U. S. Department of the Interior

Bureau of Land Management
Lander Field Office, Wyoming

April 2009

Lander Field Office Planning Area

Final Mineral Occurrence and Development Potential Report

ACRONYMS AND ABBREVIATIONS

% percent
> greater than
< less than
ACEC Area of Critical Environmental Concern
ACL Alternate concentration limit
CAAA Clean Air Act Amendments
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
CBNG coalbed natural gas
CDP Coal Development Potential
CFR Code of Federal Regulations
CO_2 carbon dioxide
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
ISR in-situ recovery
mg/l milligrams per liter
MMBNGL million barrels of natural gas liquids
MMBO million barrels of oil
MMS Mineral Management Service
MSL mean sea level
MWD measurement while drilling
N/A not applicable
NEPA National Environmental PolicyAct
NGL natural gas liquids
NOI Notice of Intent
NOS Notice of Staking
ppm parts per million
PRI Power Resources Inc.
RBCA risk-based corrective active
RCT Regional Coal Team
RFD Reasonable Foreseeable Development
RMG Resource Management Group
RMP Resource Management Plan
SMA Surface Management Agency
SO_2 sulfur 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
WYDEQ Wyoming Department of Environmental Quality

FINAL MINERAL OCCURRENCE AND DEVELOPMENT POTENTIAL REPORT

Lander Field Office Planning Area

U. S. Department of the Interior

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April 2009

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

The 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) Lander, Wyoming Field Office (LFO). The RMP encompasses the vast majority of Fremont County, the southwest corner of Natrona county and minor portions of Sweetwater, Carbon, and Hot Springs 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 in 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 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). The report of the initial inventory reviewed federal oil and gas resources and constraints on their development in five basins in the Interior West. Following this initial assessment, further work published in December 2005 included assessment of the Wind River Basin (WRB), the majority of which lies within the Lander Planning Area (DOI et al. 2005). The 2005 results for WRB were used in preparation of this mineral occurrence and development report.

The Lander Field Office encompasses an area of 6.6 million acres. Of the 6.6 million acres, 4.7 million acres of federal mineral estate and 2.5 million acres of public lands are managed by the BLM. The Lander Field Office manages a wide diversity of resources and uses including National Historic Trails, the Continental Divide National Scenic Trail, historic mining areas, rock climbing, hiking, mountain biking, hang gliding livestock grazing and wild horses. The Lander Field Office also has trust responsibility for approximately 2.1 million acres of tribal and allotted mineral estate.

BLM mineral ownership within the Lander Planning Area is 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 Lander 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 remain above levels associated with other leasable, locatable, or salable minerals.

Mineral occurrence and development potential in the Lander Planning Area is associated with oil and gas, coal, coal-bed natural gas (CBNG), uranium, phosphate, bentonite, zeolites, gold, limestone, building stone, and sand and gravel production. Natural gas production from unconventional sources, such as CBNG, is projected to increase more rapidly than conventional production. Overall, oil and gas development in the WRB is expected to generally increase. The WRB 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. Commercial interests suggest good potential for the development of some oil and gas reserves.

Any possible demand for WRB coal (low occurrence potential) is expected to be affected by new environmental regulations expected to take effect in 2008. New regulations for the control of mercury could eliminate much of the current advantage of the low sulfur western coal. The Lander Planning Area is likely to experience an increase in uranium exploration activity and production levels of uranium.

Uranium and bentonite production is expected to increase in the near future. Other locatable mineral commodities including nephritic jade, iron, silver, copper, and tungsten are subject to market conditions that are not easily forecasted. 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 clay, limestone, shale, decorative or building stone, marble, and clinker are likely to see a growth rate similar to the growth of Wyoming's economy.

BLM Manual 3031 (Energy and Mineral Assessment) specifies that minerals be classified according to mineral potential (utilized to rank the potential for presence or occurrence, as opposed to the potential for development or extraction. This classification system rates potential for the occurrence of mineral resources in categories of high (H), moderate (M), low (L), and no potential (O). The potential classification is followed by a rating of the level of certainty of the data supporting the occurrence potential. Certainty levels range from A to D indicating increasing degrees of confidence in the evidence regarding the presence of a particular mineral occurrence. An "A" rating indicates insufficient data while a "D" rating indicates a high degree of certainty regarding the data.

The mineral resources that were reviewed in this report have been classified accordingly:

Mineral Resource	**Classification**
Leasable minerals	
Oil	H/D
Natural gas	H/D
Coal-bed natural gas	H/D
Coal	M/C
Phosphate	H/D
Locatable Minerals	
Uranium	H/D
Bentonite	M/C
Precious metals	H/D
Base metals	L/C
Jade	H/D
Opal	M/B
Agate	M/B
Salable Minerals	
All	H/D

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 Lander Planning Area will be developed during the resource management planning process.

1 INTRODUCTION

1.1 Purpose of Report

This Mineral Occurrence and Development Report is prepared to support the process of revising the Resource Management Plan (RMP) for the Bureau of Land Management (BLM) Lander, Wyoming Field Office. The RMP will encompass the area described in the report as the Lander Planning Area. The Mineral Occurrence and Development Potential Report provides an intermediate level of detail for mineral assessments as prescribed in BLM Manual 3021. Information provided in the report will be incorporated into the affected environment of the RMP and will form part of the environmental analysis in 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 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 resource 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. The Lander Planning Area includes a small portion of the Southwestern Wyoming basin. The five basins contain most of the onshore natural oil and gas and much of the oil under federal ownership within the lower 48 states (DOI et al., 2003).

Since EPCA required that all onshore federal lands be inventoried, the inventory was expanded from the original five basins 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 resource protection to the environment or promote appropriate resource development (DOI et al., 2003). Since the time of the release of the original five basins, additional basins have been assessed. In 2005, the assessment for the WRB was released (USGS, 2005). The EPCA results for the WRB were used in preparation of this mineral occurrence and development potential report.

The mineral occurrence and development potential report for the Lander Planning Area is organized into five chapters and one appendix. Chapter 2.0 summarizes geological resources as they relate to the development 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 Lander Planning Area and provides recommendations developed by BLM staff regarding the future development of leasable, locatable, and salable minerals for the planning period.

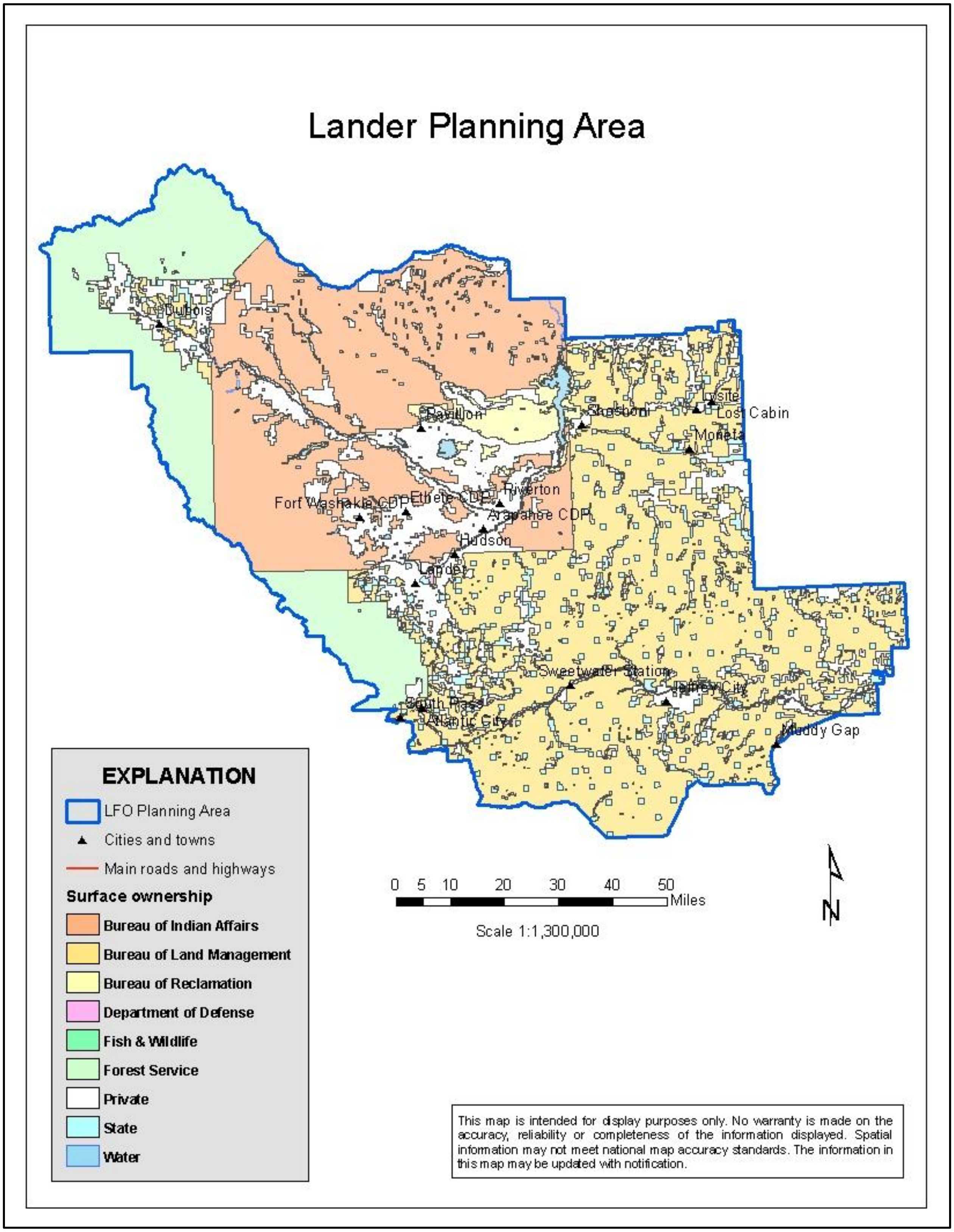
Chapter 5.0 lists references used in development of the report. Appendix A provides a description of oil and gas operations procedures.

1.2 Lands Involved and Record Data

The Lander Planning Area is located in west-central Wyoming, encompassing the vast majority of Fremont County, the southwest corner of Natrona county and minor portions of Sweetwater, Carbon, and Hot Springs counties (Figure 1-1).

The Lander Planning area encompasses 6.6 million acres. Of these 6.6 million acres, the Lander Field Office manages 2.5 million surface acres of public land and approximately 2.7 million acres of federal mineral estate. The remainder of the federal land in the planning area is divided among the Bureau of Reclamation (290,000 acres), and the Shoshone National Forest (850,000 acres). Of the non-federal land, 2 million acres are within the Wind River Indian Reservation, 700,000 acres are privately owned, and 300,000 acres are owned by the State of Wyoming.

Figure 1-1 Lander Field Office Planning Area.



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2 AREA PROFILE

2.1 Physiography

The Lander Planning Area lies within the regional geologic provinces of the Wyoming plains and Rocky Mountains. Igneous, metamorphic and sedimentary rocks of all geologic periods, except Silurian, are present and represent a time span from 3 billion years to the very recent—10,000 years before present. The geologic setting is one of basin, separated and surrounded by mountain ranges. The mountain ranges include the Owl Creek, Washakie, Absaroka, Wind River, Granite, and Rattlesnake ranges. Basins include most of the Wind River, and the northern portion of the Great Divide basin (Figure 2-1).

The Lander Planning Area is more or less contained within the boundary of the larger Wind River basin (WRB), a representative example of the numerous structural and sedimentary basins which formed in the Rocky Mountain region in response to Laramide-age tectonic activity (Keefer, 1965). The WRB is a physiographic as well as a structural basin, with drainage primarily out of the basin to the north and southeast, with the bulk of the stream flow originating in the high country of the Wind River Range. Streams flowing out of the Lander Planning Area actually contribute to two major drainages- the Missouri River drainage which ends up in the Gulf of Mexico, and much less significantly, the Snake River drainage, tributary to the Columbia River system which ends up in the Pacific Ocean.

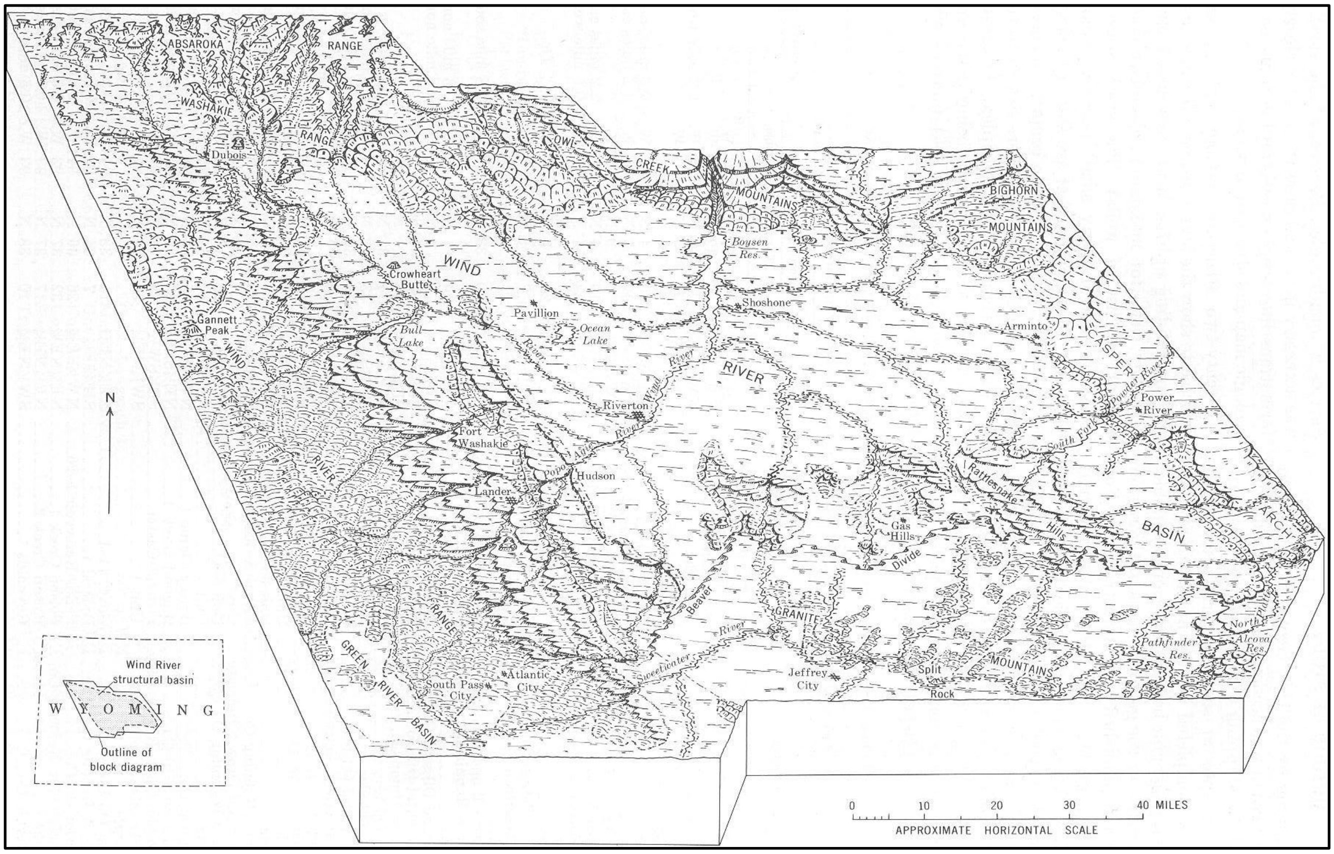
Several major streams of the Missouri River drainage drain the Lander Planning Area. These include streams of the Wind River System, such as the Wind River, the Little Wind River, and the North, Middle and Little Forks of the Popo Agie River, The Wind River flows north out of the Wind River Basin, through the Owl Creek Mountains, where it is renamed the Big Horn River as it emerges from the north side of the canyon. The Bighorn River continues to flow north, and eventually connects to the Yellowstone River, which is tributary to the Missouri River. The Sweetwater River drains the southern portion of the Lander Planning Area from South Pass east to Pathfinder Reservoir, where it meets the North Platte River, tributary to the Missouri River. Beaver Divide separates surface water which flows into the Wind River watershed from surface water which flows into the Sweetwater River watershed.

Near Dubois, Fish Creek drains about 30 sq. miles of the Lander Planning Area to the west. The waters of Fish Creek flow to the Gros Ventre River, which in turn, makes confluence with the Snake River near Jackson, Wyoming. There is also a very small portion of the Lander Planning Area which is drained north to the Power River Basin. This is by about a 1/2 mile stretch of Wallace Creek in the Rattlesnake Hills in Section 6; T 32 N. R 87 W. Wallace Creek is tributary to the South Fork of the Powder River, which connects to the Powder River, which in turn is tributary to the Yellowstone River.

2.2 Structure

The configuration of structural geologic features of the WRB which impact the nature and occurrence of mineral resources presently found in the Lander Planning is closely controlled by events dating back to the Laramide orogeny. During the latest part of the late Cretaceous Period, tectonic activity that represented the initial stages of the Laramide orogeny began in the form of down warping of the basin and broad doming of other areas peripheral to the basin (Keefer, 1970). These structural events and those occurring during the bulk of the Laramide event, exerted significant influence on the style and pattern of sedimentation during all subsequent Tertiary time (Keefer, 1965).

Figure 2-1 Physiography of the Lander Planning Area vicinity.



Source: Keefer (1970).

A major feature of the Laramide-age deformation is the Wind River uplift. This uplift is responsible for the Wind River Range and started as a large fold, and as movement progressed, deformation continued as faulting where the upper crust acted as a rigid slab and the lower crust behaved more fluidly (Smithson et al., 1979). Crustal shortening occurred as a result of predominately horizontal movement. This compression and resulting shortening along moderately dipping thrust faults can be related to plate movements during the Laramide orogeny (Brewer et al., 1980). The modern topographic Wind River Range is underlain by a large, doubly plunging, asymmetrical anticline cored by Archean crystalline rocks. The axis of this folded belt of rocks was breached by erosion exposing the crystalline core of the uplifted block as displayed in the central part of the Wind River Range.

Parallel to and towards the center of the basin from the mountain uplifts are many smaller structures such as the asymmetrical syncline in which the town of Lander is sited. On the west margin of the basin, the Sheep Mountain anticline, Lander-Hudson anticline, Derby Dome, and Dallas Dome are examples of smaller anticlinal features from which oil and gas are produced. In fact, the first commercial oil well in Wyoming was at Dallas Dome, located on the western edge of the WRB, about 8 miles south of Lander. Many significant anticlines are unconformably covered with several hundred feet of younger, flat-lying sediments, generally of Tertiary age. Numerous faults of all variations are found in the Lander Planning Area. Over-thrusting along major faults throughout the resource area represents good prospects for future oil and gas exploration.

2.3 Stratigraphy

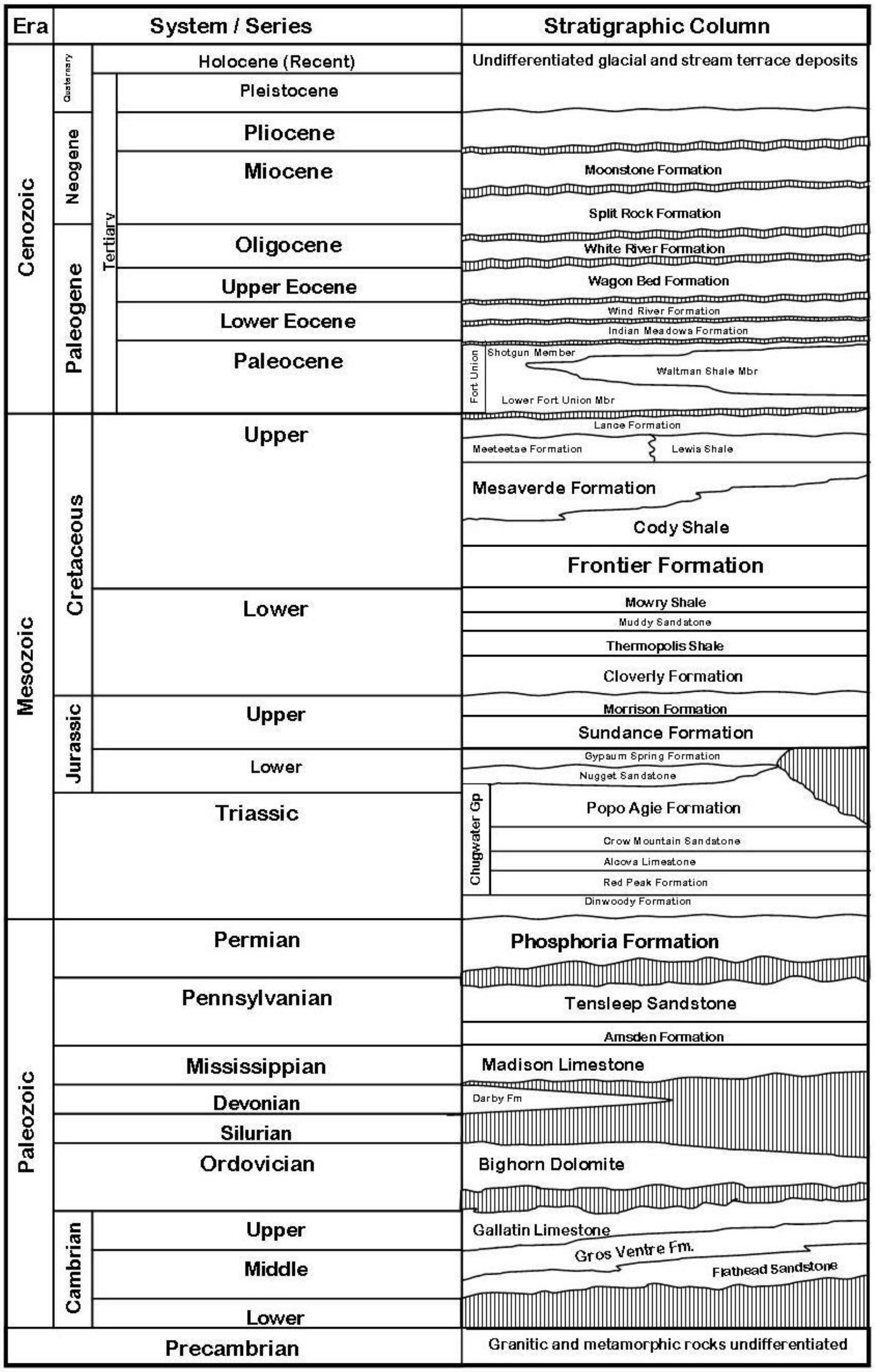
This section describes the historical geology of the Lander Planning Area. Rocks can be roughly split into two main divisions based on their supposed ages: the pre-Cambrian eon, and the later Phanerozoic eon, which is the current eon in the geologic timescale. Phanerozoic time began 542 million years before present (B.P.), and is the eon during which abundant animal life has existed. Though the use of the term pre-Cambrian is currently discouraged by the scientific community in favor of more exact terms, this document will retain the usage of the term to describe all rocks originating before Phanerozoic time.

Rocks in the Lander Planning Area range in age from Pre-Cambrian to Recent (Figure 2-2). Rocks from practically every Phanerozoic time period save for the Silurian (408 to 438 million years ago) are present. Pre-Cambrian rocks generally consist of crystalline and metamorphic rocks exposed mostly in the core of uplifted areas, usually near the periphery of the basin, while Phanerozoic rocks include various kinds of sandstones, siltstones, carbonates, shales, and mudstones. Within the WRB, the thickest accumulation of Phanerozoic sedimentary rocks is generally in the range of 20,000 to 30,000 feet. Tertiary-age sediments, generally of Eocene age, cover most of the central basin floor and in places abut crystalline rock exposures, as in the Granite Mountains area. Paleozoic and Mesozoic sedimentary rocks are exposed most often where structural conditions permit (along mountain fronts, uplifts, eroded canyons, etc).

2.3.1 Pre-Cambrian Eonothem

The Pre-Cambrian “super-eon” is an informal name for the time span which comprises the eons of the geologic time scale that came before the current Phanerozoic eon. It spans from the formation of the Earth about 4.5 billion years B.P. to approximately 542 million years B.P. The pre-Cambrian eonothem refers to all rocks which originated during that time span. It is generally broken up into three eons (from earliest to youngest: the Hadean, the Archean, and the Proterozoic eons.

Figure 2-2 Generalized stratigraphic column for the Lander Planning Area



The pre-Cambrian rocks exposed in the Lander Planning Area are found in several main areas including the Wind River Range, the Owl Creek Mountains, the Sweetwater uplift (Granite Mountains), Rattlesnake Hills, South Pass, and also smaller exposures including the Sweetwater Crossing anticline, and in the Ramshorn area north of Dubois. These rocks by and large consist of crystalline rocks of granite composition and especially in the South Pass area, metamorphosed crystalline and sedimentary rocks that have been re-melted, sheared, and otherwise affected by temperature and pressure due to forces within the crust.

2.3.2 Paleozoic Era

From Paleozoic time until Late Cretaceous time, the present site of the WRB was part of the foreland or stable shelf region where rocks up to that time were deposited during transgressions and regressions of epicontinental seas across the region (Keefer and Van Lieu, 1966).

Rocks from practically every geologic period save for the Silurian (408 to 438 million years ago) are present. Where the rock record is complete, these ancient incursions are typically represented by a transgressive marine sequence, including a basal sandstone unit (near shore deposits), middle shale unit (off-shore mud), and upper limestone unit (deeper water sediments).

Subsequent erosion can remove any one or more of the members of a complete sequence, so that the stratigraphic column does not always reflect the ideal configuration as described above. Even when the units occur in the described order, there can be significant lateral inter-fingering of successive layers.

Paleozoic and Mesozoic foundations are exposed along the flanks of the several anticlines throughout the resource area. Inasmuch as this is the case, studies have shown that basins of central Wyoming were once filled with thick sequences of post-lower Eocene rocks that buried all but the highest mountain ridges. These package of rocks, perhaps 3,000 feet thick, have almost been completely removed by erosion in the basin proper, leaving lower Eocene and younger rocks at land surface (Keefer, 1970).

2.3.2.1 Cambrian System

The Cambrian System includes all rocks formed during the span of geologic time generally accepted as 542 to 488 million years B.P. These rocks, listed in ascending stratigraphic order from the bottom, include the Flathead Sandstone, the Gros Ventre Formation, and the Gallatin Limestone, all of which comprise a complete transgressive sequence of rocks deposited during the middle to late Cambrian time. This sequence varies in thickness depending upon location but is readily observable in the Wind River Range where thicknesses of the entire sequence can be as large as 1200 feet.

Each of the rock units are described in the following sections based on information provided in Keefer and Van Lieu (1965).

2.3.2.1.1 Flathead Sandstone

The Flathead Sandstone unconformably overlies the older Precambrian basement, and consists of a pink reddish brown tan and gray, fine to coarse-grained sandstone, averaging perhaps 200 feet in thickness. The basal beds are commonly conglomeratic and arkosic especially where the contact overlies massive granite and granite gneiss.

2.3.2.1.2 Gros Ventre Formation

The contact of the Gros Ventre Formation and underlying Flathead Sandstone is conformable and gradational and can inter-finger laterally. The boundary is usually designated at the top of the uppermost persistent sandstone in the Flathead. The Gros Ventre Formation consists of multiple units consisting of a shale and shaly sandstone (Wolsey Shale Member), and middle thin-bedded limestone (Death Canyon Limestone), and an upper shale and limestone unit (Park Shale). In most places the Gros Ventre Formation is generally a slope former divided in the middle by the vertical cliffs of the limestone unit. The Wolsey Shale is about 100 feet thick and consists of greenish-gray to tan or pink, micaceous sandy shale and very fine-grained shaly sandstone often containing abundant glauconite.

The Death Canyon Limestone is somewhat over 200 feet thick and is characterized by cliff-forming thin--bedded gray crystalline (micritic) limestone. The upper Park Shale member consists of well over 400 feet of soft greenish-gray, micaceous shale with varying amounts of thin gray limestone beds increasing in abundance towards the top. Aggregate thickness of the Gros Ventre Formation is variable, but can be over 700 feet in some places.

2.3.2.1.3 Gallatin Limestone

The youngest unit of the Cambrian System is the Gallatin Formation, Late Cambrian in age, which consists of thick resistant cliff-forming limestone often separated by an intervening shaly bed. The appearance of the Gallatin Limestone can vary but is generally thin-bedded to thick-bedded, gray in color, with tan colored mottling.

2.3.2.2 Ordovician System

The Ordovician System includes rocks deposited in the time span between 488 and 443 million years B.P. The geologic history of Early Ordovician time is unclear but it is thought that at some point near the beginning of Middle Ordovician, the entire region was once again inundated by seawater deep enough for the accumulation of carbonate sediments.

The contact with rocks of the Cambrian System is erosional, and varies in places with respect to the degree of rock record thought to be missing. Overall, however, the contact shows little evidence of the considerable amount of time between the Late Cambrian (Gallatin Limestone) and the Middle Ordovician Bighorn Dolomite. Therefore the hiatus may be more representative of a break in deposition rather than a subsequent stripping of deposits that may have been present in that time period between Late Cambrian and Middle Ordovician.

2.3.2.2.1 Bighorn Dolomite

The Ordovician System is represented by the Bighorn Dolomite which in the WRB consists of basal light-gray sandstone, a middle massive buff-colored dolomite, and an upper thin-bedded white to gray, limey dolomite, ranging in age from Middle to Late Ordovician. On the east flank of the Wind River Range, the basal sandstone member is referred to as the Lander Sandstone due to exposures in Sinks Canyon about 5 feet in thickness. One of the more conspicuous identifying features of the Bighorn Dolomite is the weathering pattern, where the gray massive middle section displays a very rough pitted surface.

The uppermost member, called the Leigh Dolomite, typically forms a recessed white band along cliff faces and can be as thick as 85 feet in places. Aggregate thickness for the Bighorn Dolomite can approach 300 feet in places.

2.3.2.3 Devonian System

The Devonian System includes rocks deposited in the time span between 416 and 359 million years ago. The erosional hiatus responsible for the absence of Silurian age rock (443 to 416 million years ago) in central Wyoming may have lasted though at least the beginning of the Devonian, perhaps as late as middle Devonian. During the Devonian Period, the first fish evolved legs and started to walk on land as tetrapods around 365 million years B.P., and various terrestrial arthropods also became well-established.

Subsequent eastward advance of a sea in Late Devonian time covered the area not occupied by a presumed broad landmass in the area represented by the eastern WRB. The sea is thought to have withdrawn from the area near the close of the Devonian only to be followed by a period of intense erosion, culminating in perhaps another series of re-advancement and retreat of seawater. The so-called "Late Devonian extinction" had a major impact on biodiversity, with approximately 19% of all families and 50% of all genera going extinct according to some sources.

2.3.2.3.1 Darby Formation

The sole representative of the Devonian System in the WRB is the Darby Formation, thought to be the result of an eastward advancing sea. Strata assigned to the Darby Formation have the most limited distribution of any of the Paleozoic rock units in the WRB. In the Lander Planning Area, this formation is primarily restricted to the western flank of the central and northern Wind River Range, the Washakie Range and the Western half of the Owl Creek Mountains. It thins from approximately 190 feet in the northwestern end of the Wind River Range to a thin wedge, perhaps 20 feet thick in Sinks Canyon above Lander. In general, the Darby Formation consists of a variable sequence of buff, gray, and brown dolomite, and greenish-gray and red siltstone, shale, and sandstone. The exposure near Lander is marked by tan crystalline dolomite imbedded with coarse-grained quartzitic sandstone. A conspicuous feature of the Darby is its characteristic "fetid" odor caused by the release of incorporated hydrocarbons when the dolomite is broken.

2.3.2.4 Mississippian Series

The Mississippian epoch is the earliest/lowermost of two divisions of the Carboniferous Period lasting from roughly 359 to 318 million years B.P. (the usage of this terminology rather than Carboniferous seems peculiar to only the United States). The Mississippian Series represents rocks deposited during the time span of approximately 359 to 318 million years ago. The contact with rocks of the older Devonian System is unclear— in some places it appears to be transitional, and in others an erosional unconformity may be present.

2.3.2.4.1 Madison Limestone

The geographic name Madison has been used to designate all rocks of Mississippian age in central Wyoming, and in the Lander Planning Area region these rocks are represented by the Madison Limestone.

Where present, the unconformity at the base of the Madison Limestone is one of the most prominent in central Wyoming. In the western part of the Lander Planning Area, the Madison rests on the underlying Darby Formation with little evidence of intervening erosion, but further east, the contact is with increasingly older strata, most distinctly in the southeast part of the basin where it rests on Flathead Sandstone.

The Madison Limestone is described as a lower bluish-gray to gray, massive to thin-bedded, micritic limestone and dolomitic limestone about 500 to 600 feet thick. The upper part is described as chiefly thin to massive-bedded, gray to tan and yellowish-tan dolomite and limestone, about 100 feet thick, with local thin beds of red shale and siltstone. The Madison generally thins from the Northwest to the southeast across the basin, varying in thickness from over 600 feet to less than 200 feet. The Madison is a noted hydrocarbon gas producer and also a source for carbon dioxide in the basin.

2.3.2.5 Pennsylvanian Series

The Pennsylvanian Series is the younger series of the Carboniferous System. It includes rocks between 318 and 299 million years old. After the Mississippian Madison Limestone was deposited under marine conditions, central Wyoming again emerged and the exposed carbonate rocks of the Mississippian System were eroded subaerially into a highly irregular surface. At or about the start of the Pennsylvanian Period, a shallow sea is then thought to have spread into the area probably from the west, laying down extensive deposit of sand, followed by clay and silt, and finally a thick sequence of sand.

2.3.2.5.1 Amsden Formation

The Amsden Formation is named for a variable sequence of rocks occurring in position between the underlying Madison Limestone and the overlying Tensleep Sandstone. The geologic history of the Amsden is considered controversial by some because it is thought to contain strata of both Mississippian and Pennsylvanian ages, though some workers had called the systemic boundary at the erosional contact below the bottom-most member of the Amsden Formation. However, its basal beds appear consistent in age throughout the basin and they are younger in age than the uppermost member of the Madison Limestone.

In most areas, the Amsden is characterized by a basal sandstone unit (Darwin Sandstone) overlain by red and gray siltstones and shale with local minor thin beds of sandstone, cherty limestone and dolomite. As a whole, the Amsden ranges in thickness from about 190 to 250 thick in the northern part of the Lander Planning Area to about 100 to 180 feet in the south.

2.3.2.5.2 Tensleep Sandstone

The contact between the Amsden Formation and the overlying Tensleep Sandstone is marked by a change in topography from weathered talus covered slopes to massive near vertical cliffs. In most places the contact is thought to be gradational. The Tensleep Sandstone is predominately buff, tan cream-colored and white fine-grained massive to cross-bedded sandstone. Weathering can sometimes result in brown or rusty staining, which when viewed at a distance, appears black in color. The Tensleep Sandstone ranges in thickness from approximately 200 feet at the north end of the Wind River Range to as much as 600 feet at the southeast end.

The Tensleep Sandstone is a prolific aquifer in the planning area, but perhaps not utilized to its potential due to its depth in most of the area, and also is noted as a important reservoir rock for hydrocarbons.

2.3.2.6 Permian System

Rocks of the Permian System (299 to 251 million years B.P.) comprise one of the most complex and also most closely studied Paleozoic systems in the Lander Planning Area. These strata are important reservoirs for oil and gas and an important source of phosphate in the intermountain west. Within the Lander Planning Area all major sedimentary rock types are represented— clastic red beds, mudstone, chert, phosphorite, sandstones, dolomite and limestone, but correlation problems between intertonguing rock units first defined in several type areas cloud a concise understanding of Permian geology.

Relations between the rocks assigned to the Park City Group and Phosphoria Formation have been worked out to some degree (McKelvey et al., 1959), and further discussion of this problem may be gained from review of the pertinent literature. For the purposes of resource assessment, the argument is largely academic in nature. Because the assemblage of rocks found in any complete vertical section of the whole sequence (or any major part of it), is diverse in lithology, pinches out by overlap, or passes laterally into rocks of other composition, one might simplify the problem by lumping all the rocks between the Pennsylvanian Tensleep Sandstone and the Triassic Dinwoody Formation into one formation, and that is apparently how some workers have dealt with the issue in the past.

2.3.2.6.1 Phosphoria and Park City Formations

McKelvey et al. (1959) described a measured section of Permian strata near Lander which consists of 282 feet of intertonguing Park City and Phosphoria formation rocks (Table 2-1). The relationships presented in Table 2-1 are illustrative of the problems in attempting to work out the stratigraphy exhibited in various places in the Lander Planning Area. The assemblage of rocks present between older and younger formations is not necessarily the same age in all locations where they might be identified for mapping purposes. The 282-ft sequence of rocks between the Tensleep Sandstone and the Dinwoody Formation near Lander (Table 2-1) is not similar to the 345-ft sequence of rocks between the Tensleep Sandstone and the Dinwoody Formation exposed 40 miles to the east of the Lander section on the Conant Creek anticline (Table 2-2).

2.3.3 Mesozoic era

The Mesozoic Era extends from 251 million years B.P to 65 million years B.P. and consists of the three periods Triassic (the oldest), the Jurassic, and the Cretaceous (the youngest). Mesozoic means "middle animals" (derived from Greek) and is often called the "Age of the Dinosaurs" after the dominant fauna of the era.

2.3.3.1 Triassic System

The Triassic System in Wyoming, especially in the vicinity of the Lander Planning Area, provides some of the more spectacular exposures of red-bed geology in the Rocky Mountains. Red Canyon, approximately 8 miles south of Lander on the flank of the Wind River Range, is a well-known locality for well-exposed rocks from this time period. Rocks formed in this Triassic are considered to range from 251 to 199 million years old.

Table 2-1 Measured Permian section near Lander, Wyoming.

Thickness	Geologic Map Unit	Stratigraphic Interval	Description
top contact	Dinwoody Formation	—	—
40 feet	Park City	Ervay Member	sandy and argillaceous carbonate rock
15 feet	Phosphoria Formation	Tosi Chert Tongue	chert
50 feet	Phosphoria Formation	Retort phosphatic shale tongue	dark mudstone and phosphorite
130 feet	Park City Formation	Franson Member	Inter-bedded light-gray carbonate rock and greenish-gray carbonatic shale
2 feet	Phosphoria Formation	Meade Peak phosphatic shale tongue	phosphorite
45 feet	Park City Formation	Grandeur member	light-gray carbonate rock and sandstone
unknown	disconformity		erosion or sedimentary hiatus
bottom contact	Tensleep Sandstone	—	—

Source: McKelvey et al. (1959)

Table 2-2 Permian section at Conant Creek Anticline, Wyoming.

