total Minerals (Cogema Resources) (Irigary Ranch and Christiansen Ranch) |
| 1994 | 1,153,600 | 3 | PRI, Cogema Resources |
| 1995 | 1,301,800 | 3 | PRI, Cogema Resources |
| 1996 | 1,911,400 | 2 | PRI, COMIN (formerly Cogema) |
| 1997 | 2,231,116 | 3 | PRI, COMIN, RAMC |
| 1998 | 2,327,463 | 3 | PRI, COMIN, RAMC |
| 1999 | 2,760,255 | 3 | PRI, COMIN, RAMC |
| 2000 | 2,072,396 | 2 | PRI, RAMC |
| 2001 | 1,640,669 | 2 | PRI, RAMC |
| 2002 | 1,405,353 | 2 | PRI, RAMC |

*Source: WSGS 2003a*

### 3.2.2 Gypsum

Gypsum is mined at three locations in Wyoming, none of which is within the Casper Planning Area (WSGS 2002b). The WSGS 2001 report on the mineral industry in Wyoming did not identify any important gypsum-producing areas within the Casper Planning Area (WSGS 2001).

### 3.2.3 Bentonite

Bentonite is sodium montmorillonite clay used as a binder in foundry molds, pet litter, drilling mud, iron ore pelletizing, and for other uses (WSGS 2003b). During the Cretaceous, ash from volcanic eruptions dropped into the seas that covered much of Wyoming, forming a sediment as thick as 50 feet. These sediments formed the clay, bentonite (Black Hills Bentonite 2002). Bentonite was first mined on a small scale in Wyoming during the 1880s. More substantial deposits were discovered during the 1920s (Black Hills Bentonite 2002).

Wyoming is the leading producer of bentonite in the U.S. (WSGS 2003b). Wyoming's bentonite production was 4,777,026 short tons in 2001, decreasing to 3,454,582 short tons in 2002 (WSGS 2003b). Black Hills Bentonite Company's operation in east central Natrona County is the major bentonite producer in the Casper Planning Area. Table 3-8 lists 2002 bentonite production statistics for Natrona County.

**Table 3-8. Natrona County Bentonite Production, 2002**

| Operator | Mine | Facility | Production (short tons) |
|---|---|---|---|
| Black Hills Bentonite Corp. | Casper Mill | Bentonite Mill | 117,789 |
| Black Hills Bentonite Corp. | Harry Thorson Plant | Bentonite Mill | 494,000 |
| Black Hills Bentonite Corp. | Mills Plant | Bentonite Mill | 41,949 |

*Source: State Inspector of Mines, 2002*

## 3.2.4 Metallic and Precious Minerals

### *3.2.4.1 Gold*

Past exploration in the Rattlesnake Hills, to the north of Barlow Gap, resulted in the discovery of several significant gold anomalies by the WSGS in 1981 (WSGS 2003e). Follow-up exploration by mining companies resulted in the identification of a low-grade disseminated gold deposit with a resource of 250,000 ounces (WSGS 2003e). This resource was later valued at more than 1 million ounces (WSGS 2003e). Within the Casper Planning Area G&O Mining (Orion Minerals) has maintained 97 lode mining claims in central Natrona County.

### *3.2.4.2 Copper and Iron*

Historically, significant mining of copper and iron occurred in the Casper Planning Area. In the early 1880s, rich deposits of copper were found in the Hartville Uplift. Although successful at the time, these mines have long since been reclaimed. There have been other copper mines on Casper Mountain and in the South Bighorns, located in north central Natrona County. Chromite was mined in the Deer Creek range (part of Laramie range), but these operations have been closed for many years (WSGS 2003d). Converse County copper mining districts include the Deer Creek Copper District, and the La Prele (MinDat 2003). Platte and Goshen County districts include the Hartville iron-copper district (MinDat 2003).

### *3.2.4.3 Precious Minerals*

Nephrite jade was discovered in Wyoming in the early 20$^{th}$ century. The largest jade boulder was 14,000 pounds of low-quality black jade reportedly found in the Prospect Mine at the southern end of the Wind River Mountains (WSGS 2003g). The Casper Planning Area has seen only sporadic development of jade. There are jade claims near Pathfinder Reservoir and a jade deposit at Sweetwater Arch in Natrona County. Currently, the Lone Tree Mine is being developed for jade. No major jade-producing locations have been identified within the Casper Planning Area by the WSGS (WSGS 2001).

In 1975, diamonds were discovered in kimberlite in southeastern Wyoming, south of Laramie (WSGS 2003g). Since then, more than 130,000 diamonds have been recovered from the area south of Laramie (WSGS 2003g). The Casper Planning Area has seen only sporadic development of diamonds. Diamond potential is high for much of the state of Wyoming (Hausel 2003). Although this potential exists for the Casper Planning Area, current development is minimal. No major gemstone-producing locations have been identified within the Casper Planning Area by the WSGS (WSGS 2001).

### 3.2.5 Feldspar

Feldspar, though once an important resource in the planning area, is currently not being produced (WSGS 2003d). In 2001, the WSGS had identified Natrona County as a major feldspar-producing area (WSGS 2001) at the Koch Deposit (MinDat2003).

### 3.2.6 Limestone

Locatable limestone is chemical-grade (as compared to limestone used for aggregate, a salable mineral). It is an important ingredient in cement manufacturing, in emissions control for coal-fired power plants, and as a clarifying agent in the process of refining sugar from sugar beets (WSGS 2003c). In distinguishing between common variety limestone and uncommon variety, *U.S. v. Alaska Limestone Corp. (1982)* stated that "Limestone that is suitable for use in the production of cement is not a "common variety" of mineral." It further stated that "…in order for cement-grade limestone claims to be valid, it is still necessary to show a reasonable prospect that the limestone can be mined, removed, and marketed at a profit in order to satisfy the requirements for discovery under the general mining laws" (Maley 1985). Prior to this case, *U.S. v. Chas. Pfizer & Co, Inc.* (1969) had stated that limestone must contain 95 percent or more calcium and magnesium carbonates for it to be locatable (Maley 1990). In the Casper Planning Area, there is a locatable limestone mine associated with the Hartville Anticline in Platte County (developed by the Divide Construction Company). Figure 3-11 depicts limestone outcrops in the planning area.

### 3.2.7 Building Stone

Locatable building stone has seen minimal production in the Casper Planning Area in recent years. Building stone is manufactured exclusively by Imery's Marble, Inc. which produces stone at the Silvergreen Quarry. Imery's Marble, Inc. operates the only white marble mine in the planning area, in the Laramie Range in Platte Country. The Annual Report of the State Inspector of Mines (2002) reported that Imery's Marble, Inc. produced 76,888 short tons of marble from its quarry in Platte County.

## *3.3 Salable Minerals*

Mineral materials such as sand and gravel, moss rock, flagstone, rock aggregate, riprap, leonardite, and scoria are available on demand for sale or free use within the Casper Planning Area. Materials in all areas are available except for those within 0.25 mile of the North Platte River and those within bald eagle roost areas (BLM 2003c). The Casper Field Office maintains community mineral material sites open to the public to obtain sand, moss rock, and boulders at a reasonable price.

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**Figure 3-11. Limestone Outcrops, Casper Field Office Planning Area**

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According to the *Materials Act of 1947* (as amended) certain mineral and vegetative materials may be disposed either through a contract of sale or a free-use permit (Legal Information Institute 2003b). These types of minerals, also known as salable or mineral materials, include common varieties of sand, stone, gravel, pumice, pumicite, cinders, clay, petrified wood, and other mineral materials. Under the mineral materials program, the BLM manages the exploration, development, and disposal of mineral materials from public lands by sale or free use. Disposal of the minerals is made in conformance with the BLM land use plans. Use authorization includes National Environmental Policy Act (NEPA) compliance and appraisal of the fair market value of the mineral materials. Inspection and production verification are conducted to assure compliance with the terms of the contract or permit, prevention of unnecessary and undue damage to surface resources, and prevention and abatement of unauthorized use.

Some salable minerals, such as building stone and limestone, can be either locatable (uncommon variety) or salable (common variety). To distinguish between the varieties of minerals, the DOI has defined common varieties as follows (Maley 1985):

> "'Common varieties' includes deposits which, although they may have value for use in trade, manufacture, the sciences, or in the mechanical or ornamental arts, do not possess a distinct, special economic value for such use over and above the normal uses of the general run of such deposits. Mineral materials which occur commonly shall not be deemed to be 'common varieties' if a particular deposit has distinct and special properties making it commercially valuable for use in a manufacturing, industrial, or processing operation."

The primary salable minerals in the Casper Planning Area are sand and gravel, limestone, leonardite, riprap and boulders, and clay. Other salable minerals with less significant production levels include decorative stone, flagstone, marble, and clinker. Converse County is a major producing area for leonardite and crushed stone. Natrona County produces construction sand and gravel, feldspar, and crushed stone. Platte and Goshen counties produce crushed stone and construction sand and gravel (WSGS 2001). Table 3-9 lists the active salable mineral sites, the operators, site locations, and commodities produced from federal lands in the Casper Planning Area.

Table 3-10 summarizes salable mineral production in the Casper Planning Area by commodity for fiscal years 2002 and 2003. In 2002, 60 material sales totaled $299,229 from 475,283 tons (BLM 2003b). The Casper Field Office administers the permits and purchases of salable minerals. Table 3-11 displays the types of salable permits issued in fiscal year 2003.

## Table 3-9. Active Salable Mineral Sites, Casper Planning Area (Page 1 of 3)

| Permit Number | Operator | Site | Mineral |
|---|---|---|---|
| WYW140431 | Wyoming Red Rock | Serpentine Quarry | Decorative stone |
| WYW148818 | C.W. Mosteller | Flagstone Quarry | Flagstone |
| WYW147767 | Chapman Const. | Cotton Wood Creek | Gravel |
| WYW139866 | Umetco Minerals | Rattle Snake Quarry | Mineral rip-rap |
| WYW148836 | Rissler & McMurry | Alcova LS Quarry | Limestone for aggregate |
| WYW144014 | Rissler & McMurry | Eagle Canyon | Boulders |
| WYW142519 | Wyoming Wonderstone | Rocky Pass Quarry | Decorative rock |
| WYW106228 | Natrona County Road and Bridge | Grieves Field Pit | Gravel |
| WYW109012 | Natrona County Road and Bridge | Airport Pit | Gravel |
| WYW124663 | Natrona County Road and Bridge | Smokey Gap | Gravel |
| WYW088806 | Natrona County Road and Bridge | Gray Reef Reservoir | Gravel |
| WYW151540 | Natrona County Road and Bridge | Poison Spider Pit | Gravel |
| WYW135324 | Dale Valentine | Deer Creek Pit | Gravel |
| WYW145998 | Guernsey Stone Co. | Sparks Canyon Quarry | Broken limestone and fines |
| WYW145336 | Guernsey Stone Co. | Sparks Canyon Quarry | Broken limestone and fines |
| WYW144744 | Guernsey Stone Co. | West Pit | Broken limestone and fines |
| WYW144745 | Guernsey Stone Co. | West Pit | Broken limestone and fines |
| WYW145334 | Guernsey Stone Co. | Permit #3 fine Quarry | Broken limestone and fines |
| WYW145335 | Guernsey Stone Co. | Permit #3 fine Quarry | Broken limestone and fines |
| WYW146010 | City of Casper | New Balefill | Sand |
| WYW155703 | Goshen County Road and Bridge | Fort Laramie Pit | Gravel |
| WYW121087 | Goshen County Road and Bridge | Lingle Pit | Gravel |
| WYW138857 | Goshen County Road and Bridge | Johnson Pit | Gravel |
| WYW133810 | Goshen County ID | Shale Pit | Gravel |
| WYW133806 | Goshen County ID | Cherry Creek Pit (PH) | Gravel |

## Table 3-9. Active Salable Mineral Sites, Casper Planning Area (Page 2 of 3)

| Permit Number | Operator | Site | Mineral |
|---|---|---|---|
| WYW 133808 | Goshen County ID | Fort Laramie Pit | Gravel |
| WYW144773 | Black Hills Bentonite | Leonardite Mine #3 | Leonardite |
| WYW148325 | BLM - Moss Rock | Notches Dome Pit | Moss rock |
| WYW151026 | BLM - Moss Rock | Clarkson Hill | Moss rock |
| WYW152925 | BLM - Sand Pit | Poison Spider Pit | Sand |
| WYW148825 | Star Trucking | Arminto Test Pits | Gravel |
| WYW151018 | 71 Construction | Sheep Mountain Moss Rock | Moss rock |
| WYW153426 | JTL Group, inc. | Boner Ranch Pit | Gravel |
| WYW153456 | Toby SerVoss | Bass Property | Decorative rock (sandstone and limestone) |
| WYW154362 | P.E. Grosch Construction | Bear Creek Pit | Shale |
| WYW151057 | Jay Collins | Elk Horn Creek Pit | Sand |
| WYW155146 | Mobile Concrete | Trappers Route | Sand and gravel |
| WYW155551 | Hoffman G. Construction | Hoffman Pit | Sand and gravel |
| WYW155182 | Umetco Minerals | Rattle Snake Hills Pit | Rip rap |
| WYW156630 | Retec Group, Inc. | East Borrow Pit | Clay |
| WYW156644 | Retec Group, Inc. | West Borrow Pit | Clay |
| WYW156507 | 71 Construction | Lawn Creek Pit | Moss rock |
| WYW156626 | Casper Jehovah's Witness | Clarkson Hill Moss | Boulders |
| WYW140431 | Retec Group, Inc. | East Borrow Pit 2 | Clay |
| WYW158096 | Natrona County Road & Bridge | Johnson Pit | Gravel |
| WYW158097 | Natrona County Road & Bridge | Arminto Pit | Gravel |
| WYW158098 | Natrona County Road & Bridge | Sun Ranch Pit | Gravel |
| WYW158099 | Natrona County Road & Bridge | Lone Bear Pit | Gravel |
| WYW158100 | Natrona County Road & Bridge | Notches Dome Pit | Gravel |
| WYW158101 | Natrona County Road & Bridge | Rattlesnake Hills Pit | Gravel |
| WYW158102 | Natrona County Road & Bridge | Bear Creek Pit | Gravel |
| WYW158103 | Natrona County Road & Bridge | Deadman Butte Pit | Gravel |
| WYW158104 | Natrona County Road & Bridge | Poison Spider Pit | Gravel |

## Table 3-9. Active Salable Mineral Sites, Casper Planning Area (Page 3 of 3)

| Permit Number | Operator | Site | Mineral |
|---|---|---|---|
| WYW156982 | Rissler & McMurry | Alcova Limestone | Rock aggregate |
| WYW158753 | Goshen County Road & Bridge | Lingle Jones Pit | Gravel |
| WYW158754 | Goshen County Road & Bridge | Fort Laramie Pit | Sand |
| WYW138857 | City of Casper | Balefill sand Pit | Sand |
| WYW151536 | Menter Sand | Wills Quarry Aggregate | Limestone |
| WYW159089 | BLM | Circle Drive Stockpile | Bentonite |
| WYW159090 | Bruce Bummer | Circle Drive Stockpile | Bentonite |

*Source: BLM 2003a*

## Table 3-10. Salable Materials Production

| Resource | Cubic Yards | | Value | |
|---|---|---|---|---|
| | FY 2002 | FY 2003 | FY 2002 | FY 2003 |
| Leonardite | 22,500 | 25,000 | $20,250 | $22,500 |
| Clay | 256,349 | 298,165 | $58,175 | $71,124 |
| Sand and Gravel (including crushed and broken stone) | 101,243 | 45,392 | $79,638 | $31,898 |
| Specialty stone (decorative stone, flagstone, moss rock) | 37 | 122 | $561 | $2,105 |
| **Total** | **380,129** | **439,879** | **$158,354** | **$164,727** |

*Source: BLM 2003c*
FY - Fiscal Year

## Table 3-11. Salable Permits, Fiscal Year 2003

| Types of Sales | Number of Sales |
|---|---|
| Free Use Permits (FUPs) | 34 |
| Negotiable Sale (<300,000 cubic yards per sale) | 27 |
| Competitive Sales (>300,000 cubic yards per sale) | 1 |
| Community Pits | 3 |
| Material Sites Rights-of-Way (not managed by the BLM) | 11 |

*Source: BLM 2003b*
< less than
> greater than

### 3.3.1 Limestone

As noted in section 3.2.6, salable limestone is not of chemical grade. The majority of the limestone in the Casper Planning Area is common variety, salable limestone. Much of the sand and gravel produced in the Casper Planning Area is crushed limestone. Limestone is an inexpensive and abundant resource, found around the Douglas Anticline (south of the town of Douglas) and nearby mountain ranges. Not only is crushed limestone a valuable resource, but also the fines (small particles produced in the crushing process) are used for various construction projects. The utility of this resource results in minimal waste in the production process (Durst 2003). Guernsey Stone Company has several active sites in the planning area where they develop crushed limestone and fines, including the Sparks Canyon Quarry and the West Pit. Other companies developing limestone for aggregate include Rissler and McMurry at the Alcova Quarry, Menter Sand at Wills Quarry, and the Hakalo Quarry. Figure 3-11 depicts limestone locations in the planning area.

### 3.3.2 Aggregates (Sand and Gravel)

The WSGS identified Converse, Platte, and Goshen counties as major sand and gravel producing areas in 2001 (WSGS 2001). Sand and gravel (aggregate) is one of the most widely used salable resources in Wyoming and in the Casper Planning Area. Sand and gravel produced from the planning area is largely used for construction purposes and is necessary for streets, highways, bridges, houses, and buildings (WSGS 2003i). Construction aggregate is the fourth most important (in value) mineral product produced in Wyoming after oil and gas, coal, and trona. On a statewide-scale, the value of construction aggregate is higher than the value of other important minerals such as bentonite, uranium, and gypsum (WSGS 2003i).

Within the Casper Planning Area, sand and gravel is extracted from various pits including Grieves Field Pit, Airport Pit, Sparks Canyon Quarry, Arminto Test Pits. Although the majority of the pits are located in Natrona County, there are also pits scattered throughout other areas. The pits are generally located near county roads to avoid excessive transportation costs (Specht 2003). Materials from some of the smaller pits are used to build roads to oil and gas fields within the planning area (Specht 2003). Companies developing gravel resources include Guernsey Stone Company, Star Trucking, Mobile Concrete, and Natrona County Road and Bridge. In fiscal year 2003, the planning area produced 34,310 cubic yards of sand and gravel, with a total value of $22,258. The amount of sand and gravel the Wyoming Department of Transportation (DOT) extracts from the planning area (through material site rights-of-way) is not included in these figures. Currently, there are 11 materials sites rights-of-way administered by the Wyoming DOT in the planning area.

### 3.3.3 Leonardite

Leonardite or lignite is a low-ranking coal. It is applied to products with a high content of humic acid, and is used as a drilling mud thinner. Leonardite came into use as a replacement for quebracho in 1947 (Black Hills Bentonite 2002). Quebracho is a powdered form of tannic acid extract from the bark of the quebracho tree, used as a high-pH and lime-mud deflocculant. It was imported from South America and used as a drilling mud thinner until import restrictions were placed on it during World War II. Leonardite was also later considered to have some qualities as a fertilizer because of its high humic acid content (Black Hills Bentonite 2002). In 1987, Black Hills Bentonite acquired the reserves and the building of a processing plant near the town of Glenrock, Wyoming, with mineral reserves approximately 10 miles to the north (Black Hills Bentonite 2002). Initially the operation sold to the oil well drilling fluids market, later expanding to the fertilizer and foundry industrial markets.

The WSGS identified Converse County as a major leonardite-producing area in 2001 (WSGS 2001), although leonardite production from Wyoming has decreased slightly during the past two years (BLM 2003f). In fiscal year 2002, there were 22,500 cubic yards of leonardite produced in the planning area, with a value of $20,250. Production levels increased slightly in 2003 to 25,000 cubic yards with a value of $22,500.

### 3.3.4 Other Salable Minerals

Within the Casper Planning Area, there are a number of minerals with insignificant production levels, or that may have the potential to be developed. These include various types of specialty stones (including decorative stone, flagstone, moss rock), marble, and clinker (scoria).

Decorative stone is a rock product (excluding aggregate) that is used for its color or appearance (Harris 1993). Wyoming and the Casper Planning Area contain extensive outcrops of rocks, in a range of colors, that are ideal for quarrying (WSGS 2003j). The red sandstone of the planning area has been used to construct college campus buildings in the state. There are active decorative stone sites at the Rocky Pass Quarry and at the Bass Property operated by Wyoming Wonderstone and Toby SerVoss, respectively. The only flagstone producer in the Casper Planning Area is C.W. Mosteller, which produces at the Flagstone Quarry. Moss rock, decorative limestone, and salable marble have seen minimal activity in the past. In fiscal year 2002, the Casper Planning Area produced a total of 37 cubic yards of decorative stone (worth $561), and in fiscal year 2003 it produced 122 cubic yards (worth $2,105).

Clinker (also known as scoria) is reddish baked and melted rock formed by the natural burning of underlying coal beds. It has been mined in the northeastern part of the planning area in the Powder River Basin of Converse County. Clinker is used for mine haul roads, county roads, and oil and gas well pads and access roads. Currently, there is no scoria production from federal lands, classified as salable, in the planning area.

Currently, Retec Group, Inc. produces clay at the West Borrow Pit, which is primarily used for remediation projects. In fiscal year 2003, there were 298,165 cubic yards of clay produced with a value of $71,124. This value is up from the fiscal year 2002, when 256,349 cubic yards of clay valued at $20,250 were produced. All of the clay is used for remediation clean-up.

Riprap is a form of aggregate commonly used as fill in large construction projects (WSGS 2003i). In fiscal year 2003, 71,200 cubic yards of riprap with a value of $37,100 were produced in the planning area. Currently, there is one competitive riprap contract with UMETCO Minerals on the west end of the Rattlesnake Hills for 500,000 tons (or equivalence in cubic yards) of riprap for mine reclamation projects. Total area authorized in the contract is 41.6 acres.

## *3.4 Abandoned Mines*

More than a century of mining in the Casper Planning Area has left some constructed mining hazards. Extreme physical hazards are common at abandoned mine sites. For hikers, cave explorers, and other recreationists, the hazards are not always apparent and serious injury or death can occur. Common hazards include: open shafts, unstable rock and decayed support structures, deadly gases and lack of oxygen, explosives and toxic chemicals, disorientation, and high walls, open pits, and open drill holes. In 1999, 17 people died at abandoned mines sites in the U.S. (Wyoming DEQ 2002). In addition to physical hazards, abandoned mines can also cause environmental degradation. Abandoned Mine Lands (AML) often contain unmined mineral deposits, mine dumps, and tailings that can contaminate the surrounding watershed and ecosystem (USGS 1999b). Streams that flow near or through AML sites can pick up heavy metals and other contaminants, which can result in a loss of aquatic life (USGS 1999b).

In the spring of 2000, the Casper Field Office began prioritizing and identifying the constructed mining hazards based on the nature of the hazards it presented to people, wildlife habitat, and the environment. The most critical underground mines in the planning area are in the Hartville uplift area of Goshen County. The mine openings at these sites have been capped with metal grates to protect wildlife and humans from falling into the shaft. In addition, there are hazardous mine shafts in the Southern Big Horn Mountains of northern Natrona County, and near Muskrat Creek in Goshen County. The reclamation of these sites is a high priority for the Casper Field Office.

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# 4.0 MINERAL RESOURCE POTENTIAL

Future mineral development in the Casper Planning Area is influenced by the price of commodities, management, laws, and regulations. With all commodities whether they are locatable, leasable, or saleable, the level of resource potential can be difficult to predict, even with extensive geological studies.

## 4.1 Leasable Minerals

### 4.1.1 Non-Coalbed Hydrocarbons

#### 4.1.1.1 Non-Coalbed Hydrocarbon Plays

An oil or gas play is an area, geologic formation, or geologic trend that has good potential for oil or gas development, or is generating interest for leasing and drilling (BLM 2001). A play is defined by the geological properties (such as trapping style, type of reservoir, nature of the seal) that are responsible for the accumulations or prospects (BLM 2003g). Geologic heterogeneity, uneven distribution of resources, and reservoir size variations keep hydrocarbons from being evenly distributed across a play area (BLM 2001). A conventional play contains oil and gas accumulations that have hydrocarbon-water contacts (due to the hydrocarbons being a separate phase and the buoyancy of hydrocarbons in water) and seals that hold or trap the hydrocarbons. Hydrocarbons in conventional plays can be recovered using traditional development and production practices (BLM 2003g). Unconventional, continuous-type plays are pervasive throughout a large area and are not a result of the buoyancy of hydrocarbons as conventional accumulations are. The reservoir rock of a continuous-type accumulation is oil-or gas-charged everywhere. Other characteristics include low reservoir permeability, abnormal pressures, and close association of the reservoir with the source rocks from which hydrocarbons were generated (BLM 2003g).

##### POWDER RIVER BASIN

The plays in the Powder River Basin are both structural and stratigraphic, and occur in three major petroleum source rock and reservoir systems: Pennsylvanian-Permian, Lower Cretaceous, and Upper Cretaceous.

**PLAY 3301. BASIN MARGIN SUBTHRUST.** This play includes petroleum trapped in deformed strata below major thrusts along the basin margins. Geologic data are very limited, and do not allow easy exploration of this play (Dolton and Fox 1995). Although hypothetical, this play is productive in the adjacent Wind River Basin (Dolton and Fox 1995). Reservoirs range in age from Mississippian to Late Cretaceous and include sandstones, carbonates and possibly fractured shales. The play covers about 1,400 square miles on the western and southern margins of the basin. This play is considered to carry a considerable risk with modest overall potential, but it also has the possibility for accumulations of substantial size (Dolton and Fox 1995).

**PLAY 3302. BASIN MARGIN ANTICLINE.** This play is characterized by oil and gas accumulations trapped in large and small anticlines along the southern and western margins of the basin. Exploration of the anticline play has been ongoing for approximately 100 years with discovery of a series of major fields, including Salt Creek, Teapot Dome, Big Muddy, and Lance

Creek. Most were found early in the exploration history of the basin. Exploration in this play is nearing its conclusion, and little potential remains (Dolton and Fox 1995). Future discoveries are likely to be made in small and subtle traps (Dolton and Fox 1995). The major reservoirs are sandstones. The most important are the Cretaceous Frontier, Muddy, and Dakota sandstones, and the Pennsylvanian-Permian Tensleep-Minnelusa sandstone. In some places, fractured shales of Cretaceous age are productive.

**PLAY 3306. FALL RIVER SANDSTONE.** This play is indicated by oil and gas occurrence in stratigraphic traps in the Fall River formation (Dakota Sandstone) of the Lower Cretaceous Inyan Kara Group. The play covers about 14,000 square miles, largely in the east and central part of the basin. Other than production at the western margins of the Dakota wedge from combination traps such as South Glenrock, most of the oil and gas accumulations in the sandstone play occur on the structurally uncomplicated east flank of the basin. Exploration in the play has continued for approximately 30 years and has resulted in the discovery of more than 30 individual pools or fields (Dolton and Fox 1995). The largest accumulation of known recoverable oil is at South Glenrock Creek field. Undiscovered resources in this play are estimated to be modest, and would probably be similar in size to those previously found (Dolton and Fox 1995).

**PLAY 3308. MOWRY FRACTURED SHALE.** This unconventional play is indicated by the occurrence of oil and gas in highly fractured Mowry Shale reservoirs in the deep parts of the basin (Dolton and Fox 1995). The shale is considered to be both a reservoir and a source. The play occupies an area of thermally mature Mowry Shale in the central part of the basin, covering approximately 10,000 square miles (Dolton and Fox 1995). At least six fields in the deeper parts of the basin have shown production from fractured Mowry Shale, usually with productive Muddy Sandstone (Dolton and Fox 1995). A large quantity of in-place hydrocarbons that are relatively dispersed and non-conventional may exist in this play (Dolton and Fox 1995). The play is hypothetical and data were insufficient to permit a satisfactory assessment of recoverable resources (Dolton and Fox 1995)

**PLAY 3311. NIOBRARA FRACTURED SHALE.** This unconventional play is indicated by the occurrence of oil and gas, principally in fractured shale reservoirs of the Niobrara formation. Reservoirs also include some fracture reservoirs of underlying formations. The Niobrara is amenable to horizontal drilling. Conventional drilling has produced modest amounts of oil at West Salt Creek and Smokey Gap. Some production from Niobrara exists in deep parts of the basin; however, the play remains virtually unexplored (Dolton and Fox 1995). The play is hypothetical, and data were insufficient to permit a satisfactory assessment of recoverable resources, which were thought to be large (Dolton and Fox 1995).