Thickness	Geologic Map Unit	Stratigraphic Interval	Description
top contact	Dinwoody Formation	—	—
50 feet	Park City Formation	Ervay member	sandy and argillaceous carbonate rock
15 feet	Phosphoria Formation	Tosi Chert tongue	Chert
15 feet	Phosphoria Formation	Retort phosphatic shale tongue	Dark mudstone and phosphorite
35 feet	Park City Formation	Grandeur and Franson members undifferentiated	Carbonate rock
170 feet	Park City Formation	Grandeur and Franson members undifferentiated	Greenish-gray siltstone
60 feet	Park City Formation	Grandeur and Franson members undifferentiated	Cherty carbonate rock
unknown	disconformity		Erosion or sedimentary hiatus
bottom contact	Tensleep Sandstone	—	—

Source: McKelvey et al. (1959)

The lower (Triassic) boundary is set by the Permian-Triassic extinction event, during which approximately 90% to 96% of marine species and 70% of terrestrial vertebrates became extinct—considered the largest mass extinction in history.

2.3.3.1.1 Dinwoody Formation

In most of Wyoming, the base of the Triassic System is more or less picked as the Dinwoody Formation (Picard, 1978). The Dinwoody Formation was originally named for exposures along Dinwoody Canyon on the northeastern slope of the Wind River Mountains, near Dubois, Wyoming. In the WRB, where present, the Dinwoody Formation ranges in thickness from 50 to 250 feet. Some of the early work on the formation indicated that the formation thins in a northwest-trending area along the west margin of the basin (Love et al., 1945).

The Dinwoody Formation is marine in origin and commonly includes rock types such greenish-gray, sandy dolomitic sandstone, greenish-gray silty claystone, sandy dolomite, and thin, fine-to- very fine-grained sandstone. Petroleum production from the Dinwoody has not been significant (Picard, 1978).

2.3.3.1.2 Chugwater Group

As a result from stratigraphic work presented in Pipiringos (1968), the rocks formerly known as the Chugwater Formation were raised to group status. At least in the Lander Planning Area the constituents of the Chugwater Group include the Red Peak, Alcova Limestone, Crow Mountain, and Popo Agie, and are all given formation status within the Group.

Most of the rocks in the Chugwater Group have a marine or probable marine origin, although more recent work has presented evidence of an Aeolian origin for at least two parts of the Red Peak and Crow Mountain Formations (Irmen and Vondra, 2000).

2.3.3.1.2.1 Red Peak Formation

The Red Peak Formation lies above the Dinwoody Formation (probably conformably), and consists of a thick sequence of red beds, ranging from about 590 to 1120 feet in the Lander Planning Area, generally thickening westward. The dominant rocks in the formation are red, very fine-grained sandstone, sandy siltstone, clayey siltstone, siltstone, silty claystone, and claystone. These rock types can be grouped in four facies or depositional environments, but for the purpose of this report this has no bearing on resources.

Though there have been some indications of oil and gas possibilities in the Red Peak Formation, the full potential of this formation as a producer is not yet known. The probably source of hydrocarbons is most certainly from underlying rocks of the Phosphoria or Dinwoody Formations (Picard, 1978).

2.3.3.1.2.2 Alcova Limestone

The Alcova Limestone member of the Chugwater Group was originally named for outcrops near Alcova Wyoming, forms a thin, but relatively persistent unit throughout the basin. Because it typically forms a thin but prominent outcrop and is typically light olive-gray, grayish-pink and pale yellowish-brown in color, the Alcova is a convenient marker bed and easily identified in the enclosing red beds making up the vast majority of the Chugwater Group.

Lithologically, the Alcova Limestone consists of very thinly laminated, thinly-bedded, finely crystalline, slightly fossiliferous limestone or dolomite that is marked by a distinctive laminated stromatolitic algal zone in the lower part (Picard, 1978).

2.3.3.1.2.3 Crow Mountain Sandstone

The Crow Mountain Sandstone includes rocks roughly equivalent to sequences lying above the Alcova Limestone and below the Popo Agie Formation referred to by other workers as the Jelm Formation (Pipiringos, 1968), although mostly in areas east of the Lander Planning Area. More recent work in the Lander Planning Area indicates an acceptance for these rocks as Crow Mountain Sandstone over a more wide spread area (Love et al., 1993) and this nomenclature will be retained here.

The Crow Mountain Sandstone in the Lander Planning Area is typically about a 160-feet thick section consisting of a basal sandstone unit described as dominantly red in color, calcareous, well-sorted and well-rounded, and fine-grained. This unit ranges in thickness from about 16 to 130 feet and is overlain by an upper sandstone and siltstone unit differentiated from the rocks below by lithologic changes, sedimentary structures, and thickness of beds (Picard, 1978). The upper unit is characterized by red and drab-colored, calcareous, well-sorted, sub-rounded, very fine-grained sandstone and siltstone of similar color and composition but with grains exhibiting a more sub-angular rounding. The Crow Mountain Formation has been a secondary target for oil and gas exploration (Picard, 1978).

2.3.3.1.2.4 Popo Agie Formation

The type section for the Popo Agie Formation of the Chugwater Group is at Dallas Dome near Lander. Here the Popo Agie Formation is about 100 feet thick and consists of a lower bed of mostly pale-red to purplish-red silty and locally grey-mottled claystone and grayish-yellow silty sandstone grading upwards into dolomitic siltstone. At the type section, this interval is overlain by about 60 feet of purple and ocher siltstone, analcime-rich claystone and analcimolite. The formation as a whole is considered lithologically homogeneous for the most part and as such the formation typically forms smooth, slope forming outcrops (Pipiringos, 1968).

2.3.3.1.3 Nugget Sandstone – Bell Springs Member

The Nugget Sandstone likely transcends the Triassic-Jurassic boundary and can be divided into two members in the Lander Planning Area, though elsewhere this division is considered controversial or unwarranted (Knapp, 1978). The lower member, referred to as the Bell Springs member by Zipringos (1968) is most probably wholly Triassic in age and marine in origin. Where present, the Bell Springs always disconformably overlies the Popo Agie Formation of the Chugwater group, often incorporating pebbles eroded from underlying Popo Agie Formation in its base. However, in the WRB, the overlying strata are not consistent due presumably to lateral pinch-outs or erosional disconformities.

In the Lander Planning Area, the Bell Springs averages about 100 feet in thickness and represents the lower part of the Nugget Sandstone. The Bell Springs is described as a sequence of thin-bedded, ripple--marked red and gray sandstone and red, green, and pale-purplish-red to pale-red siltstone and shale (Pipiringos, 1968).

2.3.3.2 Jurassic System

The Jurassic System in central Wyoming includes rocks which range in age from 199 to 145 million years ago.

During middle Jurassic time, a shallow sea invaded the area from the north and resulted in deposition of siltstones, carbonates and evaporites. This sea, actually consisted of a series of five successive marine transgressions, each separated by an erosional hiatus.

The Triassic-Jurassic boundary in Central Wyoming is unclear on a formational scale and because of this the Nugget Sandstone in assigned an uncertain age (Love et al. 1993).

2.3.3.2.1 Nugget Sandstone

The upper part of the Nugget sandstone can be easily differentiated from the lower division based on lithology and the presence of striking cross-bedding. Though the presence of a gradational relation of the upper unit with the lower Bell Springs has been identified in some places (Pipiringos 1968), the upper unit is more or less considered to the “representative” lithology when discussing the Nugget Sandstone, and workers such as Knapp (1978) only include the upper part in the Nugget designation. For the purposes of this report, the upper Nugget Sandstone is included rocks of the Jurassic System.

In general, the upper part of the Nugget Sandstone is a fine-to-medium grained, moderately well sorted to well sorted yellowish-white to pink sandstone and some reddish-brown silty sandstone. The large scale cross-bedding, often on the scale of 10 to 30 feet, dominates the upper part of the Nugget sandstone. The large scale and high dip of the cross-bedding most probably indicates an eolian (dune) depositional environment (Knapp, 1978).

In the Lander area, some small scale cross stratification and wavy-bedded and flat-bedded zones indicate some presence of subaqueous deposition which may be the result of facies change or minor sea transgression and regression (Knapp, 1978). The upper Nugget unit is also readily identifiable by a characteristic weathering pattern where outcrops often take on a ribbed beehive-like morphology. The Nugget Sandstone has excellent porosity and permeability and could be considered an excellent reservoir rock, but so far has not proved to be a significant source of hydrocarbons in the Lander Planning Area.

2.3.3.2.2 Gypsum Spring Formation

The Gypsum Spring Formation consists of reddish-brown siltstone in the lower part, gypsum in the middle part, and reddish-brown claystone and gray fossiliferous limestone in the upper part (Pipiringos, 1968). The formation is about 200 feet thick near Lander, but thins eastward. It is everywhere separated from the underlying Nugget Sandstone by a regional unconformity. The most voluminous and economically significant reserves of gypsum lie in the Gypsum Spring Formation. In the WRB, this formation contains a single massive high-grade gypsum bed which ranges in thickness from 40 to 100 feet (Hausel and Holden, 1978).

2.3.3.2.3 Sundance Formation

After a period of freshening and deepening of sea waters across the shelf area in Late Jurassic time, more normal marine conditions prevailed. The resulting Sundance Formation consists of sandstone, siltstone, and shale, with minor limestone, averaging 250 thick in the basin. The formation is marine in origin and thickest in the north-central part of the Lander Planning Area and thins to the west, east, and south. The formation is separated by older underlying rocks by a regional unconformity and due to differential uplift in Jurassic time, Sundance sediments can rest on Gypsum Spring or the Nugget Formation.

While some have divided the Sundance Formation into as much as seven members, for the purposes of this report, it is divided into a lower member and an upper member. The lower member is an important hydrocarbon reservoir rock.

2.3.3.2.4 Morrison Formation

Following the northward withdrawal of the Sundance Sea in Late Jurassic time, a long period of non-marine deposition began. Northward-flowing streams originating in newly-formed highlands in the intermountain west spread vast quantities of sand, silt, and volcanic rich mud which together comprise the sediments of the Morrison Formation. The terrestrial sediments of the Morrison Formation—eroded from rising highlands to the west—were deposited on top of the Sundance sediments as the sea regressed for the last time late in the Jurassic.

The Morrison Formation is one of the best known, widespread, and readily identifiable formation in the Rocky Mountain region, and is named after a Colorado town just west of Denver where it outcrops in characteristic fashion. The formation is composed of several hundred feet of sandstone, siltstone, and variegated shale and mudstone which were deposited in fluviatile and lacustrine environments (Keefer, 1965). The Morrison is well-known for its abundant dinosaur bones and the bright hues of red, brown, violet, and green shales and mudstones which are rich in altered volcanic ash. Outside of Wyoming, the formation is a well-known host rock for uranium deposits.

2.3.3.3 Lower Cretaceous Series

The Cretaceous System includes rocks which range in age from 145 to 66 million years B.P., with the Early Cretaceous epoch encompassing time from 145 to about 99 million years ago. By the end of the Jurassic following the flood of sediments across the region in late Jurassic, the region was subjected to erosion (Young, 1970). Then as the region along the Wyoming-Idaho border was uplifted, the area east of the upward began to subside to form a part of a large down warp trending from the Gulf of Mexico through Canada called the Rocky Mountain geosyncline, or the Western Interior Seaway. Streams from the east and the west entered this broad trough, and turned north, probably eventually entering the Arctic Sea (Young, 1970). These Early Cretaceous Series sediments formed during this early fluvial phase consist of floodplain conglomerates, conglomeritic sandstone, and variegated mudstones whose base comprises rocks of the Cloverly Formation.

As the depositional environment became predominately marine during the remainder of Early Cretaceous time, extensive, thick black shales were deposited by transgressive seas moving slowly southward across the region (Young, 1970). The lower contact of these shales are gradational (i.e. conformable) to the Lower Cretaceous Rusty Beds. It should be pointed out that some workers include the Rusty Beds Member in the lower part of the Thermopolis Shale.

2.3.3.3.1 Cloverly Formation

Strata assigned to the Cloverly Formation are about 400 thick in the northern part of the WRB. Here the formation can be divided into three relatively distinctive units (Keefer and Troyer, 1964). The lower 30 feet or so is a conglomerate and sandstone unit, containing large chert pebbles and appears to be deposited into channels cut into the underlying Morrison Formation.

The middle unit, about 220 feet thick, consists mainly of variegated red and purple claystone and siltstone interbedded with minor fine-to-medium grained sandstone. The upper 150 feet, known as the Rusty Beds Member, is characterized by fine-to-medium grained sandstone with minor siltstone and shale. The lower two Cloverly units are non-marine in origin, while the Rusty Beds Member is marine (Keefer, 1997).

The Cloverly Formation thins to about 150 feet in the east part of the WRB where its lower part is mainly variegated mudstone, and its upper part is generally conglomerate and sandstone. A disconformity separates the Cloverly from the underlying Morrison Formation (Keefer, 1997). Toward the end of Cloverly deposition, the region was again flooded in response to further down warping and depositional styles were represented by shallow marine and brackish near-shore environments as preserved in sediments of the Rusty Beds Member.

2.3.3.3.2 Thermopolis Shale

The Thermopolis Shale is characterized almost entirely by black, soft, fissile shale with thin bentonite stringers and non-persistent silty sandstone intervals. This formation is of marine origin and can be as thick as 500 feet or more and is easily recognized in both surface and subsurface sections.

A distinctive geophysical log marker (informally called the "Dakota silt") present in about the middle of the formation is an important datum used in subsurface mapping and stratigraphic correlation.

2.3.3.3.3 Muddy Sandstone

The Muddy Sandstone is a variable unit of sandstone and shale, and exhibits characteristics which indicate deposition in fluviatile, marine, and deltaic environments (Fox and Dolton, 1989). The thickness of the Muddy Sandstone is variable though out the basin, generally ranging from zero to as much as 75 feet, with as much as 150 feet in places along the western margin of the basin (Keefer, 1969). Despite its variability, it is easily recognized in most subsurface and surface sections (Keefer, 1997). The Muddy Sandstone is an important hydrocarbon resource in the WRB, producing from stratigraphic traps. Hydrocarbons produced in the Muddy are thought to be sourced from black shales of the underlying Thermopolis and overlying Mowry Shale.

2.3.3.3.4 Mowry Shale

The carbon rich rocks of the Mowry Shale are considered potential petroleum source rocks in the WRB. The Mowry Shale is also a resource of bentonite, reflecting widespread volcanism taking place in areas west and northwest of Wyoming. These beds crop out at or near the surface on the periphery of the basin and are the object of recent interest by bentonite-producing companies.

2.3.3.4 Upper Cretaceous Series

The upper boundary of Late Cretaceous time is set at the Cretaceous-Tertiary (KT) extinction event (defined at 66.4 million years B.P.) which some researchers think may have been caused by a supposed asteroid impact that created Chicxulub Crater on the Yucatán Peninsula. Approximately 50% of all genera became extinct, including all of the non-avian dinosaurs.

Rocks of the Late Cretaceous Epoch range in age from about 99 to about 66 million years old and in the WRB, exhibit a complex history of marine transgression and regression.

Uplift in certain areas caused sedimentary accumulations to reorganize as clastic debris was shed from these highlands. As seas moved eastward out of central Wyoming, extensive regressive sandstone, which forms the base of the Frontier Formation, was deposited over the black marine Mowry shale. After this initial retreat, a period of extended sub-aerial deposition began.

Minor readvances and retreats are recorded by intertonguing sediments in the middle part of the Frontier Formation which represent marine and near shore non-marine environments marine (swamps, lagoons, etc.). Towards the end of the Frontier Formation deposition, there was a major advance of the sea that extended westward across all of central and western Wyoming. The initial deposit of this transgression is considered to be the top of the Frontier Formation, and consists of conspicuous highly fossiliferous sandstone.

2.3.3.4.1 Frontier Formation

The Frontier Formation consists of an alternating sequence of sandstone and shale ranging in thickness from about 750 feet near Dubois, 650 feet at Yellowstone Ranch southeast of Lander, and thickening to as much as 740 feet at Conant Creek (Burgess, 1970; Keefer 1997). In some areas, the Frontier Formation may be as thick as 1050 feet depending on the degree of inter-fingering with younger and older sediments (Keefer, 1972).

Sandstone is the predominant lithology in the west with shale to the east, but in much of the area, the amounts of each are about equal. Sandstones in the Frontier are often described as “salt and peppery” in appearance due to the abundant amount of dark mineral grains present. Three prominent zones of sandstone, referred to by oil and gas operators as the “First, Second, and Third Wall Creek” sands, are present in the subsurface at most localities in the basin. In most places in the WRB, sediments equivalent to strata known as Carlisle shale outside the WRB, are present in the upper part of the Frontier Formation and may be noted as such in some localities, especially in the subsurface section. The Frontier Formation is a major oil and gas producer in the WRB.

2.3.3.4.2 Cody Shale

The name Cody Shale was originally given to all strata between the Frontier Formation and the Mesa Verde Formation. The Cody Shale consists predominately of shale in its lower part and of interbedded shale and sandstone in its upper part. In total, its thickness ranges from 3150 to 4700 feet. The shale is highly fossiliferous and consists of gray to black, soft, finely fissile, and commonly bentonitic and calcareous. Numerous brown and gray claystone and limestone concretions occur within the thick shale units in many areas. These strata represent a major westward transgression of the sea following the deposition of the Frontier Formation. The contact between the marine Cody shale and the underlying Frontier Formation is gradational with inter-fingering in places, and is generally defined where the lithology changes from predominately sandy to predominately shaly (Keefer, 1972).

Because of the widespread area inundated by the Cody Sea and the great thickness of accumulation, nomenclature of Cody aged strata is somewhat regionally variable. Thick sands as much as 200 feet thick in the north-central part of the Lander Planning Area are important gas producers in the Madden field. These sands are referred to informally as the “Sussex” and the “Shannon” sands by oil and gas operators in some areas.

The lower part of the Cody shale can also be generally correlated to similar deposits known elsewhere as Niobrara Shale or perhaps the Steele Shale. These names are not necessarily indicative of lithologic equivalence but help to orient one in the section where local terminology abounds.

2.3.3.4.3 Mesaverde Formation

Regionally, the contact between the Cody Shale and the Mesaverde Formation is defined as the dividing line between strata that was deposited primarily in an offshore environment (the shale) and those deposited in near-shore, brackish-water, swampy and fluviatile environments. The Mesaverde Formation is generally regarded as the last formation deposited representing the final major regression of an epicontinental sea in central and western Wyoming. The type section for the Mesaverde Formation is in Colorado, but in Wyoming the name is applied to sediments lying between the Cody Shale and the Lewis/Meeteetsee Formations.

The Mesaverde Formation is a highly variable sequence of sandstone, siltstone, shale, carbonaceous shale, and coal. The thickness ranges from 550 to 2000 feet with much of the variation in thickness resulting from intertonguing at the base with Cody Shale. In many places the Mesaverde can be divided into three units: basal sandstone, a middle interbedded sandstone and shale unit, and upper sandstone. Because of the lenticular nature of most of the sandstone beds, most intervals cannot be traced laterally with any certainty.

Sandstones in the lower and middle parts of the Mesaverde Formation are characteristically tan, gray, and yellowish-gray in color, very fine-to-medium-grained, friable to well-cemented. Bedding can be irregular to massive and cross-bedded and locally some black mineral grains are present (Keefer, 1972). Shales and siltstones in the Mesaverde are gray-to-brown and commonly carbonaceous. Coal beds occur both in the lower and middle parts of the formation but most abundantly in the lower (Keefer, 1972).

The Mesaverde Formation is a minor resource for coal, generally in the western part of the Lander Planning Area where lenticular beds are present between thin beds of shale. With little production from a few isolated fields, the Mesaverde is not a prolific producer of oil and gas in the WRB. As a hydrocarbon source rock, however, the Mesaverde does generate some considerable interest (Shapurji, 1978), and coal bed natural gas from this formation has shown some promise in the Lander Planning Area.

2.3.3.4.4 Meeteetse Formation and Lewis Shale

Rocks which occur in the stratigraphic interval above the Mesaverde and below the Lance Formation are referred to differently depending on location and lithology. In the central and western parts of the WRB, these rocks are largely non-marine and are referred to as the Meeteetse Formation. In the eastern part of the WRB rocks of this interval consist of interbedded marine and non-marine rocks with the marine sequences referred to as the Lewis Formation (Keefer, 1965).

Exposures of these rocks are for the most part in the south and east edges of the basin and thus are encountered primarily in the subsurface. Where observable at surface, the Meeteetse strata differs from adjoining rocks in that it is generally nonresistant and forms conspicuous strike valleys that contain only a few outcropping beds. The Meeteetse Formation was deposited in widespread swamps, broad flood plains, and lagoons on the periphery of the late Cretaceous seaway (Keefer, 1965).

These rocks can be divided into a lower and upper unit (Keefer and Troyer, 1964). The lower part is an interbedded sequence of sandstone, siltstone, shale, carbonaceous shale and coal ranging in thickness from about 650 to 1100 feet. Some beds contain bentonite and several of the coal beds are of minable thickness. The upper unit consists of massive lenticular sandstone ranging in thickness from 0 to 300 feet with individual beds as thick as 120 feet. The sandstone is buff and gray in color, fine to coarse-grained, massive, moderately porous and friable.

The Lewis Shale in the Lander Planning Area consists of an upper and lower tongue, each consisting of interbedded gray, olive-gray, and buff shale and fine-to-medium-grained sandstone, which represent minor readvances of the sea into the eastern part of the WRB (Keefer, 1965). The lower tongue ranges in thickness from 0 to about 400 feet and directly overlies the Mesaverde Formation. The upper tongue, up to 200 feet in thickness, is separated from the lower tongue by an eastward projecting tongue of the Meeteetse Formation.

Because of the alternating of thin beds of differing lithology, the Meeteetse and Lewis rocks in the subsurface produce distinct uneven and jagged resistivity electric logs. Well cuttings also show an abundance of coal and carbonaceous material compared to adjacent strata (Keefer and Troyer, 1964).

2.3.3.4.5 Lance Formation

The Lance Formation is both conformable and unconformable with underlying strata, with the majority of subsurface data suggesting a conformable but distinct contact. The Lance Formation crops out extensively along the south and east margins of the WRB, and is widespread in the many wells which are deep enough to encounter these rocks. The Lance Formation is a sequence of interbedded white, gray, and buff, fine-to-coarse-grained and conglomeratic sandstone, gray to black shale and claystone, and brown to black carbonaceous shale and coal thought to have accumulated in broad flood plains and swamps and large lakes and brackish water environments.

In contrast with older strata of Cretaceous age, the Lance Formation was significantly influenced by tectonic movements representing the start of basin growth. This down warping was especially significant along the present northern margin of the WRB where up to 6000 feet of Lance sediments are thought to have accumulated (Keefer, 1965). The Lance Formation is an important gas producer in the northeast part of the Lander Planning Area between Shoshoni and Lysite.

2.3.4 Cenozoic Era

The Cenozoic Era is a major division of geologic time which is assigned an age which ranges from about 65 million years ago to the present (recent) time. This era includes three periods (ranging from oldest to youngest): the Paleogene Period (about 65 million to 23 million years B.P.), the Neogene Period (about 23 million to 1.8 million years B.P.), and the Quaternary Period (1.8 million years to the present).

Each period of the Cenozoic Era is assigned various epochs, which separate the time spanned into smaller divisions: the Paleocene, Eocene and Oligocene epochs are assigned to the Paleogene Period, the Miocene and Pliocene epochs are assigned to the Neogene Period, and the Pleistocene and Holocene epochs belong to the Quaternary Period.

2.3.4.1 Paleocene Series

The Wind River Range probably began to be uplifted along the west side of the WRB at the beginning of Paleocene time. Rocks deposited during the Paleocene Epoch range in age from about 66 to 55 million years ago. Broad low northwest-trending folds also formed at this time at the present location of the Owl Creek Mountains. The Granite Mountains and the Washakie Range also continued to rise and some folding took places along the margin of the basin.

By mid-Paleocene time, the pre-Cambrian cores of the Wind River Range and the Granite Mountains had likely been breached (Keefer, 1965). Deposition during the Paleocene time was largely confined to the central down-warped portion of the basin.

2.3.4.1.1 Fort Union Formation

The Fort Union overlies the Lance Formation with erosional and/or angular unconformity (Keefer, 1965). As originally defined by Keefer (1961), the Fort Union Formation consists of three members. In ascending order these members include the Lower Fort Union, Waltman Shale Member and the Shotgun Member.

The lower Fort Union Formation consists of interbedded sandstone conglomerate, conglomerate, shale, and carbonaceous shale deposited in a fluviatile environment. The Waltman Shale and Shotgun Members represent contemporaneous environments of deposition which include marginal (Waltman) and offshore (Shotgun) areas of a large lake. In the western, southern, and southeastern portion of the basin the Fort Union Formation is undivided primarily due to the absence of the Waltman Shale.

The Fort Union Formation is an important source of natural gas in the Wind River Basin, and historically the Fort Union was also a minor source of subbituminous coal where it outcrops at or near the surface. Increasingly, the Fort Union Formation has earned a reputation as a major coal-bed natural gas producer, especially in the Powder River Basin, outside of the Lander Planning Area.

2.3.4.1.1.1 Lower Fort Union

These strata are characterized by white to gray fine-to-coarse-grained massive to cross-bedded sandstone, interbedded with dark gray to black shale, claystone, siltstone, and brown carbonaceous shale. Some of the uppermost sandstone beds are highly glauconitic. Along the main trend of the WRB, the Lower Fort Union can be as thick as 3500 feet (Keefer, 1965).

2.3.4.1.1.2 Waltman Shale

The Waltman shale member is characterized by a homogeneous dark brown to black, silty micaceous shale, and gray silty and shaly claystone. The abundant white mica disseminated throughout the claystone is a conspicuous diagnostic feature.

Though the Waltman shale does not outcrop within Lander Planning Area, it is, however, widespread in the subsurface and ranges in thickness from zero in the south and west parts of the basin to as much as 3000 feet near the north margin (Keefer, 1965). While the Waltman Shale is not considered an important source rock for hydrocarbons, it does host some minor production in the Lysite area.

2.3.4.1.1.3 Shotgun Member

The Shotgun Member is characterized by even-bedded gray and tan shale, siltstone, claystone, and sandstone with local thick conglomerate beds in the upper part. In the Lander Planning Area, the Shotgun Member outcrops only on the extreme northeast border near Badwater, where 1600 feet is exposed on the south side of Badwater Creek. Otherwise the unit is widespread in the subsurface where thicknesses Range from zero to as much as 1100 along the south margin of the basin, and 150 to 2200 feet along the north part of the basin (Keefer, 1965).

2.3.4.2 Eocene Series

Rocks deposited during the Eocene epoch range in age from about 55 to 34 million years ago. In earliest Eocene time, folding and uplift of the mountain masses in and about the Lander Planning Area became more prominent, basin marginal folds became more pronounced and large scale reverse faulting took place in the northwestern portion of the WRB

2.3.4.2.1 Indian Meadows Formation

Very coarse debris accumulated in extensive alluvial fans in front of the rising highlands to the north and northeast. In the southeastern part of the basin a broad fan was spread eastward and northeastward. This huge delta-like deposit formed the Indian Meadows Formation and is composed of red to variegated claystone, sandstone, algal limestone, and some beds of allogenic boulders and faulted masses of Paleozoic and Mesozoic rocks. Thick deposits accumulated in the central part of the WRB which continued to subside through epoch and also in a narrow synclinal trough in the northwestern part of the basin (Keefer, 1965).

After deposition of the Indian Meadows Formation, the central and eastern parts of the Owl Creek Mountains and the Casper Arch were uplifted along extensive reverse faults. Large areas of Precambrian rocks in the Wind River Range and Granite Mountains as well as smaller portions of the Owl Creek, Washakie, and Big Horn Mountains continued to be exposed.

Extensive volcanic activity during late early to middle Eocene and later times in the Absaroka - Yellowstone volcanic field north of the Lander Planning area is responsible for the thick sequence of volcanic rocks of intermediate composition which probably buried the Casper Arch as well as parts of the Washakie and Owl Creek Ranges. This thick package of rocks is readily observable just north of Dubois.

Before the close of Eocene time, the WRB began a period of virtually continuous aggradation which continued to nearly the close of the Pliocene Epoch (approximately 1.6 million years ago).

2.3.4.2.2 Wasatch and Battle Springs Formations

There is difference in opinion as to the nomenclature of lower to middle Eocene rocks. The term Battle Spring Formation was first applied by Pipiringos (1955) for a thick sequence of up to 3000 feet of arkosic sandstone occurring south of the Granite Mountains. These sediments underlie most of the Great Divide Basin area at land surface and are present n the extreme southeast corner of the Lander Planning Area. According to Love (1970), the Battle Spring Formation should not have been introduced into the literature for rocks are described as mere facies of the main body of the Wasatch Formation.

Other authors have noted that strata that is referred to as Battle Springs Formation inter-tongues with subdivisions of the Wasatch Formation and probably the Green River Formation (Sullivan, 1980).

2.3.4.2.3 Wind River Formation

The Wind River Formation underlies the surface of the vast majority of the Lander Planning Area, and the WRB in general. Wind River sediments unconformably overlie younger Eocene Series strata due to the fact they were deposited during the active erosional period that followed the uplift of the mountain ranges along the margins of the WRB (Keefer, 1965). Also as a result of these conditions, its thickness and lithology vary considerably from place to place. By the end of Eocene time, most of the granitic cores of surrounding mountain ranges had been deeply eroded and coarse debris had been spread many miles into the basin proper. Extensive flood plains and board stream channels characterized the interior of the basin.

In general, the formation can be subdivided into a coarse arkosic facies representing deposition long mountain slopes and a fine-grained variegated facies representing deposition further out in the basin. Some of the spectacular exposures of the basin-ward facies occur near Dubois where some 1800 feet of brightly variegated beds form badlands north of the Wind River channel. South of the Wind River channel the coarse-grained facies contains white to tan arkosic sandstone and locally boulders as much as 10 feet across. Crow Heart Butte, another feature of geologic interest in the area, is mostly composed of Wind River Formation strata. Bentonite also occurs in the Wind River Formation.

In the northeastern part of the basin near Lysite, the Wind River Formation is divided into two members, the Lysite and Lost Cabin Members. Near the Gas Hills, the formation is also divided into two members. The lower unit, more or less equivalent to the Lysite Member, consists of grayish green to light-gray siltstone and claystone and some gray very fine-grained sandstone.

Near the Gas Hills, erosional remnants of fine-grained Wind River Formation sediments form interesting castle-like hillocks known locally as Clay City Ruins. The upper member, referred to in this area as the Puddle Springs Member is more or less equivalent to the Lost Cabin Member some 30 miles to the north. Here the upper member consists of a thick sequence of yellow-gray arkosic medium-grained to very coarse grained arkosic sandstone with some intercalated mudstone, carbonaceous shale and siltstone. Locally, conglomerate beds are common with clasts up to 2 feet in diameter. The Puddle Springs Member is notable for the fact that it hosts most if not all the uranium ore deposits in the Gas Hills area (Soister, 1968). The uranium bearing minerals generally occur as interstitial fillings in irregular tabular bodies of sandstone.

Uraninite and coffinite are the chief ore minerals in the unoxidized zone, where uranium phosphates, silicates, and hydrous oxides host in the oxidized zone. Most beds in the Puddle Springs are poorly consolidated, making for advantageous mining using open-pit methodology. In similar fashion, sandstone units mapped as lower Battle Spring Formation hosts uranium in the Crooks Gap uranium district (Stephens, 1964).

2.3.4.2.4 Wagon Bed Formation

The Wagon Bed Formation is exposed along almost the entire Beaver Divide and as far to the east as the Rattlesnake Hills. The Wagon Bed Formation consists of bentonitic, tuffaceous, and arkosic mudstone, sandstone and conglomerate and is sometimes subdivided into several lithologic units.

In general, however, up to 300 feet of lenticular soft yellow to gray conglomeratic arkosic sandstone and evenly layered mudstone form the base of this unit which then grades upward into increasingly more volcanic rich sediments. This material represents reworked material derived from surrounding areas undergoing uplift and contains the earliest known locally derived volcanic debris from vents in the Rattlesnake Hills area (Love, 1970).

2.3.4.3 Oligocene Series

Rocks of the Oligocene Series range in age from about 34 million to 23 million years B.P. In the Lander Planning Area, these rocks include the White River Formation and possibly the lower portion of the Split Rock Formation, which is discussed in the Miocene Series section.

2.3.4.3.1 White River Formation

The White River is an extensive formation throughout the Rocky Mountain region and northern plains. In the Lander Field Area it is present primarily east of the Miner’s Delight area, east of the Sweetwater Canyon area, and all along Beaver Divide. This unit consists of white to grayish pink or orange friable clayey tuffaceous siltstone, sandstone, and conglomeratic beds and contains abundant shards and tiny biotite flakes. Thickness is on the order of up to 1000 feet. Because upper Eocene rocks were gently warped in the south part of the Lander Planning Area, the White River Formation was subsequently laid down across truncated edges of all older rocks on the flanks of the Wind River Range (Love, 1970).

2.3.4.4 Miocene Series

Rocks of the Miocene Series range in age from about 23 million to 5 million years B.P., and only the Split Rock Formation is identified as originating during this time span.

2.3.4.4.1 Split Rock Formation

The Split Rock Formation was named for exposures in the vicinity of Split Rock in the Granite Mountains area. This unit caps the Beaver Divide in most places and forms the south-facing dip slopes of the Sweetwater Plateau, covering most of the northern half of the Crooks gap area. According to Love (1961), the Split Rock Formation has an outcrop area of about 1500 sq. miles, making it one of the most widely distributed of any sedimentary sequence in the south Lander Planning Area.

Most notably, the Split Rock Formation comprises the apron of sediment which almost buries the Granite Mountains with up to 3000 feet of sandy sediments. This formation consists of pinkish-gray fine-to medium-grained unconsolidated sandstone with lesser amounts of tuff, pumicite, limestone, and claystone. As mentioned, the Split Rock sediments are lying unconformably on Granite Mountains Precambrian rocks, but also is observed faulted against Oligocene rocks, and Battle Spring Formation rock. Several "soda lakes" occupying wind-scooped depressions in the upper part of the Split Formation contain deposits of sodium bearing minerals.

Though earlier work assigned a Miocene age to the Split Rock Formation (Love, 1961) more recent work (Love et al., 1993), has indicated that the lower portion of the formation may actually be late Oligocene in age.

2.3.4.5 Pliocene Series

The Pliocene Epoch includes rocks ranging in age from 5 million to 1.8 million years B.P., and in the Lander Planning Area includes only the Moonstone Formation.

2.3.4.5.1 Moonstone Formation

The Moonstone Formation is difficult to differentiate from the underlying Split Rock Formation, but its outcrop area is significantly less- about 50 square miles. Over 1300 feet of this formation is exposed near the central part of the Granite Mountains where it had escaped quaternary erosion, and it overlies with Split Rock Formation with a slight angular unconformity (Love, 1961). The base consists of a soft, poorly cemented arkosic conglomerate and sandstone in valley area with younger fine-grained material in contact with granitic outcrops.

Near the type section for the formation is a sequence containing agate pebble "reefs" that crop out as ledges for about a mile. In the middle part of the formation are up to eight zones that locally contain between 0.003 and 0.034 percent uranium. Algal limestone reefs are also present locally, presumably of lacustrine origin [(Love, 1970)] and several lenses of thorium-bearing limestone are present (love, 1961).

The abnormally high uranium content of the rocks and groundwater of the Moonstone Formation suggests that a considerable amount of the uranium in the Gas Hills area 10 miles to the north and the Crooks Gap area 15 miles to the southwest may have been leached from the Moonstone Formation before it was removed by erosion from these locations.

2.3.4.6 Quaternary System

The Quaternary Period ranges in age from about 1.8 million years B.P. and includes geologic time up to the recent (present). Currently, it includes both the Pleistocene Epoch (1.8 million to 11,800 years B.P.), and the Holocene Epoch (11,800 year B.P. to present). It should be mentioned that on-going research may redefine the base of the Quaternary Period to an older age, but this is a matter of academic interest.

Sediments deposited during the Quaternary Period in the Lander Planning Area are represented mainly by glacial deposits and stream terraces.

2.3.4.6.1 Glacial Deposits

In general, deposits from the three main glacial periods are recognized in the Lander Planning Area. These deposits are generally assigned to the Pleistocene Epoch, which by definition includes rocks which were deposited between about 1.8 million and 11,800 years ago. The youngest, called the Pinedale glaciation, is named for deposits near Pinedale Wyoming. The second youngest, called Bull Lake is named for exposures near Bull Lake located between Lander and Dubois. In fact, this area of the Wind River Range is the type area for glacial deposits of the so-called Bull Lake glaciation.

The oldest deposits are referred to as being derived from the Buffalo glaciation, but they have since been subdivided into deposits originating from three "pre-Bull Lake" events which are referred to as the Sacajawea Ridge, Cedar Ridge, and Washakie Point (Dahms, 2004). These subdivisions are also a matter of continuing academic research.

2.3.4.6.2 Stream Terrace Deposits

The Wind River and its tributaries have been incising WRB sediments throughout the Quaternary Period. Younger river terraces are still well preserved, but older terraces are mostly represented by scattered remains. These terraces are notable for hosting large quantities of sand and gravel, which may be exploited for various construction projects.

2.4 Notable Geologic Features

This section describes notable geologic features that have significance based in their scenic, gemological or paleontological value.

2.4.1 Scenic Features

There are several geologic features throughout the Lander Planning Area that are of special interest because of their unusual characteristics: Red Canyon National Natural Landmark, various picturesque badland areas, and the Beaver Rim escarpment are just a few examples in the area. The Sweetwater Canyon, Devil's Gate and Wind River Canyon are outstanding examples of how rivers have eroded through mountain ranges by the process of superposition. There are outstanding glacial features displayed along the north flank of the Wind River Range near where glacial sculpting has formed picturesque mountains, with the subsequent transport and deposition of the glacially quarried material being reflected in extensive till and outwash deposits. The type section for the Bull Lake glacial episode, major glacial episodes in the Rocky Mountains is at Bull Lake, south of Dubois.

2.4.1.1 Red Canyon

The Red Canyon Area about 24 miles south of Lander on Highway 28 offers one of the most accessible and dramatic examples of Laramide-age range-front structures in the Rocky Mountains. The canyon was formed some 60 million years ago during the uplift of the Wind River Range to the west. The Wind River Range was uplifted during the Laramide orogeny (a period of mountain building) along a reverse fault that bounds the range on the southwest. During uplift, the strata on the north flank, represented by Paleozoic and Mesozoic rocks, were tilted to the northeast.

As the mountains were uplifted, the Wind River Basin was down-warped so that the total structural relief between the granitic ridge crest of the Wind River Range and the basement below the basin floor is 30,000 feet. Subsequent erosion by the Wind River and its tributaries removed much of the sedimentary basin fill and incised deep east-west canyons and sculptured the hog backs along the range front. At Red Canyon, the more easily erodible rocks were removed by the action of water, leaving more resistant rocks as hogbacks, creating the canyon as it is seen today.