### *WIND RIVER BASIN*

The plays in this basin are defined by both structural and stratigraphic traps and occur in Permian, Cretaceous, and Tertiary source rock and reservoir systems (Fox and Dolton 1995).

**PLAY 3504. MUDDY SANDSTONE STRATIGRAPHIC.** This is a stratigraphic play with anticipated entrapment of oil and gas in updip pinchouts of discontinuous Muddy Sandstone bodies (Fox and Dolton 1995). This demonstrated play is heavily explored along the southern margin of the basin. Fields include Austin Creek, Grieve, Grieve North, Sun Ranch, Wallace Creek, and Wild Horse Butte.

**<u>PLAY 3503. DEEP BASIN STRUCTURE</u>.** This is a demonstrated gas play with entrapment in large intrabasin, anticlinal, domal, and fold nose structures within the deep axial portion of the basin (Fox and Dolton 1995). This play is moderately well explored to well explored (Fox and Dolton 1995). Fields include Madden, Boone Dome, Frenchie Draw, Pavillion, and Waltman-Bull Frog. Potential for undiscovered resources may be good in this play. Reserve estimates of many of the currently discovered fields do not include Paleozoic units such as the Madison Limestone, a major reservoir at Madden field (Fox and Dolton 1995). Although the quality of this gas is not good, considerable potential exists for other productive reservoirs, as well as shallower zones, elsewhere in the basin (Fox and Dolton 1995).

### *DENVER BASIN*

The plays in this basin are defined by both structural and stratigraphic traps and occur in Permian and Cretaceous source rock and reservoir systems (Higley et al. 1995).

**<u>PLAY 3908. PERMIAN-PENNSYLVANIAN</u>.** This play covers most of the Denver Basin, excluding areas west of the Basin-Margin Structural play (3907) boundary. Production is located in northeastern Colorado and the Nebraska Panhandle, rather than in Wyoming.

**<u>PLAY 3921. FRACTURED NIOBRARA-GREATER NORTHERN DENVER BASIN OIL</u>.** Oil is produced from fractured Niobrara and commonly commingled with the immediate underlying fractured Codell Sandstone in the greater Denver Basin (Higley et al. 1995). This play is considered to have moderate to low potential throughout the basin. The play area excludes the Silo-Dale Salt-Edge Oil Play (3920) in southeastern Wyoming and is generally defined from Chug Springs field in Platte County, Wyoming south through Laramie County, Wyoming, and into Colorado. This play is probably best represented by the low to moderate production in wells throughout the area (Higley et al. 1995).

### *CASPER ARCH*

The Casper Arch uplift separates the Powder River Basin from the Wind River Basin. The Wind River Basin was partitioned from the remainder of the Rocky Mountain foreland in the late Paleocene by the Casper Arch (Perry and Flores 1997). Isolation from long-distance migration of hydrocarbons from previously downdip areas to the west and southwest occurred earlier, during the late Cretaceous to early Palocene (Perry and Flores 1997). Tepee Flats is a significant ultradeep oil and gas field located beneath the lip of the Casper Arch. The field is separated from the Arch by a major blind basement-involved thrust system that dips northeastward beneath the Arch (Perry and Flores 1997).

Oil and gas development is occurring where the older rocks of the Casper Arch thrust out over the younger sedimentary rocks in the basin. The Cave Gulch Unit is a 440-acre block under development by Barrett Resources Corporation. The Boone Dome project area consists of approximately 1,800 acres under development by Amalgamated Explorations, Inc. Amalgamated Explorations believes the potential for development of significant oil and gas reserves at depth in the Boone Dome project area is good pending evaluation of geologic reports and the results of Barrett Resources' 3D seismic shoot that covered Amalgamated's leasehold (Amalgamated Explorations, Inc. 2004).

#### 4.1.1.2 Non-Coalbed Hydrocarbon Resources

To meet the requirements of the EPCA, the USGS conducted an assessment of undiscovered oil and gas resources in five Rocky Mountain provinces. Two of these, the Powder River Basin Province and the Denver Basin Province, are partially within the Casper Planning Area (USGS 2003a). The USGS assessments were based on the geologic elements of each Total Petroleum System (TPS) defined in a province, including hydrocarbon source rocks (source-rock maturation, hydrocarbon generation and migration), reservoir rocks (sequence stratigraphy and petro-physical properties), and hydrocarbon traps (trap formation and timing) (USGS 2003a).

##### POWDER RIVER BASIN

The USGS identified three TPSs with five assessment units (AUs) within the Powder River Basin portion of the Casper Planning Area (USGS 2002a):

- Mowry TPS
  - Mowry Continuous Oil AU
- Tertiary-Upper Cretaceous CBM TPS
  - Lower Fort Union-Lance Formations AU
  - Upper Fort Union Formation AU
  - Wasatch Formation AU
- Niobrara TPS
  - Niobrara Continuous Oil AU

The USGS has estimated a mean of 16.5 trillion cubic feet of undiscovered gas, a mean of 1.5 billion barrels of oil, and a mean of 86.5 million barrels of total natural gas liquids (USGS 2002a). Most of the undiscovered gas (15.5 trillion cubic feet) is continuous. Of this, about 14.3 trillion cubic feet are estimated to be CBM in the Tertiary-Upper Cretaceous CBM TPS (USGS 2002a). The Cretaceous Biogenic Gas TPS is estimated to contain a mean of 0.78 trillion cubic feet of gas. The Mowry TPS is estimated to contain a mean of 198 million barrels of undiscovered continuous oil. The Niobrara TPS is estimated to contain a mean of about 227 million barrels of undiscovered continuous oil (USGS 2002a). Figure 4-1 depicts USGS oil and gas assessment units in the Powder River Basin. Table 4-1 lists USGS estimates in barrels for the Powder River Basin.

##### WIND RIVER BASIN

The Wind River Basin was assessed in 1996 as holding 935 trillion cubic feet of gas in-place, but was not included in the USGS 1995 National Assessment (Boswell et al. 2002). In the past, the majority of the gas believed to exist within the Wind River basin has been considered not technically recoverable (Boswell et al. 2002). However, according to DOE reports (DOE 2003b), the Wind River Basin could hold significantly more technically recoverable natural gas than reported in response to EPCA.

**Figure 4-1. USGS Oil and Gas Assessment, Powder River Basin Province, Casper Field Office Planning Area**

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## Table 4-1. Estimates of Total Undiscovered Resources, Powder River Basin

| | Oil (MMBO) Mean Estimate | Gas (BCFG) Mean Estimate | Natural Gas Liquids (MMBNGL) Mean Estimate |
|---|---|---|---|
| **Powder River Basin Oil Fields** | | | |
| Conventional resources | 1,131.20 | 739.22 | 44.75 |
| Continuous resources | 424.28 | 424.28 | 25.46 |
| **Powder River Basin Gas Fields** | | | |
| Conventional resources | N/A | 271.80 | 16.31 |
| Continuous resources | N/A | 15,051.13 | 0 |

*Source: USGS 2003a*
BCFG – billion cubic feet of gas
MMBNGL – million barrels of natural gas liquids
MMBO – million barrels of oil
N/A – not available

Using the Gas Systems Analysis Model (GSAM), analyses were conducted to estimate the amount of gas in place that is technically and economically recoverable with current technologies. Roughly 10 percent of the gas in place in the Wind River Basin (120 trillion cubic feet) was determined to be recoverable (National Energy Technology Laboratory [NETL] 2003). GSAM estimates significantly exceed those of the USGS (2002a) and other organizations. USGS estimates are based on extrapolation of current conditions and serve as a basis for predicting the productivity that can be expected from select resource elements. GSAM estimates what could happen if the entire resource was fully developed using the most current technology as a baseline for identifying the most promising research and development avenues.

The GSAM work documented the sensitivity of resource recoverability to technology and price, and found that roughly 11 percent of the technically recoverable resource is economically recoverable at $2.00/million cubic feet wellhead gas price. This expands to 28 percent economically recoverable at $3.50/million cubic feet price (NETL 2003). Technology sensitive analyses show that modest reductions in drilling costs or gains in recovery efficiency, which should be obtainable with continued advances in technology, lead to appreciable gains in the recoverable resource (NETL 2003).

### DENVER BASIN

Three TPSs have been identified within the Denver Basin Province portion of the Casper Planning Area (USGS 2002b): the Permian-Pennsylvanian TPS, the Lower Cretaceous TPS, and the Upper Cretaceous Fractured Niobrara TPS. Permian-Pennsylvanian reservoirs are conventional, with structural traps in limestones and sandstones (USGS 2002b). Using analyses based on the TPSs, USGS mean estimates of petroleum potential in the Denver Basin Province are: 104.23 million barrels of oil; 2,519 billion cubic feet of gas; and 51.81 million barrels of natural gas liquids (USGS 2002b). More than 95 percent of that gas volume is in continuous (unconventional) AUs (USGS 2002b). Figure 4-2 shows USGS-identified TPSs in the Denver Basin.

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## Figure 4-2. USGS Oil and Gas Assessment, Denver Basin Province, Casper Field Office Planning Area

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### *CASPER ARCH*

Estimates of oil and gas potential in the Casper Arch were not identified in the USGS assessment of undiscovered oil and gas resources of the adjacent Powder River Basin Province (USGS 2002a), or in assessments of sub-economic or marginal gas resources for the Wind River Basin (Boswell et al. 2002, NETL 2003). Commercial interests indicate good potential for development of significant oil and gas reserves at depth in the Boone Dome project area (Amalgamated Explorations, Inc. 2004).

## *4.1.1.3 Non-Coalbed Hydrocarbon Occurrence Potential*

The primary occurrence areas for non-CBM hydrocarbons in the Casper Planning Area are in the southern Powder River Basin of Converse and Natrona counties, and in the eastern Wind River Basin of Natrona County. All oil and gas plays defined by the USGS are considered to be areas of high occurrence potential. An estimated 1/3 of lands in the planning area are in this category. The majority (2/3) of the planning area falls outside USGS-designated play areas.

## *4.1.1.4 Non-Coalbed Hydrocarbon Future Activity*

This section summarizes reports from a variety of sources that describe potential future oil and non-CBM gas activity. The numbers used by these sources are assumed to be correct, but have not been independently verified. RFD scenarios for oil and gas development in the Casper Planning Area are expected to be completed by the BLM in spring of 2004.

### *OIL AND NATURAL GAS PRICE ESTIMATES*

The Energy Information Administration (EIA) Annual Energy Outlook (AEO) has projected average world oil prices to increase from $22.01 per barrel (2001 dollars) in 2001 to $25.83 per barrel in 2003, then to decline to $23.27 per barrel in 2005. Rising prices are projected for the longer term, to roughly $25.50 in 2020 and roughly $26.50 in 2025 (EIA 2003a).

After 2002, natural gas prices are projected to move higher as technology improvements prove inadequate to offset the impacts of resource depletion and increased demand (EIA 2003a). Natural gas prices are projected to increase in an uneven fashion as higher prices allow the introduction of major new, large-volume natural gas projects that temporarily depress prices when initially brought on line. EIA projects prices to reach about $3.70 per thousand cubic feet by 2020 and $3.90 per thousand cubic feet by 2025 (EIA 2003a). At $3.70 per thousand cubic feet, the 2020 wellhead natural gas price in AEO 2003 is more than 35 cents higher than the AEO 2002 projection. This is due to a downward revision of the potential for inferred natural gas reserve appreciation and a reduced expectation for technology improvement over time. As demand for natural gas increases, expected technology improvements do not completely offset the effects of resource depletion (EIA 2003a).

### *LEASING*

Leases on lands where the U.S. owns the oil and gas rights are offered at auction at least quarterly. The maximum lease size is 2,560 acres and the minimum bid is $2.00 per acre. An administrative fee of $75.00 per parcel is charged and each successful bidder must meet citizenship and legal requirements. Leases are issued for a ten-year term and a 12.5 percent royalty rate on production is required. Leases that become productive do not terminate until all wells on the lease have ceased production. Many private oil and gas leases contain a Pugh Clause, which allows only the developed portion of the lease to be held by production. However, federal leases have no such clause, allowing one well to hold an entire lease. Since 1996, only lands requested for lease have been offered. Before that, virtually all federal lands available for lease were offered at each sale (BLM 2003g). Appendix A describes oil and gas leasing procedures.

### SEISMIC SURVEYS

Seismic surveys are authorized on BLM administered surface by approval of NOIs to Conduct Geophysical Operations. Over the past eight years, 34 seismic projects were conducted in the Casper Planning Area (BLM 2003c). Large, three-dimensional (3D) seismic acquisition projects have been conducted in areas that have the greatest remaining oil and gas potential in western Natrona County and northern and western Converse County. Some areas in western Natrona County, such as the Cedar Ridge, Arminto, Boone, Dome, and Wallace Creek areas, have been covered by multiple large 3D seismic projects (BLM 2003c). It is unlikely that the planning area will experience an increase in seismic projects (BLM 2003b). It is estimated that the number of seismic projects to be conducted in the reasonably foreseeable future would coincide with the number that has been conducted over the past several years. Three or four seismic projects are likely to be conducted each year in the planning area over the next 20 years. The majority of these projects would probably be 3D projects and cover large areas with a small number of two-dimensional projects (BLM 2003b). Refer to Appendix A for seismic survey procedures. Table 4-2 lists seismic projects in Casper Planning Area counties that were permitted by WOGCC from 2000 through 2003.

**Table 4-2. Seismic Projects Permitted by WOGCC 2000 - 2003**

| | 2000 | | | 2001 | | | 2002 | | | 2003 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| County | Permits | Mile | 3-D (Square Mile) | Permits | Miles | 3-D (Square Mile) | Permits | Miles | 3-D (Square Mile) | Permits | Miles | 3-D (Square Mile) |
| Converse | 1 | 15 | 0 | 0 | 0 | 0 | 2 | 6 | 47 | 1 | 0 | 75 |
| Goshen | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natrona | 5 | 36 | 135 | 2 | 19 | 63 | 4 | 11 | 72 | 0 | 0 | 0 |
| Platte | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Totals** | **6** | **51** | **135** | **2** | **19** | **63** | **6** | **17** | **119** | **1** | **0** | **75** |

*Source: WOGCC 2003*

### *FUTURE ACTIVITY*

In the lower 48 states of the U.S., crude oil production is projected to increase from 4.8 million barrels day in 2001 to 5.3 million barrels per day in 2007, and then to decline to 4.2 million barrels per day in 2025 (EIA 2003b). U.S. natural gas production is expected to increase by 7.3 trillion cubic feet through 2005 (EIA 2003b). The largest increase in domestic natural gas production from 2001 through 2025 is projected to come from the Rocky Mountain region, predominantly from unconventional sources. Rocky Mountain natural gas production is projected to increase by 2.7 trillion cubic feet between 2001 and 2025 (EIA 2003b).

A trend analysis conducted by the Casper Field Office indicates that a total of 2,100 oil and non-CBM gas wells may be drilled on federal, state, and fee minerals in the Casper Planning Area within the next 20 years (BLM 2003c). Most drilling is expected to take place in existing oil and gas fields in the eastern Wind River Basin and the southern Powder River Basin (Salt Creek Field) because the planning area is located in a mature oil and gas-producing region with limited potential for new field discoveries (BLM 2003c).

Overall, oil and gas development in the Powder River Basin, excluding CBM (see section 4.1.2), is expected to decline slowly (BLM 2003a). A sharp increase in permits is not expected until oil prices are above $25 to $30 per barrel for a sustained period. Historical data indicate total non-CBM permits are likely to range from 100 to 300 per year through 2010 (BLM 2003a). They could possibly go as high as 400 per year, although this is not likely unless oil prices are above $25 to $30 per barrel for a sustained period (BLM 2003a). The number of non-CBM wells abandoned through 2010 is expected to exceed the number of non-CBM wells drilled during that same period (BLM 2003a). Figure 4-3 shows numbers of plugged wells from 1997 through 2002.

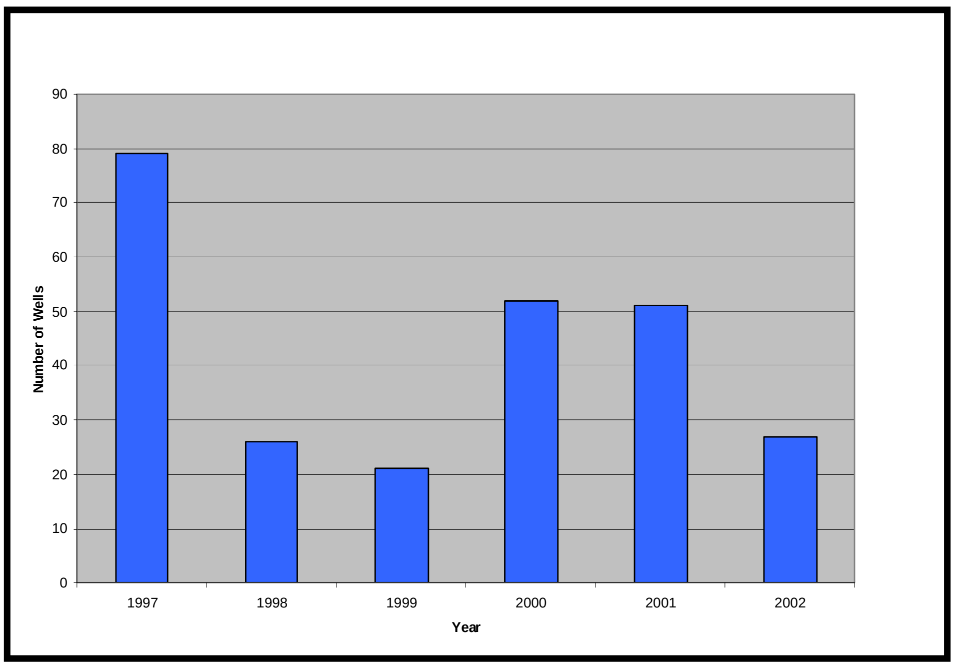



**Figure 4-3. Plugged Wells in the Casper Field Office Planning Area, 1997-2002**
*(Source: BLM 2003b)*

Approximately 250 federal wells have been plugged in the planning area since 1997, an average of 40 wells per year being plugged. The number of wells to be plugged in the foreseeable future is expected to increase significantly as fields reach their economic limits. There are 755 federal stripper wells in the planning area that produce 10 barrels of oil a day or less. Based on BLM's idle well progress report ending October 31, 2002, there are approximately 664 shut-in or temporarily abandoned federal wells in the planning area (BLM 2003b). Most of these stripper wells, shut-in wells, and temporarily abandoned wells are likely to be plugged and abandoned in the next 20 years, and their well pads and access roads reclaimed. This would result in about 7,095 acres being revegetated (BLM 2003b).

Completed wells in the Casper Planning Area have been declining steadily since 1981 (BLM 2003b). An estimated 600 conventional federal oil and gas wells are likely to be drilled in the planning area over the next 20 years based on trend analysis (BLM 2003b). Figure 4-4 graphs federal spudded wells in the planning area, with a projected decline for the next 20 years (BLM 2003b).

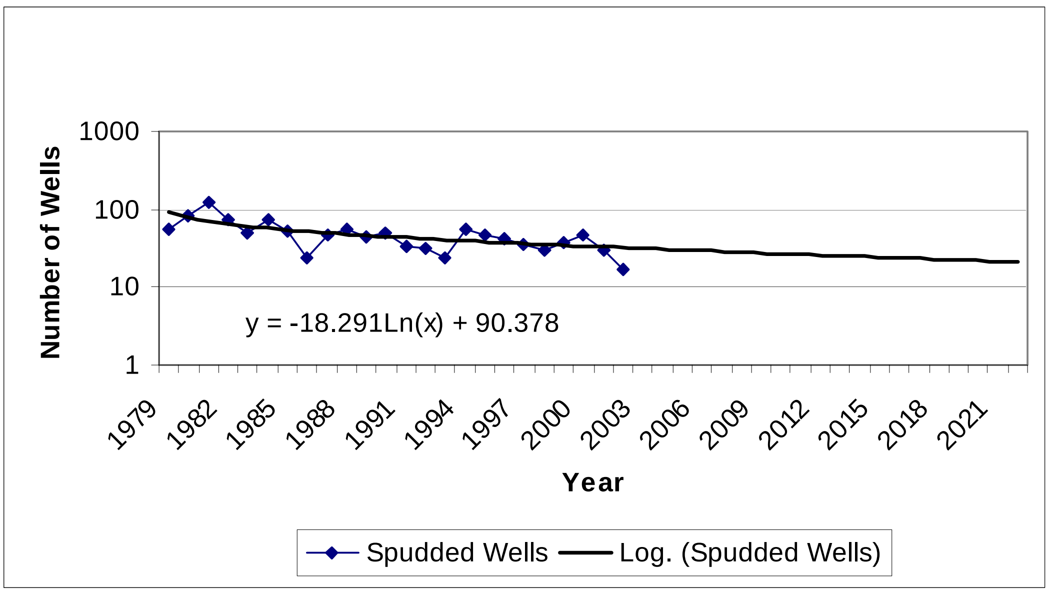



**Figure 4-4. Federal Spudded Wells in the Casper Field Office Planning Area**
*(Source: BLM 2003b)*

In addition to the numbers projected by the trend analysis, 180 federal wells are projected to be drilled in the next ten years by Howell Petroleum Corporation in conjunction with the implementation of carbon dioxide flooding operations at Salt Creek Oil Field (BLM 2003b). Drilling plans include 128 federal wells in Waltman Field in Natrona County over the next ten years and 43 federal wells in Cooper Reservoir Field over the next 5 years (BLM 2003b). From 1980 to 2002, 392 state and fee wells were drilled in the planning area. A similar number of wells are anticipated to be drilled on state and fee lands in the planning area over the next 20 years. Based on trend analysis and known drilling plans, a total of 1,343 conventional oil and gas wells are likely to be drilled on federal, state, and fee minerals in the planning area (BLM 2003b).

The planning area is located in a mature oil and gas producing region with limited potential for new field discoveries. Only a few new fields have been discovered in the planning area in the past several years: Lost Dome field in Natrona County and Diamondback and African Swallow fields in Converse County. Based on prior drilling, about 10 percent (134) of the 1,343 wells are likely to be deep wells and 10 percent (134), exploratory wells (BLM 2003b). The remaining wells are likely to be development wells.

### *ENHANCED OIL RECOVERY*

The injection of carbon dioxide gas into oil reservoirs to enhance recovery has been explored since the early 1980s (BLM 2001). Carbon dioxide injection is of interest where existing waterflood operations in old fields are approaching the end of their productive lives. The Powder River Basin contains several oil fields that are candidates for carbon dioxide injection (BLM 2001). The use of carbon dioxide to enhance oil recovery is currently occurring in the Casper Planning Area and is expected to increase (BLM 2003c). This section summarizes related projects in the planning area.

The DOE's Teapot Dome Oil Field (Naval Petroleum Reserve No. 3), north of Casper, is planned to be the location of a large-scale, region-wide carbon sequestration program (DOE 2003a). DOE's Rocky Mountain Oilfield Testing Center (RMOTC) will link carbon sequestration and enhanced oil recovery through under-ground injection of carbon dioxide gas into older fields to boost production that has declined. Carbon sequestration potential from the program is projected to be at least 2.6 million tons of carbon dioxide annually (almost 700,000 tons of carbon) with a concurrent rise in related oil production of about 30,000 barrels a day, almost six times the current production level (DOE 2003a). The Teapot Dome project is considered to have the potential to be one of the three largest sequestration tests in the world. Its test area encompasses the contiguous Salt Creek Oil Field, for a potential surface area of 50 square miles.

DOE (2003a) expects the RMOTC project to:

- Store large amounts of by-product carbon that would otherwise be vented into the atmosphere;
- Serve as a national field laboratory on sequestration;
- Provide a site for scaling up carbon technologies previously successful in small tests;
- Allow the harvesting of a variety of basic and applied research;
- Serve as an international technology showcase;
- Develop a prototype for large scale sequestration; and,
- Establish a means of evaluating and locating potential sequestration reservoirs throughout the Rocky Mountain region.

As part of this project, Howell Petroleum (a wholly-owned subsidiary of Anadarko) plans to inject about 7,200 tons a day of carbon dioxide gas into the century-old Salt Creek Field, boosting production from about 5,300 barrels a day to 35,000 barrels (DOE 2003a). In 2003, the company completed a 125-mile pipeline extension to move by-product gas there from western Wyoming. The venture is expected to yield important assessments of optimal carbon sequestration levels in depleted oil and gas fields throughout the Rocky Mountain region, and the optimum combination of sequestration and enhanced oil recovery (DOE 2003a). Carbon dioxide injection would begin about 2006 and continue for seven to 10 years. If the pilot flood is successful, all of Salt Creek Oil Field would be subjected to flooding operations, and the life of this field would likely be extended by 20 or 30 years (BLM 2003b). Production is expected to increase by an additional 150 million barrels of oil from the Salt Creek Oil Field.

Some of the identified hazards in the Salt Creek Area of Critical Environmental Concern would expect to continue for the remaining life of the field (BLM 2003b). Hazards such as circulation between wells and other formations would likely decrease as Howell Petroleum re-enters all wells to ensure that they will adequately contain the pressure of the carbon dioxide flood. The pipeline infrastructure would also have to be replaced for the carbon dioxide flood. This would result in fewer oil and produced-water spills (BLM 2003b). After the flood is finished, Salt Creek Oil Field would be reclaimed.

In addition to the Salt Creek and Sussex Oil Fields, a number of other fields have already had some type of pilot carbon dioxide flood or have been mentioned as having potential for a flood. Candidate fields are: Hartzog Draw, House Creek, Rozet, Kitty, Slattery, Meadow Creek, Culp Draw, Triangle U, House Creek, Hilight, Mush Creek, Lance Creek, Mule Creek, Dillinger Ranch, Cole Creek, and Glenrock (BLM 2001). Only the Salt Creek, Cole Creek, and Glenrock fields are within the Casper Planning Area. Existing wellbores are expected to be adequate for use in any carbon dioxide flood, and few new wells will be needed. Some new wells may be required to optimize the pattern of injection or production from a reservoir. Most new wells would be placed on an existing pad (BLM 2001).

In 2001, the BLM analyzed the effects of laying a pipeline (Petro Source Carbon Dioxide Pipeline Project Environmental Assessment) into the Powder River Basin from Baroil in south central Wyoming (BLM 2001). During its initial construction phase, the pipeline was planned to extend to the area of the Salt Creek and Sussex Oil Fields north of Casper (BLM 2001). Petro Source right-of-way was purchased by Howell Petroleum in October 2002. The 16-inch carbon dioxide pipeline and a 12-inch lateral to supply the Salt Creek Oil Field were completed in November of 2003.

### 4.1.2 Coalbed Methane

#### *4.1.2.1 Coalbed Methane Potential Production Sites*

##### *POWDER RIVER BASIN*

The Powder River coalfield contains a large resource of biogenic CBM associated with thick Tertiary coalbeds. The primary targets are the coalbeds of the Tongue River Member of the Fort Union formation and the Wasatch formation (DeBruin et al. 2001). The eastern edge of the target area is the outcrop or subcrop of the Wyodak and equivalent coalbeds. The western edge of the target area is the inferred subsurface extent of the Big George coalbed and the inferred subsurface extent of the Wyodak coalbed and its equivalents (DeBruin et al. 2001).