The Red Canyon area is unique for several reasons. First it offers a unique three-dimensional perspective of the processes described above. While the style of deformation along the Wind River Range is fairly uniform, only at Red Canyon are the strata exposed such that the deformation can be simultaneously viewed along both the strike and dip of the uplifted rocks. Second, the particular rocks exposed have a wide range in origin (depositional environment), texture, color, and erodibility, which also have bearing on the resulting geomorphic land forms.

The result is an excellent example of differential erosion of sedimentary layers, the harder, more resistant layers of sandstone and limestone form cliffs and benches, while the soft, easily eroded shales and siltstones form valleys and gulches. The variability in color also lends to an in-depth understanding of stratigraphy and structure to the untrained eye as the geometry of particular beds are easily traced and differentiated from numerous vantage points.

2.4.1.2 Beaver Rim – Table Mountain

Beaver Rim is a scenic feature that is also important geologically because it represents an unusually complete sequence of Tertiary deposits which are exposed along the slopes of the Rim. This sequence includes representative exposures of virtually complete Early Eocene Epoch (~53 million years ago) through Middle Miocene Epoch (~10 million years ago) stratigraphy. This nearly-complete sequence is rarely exposed as a unit, and is important to the understanding of Wyoming Tertiary geology. Its significance is increased by its proximity to U.S. Highway 287, where the most intact section occurs near Green Cove and can be easily viewed by travelers. The area also represents the erosional boundary between the degrading Wind River Basin to the north and west, and the stable upland Sweetwater Plateau.

In addition, rare fossil remains within the exposed stratigraphy along Beaver Rim have attracted professional paleontological expeditions to this area for over a century. The Beaver Rim area is also significant for the preservation of volcanic deposits derived from the Yellowstone-Absaroka volcanic field to the northwest, and the Rattlesnake volcanic field to the east.

Table Mountain is a mesa-like surface which truncates the Triassic and Cretaceous rocks steeply dipping off the Wind River Range uplift. Located a few miles south of Lander, Table Mountain is interpreted as a pediment, and its surface represents a previous valley floor formerly contiguous with Beaver Rim, which was isolated as a mesa during the excavation of the Wind River Basin.

The Highway 28 near South Pass is a popular vista where the viewer is provided with a unique perspective on the later phases of the Wind River Basin development. In the distance to the northwest, Table Mountain slopes gently northeastward. This vantage point is a unique perspective for viewing the nature and extent of the evolution of the Wind River Range uplift, basin down-warping, sedimentary infilling, and subsequent excavation of the Wind River Basin during the last 60 million years.

2.4.1.3 Granite Mountains – Sweetwater Rocks

The Granite Mountain – Sweetwater Rocks (GMSR) Area of Wyoming is located in south-central Wyoming, and comprises a major up-warp exposing Precambrian-age rocks in a belt about 85 miles long and 30 miles wide. The GMSR occupy much of the divide between the Wind River Basin and the Great Divide Basin to the south.

The Precambrian rocks in the GMSR are primarily composed of granite with lesser amounts of older metasedimentary black and green schist, slate, phyllite and quartzite in the Black Rock-Long Creek area and also along the south margin of the Rattlesnake Hills. Granite is defined as a plutonic rock, consisting essentially of alkali feldspar and quartz and often lesser amounts of sodium feldspar and other accessory minerals such as mica or hornblende may be present. Such granitic rocks are formed at depth in the earth’s crust by the ascent and subsequent cooling of magma while buried, hence the term “plutonic.”

The relatively slow rate of cooling while emplaced in the earth's crust results in a coarse-grained texture, and allows individual mineral grains to be readily identified by the naked eye. At some time after solidification, these rocks were uplifted and exposed to the surface by erosion.

The GMSR area is special for several reasons. The most conspicuous physical feature of the granite rocks is that much of the surface has weathered into a series of massive domes, knobs, and peaks, and an almost ubiquitous system of joints and fractures which give rise to such landmarks as Split Rock. The massive and smooth surfaces exhibited by much of the GMSR granite is attributed to the phenomenon known as exfoliation, which results from the relaxation of residual stress after initial exposure to the elements at the earth's surface. Other well-known examples of this rock type and resultant geomorphology include the Sierra Nevada in California, various parts of the Idaho Batholith and Stone Mountain, Georgia.

The GMSR also represents a uniquely preserved landscape from Wyoming's geologic past. The GMSR area is unique in Wyoming because the individual peaks remain partially buried by upper Tertiary sedimentary deposits whereas other mountain ranges have been almost entirely exhumed and the Tertiary sedimentary record thereby destroyed by erosion. Preservation of Tertiary strata in the area of the GMSR is made possible by subsidence of almost the entire uplift during late Tertiary time, either prior to or contemporaneous with regional uplift that launched the present cycle of regional degradation operating today. Rocks associated with these erosive cycles are thought to be sources of uranium found in strata such as the Wind River Formation, an important source of uranium ore in the Gas Hills area.

This scenario had unique effects on the development of drainages in the region over the past couple of million years. One might wonder how a flat, meandering river such as the Sweetwater could cut a path through the resistant outcrops of Granite in the GMSR. The easterly course of the Sweetwater River was established across the trough line of the Split Rock syncline, but the continued sagging of the GMSR reduced the ability of this stream to erode. The Sweetwater River was thus trapped along a course established on young sediments burying the older granitic rocks. With uplift, the course was maintained as the stream cut down through the young rocks into the older granites, resulting in what is referred to as a "superposed" drainage. The Devil's Gap, a notable landmark along the pioneer trail, is an excellent example of this phenomenon.

In addition, the differential uplift in this area caused the Wind River to divert northward and its gradient to increase several times that of the east flowing Sweetwater River. Headward erosion of the Wind River and its tributaries resulted in the development of Beaver Rim, and in doing so, captured many segments of streams in the Sweetwater River drainage system. As time goes on, this headward erosion will eventually also capture the Sweetwater River and cause it to become a tributary of the Wind River. Also because of differential tilting of the area, north-flowing tributaries of the Sweetwater, such as Crooks Creek, were not everywhere able to reach the river and were cut off.

2.4.2 Gemstone Collecting

The Lander Planning Area is notable for its abundance of many gemstone collecting and recreational mining opportunities. Rock-hounding for jade, petrified wood, agate, sapphire, beryl, and garnet is a long-lived custom in the planning area as is recreational gold-panning in the South Pass Area and parts of the Sweetwater River.

2.4.2.1 Jade

Jade was first recognized in the Granite Mountains area in the 1930s. The hunt for jade in this area intensified and thousands of people participated in the jade collecting each summer. These jade deposits occur as boulders in alluvial deposits or as pods or veins in various locations in Precambrian rocks. Colors range from apple-green to olive-green, dark green, black, and the most prized of all, emerald green.

2.4.2.2 Agates

Agates locally known as "Sweetwater moss agates" are also found in abundance in the Granite Mountains area. These occur principally in gravel deposits weathering out of the Split Rock Formation on about 50 square miles of dip slopes in the north-central part of the Granite Mountains. Closely related are the so-called "Angel agates" which are found in sandstones of the Split Rock Formation. These are translucent and pale greenish-gray, and fluoresce a brilliant greenish yellow.

2.4.2.3 Opal

In 2005, a large deposit of opal was discovered near Cedar Rim, north of Sweetwater Station. This discovery was publicized by the Wyoming State Geological Survey and touched off a modern-day "land rush" which resulted in over 1000 mining claims registered at the Fremont County Courthouse in a span of two months. Most of the opal is "common opal," but some of the highly valued "precious opal" was reportedly found leading some to conclude that there was more to be found. This activity has significantly abated over the last few years and only a few claims remain.

2.4.2.4 Gold-Panning

Gold panning is a popular activity in the South Pass area, and also on stretches of the Sweetwater River to the south. Gold was initially discovered in this area about 1842 and it wasn't until about 1870 that significant interest was shown in prospecting. In 1871, over ten stamp mills were operating in the area, but several years later, the area was nearly deserted. Since the gold rush of the early days, there have been several attempts to reopen old workings, most of which failed after a couple years.

Today, many people converge on the area during the summer months to stake claims and try their hand in recreational gold panning and several clubs operate claims in the area for the sole use of the members. On occasion, these modern-day miners are rewarded with small amounts of gold flakes or dust.

2.4.3 Paleontological Values

Paleontological resources have been found throughout the entire Lander Planning Area. Fossil resources include invertebrate marine fossils from numerous formations, dinosaur skeletal remains from formations of the Mesozoic Era, and mammalian remains from formations of the Mesozoic and Cenozoic Era, especially from the Tertiary Period of the Cenozoic Era.

Formations known to have high potential for significant paleontological remains in the Lander Planning Area include the Triassic age Chugwater Formation, the Jurassic age Morrison Formation and the Cretaceous Lance Formation.

Younger strata of such as the Fort Union Formation (Paleocene Epoch), the Wagonbed Formation, Wasatch Formation, Green River and Wind River formations (Eocene Epoch), White River Formation (Oligocene Epoch), and the Split Rock Formation (Miocene Epoch) all contain outstanding paleontological resources including gastropods, fish, turtles and other vertebrates. Several of the remains found so far have been considered highly significant, and numerous significant remains are expected to be found in the future as studies continue.

The Wind River Formation deserves special mention due to the outstanding examples of vertebrate fossils of national significance. These fossil occurrences also include some of the earliest known examples of modern mammal orders.

3 DESCRIPTION OF MINERAL RESOURCES

3.1 Introduction

Minerals within the Lander Planning Area are classified into three main categories: leasable minerals (e.g., oil, gas, and coal), locatable minerals (e.g., metals, bentonite, and gemstones), and salable minerals (e.g., sand, gravel, pumice, pumicite, cinders, clay, and other common varieties of stone). This categorization has basis derived from several laws, beginning with the *General Mining Law of 1872* (as amended), which allows for the location of lode and placer mining claims as well as a prescription for patents. This law declared "all valuable minerals 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 claim to a locatable mineral is valid depends on such factors as quality, quantity, mineability, demand, and marketability. The law encourages mining companies (and individuals for that matter) to initiate exploration and development, stating that "all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, to be free and open to exploration and purchase.

In addition to the *General Mining Law of 1872*, an assortment of laws governs mineral activity in the Lander Planning Area. They include:

- *Mineral Leasing Act of 1920* (as amended). Under this federal law, the BLM issues leases for developing deposits of coal, phosphates, petroleum, natural gas and other hydrocarbons and sodium on public domain lands and lands having federal reserved minerals.

- *Materials Act of 1947*. Under this federal law, the BLM (under rules and regulations prescribed by the Secretary of the Interior) is authorized to dispose of mineral and vegetative materials through a contract or a free-use permit. These materials commonly include the salable minerals such as sand and gravel, pumice, pumicite, cinders, clay, petrified wood, and other common varieties of stone, and vegetative materials including but not limited to yucca, manzanita, mesquite, cactus, and timber or other forest products) on public lands of the United States.

- *Mineral Leasing Act for Acquired Lands of 1947* (as amended). This federal law states that the leasing of all deposits of coal, phosphate, oil, oil shale, gas, sodium, potassium, and sulfur which are owned by the United States on lands legally acquired by the United States may be leased by the Secretary of the Interior under the same conditions as contained in the leasing provisions of 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.

This act includes all minerals, including sand and gravel, geothermal, coal, and oil and gas. The act directs the Secretary of the Interior (and thus the BLM) to formulate a policy that encourages (1) the development of an economically viable and stable domestic mining industry, (2) research to further "wise and efficient use" of minerals, (3) the marketing of domestic mineral sources in an orderly manner, and, (4) the development of methods of mineral extraction and processing that would be as environmentally benign as possible.

- *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, which as a result, provides an opportunity for any interested party to competitively bid for a federal coal lease. This act also provides that no lease sale may be held on Federal lands unless the lands containing the coal deposits have been included in a comprehensive land use plan. The Act provides that the Secretary of the Interior is authorized and directed to conduct a comprehensive exploratory program designed to obtain sufficient data and information to evaluate the extent, location, and potential for developing the known recoverable coal resources within the coal lands.

- *The Surface Mining Control and Reclamation Act of 1977* (SMCRA). This Act directs the Secretary of the Interior to establish a program for the regulation of surface mining activities and the reclamation of coal-mined lands. It establishes mandatory uniform standards for these activities on state and federal lands, including a requirement that adverse impacts on fish, wildlife and related environmental values be minimized. The Act created an Abandoned Mine Reclamation Fund for use in reclaiming and restoring land and water resources adversely affected by coal mining practices.

- *Federal Land Policy and Management Act of 1976* (FLPMA).This act constitutes the "organic act" for the BLM that establishes the agency’s multiple use mandate to serve present and future generations and governs most uses of the public lands. Among other things, this act states that the public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use. However, the act further states that the public lands be managed in a manner which recognizes the Nation’s need for domestic sources of minerals, food, timber, and fiber from the public lands including implementation of the *Mining and Minerals Policy Act of 1970* as it pertains to the public lands.

It should be noted that because land within the Lander Planning Area falls under various ownership, commercial industry has had to rely on other resources in addition to public lands to meet their business needs. Mineral industry 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 discuss the important leasable, locatable, and salable minerals in the Lander Planning Area.

3.2 Leasable Minerals

Under the *Mineral Leasing Act of 1920* (as amended), the BLM issues leases for the development of leasable minerals. In addition to coal, oil, and gas, leasable minerals include asphalt, chlorides, sulfates, carbonates, borates, silicates or nitrates of potassium or sodium, phosphates, gilsonite, and sulfur in Louisiana and New Mexico (43 CFR 3501.5). This law includes specifications for 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 manages coal leasing and other administrative duties relating to coal production on federal coal lands throughout the U.S. 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, a preference right lease may be obtained 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.

Leasing procedures for oil, gas, and coal-bed natural gas (CBNG 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. The act requires that competitive sales are held at least quarterly and by oral auction. In Wyoming, the quarterly requirement is met in practice by holding such auctions every two months.

Competitive and noncompetitive leases are both issued for a term of ten years. If the lessee establishes hydrocarbon production, the competitive and noncompetitive leases can be held as long as oil or gas is capable of production in paying quantities. The federal government receives annual rental fees on all leases. Royalty on production received in producing leases, one half of which is returned to the State of Wyoming.

The primary leasable minerals in the Lander Planning Area are oil and gas. There is potential for phosphate and to a lesser degree coal, however, there is no current phosphate or coal lands under lease in the Lander Planning Area as of this writing, but in 2008 two proposals were submitted for phosphate prospecting and leasing respectively, both of which will not be considered until the RMP revision is complete.

3.2.1 Non Coal-bed 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 Lander Planning Area contains portions of two oil and gas basins: the WRB (Fremont and Natrona County), and a small portion of the Great Divide Basin (Sweetwater County). Figure 3-1 depicts oil and gas basins in the Lander Planning Area. Figure 3-2 presents oil and gas fields and Figure 3-3 presents oil and gas wells.

Figure 3-1 Oil and Gas basins of the Lander Planning Area

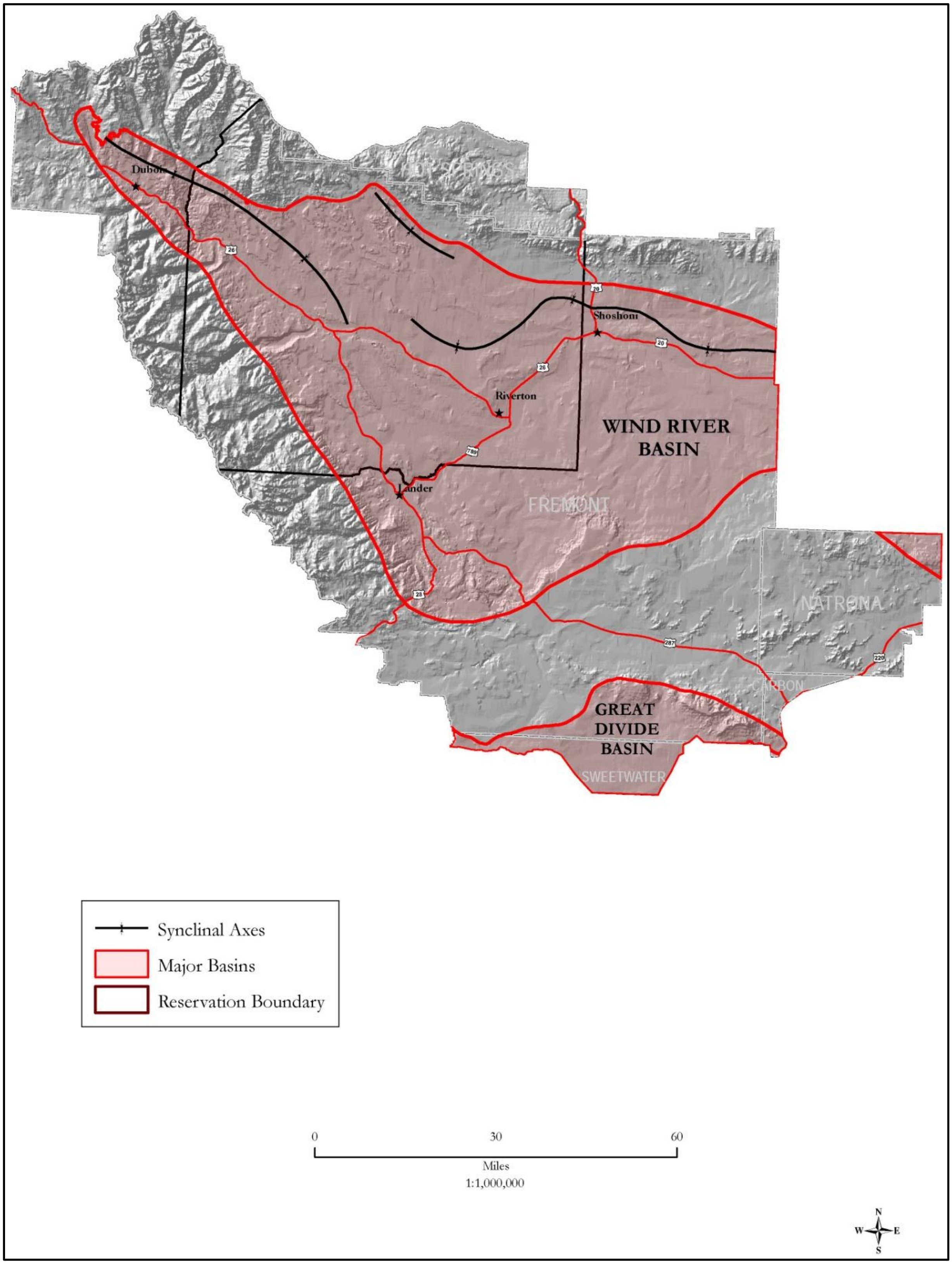


Figure 3-2 Oil and Gas Fields of the Lander Planning Area

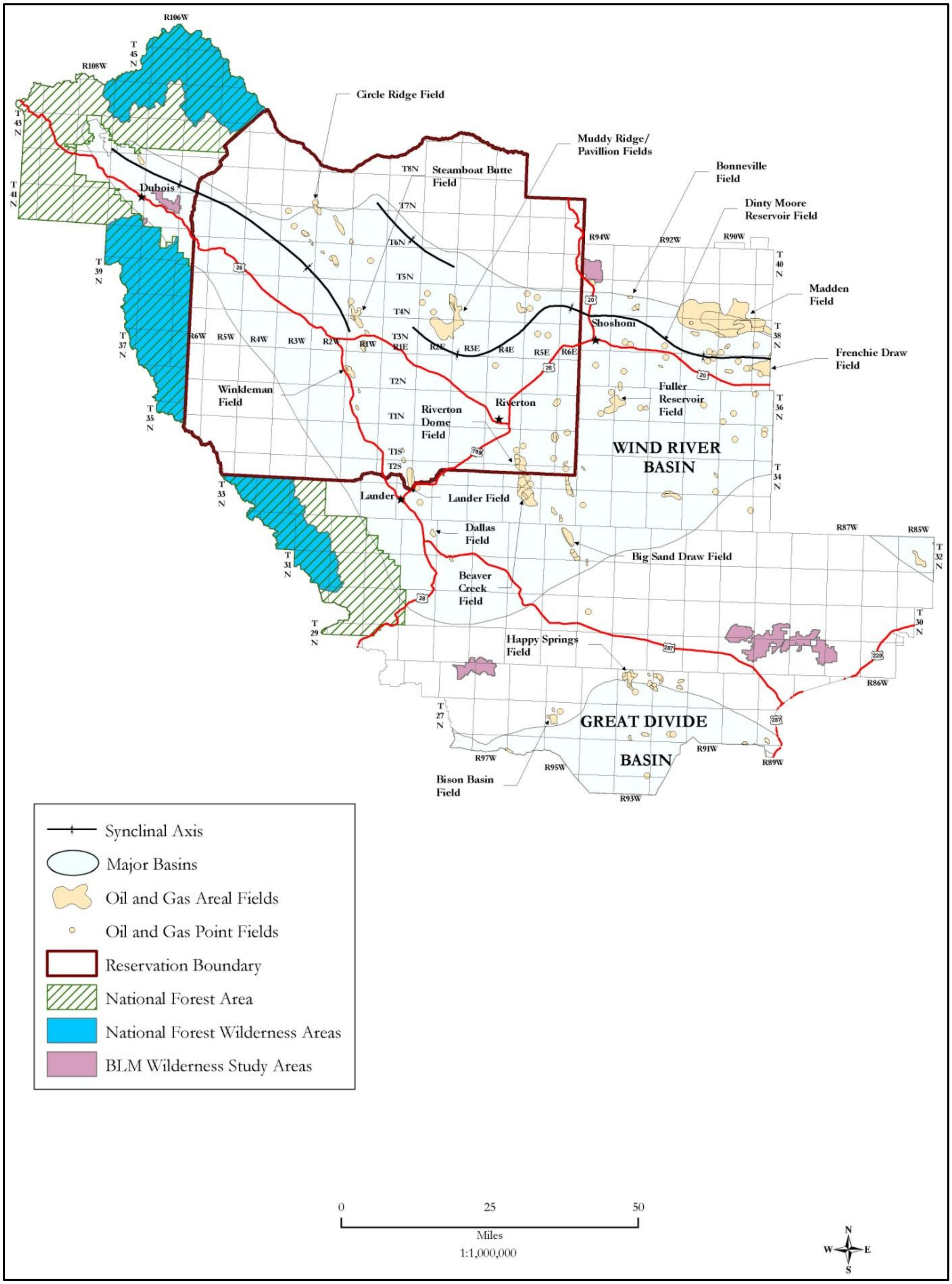
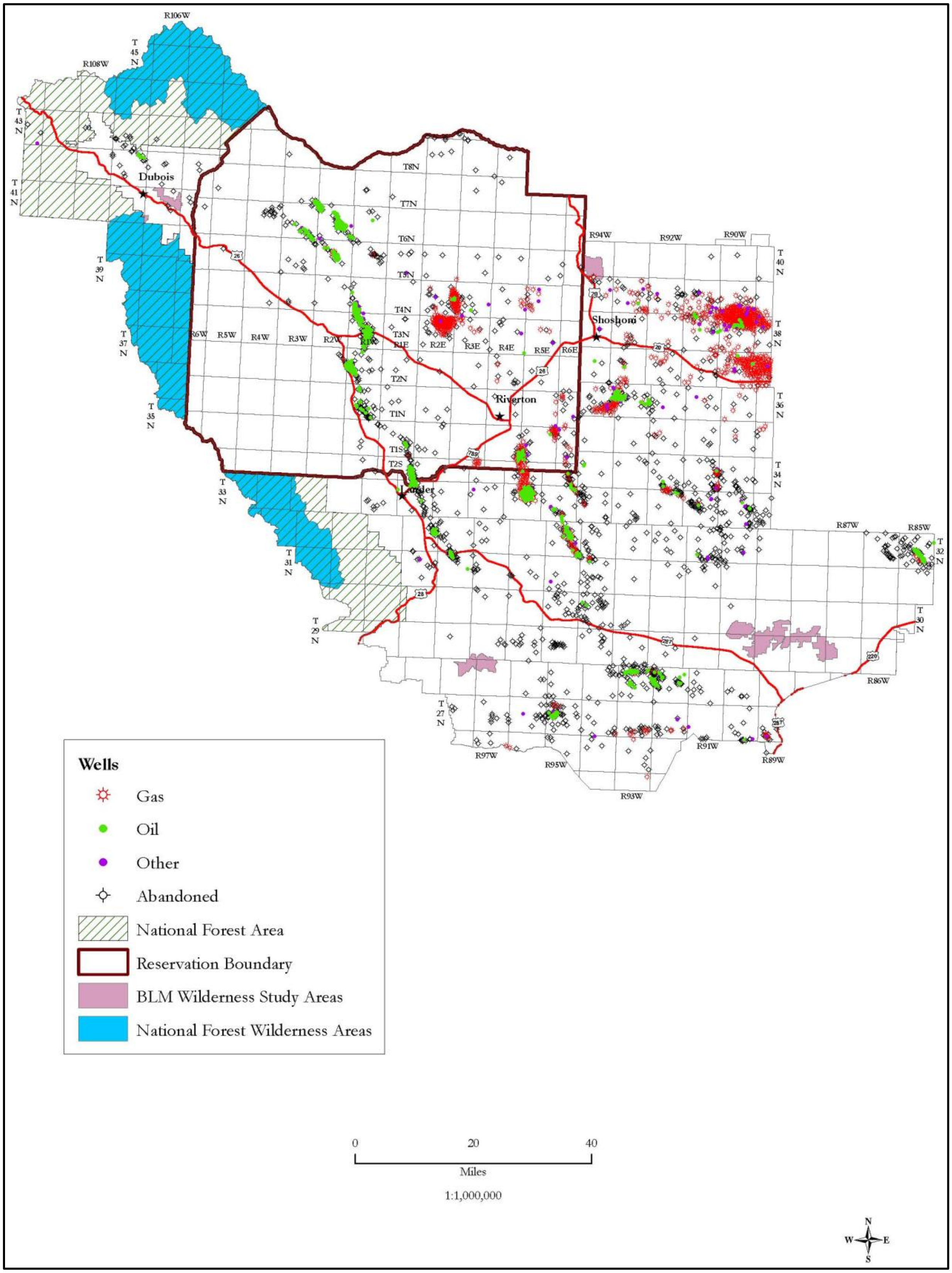


Figure 3-3 Oil and Gas Wells of the Lander Planning Area



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. Compared to other Wyoming BLM planning areas, the Lander Planning Area contains comparatively little oil production

Based on year 2006 production statistics from the Wyoming Oil and Gas Conservation Commission (WOGCC), the majority of the oil produced in the Lander Planning Area comes from two fields: Frenchie Draw near Moneta and the Beaver Creek Field south of Riverton. In 2006, these two fields alone accounted for approximately 56% of the oil production in the Lander Planning Area. Total federal oil production in the Lander Field Area in 2006 was calculated at 1,032,123 barrels of oil (BBLs). As a percentage of total state oil production, the LFO accounted for approximately 2% of the 52,903,162 BBLs produced in 2006.

Gas production in the Lander Planning Area is significant, however. The Madden Field near Lysite accounted for about 158 million cubic feet (MMCF) of gas in 2006. The next most productive gas field is Frenchie Draw with over 11 MMCF of gas produced in 2006. Together these two fields account for over 93% of the 81 billion cubic feet (BCF) of federal gas produced in 2006 in the Lander Planning Area. Based on production records from the WOGCC for 2006, the Lander Planning Area produced approximately 8.6% of the 2.1 trillion cubic feet (TCF) of gas produced in the State of Wyoming in 2006.

Please refer to Table 4-3 in Section 4.2 for a definition of volumetric units for oil and gas.

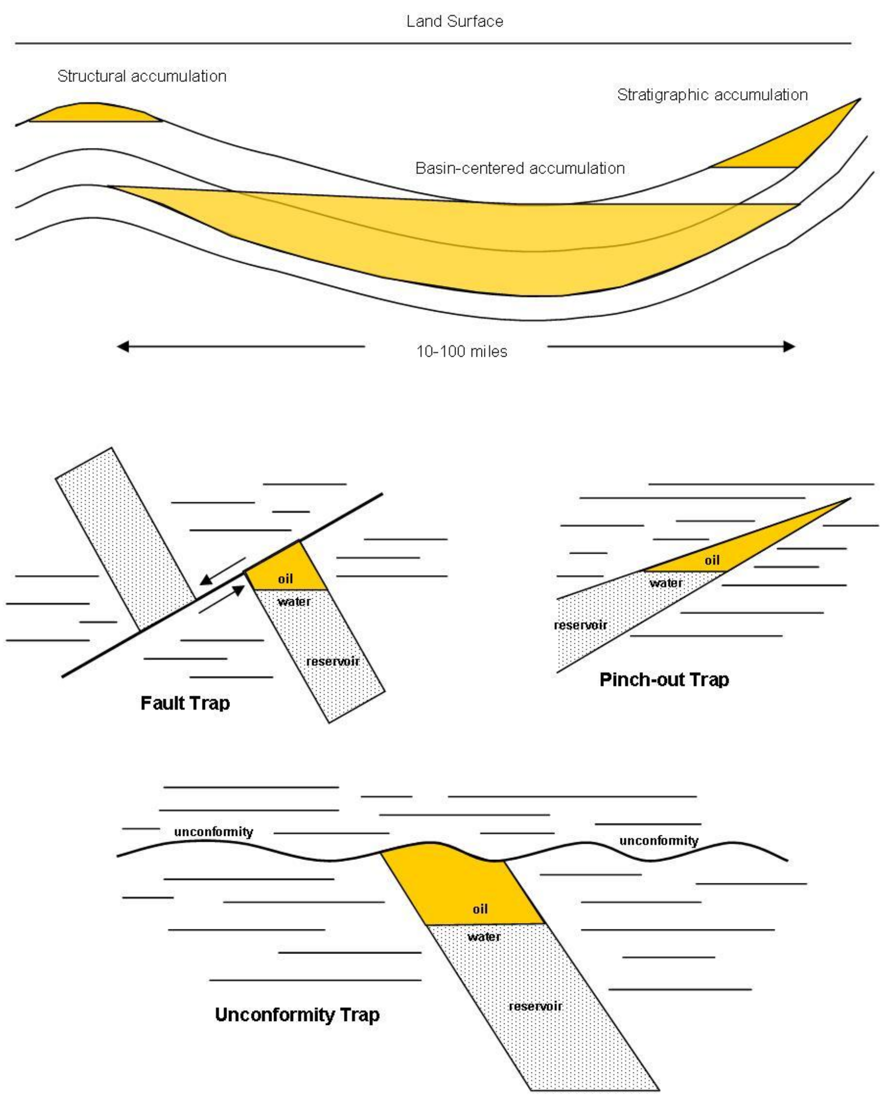
3.2.1.1 Origin, Occurrence and Trapping

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. Examples of organic-rich source rocks include the Phosphoria Formation and the Cody, Mowry, and Thermopolis shales. Examples of rock units within the Lander Planning Area that commonly exhibit oil reservoir characteristics include the Phosphoria and Frontier formations, the Tensleep Sandstone, the Madison Limestone, and various porous intervals in the Fort Union Formation.

There are three types of petroleum traps: structural, stratigraphic, and combination or unconventional traps (See Figure 3-4). When forces within the earth cause a buildup of stress within the crust this stress is commonly relieved through folding or faulting of rock layers which then in turn can form structural traps if hydrocarbons are present. Because oil and gas are relatively immiscible in connate water (water incorporated in rock as the rock was being deposited), and are less dense, oil and gas will migrate upward to the highest point it can occupy in the permeable reservoir. Stratigraphic traps can form as a result in lateral change in rock permeability, resulting in a situation where hydrocarbons migrate to an area beyond which they can no longer move, resulting in an accumulation.

Figure 3-4 Hydrocarbon trapping mechanisms



Unconventional traps include fractured reservoirs, coal seams, diapiric traps and basin-centered gas. According to Johnson et al. (1996) in basin-centered gas traps (also referred to as continuous-type, or "tight" gas reservoirs), accumulations differ from conventional hydrocarbon accumulations in that they

(1) cut across stratigraphic units,

(2) commonly are structurally down-dip from more permeable water-filled reservoirs,

(3) have no obvious structural or stratigraphic trapping mechanism, and

(4) Commonly are either abnormally over-pressured, or under-pressured.

The preceding is an important distinction considering the importance of basin-centered gas in the Lander Planning Area because traditional geologic exploration indicators do not necessarily identify areas favorable for these types of hydrocarbon accumulations. Therefore, without the application of more recent technological advances in the field of petroleum exploration followed up by testing hypothetical plays with wildcat wells, such tight-gas reservoirs may be overlooked. Increasing price, price stability and improved technologies are the key to successful development of continuous-type reservoirs.

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3.2.1.2 Wind River Basin-Centered Gas

The Lander Planning Area contains the vast majority of the WRB (as defined in petroleum geology terms) save for a small portion of the southeastern arm. The WRB produces mainly oil around the basin margins and mainly gas from the deeper areas of the basin. Most of this deeper gas is from reservoirs of Upper Cretaceous and Tertiary age with permeabilities that vary from conventional to tight (Johnson and others, 1996).

The basin-centered gas accumulations in the Wind River Basin appear to extend through an enormously thick stratigraphic interval near the basin trough. These gas accumulations occur down-dip from more permeable water-wet rocks, and the idea is that the presence of water above the gas accumulations renders the rocks lying at higher elevation impervious to gas, thus resulting in a trap facilitated by a capillary seal (Masters, 1979).

According to the United States Geological Survey estimate published in 2005, approximately 2.4 trillion cubic feet (TCFG) of undiscovered natural gas exists in the WRB. Of this resource, approximately 81% (about 1.9 TCFG) is found in continuous or basin-centered gas accumulations (DOI et al., 2005).

3.2.1.3 Wind River Basin Oil Plays

As mentioned previously, the majority of oil fields in the WRB are located on the margins of the basin. About 70% of the oil produced in the WRB is found late Paleozoic reservoirs with Pennsylvanian and Permian rocks as the most important producers (Fox and Dolton, 1989). By 1983, approximately 0.5 billion barrels of oil had been discovered in the WRB. Most of the traps are structural in nature, with a small number appearing to be stratigraphic and combination (Fox and Dolton, 1989).

According to the United States Geological Survey estimate published in 2005, 41 million barrels of undiscovered oil (MMBO) exists in the WRB.

3.2.1.4 Historical Petroleum Production

In 1884, the first oil well in Wyoming was drilled southeast of the present day town of Lander. Oil seeps or springs had been previously observed at three locations in the area, one in the valley of the Little Popo Agie River near the site of the eventually discovery well in 1884, another eight miles north of Lander on Sharp Nose Draw (leading to the drilling of the so-called Plunkett wells), and a third in the valley of the Little Wind River about a mile or so northeast of present day Fort Washakie (Woodruff, 1911). With the exception of the oil from the Plunkett wells, these fields produced heavy asphaltic oil out of Permian-age formations. The Plunkett wells reportedly produced paraffin-based oil from the Mowry shale.

By 1903, thirteen wells had been drilled in the Dallas field south of Lander, and in 1909, one additional well at the Plunkett Field, and two wells were drilled at the Little Wind River district, one near the spring and the other at Sage Creek. By 1910, 27 wells had been completed and five more were being drilled. By then, a pipeline from the Dallas Field to Wyopa was in operation to supply the railroad with oil from two 37,500 gallon tanks, and the Plunkett well was supplying a local market with crude oil and also a small gasoline refinery in Lander (Woodruff, 1911). By 1920, eight fields were producing in Fremont County, and by 1940, that count had doubled. According to the U. S. Bureau of Mines (1960), 29 fields were operating in the Lander Planning Area by 1960.

3.2.2 Coal-bed Natural Gas

The presence of methane in coal seams was historically recognized as a potential hazard in coal mining (BLM, 2003g). Methane (CH_4) 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 which in the 100-year time horizon has approximately twenty-five times more global warming potential than carbon dioxide (IIPC, 2007) and thus is harmful to the environment when vented to the atmosphere during the mining process. However, when captured and marketed through coal-bed natural gas (CBNG) development, methane is an economically valuable resource.

In the early 1980s, Congress considered CBNG 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, and completion procedures) most CBNG can presently be economically produced without tax or other incentives.

3.2.2.1 CGNG Origin and Occurrence

CBNG 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., 2004). 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., 2004).

Because most coals have micro-fractures, or cleats, 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 Fahrenheit (°F). At higher temperatures and in higher rank coals, methane is still generated, but at lower volumes (DeBruin et al., 2004).

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. In general, there is no specific State of Wyoming regulation pertaining to water quality parameters which would bear on an operator's ability to discharge produced water from a CBNG well. These determinations are largely based on a policy that does not allow degradation of the "Class of Use" assigned to the receiving waters.

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 CBNG extraction would be expected to draw some portion of the methane outside of the coal seam back to be extracted.

CBNG is stored in four ways (Yee et al., 1993):

(1) as free gas within the micro-pores 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), micro-pores, and cleats in the coal; and

(4) Absorbed gas within the molecular structure of the coal.

3.2.2.1.1 CBNG Occurrence

Wyoming 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 CBNG. However, they may contain biogenic CBNG (DeBruin et al., 2004). Deeply buried Cretaceous coals in the WRB have probably reached ranks that could result in significant thermogenic methane generation (DeBruin et al., 2004). 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 coal-beds are located in the deeper parts of the Wind River and other coal fields.

Exploration targets for CBNG can be defined by but not limited to the following criteria (DeBruin et al., 2004):

(1) Known, thick, abundant, and laterally continuous coal beds;

(2) coal-bearing areas with coals of appropriate rank;

(3) Adequate conditions for accumulation and preservation of coal-bed methane;

(4) Depth to the coal bed which influences economic and mechanical limits on development; and

(5) Other evidence such as degree and location of fracturing (cleats) faulting, geothermal gradient, high pressure or over-pressured areas in the subsurface, and the presence of gas fields producing from known coal-bearing rocks.

3.2.2.2 Historical and Current CBNG Production

Up to 2004, evidence for CBNG potential within the Lander Planning Area has been limited to perhaps five exploration targets, generally in the Mesaverde Formation with less than 5,000 feet of overburden (DeBruin et al., 2004). Two of these occurrences were observations from a coal exploration well and from a coal mine. The remaining three were inferred from desorption of coal cores. Steeply dipping Lance and Meeteetse coal beds in the Waltman area of the Wind River Coal Field may present additional targets for coal-bed methane development.

By the end of 2007, two CBNG fields in the Lander Planning Area were either in the early stages of exploration or environmental permitting. These two fields include the Pappy Draw area south of Crooks Gap and the Beaver Creek area southeast of Riverton. At Beaver Creek 26 applications for permit to drill (APD) have been filed with the Wyoming State Oil and Gas Commission (WOGCC) wells. Five of the 26 are on state land and have been completed. The remaining 21 wells are on federal land and 5 have drilling underway.

At Pappy Draw, 14 APDs have been approved by the WOGCC, all on federal lands. These wells and an additional five were analyzed by the Lander Field Office under an Environmental Assessment, which resulted in an approved record of decision with a finding of no significant impact (FONSI).Subsequently the operator did not meet the obligation of the Pappy Draw Units and as a result the units were terminated. Therefore, this proposal as originally planned is currently in an undefined status and subsequent proposed development would need to be reanalyzed for environmental impact.

3.2.3 Coal

3.2.3.1 Distribution and Occurrence

The most widespread coal-bearing rocks in the Wyoming are Cretaceous in age and usually crop out at the surface in narrow bands of upturned rocks along the margins of structural basins and uplifted areas in the Wyoming region. Coal-bearing formations contain numerous coal seams separated from one another by as little as a few inches of shale or claystone to hundreds of feet of rock that may vary from coarse sandstone or conglomerate to siltstone, claystones and shales (Rieke and Kirr, 1985).

3.2.3.1.1 Cretaceous WRB Coal

Although coals are reported in the Frontier Formation, the Cody Shale, and the Lance, Fort Union and Wind River Formations, the thicker and more important coals in the WRB are limited to the upper Cretaceous Mesaverde Formation (Glass, 1978; Rieke and Kirr, 1985). Although the Cretaceous coals intercalated in these rocks are generally less than 10 feet thick, a few Cretaceous coals are 30 to 100 feet in Westernmost Wyoming, but generally much less in the WRB.

3.2.3.1.2 Paleogene WRB Coal

Younger (Paleogene) coals in the WRB are mainly found in the Paleocene Fort Union Formation and subordinately in the Eocene Wind River Formation (Flores and Keighin, 1999). The Paleocene Fort Union Formation is considered a minor coal-bearing formation in the Wind River basin; exposed coal is uncommon and thin, seldom reaching 3 ft in thickness (Hogle and Jones, 1991). The surface occurrence of this coal is mainly in isolated and widely scattered outcrops of found along the margins of the basin, and mainly occurs in the Lower Fort Union Member (Figure 3-5) and the Shotgun Member (Figure 3-6). The isopach contours depicted in Figure 3-5 and Figure 3-6 demonstrate that the Fort Union Formation includes only minor amounts of coal at the surface; the coal-bearing intervals are almost entirely in the subsurface (Johnson et al., 1994). In the western part of the WRB, one subsurface coal bed in this coal zone is reportedly as much as 40 ft thick (Flores and Keighin, 1999).

According to the USGS (Flores and Keighin, 1999), these younger deposits have low importance in the current National Coal Resource Assessment because it is improbable they will be utilized in the next 20-30 years. Coal in the Wind River Formation was not included the USGS assessment because it is generally occurs in beds which are less than 1 ft thick.

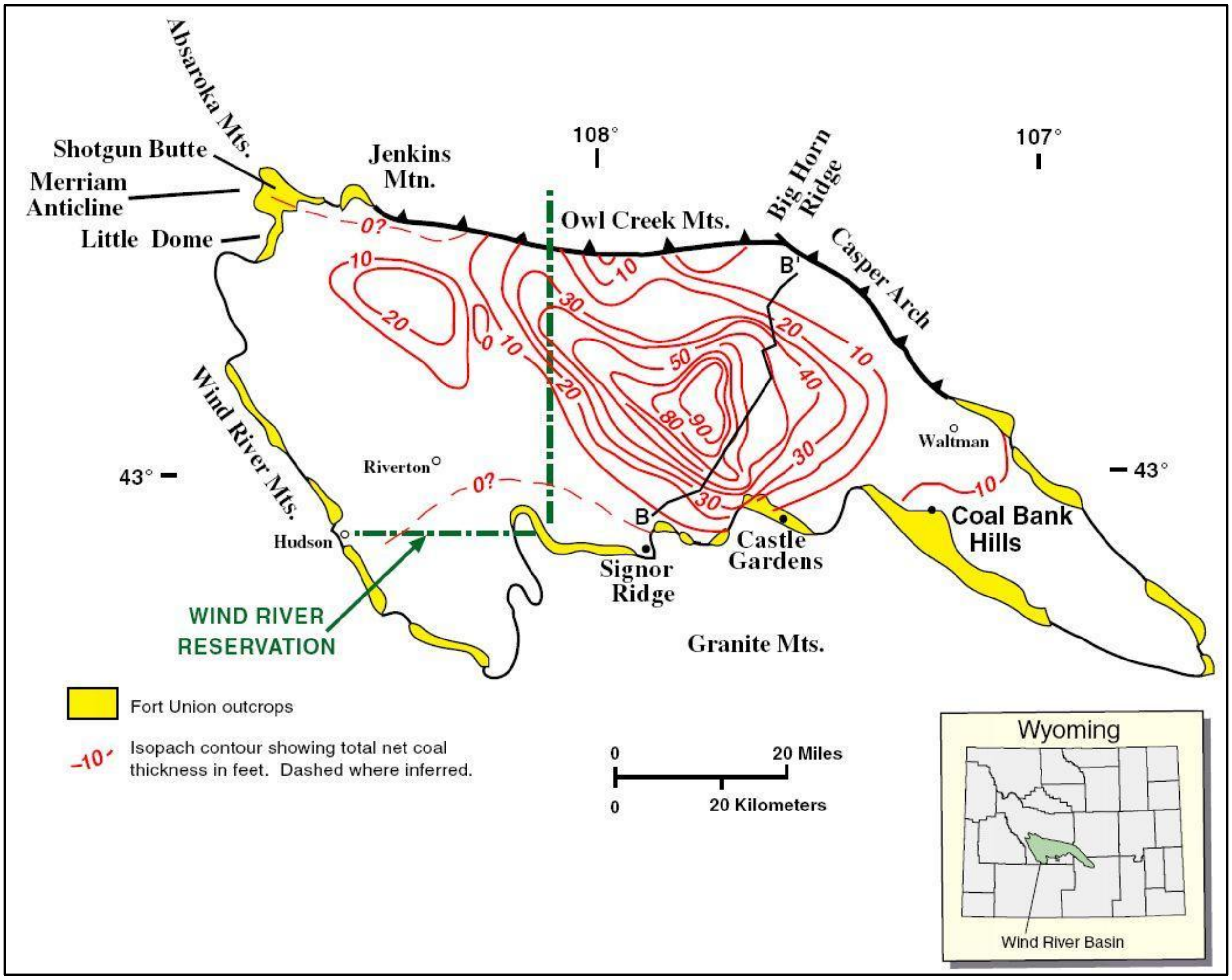
3.2.3.2 Rank

As geological processes apply pressure to accumulated dead biotic matter (e.g., peat) over time, under suitable conditions it is transformed successively or altered into higher “grades.” The degree of alteration (or metamorphism) that occurs as a coal matures from peat to anthracite is referred to as the "rank" of the coal. The kinds of coal, in increasing order of alteration, are lignite (brown coal—immature), sub-bituminous, bituminous, and anthracite (mature), and eventually with enough time, burial pressure and heat, coal can be transformed into graphite. In general, Wyoming coal ranges in rank from lignite to high-volatile A-bituminous (Rieke and Kirr, 1985). WRB coals are generally considered to be subbituminous, (Flores and Keighin, 1999; Rieke and Kirr, 1985; Glass and Roberts, 1978).

3.2.3.3 Historical WRB Coal Production

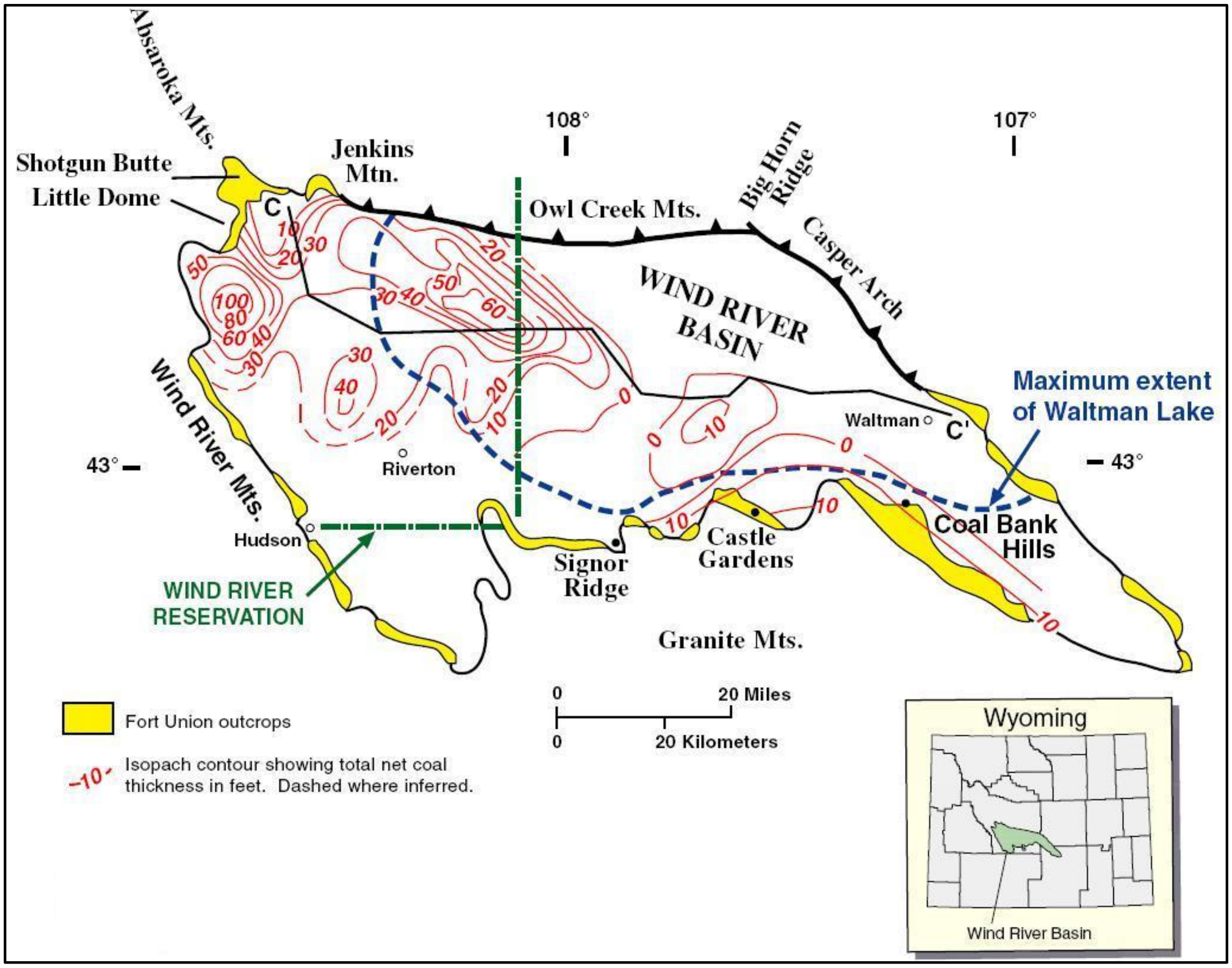
According to Woodruff and Winchester (1910), coal occurrence in the WRB is generally categorized into seven coal fields and regions: Muddy Creek coal field, Pilot Butte coal field, the Hudson (Lander) coal field, Beaver Creek coal field, Big Sand Draw coal field, Alkali Butte coal field, and the Arminto coal field. The major deposits of these fields are found in the Mesaverde and Meeteetse Formations along the WRB perimeter (Rieke and Kirr, 1985). The Muddy Creek Field and the Pilot Butte Fields are located on the Wind River Indian Reservation.

Figure 3-5 Surface outcrop and total net-coal-thickness isopach map of the lower member of the Fort Union Formation



Source: Flores and Keighin (1999).

Figure 3-6 Surface outcrop and total net-coal-thickness isopach map of the Shotgun member of the Fort Union Formation



Source: Flores and Keighin (1999).

Recorded coal mining in the WRB (and therefore the Lander Planning Area more or less) dates back to 1870 (Woodruff and Winchester, 1910). Approximately 58 or so coal mines are known to have historically operated in the WRB. Although coal mining activity in the WRB has had a significant history, production in the Lander Planning Area was insignificant compared to the entire historical production record for the State of Wyoming. In its best year (1920), coal from the WRB only accounted for 3 percent of the total annual production from the State of Wyoming. The 3,982,378 tons of historical coal production recorded for the WRB accounts for only 0.7 percent of cumulative production for the State of Wyoming through 1977.

Annual production in the Lander Planning Area declined after 1927, due reportedly to the remoteness of the WRB and increased competition from larger Wyoming coal fields (Glass and Roberts, 1978).

3.2.3.3.1 Hudson Coal Field

With the opening of the Wyoming Central underground mine just south of Hudson in 1870, the Hudson coal field represents the earliest coal mining in the WRB. Production in the 1800's seldom exceeded a few thousand tons per year, and came from no more than three to four mines in the Hudson area (Glass and Roberts, 1978).

In the early 1900's, the market for coal increased somewhat due to the railroad expansion in the area, eventually production expanded to almost 95,000 tons per year by 1910, finally peaking in 1920 with around 300,000 tons produced (Glass and Roberts, 1978). The last underground coal mine in the basin, the George mine, closed the door on the Hudson coal field in 1966.

3.2.3.4 WRB Coal Resources

3.2.3.4.1 Coal Reserve Estimates

The WRB coal resource is large, and most is contained in thick beds lying at depths greater than 11,000 feet within the basin (Rieke and Kirr, 1985). However, most available resource calculations were restricted to surface outcrops along strike of the beds and extending only for a short distance down-dip. Based on available estimates, total original coal resources (two and a half feet or greater in thickness) in the WRB is over 1025.79 million tons (Glass and Roberts, 1978). These data are presented by coal field in Table 3-1 and also by thickness interval in Table 3-2.

Table 3-1 Coal Resources and Reserve base for the WRB by field

WRB Coal field	Coal resource (million tons)[1]	Remaining reserve base (million tons)
Alkali Butte coal	166.74	34.53
Arminto coal field	176.86	26.97
Beaver Creek coal field	507.47	0
Big Sand Draw coal field	71.83	13.82
Hudson coal field	58.97	7.46
Muddy Creek coal field	43.56	17.93
Pilot Butte coal field	0.36	0
Totals	1,025.79	100.71

Source: Glass and Roberts (1978).

Table 3-2 Coal Resources and Reserve base for the WRB by thickness

Coal thickness	0 – 1,000 ft overburden	1,000 – 2,000 ft overburden	2,000-3,000 ft overburden	Total
➢ 2.5 – 5 ft	112.32	109.91	147.41	396.64
➢ 5 – 10 ft	86.04	91.29	79.35	256.68
➢ 10 ft	41.98	76.71	280.78	399.47
Totals:	240.34	277.91	507.54	1,025.79

Source: Glass and Roberts (1978).

The coal resource and reserve base as presented in Table 3-1 lies between the surface and 3,000 ft in depth, and consists of measured, indicated, and inferred resources of subbituminous coal. Of this original resource, 100.71 million tons of coal remains in the reserve base for the fields included in the tabulation.

Table 3-2 also includes measured, indicated and inferred resources of subbituminous coal. The reserve base here is calculated as 108.67 million tons, based on coal beds 5 feet or greater in thickness under 1,000 ft. of overburden, and including only the measured and indicated categories of reliability. These three parameters delimit today's potentially recoverable portion of the resource: the reserve base. Allowing for future mining losses equal to production, this resource is reduced to a recoverable reserve base of about 50 million tons (Rieke and Kirr, 1985). In addition, some of this quantity may not occur on land actually within the Lander Planning Area (i.e. just outside the boundary or on the Wind River Indian Reservation) and therefore, the actual amount in the Lander Planning Area may be somewhat less.

3.2.3.4.2 Coal Summary

Traditionally the largest problem facing coal mining in the WRB has been the lack of nearby markets (Glass and Roberts, 1978). In addition, the geology of coal occurrence in the WRB (steep dips, thin beds, etc.) also conspires to temper the economic viability of mining. Fort Union coal, for example, is not economically minable today because the thick deposits are found only in the deep parts of the Wind River Basin, and they are not high enough in quality (based on normal Tertiary coal quality) to warrant development of large underground mines (Flores and Keighin, 1999).

Demand low sulfur coal alone is not enough to offset the obstacles to coal development in the WRB because thin coals, conducive only to deep mining, cannot compete with strip mines on thick coal beds (Glass and Roberts, 1978). The only known strippable coal resources are located in the Wilton coalbed of the Muddy Creek field and the Signor coalbed of the Alkali Butte field. Combined they total an estimated one million tons of strippable coal (Rieke and Kirr, 1985). The Muddy Creek coal field was responsible for the only coal mined in the basin after 1966. The Muddy Creek strip mine, located on the Wind River Indian Reservation, accounted for only 85 tons in 1973, and has been inactive since then.

3.2.4 Phosphate

The phosphate deposits of the western phosphate field (Idaho, Montana, Utah, and Wyoming) are predominately owned by the United States. The right to mine and remove the publically owned phosphate is obtained by lease from the Federal Government pursuant to the Mineral Leasing Act of 1920 (as amended).

3.2.4.1 History of Public Domain Phosphate Deposits

Phosphate resources have been a source of interest from time to time over the last 100 years or so. In the early part of the 20th century, phosphate deposits in the western phosphate field were recognized as being a valuable resource (Brunelle, 1967).

3.2.4.1.1 Phosphate Withdrawals

Phosphate was originally defined as a locatable mineral and mining claims had already been located as early as 1903 and mining began near the Idaho – Wyoming border in 1906. Coincident with the recognition of phosphate as a valuable national resource, was the conservation movement of President Theodore Roosevelt's administration. To protect and preserve the phosphate lands in the Western field, withdrawals were made which precluded the entry and sale of lands under the public land laws. On December 10, 1908, the U. S. Government withdrew all the public lands suspected of containing phosphate deposits in Utah, Idaho and Wyoming. This withdrawal affected some 4,699,160 acres and was made in aid of proposed legislation providing for the leasing of phosphate deposits and restriction of exports that would result in the orderly creation of a domestic phosphate industry. In the end, approximately 2 million acres of public lands were withdrawn under executive order.

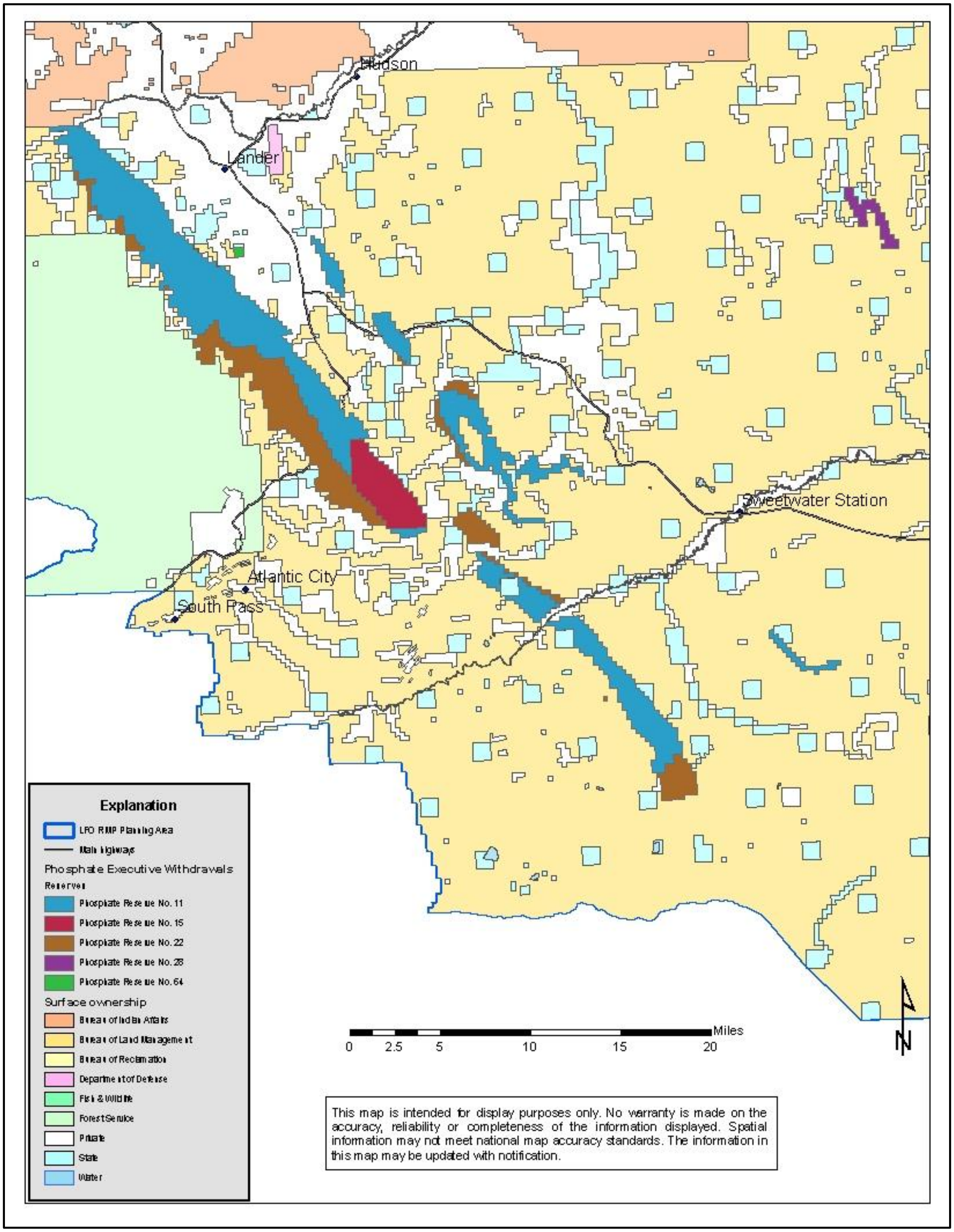
As a result of the previously mentioned resource decision made in 1908 with respect to phosphate, several withdrawals were made in the Lander Planning Area which resulted in the creation of phosphate reservations as tabulated in Table 3-3 and presented in Figure 3-7. Over the years, these lands have been adjusted somewhat by revocations, contractions and in some cases, partial restorations, but in general largely remain on the master title plats as originally defined.

Table 3-3 Phosphate Reservations in the Lander Planning Area

Reservation	Number	Date
Unknown	Wyoming No. 1	July 13, 1910
Phosphate Reserve No. 11	Wyoming No. 2	May 29, 1912
Phosphate Reserve No. 15	Wyoming No. 3	September 12, 1912
Phosphate Reserve No. 18	Wyoming No. 4	July 9, 1913
Phosphate Reserve No. 22	Wyoming No. 5	August 25, 1914
Phosphate Reserve No. 28	Wyoming No. 6	March 16, 1916
Phosphate Restoration No. 14	Wyoming No. 4	July 25, 1914

The executive withdrawals were later sanctioned by Congress with the passage of the Pickett Act of June 25, 1910. Then, by the Act of July 17, 1914 the lands withdrawn or classified for phosphate were open to appropriation, location, selection, entry, or purchase, if otherwise available, under the non-mineral lands laws with reservation to the United States of the phosphate deposits. Later, the Stock-raising Homestead Act of December 29, 1916 provided for the disposal of the public lands with all the minerals reserved to the United States.

Figure 3-7 Map of historical executive phosphate withdrawals in the planning area



3.2.4.1.2 Phosphate Leasing

With the passage of the Mineral Leasing Act of 1920, a process was finally in place for the development of federally owned phosphate deposits (Brunelle, 1967). Phosphate lands can be acquired for exploration or development in one of two ways: issuance of a phosphate prospecting permit, or in the case of lands known to contain phosphate, by competitive bidding. The regulations provide for either oral or sealed bids.

Prospecting permits, authorized by the Act of March 18, 1960 are issued on a first come, first served basis. Prospecting permits may be issued for a period of two years and may be extended for an additional period not in excess of four years. The purpose of the prospecting permit is to vest the permittee the exclusive right to prospect or explore the lands for phosphate and if a valuable phosphate deposit is discovered, the preference right to a lease.

Before a prospecting permit may be offered, the United States Geological Survey (USGS) must classify the lands to the effect that phosphate does not exist in sufficient quality and quantity to be considered workable. The determination of the USGS relative to the workability of phosphate deposits in lands under permit applications have been challenged on several occasions by appeals from decisions of BLM field office managers rejecting the applications. The appeals are decided by the Director of the BLM and his decision may be further appealed to the Secretary of the Interior.

From 1920 until 1963, the USGS handled each prospecting permit application for phosphate on a case-by-case basis to determine whether the land should be leased competitively or whether prospecting should be allowed. In 1963, the geological survey began a systematic evaluation of all Federal phosphate deposits to determine which should be leased competitively.

With the passage of the Federal Land Policy and Management Act of 1976 (FLPMA), numerous changes in the classification process occurred. While classification to prevent improvident disposal of Federal mineral rights was a major responsibility under the previous classification mission, it was not the only requirement. Under FLPMA, the USGS still had classification responsibilities including:

1. The identification of competitive leasing areas for leasable minerals,
2. the inventory of leasable mineral resources;
3. To furnish the Federal land-managing agencies (e.g., the BLM) adequate leasable mineral data on federal lands for land-use planning and multiple-use or best-use decisions; and
4. To furnish congress and other Federal agencies leasable mineral data on the Federal lands being considered for withdrawal by Congressional or executive action.

3.2.4.2 Phosphate Characterization Efforts in the Planning Area

Sometime after the reservations were created, the land classification process was started. Not all historical land classification data is available, but evidence is available that indicate classification efforts were on-going at least through 1971.

Several studies have been performed by various federal government entities over the years in an attempt to quantify the distribution and grade of phosphate-bearing sedimentary rocks on lands in the Lander Planning Area. Phosphate-bearing rock occurs in the Permian Phosphoria Formation in three general locations within the Lander Planning Area. The largest and most well known occurrence is on the northwest flank of the Wind River Range, particularly in the area known as the Lander Front. The rock along the Lander Front can be traced south from the Dubois area to the Sweetwater River. The other occurrences are Crooks Mountain and the Conant Creek Anticline southeast of Riverton. Less information is available about the latter two areas.

Data regarding the grade and extent of phosphorus rock in the planning area are available from several of these studies mentioned above and are presented in following sections.

3.2.4.2.1 Early USGS Work in Planning Area

Field work on the Wind River Range deposits conducted by the U.S. Geological Survey began at the reconnaissance level in 1910, and then in earnest in 1913. Approximately 50 miles of the northeastern flank of the Wind River Range was mapped during the 1913 effort, culminating in a report of phosphate deposits that was issued in 1924 (Condit, 1924). This study found that in general there are two principal phosphate bearing beds in the Permian-age Phosphoria Formation. The lower bed apparently lies approximately 40 to 55 feet above the base of the Phosphoria Formation and the upper beds lies about 60 to 75 below the top of the Phosphoria. The upper bed was found to be more persistent but variable in thickness. The lower bed, while more variable in thickness and ore grade, and absent altogether at Sheep Mountain, contains richer ore zones as a whole than the upper bed and therefore was judged by Condit (1924) to be the more promising source of phosphate ore. Both beds were found to be most favorably developed along the Lander front from Baldwin Creek on the northeast to Tweed Creek on the southeast.

Condit (1924) presented analyses of samples taken from selected areas on the Lander Front from Mexican Creek on the north to approximately Stambaugh Creek on the south. In addition, samples were obtained and analyzed from Sheep Mountain and a location a couple miles north of the Sweetwater River. Table 3-4 presents results of analyses performed on upper bed samples taken from selected locations where most favorably developed along the Wind River Range front between Baldwin Creek and Tweed Creek (Condit, 1924). Table 3-5 presents results of analyses performed on lower bed samples taken from selected locations where most favorably developed along the Wind River Range front between Baldwin Creek and Tweed Creek. Based on these analyses as well as other analytical data available from areas along the Lander Front, Condit (1924) concluded that in comparison to phosphate rock currently being mined in Idaho, the deposits near Lander were less rich, with the lower bed being the more promising of the two.

Following the Condit (1924) study, the Geological Survey of Wyoming released a report in 1947 (King, 1947), and shortly thereafter in 1949, the USBM released a report (King and Schumacher, 1949), both dealing with the nature and extent of the Lander deposits. During the first study, additional samples were obtained from numerous trenches where the outcrop of the formation was exposed in drainages, two of which exposed the entire thickness of the Phosphoria Formation, and a reserve estimate was developed from detailed mapping and sampling. The USBM effort was concerned with drilling test borings and sinking a shaft to obtained bulk sample material at the Red Canyon and Twin Creek areas.

Table 3-4 Analytical results of samples from the upper phosphate bed

Location	Thickness (ft.)	Calculated phosphorus pentoxide (% P_20_5)[1]
Baldwin Creek sec. 18, T. 33 N., R. 101 W.	2.25	16.2
Squaw Creek, sec. 29, T. 33 N., R. 101 W.	3.25	18.8
Sec. 5, T. 32 N., R. 100 W.	3.5	19.8
Middle Fork Popo Agie River, sec. 8, T. 32 N., R. 100 W.	3.5	19.3
Sec., 27, T. 32 N., R. 100 W.	6	19.9
Sec. 25, T. 32 N., R. 100 W.	5	22.6
Little Popo Agie River, sec. 8, T. 31 N., R. 99 W.	7.2	16.3
Sec 33, T. 31 N., R. 99 W.	3.2	16.9

1. Percent phosphorus pentoxide (P_20_5) is calculated from the original data given in units of tri-calcium phosphate by a applying a multiplication factor of 2.183.

Source: Condit (1924).

Table 3-5 Analytical results of samples from the lower phosphate bed

Location	Thickness (ft.)	Calculated phosphorus pentoxide (% P_20_5)[1]
Tweed (Usher) Creek, sec 24, T. 30 N., R. 99 W.	4	27.9
Deep Creek, sec. 26, T. 31 N., R. 99 W.	4.9	23.9
Little Popo Agie River, sec. 8, T. 31 N,.R. 99 W.	2.5	24.4
Willow Creek, sec. 26, T. 32 N., R. 100 W,	2.9	20.5
Crooked Creek, sec. 21, T. 32 N., R. 100 W.	2.25	27.9
Squaw Creek, sec 29, T. 33 N., R. 101 W.	2.67	26.6

1. Percent phosphorus pentoxide (P_20_5) is calculated from the original data given in units of tri-calcium phosphate by a applying a multiplication factor of 2.183.

Source: Condit (1924).

3.2.4.2.2 King (1947) Lander Front Reserve Calculations

As mentioned above, King (1947) calculated reserves along the Lander Front from Baldwin Creek on the north to Cherry Creek on the south. Reserve estimates where made of twenty-two individual "block" areas developed on mapped outcrop of the Phosphoria Formation on the dip slope of the Lander Front. These reserve estimates were based on four factors: area covered by the gently dipping sedimentary deposit, thickness of the phosphate rock, grade of the phosphate rock, and a tonnage factor. Each block was trenched on either side of the block, and each phosphate zone in a trench was assigned an average ore grade based on combining the analytical results of each sample weighted by the thickness of the ore zone sampled. Then the average grade of each block itself was estimated by interpolation between the trenches on each side of the block.

3.2.4.2.2.1 Lower Zone Analysis Results

The King (1947) analysis found that the phosphate rock in the lower zone constituted medium grade except in the vicinity of Squaw Creek and the southern-most areas where it was below medium grade. For the ore blocks calculated, the range in grade of the lower zone phosphate rock was from 21.5 to 29.7 percent phosphorus pentoxide (P_20_5) with an average of 23.6 percent.

3.2.4.2.2.2 Upper Zone Analysis Results

The phosphate rock in the upper zone was all found to be low grade. No individual sample yielded over 22 percent P_20_5. The grade in the calculated ore blocks ranged from 15.2 to 20.2 percent P_20_5 and the average for the upper zone throughout all blocks was 17.1 percent P_20_5.

3.2.4.2.2.3 Total Reserves Estimate

King (1947) calculated the upper phosphate zone (above drainage level) to contain 100,000,000 short tons of phosphate rock 36 ft. thick and averaging only 16 percent P_20_5 which is indicative of a low grade rock. An additional 13,825,000 tons is estimated for each 100 ft. vertically below drainage level. The lower phosphate zone was estimated to contain above drainage level 30,000,000 short tons of phosphate rock 3 to 4 ft. thick, averaging about 23.9 percent P_20_5.These data are indicative of a medium-grade rock. An additional 3,780,000 tons is estimated in place for each 100 ft. below drainage level.

As a general rule, lower grades of phosphate rock require lower strip ratios (i.e., less overburden) in order for a deposit to be economically strip-mined. Underground mining is likely out of the question for thin, low-grade beds.

3.2.4.2.3 U.S. Bureau of Mines (1949) Characterization

In the late 1940s, the U. S. Bureau of Mines was chartered to prepare requirements for new mining enterprises on behalf of the Department of Interior’s Missouri Basin Field Committee who were engaged in various energy development and power requirement studies. As part of a phosphoric acid production plant proposal near Lander, Wyoming, it was determined that basic information on the physical and chemical characteristics of the phosphate beds to determine costs of mining and treatment was lacking (King and Schumacher, 1949).

In response to this lack of data, a drilling program was undertaken in two phosphate areas south of Lander, one in Red Canyon near the little Popo Agie River, and the other on Twin Creek about 10 miles to the south. Along with the drilling program, additional data were obtained from the sampling and analysis of a large bulk sample obtained from the construction of 75-ft deep shaft. A summary of the analytical results from these exploration programs are presented in Table 3-6.

Table 3-6 Summary of USBM analyses (weighted averages) of the lower phosphate zone

Borehole	Lineal feet of sample	Phosphorus pentoxide (% P_20_5)[1]
Twin Creek #1	14	24.8
Twin Creek #2	13.3	22.7
Twin Creek #3	No sample	—
Twin Creek #4)	13.7	23.0
Twin Creek #5	No sample	—
Twin Creek #6	14.4	22.5
Twin Creek #7	14	21.9
Twin Creek #8	14.5	22.7
Macfie #1	4.8	25.8
Macfie #2	8.9	23.8
Macfie #3	8.2	23

1. Percent phosphorus pentoxide (P_20_5) is calculated from the original data given in units of tri-calcium phosphate by a applying a multiplication factor of 2.183.

Source: King and Schumacher (1949)

Drilling activity in Red Canyon centered in the vicinity of the Macfie Ranch where three holes totaling 871 feet were drilled. The Twin Creek prospect was drilled with eight holes aggregating 717 feet. Core samples were obtained during drilling and sent to the Intermountain Experiment Station in Salt Lake City. These data indicate similar values to previous investigations for the lower phosphate zone (refer to Table 3-5). Here no weighted average for the intervals samples exceeded 25.8 percent P_20_5 and no individual sample yielded results exceeding 28.8 percent P_20_5.

The results of the 50-ton bulk metallurgical sample from the shaft sunk in the Twin Creek area and an earlier one-ton sample (King, 1947) from the trench on the Little Popo Agie River near Macfie Ranch was reported by the Natural Resources Research Institute at the University of Wyoming (Duncan and Fisk, 1957).

The one-ton sample from Little Popo Agie yielded a bulk average of 27.1 percent P_20_5 while the 50-ton sample from Twin Creek yielded a bulk average of 20.7 percent P_20_5. Both bulk samples of phosphate rock were obtained from the lower phosphorus zone and are indicative of low grade material.

The experimental work conducted by the Natural Resources Research Institute (Duncan and Fisk, 1957) also indicated that the economics of mining prospects represented by the sample results should be characterized as "marginal." This was apparently due to several reasons: (1) the low grade of the ore, (2) the thinness of the deposit, (3) the main reserves would have to be mined by underground methods, and (4) excess lime in the formation would have fluxing by the addition of silica, adding to the cost of processing.

3.2.4.3 Planning Area Phosphate Classification Results

3.2.4.3.1 Classification Methodology

According to the U. S. Bureau of Mines (USBM, 1982), the classification of phosphate deposits are currently based on two aspects: how well understood the physical extent of the deposit is (degree of geologic assurance) and how feasibly the deposit can be mined and marketed with existing technology and under current market conditions (feasibility of economic recovery). This publication also lists grade, accessory mineral content, bed thickness, strip ratio, and deposit size as factors which are assessed in calculating the reserve base (the in-place demonstrated resource from which reserves are estimated). The minable unit of phosphate rock must be weathered or oxidized and must average greater than 18 percent phosphorus pentoxide (P_2O_5) by weight (equal to approximately 39.2 percent bone phosphate of lime (B. P. L), using a conversion factor of 2.183).

3.2.4.3.2 Grade Estimation for Classification

For purposes of grade estimates, the phosphate industry reserves the term "phosphate rock" for material containing at least 18 percent phosphorus pentoxide (P_2O_5) by weight. Phosphate rock containing between 18 and 24 percent P_2O_5 is classified as low grade, while 24 to 31 percent is medium grade, and greater than 31 percent P_2O_5 is considered high grade. Accessory mineral content of the rock must include a ratio of CaO to (P_2O_5 of less than 1.55, an MgO content of less than1.0 percent, and a combined analysis of Fe_2O_3 and Al_2O_3 of less than 3 percent. In addition, phosphate rock bed thickness must be more than 5 feet, the stripping ratio of overburden per ton of phosphate rock must be greater than 3.5 and the size of the deposit must be greater than 20 million tons of rock (USBM, 1982).

3.2.4.3.3 USGS 1976 - 1987 Phosphate Classifications

The first apparent results of area-wide classification efforts are available as U.S. Geological Survey open-file reports in the form of 1:250,000 scale maps (Shoaff and Lutz, 1976a; Shoaff and Lutz, 1976b). There are no accompanying narratives included with the maps, and because the principles of a phosphate classification system were first published in 1980 and then later revised in 1982 (USBM, 1982), it is unclear what standards were used in determining which lands were to be included on these maps in 1976. In any case, Figure 3-8 presents planning area lands classified as valuable for phosphate in 1976. As mentioned, the USBM in cooperation with the USGS later revised phosphate land classification standards (USBM, 1982) and apparently as a result of the new standards, another revision was performed in 1987, for which data on 1:100,000 scale maps are available. These data are presented in Figure 3-9.