CBM production is expected to be essentially continuous across the basin. The rank of coal in the Fort Union formation is low over the entire basin, ranging from lignite to sub-bituminous type B, which are the lowest rank coals in the U.S. from which commercial production has been established (Dolton and Fox 1995). The level of thermal maturity is also low in the underlying Upper Cretaceous shales, indicating a relatively low geothermal gradient for the basin. The gases are thought to be biogenic based on carbon isotope analyses, but the timing of the gas generation is questionable. Biogenic gas was undoubtedly generated and accumulated shortly after deposition of the peat during a time of rapid subsidence and deposition. Relatively recent groundwater flow in the basin also probably lead to generation of biogenic gas, particularly along the flanks of the basin (Dolton and Fox 1995). Dolton and Fox (1995) note that the widespread generation of late-stage biogenic gas in association with groundwater flow may be uncertain because of the discontinuous nature of the coal beds. However, Finley and Goolsby (2000) indicate that the coal beds corkscrew like levels in a parking garage, and that many of the splits connect with other splits rather than pinching out.

#### *WIND RIVER BASIN*

The Tertiary coal of the Wind River Basin, at depths of less than 1,000 feet, is normally of low rank and does not show the maturation characteristics needed for significant methane generation (BLM 2003a). Coalbed gases found in the structurally shallow areas of the basin are mixtures of biogenic and thermogenic gases. These coalbeds are immature and were not buried deeply enough to have generated significant quantities of thermogenic gas. Thermal maturity levels of the Fort Union formation vary from very immature in outcrops in the southern part of the basin to mature for the lower, unnamed member in the deeper part of the basin. The higher level of thermal maturity is sufficient to generate thermogenic gas. Less thermally mature coal in shallow parts of the basin may serve as a source of biogenic gas. The Tertiary Fort Union coal in the basin has been considered too deeply buried to be a target for CBM production (Fox and Dolton 1995). The rank of Fort Union coalbeds ranges from sub-bituminous C near the surface to high volatile type A bituminous at a depth of 11,000 feet. Coalbed gases consist mainly of methane but also contain heavier hydrocarbon gases and carbon dioxide of biogenic and thermogenic origin (Fox and Dolton 1995). The Wind River Basin's steep dips limit the area where coalbeds occur at depths favorable for recovery of coalbed gas (a depth of less than 6,000 feet) (Fox and Dolton 1995).

Exploration targets for CBM in the Wind River Coal Field consist primarily of coal beds in the Mesaverde formation, under less than 5,000 feet of cover. Steeply-dipping Lance and Meeteetse coal beds in the Waltman area of the Wind River Coal Field may present additional targets for CBM development (DeBruin et al. 2001). One potential production site, the Wind River Basin – Mesaverde (3550) has been identified in the Wind River Basin Province (Fox and Dolton 1995). Significant coal deposits are in the Upper Cretaceous Mesaverde and Meeteetse formations and Paleocene Fort Union formation. The rank of Mesaverde and Meeteetse coal beds varies from lignite at or near the surface to anthracite at depths of more than 18,000 feet along the deep-basin trough (Fox and Dolton 1995).

### 4.1.2.2 Coalbed Methane Resources

#### *POWDER RIVER BASIN*

In 2000, the WSGS estimated Powder River Basin CBM gas content at 65 cubic feet per short ton of coal, with 37.581 trillion cubic feet of gas in place, and 25.179 trillion cubic feet of recoverable gas resources (DeBruin et al. 2001). Ninety-eight percent of the Powder River Basin's CBM resources are in the Buffalo Planning Area, north of the Casper Planning Area. Converse and Natrona counties, in the Casper Planning Area, contain the remaining 2 percent of the basin's CBM (BLM 2001). Table 4-3 lists 2001 estimates of gas-in-place and recoverable CBM resources in Converse and Natrona counties. More current estimates by county are expected to be developed as part of the Casper Planning Area RFDs in early 2004.

## Table 4-3. Gas-in-Place and Recoverable CBM Resource Estimates, 2001

| County | Gas in Place (BCFG) | Recoverable Cbm Resource Estimate (BCFG) | | |
|---|---|---|---|---|
| | | Low | Moderate | High |
| Converse | 666 | 327 | 426 | 526 |
| Natrona | 24 | 12 | 15 | 19 |

*Source: BLM 2001*
BCFG –billion cubic feet of gas

***WIND RIVER BASIN***

The USGS estimated in 1995 that the Wind River Basin, as a whole, had 0.43 trillion cubic feet of CBM reserves. In 2000, the WSGS estimated Wind River Basin CBM gas content at 59 cubic feet per short ton of coal, with 4.779 trillion cubic feet of gas in place, and 0.956 trillion cubic feet of recoverable gas resources (DeBruin et al. 2001).

### 4.1.2.3 Coalbed Methane Occurrence Potential

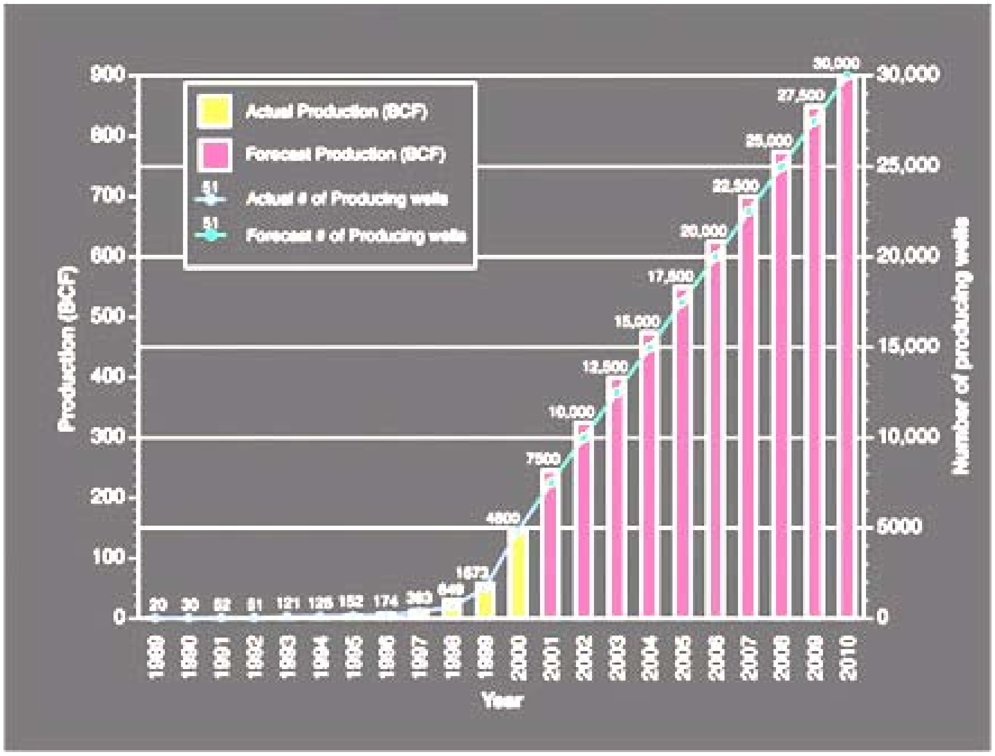
The primary occurrence area for CBM in the Casper Planning Area is expected to be in the southern Powder River Basin. However, no CBM has been realized to date in the portion of the basin that extends into Converse County and the Casper Planning Area (BLM 2003c). Four CBM fields are located in northern Converse County.

### 4.1.2.4 Coalbed Methane Future Activity

CBM production is expected to rapidly increase in the next ten years. Although there are no known current production fields in the Casper Planning Area, the likelihood of such development is high. Figure 4-5 depicts projected increasing yearly production and number of producing CBM wells in the Powder River Basin.

As a result of technological improvements and rising natural gas prices, natural gas production from unconventional sources (tight sands, shale, and CBM) is projected to increase more rapidly than conventional production (EIA 2003b). The RFDs for CBM development in the Casper Planning Area are expected to be completed by the BLM in spring of 2004. This section summarizes presently available sources of information that address future CBM activity.

The Wyoming CBM industry has grown explosively in recent years (UWYO 2003a). Coalbed methane wells in the state increased from 52 in 1992 to 4,800 in 2000. In 2000, the monthly production in the state was 14 billion cubic feet and climbing (UWYO 2003a). A 2001 report indicated that although drilling on federal land had slowed because of a moratorium on permitting, it was expected to increase following the completion of an EIS (DeBruin et al. 2001). As of 2001, completion of several new pipelines had added nearly a billion cubic feet per day of new capacity out of the Powder River Basin. Exploration projects in other parts of the state were ongoing, but development of new CBM fields outside the Powder River Coalfield had not yet occurred (DeBruin et al. 2001).




*Sources: WOGCC production reports, 1998- 2000; WSGS forecast, 2001 – 2010.*

**Figure 4-5. Annual CBM Production, Powder River Basin**

Research reported in the Powder River Basin Oil and Gas Project EIS indicated that about 25 trillion cubic feet of CBM may be recoverable from coal beds in the Wyoming portion of the basin (BLM 2003a). To develop this estimate, data for coals greater than 20 feet thick and occurring at depths greater than 200 feet below the surface were used, assuming a recovery factor of 67 percent (BLM 2003a). Technological advances have increased estimates of recoverable CBM in the U.S. from 90 to 141 trillion cubic feet over 10 years.

A trend analysis conducted by the Casper Field Office indicated that approximately 700 CBM wells may be drilled on federal, state, and fee minerals in the Casper Planning Area within the next 20 years (BLM 2003c). Based on the Powder River Basin Oil and Gas Project EIS, an estimated 1,451 CBM wells (federal, state, and fee) will be drilled over the next 10 years in the Antelope Creek watershed (southern Campbell County and northern Converse County). An estimated 20 percent of these wells (290 wells) are expected to fall within the Casper Planning Area, based on the areal extent of the Antelope Creek watershed in Converse County (BLM 2003c).

In the Wind River Basin, thermogenic and biogenic gases from the Fort Union coal, in the deep and shallow parts of the basin, may serve as potential CBM resources (Flores and Keighin 1999). Much of the infrastructure for coalbed methane transportation, such as gas pipelines, is in place in the basin (Flores and Keighin 1999).

### 4.1.3 Coal

#### *4.1.3.1 Coal Resources*

In 1999, the USGS assessed coal resources in five regions of the U.S., including the Powder River Basin, to determine the quantity, quality, and minability of coal likely to be used within the next 20 to 30 years. Early estimates of the coal resources in the Powder River Basin were based mainly on outcrop data from shallow coal beds in the Tongue River Member (Flores and Bader 1999). In the 1950s, the original resources of the greater-than-3-foot-thick Roland and Smith coal beds (partly equivalent to the Wyodak-Anderson coal zone) were estimated to include more than 45 billion short tons (Flores and Bader 1999). Estimates from the 1970s figured the strippable resource base of the Wyodak-Anderson coal zone south and north of Gillette to be about 19 billion short tons. Another study estimated the resource of the Wyodak-Anderson coal zone to be 100 billion short tons (Flores and Bader 1999). In 1999, the basin-wide resources of the Wyodak-Anderson coal zone were estimated to be as much as 550 billion short tons (Flores and Bader 1999).

Coal resources in the Wind River Basin have been identified as having low importance because it has been considered improbable that the coal would be used in the next 20 to 30 years (Flores and Keighin 1999). The Fort Union coal is not economically mineable because the thick deposits are found only in the deep parts of the Wind River Basin and are not of sufficiently high quality to warrant development of large underground mines (Flores and Keighin 1999). Rail systems are not available for coal transportation from areas of thickest coal accumulation (Flores and Keighin 1999).

#### *4.1.3.2 Coal Future Activity*

Demand for Wyoming coal is expected to increase annually (Gaskill 2002). There is significant potential for increased production from mines in the basin if the demand should increase. Potential exists for increased production from the Powder River Basin, a portion of which is within the Casper Planning Area.

##### *PRICE ESTIMATES*

The sale price of federal coal in Wyoming has fluctuated since 1985 from about $14.00/ton to about $3.00/ton. The average price of federal coal in the Powder River Basin is about $5.50/ton. Current coal prices in *Coal Outlook* range from about $5.50/ton for 8500 BTU coal to $6.76/ton for 8,800 BTU coal. Because of higher coal quality, the southern group of Powder Basin mines, extending into the Casper Planning Area, is experiencing a price differential of about $1.50 to $2.00 per ton over the northern mines (BLM 2003a).

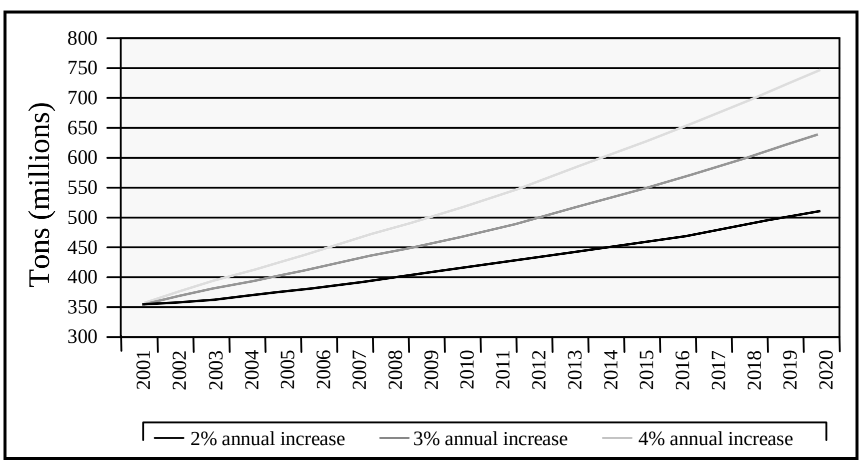
Royalties received from the mining of federal coal in Wyoming have increased since 1983 due to adjustments in royalty rates paid on the coal mined and due to increased production. Prior to 1977, royalty rates were 17.5 or 20 cents per ton. All leases issued after 1977 have a royalty rate of 12.5 percent (one/eight). As of 2003, all leases in the Casper Planning Area have a 12.5 percent royalty rate (BLM 2003a).

### *FUTURE ACTIVITY*

The EIA, an official U.S. government information agency, provided coal predictions in a 2003 draft report (Gaskill 2002). These predictions are summarized as follows:

- As domestic coal demand grows, U.S. coal production is projected to increase from 1,138 million short tons in 2001 to 1,359 million short tons by 2020, an average rate of 0.9 percent per year. By 2025, U.S. coal production is projected to reach 1,440 million short tons.
- Net coal exports are expected to fall, reflecting declining coal demand in some countries and intense competition from other international producers.
- Generation from natural gas, coal, nuclear, and renewable fuels is generally projected to increase through 2025 to meet growing demand for electricity and to offset the projected retirement of existing generating capacity. Fossil steam capacity is expected to be displaced by more efficient natural-gas-fired combined-cycle capacity. The share from coal is projected to decline from 52 percent in 2001 to 48 percent in 2025.
- Industry invests in less capital-intensive and in natural gas generation technologies that burn more cleanly. However, coal is expected to remain the primary fuel for electricity generation through 2025.

The average mine mouth price of coal nationally is projected to decline from $17.59 in 2001 to about $14.40 per short ton (2001 dollars) in 2020, remaining at about that level through 2025. Prices are expected to decline because of increased mine productivity, a shift to western production, and competitive pressures on labor costs. Two major factors that may affect demand for Powder River Basin coal are Clean Air Act Amendments (CAAA) requirements on sulfer dioxide ($SO_2$), which are expected to take effect in 2008, and National Ambient Air Quality Standard (NAAQS) for pollutants ($SO_2$, NOx, Hg, and $CO_2$), that are particulate matter of 2.5 microns or less in diameter ($PM_{2.5}$). In particular, Hg emission reductions could have a considerable effect on future growth of Wyoming coal production. Figure 4-6 depicts Powder River Basin coal production predictions.




*Source: Gaskill 2002*

**Figure 4-6. Powder River Basin Coal Production Predictions**

For coal resources, a progressive increase in stripping ratios and production costs is expected over time. In general, stripping ratios in the Powder River Basin are projected to increase from current ratios of approximately 1.8 to 2.7 bank cubic yards of overburden per ton to 2.0 to 3.5 bank cubic yards of overburden per ton of coal by approximately 2011, with similar increases in the subsequent 10-year period (Hill and Associates, Inc. 2003). Mines in the northern part of the basin would be less affected by stripping ratio increases than mines in the southern part of the basin (BLM 2003f).

Eastern Wyoming's coal mines also offer a potential site for Future Gen, the White House's $1 billion zero-emissions power generation and carbon dioxide sequestration initiative (Bleizeffer 2003). FutureGen is a partnership between private industry and the DOE to build a 275-megawatt, coal-fired power plant that would serve as a prototype for coal gasification and other emerging clean-energy technologies. The plant would turn coal into a hydrogen-rich gas, then fire the hydrogen to generate electricity (Bleizeffer 2003). Air pollutants such as nitrogen oxides and sulfur dioxide would be captured and converted to usable by-products. Carbon dioxide, a major greenhouse gas, would be injected into the ground (Bleizeffer 2003). Converse County is considered by some to offer the best location for FutureGen (Bleizeffer 2003). In addition, the Dave Johnston power plant could be used as a testing facility for the coal gasification process as FutureGen is being built. Converse County also has oil fields for carbon sequestration, and it is close to Powder River Basin coals (Bleizeffer 2003).

### *Leasing*

The FCLAA amended Section 2 of the *Mineral Leasing Act of 1920* to require that all public lands available for coal leasing be offered competitively. Competitive leasing provides an opportunity for any interested party to competitively bid for a federal coal lease. There are several specific requirements that are part of every competitively issued lease. These are: a royalty rate of 12.5 percent for coal mined by surface mining methods, and 8 percent for coal mined by underground mining methods. There is a diligent development requirement that requires commercial quantities of coal to be produced from the lease within 10 years of lease issuance. Failure to meet this requirement results in termination of the lease. A lease can only be issued if the competitive bid for the lease meets or exceeds the BLM's estimate of fair market value.

Federal coal land, as identified in the 1985 Platte River RMP, can be considered for further leasing through the competitive leasing program, emergency leasing, lease modifications, or exchanges. Delineated coal tracts on federal coal lands are available for competitive leasing. Any coal tract not selected for inclusion in a lease sale or any tract included in a lease sale but not sold can be either re-delineated or dropped from further consideration for sale. Coal leasing may be deferred in producing oil and gas fields where coal development would interfere with oil and gas operations and the economic recovery of the existing oil and gas resource. An exception to this would occur where it can be shown that economic recovery of oil and gas has been or will be completed before coal mining operations begin. On coal leases where mining and reclamation plans have been approved, oil and gas drilling and production are authorized where such activities would not conflict with coal mining.

Coal leasing is expected to continue in the Powder River Basin as existing reserves are depleted. The amount of coal being mined from existing leases must be replaced with new reserves for a mine to stay operational. Most of the activity will be in the Buffalo Field Office Planning Area, but some increased production may occur in Converse County in the Casper Planning Area (Gaskill 2002).

Little, if any, activity is anticipated in the Ross area (Dave Johnston Mine) because the market for this quality of coal is limited. Table 4-4 lists the quantity of leasing that would be required during five-year increments for the Powder River Basin mines to remain stable.

**Table 4-4. Future Coal Leasing Requirements, Powder River Basin**

| Year | 2000-2005 | 2006-2010 | 2011-2015 | 2016-2020 |
|---|---|---|---|---|
| Coal (billion tons) | 2.16 | 0.93 | 2.34 | 2.93 |

*Source: Gaskill 2002*

On October 31, 1989, the Regional Coal Team (RCT) recommended that the Secretary of the DOI decertify the Powder River Basin coal area. This decision was based on RCT's belief that the basin did not have high competitive interest for regional leasing. The decertification allowed for leasing through a LBA process by parties interested in coal leasing to replenish reserves that had been mined. The RCT annually monitors the activities in the Powder River Basin and makes recommendations regarding whether the area should become certified again or remain decertified. Decertification remains in effect today and governs the process by which coal leasing is accomplished until the region is certified. Since 1989, the Casper Field Office Solids Group has processed 11 LBAs and is currently working on nine pending applications. Two pending applications (North Antelope South and Antelope Mine) are partially within the boundaries of the Casper Planning Area. Figure 4-7 depicts areas of coal development potential within the Casper Planning Area.

#### *4.1.3.3 Effects of Environmental Regulations*

Two major factors are expected to affect demand for Powder River Basin coal: 1) Clean Air Act Amendments of 1990 on sulfer dioxide requirements expected to take effect in 2008; and, 2) National Ambient Air Quality Standards for $PM_{2.5}$ pollutants expected to affect the market by 2004. Currently applicable air quality regulations affecting coal-fired power plant emissions are those promulgated and implemented under the Phase I implementation program of Title IV of the 1990 Clean Air Act. Under existing court decisions, more restrictive limits for $NO_x$ would be in force by 2004. New regulations for the control of mercury emissions are proposed for development and implementation in the 2004 to 2010 timeframe. The proposed mercury emission regulations are the most likely regulations to have an adverse impact on Wyoming coal production.

More stringent controls would eliminate much of the current advantage of the low sulfur western coal. The current cost advantage of those coals is that they do not require the installation and use of scrubber units of the power plants using this coal. The more stringent emission controls would require the installation of more sophisticated scrubber units on most if not all power plants. Once this capital cost is required, the incremental cost of using the scrubbers is not as great as the transportation costs of Wyoming coal. In addition, the Wyoming coals are thought to contain Hg in a form that is not as easily removed as some other coals. This regulation would likely result in a shift from Wyoming coals to coal from the Illinois and Appalachian areas for utilities in the Midwest and Great Lakes area.

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## Figure 4-7. Coal Development Potential, Casper Field Office Planning Area

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## 4.2 Locatable Minerals

The Casper Planning Area is likely to continue with high production levels of uranium. Most of the uranium in the state is located within the Casper Planning Area (Durst 2003). PRI projects that they will produce about 700,000 pounds of yellow cake in five to 10 years, depending on the market at its Highland flat mine. *Wyoming Geo-notes* (2003) predicts there to be about 1.5 millions of pounds of yellow cake produced every year from 2003 to 2008 in the state. A large portion of that figure is likely to come from the Casper Planning Area.

The WSGS (2003a) predicts that Wyoming's bentonite production will remain stable in the near future. Black Hills Bentonite plans to produce 50,000 tons of bentonite over the next five to 10 years from its Salt Creek and Lone Bear mine in Natrona County. New uses are being identified for bentonite, however no large increase or decrease in bentonite production is anticipated in the foreseeable future (WSGS 2003a).

Other locatable mineral commodities including gypsum, limestone, feldspar, flagstone, marble, metals, jade, emeralds, and diamonds are subject to market conditions that are not easily forecast. Like other minerals, locatable minerals in the Casper Field Office could see a growth rate similar to the growth of Wyoming's economy. In addition, Wyoming has large gypsum and locatable limestone resources both of which are capable of supporting additional production.

Diamond potential is high for the state of Wyoming as a whole, except for in the Yellowstone area (Hausel 2003). A large portion of southern Wyoming and almost all of central and northern Wyoming remain unexplored for diamonds. Although this potential exists for the Casper Planning Area, current development is minimal. There is no current emerald activity, but as with diamonds, it is possible that future development could occur.

## 4.3 Salable Minerals

Of the salable minerals in the Casper Planning Area, sand and gravel are likely to have the largest demand as these materials are fundamental to many construction projects. The Casper Field Office anticipates occasional requests for new sand and gravel permits from government and private entities, depending on local demand, along with occasional requests for exploration authorizations for sand and gravel (Durst 2003).

Other salable minerals including leonardite, riprap, clay, decorative stone, marble, flagstone, and clinker will most likely see a growth rate similar to the growth of Wyoming's economy. Because salable minerals represent such an important resource for everyday life, it is likely that there will be a steady demand. Nonetheless, extensive geologic studies of these materials have not been conducted and predicting future demand and occurrence is difficult.

## 4.4 Mineral Potential Summary

Potential mineral occurrence and development potential in the Casper Planning Area for leasable minerals is associated with coal, oil and gas, and CBM. Potential occurrence and development of locatable minerals is associated with uranium and bentonite. Potential occurrence and development for salable minerals is associated with sand and gravel, building stone, scoria, and limestone. Levels of potential and certainty for these minerals, as identified in BLM Manual 3031, have not been identified for the presence or occurrence of minerals in the Casper Planning Area.

The Casper Planning Area is likely to continue with high uranium production levels. Most of the uranium in the state is located within the Casper Planning Area (Durst 2003). PRI projects production of about 700,000 pounds of yellow cake in five to 10 years, depending on the market. *Wyoming Geo-notes* (2003) predicts about 1.5 millions of pounds of yellow cake produced every year from 2003 to 2008 in the state. A large portion of that figure is likely to come from the Casper Planning Area.

As a result of technological improvements and rising natural gas prices, natural gas production from unconventional sources (tight sands, shale, and CBM) is projected to increase more rapidly than conventional production (EIA 2003b). Approximately 700 CBM wells may be drilled on federal, state, and fee minerals in the Casper Planning Area within the next 20 years (BLM 2003c). Based on the Powder River Basin Oil and Gas Project EIS, an estimated 1,451 CBM wells (federal, state, and fee) would be drilled over the next 10 years in the Antelope Creek watershed (southern Campbell County and northern Converse County). An estimated 20 percent of these wells (290 wells) are expected to fall within the Casper Planning Area, based on the areal extent of the Antelope Creek watershed in Converse County (BLM 2003c).

A total of 2,100 oil and non-CBM gas wells may be drilled on federal, state, and fee minerals in the Casper Planning Area within the next 20 years (BLM 2003c). Most of the drilling is expected to take place in existing oil and gas fields in the eastern Wind River Basin and the southern Powder River Basin, as the planning area is located in a mature oil and gas-producing region with limited potential for new field discoveries (BLM 2003c). Overall, oil and gas development in the Powder River Basin, exclusive of CBM, is expected to decline slowly (BLM 2003a), although the Powder River Basin contains a large number of oil fields that are candidates for carbon dioxide injection (BLM 2001). The use of carbon dioxide to enhance oil recovery is currently occurring in the Casper Planning Area and is expected to increase (BLM 2003c).

Two major factors are expected to affect demand for Powder River Basin coal: 1) Clean Air Act Amendments of 1990 on sulfer dioxide, expected to take effect in 2008; and 2) NAAQS for $PM_{2.5}$ pollutants expected to affect the market by 2004. New regulations for the control of mercury emissions are proposed for development and implementation in the 2004 to 2010 timeframe. The proposed mercury emission regulations are the most likely regulations to have an impact on Wyoming coal production. More stringent controls would eliminate much of the current advantage of the low sulfur western coal. In addition, a progressive increase in stripping ratios and therefore production costs is expected over time. Mines in the northern part of the Powder River Basin would be less affected by stripping ratio increases than mines in the southern part of the basin (BLM 2003f).

The Casper Planning Area is likely to continue with high production levels of uranium. Bentonite production is expected to remain stable in the near future. Other locatable mineral commodities including gypsum, limestone, feldspar, flagstone, marble, metals, jade, emeralds, and diamonds are subject to market conditions that are not easily forecast. They could grow at a similar to the growth of Wyoming's economy.

Of salable minerals, sand and gravel are likely to have the largest demand in the planning area. Other salable minerals such as leonardite, clay, decorative stone, marble, flagstone, and clinker are likely to see a growth rate similar to the growth of Wyoming's economy.

## 5.0 RECOMMENDATIONS

No recommendations or stipulations have been developed at this time. However, appropriate recommendations relating to management of the future development of mineral resources within the Casper Planning Area will be developed during the resource management planning process.

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# APPENDIX A

# OIL AND GAS OPERATIONS

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# APPENDIX A OIL AND GAS OPERATIONS

The operations information in this appendix was prepared for the Bureau of Land Management (BLM) as part of the *Mineral Occurrence and Development Potential Report* for the Rawlins, Wyoming Planning Area (ENSR 2003). It has been shortened and edited for use in this report. Oil and gas operations on public land are authorized by the *Mineral Leasing Act of 1920* (as amended), Federal Land Policy and Management Act, and implementing regulations in 43 Code of Federal Regulations (CFR) 3000 and 2800, and BLM manuals in the 2800, 3000, and 9100 series.

### 1.0 GEOPHYSICAL EXPLORATION

Oil and gas reservoirs are discovered by either direct or indirect exploration methods. Direct methods include mapping of surface geology, observing seeps, and gathering information on hydrocarbon shows observed in drilling wells. Indirect methods, such as seismic, gravity, and magnetic surveys, are used to delineate subsurface features that are not directly observable, but that may contain oil and gas.