Figure 3-8. Lands classified as valuable for phosphate by the USGS in 1976

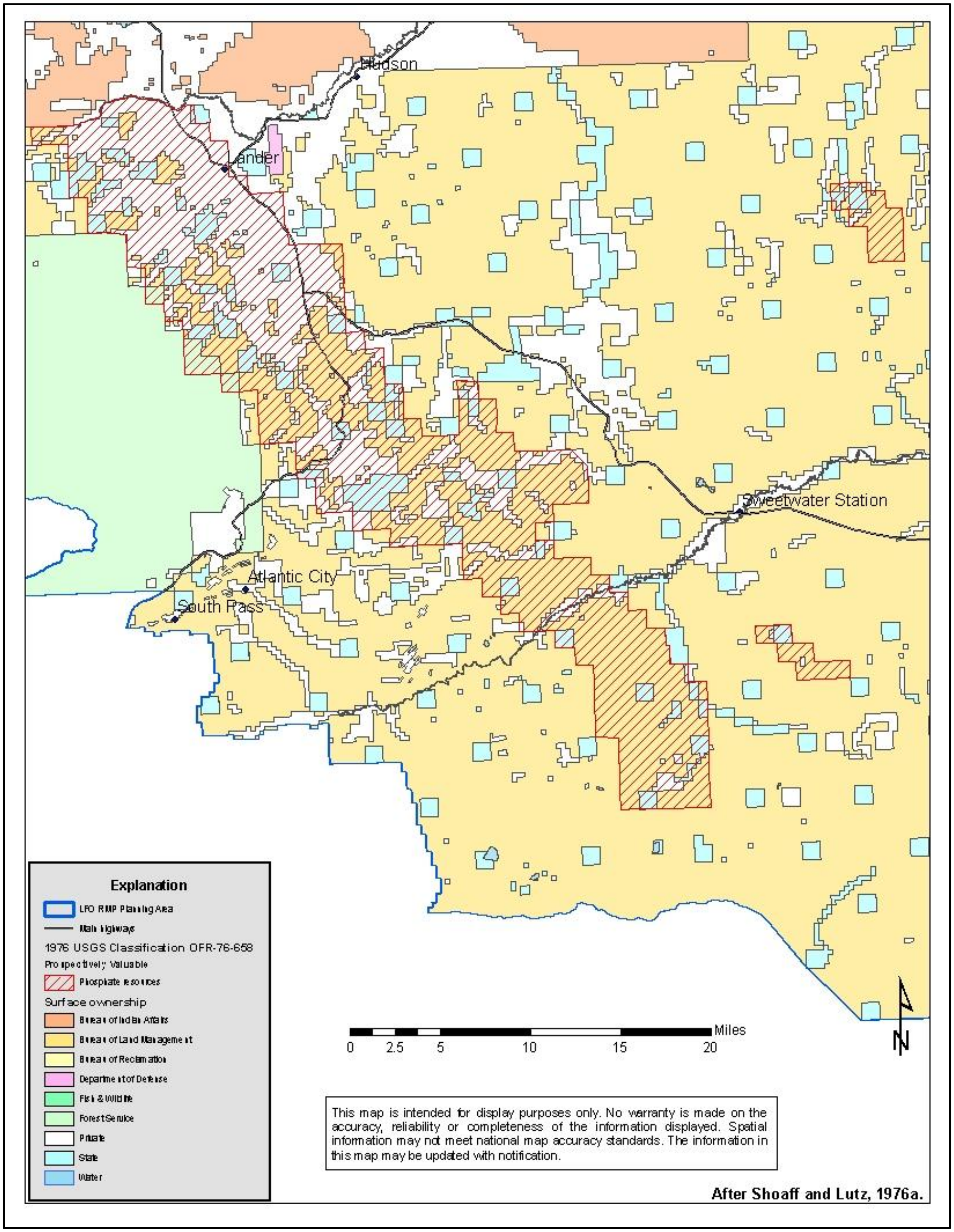
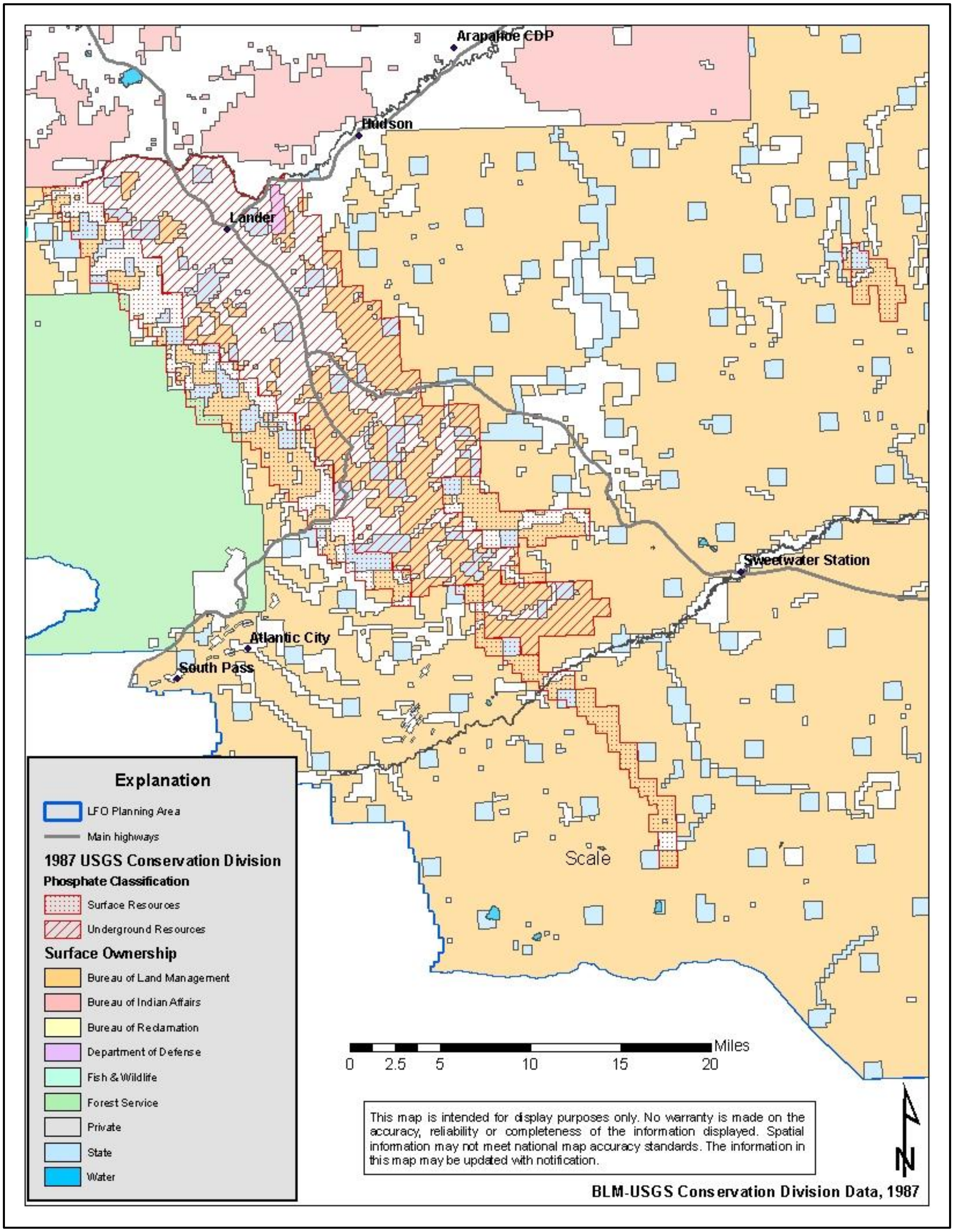


Figure 3-9. 1987 USGS Conservation Division phosphate classification in planning area



3.2.5 Geothermal Energy

High temperature geothermal resources are generally used for electric power generation. Lower temperature resources are used directly (direct-use) and for ground-source heat pumps (Geothermal Resources Council [GRC] 2003). Geothermal energy has the third highest production rates among renewable energy sources, behind hydroelectricity and biomass, and ahead of solar and wind energy (GRC 2003). Technology is still being developed to capture the geothermal resources available.

Geothermal resources occur in numerous places in the Lander Planning Area as evidenced by flowing springs with elevated groundwater temperatures. There are also several areas where measured temperature gradients in groundwater wells may indicate potential for low or medium grade geothermal energy contained in those aquifers. Those areas include north of the Gas Hills, the Diamond Springs area, Big Sand Draw, and the Copper Mountain area. Known thermal springs in the Lander Planning Area are presented in Table 3-7. Figure 3-10 presents a map of geothermal resources which include thermal springs and aquifers with temperatures that exceed 90 degrees Celsius (about 200 degrees F).

Table 3-7 Thermal springs in the Lander Planning Area

Thermal Spring	Location	Temperature (°C)	Flow (liters/minute)
Warm Springs Creek Springs	T. 42 N., R. 107 W.	29	503
Little Warm Springs	T. 41 N., R. 107 W.	25	2120
Jakey's Fork Spring	T. 41 N., R. 106 W.	20	15
Conant Creek Springs	T. 33 N., R. 94 W.	16	1136
Sweetwater Station Spring	T. 29 N., R. 95 W.	32	1890
Horse Creek Springs	T. 32 N., R. 86 W.	24	8327

Source: Heasler (1983).

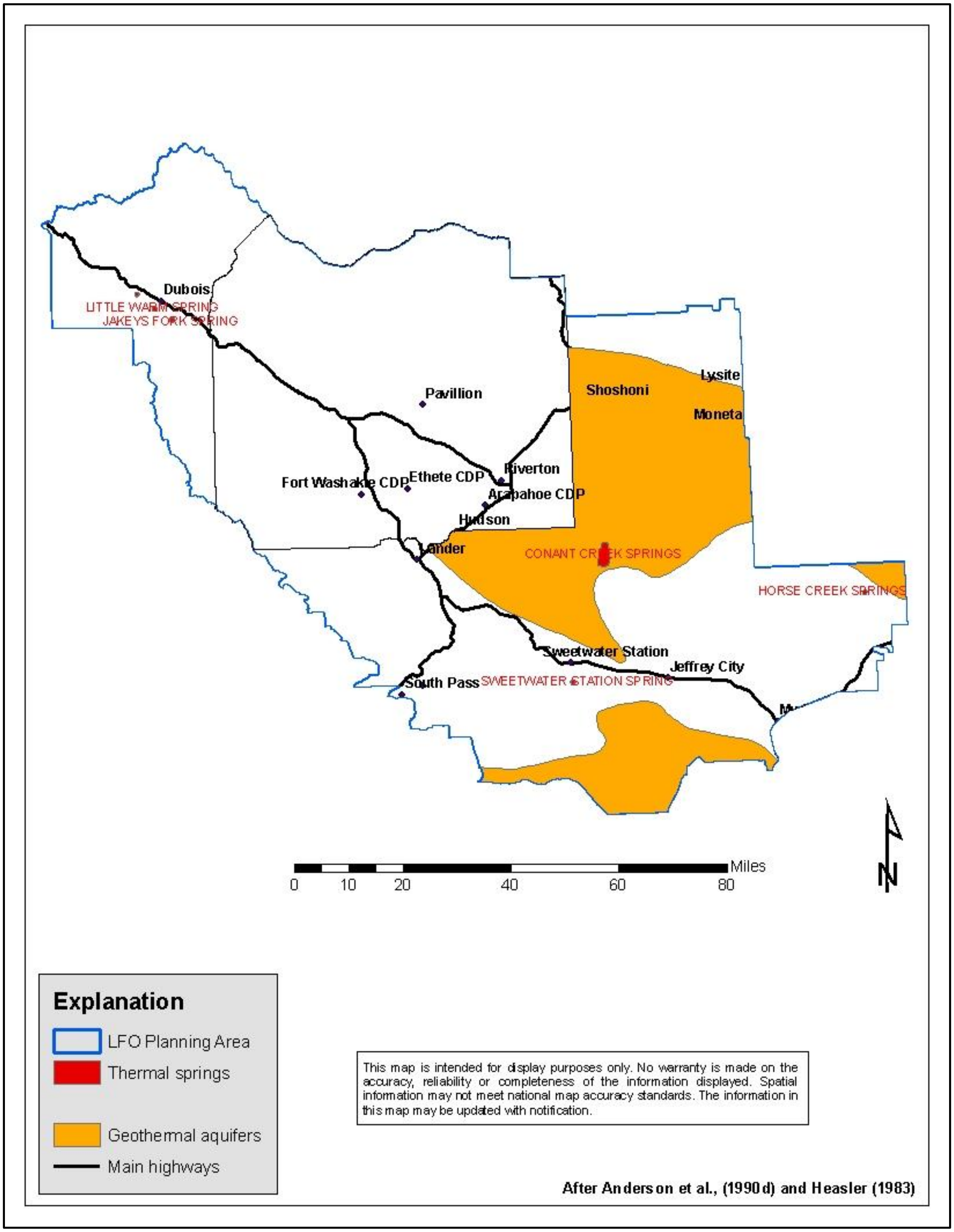
None of the thermal springs included in Table 3-7 were apparently either significant enough or did not meet the criteria to be included in the inventory of hot and warm spring inventory included in the Draft Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States (BLM USFS, 2008).

Overall, there has been minimal geothermal development activity in the Lander Planning Area. There are no current geothermal leases in the Lander Planning Area. There are also no pending geothermal lease applications in the Lander Planning Area (BLM USFS, 2008), and only one application had been received during the past (year 2000). This application was rejected because the previous RMP had not addressed this land use.

Though the country is faced with developing alternate sources of renewable energy, the limited geothermal resources in the Lander Planning Area are not expected to be developed for electric power generation in the near future. Because of the more widespread occurrence of lower temperature resources, direct-use applications may have more potential in the planning area in the future.

More information on geothermal resources and their development potential will be available in the Geothermal Reasonable Foreseeable Future (RFP) document which will be prepared for the Lander RMP.

Figure 3-10 Geothermal resources exceeding 90 degrees Celsius in the planning area



3.3 Locatable Minerals

The Lander Planning Area contains 6.6 million acres of public land and 4.7 million acres of federal mineral estate. The primary locatable minerals that have had production activity, or potential for activity in the planning area, include uranium, other metals such as iron and gold, bentonite, and gemstone and lapidary materials. Authorized mining notices and plan of operations in the Lander Planning Area are summarized in Table 3-8. Figure 3-11 presents a map of major metallic ore deposit districts in the Lander Planning Area as based on USBM known mineral deposits areas (KMDAs), which will be discussed by commodity in following sections.

Table 3-8 Mining notices and plans in the Lander Planning Area as of end of 2008.

Commodity	No. of Notices	No. of Plans of operation	Total acres of disturbance
Bentonite	5	1	121
Gemstones[1]	1	0	4.5
Gold, lode[2]	2	4	10.6
Gold, placer[3]	4	3	145
Uranium[4]	16	2	80
Zeolites[5]	1	0	1

1. Includes diamonds, rubies, sapphires, emeralds, jade, opal, and other precious and semi-precious stones.
2. Does not include nine notices and one plan with a pending status for an additional 169 acres.
3. Does not include four notices with a pending status for an additional 3 acres.
4. Does not include two notices and five plans with a pending status for an additional 8,017 acres.
5. This case is actually pending.

Source: BLM LR2000 database, March 2009.

3.3.1 Uranium

Fremont County has accounted for over 26,000,000 tons of uranium ore since mining began in the 1950s. The county presently ranks second in the state for total uranium produced. There are two major uranium districts in the Lander Planning Area: Gas Hills and Crooks Gap (including Green Mountain) and a third district in the Bison Basin area which is of lesser importance historically. Figure 3-12 presents a map showing the general location of these three districts.

Currently, all three districts are under active exploration by various entities under 43 CFR 3809 mineral exploration notices or plans of operations. Active notice and plan of operations as of April 2009 are presented in map view in Figure 3-13. New major exploration activity on Green Mountain occurred through the 1990's with the development and subsequent reclamation of the Jackpot Mine by the Green Mountain Mining Venture which then followed up with minor exploration drilling in 2007. The Gas Hills District has been experiencing on-going exploration activity since the late 1990s, and the Bison Basin area has experienced exploration activity since the mid-2000s.

Since the early 1980s, there has been little in the way of actual mining as uranium market conditions all but decimated the U.S. industry. The last production in the Gas Hills was in 1984, in Crooks Gap at Sheep Mountain in 1985, and in 1982 at the ISR uranium mining project in Bison Basin, which produced for several months before shutting down.

Figure 3-11. Map of major metallic mineral districts in Lander Planning Area

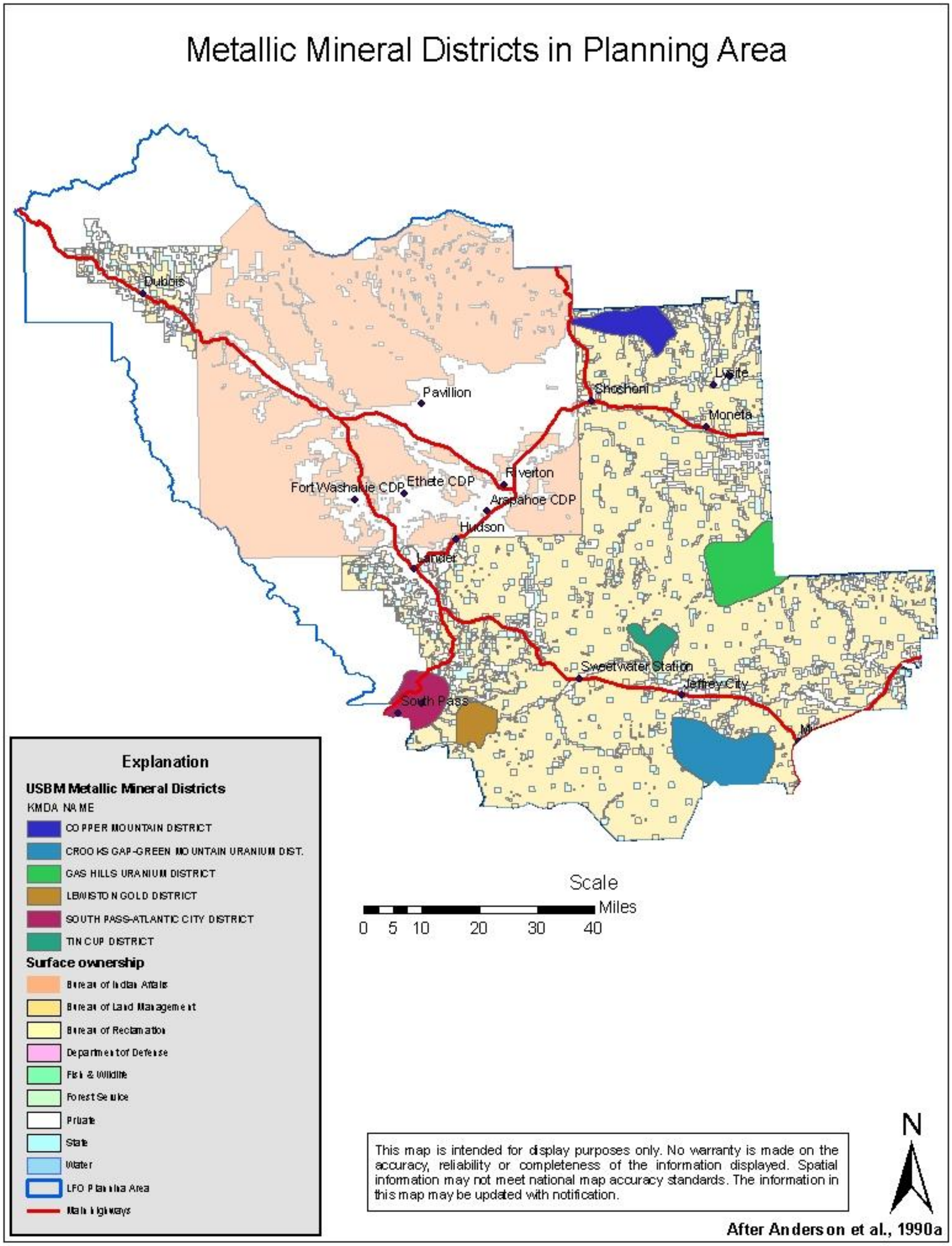


Figure 3-12 Major Uranium Districts of the Lander Planning Area

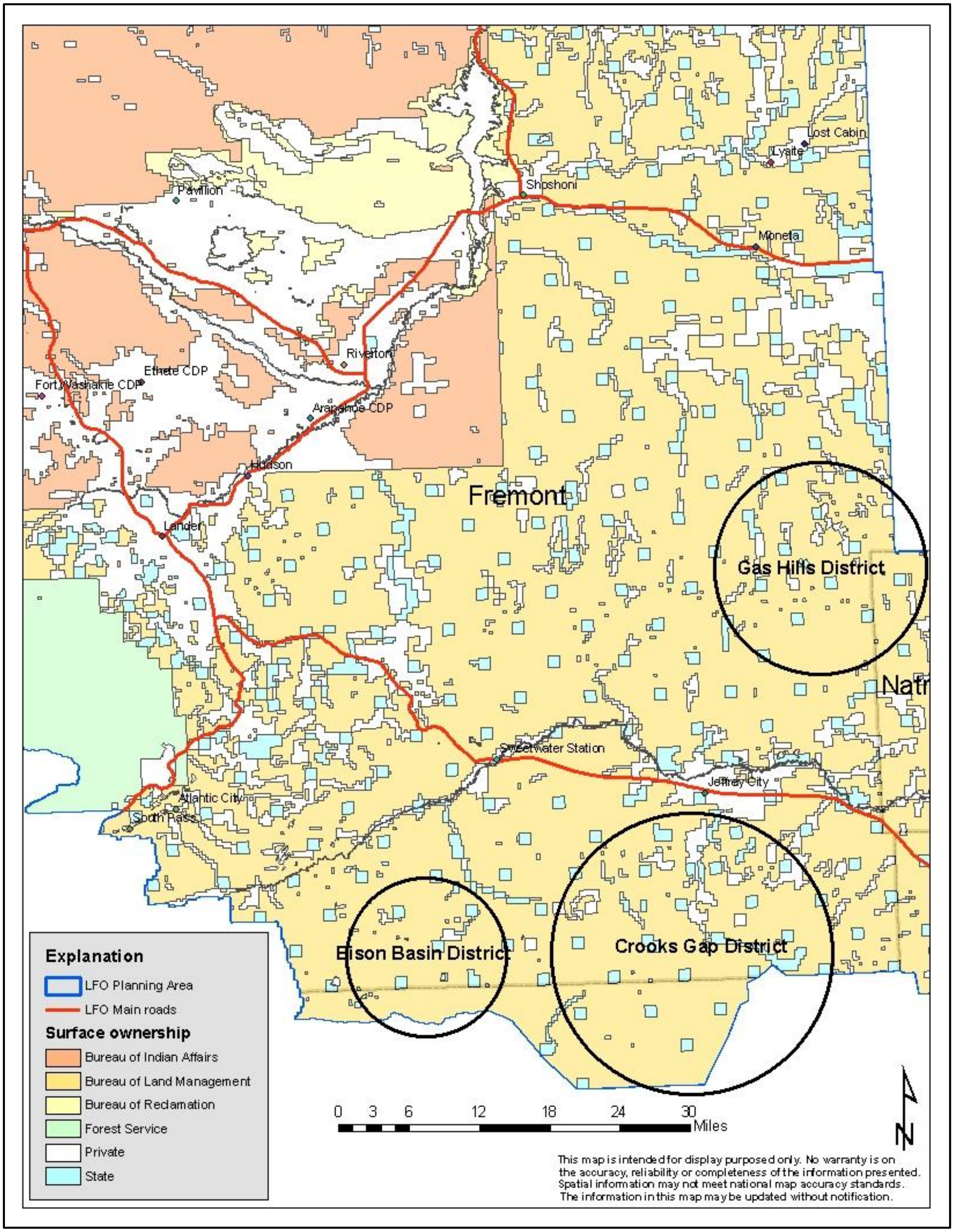
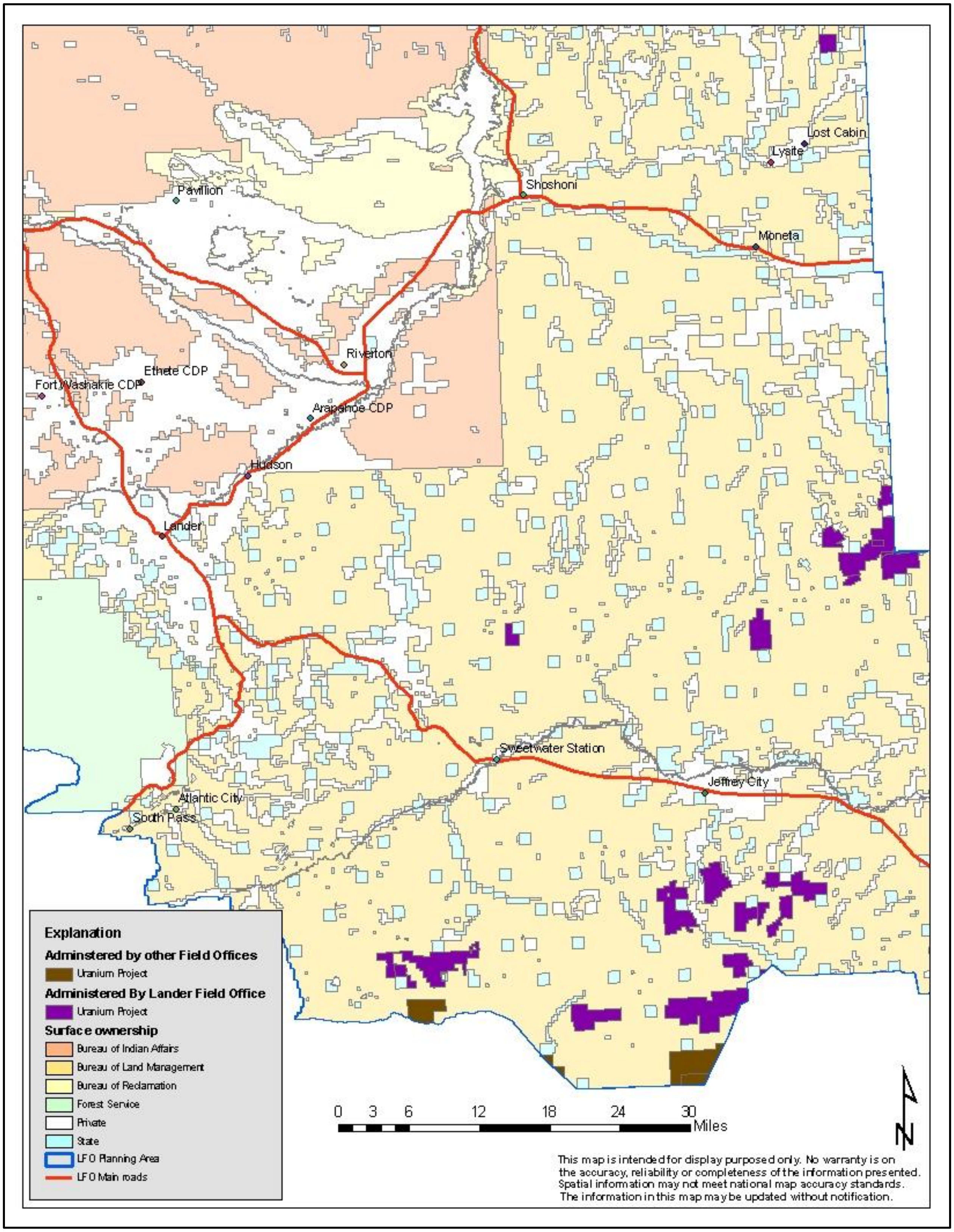


Figure 3-13 Current uranium mining plans and notices in the Lander Planning Area



Some projects such as Big Eagle Mine on Green Mountain attempted to enter interim management to wait for better market conditions to return, but eventually all producing mining ventures began reclamation activities. There are several other known occurrences of uranium-bearing ore bodies in the Lander Planning Area, but are of lesser importance and only produced small volumes of ore.

Mining in the Gas Hills District historically has been predominately by open-pit methods. In the Crooks Gap district, mining was accomplished by both open-pit and underground operations. Mining in the Bison Basin district was accomplished by *in situ* recovery (ISR) methods. All past mining operations have been reclaimed or are in the process of being reclaimed. Of the mines which began reclamation activities, the majority of the sites are administered by the state Abandoned Mine Lands (AML) program due to a variety of reasons including bankruptcy of mine operators, insufficient bond to carry out reclamation, or the fact that many operations were initiated long before mining law required reclamation and bonding.

3.3.1.1 Ore Deposit Geology

Uranium deposits in the Gas Hills area are hosted in the Eocene Wind River Formation. In the Crooks Gap area, ore is mined from the Eocene Battle Springs Formation while ore bodies in the Bison Basin region are found within sandstones in the Eocene Wasatch - Green River Formation. Another significant deposit in the Copper Mountain area contains low-grade uranium in the Eocene Teepee Trails Formation, and igneous rocks including Precambrian granites and quartz monzonites.

Uranium occurs geologically in four main classes of deposits, one of which is dominant in the United States (the “roll front” deposit). The “fronts” form when a uranium-rich source rock is leached by ground water passing through. The uranium is dissolved and re-deposited when the groundwater loses its dissolved oxygen. These geologically favorable areas occur in certain groundwater basins in southwestern Wyoming, and are the host for uranium deposits in the Lander planning Area.

Roll-type deposits are the most important uranium deposit-type being extracted by ISR technology. Ore bodies with the simplest form occur as classical rolls formed in sands of uniform lithology and permeability. These aquifers hosts generally consist of fine grained, well-graded sands that were deposited in marine or in-shore/marine environments. The water-bearing grey-colored horizons with inhomogeneous lithology and variable permeability, as a rule, consist of variable grain size alluvial sediments (IAEA, 2001).

3.3.1.2 Uranium Milling

3.3.1.2.1 Mill Process Overview

The process of uranium recovery focuses on extracting (or mining) natural uranium ore from the Earth and concentrating (or milling) that ore. These recovery operations produce a product, called "yellowcake," which is then transported to a fuel cycle facility.) Several types of milling methods are typically used in uranium recovery:

> Conventional Milling—refers to the process in which uranium ore is removed (mined) from deep underground shafts or shallow open pits and then crushed and subjected to physical and chemical processes to extract uranium from the mined ore.

Heap Leach—a process similar to conventional milling where physical and chemical processes are used to extract uranium from mined ore that has been crushed and piled in a heap. The solution drains through the heap and is captured in a system of drains to further processing.

In Situ Recovery—the *in situ* recovery (ISR) process utilizes a chemical process to extract uranium from underground deposits. However, the chemical solution is delivered directly to the ore body by injection wells, circulated and then pumped out.

The solution, once laden or "pregnant" with soluble uranium is processed further to precipitate the uranium. The in situ recovery facility can be thousands of acres in size, whereas the conventional and heap leach sites are restricted to 40 acres per impoundment.

The challenge in operating any uranium milling facility is to limit groundwater contamination and restoring groundwater quality after a mill site is decommissioned. In some cases, alternate concentration limits (ACLs) are used as standards for restoring groundwater quality impacted by the operation of uranium milling facilities. ACLs are risk-based concentration limits that can be used to establish alternate ground water protection standards. Specifically, ACLs are contaminant concentrations that EPA or authorized State agencies determine will not pose a substantial hazard to human health or environmental receptors (given exposure pathways and other factors). In essence, ACLs are alternatives to setting ground water protection standards at background concentrations and to using Maximum Concentration Levels (MCLs) or their equivalent as a cleanup or regulatory compliance level.

3.3.1.2.2 Conventional Mill Site disposition

In the past 50 years, numerous conventional uranium milling facilities were in operation in Lander Planning Area, including several in Gas Hills, one in Riverton, and the Split Rock Mill in Crooks Gap, which was the first uranium mill in Wyoming. Presently, with the exception of one, all mills are undergoing or have been decommissioned. The still existing Sweetwater Mill, is the only conventional mill left in the State of Wyoming and is located south of the Lander Planning Area about 45 miles northwest of Rawlins. This mill, owned by Kennecott Uranium Company, is one of six operational conventional mills left in the United States and has been on standby status since 1983.

It is the policy of the Nuclear Regulatory Commission (NRC) to transfer lands used for uranium mill sites, processing and the storage of processing waste (tailings) to the U.S. Department of Energy (USDOE) for long term monitoring and oversight. Table 3-9 presents lands segregated from land use laws in preparation for withdrawal and transfer to the USDOE. The status of each mill site is discussed below in the following sections.

3.3.1.2.2.1 American Nuclear Corp. - ANC Mill

Reclamation oversight of this facility has been transferred to the State of Wyoming, Department of Environmental Quality (WYDEQ). This transfer occurred because ANC had become insolvent in May 1994 and site reclamation was incomplete. A Confirmatory Order between U. S. Nuclear Regulatory Commission (NRC) and the WYDEQ describing the requirements for reclamation activities was agreed upon by both parties and was issued in October 1996. The licensed site encompasses approximately 550 acres of which approximately 80 acres consist of Tailings Pile No. 2 and 40 acres of Tailings Pile No. 1.

Table 3-9 Lands under segregation at Lander Planning Area Uranium mill sites

Mill site	Township / Range	Section(s)	Acreage[1]
Western Nuclear - Split Rock Mill (WYW172386)	T. 29 N., R. 91 W.,	Sec. 6, lots 8 through 13, incl., E1⁄2SE1⁄4;	749.09
	T. 29 N., R. 92 W	Sec. 1, lots 1 and 2, S1⁄2NE1⁄4, SE1⁄4SE1⁄4; Sec. 2, SE1⁄4SW1⁄4, SW1⁄4SE1⁄4; Sec. 11, NW1⁄4NE1⁄4, NE1⁄4NW1⁄4; Sec. 12, W1⁄2NE1⁄4.	
Pathfinder - Lucky Mac Mill (WYW161764)	T. 33 N., R. 90 W.,	Sec. 9, lots 1 and 2, and NE1⁄4SE1⁄4; Sec. 10, lots 1 through 3, inclusive, NW1⁄4, W1⁄2SE1⁄4, and that unpatented portion of Mineral Survey No. 644 lying within sec.10; Sec. 15, lots 1 through 8, inclusive, S1⁄2NE1⁄4, NW1⁄4NE1⁄4, N1⁄2SE1⁄4, SE1⁄4SE1⁄4, and those unpatented portions of Mineral Survey Nos. 587 and 644 lying within sec. 15; Sec. 21, E1⁄2NE1⁄4, and NE1⁄4SE1⁄4; Sec. 22, lots 1 through 4, inclusive, NE1⁄4NE1⁄4, and those unpatented portions of Mineral Survey Nos. 582, 584, and 587 lying within the N1⁄2, NW1⁄4SW1⁄4 and N1⁄2SE1⁄4.	1,091
Umetco – East Gas Hills Mill (WYW164606)	T. 33 N., R. 89 W.,	Sec. 9, SE1⁄4; Sec. 10, S1⁄2; Sec. 15, N1⁄2, SE1⁄4SE1⁄4; Sec. 21, NE1⁄4; and Sec. 22, N1⁄2.	1,320
American Nuclear - Gas Hills Mill	T 33 N., R 93 W	Unknown, under WYDEQ reclamation responsibility	unknown

1. Values are shown are for public surface (any additional subsurface mineral estate not included).

Tailings Pile No. 2 reclamation activities were completed and approved by NRC in February 1998 and Tailings Pile No. 1 activities are on hold. Additionally, the site has an active groundwater recovery and corrective action program. Reclamation activities were targeted to restart in 2005 but have not yet begun. Since the last inspection on May 2-3, 2007, no site reclamation activities had been performed. During this inspection, the NRC found that the WYDEQ had failed to perform the prescribed settlement and groundwater monitoring program, and issued a Notice of Violation on June 22, 2007.

After approval of the reclamation plan for Tailings Pile 1, activities will include the following: (1) windblown area cleanup activities, (2) capping with clay, (3) radon testing, and (4) placement of riprap rock. WYDEQ's goal was to submit the final reclamation plan for Tailings Pile 1 for NRC review and approval in 2004 and complete the associated reclamation in 2005 but that has not been accomplished. The cost for decommissioning is estimated to be approximately $3.2 million. Site closure is slated for December 1, 2011. WYDEQ has approximately $3.2 million in USDOE Title 10 funds to complete reclamation of Tailing Pile 1.

3.3.1.2.2.2 Pathfinder Corp. Lucky Mc Mill

Uranium milling began at this site in 1958 and continued through 1988 with a total of 12 million tons of ore processed. The mill utilized a conventional acid leach process. The mill was demolished and placed in the out slope of the No. 2 Tailings Dam, with a clay radon barrier placed over the material. The mill area includes approximately 56 acres.

The site has three solid tailings impoundments and three tailings solution ponds. The post-reclamation tailings piles cover approximately 241 acres. Ground water pumping operations at the facility have been on-going since 1980. The corrective action to restore groundwater quality consists of ground water pumping to evaporation ponds and the injection of fresh water to remove contamination and impede flow of contaminated ground water in the aquifer. A total of 197 million gallons of contaminated water has been collected and 193 million gallons of fresh water injected as part of the remedial effort and approximately 217 million gallons of water have been pumped from the tailings by the end of 2001.

On December 20, 2002, ACLs were approved for the Lucky Mc site, and all active correction actions ceased, such as pumping and injection. The mill tailings site reclamation was completed on December 14, 2004. The Construction Completion Report was submitted to the NRC on April 21, 2005. NRC staff approved the Construction Completion Report in October 2006, and apparently began proceedings to terminate the mill license.

Estimated date for closure is December 31, 2007. On November 15, 2006, the Notice of Proposed Withdrawal and Transfer of Jurisdiction to the USDOE was published in the Federal Register (Volume 71, No. 220, page 66553).

3.3.1.2.2.3 Umetco - East Gas Hill Mill

The site is located within the Gas Hills Uranium District of the Wind River Basin, in portions of Sections 10, 15, 16, and 22, Township 33 North, Range 89 West. The restricted area, including the tailings disposal and heap leach areas, consists of approximately 542 acres, of which Umetco Minerals Corporation (Umetco) owns 280 acres. Mill operation ended in 1984 and the mill was decommissioned in 1990. The NRC is currently reviewing the Licensee's Construction Completion Report, which details the reclamation of the GHP2, Above Grade Tailings Impoundment, Heap Leach, A9 Repository, and C18 Repository areas.

Before license termination, DOE must arrange for transfer of land that is within the long-term care boundary from the Bureau of Land Management. Estimated closure date is 12/31/2010. On April 14, 2008, the Notice of Proposed Withdrawal and Transfer of Jurisdiction to the USDOE was published in the Federal Register (Volume 73, No. 72, page 20063).

3.3.1.2.2.4 Western Nuclear Inc. – Split Rock Mill

Located approximately 2 miles north of Jeffrey City, the Split Rock mill site consists of three reclaimed tailings impoundments occupying approximately 180 acres and other reclaimed disposal areas. The Split Rock Mill has the distinction of being the first uranium mill to operate in Wyoming with operations commencing in 1958 and continuing until 1981 (Chenowith, 1991). Uranium ore processed at the mill was extracted in mines south of the facility. The mill operations consisted of physical and chemical including sulfuric acid leaching.

Decommissioning of the mill was completed on September 15, 1988. Surface reclamation has been completed for the tailings impoundments. The plan for the evaporation ponds cover was approved in October 2006, and the two evaporation ponds have been reclaimed. The Construction Completion Report for the evaporation ponds was approved on November 30, 2007. The estimated date for Split Rock Mill closure is 12/31/2008. On April 14, 2008, the Notice of Proposed Withdrawal and Transfer of Jurisdiction to the USDOE was published in the Federal Register (Volume 73, No. 72, page 20062).