## 1.1 Gravity Surveys

Gravity surveying uses micro-variations in the Earth's gravitational field, caused by the differences in rock densities, to map subsurface geologic structures. These surveys are generally of low resolution due to the many data corrections required (e.g., terrain, elevation, latitude, etc.) and to the complexity of subsurface geologic structures. The instrument used for gravity surveys is a small portable device called a gravimeter. Generally, measurements are taken at many points along a linear transect and the gravimeter is transported either by backpack, helicopter, or off-road vehicle. Surface disturbance associated with gravity prospecting is minimal.

## 1.2 Geomagnetic Surveys

Magnetic prospecting is commonly used for locating metallic ore bodies, but may also be used in oil and gas exploration. Magnetic surveys use a magnetometer to detect small variations in the Earth's magnetic field caused by mineralization or lithologic variations in the Earth's crust. These surveys can detect large trends in basement rock and the approximate depth of those basement rocks. However, they generally provide little specific data to aid in petroleum exploration. Many data corrections are required to obtain reliable information, and maps generated often lack resolution and are considered preliminary. Magnetometers vary in size and complexity. Most magnetic surveys are conducted from the air by suspending a magnetometer under an airplane. Magnetic surveys conducted on the ground are nearly identical to gravity surveys in that surface disturbance is minimal.

## 1.3 Reflection Seismic Surveys

Reflection seismic prospecting is the most popular indirect method currently used for locating subsurface structures that may contain hydrocarbons. Seismic (shock wave) energy is induced into the earth using one of several methods at a location called a source point or shot point. As the waves travel downward and outward, they encounter rock strata that transmit seismic energy at different velocities. As the wave energy encounters the interfaces between rock layers that transmit seismic energy at different velocities, some of the seismic energy is reflected upward and some of the energy continues down into the earth. Sensing devices, called geophones, are placed on the surface to detect these reflections of energy. The geophones are wired in groups and are connected to a data recording truck that stores the data. The time required for the shock waves to travel from the source point down to a given reflector and back to the geophone is related to depth. After the data are acquired, the digital information is processed with a computer. The end product of the seismic processing is a seismic section that presents the strata or structures below the surface. Figure 1 depicts the seismic survey process.

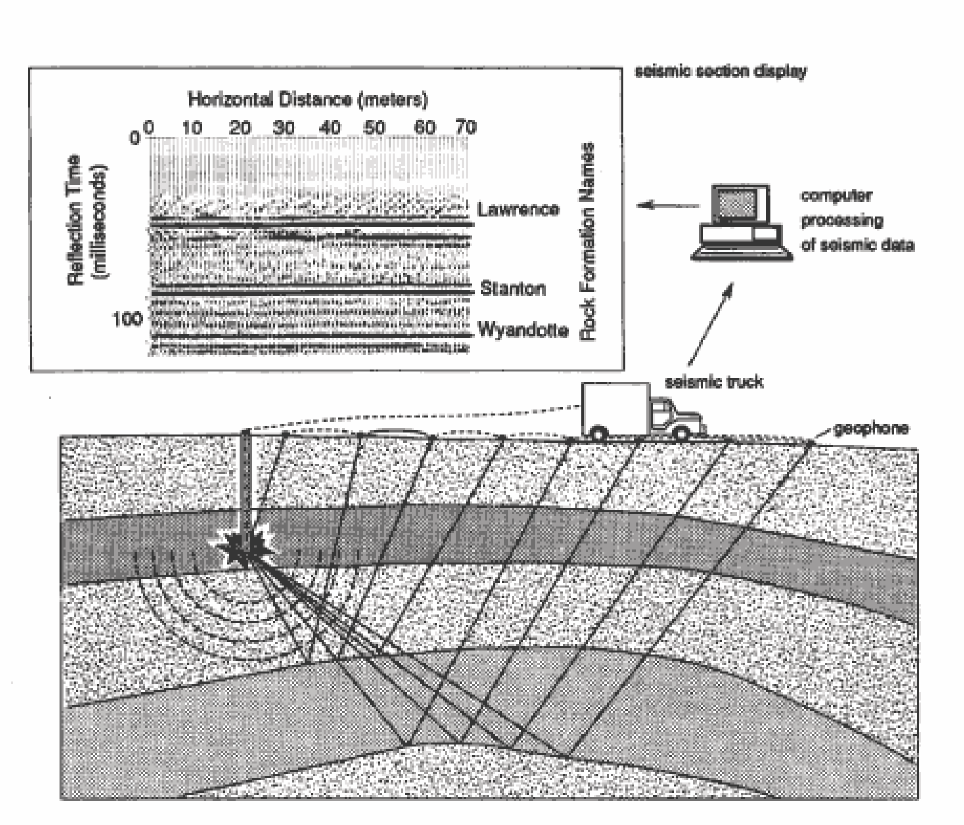



**Figure 1. Seismic Survey Process**

The seismic section is an image of the reflected seismic energy and is not the same as a geologic cross-section that is constructed from data derived directly from wells or outcrops. For onshore oil and gas exploration, there are two methods used to create the seismic energy: vibroseis and shot point. Vibroseis uses hydraulic actuated devices called vibrator pads mounted on trucks to thump on the surface of the ground to create shock wave energy. Usually four to five thumper trucks are used, each equipped with 4-foot-square vibrator pads. At a location called the source point, the trucks are spaced at specified intervals and the vibrator pads are simultaneously triggered to vibrate or thump on the ground. The thumping lasts for 10 to 30 seconds. The information is recorded and then the trucks move to the next source point and the process is repeated. As the trucks move to the next source point, groups of geophones are picked up and moved to the end of the line. Less than 50 square feet of surface area is required to operate the equipment at each source point. The geophone groups are transported by vehicle when moved, but have to be laid out and picked up by hand.

The shot-point method of creating shock wave energy uses truck-mounted drills that drill small-diameter holes to depths of up to 200 feet. Four to 12 holes are drilled per mile of line. Usually, a 50-pound explosive charge is placed in the hole, covered, and detonated. In rugged topography, a portable drill is sometimes carried in by helicopter. Charges are placed in the hole as in a truck-mounted operation. Another portable technique is to carry the charges in a helicopter and place the charges on wooden sticks, or lath, approximately 3 feet aboveground. The charges weigh 2.5 to 5 pounds. Usually 10 charges in a line on the ground are detonated at once.

In remote areas where there is little known subsurface data, a series of short seismic lines may be required to determine the attitude of subsurface formations. Seismic lines are aligned relative to the regional structure to make seismic interpretation more accurate. In seismic surveys, several seismic lines are shot and the distances of the lines and the spacing between the lines are predetermined based on the purpose of the survey. The seismic lines are often separated on a 1- to 2-mile grid spacing. Spacing of the lines is often changed to 0.25 mile on a 1-mile grid before the results will significantly affect the investigation. At predetermined source points, short cross-spreads can be laid out perpendicular to the main line to obtain higher accuracy in the survey.

A variation of this technique is the three-dimensional (3D) seismic profile survey. The methods of generating the seismic waves are the same as those used in conventional seismic surveys. This type of survey differs from the more common two-dimensional survey in the greater number of datapoints and the closer spacing of the lines. Three-dimensional seismic surveys are more computer intensive in the processing of the data, but they result in a more detailed and informative subsurface image (with an accompanying higher cost). The orientation and arrangement of the components in 3D seismic surveys are less tolerant of adjustments to the physical locations of the lines and geophones, but they can be more compact in aereal extent. Three-dimensionsal surveys are commonly used in established field areas to help better define structure, stratigraphy, and movement of fluids between wells or used to focus on a promising exploration target in order to lessen risk in locating a exploratory drill location. A typical seismic operation conducting a shot-point survey may utilize a 10- to 15-person crew operating five to seven trucks.

Under normal conditions, 3 to 5 miles of line can be surveyed each day using the shot-point method. The vehicles used for a drilling program include several heavy truck-mounted drill rigs, water trucks, a computer recording truck, several light pickups or stake-bed trucks for the surveyors, shot hole crew, geophone crew, permit person, and party chief. Public roads and existing private roads and trails are used when available. Off-road cross-country travel may be necessary to conduct the survey. Road graders or bulldozers may be required to provide access to remote areas. Concern about unnecessary surface disturbance has caused government and industry to use care when planning surveys. As a result, earth-moving equipment is now only rarely used in seismic exploration work. Several trips a day are made along a seismic line; this usually establishes a well-defined two-track trail. The repeated movement back and forth along a line (particularly the light pickups) creates a new trail. In some areas, in order to reduce impacts, crews are instructed to deviate from straight routes and not to retrace the same route. This practice has, in some cases, prevented the establishment of new trails and has reduced impacts. Drilling water, when needed, is usually obtained from the nearest source.

Each of these methods has inherent strengths and weaknesses and the exploration team must decide which method is the most practical with regard to surface constraints (such as topography), that will still produce information that can be useful for the particular study. Extensive computer processing of the raw data is required to produce a useable seismic section from which geophysicists interpret structural relationships to depths of 30,000 feet or more. The effective depth of investigation and resolution are determined to some degree by which method is used. In the past 20 years, the technology has progressed so that better resolution has been obtained from greater depths and structures hidden beneath salt layers or overthrust blocks are more readily discernable.

## 1.4 Permitting Geophysical Surveys

Geophysical operations on and off an oil and gas lease are reviewed by the federal surface management agency (SMA), which can include the BLM, Bureau of Reclamation, or U.S. Forest Service (USFS), as appropriate. Good administration and surface protection during geophysical operations is accomplished through close cooperation of the operator and the managing agency. In the process of permitting geophysical surveys, the responsibilities of the geophysical Operator and the Field Office (FO) Manager during geophysical operations are as follows:

*Geophysical Operator* – An operator is required to file with the FO Manager a “Notice of Intent to Conduct Oil and Gas Exploration Operations” or NOI. The NOI will include a map showing the location of the line, all access routes, and ancillary facilities. The party filing the NOI will be bonded. A copy of the bond or other evidence of satisfactory bonding shall accompany the NOI. For geophysical operation methods involving surface disturbance, a cultural resources survey also may be required. A pre-work field conference may be conducted. Earth-moving equipment will not be used without prior approval. Upon completion of operations, including any required rehabilitation, the operator is required to file a Notice of Completion.

*FO Manager* –The FO Manager contacts the operator after the NOI is filed to apprise the operator of the practices and procedures to be followed prior to commencing operations on BLM-administered lands. The FO Manager is responsible for compliance with all applicable laws, including NEPA, and for considering what effect a project could have on the human environment. Then FO Manager completes a final inspection and notifies the operator that the terms and conditions of the NOI have been met or that additional action is required. Consent to release the bond or termination of liability will not be granted until the terms and conditions have been met.

BLM Manual Handbook H-3150-1 establishes procedures for processing Notices of Intent to Conduct Oil and Gas Geophysical Exploration Operations (NOI), and conducting oil and gas geophysical exploration on federal lands administered by the BLM in the lower 48 states. It describes the functions and responsibilities of the BLM as they pertain to authorization of oil and gas geophysical exploration.

## 1.5 State Standards for Seismic Surveys

In Wyoming, seismic survey operators must comply with Wyoming Oil and Gas Conservation Commission (WOGCC) rules. The standards for seismic operations are found in WOGCC Rules, Chapter 4, Section 6, Geophysical/Seismic Operations. The rules cover permitting, bonding, shot-hole drilling, and shot-hole plugging.

## 1.6 Mitigation of Conflicts with other Resources or Activities

Seasonal restrictions may be imposed to reduce conflicts with wildlife, watershed damage, and hunting activity. The most critical management practice is compliance monitoring during and after seismic activity. Compliance inspections during the operation ensure that stipulations are followed. Compliance inspections upon completion of work ensure that the lines are clean and drill holes are properly plugged.

# 2.0 FLUID MINERALS LEASING

The *Mineral Leasing Act* provides that all public lands are open to oil and gas leasing unless a specific order has been issued to close an area. Leasing procedures for oil, non-coalbed methane (non-CBM) gas, and CBM are the same. Based on the *Federal Onshore Oil and Gas Leasing Reform Act of 1987*, all leases must be exposed to competitive interest. Lands that do not receive competitive interest are available for noncompetitive leasing for a period not to exceed two years. Competitive sales are held at least quarterly and by oral auction. Competitive leases are issued for a term of five years and noncompetitive leases are issued for a term of 10 years. If the lessee establishes hydrocarbon production, the competitive and noncompetitive leases can be held for as long as oil or gas are produced. The federal government receives yearly rental fees on non-producing leases. Royalty on production is received on producing leases, one-half of which is returned to the State of Wyoming.

# 3.0 DRILLING PERMIT PROCESS

## 3.1 Permitting

A federal lessee or operator is governed by procedures set forth by the Onshore Oil and Gas Order No. 1, "Approval of Operations on Onshore Federal and Indian Oil I and Gas Leases," issued under 43 Code of Federal Regulations (CFR) 3164. Operating Order No. 1 lists the following as pertinent points to be followed by the lessee or operator: notice of staking (NOS); application for permit to drill (APD), which includes a multi-point surface use and operations plan; approval of subsequent operations; well abandonment; conversion to water well; responsibilities on privately-owned surface; and reports and activities required after well completion. The permitting process for drilling is the same for oil, non-CBM gas, and CBM.

The lessee or operating company selects the location of a proposed drill site. The selection of the site is based on well location and spacing requirements, the subsurface geology as interpreted by the operator's geoscientists, and the topography. Well location and spacing requirements are established by the WOGCC. Each well is to be drilled within a given distance from the center of a legal subdivision (such as a quarter/quarter of a section or quarter section, depending on the spacing assigned to the particular area). A proposed location may be moved within the tolerance established by rule or outside the designated tolerance with a location exception granted by the WOGCC.

There are two procedural options for obtaining approval to drill a well. After an operator decides to drill a well, the operator must decide whether to submit NOS or an APD. The NOS process, if properly planned and coordinated, can expedite permit approval. In either case, no surface activity can be conducted until the well is approved by the BLM. Figure 2 depicts the NOS and APD processes.

| | NOS OPTION | APD OPTION |
|---|---|---|
| Step I | Staking Notice Submitted | Application for Permit to Drill |
| Step II | Onsite Inspection | Onsite Inspection |
| Step III | ADP Submission and Processing | ADP Review and Processing |

| | APPROVED DRILLING PLAN |
|---|---|
| Step IV | Operations Conducted Under an Approved Plan |
| Step V | Production/Dry Hold-Subsequent Actions |
| Step VI | Abandonment |

**Figure 2. Federal Permitting Process**

The NOS process is as follows:

- The operator submits an outline of the plan to the BLM, which includes a location map and sketched site plan. The NOS is then used as a document to review any conflicts with known critical resource values.
- The BLM and operator conduct an on-site inspection. The NOS provides preliminary site-specific information, which will be reviewed during the on-site inspection. As a result of this inspection and review, additional information required for the APD process is identified.

An APD is submitted based on the findings of the inspection and review of potential conflicts. The APD procedure is as follows:

- The operator may submit a completed APD in lieu of the NOS.
- A field inspection is held with the operator and any other interested party. The purpose of the field inspection is to evaluate the operator's plan, assess the situation for possible impacts, and to formulate resource protection stipulations.
- The APD is reviewed with respect to the field inspection.

To lessen environmental impacts, a site may be moved, reoriented, or reconfigured, within certain limits, at the site inspection. The proposed access road also may be rerouted. Normally, site-specific mitigations are added to the APD for protection of surface and subsurface resource values in the vicinity of the proposed activity. The BLM is responsible for preparing environmental documentation necessary to satisfy the National Environmental Policy Act (NEPA) requirements and provide any mitigation measures needed to protect the affected resource values.

Consideration also is given to the protection of groundwater resources. When processing an APD, the BLM geologist is required to identify the maximum depth of usable water as defined in Onshore

Oil and Gas Order No. 2 (BLM 1988). Usable water is defined as that water containing 10,000 parts per million (ppm) or less of total dissolved solids (TDS). Water quality is protected by running surface casing to a depth prescribed by the geologist. Determining the depth to fresh water requires specific water quality data in the vicinity of the proposed well or geophysical log determination of water quality. Information on water quality is obtained from analytical data from nearby water wells or from geophysical well logs. If water quality data or well logs from nearby wells are not available, the depth to the deepest fresh water zone in wells within a 2-mile radius of the proposed well is determined. Surface casing for the proposed well is required to be set below the deepest fresh water zone found in nearby water wells or to reach a depth below the reasonably estimated level of usable water that will be protective of usable water.

When final approval is given by the BLM, the operator may begin construction and drilling operations. Approval of an APD is valid for one year. If construction does not begin within one year, the stipulations must be reviewed prior to approving another APD.

## 3.2 Surface Disturbance Associated With Drilling

Upon receiving approval to drill the proposed well, the operator moves construction equipment over existing roads to the point where the access road is to begin. Surface disturbing activities for oil, non-CBM gas, and CBM are similar, except the typical CBM drilling location generally requires less surface area than for oil and gas wells. Road and drill-pad construction must conform to the standards set forth by the BLM. The information provided on construction in this section is taken from the construction standards manual published jointly by the BLM and USFS (1989).

Generally, the types of construction equipment used include bulldozers (track-mounted and rubber-tired), scrapers, and road graders. Equipment is transported to the construction area by semi-trailer trucks over public and private roads. Existing roads and trails may be improved in places and, occasionally, culverts and cattleguards are installed, if required. The lengths of the access roads vary. Generally, the shortest feasible route should be selected to reduce the haul distance and construction costs. Environmental factors or the surface landowner's wishes may dictate a longer route.

During construction of well locations, all soil material suitable for plant growth is first removed from areas to be disturbed and stockpiled in a designated area. Sites on flat terrain typically require minimal earthwork including the removal of topsoil and vegetation. Drilling sites on ridge tops and hillsides are constructed by cutting and filling portions of the location. The majority of the excess cut material is stockpiled in an area that will allow easy recovery for rehabilitation. It is important to confine extra cut material in a stockpile rather than cast it down hillsides and drainages where it cannot be recovered for rehabilitation.

The amount of level surface required for safely assembling and operating a drilling rig varies with the type of rig. Excluding CBM well pads, the average would be 4.0 acres for a typical single wellpad layout, an average of 300 feet by 400 feet. The dimensions of a typical CBM location are smaller than oil or non-CBM gas locations because of the shallower drilling depths and smaller drilling rigs that are required. An average CBM well pad would be 3 acres, with 5 acres for a deep well. The well pad should be constructed such that the drilling rig will sit on solid ground and not on fill. This ensures that the foundation of the drilling derrick is on solid ground and prevents it from leaning or toppling due to settling of uncompacted soil.

In addition to the drilling platform, a reserve pit is constructed, usually square or rectangular but sometimes in other shapes, to accommodate topography. Reserve pits are used to store water, drilling fluid, and drill cuttings. Generally, the reserve pit is 8 to 12 feet deep, but may be deeper to compensate for smaller length and width or deeper drilling depths. Generally, the deeper the well, the larger the reserve pit. If possible, pits should be constructed on cut material and not fill. If constructed on fill, there is a high potential for leakage. Depending on specific site conditions, the WOGCC or BLM may require that pits be lined with suitable plastic material to prevent leakage of pit fluids into shallow aquifers. Pits may be divided into compartments separated by berms for the proper management of derived waste (e.g., drill cuttings, mud, water flows).

Depending on how the drilling location is situated with respect to natural drainages, it may be necessary to construct water bars or diversions. The area disturbed for construction and the potential for successful revegetation depends largely on the steepness of the slope. Water for drilling is hauled to the rig storage tanks or transported by surface pipeline. Water sources are usually rivers, wells, or reservoirs. Occasionally, water supply wells are drilled on or close to the site. The operator must obtain a permit from the Wyoming State Engineer for the use of surface or subsurface water for drilling. When the BLM holds a water right on a facility such as a stock pond, spring, or well, the operator must get approval from the BLM to use that facility (in addition to the permit from the SEO). During drilling operations, water is continually transported to the rig location. Approximately 40,000 barrels or 1,680,000 gallons of water are required to drill an oil or gas well to the depth of 9,000 feet. Water demand may vary depending on the specific subsurface conditions that are encountered during the drilling of the well.

Drilling activities begin as soon as practicable after the location and access road have been constructed. The drilling rig and associated equipment are moved to the location and erected. Moving a drilling rig requires moving 10 to 25 truck loads of equipment (some over legal weight, height, and width) over public highways and private roads. The derrick, when erected, can be as tall as 160 feet; derrick heights vary depending on the depth and weight capacity of the rig

## 3.3 Rights-of-Way

Rights-of-way are required for all facilities, tank batteries, pipelines, truck depots, powerlines, and access roads that occupy federally owned land outside the lease or unit boundary. When a third-party contractor (someone other than the lease operator or the federal government) constructs a facility or installation on or off the lease, a right-of-way also is required. Rights-of-way on federal lands are issued by the BLM.

## 3.4 Drilling Operations

### 3.4.1 Oil and Non-CBM Gas

#### 3.4.1.1 Drilling Procedures

Starting to drill is called spudding in the well. Initially, drilling usually proceeds rapidly mainly because of the unconsolidated shallow formations. Drilling is accomplished by rotating special bits under pressure. While drilling, the rig derrick and associated hoisting equipment bear most of the drill string weight. The weight on the bit is generally a small fraction of the total drill string weight. The combination of rotary motion and weight on the bit causes rock to be chipped away at the bottom of the hole. The rotary motion is created by a square or hexagonal rod, called a kelly, which is attached to the top of the drill pipe. The kelly fits through a square or hexagonal hole in a turntable, called a rotary table. The rotary table is turned by diesel or diesel-electric combination motors on the drill rig. The rotary table sits on the drilling rig floor and, as the hole advances, the kelly slides down through it. When the full length of the kelly has moved through the rotary table, drilling is stopped and the kelly is raised and an additional piece of drill pipe (or joint) about 30 feet in length is placed on top of the drill string. The top of the drill pipe is then lowered to the rotary table and held in place by devices called slips and the kelly is attached to the top of it. The slips are removed by pulling up on the pipe, and drilling recommences.

Drilling fluid or mud is circulated through the drill pipe to the bottom of the hole, through the bit, up the bore of the well, and finally to the surface. When the mud emerges from the hole, it goes through a series of screens to remove rock chips and sand-sized solids. When the solids have been removed, the mud is placed into holding tanks and from the tanks it is pumped back into the well. The mud is maintained at a specific weight and viscosity to cool the bit, seal off any porous zones (to protect aquifers or prevent damage to producing zone productivity), control subsurface pressure, lubricate the drill string, clean the bottom of the hole, and bring the rock chips to the surface.

There are three common types of drilling fluids: water-based, oil-based, and synthetic. Water-based muds are the most common and are largely made up of water and bentonite, a clay that has special characteristics used to maintain proper viscosity and other properties over a wide range of drilling conditions. Fresh water is usually used, but brine is used if salt layers are to be drilled (to prevent solution of the salt). Oil-based mud is used for subsurface conditions where water may react with shale and cause caving and sloughing of the sides of the wellbore. Synthetic drilling fluids are used for special conditions and have become more common in recent years. They are composed of organic polymers or other chemicals and are often designed to be environmentally benign. Additives are used to maintain the drilling mud properties for specific conditions that may be encountered during drilling. Some of the additives may be potentially hazardous in large quantities, but these additives are used in relatively small amounts during drilling operations. Other additives are composed of organic materials, such as cottonseed hulls, and are not hazardous.

Another common drilling system uses the pump pressure that is used to circulate the drilling fluid to turn the bit. This type of system is called a mud-motor and consists of a turbine that is part of the bottom-hole-assembly (BHA) at the bottom of the drill string. The pump pressure turns the turbine that rotates the bit. There is no rotating movement in the drill string above the mud-motor. Mud–motors are used under special conditions such as directional or horizontal drilling, but also are commonly used in normal drilling operations in conjunction with special bits to drill long sections of hole at fast rates and without the need to trip the drill string to change out the bit.

Eventually, the bit becomes worn and must be replaced. To change bits, the entire string of drill pipe must be pulled from the hole in 60-foot or 90-foot sections (stands) until the bit is brought out of the hole. The stands of drill pipe are stacked vertically in the rig derrick. The bit is replaced and then the drill string is reassembled and lowered into the hole stand by stand and drilling is started again. The process of removing and reinserting the drilling string is called a trip and may take up to 24 hours or more on a deep well to make a round trip to retrieve a worn bit.

Drilling operations are continuous, 24 hours a day, 7 days a week. There are three 8-hour or two 12-hour shifts or tours (pronounced “towers”) a day. Pickups or cars are used for workers' transportation to and from the location. Upon completion of the drilling, the equipment is removed to another location.

If hydrocarbons are not discovered in commercial quantities, the well is called a dry hole. The operator is then required to follow state and BLM policy procedures for plugging a dry hole. The drill site and access roads are rehabilitated according to stipulations attached to the approval of the well site.

#### 3.4.1.2 Casing and Cementing

Casing consists of steel pipe that is placed into the hole to prevent the collapse of the hole, to protect aquifers, and to isolate producing zones from other formations. Several strings of casing that have different purposes may be placed into the well. In the initial stages, the first casing set into the hole is called a conductor pipe. The conductor pipe is a large diameter pipe (greater than 12 inches) that is set at a fairly shallow depth (50 feet or less). The conductor pipe provides support for unconsolidated surface material. The conductor pipe is usually drilled and set in by a small auger rig prior to the set up of the drilling rig.

The next casing to be placed into the well is called surface casing. The well is drilled to a predetermined depth and the surface casing is run into the hole and cemented in place. The cementing operation involves pumping cement down through the bottom of the casing and up around the annulus (the space between the pipe and the sides of the hole). The cement holds the casing in place and protects potential shallow aquifers. Surface casing can be set from a couple hundred feet to over one thousand feet, depending on local requirements. Surface casing should be set to a depth greater than the deepest freshwater aquifer that could reasonably be developed. Surface casing must be large enough to accommodate one or more sets of casing strings that may be set as the well is drilled deeper.

In many cases, the next string of casing to be set in the hole is called the production string. Once the target zone is reached, the well is deepened slightly below the zone and the production string is run and cemented in place. Generally, only the bottom few hundred feet of the production string are cemented in place, enough to cover the producing zone plus enough cement above the producing zone to provide adequate protection against leakage of the reservoir into the annulus. Operators are required to cement off hydrocarbon bearing zones to prevent contamination of aquifers. Operators also are required to protect other hydrocarbon productive and water-containing strata as directed by the WOGCC or the BLM.

For some drilling conditions, one or more intermediate casing strings may be required before the well reaches total depth. Intermediate strings are used to prevent loss of the hole while drilling deep wells, to control over-pressured zones, to protect hydrocarbon zones, to provide a point from which to drill a deviated hole, and to isolate lost circulation zones. Lost circulation occurs when the hydrostatic pressure of the mud breaks down a formation and large volumes of mud are lost into that zone . Intermediate casing is often the only way to prevent lost circulation from occurring and potential loss of the hole when drilling deep wells.

### 3.4.1.3 Blowout Prevention

In the early days of drilling, no blowout prevention equipment was used. However, because of concerns for environment, safety, and conservation of oil and gas resources (prevention of waste), blowout prevention is a primary concern during well drilling. Blowout prevention begins with an understanding of the subsurface pressure regime. In normally pressured rocks, the pressure increases with depth in a relationship expressed as 0.433 pound per square inch per foot. Blowout prevention is a concern in areas of abnormally high-pressure gradients. When a drill bit penetrates an abnormally high-pressured zone, there is a risk that a blowout, or uncontrolled flow of fluids to the surface, will occur. Abnormally high pressures have several causes. The main cause of over pressures are hydrocarbon generation and a sealing overburden. In the Greater Green River Basin, one cause of abnormally high pressures is the presence of basin-centered gas trapping in Tertiary and Cretaceous rocks.

The drilling fluid is the first line of defense against a blowout. But if abnormally high pressures are encountered, the weight of the mud itself may not be enough to hold back formation fluids. Therefore, by rule, drilling rigs must be equipped with a device called a blowout preventer (BOP). During drilling of a well, the BOP is placed on top of the surface casing string. Blowout prevention equipment is tested and inspected regularly by both the rig personnel and the inspection and enforcement branch of the BLM. Minimum standards and enforcement provisions are currently in effect as part of Onshore Order No. 2. Well-trained rig site personnel also are a necessity for proper blowout prevention. Through a system of hydraulically activated valves and manifolds, the BOP is designed to shut the well in and prevent the uncontrolled flow of fluids. In addition, BOPs also are designed to allow fluid to be pumped into the hole (to kill the well) and allow drill pipe to move in and out of the hole.

### 3.4.1.4 Formation Evaluation

One of the primary activities that occurs during the drilling of the well is the acquisition of downhole information. Formation evaluation covers a variety of data gathering and retrieving methods that include mud logging, wireline logging, formation testing, coring, and measurement while drilling (MWD) surveys. In wildcat wells (wells drilled outside of areas of established production or into deeper untested zones in established fields), it is important that quality data be obtained in order to justify the costly decision to run (or not run) production casing and complete the well. In producing areas, adequate formation evaluation also is important so that reservoir properties are understood in order to make informed decisions about the development of a field.

#### MUD LOGGING

While the well is being drilled, the drilling mud is evaluated for the presence of hydrocarbons. This is commonly done through a technique called mud logging. As the mud comes up out of the hole, instruments are used to monitor the presence of gas or oil that may be present as the bit penetrates the subsurface. Evidence for the presence of hydrocarbons is called a show, which must be evaluated to determine whether a show is indicative of commercial hydrocarbon reservoirs. Mud logging evidence of hydrocarbons often is not definitive of a commercial show, but mud logs, in combination with other formation evaluation tools, are an important part of the overall evaluation of the hydrocarbon potential.

Mud logging equipment also monitors for the presence of hydrogen sulfide, a deadly gas. The mud log, in addition to recording the presence of hydrocarbons and other gases, also is used to record and describe the rocks that are encountered in the well. The equipment used to remove rock cuttings from the mud also is used to obtain chips for sample description. Samples of rock cuttings from downhole are taken at prescribed intervals. The depths from which the samples came is determined by knowing the lag time it takes for the cuttings to reach the surface. The mud log can summarize all the formation evaluation activities for the well. The mud log format is a strip-chart display of the intervals logged depicting shows, formation tops, lithologic descriptions, wireline log data, gas readings, drilling data, and core and test intervals and descriptions.

### WIRELINE WELL LOGS

Wireline well logs (or geophysical well logs) are basic to formation evaluation. Open-hole (hole without casing) wireline well logs can be run before intermediate casing strings are set and when the well reaches total depth. Wireline well logs also may be run in cased holes. Wireline logs use a variety of techniques to provide indirect measurements of rock properties and are used to precisely determine the elevation and thickness of individual rock units or potential producing zones. In general, wireline logs require the application of electrical, sonic, mechanical, or radioactive energy to the rocks in order to obtain measurements that can be related to rock properties such as porosity, permeability, and fluid ratios. Only a few types of wireline logs do not require the application of energy to the rocks to make measurements. For example, the gamma ray log measures the natural gamma ray radiation from the rocks and is used to determine lithology (shale versus nonshale).

Wireline logs are created by lowering instruments (the logging tool) into the well. The instruments are suspended by a cable that not only supports the logging tools, but also relays measurement data by electrical signals to the surface. The general procedure is to lower the logging tool to the bottom of the hole and take measurements while hoisting the tools back to the surface. Several types of logs can be run in combination. The data from the tools are digitally processed at the surface and the information is summarized on what are generally described as well logs.

### FORMATION TESTING

Zones with porosity can be determined while drilling when the rate of penetration begins to increase. When combined with evidence of the presence of hydrocarbons in the increased penetration interval, the well can be temporarily completed. The temporary completion of the well is called a drill stem test (DST) and can be useful in determining if hydrocarbons are present in commercial quantities. In a DST, a tool is placed on the end of the drill string and run back into the hole opposite the prospective interval. A device called a packer is placed above the tool in the BHA and is inflated against the walls of the hole to seal the zone from the mud column above. The tool is opened and fluids from the formation are allowed to enter the drill stem.

A typical DST includes several periods of flow and shut-in. Pressure recorders are present in the test tool as well as sample chambers. When the test is over, the packer is released and the tool is brought to the surface. The pressure recorder charts are analyzed and the potential productivity of the zone can be estimated. Sample chambers placed near the formation are opened after a test and may contain oil, water, or gas. In addition, fluids produced into the drill stem may include varying amounts of oil, gas, and water. A good test can recover hundreds or thousands of feet of oil in the drill pipe or enough gas to the surface to flare.

A variation of the DST is the repeat formation test tool that is run into the hole by use of a wireline. The tool is pressed up against the sides of the borehole in the interval of interest. One of the major advantages of the wireline tester is the ability to obtain real-time pressure readings and the ability to test multiple zones. The wireline formation tester also has sample chambers for the recovery of formation fluids.

#### *CORING*

Coring is a method of formation evaluation whereby a whole sample of the subsurface rock is brought to the surface. Cores are obtained by placing a special bit and core barrel at the end of the drill string. Instead of drilling the rock into small pieces, a cylindrical core is cut. Core barrels are commonly 30 to 60 feet in length. When the core is brought to the surface, it is described by a geologist and then packaged and sent to a laboratory where it can be analyzed for certain properties such as porosity (space in the rock that is filled by fluids), permeability (the ability of the rock to transmit fluids), and the ratio of fluids present in the pores of the rock (oil, gas, and water).

Another method used to obtain whole rock samples is the side-wall core sampler. Side-wall cores are obtained using a wireline tool that shoots small core barrels into the side of the well bore. The barrels are secured to the wireline tool by cables and the core is retrieved by pulling on the tool.

#### *MEASUREMENT WHILE DRILLING*

MWD is a well logging technique developed in the last two decades that allows some of the same measurements that are done by wireline logs to be accomplished in real time while the well is being drilled. This technique allows certain types of information to be gained in case the hole is lost before the wireline logs are run and to monitor rock properties that can indicate the presence of abnormal pressure conditions before drilling into them. Data from the measurement sensors near the bit are transmitted as fluid pulses through the drilling mud. MWD also is critical to directional and horizontal drilling providing real-time measurements so that immediate adjustments can be made in hole attitude and direction.

## 3.4.2 Coalbed Methane

### *3.4.2.1 Drilling Procedures*

Drilling for CBM is very similar to drilling for conventional oil and gas except that generally much smaller drilling rigs are used since, at present, CBM resources are generally at much shallower depths on average than oil and gas.

### *3.4.2.2 Casing and Cementing*

Surface casing is required to be set in CBM wells to protect potential aquifers. The depth of surface casing is determined by the regulatory agency and depends on the depth of water zones that need to be protected. Production casing can be set in either of two ways: 1) the casing can be set below the coal zone, cemented in and completed like typical oil and gas wells; or 2) the casing can be set above the coal zone, in an open hole completion. Generally the open hole under the casing is under-reamed by a bit that expands to a large diameter and drills a larger hole.

#### 3.4.2.3 Blowout Prevention

BOPs are required for drilling CBM wells as required by Onshore Rule No. 2.

#### 3.4.2.4 Formation Evaluation

Wireline well logs are common formation evaluation tools for CBM wells. The well logs provide information on depth, thickness, and total number of coal seams. In addition, other properties can be determined such as porosity, fractures, and the amount of ash (mineral material) in the coal. An important aspect of formation evaluation of coals for methane production is to estimate the amount of gas that is potentially available to produce from the coal. The gas in coal is present through a process called sorption, whereby the gas is attached to the surface of the coal in a molecular state. In order to produce the gas, it must be desorped from the coal. Desorption is accomplished by lowering the hydrostatic pressure on the coal by producing the water in the coal.

In CBM formation evaluation, the amount of gas that can be desorped is critical in determining whether a well or number of wells will be economic. The amount of gas that can be produced can be estimated using direct or indirect methods. One direct method is to conduct tests on whole core or drill cuttings whereby the coal samples are put into a gas-tight chamber and the gas is allowed to evolve and is measured. Corrections are made for the potential lost gas that occurs when the cores are brought to surface and before they can be placed into the gas-tight containers. A variation on this technique is to obtain pressure cores, a method that seals the core under formation pressure. In the pressure core method, gas losses are minimized and a more accurate estimate of potential gas can be made. Indirect methods of desorption potential do not measure gas directly but rather measure the sorption capacity of the coal.

# 4.0 FIELD DEVELOPMENT AND PRODUCTION

## 4.1 Oil and Natural Gas

### 4.1.1 Field Development

New field developments are analyzed under NEPA by means of an environmental assessment (EA) or environmental impact statement (EIS) after the second or third confirmation well is drilled. The operator should then have an idea of the extent of drilling and disturbance required to extract and produce the oil and gas. When an oil or gas discovery is made, a well spacing pattern must be established before development drilling begins. Well spacing is regulated by the WOGCC.

Factors considered in the establishment of a spacing pattern include reservoir data from the discovery well including porosity, permeability, pressure, composition, and depth. Other information pertinent to determining spacing includes well production rate, relative amounts of gas and oil in the production stream, type, and the economic effect of the proposed spacing on recovery. Spacing for oil wells usually varies from 40 to 320 acres per well, but can be as dense as 10 to 20 acres per well. Spacing for gas wells is generally from 160 to 640 acres per well, but spacings of 20 to 40 acres are possible.

Spacing requirements can pose problems in selecting an environmentally sound location. Reservoir characteristics and the drive mechanism determine the most efficient spacing to achieve maximum production. If an operator determines that a different spacing is necessary to achieve maximum recovery, the state and federal agencies may grant exceptions to the spacing requirements. Exceptions also may be obtained if the terrain is unsuitable, provided no geologic or legal problems are encountered.

The procedures for obtaining approval to drill and for the drilling of development wells are generally the same as those for wildcat (exploration) wells. Many fields go through several development stages. A field may be considered fully developed and produce for several years and then new producing zones may be found. If commercial hydrocarbons are discovered in a new producing zone in an existing field, it is called a new pool discovery, as distinguished from a new field discovery. New pools can either be deeper or shallower that the existing producing zone. A new pool discovery may lead to the drilling of additional wells. Shallower pay might be exploited from existing wells or deeper zones may be accessed by deepening existing wells. Often it is found that an established spacing rule is not effectively draining the producing zone in the field because of factors such as reservoir heterogeneity or non-continuity of the reservoir that were not detected when the field was initially developed. If an operator can substantiate (through pressure testing, 3D seismic surveys, or other evidence) that the initial spacing is not effectively draining the reservoir, the operator can petition the WOGCC for a new spacing.

As more wells are placed in production, roads are improved by regular maintenance, surfacing with gravel or scoria, and installing culverts. Mineral materials are usually purchased from local contractors and obtained from federal sources. Materials that are obtained from areas of federally owned minerals require a sales contract and are processed through the FO where the materials occur. A new stage of field development can lead to changes in locations of roads and facilities. All new construction, reconstruction, or alterations of existing facilities (including roads, dams, pits, flowlines, pipelines, tank batteries, or other production facilities) must be approved by the BLM.

Production from multiple wells on one lease may be carried by flowlines to a central processing facility. Central processing and storage facilities can be used for multiple wells on the same contiguous lease or multiple wells in an established unit. During the productive life of a field, problems may arise such as erosion, barren to sparsely vegetated areas, washouts of drainage crossings, plugging of culverts, deterioration of cattleguards, accumulation of derelict equipment, construction of unnecessary roads, unauthorized off-road cross-country travel, and improperly placed or out of service pipelines.

Rehabilitation plans are prepared by either BLM or industry to correct these problems and to return the field surface area to its original productivity. Corrective action is taken as problems arise. This ongoing restoration allows total rehabilitation to be more quickly accomplished at the end of a field's productive life.

### 4.1.2 Unitization

In areas of federally owned minerals, an exploratory unit can be formed before a wildcat exploratory well is drilled. Federal units were authorized by *The Mineral Leasing Act of 1920*. Title 43 CFR Subpart 3186 (2002) sets forth a model onshore unit agreement for unproven areas. The boundary of the unit is based on geologic data. A unit operator is determined by agreement of the leaseholders. Often the leaseholder with the largest leasehold position is designated operator of the unit.

As oil and gas are discovered, unit development can proceed in a deliberate and efficient manner to minimize waste of hydrocarbon resources. For instance, pressure maintenance wells can be installed prior to full-scale production, which, in some types of reservoirs, may significantly increase recovery factors. Spacing in a unit is not regulated except for offset distances to the unit boundary. This allows location of wells to take advantage or reservoir heterogeneity and thereby increasing recovery. Another advantage of unitization is that surface use is minimized because all wells are operated as though on a single lease. Duplication of field processing facilities is minimized because development and operations are planned and conducted by a single operator. Often powerlines can be distributed throughout the unit, and well pumps can be powered by electric motors. Unitization may enable the field to be developed with fewer wells, thereby minimizing surface disturbance through fewer locations and less road mileage.

It is the general intent of unitization to pool or unitize the interests in an entire structure or area in order to provide for adequate control of operations so that development and production can proceed in the most efficient and economical manner and with minimized environmental impact. Each proposal to unitize federally supervised leases is evaluated on its specific merits. The unit agreement provides for the exploration, development, and production by a single operator. In effect, the unit functions as one large lease. The purpose of a unit is to conserve the natural resources of the pool, field, or area involved. The early consolidation of separate exploration and development efforts through unitization of separate leasehold interests eliminates the need (with respect to drainage) to drill protective wells along common boundaries between leases and serves to maximize benefits through a consistent exploration and development program.

### 4.1.3 Production Practices

#### *4.1.3.1 Well Completion*

After the production string is cemented into place, the drilling rig is moved off and a smaller rig (called a workover rig or pulling unit) is set in place over the hole. After time is given for the cement to cure, an interval coinciding with the producing zone is perforated. Perforating is accomplished through the use of bullet-like projectiles or, more commonly, with shaped charges. Perforating cuts holes through the casing and to several feet into the formation. After the zone is perforated, the holes may be cleaned out using a fluid flush treatment, commonly acid. The acid helps remove invaded drilling mud and pulverized rock particles created by perforating.

Generally, most hydrocarbon wells require stimulation beyond cleanup of the perforations. Additional stimulation is accomplished through hydraulic fracturing of the producing zone. Hydraulic fracturing is accomplished by pumping large volumes of liquid, usually water and proppant material under pressure into the formation. The fluids from the fracturing are recovered, and the proppant is left in the fractures. The proppant may be composed of silica sand obtained from natural sandstone formations or may be derived from artificial materials such as ceramic. The proppant is used to keep the fractures open once the pumping pressure is stopped in the fracturing process. After stimulation is complete, production tubing is run into the well and may be anchored to the inside of the production string by the use of a production packer. The packer not only anchors the tubing but also prevents fluid from entering the annular space between the casing and tubing. At the surface, equipment is installed on the tubing to control pressure and the flow of the production stream to processing equipment.

#### 4.1.3.2 Well Production

The following describes typical production practices at gas and oil wells.

##### GAS WELLS

Production and processing equipment at a typical gas well location might consist of a wellhead (called christmas tree), a production separator, a dehydrator, and tanks. The christmas tree has valves used to control the flow of gas and liquids from the well. As gas comes to the surface, it is diverted to processing equipment on the location. The gas must be separated from liquids in the production stream that may consist of water, gas condensates, or light crude oil. The production stream is placed into a production separator where the majority of the water and liquid hydrocarbons are removed from the gas. The gas is then fed into a device called a dehydrator to remove water that may remain in the gas. There are several processes used for dehydration, one of the most common being the use of glycol. The gas then goes through a metering facility and then into a sales or gathering pipeline. The hydrocarbon liquids are recovered and placed into tanks. Often 400-barrel tanks (1 barrel equals 42 gallons) are used, but commonly gas wells make so little hydrocarbon condensate (drip) that it can be placed in smaller tanks. Condensate or crude oil is trucked from the well for sale or placed into a pipeline.

Produced water is either placed into a tank (often a below-grade steel tank called a tinhorn) or, if permitted, into a shallow evaporation pit. Unlined evaporation pits can be used if water production is less than 5 barrels of water per day and if there are no potential impacts to shallow groundwater. Water also may be disposed into the natural drainages if the required permit is obtained from the Wyoming Department of Environmental Quality (DEQ).

Methanol is commonly used to keep production and surface lines from freezing because of pressure drops that occur when gas comes to the surface and result in line freeze ups, even in summer. Methanol is injected into the wellhead. Sometimes a device called an intermitter is used to either shut in the well to build up pressure or to open up the well (blow down) if it is being loaded with fluid. If too much fluid is coming into the well bore, gas may cease to flow, a condition called loading up. Loading up may cause loss of productivity or permanent damage to the well, which may result in the loss of flow.

After dehydration, the gas is moved into field pipeline gathering systems. In order to move the gas through the pipelines, compression equipment is used. Field compression units are small and mobile and are often skid-mounted for portability. Field units are sized for the amount of gas that needs to be moved and are often temporary because of the changing compression needs in a field, especially as it undergoes initial development. From the field gathering lines, the gas is fed into larger transportation lines, often at compressor stations along the transportation line. Before the gas is put into the transportation lines, it may undergo further processing to remove hydrocarbon condensates and water to ensure the gas meets stringent transportation pipeline specifications.

Commonly, natural gas needs more than simple wellsite processing. Large scale gas processing is conducted at facilities called gas plants. Gas plants typically handle large volumes of gas from multiple wells and can be designed to handle a variety of product and impurity separation processes.

Sometimes the gas contains heavier hydrocarbon compounds known as natural gas liquids (NGLs). In addition to being valuable products, these NGLs need to be processed out of the methane stream to meet the transportation pipeline specifications. In addition to NGLs, natural gas may contain impurities or large amounts of non-flammable gases that need to be removed from the methane. A major impurity is hydrogen sulfide that, for safety and environmental concerns, needs to be removed from the gas. Carbon dioxide ($CO_2$) is an important nonflammable gas that, if found in large enough quantities, may be commercially viable as a byproduct.

## OIL WELLS

Typical oil well locations consist of a wellhead, pumping equipment, phase separation equipment, and storage tanks. Multiple wells on the same lease or unit may produce into central processing facilities, whereas more remote wells or a single well on a lease will have all the necessary processing and storage equipment. Oil wells can be completed as flowing wells or pumping wells. Flowing wells have sufficient formation pressure to raise the oil to the surface. If formation energy is insufficient to raise the fluids to the surface, the oil is pumped.

The most common types of pumps are called rod pumps. These pumps are placed next to the perforations and are actuated by surface beam pumping units at the surface (or pump jacks). The downhole pumps are connected to the pump jacks by a string of steel rods called sucker rods. In both types of pumps, movement of the sucker rods moves traveling valves that either open or close and cause the fluid to move into the well casing and up the tubing. Pump jacks come in a variety of sizes depending on the depth and the total amount of fluid anticipated to be pumped, the larger ones reaching a height of 30 to 40 feet. Pump jacks are powered by internal combustion engines or electric motors. Fuel for the internal combustion engines may be casinghead gas (gas produced with the oil) or propane.

Another pumping method involves the use of electrically powered submersible pumps that are suspended below the fluid level in the well. The fluids are pulled into the tubing and pumped to the surface. Submersible pumps are used when large volumes of fluid have to be produced such as wells where there are large amounts of water produced with the oil. Submersible pumps can pump higher volumes of fluid and enable wells with high water cuts to remain economically viable. Artificial lift, called gas lift, is a method whereby natural gas is pumped into a well to provide the energy to lift the fluids to the surface. Hydraulic pumps are also used. With hydraulic pumps crude oil is pumped down one tubing string, activating a hydraulic piston and well fluids plus the hydraulic fluids are returned to the surface in a second string or the casing annulus.

Fluids produced from an oil well are generally composed of three phases: oil, water, and gas. When the fluids reach the surface, they must be separated. This is accomplished through the use of separation equipment that is appropriate for the proportions of fluid that are being produced. If there are large amounts of water, the water is separated by a vessel called a free water knockout (FWKO). Free water is water that is easily gravity separated from the oil. The remaining fluid is fed into heater-treaters, which separate not only the gas and the oil, but also break apart water-in-oil emulsions that may occur during the production process. Dilute brines can form emulsions that are difficult to separate into distinct oil-water phases. Produced water that is separated from the oil is routed into tanks for disposal.

FWKOs and heater-treaters burn gas to facilitate separation of the fluids. The gas may be used to heat the fluids and is either provided from commercial propane or casinghead gas. Emulsions are usually treated with chemicals for severe or difficult emulsion problems. The casinghead gas, depending on the quantities produced, can be used on the lease, recovered and placed into pipelines for sale, or vented. The WOGCC prohibits the flaring or venting of natural gas except during testing of a new well or when the amount of gas produced with the oil is so small that pipeline construction is not practical. An operator who intends to vent gas must submit an air quality permit application to the DEQ. Normally gas produced in such circumstances is granted a waiver of permit because the amounts are small. Flaring of gas also requires submission of an air quality permit application. If an oil well produces sufficient quantities of gas, provisions for recovering the gas must be made before oil production can commence. If casinghead gas is placed in gathering or sales pipelines, it must be dehydrated and metered as at a gas well.

After the separation process, oil and water are stored in tanks either at the location or at central processing facilities. The capacities of the tanks are generally from 400 to 500 barrels and any given tank battery will have varying numbers of tanks depending upon the productive capacity of the well. Tanks and separation vessels are placed in earthen berms or other containment structures in order to contain spilled fluids in case of an upset condition or rupture of a tank or vessel. Production equipment is required to be painted in colors that will blend into the surrounding environment. Popular colors are brown and green. Some or all of the facility must be fenced. If production pits are present, the pits must be fenced and netted to protect livestock and wildlife.

Two main methods of oil measurement are used. These are: lease automatic custody transfer meters for pipeline transport; and tank gauging by company personnel. Measurement is required by 43 CFR 3162.7-2 (2002) and Onshore Order No. 4 (BLM 1989) to ensure proper and full payment of federal royalty.

### *PRODUCTION WASTE*

Water is produced in large quantities and is the largest volume of waste generated in oil and gas production. Disposal of water produced on leases managed by the BLM is regulated by the Onshore Oil and Gas Order No. 7 (BLM 1993) and the State of Wyoming. Produced water with less than 5,000 ppm TDS can be disposed of in natural drainages for livestock and irrigation if the required permits are obtained from the DEQ. If the water has greater than 5,000 ppm TDS, it cannot be used for beneficial purposes and must be disposed in a manner protective of the environment.

The water can be handled in several ways. One of the most common methods is to re-inject the water into the producing formation to maintain pressure in the reservoir as part of a secondary recovery waterflood. Another method involves the injection of the fluid into brine disposal wells, owned either by the operator or by third parties. A new method has been developed that injects water into another zone in the same well and much of the water never reaches the surface. Subsurface water disposal methods are permitted by the WOGCC under the underground injection control program. Downhole injection in the same well is still a relatively new and experimental method for disposing of water and is still being evaluated by the U.S. Environmental Protection Agency.

Water can be placed into evaporation pits if water volumes are small. Pits may be lined or unlined depending upon the discretion of the permitting authority. Water also can be hauled from the location by third-party commercial contractors and disposed of in large lined evaporation pits. Such commercial facilities are licensed and regulated by the Wyoming DEQ.

Much of the waste generated by production operations is exempt from regulation as hazardous waste. However, the waste must be disposed of in a manner acceptable by law. Waste that is exempted is waste intrinsic to the production process. Examples of exempt waste are formation water, hydrocarbon impacted soil, drilling mud, and drill cuttings. These wastes can be dealt with in a variety of ways under existing regulations, but must be handled in a manner protective of public health and the environment. Other wastes, not classified as exempt, must be disposed of properly according to regulation.

#### *PRODUCTION PROBLEMS AND WORKOVERS*

Weather extremes pose problems for operators by causing roads to become impassable, equipment to malfunction, and freeze-up of flowlines, separators, and tanks. Other problems that operators face are hydrogen sulfide, $CO_2$, paraffin, corrosion, electrolysis, and broken flowlines. During the life of a producing well, it may be necessary to take the well off-line and service the well or conduct a workover. Often workovers are done for routine maintenance (replace pumps, clean out perforations) or may be conducted because of severe operating malfunctions (e.g., rod separation, casing leaks, cement breakdowns). Workovers are conducted with small rigs called workover rigs or pulling units. Pulling units are typically self-propelled rigs that have a mast that is erected over the hole. Rods and tubing are pulled out of hole and stacked vertically within the mast.

### 4.1.4 Secondary and Enhanced Recovery

The initial stages of production, whether by natural flow or by pumping, is referred to as primary recovery. As the reservoir is produced over time, the energy needed to move fluid from the formation to the wellbore is depleted. Depending on economics, additional recovery methods may be used. These methods are referred to as secondary recovery. There are two basic secondary recovery methods in use, water flooding and displacement by gas. The most important secondary recovery method in use is water flooding. Water flooding is the process of injecting large volumes of water into oil reservoirs where primary reserves are being depleted to enhance and accelerate recovery. The process of injecting gas into the producing zone is another, less common secondary recovery technique.

Historically, produced gas was often flared (burned) at the point of production because of poor market conditions or absence of pipelines to transport the gas. Later, it was recognized that the energy could be conserved and the recovery of oil increased if the produced gas was re-injected into the producing zone. This increased production was achieved by: 1) maintaining reservoir pressure by injecting the gas into the existing gas cap; and 2) by injecting the gas directly into the oil saturated zone, creating an immiscible or miscible gas drive, which displaced the oil.

Beyond secondary recovery, enhanced recovery is used to describe recovery processes other than the more traditional secondary recovery procedures. These enhanced recovery methods include thermal, chemical, and miscible (mixable) $CO_2$ drives. When enhanced recovery methods are used after secondary recovery methods have reached viable limits, they are often referred to as tertiary recovery.

Some reservoirs contain large quantities of heavy oil that cannot be produced using primary or secondary methods. In thermal drive processes, heat is introduced from the surface or developed in place in the subsurface reservoir. In the thermal drive process, hot water or steam is injected. In the in-situ process, spontaneous or induced ignition of in-place hydrocarbons are created in the presence of injected air to develop an in-situ fire front. Raising the temperature of heavy oil causes it to become less viscous and more mobile so that it may be produced through gravity forces or preferably by displacement.

There are several chemical drive techniques currently in use including: 1) polymer flooding, 2) caustic flooding, and 3) surfactant-polymer injection. These methods attempt to change reservoir conditions to allow additional oil to be recovered. Another form of gas injection is accomplished with $CO_2$, which is miscible with both crude oil and water. $CO_2$ can also be used in a secondary recovery process with CBM reservoirs. This process reduces the partial pressure of methane and strips the methane off the coal to be replaced by the $CO_2$. This process would probably require relatively thick coals with high methane contents to be economically feasible. Most enhanced or tertiary recovery processes are very costly and highly dependent upon large recoverable reserves in reservoirs of adequate flow characteristics.

## 4.2 Coalbed Methane

### 4.2.1 Field Development

Because a CBM reservoir has some inherent differences from oil and non-coalbed gas development, CBM field development occurs in a different way. The economic viability of any particular project may not be known until several wells have been drilled and completed and the coal has been depressured enough to determine if gas can be produced in commercial quantities. When federal managed lands are involved, new CBM developments are analyzed under the NEPA usually by means of an EA, although sometimes an EIS is needed.

In initial CBM development, the operator may drill two or three wells from which to obtain core samples to determine methane desorption potential, total aggregate thickness of coal seams, and other data from which to get an estimate of future production. If it is determined that there is commercial potential for CBM, the typical route to development is to begin to produce the wells in order to draw off the water to see if the coal seams are able to produce at preliminary estimated rates. Often a pilot project will be proposed in which a few wells are drilled at an adequate spacing to test the efficacy of dewatering the reservoir to cause gas to desorb from the coal. Usually 8 to 10 wells are drilled and pumped to the point at which significant gas is produced. If the production proves to be economical, then the operator will propose to drill a number of wells that will most efficiently drain the gas from the coal.