3.3.1.2.2.5 Riverton Custom Mill

In 1958, the Riverton Custom Mill became the third such uranium mill to be constructed in Wyoming (after the Split Rock Mill and the Lucky Mc Mill). This mill was unique as it had both acid leaching and alkaline leaching circuits (Chenowith, 1991). This mill was constructed by Fremont Minerals, Inc. a subsidiary of Susquehanna – Western Inc. and was designed for a total capacity of 600 tons per day. This former mill operated until 1963 and was located on ground now owned by the state of Wyoming.

3.3.1.3 Current Uranium Exploration Activity

In the time since the downturn of the uranium market in the early 1980s, exploration activities were slowed considerably until the mid-2000s, when the price of uranium experienced a spike in price similar to that of petroleum crude oil. Activity is centered in historical uranium districts as well as other outlying areas within the Lander Planning Area. The vast majority of the activity has emphasized ISR prospects rather than conventional open-pit methods.

3.3.1.3.1 Gas Hills District

In 2007, Power Resources (dba Cameco Resources) revived its interest in its ISR mine proposal in Gas Hills along the base of Beaver Divide southeast of the Lucky Mac area. This mine proposal has been underway in some shape or form since the early 1990s and an Environmental Assessment was prepared by the NRC with a Finding of No Significant Impact (FONSI) for their permit and finalized in 2004. This mine has been permitted by the State of Wyoming as a satellite facility to the Cameco Resource Highland Ranch facility currently operating in Natrona County. The proponent is currently preparing an updated plan of operations which will receive additional analysis under the NEPA process.

Other activity in the Gas Hills includes Strathmore Resource's George/Ver open-pit mine proposal near the old Lucky Mc mine which is currently undergoing reclamation. Strathmore also has submitted a notice for their South Black Mountain prospect several miles southeast of Gas Hills on Beaver Rim.

Strathmore has also submitted a notice for their Jeep property about 10 miles southwest of Gas Hills near Muskrat Basin, and has conducted limited exploration drilling to identify ore bodies favorable to exploitation by ISR methodology.

3.3.1.3.2 Crooks Gap District

Interest in developing known deposits on or near Green Mountain have been on-going with a drilling program conducted by the Green Mountain Mining Venture (GMMV) in 2007, and a 2008 proposal to drill within the Green Mountain ACEC by Uranium Energy Corporation. In addition, Uranium One has expressed interest in the re-opening of the Sheep Mountain mine, as well as for the potential North Gap open pit on the same property.

Uranium One has also conducted extensive drilling exploration operations just north of Osborne Draw on their JAB and Antelope notices. These projects, located in Township 26, Range 92-84, were combined into one 14,574-acre plan of operations which is currently under NEPA evaluation. The application for this project was submitted to the NRC in FY08.

In 2008, Ur-Energy completed drilling of the RS Project located just south of Crooks Mountain near the south border of the Green Mountain ACEC. Ur-Energy also filed a notice in 2008 for the North Hadsell project, located just south of Crooks Creek near the Fremont –Sweetwater county line in Townships 26-27, Range 91-92. As of April 2009, this project has yet to be explored by Ur-Energy.

Further to the south straddling the Lander Planning Area boundary in Township 25, Range 93-94, UR-Energy is developing the Lost Creek ISR uranium project. This project is administered by the Rawlins Field Office.

3.3.1.3.3 Bison Basin - Great Divide Basin

As of 2007, Wildhorse Energy has been conducting operations on their West Alkali Creek project which is located on the site of the former Ogle Petroleum ISR project. Wildhorse Energy's current activities include exploration drilling to delineate the ore body of an ISR prospect. Wildhorse has submitted a Plan of Operation to the BLM for the purposes of significantly expanding their exploratory operations. As of late 2008, the plan of operations was under review by the NEPA process. Wildhorse Energy is expected to make application to the NRC in FY09 for their operations in the Bison Basin area.

In 2008, Black Range Minerals completed a drilling program under a Notice along Cyclone Rim just south of the former Bison Basin ISR leach project. For logistical purposes, this project is administered out of the Rawlins Field Office, but the majority of the Federal lands are within the Lander planning area. Also included in this area is the CR-Trend project, conducted under a notice by Tournigan USA. While some of the Federal land included in this project is within the Lander planning area, the majority of the project occurs south of the planning area border, and as such, is administered by the Rawlins Field Office.

3.3.1.3.4 Other Areas of Interest

Other areas which are of note in the Lander Planning Area include the Strathmore Resources Sky prospect, an ISR project just south of Big Sand Draw oil field on Beaver Divide. This project is expected to make application to the NRC in FY09.

In addition, Magnum Minerals conducted limited drilling exploration on a prospect near Lysite in 2006 and 2007. According to the proponent, no further work is expected at this location.

3.3.2 Precious Metals

Mining operations for precious metallic ores has a long and varied history in the Lander Planning Area. The most well known district is the South Pass - Atlantic City area. Metals mining districts of lesser prominence include the Lewiston District, the Granite Mountains, the Copper Mountains, and various placers on streams mostly sourced in the Wind River Range (Hausel, 1989). Figure 3-10 presented earlier, includes major precious metals mining districts in the planning area. With one exception, most of the current activity in the planning area is recreational in nature.

In addition, several mining districts in the planning area such as the South Pass – Atlantic City and the Copper Mountains are currently undergoing extensive reclamation under the State of Wyoming Abandoned Mining Lands (AML) project office. The AML program seeks to mitigate the dangers to the public from shafts, pits, tunnels etc, left open from historic mining operations and preserve historic mining features where appropriate.

3.3.2.1 South Pass - Atlantic City Mining District

The South Pass – Atlantic City District lies along the northwestern flank of the South Pass Precambrian greenstone belt and has been Wyoming's most prolific source of gold and iron ore (Hausel, 1989). Gold was discovered here in the 1860's, touching off a gold rush in 1867 which resulted in over 1000 inhabitants settling in South Pass City. By 1872, only a few hundred people remain and the boom was over. Historically, approximately 50 mines were in operation at one point or another. However, most gold mining efforts in the district met with disappointment though several did produce for a number of years.

The vast majority of these mines had total gold production amounting to little over a few hundred ounces. Very little is known about ore grades in the district and most available figures vary greatly. More successful and longer lived operations are tabulated in Table 3-10. Optimistic estimates of the total gold production the district range as high as 334,000 oz (Hausel, 1987).

Most of the gold in this district is orientated along shear zones trending east - northeast in a suite of granitic and metamorphic rocks including banded iron formation, quartzite, schist and other rocks referred to as greenstone, which is a field term applied to any compact dark-green altered or metamorphosed basic igneous rock that owes its color to the presence of chlorite, actinolite, or epidote. Many of the gold bearing shears are strike shears that follows the trend of the regional foliation. Some are continuous over distances up to a mile, but commonly pinch and swell along trend (Hausel, 1989). The base of the mineralized zones has not been adequately delineated because the deepest workings in the district (i.e., the Carissa Mine) were only on the order of 400 feet.

In the 1970s, several properties were explored with modern methods with numerous boreholes being drilled at both the Carissa and Duncan mines. Though the boreholes did intersect zones of gold mineralization, the grade and areal extent of the mineralization was apparently not sufficient for additional development.

Table 3-10 Production figures for mining operations in the South Pass - Atlantic City mining district

Mine	Average grade (oz./ton)	Total estimate production (oz.)
Caribou	unknown	26,450
Carissa	0.3 to 0.84	53,680[a]
Garfield (Buckeye)	unknown	21,160
Franklin	0.5[b]	15,870
Miner's Delight	unknown	63,500
Soules and Perkins	0.58	18,250[c]

a. Other sources have production as high as 180,000 oz.
b. Grab sample from mine dump.
c. This figure is likely lower based on the extent of the workings.

Source: Hausel, (1987); Hausel (1989)

The Carissa Mine was purchased by the State of Wyoming for historical purposes and is currently undergoing stabilization work with plans for a public access and on-site interpretation. Though its future status appears to be settled, the Carissa mine areas host some of the more promising possibilities for gold mineralization in the district (Hausel, 2004).

Most of the other mines in the district are now undergoing AML reclamation and/or preservation. Several properties are still privately owned and as of late, remain open to operation at little more than a hobbyist level.

3.3.2.1.1 Modern Placers

Modern stream placers in the South Pass - Atlantic City District were relatively productive and may have recovered up to 100,000 oz. of gold (Hausel, 1989). Principal placers include Rock Creek (11,500 oz. recovered), Meadow Gulch (52,910 oz. recovered), and Yankee Gulch (26,450 oz. recovered). The Rock Creek placer was mined with a dredge operation that operated until the early 1940s with grades averaging from 0.012 to 0.016 oz. per cubic yard (Hausel, 1989).

3.3.2.1.2 Paleoplacer Deposits

Two Tertiary age paleoplacer deposits have also been identified in the vicinity of the South Pass - Atlantic City District. These include the Dickie Springs - Oregon Gulch paleoplacer, and the Twin Creek conglomerate. These placers are notable because they represent perhaps the great potential for a major gold accumulation in the Lander Planning Area.

Although speculative, work done by Love et al. (1978) on the Dickie Springs - Oregon Gulch paleoplacer found that rocks of the Eocene Wasatch Formation and recent gravels derived from these rocks host low grade quantities of coarse gold (0.00185 oz./cubic yard).

However, sampling indicated an estimated 28.5 million ounces of gold may be contained in these sediments. Based on the coarseness and grade of the gold reported by Love et al. (1978) in the paleoplacer, a rich, undiscovered gold deposit is suggested along the southern or western margin of the South Pass greenstone belt (Hausel, 1987).

Similarly, Oligocene bearing conglomerates of the White River Formation lie immediately northeast of the South Pass greenstone belt. Antweiler et al. (1980) considers the source region to be the head waters of Twin Creek, which is underlain by Louis Lake granodiorite, banded iron formation, and other metamorphic rocks. These workers suggest that a small but very rich source area is still in place, but buried by sediments of the White River Formation. These conglomerates were hydraulically mined in the early 1900’s, and perhaps earlier than that. Gold production was on the order of perhaps several thousand ounces (Hausel, 1987). The amount of gold remaining far exceeds the amount mined (Antweiler et. al, 1980).

3.3.2.2 Lewiston District

The Lewiston District is related both spatially and genetically to the style of ore deposits in the South Pass - Atlantic City District. The Lewiston mines were also developed along southwest - northeast trending shears in Precambrian metamorphic rocks, including banded iron formation, and amounted to eight to ten properties. Production figures include approximately 21,000 oz. of gold that were apparently extracted from the Bullion Mine. Though the district is smaller and less gold was taken out on a district-wide basis, reports of grade appear to run somewhat higher.

Placers were also productive in the Lewiston District and occur along Strawberry Creek and at Wilson Bar on the Sweetwater River; however production figures are not generally available.

As part of the assessment of mineral resources for the Sweetwater Canyon Wilderness Study Area (WSA), the U. S. Geological Survey and the U. S. Bureau of Mines cooperated on study whose boundaries encompassed eastern portions of the Lewiston district (Day, et al., 1988). Mineral resources in outlining areas such as Wilson Bar and the South Pass - Atlantic City District were also discussed for the purposes of developing background information and for comparative analysis.

Geologic mapping, geophysical surveys, geochemical sampling and well as review of available historical prospect information indicated an area of "identified resources of load gold of moderate grade and low tonnage in faults and veins" in the extreme west of the study area in the northwest quarter of section 4, T. 28 N., R. 98 W. (Day, et al., 1988). There are minor historical prospects in this immediate area and they appear on trend with the regional foliation and veining, identified resource is perhaps 1/4 to 1/2 mile east of the trends that the major mines in the district appear to follow. According to Day, et al.,(1988) the study also identified the western part of the Sweetwater Canyon WSA has having "high mineral resource potential for gold in similar deposits" with a high mineral resource potential for resources of placer gold along the Sweetwater River and Strawberry Creek."

Numerous claims are still held in the Lewiston District, but little activity other than limited placer exploration at the hobbyist level is currently being conducted.

3.3.2.3 Copper Mountain District

The Copper Mountain District lies east of the Wind River Canyon, near the easternmost extent of the Owl Creek Mountains. These deposits occur in metamorphosed Precambrian rocks intruded by granites that exhibit northeast trending foliation and fault zones. This supra-crustal belt is one of several fragmented Archean volcanogenic terranes located within the so-called Wyoming Province. The Wyoming Province includes several greenstone belts, such as South Pass and Copper Mountain, which are relatively enriched in mineral deposits compared with the vast granite-gneiss terrane that surrounds them (Hausel et al., 1985).

The volcanogenic sequence of rocks at Copper Mountain representative of high-grade supra-crustal belts (Hausel et al.,1985). They lack the stratigraphic character of the classic greenstone belt, and exhibit a higher metamorphic grade. At Copper Mountain, this sequence occurs as intercalated quartzo-feldspathic gneiss, biotite schist, amphibolite, metapelite, quartzite, (banded) iron formation, and local marble.In turn, these supra-crustal rocks are intruded by Precambrian granitic and intermediate plutonic rock, and then by younger Precambrian mafic dike rocks (Hausel et al., 1985).

Principal historical mines include the DePass mine and the Gold Nugget mine area. Both had extensive workings, and the Gold Nugget camp also had a mill. The DePass Mines includes over 11,000 feet of workings and shaft sunk to at least 810 feet. This property is mineralized with gold, silver, and copper, and shipped at least 568,000 pounds of mill concentrates for smelting, while the Gold Nugget seems to have little evidence of significant production. Both of these mines appear to exploit mineralization associated with the contact of the metamorphosed country rock and the granitic intrusive rocks, with the Gold Nugget vein being enclosed in a roof pendant completely engulfed in granite (Hausel et al., 1985).

A large centrally-located metamorphic rock unit is present in the central area of the district and hosts several mines developed in banded iron formation and strike veins. These include the McGraw Mine, the West Bridger Mine, and several other miscellaneous inclines or shaft. Sample and analysis of these properties yield copper and iron, but little in the way of gold or silver (Hausel, 1989).

3.3.2.4 Granite Mountains

The Granite Mountains are located in the southeast corner of the Lander Planning Area. The Granite Mountains are host to two principal mining districts: Tin Cup (Black Creek - Long Creek) and Rattlesnake Hills - Barlow Gap. The Granite Mountains are formed of an east-west trending belt of Precambrian rocks including highly metamorphosed rocks along the north part of the mountain, granitic rocks exposed in the center, and later dike rocks of more basic composition that intrude both the metamorphic rocks and granites.

3.3.2.4.1 Tin Cup District

This district is located along the northwestern part of the Granite Mountains and consists of five principal mines that have encountered gold, copper, and iron sulfides. Early reports claimed gold assays running anywhere from 0.08 oz. per ton to greater than 5 oz. per ton with copper values as high as 15 percent (Hausel, 1989).

An unpublished Wyoming Geological Survey report on the Anderson Mine of this district presented three assays of grab samples selected as representing material that would be expected to be mined as ore (Love, 1935). These samples assayed between 0.01 and 0.02 oz. gold per ton. According to the author of the report it was doubtful that the concentration of gold would increase in depth due to character of the deposit (Love, 1935).

3.3.2.4.2 Rattlesnake Hills

The Rattlesnake Hills are located north of the Granite Mountains on the north side of the east-west trending North Granite Mountains Fault, and encompasses an area is about 150 sq. miles. The Rattlesnake Hills were formed by a northwest plunging anticline of Laramide age, cored by Precambrian rocks and intruded by Tertiary igneous rocks and includes over 40 discrete volcanic vents and igneous bodies of Eocene age (Hausel, 1989).

Some precious metals are apparently present in the Precambrian metamorphic rocks, which also include band iron formation. Jasperoid rocks are also reported in the area. The occurrence of these rocks is significant for it is a well-known mineralization indicator rock in other mining districts, especially in the Great Basin of Nevada. Significant gold anomalies were discovered in the Rattlesnake Hills district by the Wyoming Geological Survey in 1981.

Increased interest in the region by several major gold mining companies began with a limited surface and drilling program carried out between 1983 and 1987, and again by another company in 1993 to 1995. This activity led to several discoveries, including a large-tonnage, low-grade deposit that has potential to host more than one million ounces of gold (WSGS, 2002). Subsequent drilling by the latter company targeted diatreme breccias which border of one of the alkali stocks in the area. Gold grades reported by the company ranged up to 485 feet averaging 0.07 oz. per ton (short), with higher grade intervals over narrower widths.

3.3.4.4.1.1 Current Rattlesnake Hills Exploration

The potential uncovered thus far in the Rattlesnake Hills has resulted in a third company optioning on approximately 2600 acres of claims. This company filed a mining notice of intent with the Lander Field Office and proceeded to commence a drilling program which began in the summer of 2008. Preliminary results presented in a December 2008 company news release indicate that the drilling conducted during the summer 2008 drilling program intersected anomalous values of gold in two core holes 65 meters apart. One core hole intersected 131 meters of 2.74 grams of gold per metric ton (g/t), while the other tested 2.92 g/t gold over 146.3 meters. These values are roughly equal to about 0.08 oz/ton (short).

In a following new release also released in December 2008, the company announced that it had defined a large halo of gold mineralization around the aforementioned high grade zones defined by the two core holes. The halo of gold mineralization around these high grade zones include an aggregate down-hole interval of 307.4 meters of 0.77 g/t (1,010 ft of 0.022 oz/ton), 274.0 meters at 0.65 g/t (900 ft of 0.019 oz/ton) and 269.1 meters at 0.55 g/t (885 ft of 0.016 oz/ton). Assays for 6 holes were still pending at the time of the announcement. It is believed that the mineralization is open to depth, and only a small proportion of the deposit has so far been tested.

A plan of operations has been submitted to expand the drilling program in 2009, and is currently under evaluation by the NEPA process. Figure 3-14 presents the area currently under exploration in the Rattlesnake Hills.

3.3.3 Base and Other Metals

Base metals include any of the more common and more chemically active metal elements that are usually found in mineral form as complex with other elements (e.g., as a salt), rather than as native mineral. Such metals include copper, lead, zinc, molybdenum, iron, tungsten, and others. Significant areas bearing base metal deposits largely overlay the same areas identified earlier for precious metal resources. These areas include the Depass District at Copper Mountain, Tin Cup District in the northwest Granite Mountains, the Rattlesnake Hills and the South Pass Greenstone Belt. Other than the Atlantic City Mine, there has been little activity or interest in base metal deposits in the Lander Planning Area.

3.3.3.1 South Pass - Atlantic City and Lewiston Mining District

This district was discussed earlier under precious metals. While most of the attention has been focused on the gold mineralization in this district, iron mining has a strong history in this area. There are also some minor copper credits noted in some of the gold prospects along the contact of the metamorphic rocks and the granites. These veins often cut across the regional foliation. Discrete samples of copper bearing ore from various properties showed values as high as 18.1 % but generally were lower than 1% when present at all. Minor tungsten was reported at values ranging from 232 ppm (parts per million) and nickel (up to 67 ppm) had been reported as well (Hausel, 1997).

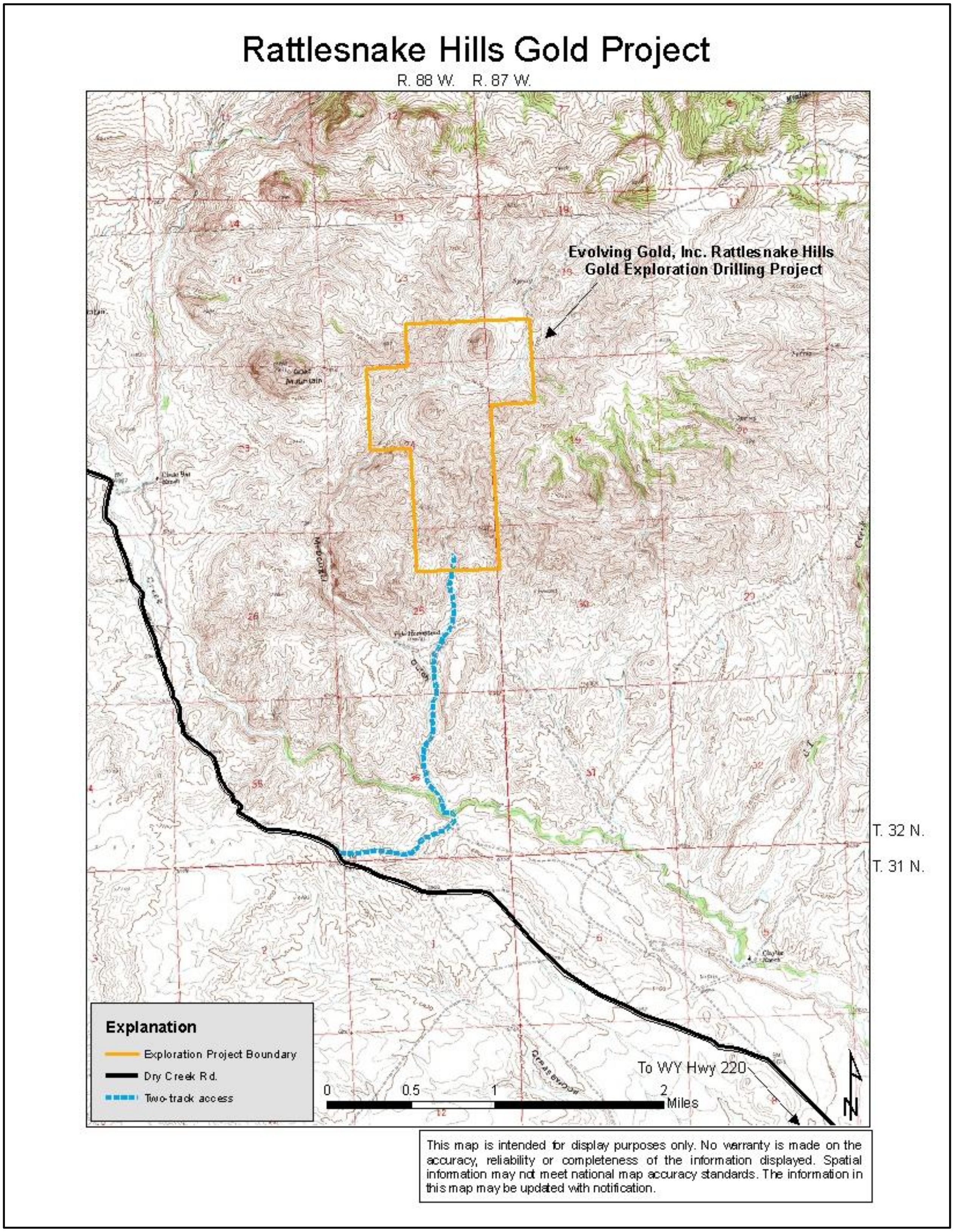
Little base metal activity has been reported in the Lewiston Mining District, although one locality showed significant arsenopyrite mineralization that assayed between 0.26 and 0.28% copper, and another hematite-rich sample assayed 0.55% copper (Hausel, 1991).

3.3.3.1.1 Atlantic City Iron Mine

Of special mention is the Atlantic City Iron Mine, which arguably is perhaps the most successful of the mining ventures in the South Pass - Atlantic City District. The open pit was developed in banded iron formation of the Precambrian Goldman Meadows Formation. The rock is banded amphibole schist with inter-beds of quartzite and banded iron formation composed chiefly of quartz, magnetite, and minor amphibole which reportedly contains up to 30 percent iron (Hausel, 1992). The iron formation is generally less than 100 feet thick but was thickened at the mine site by faulting, folding, and slippage along foliation (Hausel, 1991). Based on mapping by the USGS, there is reportedly a huge resource of iron still left at the mine (Bayley, 1963).

U. S. Steel Corporation operated the mine from 1962 until 1983, and recovered more than 90 million tons of taconite before selling the mine to another company that subsequently shut the mine down shortly thereafter due to economic factors. During its period of operations, 5.5 million tons were mined each year. The taconite was mined and pelletized at the mine site and shipped by rail to Utah to be further processed (Hausel and Hull, 1990). Demolition of the taconite mill, the railroad line, and reclamation began in the late 1980s. A decade or so later, the highway was subsequently realigned to approximate its original path across the reclaimed mines tailings pile area after it had earlier been re-routed around the tailings pond.

Figure 3-14 Map showing the area of the Rattlesnake Hills Gold Exploration Project



The closing of the iron mine in 1983 had a significant impact on the City of Lander, and contributed to a long-lasting depression in the population of Lander population and real estate prices that lasted until at least through the 1990's.

3.3.3.2 Copper Mountain District

As the name implies, the Copper Mountain region of the Owl Creek Mountains is known for hosting copper-rich mineral deposits. In addition, iron, tungsten, and lithium have been reported. Tungsten was actually produced in the district during World War II in addition to some copper. As discussed earlier, important mines in the district included the DePass Mine, mines of the McGraw Mine area, and mines of the Gold Nugget Mining Region. In the late 1980's, the U.S. Bureau of Mines evaluated pegmatites and granitic rocks on the south side of Copper Mountain primarily for the strategic metals tantalum, columbium, and beryllium.

3.3.3.2.1 De Pass Mine

At the DePass Mine (aka Williams - Luman Mine), available recorded from the early 1900's showed over 567,000 pounds of copper were shipped from the mine (Hausel et al., 1985). Ore minerals recognized at the DePass mine include chalcopyrite (copper iron sulfide), malachite (copper carbonate), azurite (copper carbonate), cuprite (copper oxide), chalcocite (copper sulfide), native copper, chrysocolla (hydrous copper silicate), and other copper silicates. Modern sampling of quartz veining within a mafic dike yielded showed copper at 1.79% copper and no detectable gold, platinum or silver (Hausel et al., 1985).

3.3.3.2.2 McGraw Mine Area

The McGraw mining area is located in the center of the band of metamorphic sedimentary rocks, generally iron formation. Though it appears that the original workings were following copper mineralized quartz veins, modern samples collected from the various dumps show mostly iron as the dominate metal. One sample ran as high as 9% copper, but most results were generally lower than 1% copper (Hausel, 1985).

3.3.3.2.3 Gold Nugget Area

Gold Nugget mining area is located along the west flank of Copper Mountain. In association with limited minor gold, base metal mineral deposits here contain principally iron sulfide or pyrite (Hausel et al., 1985).

3.3.3.2.4 Tungsten deposits

Minor production of tungsten has been reported from low grade scheelite (calcium tungstate) ore near the south central portion of the mining district. This was mainly produced during World War II. The tungsten occurs as crystals and disseminated grains of scheelite in lenses and pods that lie parallel to the foliation of the enclosing metamorphic rock (Hausel et al., 1985).

3.3.3.2.5 Strategic Metals

The U. S. Bureau of Mines evaluated pegmatites and granitic rocks on the south side of Copper Mountain primarily for the strategic metals tantalum, columbium (niobium), and beryllium in the late 1980's.

This effort was part of a program designed to lessen the U.S. dependence on foreign sources of these metals, which at the time amounted to about 11% of beryllium, 90% of tantalum, and 100% of columbium of total U. S. consumption. The study effort identified two sub-economic tantalum deposits in two pegmatites amounting to 1.5 million short tons grading 0.02 to 0.03 % Ta_2O_5 (tantalum pentoxide), which corresponds to about 0.8 million pounds. Additionally, columbium and beryllium were shown to be possible by products of tantalum mining and processing (Chatman, 1989).

3.3.3.3 Rattlesnake Hills

As noted earlier in the precious metals discussion, the Rattlesnake Hills greenstone belt consists of refolded Archean metamorphic rocks intruded by several Tertiary alkalic plugs and dikes. The Wyoming Geological Survey evaluated this area for mineral potential in 1997, and found anomalies in both brecciated Precambrian rocks and the associated Tertiary high-level volcanic rocks.

With regard to base metals, samples of brecciated Precambrian rocks along the flanks of the Tertiary-age plugs yielded 37 ppm to 0.14% copper, 25 ppm to 1.65% arsenic, and 0.012 to 0.078 ppm mercury (in addition to the precious metal content) (Hausel, 1997).

3.3.3.4 Tin Cup District

The principal mine in this district exhibiting base metal mineralization is the Sutherland (Red Boy) mine. This property contains massive pyrite. Other mineralization in the district included one copper prospect which yielded copper values up to 15%. Modern samples obtained by Hausel (1997), yielded 188 ppm to greater than 2% copper, up to 551 ppm lead, 20 to 253 ppm zinc, 5 to 14 ppm molybdenum, 20 to 342 ppm arsenic, 0.6 to 14 ppm tin, and up to 351 ppb (parts per billion).

3.3.4 Bentonite

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 currently the leading producer of bentonite in the U.S., and over 3.7 million tons of bentonite was mined in Wyoming in 2003 according to the State Inspector of Mines of Wyoming (WSGS 2003).

Bentonite is an aluminum phyllosilicate, essentially a type of impure clay usually formed from the weathering of volcanic ash, most often in the presence of water. The primary constituent of bentonite is sodium montmorillonite clay which possesses swelling, colloidial, and adsorbent properties. The physical and chemical properties of bentonite make it useful for a variety of applications which can be broken down as follows: 26% absorbents such as pet litter and minor spill cleanup, 23% drilling mud, 19% foundry sand bond, 15% iron ore pelletizing, and 17% other uses (USGS, 2008). It is increasingly used to form impermeable liners for waste disposal ponds utilized by oil and gas operators.

Bentonite deposits in the planning area region are formed from the alteration of volcanic ash deposited largely during the Cretaceous Period. This volcanic ash was deposited into the epeiric seas and regional lakes that covered much of Wyoming, forming sediments as much as 50 feet deep. Under the right conditions, the weathering and alteration of these sediments can result in the formation of clays that result in a bentonite deposit.

Bentonite in the Lander Planning area primarily occurs as discrete beds within shales and sandstones, most notably the Cretaceous Mowry Shale and Frontier Formation, and the Eocene Wind River Formation. Figure 3-15 presents a map of bentonite-bearing formations in the planning area form USBM data (Anderson et al., 1990c).

In the Lander planning area, one bentonite mine has an approved plan of operations and currently holds a mine permit from the WYDEQ. This mine is located in the Gas Hills area, in Township 32 N., Range 90 W. Though approved for operation, this mine has yet to begin production due to the lack of a permitted processing facility. The operator has stated that it expects the facility to be on line in sometime during 2009.

3.3.5 Gemstones and Lapidary material

The Lander Planning area has a long history of providing opportunities for mining gemstones, particularly opal, jade, and agates, in particular a variety known as "Sweetwater Agate. Other reported occurrences of gemstone and other lapidary materials in the Lander Planning Area include numerous locations for petrified wood, garnet, beryl, tourmaline, aquamarine, sapphire and ruby (Sutherland, 1990; Hausel, 1997). Most activity today is of interest to hobbyists but there are still a small number of gemstone prospects held by mining claims.

3.3.5.1 Petrified Wood

Collection of petrified wood is a popular pastime in the Lander Planning Area. Petrified wood is actually treated as a mineral material and specimens less than 250 lbs. may be collected free of charge provided they are used for noncommercial purposes. The daily limit for free use is 25 lbs. of material per person plus one piece and collectors are limited to a maximum annual amount of 250 lbs.

3.3.5.2 Wyoming Jade

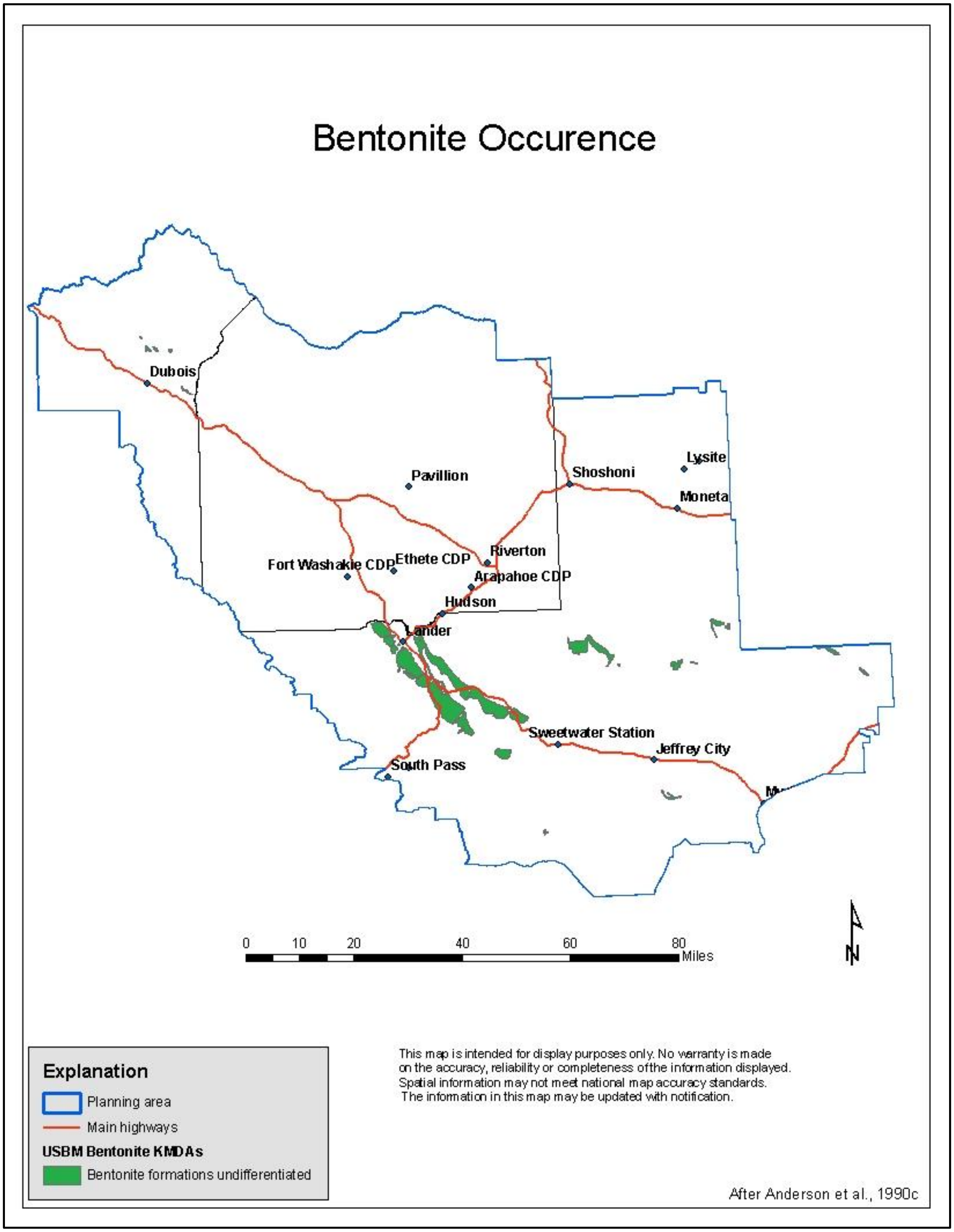
Nephritic jade, commonly known as "Wyoming Jade" is a calcium magnesium silicate, belonging to the amphibole group of minerals. It commonly varies in color from black to light-green, with darker green to olive-green colors dominating. This mineral is different from the mineral jadeite, which is more commonly known as jade, and is an aluminum-sodium silicate belonging to the pyroxene family of minerals. In either case, jade commonly originates as a contact metamorphic mineral, resulting from the intrusion of igneous rocks into pre-existing rock, usually sedimentary in origin).

Jade is more commonly found, however, in float deposits, often as large boulders, where it has been transported away from the site of outcrop by erosive forces. Most Wyoming jade is cut and polished and used in jewelry. Indeed, the first jade mineral discovery in the planning area was found as float near the Granite Mountains (Osterwald et al., 1966).

3.3.5.3 Agate

Agate most commonly occurs as variegated chalcedony, a cryptocrystalline variety of quartz. It commonly exhibits colors as stripes or bands, and is translucent. The curved, banded varieties of agate represent layers built up by successive deposition of quartz, presumably precipitated from silica-laden groundwater.

Figure 3-15 Map of bentonite-bearing formations in the planning area



The so-called "Sweetwater" agate is a type of moss agate, where visible impurities such as manganese dioxide form dendritic patterns resembling moss. Agates and moss agates are reportedly plentiful in a large area in southeast Fremont County, southeast of the Wind River, and north of Sweetwater River, and along Sage Hen Creek, north of Split Rock (Osterwald et al., 1966).

3.3.5.4 Opal

Opal is classified as a mineral gel which consists of varying amount of silica and as much as 20% water, but usually in the range of 3 to 9 %. It has been shown by electron diffraction to consist of packed spheres of amorphous silica and is deposited at low temperatures from silica-bearing water.

True precious opal is rare in Wyoming, but recently an opal land rush was triggered by a Wyoming Geological Survey discovery of an opal deposit on Cedar Rim a couple miles south of Big Sand Draw Oil and Gas Field. Over 1100 claims were staked on this deposit as a result of this announcement during the summer of 2005. According to the open file report released by the Wyoming Geological Survey, the variety of opal contained in the deposit includes common and fire opal with traces of precious opal (Hausel and Sutherland, 2005). The deposit is estimated to potentially contain tens of thousands of tons of opal ranging in size from cobble-size nodules to large boulders, as well as extensive outcrop of multi-colored siliceous material of unknown composition.

As of 2005, the deposit still relatively unexplored, and has not been developed. Figure 3-16 presents a location map of the deposit prepared by the Wyoming Geological Survey. As depicted, the main deposit is a northwest to southeast trending linear body with satellite pods to the east and west. This mostly likely represents exposure level of the outcrops known this far. There is likely more to be discovered with additional exploration. One exploration notice is currently active for opal claims in this area.