Spacing in typical CBM projects can vary from one well per 320 acres to one well per 10 or 20 acres and is under the jurisdiction of the WOGCC. The spacing depends on the amount of gas that could be recovered, depth, permeability, porosity, and net coal thickness. When a CBM project is deemed economical to warrant full-scale production, often many wells are proposed to be drilled. The number of wells is dependent upon several variables. As in oil and natural gas developments, a

CBM development requires drilling pads, roads, pipelines, compressors, and other infrastructure. On federally managed lands, the construction and installation of the production infrastructure must be approved by the BLM.

CBM development in the Powder River Basin differs from most other CBM development because of the unusually shallow coal depths. Powder River Basin wells are typically drilled with small truck-mounted rigs similar or identical to drilling rigs used at surface mines. As a result, surface use such as construction is proportionately less than for typical oil and gas development. If deeper coals in the Wind River Basin or elsewhere are developed for CBM, it is likely that surface uses would more closely resemble those of conventional oil and gas development. Another unique feature of CBM development that has been established in the Powder River Basin, and is being initiated elsewhere in Wyoming, is the establishment of a network of groundwater monitoring wells. These may be necessary for shallower coals, but may not be needed for deeper coals.

### 4.2.2 Unitization

The establishment of an exploration unit is advantageous for CBM production so that the development can be conducted in an orderly manner by one operator. Unitization also should optimize the surface planning so that roads, pipeline corridors, and other infrastructure can be located to minimize the footprint of activities.

### 4.2.3 Production Practices

#### *4.2.3.1 Well Completion*

CBM wells can either be open hole completions or cased hole completions. In open hole completions, the production casing is set above the target coal zones. In cased hole completions, production casing is placed through the coal zones and cemented in. Often there are several coal zones that are produced in one well, rather than a single coal zone. One common method of open hole completion involves creating a cavity in the coal. The cavity that is created can be 4 to 5 feet across (nominal borehole size: 7 7/8 inches) by repeated injection of compressed air into the coal zones. The cavitation process can enhance permeability without the use of hydraulic fracturing. In the traditional cased hole method, the coals may be hydraulically fractured to enhance permeability. Certain types of hydraulic fracturing can damage coal zones so that, over the years, treatments have been designed especially for CBM wells.

#### *4.2.3.2 Production Practices*

A CBM production unit consists of wells, gas and water gathering lines, compressors, gas dehydrators, measurement systems, water treatment facilities, roads, and utilities. In the production process, typically large amounts of water have to be drawn initially out of the coal seam in order to desorb the gas. Several methods of artificial lift can be used to move the water to the surface. Pumping methods include rod pumps, submersible pumps, gas lift, and progressing cavity pumps.

All that is on a CBM location is a covered wellhead, allowing for reclamation of the location to a minimal area and for less intrusion resulting from monitoring and maintenance of the separator. A separator also would be a visual intrusion, an increasing factor in environmental analysis. At this stage the gas may still be saturated with water and is put through a two-phase separator.

After separation from the water, gas is routed through a metering system and placed into a gathering pipeline system. The gas may have to go through another dehydration step prior to putting it into a sales or transportation line. Reciprocating compressors increase the compression of natural gas for delivery to high- compression transmission pipelines. Each station onsists of one to six compressors, depending on the volume of gas being delivered to the station. Booster compressors enhance the flow of gas from the wells to the reciprocating compressors.

The produced water also is routed into a gathering pipeline system for disposal. There are two major disposal options for the water: surface discharge and subsurface injection. All water disposal methods must be approved by appropriate regulatory authorities. Surface disposal is allowed only if the water meets certain permit-required limitations on quality and constituents. Often the water is usable for livestock watering and irrigation. In those cases, it can be discharged to surface drainages or, more commonly, into ponds. If the water, as pumped from the subsurface, does not meet discharge limits, it can be treated and then discharged to the surface. However, pretreatment options such as reverse osmosis are relatively expensive compared to other disposal options, may not be effective for large volumes of water, and must be properly designed to ensure that the system operates effectively. Evaporation ponds can be used for disposal but are not effective for handling large amounts of water over long periods of time, especially in Wyoming. Although Wyoming has a semi-arid climate, ideal conditions for evaporation occur only within a period of a few months of high temperatures. For most of the year, conditions are not conducive to effective evaporation of large amounts of water. Subsurface disposal can be accomplished through deep well injection. The water can be re-injected into an aquifer only if the water meets water quality requirements. To accomplish injection, the water may have to undergo limited pretreatment, such as solids settling and filtration.

As in oil and non-CBM gas wells, workover operations are conducted for routine maintenance, failure of downhole equipment (rods or pumps), or re-stimulation.

# 5.0 ABANDONMENT AND RECLAMATION

## 5.1 Plugging and Abandonment of Wells

The purpose of plugging and abandoning a well is to prevent fluid migration between formations, to protect minerals from damage, and to restore the surface area. Each well has to be handled individually due to a combination of factors including geology, well design limitations, and specific rehabilitation concerns. Therefore, only minimum requirements can be established then modified for the individual well. Oil, non-CBM gas, and CBM wells must be plugged according to the same protection requirements.

The first step in the plugging process is the filing of the Notice of Intent to Abandon to the BLM if the lease is federal or to the WOGCC if the lease is state or fee. This notice will be reviewed and approved by the controlling agency prior to plugging whether the well is former producing well or if the well was an exploratory well. If the well is an exploratory well, verbal plugging instructions can be given for plugging current drilling operations, but a Sundry Notice of Abandonment must be filed after the work is completed. If usable fresh water was encountered while the well was being drilled, the controlling agency will be allowed, if interested, to assume ownership and plugging liability of the well and convert it to a water well. Under this arrangement, the operator may be reimbursed for the costs involved. The Wyoming State Engineer must approve a water well appropriation before the well can be produced.

The operator's plan for plugging the hole is reviewed by the controlling agency. Minimum requirements are stated in Onshore Order No. 2. There are different requirements for open holes (wells without production casing) than for cased holes. In open holes, cement plugs must extend at least 50 feet above and below zones with fluid that has the potential to migrate, zones of lost circulation (this type of zone may require an alternate method to isolate), and zones of potentially valuable minerals. Thick zones may be isolated using plugs across the top and bottom of the zone. In the absence of productive zones and minerals, long sections of open hole may be plugged with plugs placed every 3,000 feet.

In cased holes, cement plugs must be placed opposite perforations and extending 50 feet above and below except where limited by the plug back total depth of the well. The cement plugs could be replaced with a bridge plug if the bridge plug is set within 50 to 100 feet above the open perforations, and only if the perforations are isolated from any open hole below. The bridge plug must be capped with 50 feet of cement. If the cement cap is placed using a dump bailer, a minimum of 35 feet of cement is sufficient. A device called a dump bailer is a wireline apparatus useful for cement placement because tubing does not have to be run and cement contamination is minimized. This method employs the use of a container of cement, which is lowered into the hole and dumped. In the event that the casing has been cut and recovered, a plug is to be placed 50 feet above and below the cut off point. No annular space may be open to the surface from the drilled hole below. At a minimum, the top 50 feet of the well must be plugged with cement.

Normally, at least 100 feet of cement is required to be spotted across the surface casing shoe. If the integrity of a plug is questionable or the position extremely vital to protect certain zones, it can be tested with pressure or by tagging the plug with the drill string. Tagging the plug means running pipe into the hole until the plug is encountered and placing a certain amount of weight on the plug to verify its placement and competency. The top surface plug must be a minimum of 100 feet and no less than 25 sacks of cement. The interval between plugs must be filled with drilling mud of a minimum weight of 9 pounds per gallon. After the casing has been cut off below the ground level, any void in the top of the casing must be filled. If a metal plate is welded over the top of the casing, weep holes should be drilled in the plate to vent the annular space.

A permanent abandonment marker is required on all wells unless otherwise requested by the SMA. This marker pipe is usually at least 4 inches in diameter, 10 feet long, 4 feet aboveground, and embedded in cement. The well identity and location must be permanently inscribed on the side of the pipe or on a cap placed on top of the pipe. The SMA is responsible for establishing and approving methods for surface rehabilitation and determining when the rehabilitation has been satisfactorily accomplished. At this point, a Subsequent Report of Abandonment can be approved.

## 5.2 Reclamation

An exploratory drilling location or an abandoned producing well location must be reclaimed according to requirements set forth by the BLM, the WOGCC, and stipulations in the original lease agreement. Once the drilling or production equipment is removed, the location and access road must be graded to original contours, pits properly closed and backfilled, and then the disturbed areas are revegetated with appropriate seed mixtures to enhance the reclamation of the area.

# 6.0 NEW TECHNOLOGIES

Drilling and production methods are constantly being improved to reduce costs and to more effectively produce oil and gas. Often new technologies create benefits for the environment. The following is a discussion of a number of new technologies that are being used or could be used in the planning area to improve production practices or help limit the impact to the environment. Innovative drilling and completion techniques have enabled the industry to drill deeper wells with fewer dry holes and to recover more reserves per well. Smaller accumulations once thought to be uneconomic can now be produced. Nationally, increased drilling success rates have cut the number of both wells drilled and dry holes. Advances in technology have boosted exploration efficiency and new advances are likely to continue this trend. Areas where significant progress has occurred and is expected to continue include the following:

- Computer power, speed, and accuracy;
- Remote sensing and image-processing technology;
- Developments in global positioning systems;
- Advances in geographical information systems;
- 3D and four-dimensional time-lapse imaging technology that permit better interpretation of subsurface traps and characterization of reservoir fluid,
- Improved borehole logging tools that enhance our understanding of specific basins, plays, and reservoirs; and
- Advances in drilling that allow more cost-efficient tests of undepleted zones in mature fields, testing deeper zones in existing fields, and exploring new regions.

These new technologies allow companies to target higher-quality prospects and improve well placement and success rates. As a result, fewer drilled wells are needed to find a new trap and production per well is increased. With fewer wells drilled, surface disturbance and volumes of waste, such as drill cuttings and drilling fluids, is reduced. An added benefit of improved remote sensing technology is the ability to identify hydrocarbon seeps.

Technological improvements have cut the average cost of finding oil and gas reserves in the U.S. The US Department of Energy (DOE) estimated finding costs at approximately $12 to $16 per barrel of oil equivalent in the 1970s. Currently, estimated finding costs are $4 to $8 per barrel.

## 6.1 Drilling and Completion

Advanced Resources International used industry guidance to determine an average time required to drill and complete a well for certain depth ranges. They predicted an average time of 40 days to drill and complete a well less than 10,000 feet deep, 65 days for wells between 10,000 and 14,000 feet deep, and 190 days for wells greater than 14,000 feet deep.

Drilling improvements have occurred in new rotary rig types, coiled tubing, drilling fluids, and wellbore condition monitoring during the drilling operation. Technology is allowing directional and horizontal drilling use in many applications. New bit types have boosted drilling productivity and efficiency. New casing designs have reduced the number of casing strings required.

The environmental benefits of drilling and completion technology advances include:

- Smaller footprints (less surface disturbance);
- Reduced noise and visual impact;
- Less frequent maintenance and workovers with less associated waste;
- Reduced fuel use and associated emissions;
- Enhanced well control for greater worker safety and protection of groundwater;
- Less time on site with fewer associated environmental impacts;
- Lower toxicity of discharges; and
- Better protection of sensitive environments and habitat.

### 6.1.1 Horizontal and Directional Drilling

Oil and gas wells traditionally have been drilled vertically. Depending on subsurface geology, technology advances now allow wells to deviate by anywhere from a few degrees to completely horizontal. Directional and horizontal drilling enable producers to reach reservoirs that are not located directly beneath the drilling rig. The capability to directionally drill has been useful in avoiding sensitive surface features. Drilling and completion costs for directional wells are higher than for conventional vertical wells. Because of this, the need for directional wells must be evaluated in regard to the increased costs. It would not be economical in all cases to a drill a directional well in lieu of a conventional vertical well.

Operators have used directional wells to avoid causing extensive surface disturbance and to try to reduce drilling and operating costs. Indications are that operators were only successful in reducing overall costs in some instances (when they could drill four or more wells from one surface location). Horizontal drilling can enhance production by increasing the amount of reservoir exposed to the well bore or in the case of production from natural fractures, allow the well bore to intercept more vertical fractures. The benefits from increased production can, in some cases, outweigh the added cost of drilling these wells. Recent advances in directional drilling have encouraged multilateral drilling and completion, enabling multiple offshoots from a single wellbore to radiate in different directions or contact resources at different depths. Multilateral drilling can increase well productivity and enlarge recoverable reserves, even in aging fields.

Environmental benefits of horizontal and directional drilling include the following:

- Fewer wells and surface disturbance;
- Lower waste volume; and
- Protection of sensitive environments.

### 6.1.2 Slimhole Drilling and Coiled Tubing

Slimhole drilling is a technique used to tap into reserves in mature fields. It has the potential to improve efficiency and reduce costs of both exploration and production drilling. Coiled tubing, used effectively for drilling in reentry, underbalanced, and highly deviated wells, is often used in slimhole drilling. In 1999, the DOE reported that a conventional 10,000-foot well in southwestern Wyoming costing $700,000 could be drilled for $200,000 by using slimhole and coiled tubing. It is expected that slimhole drilling and coil tubing technologies will be used more often in the future.

The DOE has identified several environmental benefits of using these techniques:

- Lower waste volumes;
- Smaller surface disturbance areas;
- Reduced noise and visual impacts;
- Reduced fuel use and emissions; and
- Protection of sensitive environments.

### 6.1.3 Light Modular Drilling Rigs

New light modular drilling rigs currently in production can be more easily used in remote areas and are quickly disassembled and removed. Components are made with lighter and stronger materials. The modular nature reduces surface disturbance impacts. Also, these rigs reduce fuel use and emissions.

### 6.1.4 Pneumatic Drilling

Pneumatic drilling is a technique in which boreholes are drilled using air or other gases rather than water or other drilling liquids. This type of drilling can be used in mature fields and formations with low downhole pressures and in fluid-sensitive formations. It is an important tool in drilling horizontal wells. This type of drilling significantly reduces waste, shortens drilling time, reduces surface disturbance, and decreases power consumption and emissions.

### 6.1.5 Improved Drill Bits

Advances in materials technology and bit hydraulics have yielded tremendous improvement in drilling performance. Latest-generation polycrystalline diamond compact bits drill 150 to 200 percent faster than similar bits several years ago. Environmental benefits include:

- Lower waste volumes;
- Reduced maintenance and workovers;
- Reduced fuel use and emissions;
- Less noise;
- Less time on site; and
- Enhanced well control.

Reducing the time a drilling rig spends on location reduces potential impacts on soils, groundwater, wildlife, and air quality.

### 6.1.6 Improved Completion and Stimulation Technology

Hydraulic fracturing of reservoirs enhances well performance, can minimize the number of wells drilled, and allows the recovery of otherwise inaccessible resources. However, traditional fracturing techniques have caused damage to the formations and subsequent loss in expected productivity. The flow of hydrocarbons is restricted in some low-permeability reservoirs and in unconventional resources (such as CBM), but can be stimulated by hydraulic fracturing to produce economic quantities of hydrocarbons. Fluids are initially pumped into the formation at high pressures that fracture the rock and followed by pumping a sand slurry into the fractures which props open the fractures, allowing hydrocarbons to enter the wellbore. Improvements such as $CO_2$-sand fracturing, new types of additives, and fracture mapping promise more effective fractures and greater ultimate hydrocarbon recovery.

## 6.2 Production

Once production commences, reservoir management is needed to ensure that as much hydrocarbon as possible is produced at the lowest possible cost, with minimal waste and environmental impact. In earlier days, recovery was only about 10 percent of the oil in a given field and sometimes the associated natural gas was vented or flared. Newer recovery techniques have allowed the production of up to 50 percent of the oil. Also, 75 percent or more of the natural gas in a typical reservoir is now recovered.

Operators have taken significant steps in reducing production costs. The DOE estimated that costs of production had decreased from a range of $9 to $15 per barrel of oil equivalent in the 1980s to an average of about $5 to $9 per barrel of oil equivalent in 1999. Since 1990, most reserve additions in the U.S., 89 percent of the oil reserve additions and 92 percent of the gas reserve additions, have come from finding new reserves in old fields. As of 1999, the DOE also reported that about half of the new reserve additions are from more intensive development within the limits of known reservoirs. They reported that the other half of the reserve additions were from finding new reservoirs in old fields and extending field limits. This section summarizes technologies and efficiencies that have helped reduce production costs and reduce impact on the environment.

### 6.2.1 Acid Gas Removal and Recovery

Before natural gas can be transported safely, any hydrogen sulfide or $CO_2$ must be removed. Special plants are needed to recover the unwanted gases and sweeten gas for sale. Improvements in the process have made it possible to produce sour natural gas resources, almost eliminate noxious emissions, and recover almost all of the elemental sulfur and $CO_2$ for later sale or disposal.

### 6.2.2 Artificial Lift Optimization

Improvements have enhanced production, lowered costs, and lowered power consumption, which reduces air emissions.

### 6.2.3 Glycol Dehydration

Dehydration systems use glycol to remove water from wet natural gas before it enters a pipeline. During operation, these systems may vent methane and other volatile organic compounds (VOCs) which may include hazardous air pollutants (HAPs). Improvements to these systems have allowed increased gas recovery and have reduced emissions of methane, VOCs, and HAPs.

### 6.2.4 Freeze-Thaw/Evaporation

A new freeze-thaw/evaporation process has been shown to be useful in separating out dissolved solids, metals, and chemicals that are contained in water produced from oil and gas wells. In 1998, this type of produced water facility was constructed for McMurray Oil Company (now Shell Oil) at

Jonah Field in southwestern Wyoming. Over the first winter, 17,000 barrels of water with a TDS content of 22,800 milligrams per liter (mg/l) was treated. It yielded 9,500 barrels of treated water and 5,900 barrels of brine solution (1,900 barrels were lost to evaporation and sublimation). The treated water (1,200 mg/l dissolved solids) was suitable for reuse in near-surface wellbore applications. The brine (66,900 mg/l dissolved solids) was suitable for reuse in deep drilling operations. In each of the following years (2000 and 2001), progressively greater amounts of treated water have been produced at this facility.

### 6.2.5 Leak Detection and Low-bleed Equipment

New technology is facilitating hydrocarbon leak detection and the replacement of equipment that bleeds significant gas, thus allowing increased worker safety, reduced methane emissions, and increased recovery and usage of valuable natural gas.

### 6.2.6 Downhole Oil/Water Separation

Emerging technology to separate oil and water could cut produced water volumes by as much as 97 percent in applicable wells. By separating the oil and water in the wellbore and injecting the water directly into a subsurface zone, only the oil needs to be brought to the surface. The new technology could minimize environmental risks associated with produced water handling, treatment, and disposal, and would reduce costs of lifting and disposing of produced water. In addition, surface disturbance could be reduced, oil production could be enhanced, and marginal or otherwise uneconomic wells could become producible.

### 6.2.7 Vapor Recovery Units

Vapor recovery can reduce a lot of the fugitive hydrocarbon emissions that vaporize from crude oil storage tanks, mainly from tanks associated with high-pressure reservoirs, high vapor releases, and large operations. The emissions usually consist of 40 to 60 percent methane, along with other VOCs and HAPs. Where useable, this technology can capture over 95 percent of these emissions.

### 6.2.8 Site Restoration

Regulatory agencies are allowing flexible risk-based corrective action (RBCA) as a process to ensure quicker and more efficient clean up of sites impacted by oil or other regulated substances. RBCA allows cleanup standards for soil, groundwater, and surface water to be customized to the environmental setting of a particular site. Sites where drinking water or other sensitive receptors may be at risk may have more stringent cleanup standards than sites where there is a low probability of impact. This allows for a case-by-case approach to site remediation rather than one cleanup standard for all sites, regardless of threat.

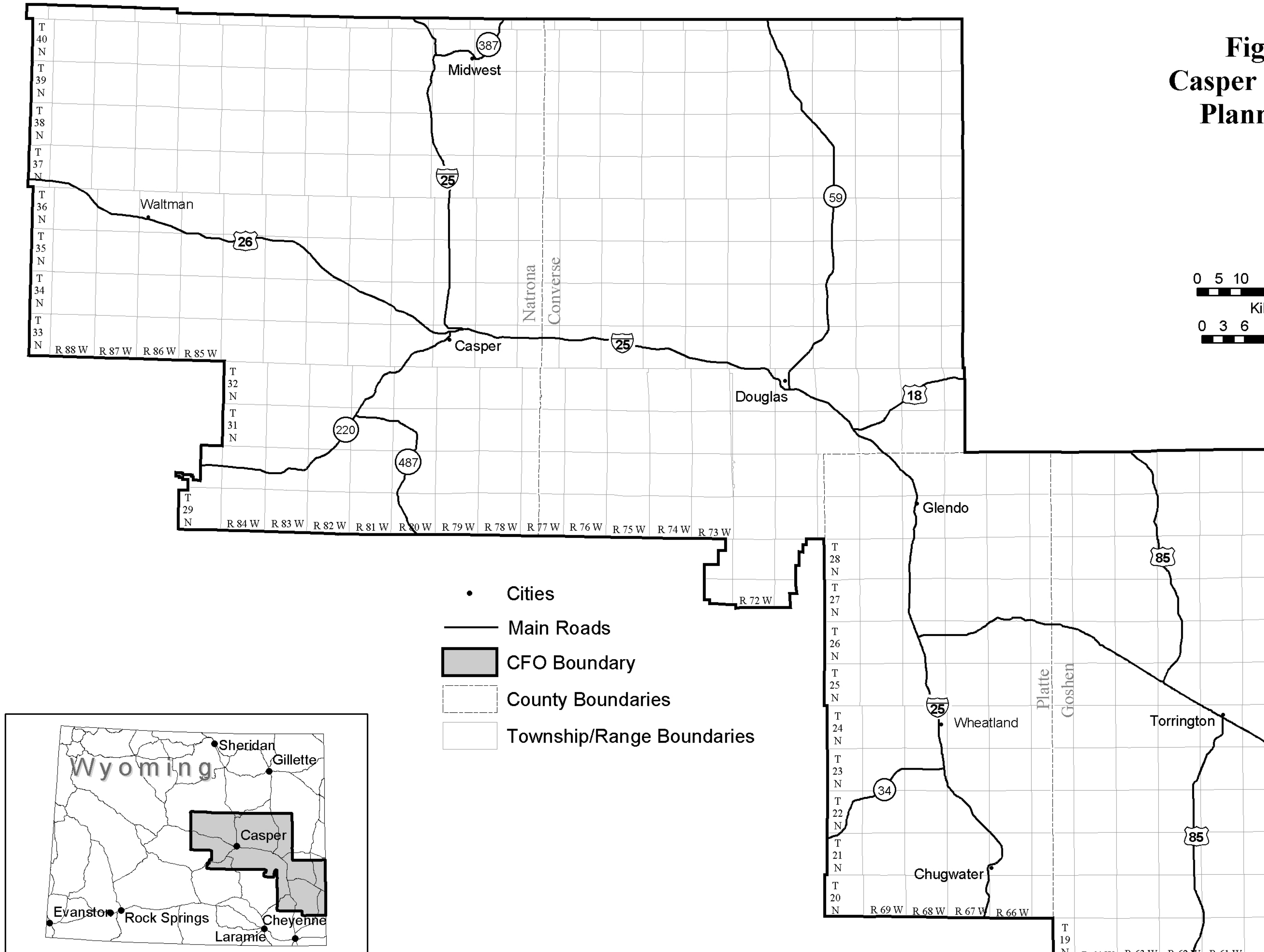
# APPENDIX B

# DATA SOURCES

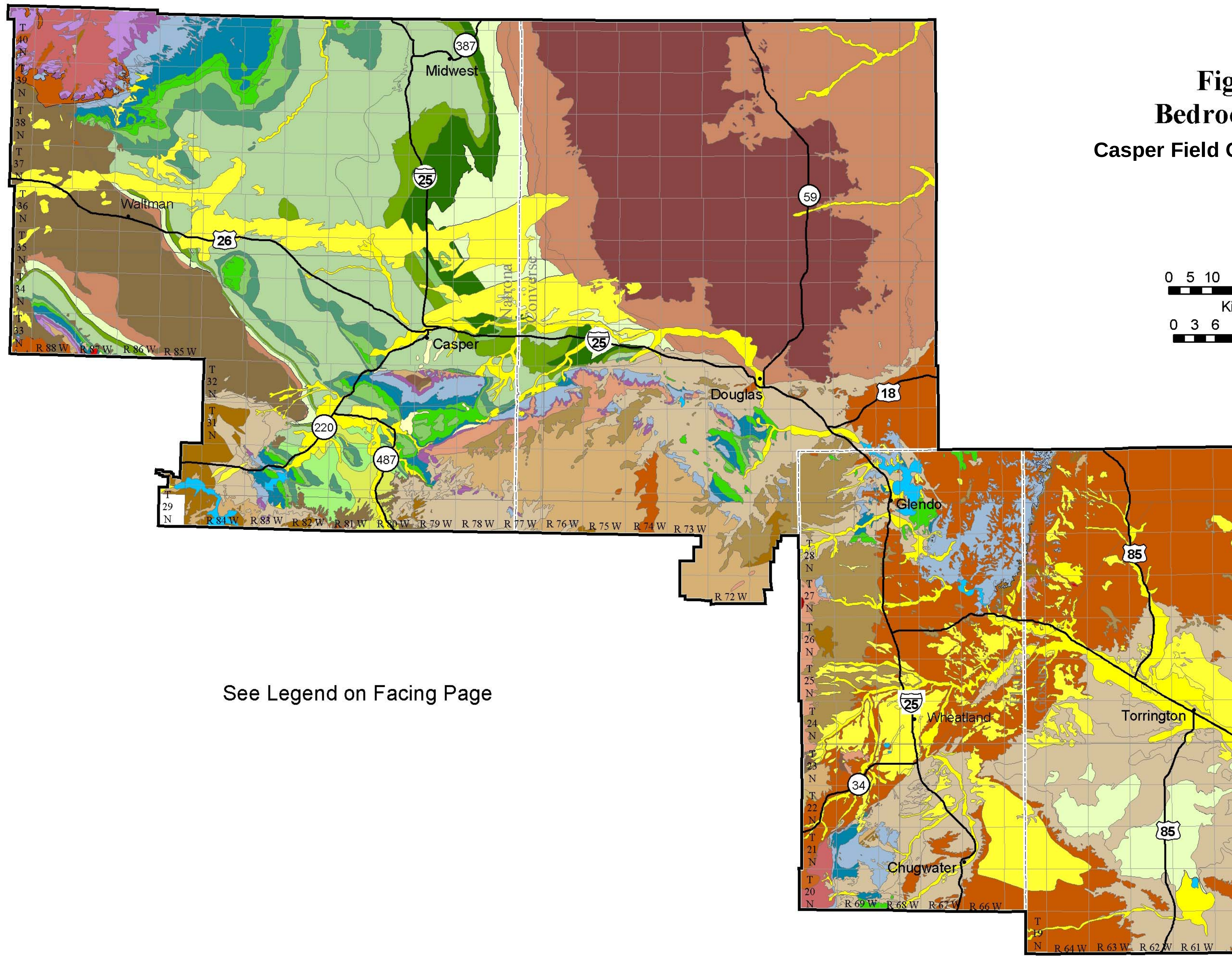
| *GIS Layer* | *Source* | *Metadata Available* | *Figures* |
|---|---|---|---|
| Casper Field Office Planning Area Boundary | BLM | Yes | 1-1, 2-2, 2-3, 2-5, 3-1, 3-2, 3-3, 3-4, 3-5, 3-9, 3-10, 3-11, 4-1, 4-2, 4-7 |
| Wyoming County Boundaries | BLM | Yes | 1-1, 2-2, 2-3, 2-5, 3-1, 3-2, 3-3, 3-4, 3-5, 3-9, 3-10, 3-11, 4-1, 4-2, 4-7 |
| Point Locations of Wyoming Cities | Tiger Data | Yes | 1-1, 2-2, 2-3, 2-5, 3-1, 3-2, 3-3, 3-4, 3-5, 3-9, 3-10, 3-11, 4-1, 4-2, 4-7 |
| Statewide Township/Range | GCDB | Yes | 1-1, 2-2, 2-3, 2-5, 3-1, 3-2, 3-3, 3-4, 3-5, 3-9, 3-10, 3-11, 4-1, 4-2, 4-7 |
| Tiger Mainroads | Tiger Data | Yes | 1-1, 2-2, 2-3, 2-5, 3-1, 3-2, 3-3, 3-4, 3-5, 3-9, 3-10, 3-11, 4-1, 4-2, 4-7 |
| Bedrock Geology | USGS | Yes | 2-2 |
| Surface Geology | USGS | Yes | 2-3 |
| Fault Locations - Lines | USGS | Yes | 2-5 |
| Fault Locations - Polygons | USGS | Yes | 2-5 |
| Dike Locations | University of Wyoming | Yes | 2-5 |
| Earthquake Locations | University of Wyoming | Yes | 2-5 |
| Locations of Solid Leasables | BLM | Yes | 3-1 |
| Locations of Fluid Leasables | BLM | Yes | 3-1 |
| 1995 Coal Development Potential (CDP) - Committed | Charlie Gaskill, BLM | Yes | 4-7 |
| 1995 CDP Uncommitted | Charlie Gaskill, BLM | Yes | 4-7 |
| 1995 CDP Unsuitable Development Areas | Charlie Gaskill, BLM | Yes | 4-7 |
| Mining Permit Areas | | Yes | |
| Potential exploitable minerals areas | U.S. Bureau of Mines | Yes | |
| Bentonite Locations | U.S. Bureau of Mines | Yes | 3-10 |
| Phosphorous Locations | U.S. Bureau of Mines | Yes | 3-10 |
| Potassium Locations | U.S. Bureau of Mines | Yes | 3-10 |
| Trona Locations | U.S. Bureau of Mines | Yes | 3-10 |
| Uranium Locations | U.S. Bureau of Mines | Yes | 3-10 |
| Authorized and Pending O&G Leases in the CFO | BLM - LR2000, Premier Data Services | Yes | 3-2 |

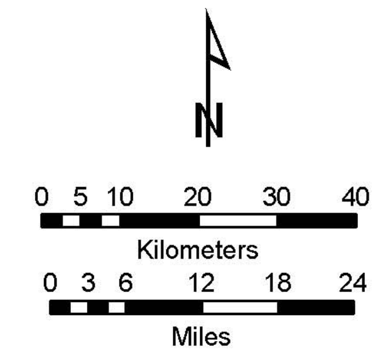
| *GIS Layer* | *Source* | *Metadata Available* | *Figures* |
|---|---|---|---|
| Wyoming Oil and Gas Wells | Wyoming Oil and Gas Conservation Commission | Yes | 3-5 |
| Wyoming Oil and Gas Fields - Polygons | Wyoming Geological Survey | Yes | 3-4 |
| Wyoming Oil and Gas Basins | Wyoming Geological Survey | Yes | 3-3 |
| Areas where CBM Exists | Wyoming Geological Survey | Yes | 3-4 |
| Areas where CBM Exists | Wyoming Geological Survey | Yes | 3-4 |
| Wyoming Oil and Gas Fields - Points | Wyoming Geological Survey | Yes | 3-4 |
| Limestone Occurrence | U.S. Bureau of Mines | No | 3-11 |
| Assessment of Undiscovered Oil and Gas Resources of the Denver Basin Province | USGS | Yes | |
| Petroleum Systems and Geologic Assessment of Oil and Gas in the Powder River Basin Province, Montana and Wyoming | USGS | Yes | |
| Powder River Basin Boundary | USGS | Yes | |

# Figure 1-1
# Casper Field Office Planning Area



# Figure 2-2
# Bedrock Geology
## Casper Field Office Planning Area



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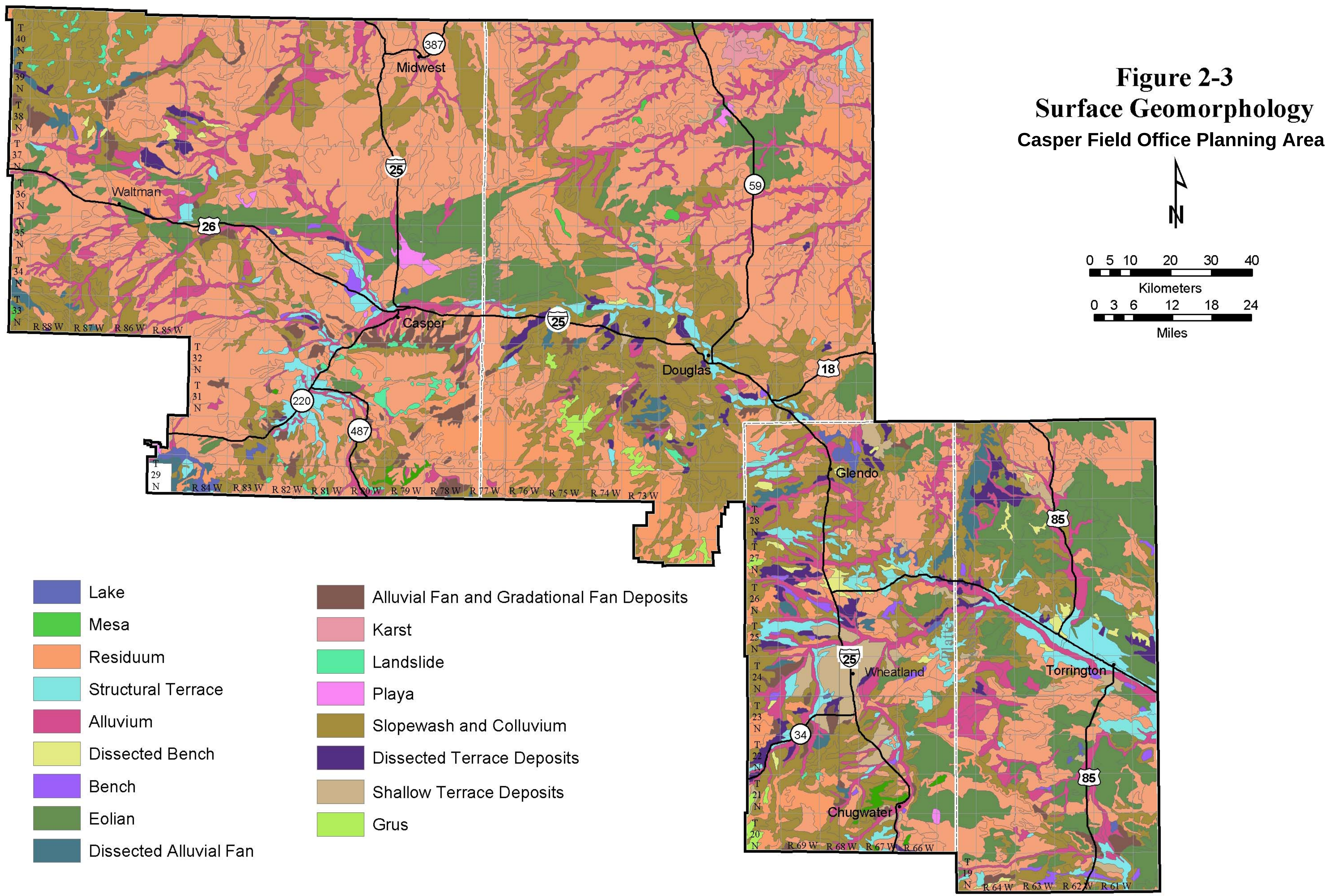
Figure 2-3
Surface Geomorphology
Casper Field Office Planning Area
N
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
Midwest
Waltman
Casper
Douglas
Glendo
Wheatland
Torrington
Chugwater
Lake
Mesa
Residuum
Structural Terrace
Alluvium
Dissected Bench
Bench
Eolian
Dissected Alluvial Fan
Alluvial Fan and Gradational Fan Deposits
Karst
Landslide
Playa
Slopewash and Colluvium
Dissected Terrace Deposits
Shallow Terrace Deposits
Grus

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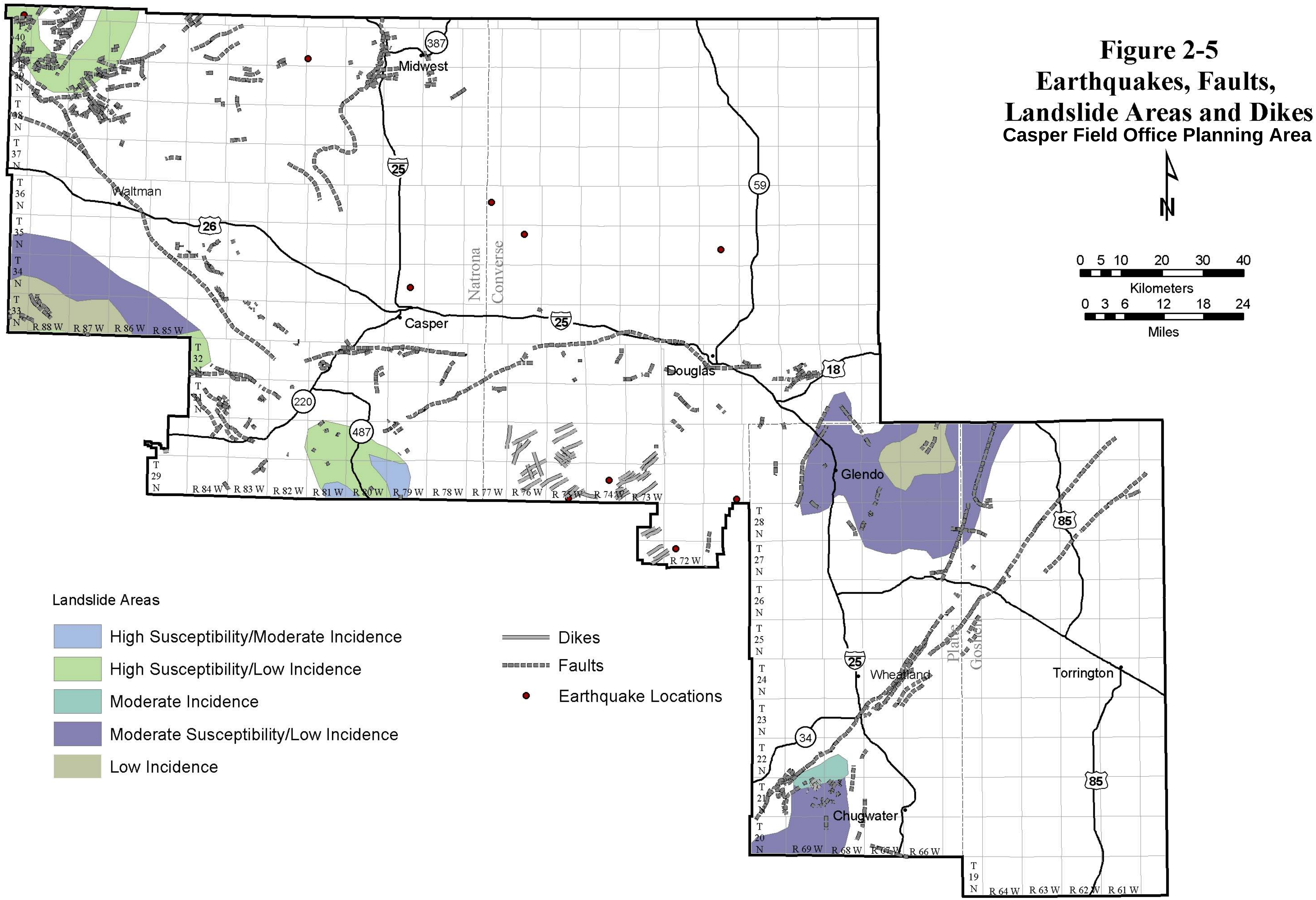
Figure 2-5
Earthquakes, Faults, Landslide Areas and Dikes
Casper Field Office Planning Area
N
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
Midwest
Waltman
Casper
Douglas
Glendo
Wheatland
Torrington
Chugwater
Natrona
Converse
Platte
Goshen
387
25
59
26
18
220
487
85
34
R 88 W
R 87 W
R 86 W
R 85 W
R 84 W
R 83 W
R 82 W
R 81 W
R 79 W
R 78 W
R 77 W
R 76 W
R 74 W
R 73 W
R 72 W
R 69 W
R 68 W
R 66 W
R 64 W
R 63 W
R 61 W
Landslide Areas
High Susceptibility/Moderate Incidence
High Susceptibility/Low Incidence
Moderate Incidence
Moderate Susceptibility/Low Incidence
Low Incidence
Dikes
Faults
Earthquake Locations

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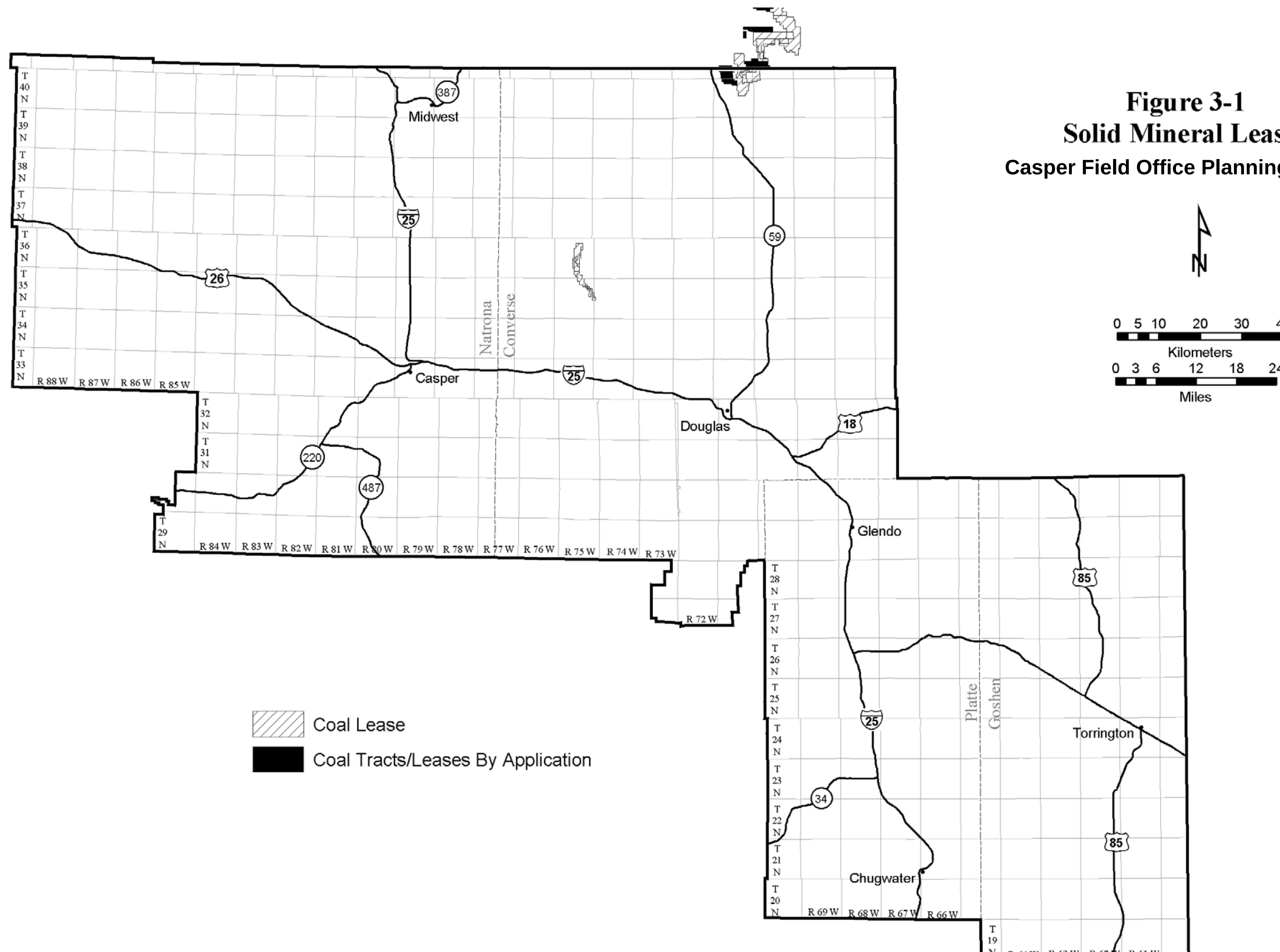
**Figure 3-1**
**Solid Mineral Leases**
**Casper Field Office Planning Area**



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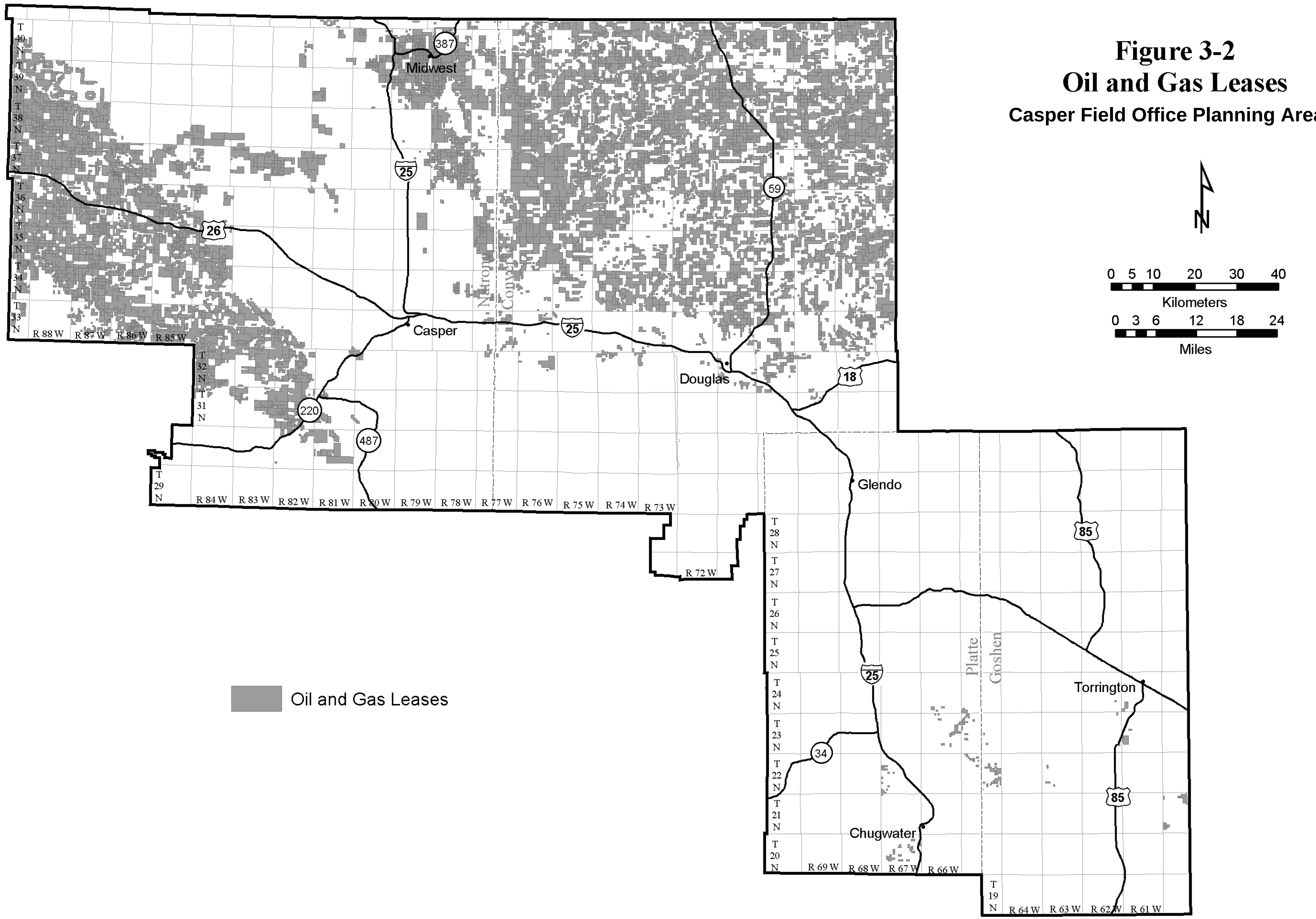
Figure 3-2
Oil and Gas Leases
Casper Field Office Planning Area
Midwest
Casper
Douglas
Glendo
Chugwater
Torrington
Natrona
Converse
Platte
Goshen
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
N
Oil and Gas Leases

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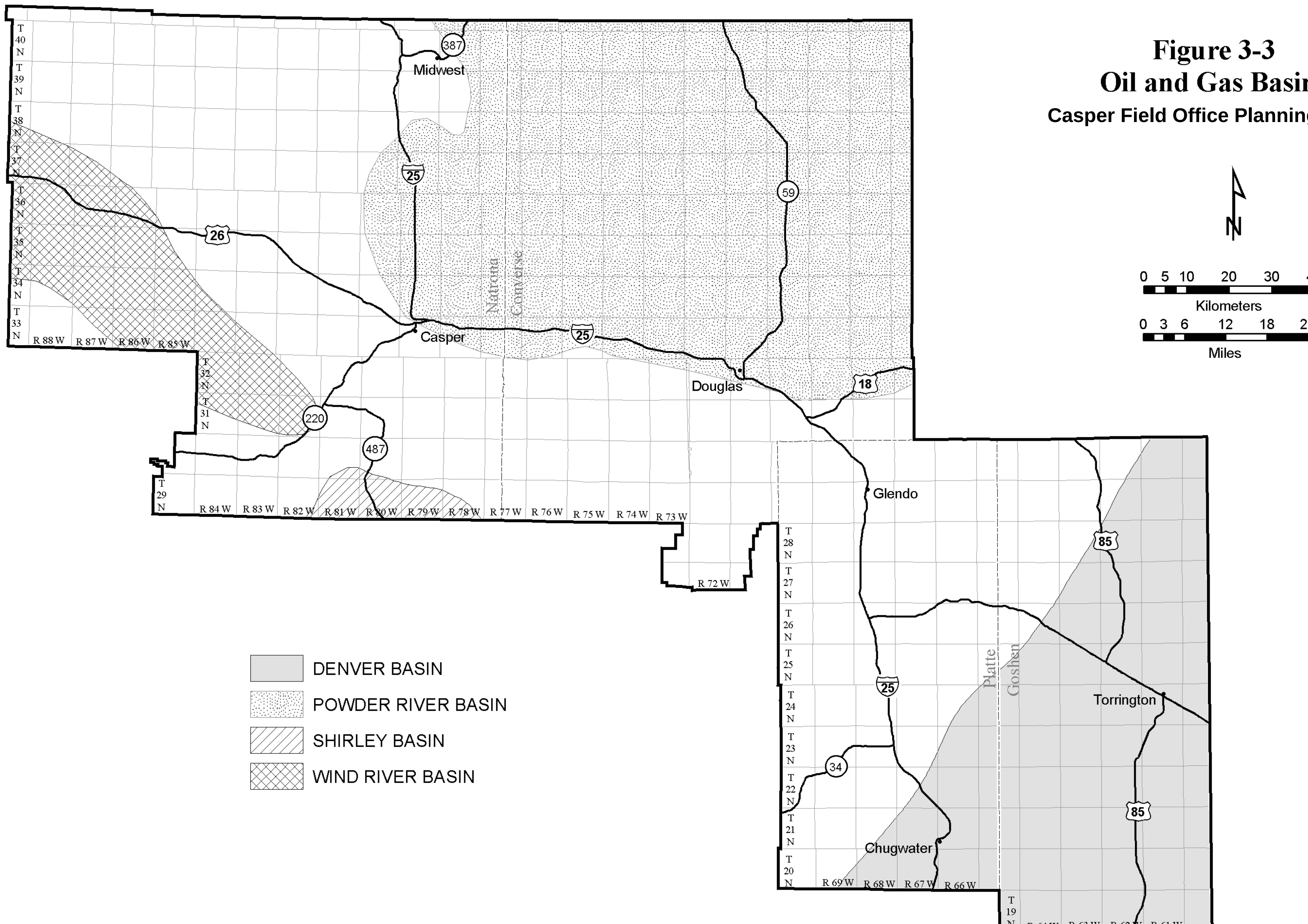
# Figure 3-3
# Oil and Gas Basins
## Casper Field Office Planning Area



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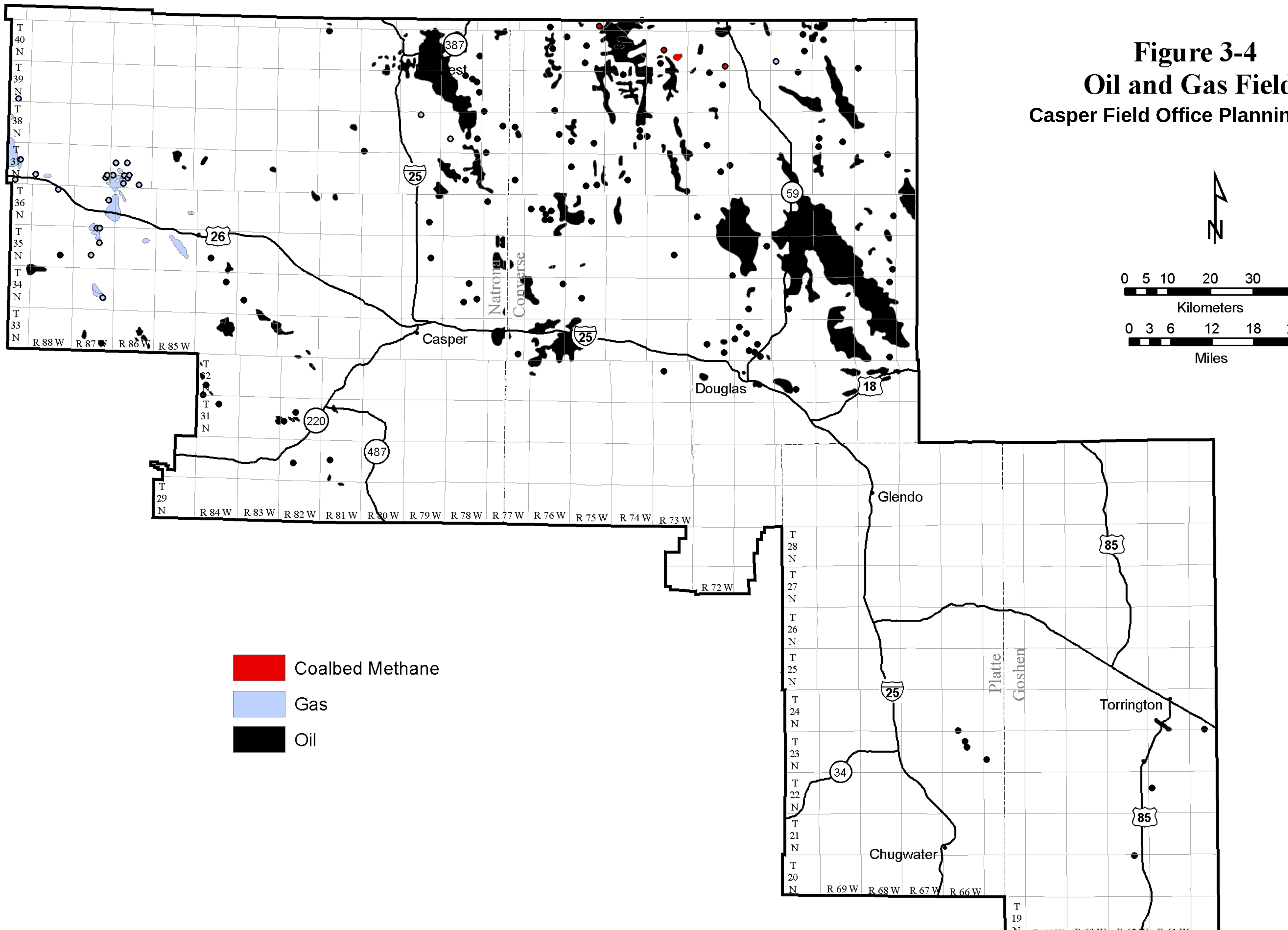