3.4 Mineral Materials

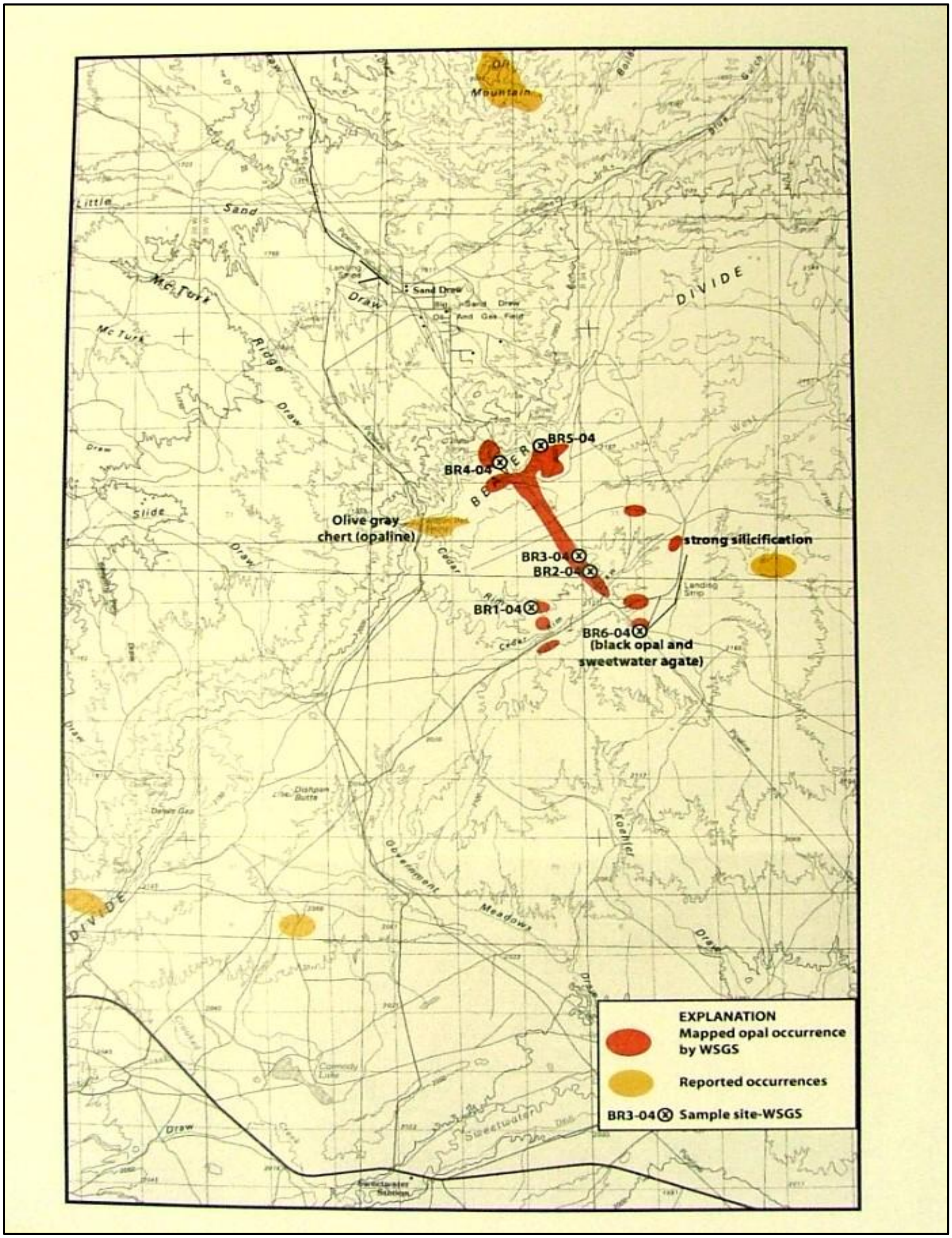
3.4.1 Overview

3.4.1.1 History

During the days of the General Land Office, and in the first year after the Bureau of Land Management was formally created, there was no authority for the disposal of mineral materials. Many common minerals were acquired under the auspices of the 1872 Mining Law and the 1892 Building Stone Placer Act. Claims were staked for sand, gravel, and building stone. However, many commodities, such as fill dirt and caliche, could not be located with a claim.

Several acts were passed in the 1930's and 1940's which identified the need for mineral materials for wartime purposes and federal reclamation projects. However, it was not until July 31, 1947, when Congress passed the Materials Act (61 Stat 681), that the Secretary of the Interior finally acquired the broad authority, "under such rules and regulations as he may prescribe," to dispose of materials including but not limited to sand, stone, gravel, ...[and] common clay ... on public lands of the United States if the disposal of materials (1) is not otherwise expressly authorized by law, including the United States mining laws, and (2) is not expressly prohibited by laws of the United States, and (3) would not be detrimental to the public interest.

Figure 3-16 Map of the Cedar Rim Opal Deposit



Source: Hausel and Sutherland (2005).

Under the Materials Act, BLM could now dispose of mineral materials by sale or on a free use basis to governmental units and non-profit organizations. As required by the act, mineral materials sales are to be made at fair market value. The 1947 Act did not bring clarity to the question whether mineral materials were locatable. There were some commodities, notably sand and gravel, which could be obtained either by purchase (or free use) or by location of a mining claim under the mining laws. In an effort to address problems relating to the improper use of mining claims and to provide for the multiple use of the surface of mining claims, Congress passed the Surface Resources Act of 1955. This Act entirely removed from the purview of the Mining Law "common varieties" of sand, stone, gravel, pumice, pumicite, and cinders (30 U.S.C. 611).

The Federal Aid Highway Act of August 27, 1958 (23 U.S.C. 317), created a process for making mineral materials available to the states. This was accomplished by authorizing grants of rights-of-way with the requirement that the mineral material would be used for the purpose of federal-aid highway construction. The BLM and the Federal Highway Administration (FHWA) have since entered into an Interagency Agreement (AA-851-IA2-40), dated July 1982 to process ROW applications.

In 1962, the Petrified Wood Act (76 Stat 652) permitted the sale or (limited) free use disposal of petrified wood from public lands, under certain specific criteria. This act also removed petrified wood from the category of locatable minerals, resulting in the placement of this material within the definition of salable minerals

The BLM will not allow the disposal of mineral material from wilderness areas, or other areas prohibited by law such as national parks or monuments. BLM will also not dispose of mineral materials from tribal lands or lands set aside for the benefit of Indians.

Uncommon varieties of such materials are a special case and usually trigger a determination of their special properties, and also require tests quality, quantity and marketability. Those deposits meeting such criteria are then regarded as locatable and therefore not subject to the requirement of sale.

3.4.1.2 Type of Disposals

Under the aforementioned Materials Act, it is the policy of the BLM to make mineral materials (i.e. salable minerals) available unless it is detrimental to do so. Therefore, mineral material disposals are discretionary and the BLM may in some cases deny the applicant's request based on various considerations such as an inadequate plan, or to protect other competing resource values (e.g., wildlife, scenic, grazing, sensitive soils, etc.) identified through NEPA analysis.

There are two broad categories of mineral material disposals: exclusive disposals and non-exclusive disposals. Under exclusive disposals the purchaser has an exclusive right to the materials and sole responsibility for development and reclamation of the site or a designated portion of the site. There are three types of exclusive disposals: negotiated sales, competitive sales, and free use permits (FUPs).

Non-exclusive disposals are made from sites to which the general public has access and more than one party has a right to remove materials. There are two types of nonexclusive disposal sites: the community pit and the common use area (CUA). The distinction between the two is that CUAs are generally broad geographic areas which, after removal of the minerals, do not require reclamation.

3.4.1.3 General Disposal Process

For exclusive disposals, the BLM is commonly approached by a private or public entity (e.g., local government agency) with a specific plan to obtain mineral materials from a certain location. The BLM must then process the request under the NEPA process and develop any necessary stipulations and mitigations required to protect other resources affected by the disposal. Typically environmental assessments are performed for each proposal. When a contract for mineral materials amounts to less than 50,000 cubic yards (CY) or the disturbance is less than 5 acres, a categorical exclusion (CX) is commonly granted.

Once a determination is made to process a mineral material disposal, a contract is issued which describes the location of the disposal, the quantity to be removed, and the total cost of the material.Contracts also include the terms of use (seasonal restrictions, access, etc.), and the required bond for reclamation. The terms of payment depend on the total cost of the material. If below $2000, the toal amount is due in full when the contact is issued. Cost of the material is determined by the most current appraisal schedule furnished by the Wyoming State Office.

Non-exclusive disposals are usually accomplished "over the counter" at the Lander Field Office. A customer seeking mineral materials will identify what type of material desired and will then be directed to one of several areas developed by the Lander Planning Office for that purpose. A contract must be signed by the customer and payment must be received in advanced for the desired quantity of material. The cost of the material is determined by the most current appraisal schedule furnished by the Wyoming State Office.

3.4.2 Common Mineral Material Categories

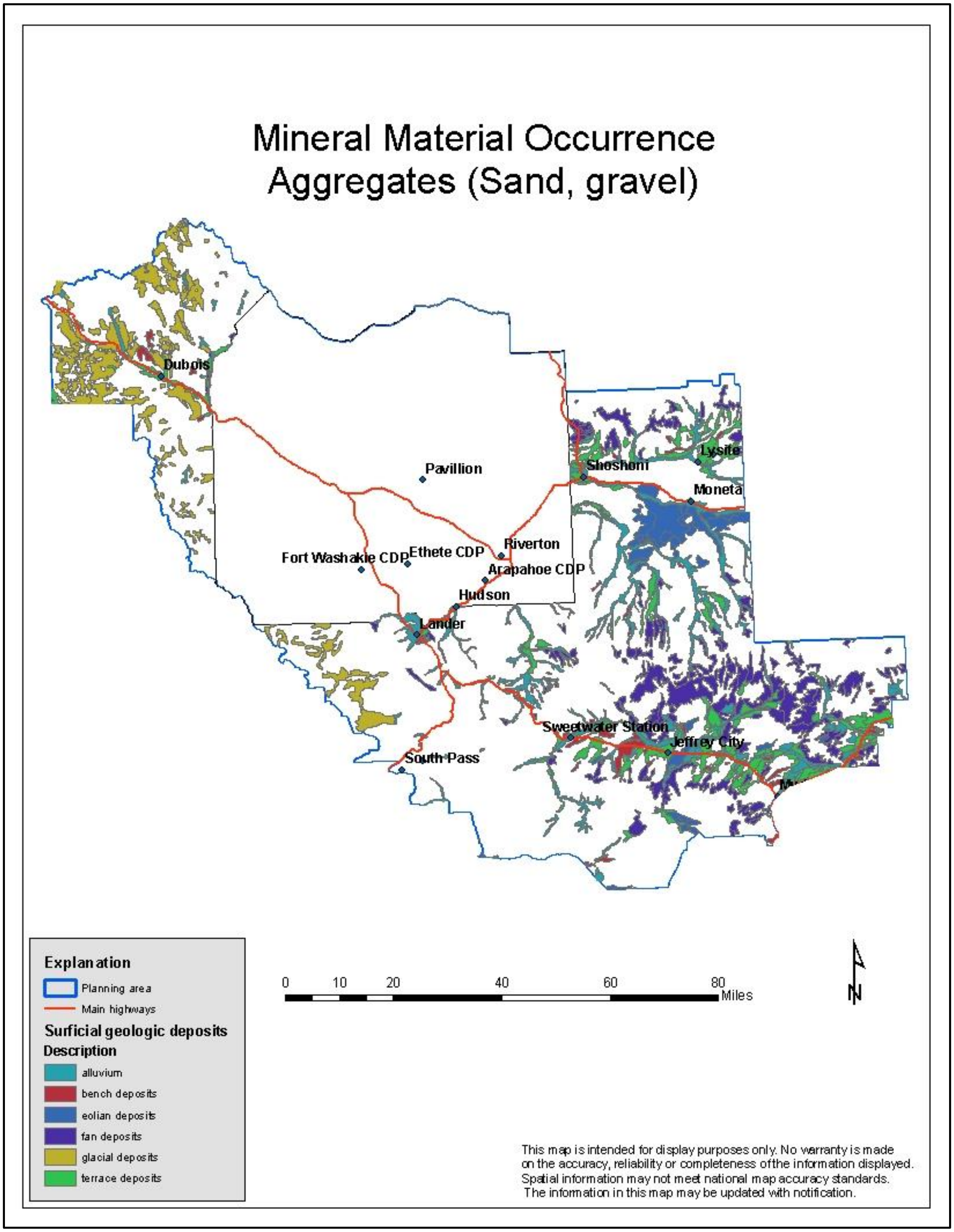
Salable minerals (mineral materials) include but are not limited to: petrified wood and common varieties of sand, stone, gravel, pumice, pumicite, cinder, clay, and rock. Vegetative material in some cases is considered salable. Sand and gravel and building stone are generally disposed by FUPs or negotiated or competitive sales. Moss Rock is another popular category of mineral material disposal in the Lander Planning Area. Community pits or CUAs are often utilized to provide small quantities of such material for sale to the general public.

3.4.2.1 Aggregates (Sand and Gravel)

Sand and gravel disposals are perhaps the most common type of mineral materials disposal in the Lander Planning Area. Sand and gravel are commonly used for road base, oil and gas drill pads, and various building construction projects. While most sand and gravel disposals are accomplished through FUPs issued to government agencies and non-profit organizations, sand and gravel are also made available to the public through negotiated sales or competitive sales. On a case-by-case basis, a requester may be granted an exploration permit for sampling and testing in order to determine grade or quantity available at a certain site. The sampling and testing permit is issued for a limited time period, and the proponent may then be issued a sale through the normal process upon determining sufficient material is available.

Most large quantities of sand and gravel in the Lander Planning Area are found on old terrace benches along former and current major drainages, and pediment surfaces adjacent to range fronts (Figure 3-17).

Figure 3-17 Sand and gravel-bearing surficial deposits in the planning area.



Deposits of glacial outwash are also sometimes utilized for sand and gravel disposals especially in the northern portion of the Lander Planning Area.

3.4.2.2 Limestone

Salable limestone is not of chemical grade. The majority of limestone in the Lander Planning Area is considered common variety, salable limestone. Crushed limestone can be used for rip rap or for road base in place of sand and gravel. Not only is crushed limestone a valuable resources, but the fines (small particles produced in the crushing process) have uses in construction as well.

Potential formations for the exploitation of limestone resources would include the Alcova Limestone member of the Chugwater Group, and the Madison Limestone. Wherever these formations are exposed at land surface and are readily accessible from maintained road are potential sites for development. For example, in the late 1980's over 500,000 cubic yards of limestone was sold in the Gas Hills, for the purpose of reclamation work at former uranium mining properties. This material was taken from the Dutton Anticline where the Alcova Limestone is exposed at land surface. Figure 3-18 presents a map of where formations containing limestone beds occur in the planning area.

3.4.2.3 Granite and other igneous rocks

Large quantities of granitic mineral material are available at various areas of the Lander Planning Area, most abundantly in the Sweetwater Rocks and the Granite Mountains area. In addition, smaller quantities of granite are located near South Pass City and along Highway 28 where the Louis Lake granite outcrops. Large quantities of granite up to 100,000 CY were sold from the so-called Black Rock quarry about 9 miles north of Jeffery City over the last decade or so.

Figure 3-19 presents a map of igneous rocks, which includes granite and associated variants, granite gneisses, and undifferentiated intrusive and extrusive igneous rocks which may be suitable for various purposes.

3.4.2.4 Shale

Salable shale is commonly obtained from exposures of Cody Shale. In recent history, large quantities of Cody Shale was sold for use on various AML reclamation projects, particularly for cap material as its low permeability retards the infiltration of meteoric water through reclaimed pits and tailings piles. About one and half million cubic yards of shale was removed from shale pits near the Gas Hills and over a million cubic yards were removed from another pit south of Jeffery City, both utilizing this material for reclamation activities during the last decade or so.

3.4.2.5 Moss Rock

Moss rock is a particularly popular salable rock type amongst the public at large. This rock is characterized by the growth lichens on their exposed surfaces. The most usable variety of moss rock is rock that contains with horizontal partings, which make for easy surface "picking" by hand methods. Several areas have been authorized by the Lander Planning Area over the past several years including three common use areas and several low-volume individual sales.

Figure 3-18 Limestone-bearing formations in the planning area

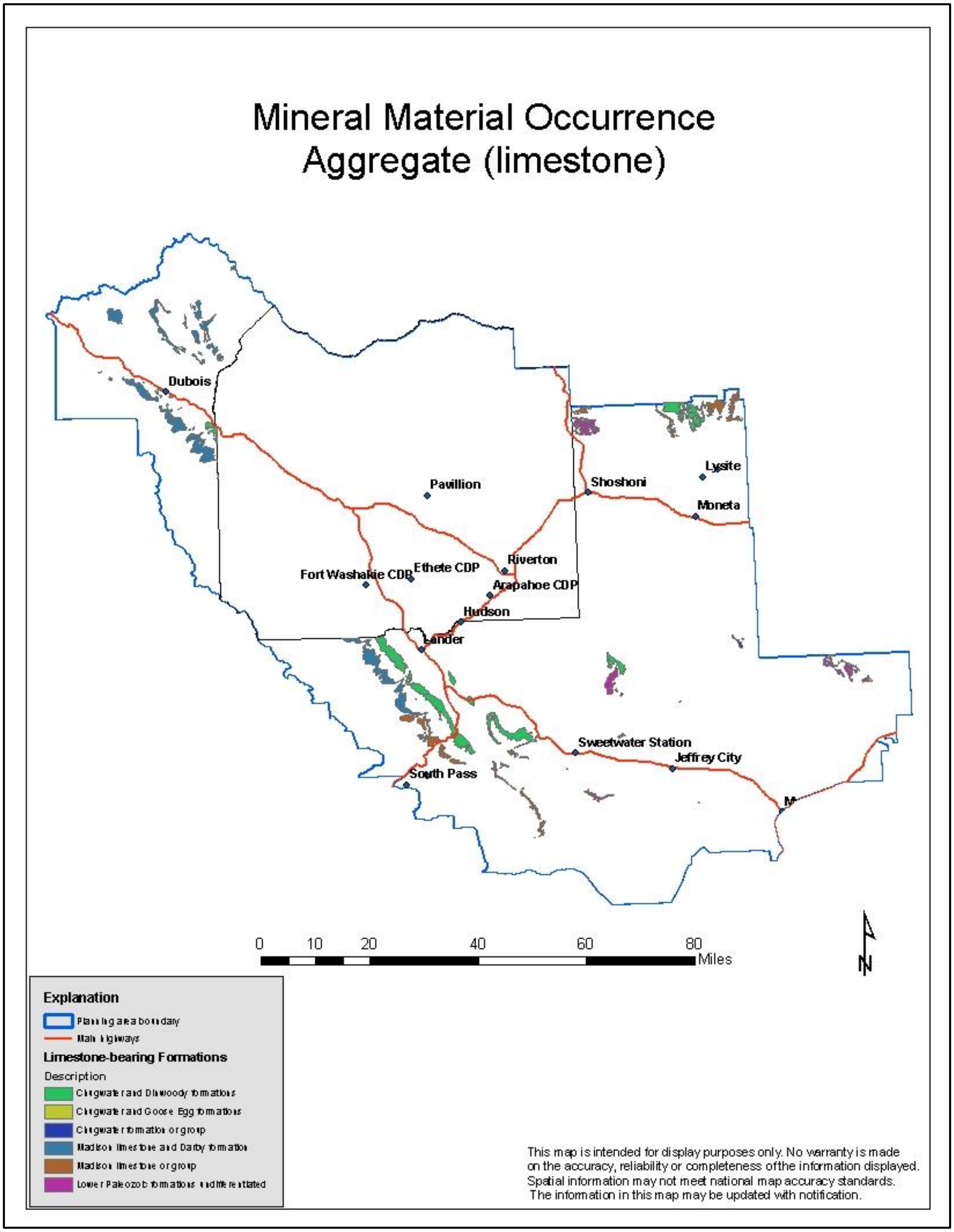
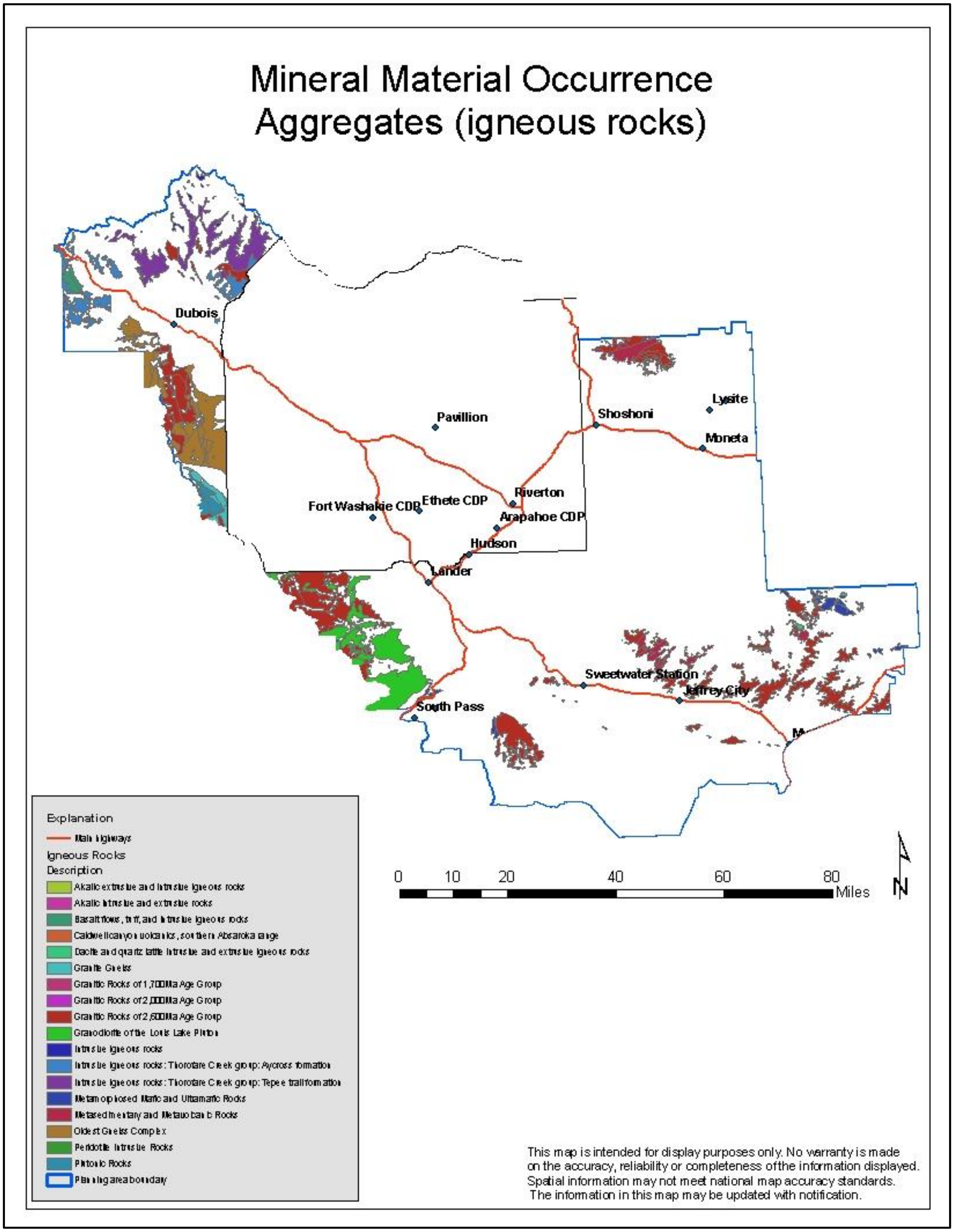


Figure 3-19 Locations of igneous rock in the planning area



3.4.3 Disposal Activity

3.4.3.1 Free Use Permits (FUPs)

As mentioned earlier, it is considered policy to permit Federal, State, Territorial, and local government entities and non-profit organizations free use of mineral materials for qualified purposes. Most FUPs have been historically issued to the Fremont County Road Department for the purpose of constructing and repairing roads.

3.4.3.1.1 3.4.3.1.1 Authorized FUPs

Table 3-11 presents free use permits currently authorized in the Lander Planning Area as of the end of 2008. These data do not include free use of materials obtained through ROW applications for federal highway construction and maintenance.

Table 3-11 Authorized mineral material free use permits in Lander Planning Area

Entity	Name or location	Case No.	Commodity	Amount
Wyoming Game & Fish Dept.	Bear Creek Pit, East Fork Wind River	WYW152033	Sand and gravel	3,000 CY
Fremont County Road Dept.	Jeffery City Pit	WYW154885	Sand and gravel	130,000 CY
Town of Dubois	Overlook site	WYW159799	Sand and gravel	10,000 CY
Fremont County Road Dept.	Moneta-Lysite Hwy Project	WYW149779	Sand and gravel	40,000 CY
Fremont County Road Dept.	Lost Cabin Pit	WYW152039	Sand and gravel	200,000 CY
WYDEQ AML	Gas Hills haul road restoration project	WYW158055	Sand and gravel	20,000 CY

Source: BLM LR2000 database, February, 2009.

3.4.3.1.2 Pending FUPs

A search of the BLM LR2000 database shows the status of numerous FUPs as pending. Table 3-12 presents pending FUPs as of the end of 2008. Many sales are pending because after the governmental entity made application for planning purposes, quantities were found elsewhere, or because they are highway-related and the project had not reached the area where the particular pit is within convenient distance to where the road base is needed.

3.4.3.2 Negotiated sales

The Lander Planning Area makes mineral materials available to individuals or private entities through negotiated sales. These sales are based on a national or regional appraisal figure per cubic yard or ton.

Table 3-12 Pending mineral material free use permits in Lander Planning Area

Entity	Name or location	Case No.	Commodity	Quantity
Fremont County Road Dept.	Sec. 23, T. 37 N., R. 94 W. (Muskrat Crossing)	WYW135187	sand and gravel	10,000 CY
Fremont County Road Dept.	Sec. 6, T. 36 N., R. 93 W. (Muskrat Pit)	WYW135188	sand and gravel	15,000 CY
Fremont County Road Dept.	Sec. 27, T. 30 N., R. 95 W. (Sweetwater Station)	WYW147151	sand and gravel	8,072 CY
Fremont County Road Dept.	Sec. 1, 12, T. 38 N., R .91 W. (Lysite Gravel Pit)	WYW147157	sand and gravel	20,000 CY
Fremont County Road Dept.	Sec. 30, T. 39 N., R. 90 W. (Badwater Borrow)	WYW159824	sand and gravel	5000 CY
Wyoming Department of Transportation	Sec. 26, T. 35 N., R. 94 W.	WYW152035	soil/fill	10,000 CY
Wyoming Department of Transportation	Sec. 9, T. 34 N., R. 92 W.	WYW152036	soil/fill	10,000 CY
Wyoming Department of Transportation	Sec. 32, T. 35 N., R. 93 W.	WYW152037	soil/fill	10,000 CY
Wyoming Department of Transportation	Sec. 3132, T. 35 N., R. 92W.	WYW152038	soil/fill	10,000 CY

Source: BLM LR2000 database, February, 2009.

A cost recovery fee is charged and an environmental assessment is performed for all negotiated sales. Categorical exclusions are granted when the amount of sale is less than 50,000 cubic yards (CY), or when the disturbance is less than 5 acres. The BLM will not approve multiple non-competitive sales that exceed a total of 300,000 CY made in any one state for the benefit of any one purchaser, in any period of 12 consecutive months. On occasion, the BLM may approve sales not exceeding 400,000 CY if the BLM determines the sale is in the public interest and the sale will be used in conjunction with an urgent public works program and time does not warrant advertising for a competitive sale.

Current pending and authorized negotiated sales are presented in Table 3-13. These sales are presented only by case number to protect the privacy of individuals as required by law.

3.4.3.3 Competitive Sales

From time to time, BLM will make sales of mineral material after inviting competitive bids through publication and posting. In general, all sales over 200,000 CY (individually) must be advertised. However, there are exceptions.

Table 3-13 Authorized and pending mineral material negotiated sales

Case Number	Name or location	Commodity	Quantity
WYW142551	Sec. 30 & 31, T. 30 N., R. 91 W.	pending sand and gravel	—
WYW142558	Sec. 1, T. 33 N., R. 90 W.	Pending shale	100,000 TN
WYW142575	Sec. 14, T. 33 N., R. 90 W.	Pending limestone	—
WYW142588	Sec. 14, T. 33 N., R. 90 W.	Pending limestone	—
WYW159791	Sec. 14, T. 26 N., R. 97 W.	Pending sand and gravel	—
WYW161699	Sec. 8, T. 31 N., R. 97 W.	authorized moss rock	10 TN
WYW167927	Sec. 5,6,8, T. 31 N., R. 97 W.	pending moss rock	150 TN
WYW167944	Sec. 21, T. 27 N., R. 93 W.	authorized sand and gravel	50,000 CY
WYW168019	Sec. 7,18, T. 39 N., R. 93 W.	authorized decorative stone	100 TN
WYW168047	Sec. 6, T. 31 N., R. 97 W.	pending moss rock	500 TN
WYW168077	Sec. 17, 18, T. 28 N., R. 97 W.	pending decorative stone	15 TN
WYW168080	Sec. 27, T. 40 N., R. 93 W.	pending sand and gravel	—
WYW168128	Sec. 20, T. 30 N., R. 99 W	Pending sand and gravel	18,000CY

Source: BLM LR2000 database, February, 2009.

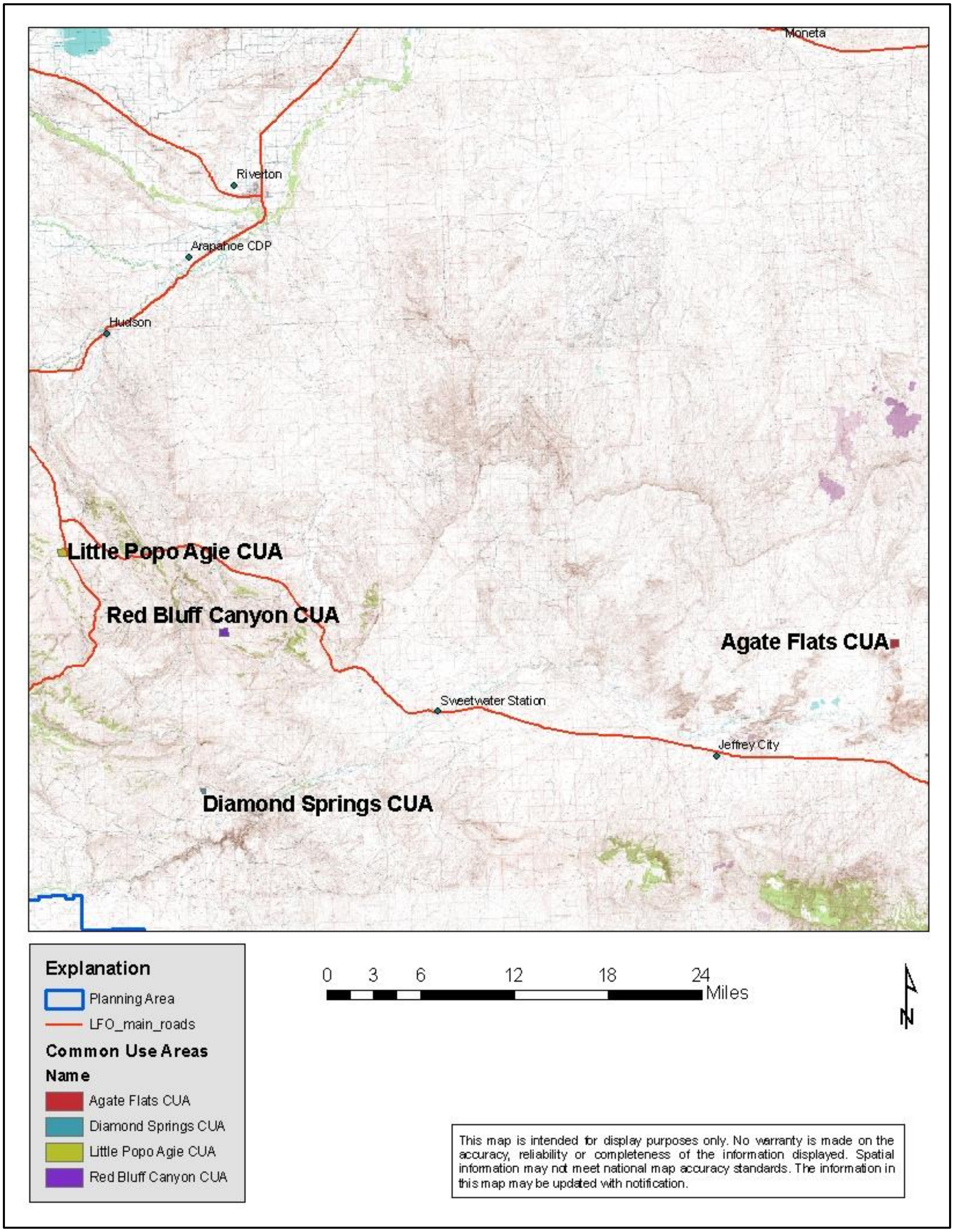
The BLM may on occasion raise this floor to 400,000 CY for specific sales if the BLM determines the sale is in the public interest and the sale will be used in conjunction with an urgent public works program and time does not warrant advertising for a competitive sale. Competitive sales are required by law to charge a cost recovery fee to the successful bidder.

The last competitive sale in the Lander Planning Area took place for limestone out of Alcova Limestone outcropping in the Gas Hills area. This material was used for rip rap on drainage channels constructed for uranium mining reclamation projects in the Gas Hills uranium district. This permit was for over 500,000 CY of material but expired in year 2000. This pit is now closed and under reclamation

3.4.3.4 Common Use Areas

Common use areas are internally generated by the BLM. Environmental Assessments are required for the development and expected lifetime of each CUA, so that mineral material disposal permits can sold over the counter at the Field Office. There are currently three public rock CUAs open to the public. These include the Little Popo Agie CUA, Agate Flats CUA, and the Diamond Springs CUA. A fourth CUA, the Red Bluff Canyon CUA, is currently not open. Figure 3-20 show the location of the four common use areas.

Figure 3-20 Mineral material common use areas in the planning area



3.4.3.4.1 Little Popo Agie CUA

The Little Popo Agie CUA (WYW152001) is an 180-acre site located in the southeast of section 34 and the southwest of section 35, T. 32 N., R. 99 W., and is developed for moss rock. Moss rock is used for landscaping, building facades, fire place mantels, etc. for its decorative beauty.

Moss rock is only obtained by hand-picking at this CUA. The use of explosives or mechanized earth moving equipment, including forklifts is not allowed. Shovels, pry bars, wheel barrows and the like are allowed. No collection after November 15 is allowed, and there is no access into the collection area for collection during wet and muddy conditions.

3.4.3.4.2 Agate Flats CUA

The Agate Flats CUA (WYW142552) was established in 1999 at the request of the public for the purpose of providing for collection of commercial quantities of so-called Sweetwater agates. Here the public expressed a need to collect small amounts of stone which can be made into jewelry and other salable products, in order to be sold or traded for example, at rock or sold in rock shops. This designation is required because if a collector acquires a contract from the BLM to purchase the semi-precious gems stones from public lands, then the collector is allowed to sell and barter the stones for commercial or industrial purposes.

The collection area is located about 14 road miles northeast of Jeffrey City, WY, in T. 30 N., R. 90 W. Existing routes are required to be used and no new roads can be constructed and no off road travel by any collectors is allowed except for an emergency. Agate stones are collected by individuals from the surface where the stones have been eroded from the soils, or the collector may dig a foot or two into the soil using a spade, pick or bar. The use of explosives or mechanized earth moving equipment, including forklifts is not allowed.

3.4.3.4.3 Diamond Springs CUA

Diamond Springs (WYW152008) is a 42-acre site located in lots 8 and 9 of section 19, T. 29 N., R. 97 W., and is also developed for moss rock. Moss rock is only obtained by hand picking at this CUA. The use of explosives or mechanized earth moving equipment, including forklifts is not allowed. Shovels, pry bars, wheel barrows and the like are allowed. No collection after November 15 is allowed, and there is no access into the collection area for collection during wet and muddy conditions.

3.4.3.4.4 Red Bluff Canyon CUA

The Red Bluff Canyon CUA is located in the northeast quarter and the north half of the southeast quarter of section 32, Township 31 North, Range 97 West. This site was developed for the purpose of collecting moss rock. Access to the site is extremely poor due to a rutted road, and thus had received less use than the other CUAs. This use of this site is not currently authorized.

3.4.3.5 Community Pits

There are currently no operating community pits in the Lander Planning Area. The last community pit (WYW102219) was closed in 1987. It operated for five years and was located in the Birdseye Pass area.

3.5 Abandoned Mining Lands

3.5.1 Introduction

The State of Wyoming initiated an Abandoned Mine Lands Reclamation (AML) program in 1980. The Wyoming Department of Environmental Quality (WYDEQ) Abandoned Mine Lands Division (WYDEQ-AML) and the BLM signed a memorandum of understanding in 1984.

In1994 the BLM and other natural resource agencies formed an interagency task force with the goal of developing a watershed approach for the cleanup of abandoned hard rock mines on public lands. These discussions and subsequent pilot programs led to the launch of a formal program in 1997. Partnering with State agencies provides federal land management agencies with additional resources for addressing not only safety, but environmental concerns as well.

In 2004 and 2005, the BLM signed cooperative agreements with the WYDEQ-AML authorizing joint reclamation projects and gives lead on AML projects to the WYDEQ-AML. BLM has an inventory of 56 known abandoned hard rock mines (excluding uranium) on public lands. BLM is coordinating with WYDEQ-AML to select the highest priority sites based on three criteria: (1) safety and environmental problems, (2) those with only safety problems, and (3) mine sites near recreation and urban areas.

3.5.2 AML Watershed Projects

There are numerous abandoned hard rock mine sites on public lands which have possible impacts on water. These watersheds were prioritized on the basis of assessments undertaken by the BLM and WYDEQAML. Six of such sites are located in the South Pass mining district and thirteen are located in the Copper Mountain mining district.

3.5.3 AML Physical Safety Sites

Over 56 high risk hard rock mine openings have been identified on BLM managed lands in Wyoming. The most significant type of mine hazard features are open shafts and adits and high-walls remaining at AML sites in the South Pass mining district (recreation concerns), and at the Copper Mountain mining district (high use area). These mines also have significant disturbed surface areas and mine wastes that may require re-grading, capping, and re-vegetation, and in some cases removal and relocation of the mining wastes to an off-site repository.

In 2008, a CX was developed for addressing sites which posed a physical safety threat. These sites were prioritized on the basis of severity of hazard (falling, entrapment), proximity to population centers, and likelihood of access (recreation). Final reclamation of these sites has not yet been determined, and therefore a fencing program was created to immediately address safety concerns at least on a temporary basis. The presence of active mining claims at each site was determined, and where existed, letters were sent to claimants asking for cooperation in fencing the hazards with free-standing buck and rail fence.

The vast majority of claimants were cooperative and the fencing at over ten sites was completed in late fall 2008. Further work is planned for the future in fencing additional sites and bringing hazardous and abandoned sites to closure through a final reclamation solution.

4 MANAGEMENT OPPORTUNITIES

4.1 Mineral Resource Potential

The mineral resource potential of the Lander Planning Area is classified using the system outlined in Bureau of Land Management Manual 3031. Under this system, occurrence potential ratings are strictly based on the geologic likelihood of the mineral to be present in the area and do not address the economic feasibility of development of the resource. These ratings address the accumulation of mineral resources and certainty of data as presented in the following sections.

4.1.1 Level of Occurrence Potential and Certainty

Occurrence potential refers to the potential of the mineral in question occurring at a specific location or geologic environment. The levels are categorized as presented in Table 4-1.

Table 4-1 Mineral occurrence potential categories

Level	Explanation
O	The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for the accumulation of mineral resources.
L	The geologic environment and the inferred geologic processes indicate low potential of accumulation of mineral resources
M	The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly, and the known mines or deposits indicate moderate potential for accumulation of mineral resources.
H	The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The known mines and deposits do not have to be within the area that is being classified, but have to be within the same type of geologic environment.
ND	Mineral potential not determined due to lack of useful data

The rating for level of certainty is presented in Table 4-2. Certainty refers to the quality of data that is available to determine the occurrence of a particular mineral resource. In other words, a particular area may exhibit characteristics which may be judged as favorable for an occurrence of a particular mineral resource. The level of certainty would be predicated upon the nature and extent of the evidence for that occurrence actually being present (e.g., sample results, geologic mapping, or direct knowledge of geologic processes or genesis).