# Figure 3-4
# Oil and Gas Fields
## Casper Field Office Planning Area

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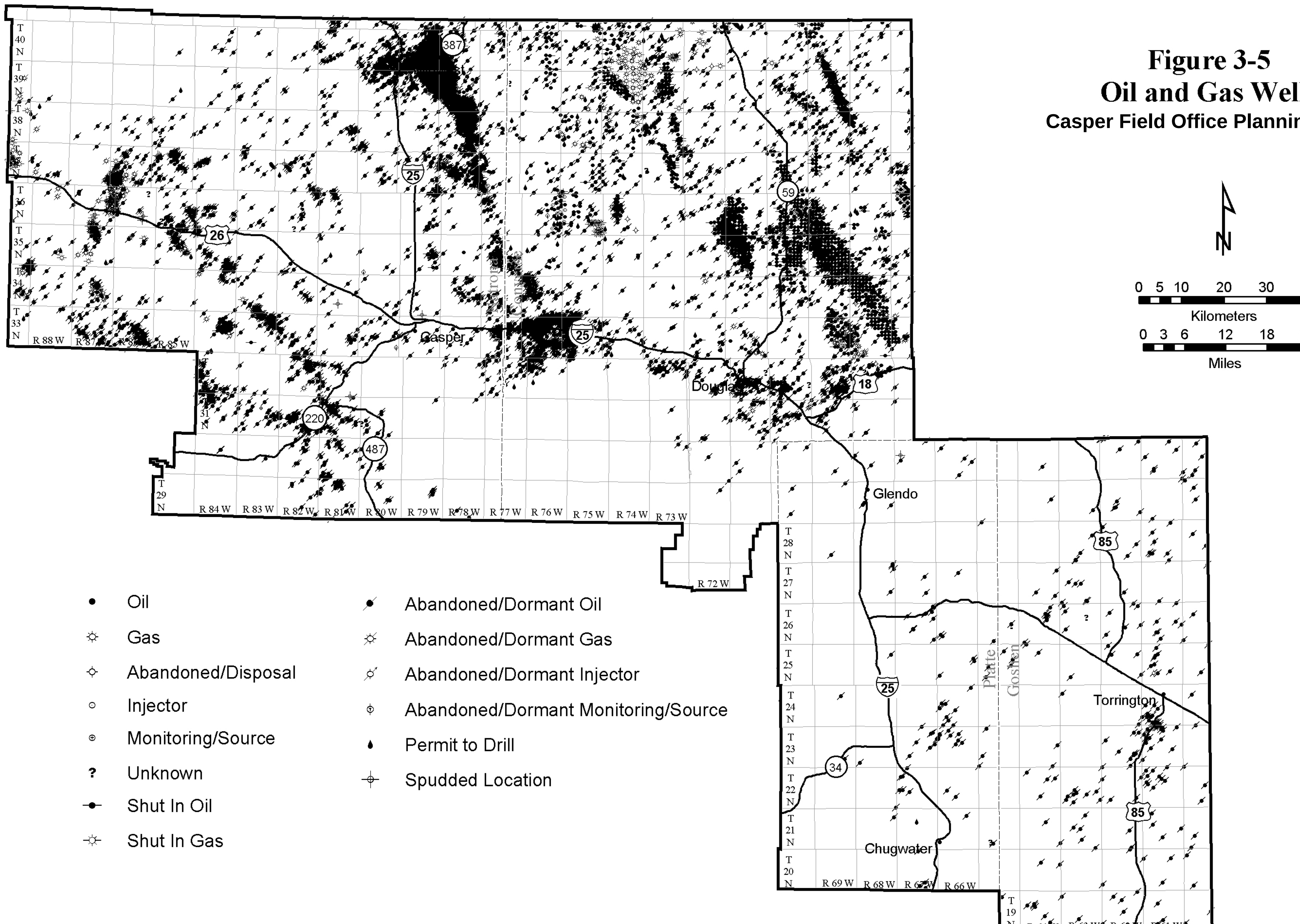
**Figure 3-5**
**Oil and Gas Wells**
**Casper Field Office Planning Area**



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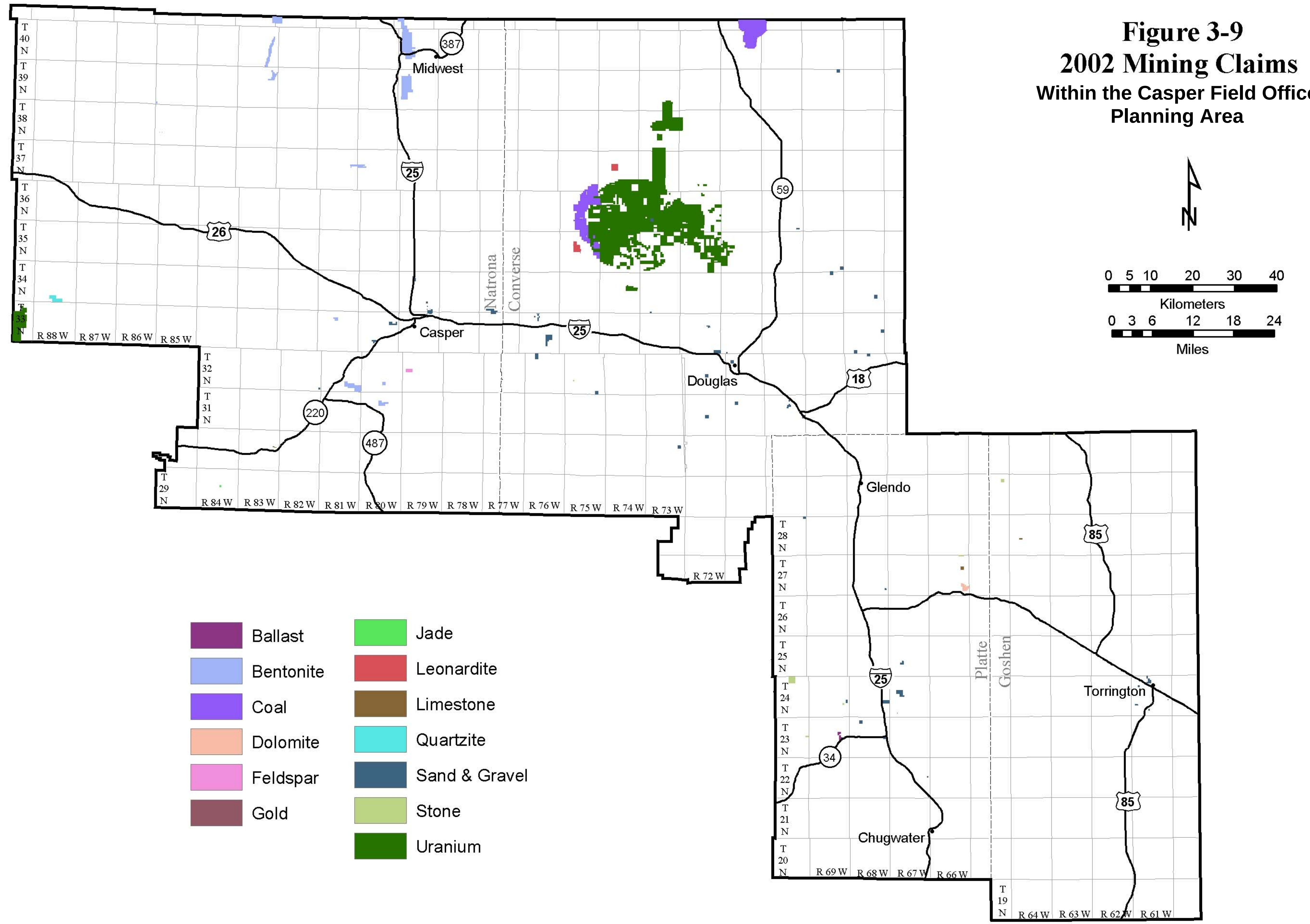

Figure 3-9
2002 Mining Claims
Within the Casper Field Office
Planning Area
N
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
Midwest
Casper
Douglas
Glendo
Torrington
Chugwater
Natrona
Converse
Platte
Goshen
387
25
26
59
220
487
18
85
34
Ballast
Bentonite
Coal
Dolomite
Feldspar
Gold
Jade
Leonardite
Limestone
Quartzite
Sand & Gravel
Stone
Uranium

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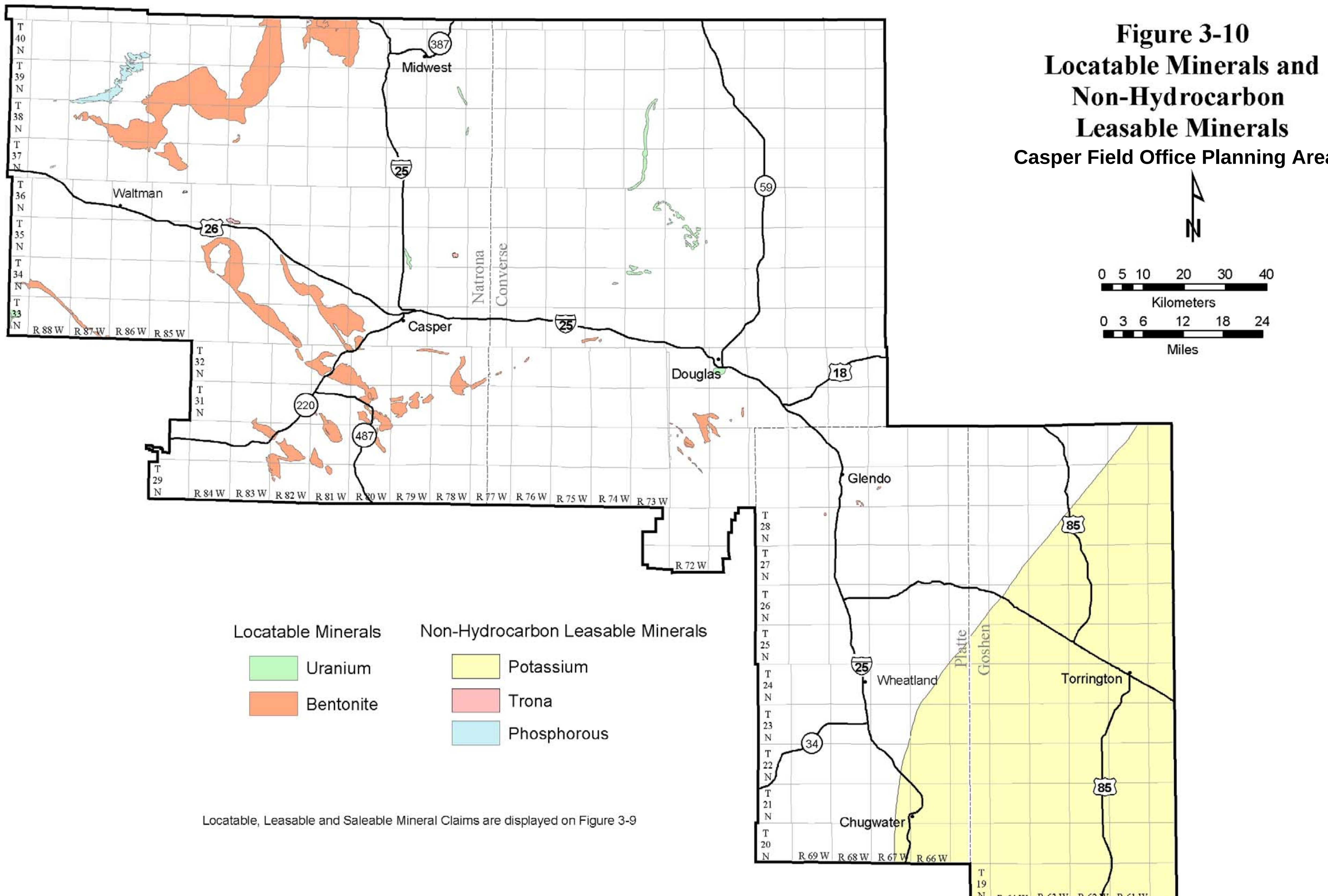
Figure 3-10
Locatable Minerals and
Non-Hydrocarbon
Leasable Minerals
Casper Field Office Planning Area
N
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
Midwest
Waltman
Casper
Douglas
Glendo
Wheatland
Torrington
Chugwater
Natrona
Converse
Platte
Goshen
Locatable Minerals
Uranium
Bentonite
Non-Hydrocarbon Leasable Minerals
Potassium
Trona
Phosphorous
Locatable, Leasable and Saleable Mineral Claims are displayed on Figure 3-9

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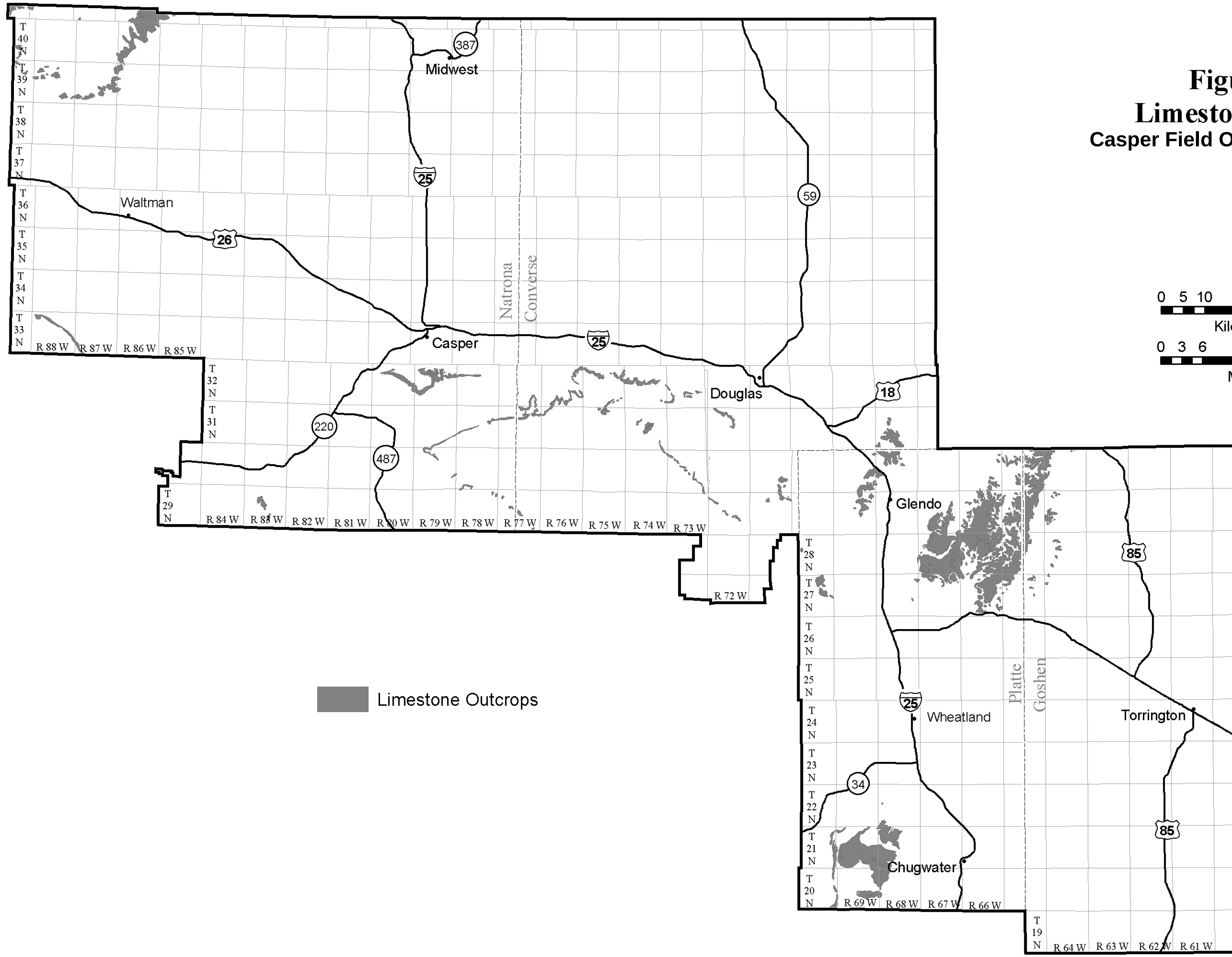


# Figure 3-11
# Limestone Outcrops
## Casper Field Office Planning Area

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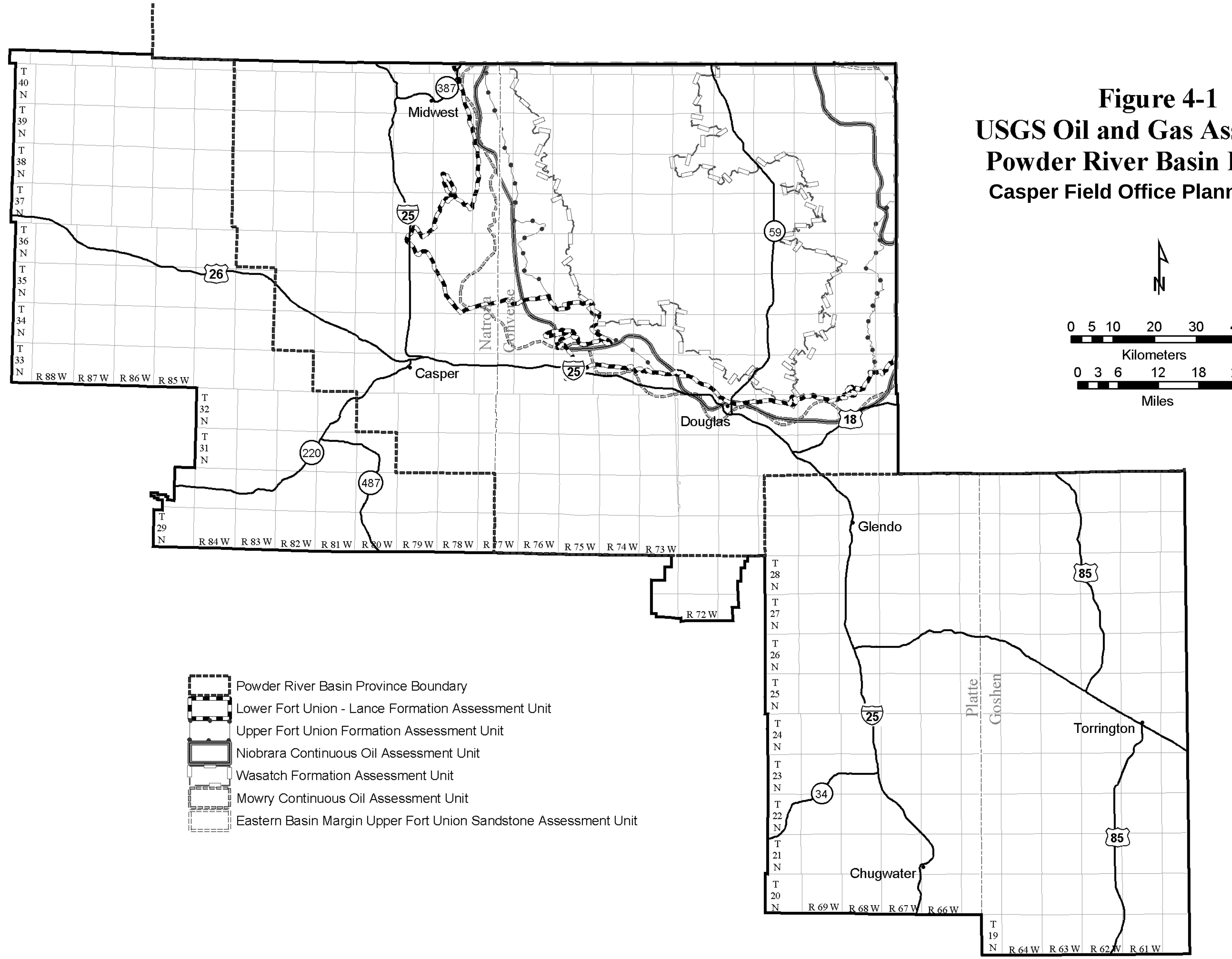
# Figure 4-1
## USGS Oil and Gas Assessment, Powder River Basin Province
### Casper Field Office Planning Area



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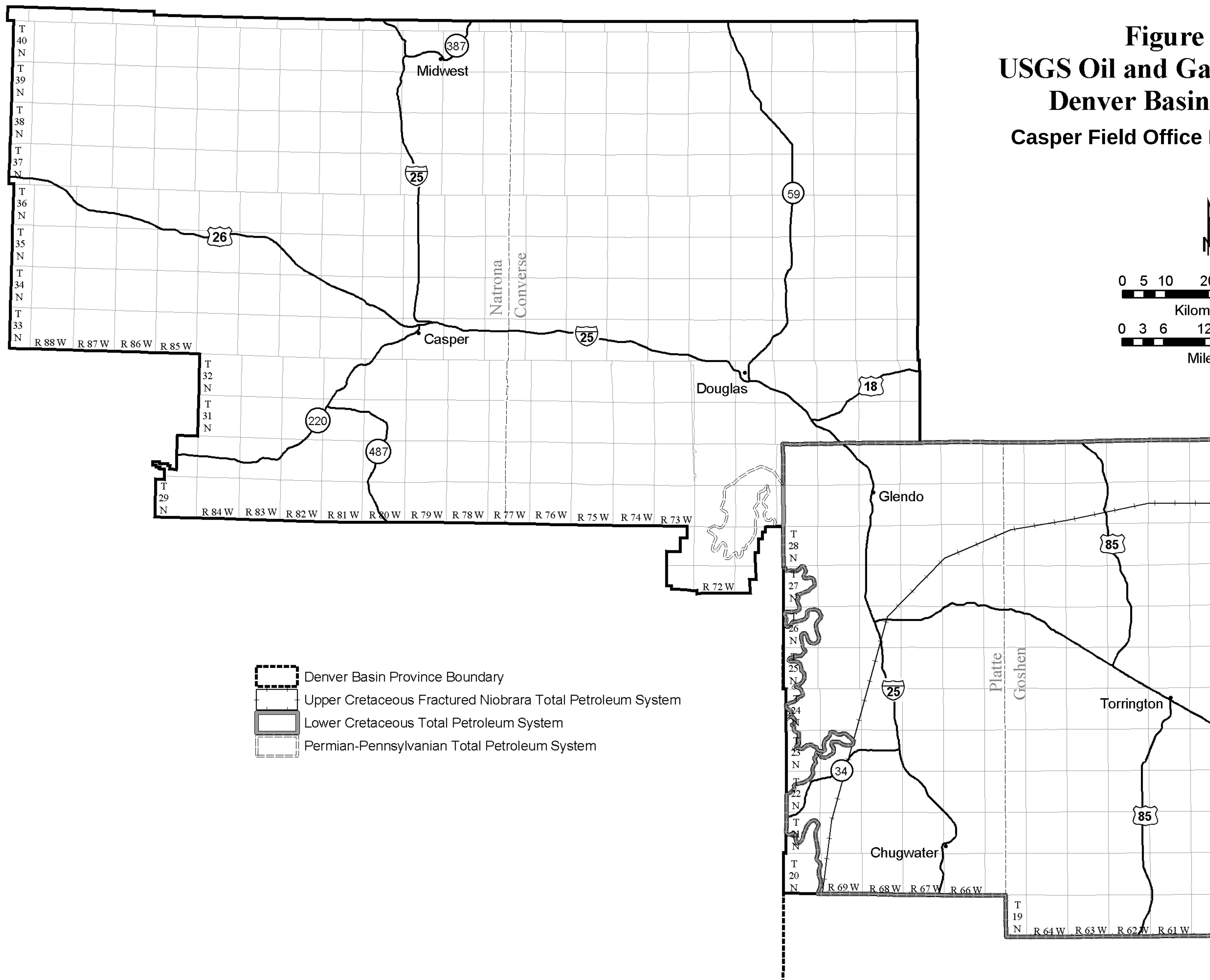
## Figure 4-2
## USGS Oil and Gas Assessment, Denver Basin Province
### Casper Field Office Planning Area



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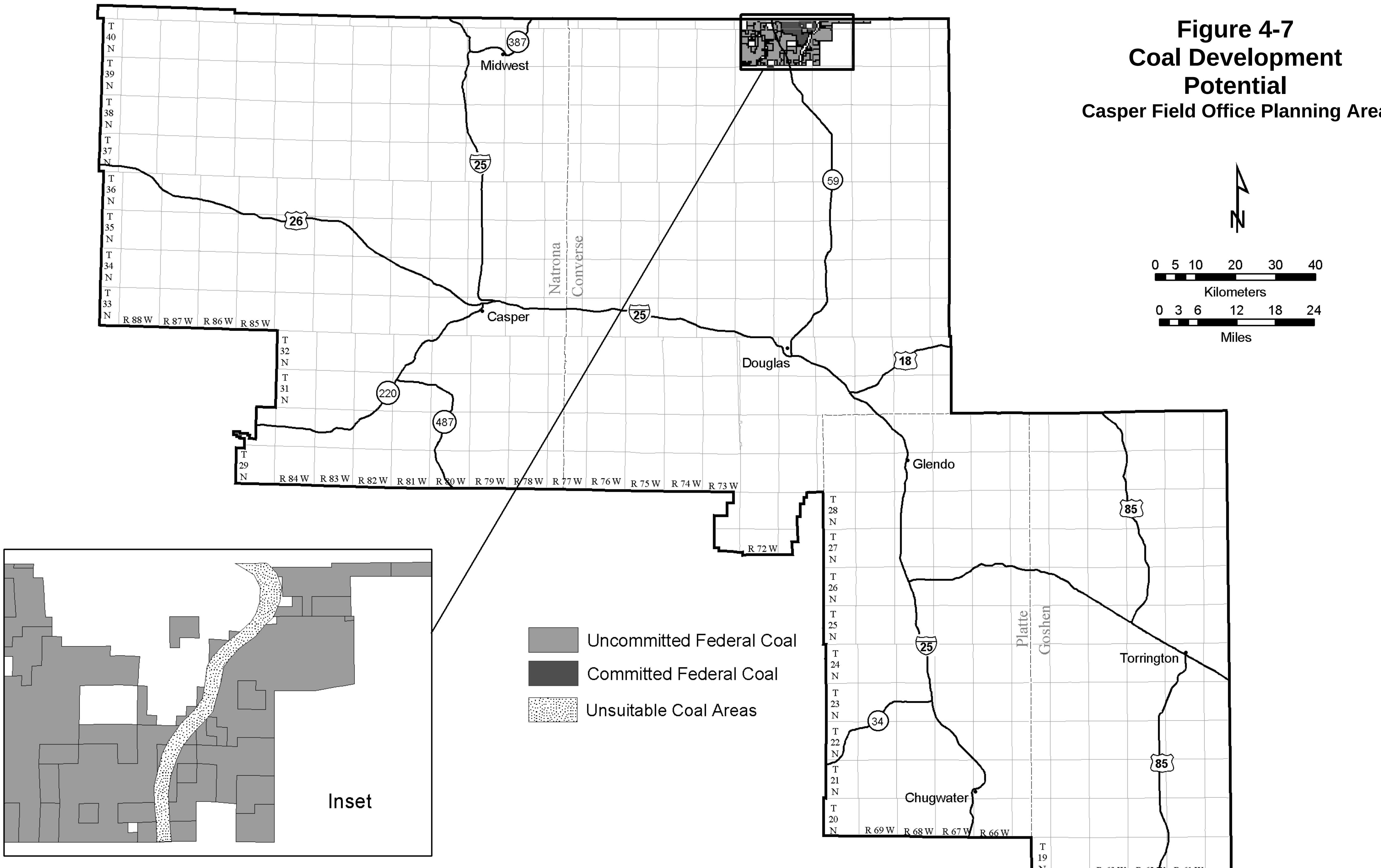
Figure 4-7
Coal Development Potential
Casper Field Office Planning Area
Uncommitted Federal Coal
Committed Federal Coal
Unsuitable Coal Areas
Inset
0 5 10 20 30 40
Kilometers
0 3 6 12 18 24
Miles
N
Midwest
Casper
Douglas
Glendo
Chugwater
Torrington
Natrona
Converse
Platte
Goshen
387
25
26
59
18
220
487
85
34
T 40 N
T 39 N
T 38 N
T 37 N
T 36 N
T 35 N
T 34 N
T 33 N
T 32 N
T 31 N
T 29 N
T 28 N
T 27 N
T 26 N
T 25 N
T 24 N
T 23 N
T 22 N
T 21 N
T 20 N
T 19 N
R 88 W
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