As an example of the application of the level of certainty, there would be no potential for coal being found in granitic rocks, and this determination would have a high level of certainty based on prior knowledge of geologic processes and origin of both granitic rocks and coal. Therefore, in this case, the determination would give rise to a rating of "O/D".

Table 4-2 Level of Occurrence Certainty Ratings

Level	Explanation
A	The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.
B	The available data provide indirect evidence to support or refute the possible existence of mineral resources.
C	The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources
D	The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

4.1.2 Development Potential

The potential for development of each mineral resource in the Lander Planning Area is projected for the life of the RMP, which is 20 years, and is rated as high, moderate, or low. The likelihood for development is based on communication with industry experts and government officials familiar with the specific resources, current or past activities in the area, as well as considerations such as mineral occurrence potential, historic development, commodity price and demand, and other factors as described. The projected development may be directly affected by planning decisions that restrict or preclude mineral exploration and/or development activity.

The development rating is also affected by the status of the land in which the commodity is found. Resources found in National Parks, National Monuments, Recreational Areas, Wilderness Areas, and Wilderness Study Areas are generally not available for mineral development, except in a few areas where there may be valid existing rights. For that reason, these areas are considered to have a low development potential.

4.2 Fluid Minerals

The potential for occurrence of hydrocarbon resources in the Lander Planning Area is based on the previously discussed geology of the area, as well as the historic exploration and production activities. The industry standard for evaluating potential for hydrocarbons is the concept of a "play." An oil or gas play is an area, geologic formation, or geologic trend that has potential for oil or gas development, or is generating interest for leasing and exploration drilling.

A play is defined by the geological properties (such as trapping style, type of reservoir, and nature of the seal) that are responsible for the accumulations or prospects. Geologic heterogeneity, uneven distribution of resources, and reservoir size variations keep hydrocarbons from being evenly distributed across a play area.

Resource quantities of fluid minerals are defined in units based on Greek numeric designations in conjunction with barrels of oil or natural gas liquids and cubic feet of gas. For convenience, selected volumetric units and their respective definitions are presented in Table 4-3.

Table 4-3 Selected fluid mineral quantity definitions

Abbreviation	Definition	Example of usage	Explanation
BO	barrels of oil	100 BO	100 barrels of oil
BNGL	barrels of natural gas liquids	100 BNGL	100 barrels of natural gas liquids
CFG	cubic feet of gas	100 CFG	100 cubic feet of gas
M	one thousand	100 MBO	100,000 barrels of oil
MM	one million	10 MMBO	10,000,000 barrels of oil
B	one billion	10 BCFG	10,000,000,000 cubic feet of gas
T	one trillion	5 TCFG	5,000,000,000,000 cubic feet of gas

4.2.1 Conventional Hydrocarbon Plays

A conventional play contains oil and gas accumulations that have hydrocarbon - water contacts (due to the hydrocarbons being a separate phase and the lower density of hydrocarbons as compared to water) and seals that hold or trap the hydrocarbons. Hydrocarbons in conventional plays can be recovered using traditional development and production practices. 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. Coal bed Natural Gas is not considered a conventional hydrocarbon play.

4.2.1.1 Wind River Basin Plays

Where otherwise not cited, the following discussions of Wind River Basin (WRB) Plays are taken from USGS data presented by Fox and Dolton (1995). The numbers associated with each play identify the play in the system used by these authors and many other USGS personnel working to assess and evaluate hydrocarbon resources in the U.S.

The WRB is a west-east trending asymmetrical intermontane basin of the Rocky Mountain Foreland, located in central Wyoming. The Wind River Basin Province is about 200 miles long and 100 miles wide, encompassing an area of about 11,700 sq. miles. Province boundaries are defined by fault-bounded Laramide uplifts that surround it. These include the Owl Creek Mountains to the north, Wind River Mountains to the west, Casper Arch to the east, and the Sweetwater Uplift to the south.

Approximately 530 MMBO, 32 MMBNGL, and 2.5 TCFG are known (as of year end 1990) since the first field, Dallas Dome, was discovered in 1884. After that first discovery, other anticlinal structures with strong surface features were soon discovered, including Lander (1912), Notches (1916), Poison Spider (1917), and Big Sand Draw (1918). Major structural fields include Beaver Creek (58.5 million barrels of oil (MMBO) and 660 BCFG), Winkleman Dome (95 MMBO), Steamboat Butte (92 MMBO), Big Sand Draw (56 MMBO and 160 BCFG), Circle Ridge (33.2 MMBO) and Riverton Dome (174 BCFG).

Major structures also occur in the deep basin area. The largest of these is Madden field, discovered in 1957 (825 BCFG). Other large fields include Boone Dome (42 BCFG), Frenchie Draw (46.5 BCFG), Pavillion (174 BCFG), and Waltman - Bull Frog (96 BCFG). A major exception to structurally entrapped hydrocarbons in the Wind River Basin is Grieve field, discovered in 1954, which includes stratigraphically trapped hydrocarbons in the Muddy Sandstone (30 MMBO and 117 BCFG). Other Muddy stratigraphic fields include Wallace Creek, discovered in 1960 (13.8 BCFG), and Sun Ranch, discovered in 1987 (3.0 MMBO and 7.5 BCFG).

4.2.1.1.1 WRB Margin Sub-thrust Play (3501)

Laramide basin margin thrusting has trapped oil and gas in upturned, overturned, folded, and faulted Phanerozoic strata below the over-thrust wedge. The limits of this demonstrated play are defined by the leading edge of basin margin thrust faults and an assumed overhang displacement of 6 miles.

Reservoirs— Reservoir type and quality are highly variable. Porous and permeable sandstone and carbonate facies may have good reservoir quality. Also, some of the less conventional lithotypes may have good reservoir quality due to extensive fracturing associated with thrusting. Reservoirs can be any age, but principal reservoirs are the Pennsylvanian Tensleep Sandstone, Permian Phosphoria carbonates, and Cretaceous Frontier sandstones.

Source rocks— Hydrocarbons in the Wind River Basin are of three geochemical source rock classes, Permian (Phosphoria Formation), Cretaceous (Mowry, Frontier, Mesaverde, Meeteetse Formations), and Tertiary (Fort Union Formation).

Timing and migration— Because Laramide thrust faults have thrust thick wedges of Precambrian rocks over Phanerozoic rocks, the depth of the source rocks is usually great enough for the source rocks to have generated hydrocarbons locally or for hydrocarbons to have migrated from mature areas in deeper parts of the basin during and after Laramide deformation. Some pre-Laramide migration may have taken place, moving hydrocarbons into reservoirs before tectonic development of the basin margin folds and faults. In this case stratigraphic traps could have formed prior to basin margin thrusting and subsequent development of basin margin folds and faults. Faulting could then have superimposed structural control on these stratigraphic traps.

Traps— Petroleum is trapped where structures with closure occur beneath the basin margin thrust and is sealed by associated rocks or by impermeable rocks of the hanging wall of the thrust. In the thrusting process the underlying beds are folded and often upturned or overturned with fault slivers typically present. Oil and gas may also be trapped in these upturned, overturned, folded, and faulted strata. Depth to production is highly variable, ranging from more than 20,000 ft on the structurally steepest side of the asymmetrical basin to less than 10,000 ft in other basin margin areas.

Exploration status— This demonstrated play is very lightly explored. One field, Tepee Flats field near Arminto, Wyoming is currently producing gas from the Frontier Formation at a depth of about 12,200 ft. but is outside the Lander Planning Area.

Resource potential— It is anticipated that about 2/3 of the fields in this play will be gas fields occurring in deeper parts of the basin, and the remaining 1/3 will be oil fields in areas where entrapment is shallower. Known recoverable resources from the Tepee Flats field are 9.0 BCFG.

4.2.1.1.2 WRB Margin Anticline Plays (3502)

This demonstrated play is defined by the occurrence of oil and gas trapped in anticlines and domes, in many cases faulted, and in faulted fold noses that formed during the Laramide orogeny. These structures are best developed along the shallow margins of the basin, with production from about 1,000 ft to about 14,000 ft. The inner boundary of the play is drawn at the approximate basin-ward limit of basin margin anticlines. The outer boundary is drawn at the top of the Tensleep on outcrop. The earliest oil discoveries in the State of Wyoming are found in these sorts of traps as demonstrated by the first well drilled in the State, just south of Lander.

Reservoirs— Producing formations range in age from Mississippian through Cretaceous and include Madison, Tensleep, Phosphoria, Crow Mountain, Jelm, Sundance, Nugget, Dakota, Cloverly, Lakota, Muddy, Frontier, Cody, and Mesaverde. Primary production has been from the Madison, Tensleep, and Phosphoria. Many of the fields have multiple pay zones and some show common oil - water contacts involving several of the Paleozoic reservoirs. Sandstone is the dominant reservoir lithology, in most cases relatively homogeneous and of good reservoir quality. Substantial quantities of hydrocarbons have also been produced from heterogeneous carbonate reservoir rocks of the Madison and Phosphoria. Reservoir thickness is highly variable: individual units reach a thickness of several hundred feet. Most reservoirs, however, are less than 50 ft thick.

Source rocks— Within the thick sequence of hydrocarbon-bearing strata are numerous organic-rich argillaceous sedimentary rocks. Hydrocarbons are derived from three distinct geochemical source rock classes, Permian (Phosphoria Formation), Cretaceous (Mowry, Frontier, Mesaverde, Meeteetse Formations), and Tertiary (Fort Union Formation). Oil and gas in the Cretaceous reservoirs have their source in associated Cretaceous organic-rich beds, whereas Paleozoic oil and gas appear to be derived primarily from a distinct Phosphoria source. Two fields in the western part of the basin, Circle Ridge and Beaver Creek, produce oil from the Madison Limestone. Properties of the oil in these two fields are nearly identical to those of the Tensleep and Park City (Phosphoria) oil in the same areas, indicating that the oil may have been derived from the younger Paleozoic sources or reservoirs. The thermal maturity is high in many areas of the basin, especially where source beds are very deeply buried, and in these areas the dominant hydrocarbon is gas.

Timing and migration— Pre-Laramide generation and long distance migration from western Wyoming prior to basin formation, followed by remigration during the Laramide orogeny, is a possibility for charging of Paleozoic reservoirs. However, local generation of oil also occurred without long distance migration. Cretaceous source rocks reached maturity by early Paleocene time in deep parts of the basin, and younger rocks later entered the hydrocarbon generation window.

Structural growth apparently coincided with this Laramide stage of maturation and was the final concentrating process in a long and complex history of generation, migration, and accumulation of hydrocarbons.

Traps— Trapping mechanism is closure in both anticlines and domes, in many cases faulted, and in faulted fold noses that formed during the Laramide orogeny. These structures are best developed around the shallow margins of the basin, with production from a few hundred feet to about 12,000 ft. Within these structures, interbedded impermeable beds act as seals.

Exploration status— Approximately 530 MMBO, 32 MMBNGL, and 2.53 TCFG have been discovered (as of year-end 1990) since the first field, Dallas Dome, was discovered in 1884. Since that first discovery, other basin margin anticlinal structures with strong surface features were soon discovered, including Lander (1912), Notches (1916), Poison Spider (1917), and Big Sand Draw (1918). Major structural fields include Beaver Creek (58.5 MMBO and 660 BCFG), Winkleman Dome (95 MMBO), Steamboat Butte (92 MMBO), Big Sand Draw (56 MMBO and 160 BCFG), and Riverton Dome (174 BCFG).

Resource potential— Most large traps had been explored by about 1950. Prospects for significant new discoveries are not good, although new production could occur as extensions and secondary features related to larger structural trends. Small fields are likely. The mix of oil and gas should be in about the same proportion as historic.

4.2.1.1.3 WRB Deep Basin Structure Play (3503)

This is a demonstrated gas play with entrapment in large intra-basin anticlinal, domal, and fold nose structures within the deep axial portion of the basin. The boundary of this play is defined on the north by the leading edge of the northern basin margin thrust fault and on the south and west by the deep limit of the Basin Margin Anticline Play (3502).

Reservoirs— Reservoir rocks range in age from Mississippian to Eocene and include the Madison, Phosphoria, Nugget, Morrison, Cloverly, Muddy, Frontier, Cody, Mesaverde (Fales Sandstone), Lance, Fort Union, and Wind River. Porosity and permeability, reduced through compaction and cementation due to deep burial, may be re-enhanced by fracturing. Early migration and entrapment may have preserved some of the original porosity and permeability. Most fields have multiple pool production from a great range of depths and thicknesses. Reservoir thickness is highly variable, ranging from a few feet to 280 ft in the Fort Union Formation. Most reservoirs are about 25–50 ft thick. Reservoirs may be over-pressured; for example, most Tertiary and Mesozoic strata on the Madden structure are over-pressured but nearly normal pressure gradients occur near the top of the Paleozoic interval. Reservoir rocks are interbedded with source rocks, facilitating migration.

Source rocks— Indigenous hydrocarbon source rocks are abundant in the Permian Phosphoria and the Cretaceous Mowry, Frontier, Mesaverde, Meeteetse, Tertiary Fort Union (including Waltman Shale Member), Wind River, and Indian Meadows.

Timing and migration— Vitrinite reflectance studies indicate that both oil and gas generation began from the Cody, Mesaverde, and Meeteetse source rocks in the early Paleocene. Paleozoic source beds were buried deeply enough to generate hydrocarbons before the Laramide orogeny.

Gas accumulations in Paleozoic strata were probably oil earlier in the development of the structure: these reservoirs passed through the oil window with continued burial and produced large quantities of thermogenic gas. Laramide folding was the final concentrating process in a long and complex history of generation, migration, and accumulation of hydrocarbons.

Traps— The primary trapping mechanisms in this play are intra-basinal anticlinal, domal, and fold-nose structures within the deep axial portion of the basin. Seals include fine-grained facies interbedded with reservoirs, some of which may also be source beds. Depth of production ranges to more than 23,000 ft. At Madden field, gas is produced from the Madison Limestone at about 23,700 ft. This field hosts the deepest production well in the Rocky Mountain Region.

Exploration status— This demonstrated play is moderately well explored to well-explored. About 10 fields with ultimate production in the category of greater than 1 MMBOE (6 BCFG) are currently producing in this play. The largest field is Madden field, discovered in 1957 (825 BCFG). Other large fields include Boone Dome (42 BCFG), Frenchie Draw (46.5 BCFG), Pavillion (174 BCFG), and Waltman - Bull Frog (96 BCFG). In 2007, a major exploration effort hosted by three companies was proposed for over 1400 new wells in the Madden Deep, Iron Horse and Gunbarrel Units.

Resource potential— 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, which is a major new reservoir at Madden field. Although quality of this gas is not good, being high in hydrogen sulfide and carbon dioxide, considerable potential exists for other productive Paleozoic reservoirs, as well as shallower zones, elsewhere in the basin.

4.2.1.1.4 WRB Muddy Sandstone Stratigraphic Play (3504)

This is a stratigraphic play with anticipated entrapment of oil and gas in up-dip pinch-outs of discontinuous Muddy Sandstone bodies, deposited as a complex series of coastal sand bodies whose distribution was controlled by paleotopography and structure. The limits of this play are defined on the south and west by outcrop limits of the Muddy Sandstone and on the north by excessive depth, the limit line coincident with the southern shallow limit line of the Basin Center Structure Play (3503). The actual sandstone may, in fact, extend beyond the limits of the play but is restricted due to excessive depth and anticipated reservoir degradation in the deeper parts of the basin. Here it may be a gas play, and it was assessed within the Basin Center Structure Play (3503). So far, the demonstrated resources are located just outside the Lander Planning Area boundary.

Reservoirs— The thickness of the Muddy is highly variable, as much as 150 ft in places along the west margin of the basin, locally thinning and grading almost completely into shale and siltstone. In known producing fields it ranges from 20 - 52 ft.

The excellent reservoir quality and the high quality of the oil (33 to 43 degrees API) make it a prime drilling objective. Porosity ranges from about 9 percent to 13 percent at depths to about 11,000 ft.

Source rocks— Source rocks for Muddy hydrocarbons are the organic-rich shales of the Mowry and Shell Creek Shales that overlie, and the Thermopolis Shale that lies below the Muddy Sandstone reservoir rocks. Depth of burial of the Muddy is in excess of 5,000 ft throughout the play area, a depth sufficient to generate hydrocarbons.

Timing and migration— The reservoir sandstone is closely associated with thick petroleum source beds, so that the conditions for primary entrapment of hydrocarbons are ideal. Vitrinite reflectance studies indicate that oil and gas generation both began from the Cody, Mesaverde, and Meeteetse source rocks, far above the Muddy, in the early Paleocene. The Mowry source beds may have generated hydrocarbons before the Laramide orogeny.

Traps— The trapping mechanism is up-dip pinch-out of discontinuous reservoirs, such as in Grieve field, the largest Muddy field, where production is from an unusually thick section of estuarine sandstone that thins abruptly up-dip on the west where the petroleum is trapped. Depth of burial is from about 5,000 to 12,000 ft. At Wild Horse Butte field (discovered in 1985, about 10 miles east of the Lander Planning Area border) the Muddy produces gas at a depth of 14,046 ft.

Exploration status— This demonstrated play is heavily explored along the southern margin of the basin (mostly just outside the boundary of the Lander Planning Area) but is lightly explored in the central or western part. Six fields greater than 1 MMBOE ultimately recoverable have been discovered. They include Grieve (discovered 1954, partially within the Lander Planning Area), Austin Creek (discovered 1988), Grieve North (discovered 1973), Sun Ranch (discovered1987), Wallace Creek (discovered 1960), and Wild Horse Butte (discovered 1985). Wallace Creek and Wild Horse Butte are primarily gas fields. Field sizes range from Grieve (30 MMBO and 117 BCFG), Sun Ranch (3.0 MMBO and 7.5 BCFG), Grieve North (4.5 MMBO and 6.6 BCFG), Austin Creek (1.5 MBO and 3.4 BCFG), and Wild Horse Butte (6.0 BCFG). All fields excepting one part of Greive are just outside the Lander Planning Area boundary.

Resource potential— Considering the fairly recent discoveries of new fields in this play, its potential is good. Most future discoveries will be small to medium size.

4.2.1.1.5 WRB Phosphoria Stratigraphic Play (Hypothetical) (3506)

High sulfur oil (20° to 30°API gravity) is stratigraphically trapped in the Ervay Member of the Phosphoria Formation along a generally north-south trend or transition zone from Phosphoria carbonates on the west to red shale and evaporites of the Goose Egg Formation on the east. The play area is located in the eastern Wind River Basin, limits of the play defined on the east by the eastern limit of the Ervay Tongue, on the west by the estimated down-dip limit of perceived oil accumulations, and on the north and south by Phosphoria outcrops.

Reservoirs— Reservoirs occur in the Permian Ervay Member of the Phosphoria Formation. They are typically dolomitized grainstones and packstones, along with local algal rocks containing fenestrate porosity. These reservoirs formed in high-energy tidal and associated environments.

At Cottonwood Creek field, oil in high-energy tidal channels is sealed up-dip by tight fine-grained intertidal and supratidal carbonates. Reservoir matrix porosities average about 10 percent, but are, in many places, fracture enhanced. Reservoir thickness ranges from about 25 - 75 ft.

Source rocks— Oil was generated from organic-rich Permian Phosphoria shale source rocks to the west where burial depth was sufficient to generate hydrocarbons.

Timing and migration— Both Laramide-related and pre-Laramide generation and migration of hydrocarbons may have occurred. Generation of oil from Phosphoria source rocks may have begun as early as the Jurassic in western Wyoming and eastern Idaho.

Traps— Stratigraphic traps occur near the edge of the carbonate tongue of the Ervay Member, in porous detrital reservoirs deposited within high energy regimes of tidal channels on a coastal flat. They were sealed up-dip by tight, fine-grained carbonates of intertidal and supratidal origin. Lateral seals for traps are the mud-supported carbonates of the Ervay Member, although the regional trap can be viewed as the facies change from carbonate into red beds. Vertical seals are the fine-grained rocks of the overlying Triassic Dinwoody and Chugwater Formations, and internal seals are provided by fine-grained red beds or carbonates. Depth to producing horizons is estimated to be from about 2,000 to 20,000 ft.

Exploration status— Exploration of the Phosphoria Stratigraphic Play was stimulated by the discovery of Cottonwood Creek field in the Bighorn Basin in 1953. This large field, well outside the Lander Planning Area, has known reserves of 59 MMBO and 42 BCFG. Subsequent discoveries in the Bighorn Basin have been infrequent and smaller in size, approximately 10. Exploration success in the Wind River Basin has been disappointing, with discovery of only one or two very small accumulations.

Resource potential— Undiscovered pools are estimated to be of small size, probably averaging less than 1 MMBO.

4.2.1.1.6 WRB Bighorn Wedge-Edge Pinch-out Play (Hypothetical) (3509)

This hypothetical play encompasses hydrocarbon occurrence in the wedge-edge or beveled-edge pinch-outs of the Ordovician Bighorn Dolomite which abut against the base of the Madison Limestone, providing potential traps. No hydrocarbon occurrences or source rocks are known.

Reservoirs— Reservoirs in the Bighorn Dolomite are characterized by inter-granular porosity, and they are anticipated to be present over most of the play area.

Source rocks— Source rocks have not been identified associated with the hypothetical reservoir rocks. Their absence implies that exploration success could be nil.

Traps— Although regional truncation is demonstrated, the presence of traps at this unconformity is undocumented and internal traps not recognized.

Exploration status— No production exists within this play, and exploration has been minimal.

Resource potential— This play bears very high risk (probability of success is less than 0.1) owing to poor charge and trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.1.7 WRB Flathead Lander and Equivalent Sandstone Stratigraphic Play (Hypothetical Play) (3510)

This hypothetical play includes hydrocarbons trapped in stratigraphic pinch-outs of the Cambrian Flathead and Ordovician Lander Sandstones.

No hydrocarbon occurrences or source rocks are known.

Reservoirs— Reservoirs comprise sandstones that are believed to be present over much of the play area, but that exhibit considerable variability. Quality of reservoirs may be poor, owing to diagenesis.

Source rocks— Source rocks have not been identified associated with the hypothetical reservoir rocks. Their absence implies that chance of exploration success is extremely minimal.

Traps— Although stratigraphic pinch-outs are anticipated, the presence of traps has not been demonstrated.

Exploration status— No production exists within this play.

Resource potential— This play bears very high risk owing to poor charge and trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.1.8 WRB Madison Limestone Stratigraphic Play (Hypothetical) (3511)

This hypothetical play encompasses oil enclosed within or at the top of the Mississippian Madison Limestone, trapped by a combination of porosity variation and topography related to karst development.

Reservoirs— Karstic vuggy reservoirs in the upper part of the Madison Limestone are expected throughout the play area.

Source rocks— Source rocks have not been identified associated with the hypothetical reservoirs. Their absence implies very minimal chance of exploration success.

Traps— The presence of traps is not demonstrated.

Exploration status— No production exists within this play.

Resource potential— This play bears very high risk owing to poor charge and trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.1.9 WRB Darwin & Amsden Sandstone Stratigraphic Play (Hypothetical) (3512)

This hypothetical play consists of stratigraphic entrapment of oil in discontinuous sandstones of the Pennsylvanian Darwin and Amsden Formations. Although no occurrence of oil in such traps is here known, these formations are productive elsewhere in structural settings.

Reservoirs— Reservoirs are sandstones believed to be present over most of the play area. Quality of reservoirs may be poor owing to burial diagenesis.

Source rocks— Source rocks have not been identified with certainty associated with the hypothetical reservoirs. Their absence implies very minimal chance of exploration success.

Traps— Considerable variability of sandstone distribution exists within the Amsden, and the belief is that traps are enhanced by structural pinch-outs.

Exploration status— No production exists within this play.

Resource potential— This play bears very high risk owing to poor charge and trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.1.10 WRB Triassic and Jurassic Stratigraphic Play (Hypothetical) (3513)

This hypothetical play encompasses stratigraphic traps in the Sundance Formation, the Morrison Formation, and the Crow Mountain Sandstone of the Chugwater Group and its equivalents (Jelm Formation (?)). It also includes wedge-edge pinch-outs and truncations of the Nugget Sandstone in the eastern and northern Wind River Basin.

Reservoirs— Reservoirs are sandstones believed to be present over most of the play area. Quality of reservoirs is expected to be good.

Source rocks— Source rocks have not been identified with certainty associated with the hypothetical reservoirs. Charging of traps appears to require migration from source beds well above or below the objectives such as from the Phosphoria Formation.

Traps— The presence of traps is not demonstrated.

Exploration status— No production exists within this play.

Resource potential— This play bears very high risk owing to poor charge and trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.1.11 WRB Shallow Tertiary-Upper Cretaceous Stratigraphic Play (3515)

Stratigraphic and combination traps contain primarily gas with some liquids in Eocene, Paleocene, and uppermost Cretaceous sandstone reservoirs.

Reservoirs— Reservoirs are Wasatch, Fort Union, Lance, and Mesaverde arkosic or lithic sandstones with good porosity and permeability at shallow depths.

Source rocks— Source rocks are primarily underlying Cretaceous and Paleocene rocks with some possible contribution from humic-rich rocks of Tertiary age. Gas appears to be thermogenic with some mixing of biogenic gas. Local oil has its source in the lacustrine Paleocene Waltman Shale. Vertical migration is necessary to charge the reservoirs.

Timing and migration— Timing of generation and migration is favorable in that traps were formed by the time of generation and migration.

Traps— Traps are primarily stratigraphic, the result of facies changes. They are typically alluvial sandstones that form localized channel bodies of limited extent.

Traps are small and sometimes occur in combination with structures. Seals are provided by associated fine-grained rocks, variously Eocene, Paleocene, and Upper Cretaceous.

Exploration status— This play has been lightly explored for many years, and a number of small accumulations have been discovered.

Resource potential— Small accumulations (less than 1 MMBO equivalent) are anticipated, and a risk was assigned to occurrence of larger accumulations.

4.2.1.1.12 WRB Cody and Frontier Stratigraphic Play (Hypothetical) (3518)

This play includes deep oil and gas accumulations in stratigraphic traps in the Upper Cretaceous Cody and Frontier Formations, in a thick sequence of marine shale and fine-grained sandstone.

Reservoirs— Reservoirs of fine-grained sandstone are distributed throughout the play area. Reservoir quality is anticipated to rapidly decrease with depth. Although equivalent reservoirs are productive in structural settings, reservoir quality in deeper, off-structural settings of this play remains problematic.

Source rocks— Cretaceous source rocks (particularly the Mowry Shale) are present, associated with the reservoir rocks, and probably have seen a favorable hydrocarbon generation and migration history.

Traps— Stratigraphic pinch-out traps involving largely marine sandstones may be distributed throughout the play area, but the presence of traps of significant size is not demonstrated.

Exploration status and resource potential— This play bears very high risk owing primarily to poor reservoir and limited trap potential. It is considered to have little likelihood of significant hydrocarbons. No quantitative estimate of resources was made.

4.2.1.2 Southwestern Wyoming (Great Divide Basin region) Plays

As defined by the USGS (2002), the Southwestern Wyoming Oil and Gas Province includes such areas as the Hoback Basin (Pinedale Anticline), Green River Basin, Washakie Basin and the Great Divide Basin (GDB). Only the northern part of the Great Divide Basin occurs in the Lander Planning Area, and therefore is considered here along with the region along the thrust faults just north of Green and Crooks Mountains.

The plays discussed here are somewhat modified from their original forms and can only be taken in the context where the area of the play coincides with the Great Divide Basin region so as to limit the consideration to the Lander Planning Area. Note that in each case, the area of the play is much larger than the portion which intersects the Lander Planning Area in the Great Divide Basin. Where otherwise not cited, the data presented in this section is found in Law (1995).

4.2.1.2.1 GDB Margin Anticline Play (3705)

The play area is a narrow tract 5 to 20 miles wide paralleling the thrust margins of the Greater Green River Basin in Wyoming, Utah, and Colorado. This is essentially a structural play that, in part, overlaps with the tight gas play. The east end of the northern trend of the play, encompassing about 497 sq. miles (318,652 acres), intersects the Lander Planning Area. The northern edge of the play trends along the thrust faults just north or Green and Crooks Mountains.

Reservoirs— Reservoirs include all oil-and gas-producing reservoirs in the geologic column.

Source rocks— Source rocks include the Mowry Shale, Phosphoria Formation, and coals and carbonaceous shale within Cretaceous and Tertiary rocks.

Timing and migration— Basin-margin anticlines are most likely Laramide features, associated with adjacent thrusting events. Therefore, hydrocarbons that were generated and migrated during and after Late Cretaceous time could have been trapped in Laramide structural features.

Traps— The trapping mechanism in this play is structural. The analogs are the anticlines associated with the Clay Basin, Pinedale, and Mickelson Creek fields. These anticlines appear to be genetically related to the structural deformation associated with thrusting along the north flank of the Uinta Mountains, the southwest flank of the Wind River Mountains, and the Overthrust Belt, respectively. Relatively impermeable lithologies such as that found in the Upper Cretaceous Shales (Cody-equivalents) provide good seals. Depth of Occurrence is as much as 30,000 ft.

Exploration status— This is an Immature to moderately mature play. However, large areas along the north flank of the Uinta Mountains and along the southwest flanks of the Wind River Mountains and Gros Ventre Range are virtually unexplored.

Resource potential— A discovery in excess of 1 MMBOE is not unlikely. However, the resource potential just in the area which intersects the Lander Planning Area is unknown.

4.2.1.2.2 GDB Sub-thrust Play (hypothetical) (3706)

The Sub-thrust Play is highly speculative. The play area is located along the overridden thrust margins of basins in Wyoming, Utah, and Colorado and has been thoroughly discussed by Gries (1983). Only the minor slivers in the southeast and southwest portion of the Lander Planning Area are present. The portion of the slivers which intersect the Lander Planning Area total about 88.2 sq. miles (56,461 acres) are considered here.

Reservoirs— Reservoirs include any of those previously discussed in the province.

Source rocks— Source rocks include Tertiary and Cretaceous shales, the Phosphoria Formation, and possibly the Pennsylvanian-age shale or equivalent rocks.

Timing and migration— In general, thrusting in the province was a Laramide event. Therefore, structural traps originating as a consequence of thrusting would constrain the timing of accumulation to no older than Late Cretaceous. However, in the case of pre-thrusting traps, hydrocarbons may have accumulated much earlier.

For example, in the sub-thrust area along the north flank of the Uinta Mountains, Law and Clayton (1987) proposed that Lower Cretaceous Dakota Sandstone reservoirs were charged with oil prior to thrusting, when the reservoirs were structurally higher than areas to the north— a structural configuration opposite to that of present-day structures. They further demonstrated that in the sub-thrust projection of the Moxa Arch, the top of the oil generation window occurs in pre-Cretaceous rocks at depths greater than 16,000 feet.

Traps— The following kinds of traps may be present in the sub-thrust play: (1) conventional anticline, (2) stratigraphic, (3) fault truncation of upturned strata, and (4) fracturing.

Anticlinal traps may be of two types, those formed as a result of the thrusting and those pre-thrusting anticlines that were overridden at the time of thrusting, such as the Moxa Arch. Seals include low-permeability Cretaceous and older shales and faults. Depths of occurrence: The depth of occurrence is unknown but is related to depths of sedimentary rocks beneath the hanging wall of the thrust margin.

Exploration status— The Southwestern Wyoming Province probably contains more wells drilled in sub-thrust plays than anywhere else in the U.S., and most certainly, in the Rocky Mountain region. However, the play is immature to moderately maturely explored. Large areas appear to be unevaluated. No fields have been established in the play area but the attributes of the play and the relatively unexplored nature of the play are intriguing.

Resource Potential— The resource potential in just the area which intersects the Lander Planning Area is unknown.

4.2.1.2.3 GDB Platform Play (3707)

The Platform Play is primarily a structural play and encompasses nearly the entire eastern half of the Southwestern Wyoming Province. It extends from the eastern edge of the Great Divide and Washakie Basins east to the Laramie Range. Without exception, existing fields are in structural traps. Some of the oldest fields in Wyoming are located within this play area.

Only the extreme northwest tip of this play occurs in the Lander Planning Area which encompasses a total of about 33.3 sq. miles (21,298 acres).

Reservoirs— Reservoir rocks include Cambrian through Tertiary sandstones and carbonates.

Source rocks— Based on unpublished oil analyses from nine fields within this area, the source of oil in Cretaceous and Jurassic reservoirs is Cretaceous rocks and the source of oil in the Casper Formation (Tensleep Sandstone equivalent) and older reservoirs is Paleozoic rocks, probably the Phosphoria and (or) some Pennsylvanian source rock. Although undocumented, structural traps probably have been present through most of the Phanerozoic history of the area.

Timing and migration— When generation and migration of oil from the various source rocks took place is not known, but structural traps likely were available for the accumulation of hydrocarbons during most of the Phanerozoic.

Traps— Existing accumulations are all in structural traps. Seals are provided by very low permeability shales. The potential for stratigraphic traps exists in several of the reservoirs such as the Casper Formation (Tensleep equivalent), Sundance Formation, Dakota Formation (approximately equivalent to the Cloverly Formation), and Muddy Sandstone, where they may undergo facies changes into finer-grained, relatively impermeable lithologies. However, this has not been demonstrated. Depth of occurrence: 1,200 to 9,200 ft and most commonly 3,000 to 6,000 ft.

Exploration status— The area is maturely explored. Some of the oldest fields in the Rocky Mountain region occur in the play area (Lost Soldier 1916, Rock River 1918, Wertz 1921). There have been only a few discoveries since 1960. Although any new discoveries in excess of 1 MMBO are unlikely, structures associated with basement-involved deformation may be identified with the application of modern geophysical techniques.

Resource Potential— The resource potential of just the area which intersects the Lander Planning Area is unknown.

4.2.2 Unconventional Hydrocarbon Plays

4.2.2.1 Wind River Basin Continuous-Type Plays

4.2.2.1.1 WRB Basin Center Gas Play (3505)

This play is characterized by an extensive and continuous over-pressured gas accumulation trapped in low permeability zones in Paleocene and uppermost Cretaceous sandstone reservoirs in deep parts of the Wind River Basin. The play is characterized by over-pressuring due to active generation of gas. Older Cretaceous rocks, which may also be geo-pressured, are not considered because of their generally thin reservoir development and limited reservoir volumes.

Reservoirs— Principal reservoirs are sandstone beds in the Fort Union, Lance, and Mesaverde Formation. They are generally arkosic or lithic, with poor to modest porosity and low permeability. They are typically alluvial sandstones, particularly localized channel bodies of limited extent, and marine sandstone of more blanket-like character. The overall sequence displays significant internal compartmentalization.

Source rocks— Source rocks are directly associated humic-rich rocks and coals, with some contribution possible from underlying Cretaceous units. Gas appears to be thermogenic.

Timing and migration— The timing of generation and migration of hydrocarbons is favorable with reference to the available reservoirs. Over-pressuring due to active generation of gas appears to generally coincide with saturated rock resistivity (Ro) of 1.0 percent or more. This play is defined vertically by the approximate Ro = 1.0 occurrence at the top of the involved section, which is approximately at 10,000 ft, and encompasses underlying Paleocene and upper Cretaceous rocks to the base of the Mesaverde Formation.

Traps— The trap is primarily a regional stratigraphic trap caused by low reservoir permeability combined with active gas generation. Alluvial sandstones, particularly localized channel bodies of limited extent, provide internal compartmentalization.

Sealing is provided within the low-permeability reservoirs and by associated fine-grained rocks, variously Paleocene and uppermost Cretaceous. Ground-water influx and hydrodynamic enhancement may contribute to trapping.

Exploration status and Resource Potential— This play has seen virtually no meaningful exploration and is speculative in nature. Field development has not yet taken place. The resource potential of this high risk play is uncertain.

4.2.2.2 Southwestern Wyoming Continuous-Type Plays

Continuous-type basin-centered plays include reservoirs from Cambrian through Paleocene rocks although the more important reservoirs are in Cretaceous and lower Tertiary rocks. These gas accumulations occur in large parts of the Great Divide, Green River, Washakie, Sand Wash, and Hanna Basins. Only the Great Divide is of specific interest here as it occurs in the Lander Planning Area. Where otherwise not cited, the data presented in this section is found in Law (1995).

Basin-centered gas accumulations are a type of unconventional gas accumulations that differ significantly from conventional gas accumulations. They have the following attributes:

(1) generally, very large accumulations occupying the more central, deeper parts of basins,

(2) absence of down-dip water contacts,

(3) abnormally over-or under-pressured,

(4) gas is the pressuring phase,

(5) produce little or no water,

(6) permeability less than 0.1 milli-Darcies (md),

(7) overlain by a normally pressured transition zone containing gas and water,

(8) contain thermogenic gas,

(9) source of gas is local--either from interbedded or adjacent lithologies,

(10) the gas is thermogenic,

(11) top of accumulations occur at 0.75 to 0.9 percent vitrinite reflectance,

(12) structural and stratigraphic trapping aspects are of secondary importance, and

(13) the "seal" for these gas accumulations is due to the presence of multiple fluid phases in low-permeability reservoirs; it is a relative permeability barrier.

Oil and associated gas production, since the 1916 discovery of the large Lost Soldier field south of the Lander Planning Area , is mainly from fields located in and adjacent to the Laramie Basin, Rawlins Uplift, Axial Arch Uplift and the La Barge Platform - Moxa Arch trend.

Productive reservoirs range from Cambrian through Tertiary age and are dominantly sandstone. Carbonate reservoirs are minor. More than 100 fields greater than 1 MMBOE in size have been discovered in the province. Cumulative production from these fields to the end of 1991 is about 849 MMBO and 7.3 TCFG.

4.2.2.2.1 GDB Greater Green River Basin Cloverly-Frontier Play (Hypothetical) (3740)

The entire play area encompasses an area of about 12,500 sq. miles. Only the upper northeast corner of the play, a total of about 93.5 sq. miles (59,862 acres), occurs within the Lander Planning area. The play area includes all of the over-pressured, deeper parts of the Greater Green River Basin in Wyoming and Colorado. Along the Moxa Arch, in the western part of the Green River Basin, the Dakota and equivalent rocks are excluded; These rocks have been assessed as conventional reservoirs in the Moxa Arch-LaBarge Play.

Reservoirs— The Cloverly-Frontier Play includes the strata in the interval from the base of the Cloverly and equivalents to the top of the Frontier Formation with the exception of the Dakota and equivalent rocks in the area of the Moxa Arch. Individual sandstone reservoirs in the play range in thickness from 10 to 70 ft.

Source rocks— Sources of gas are from coal and carbonaceous shale in the Cloverly and Frontier and shale in the Mowry.

Timing and migration— Because gas in gas accumulations is generated within, or in close proximity to reservoirs in basin-centered gas accumulations, the temporal relationships between the generation, migration, and development of a trap is not nearly as important as in conventional gas accumulations. When the reservoirs in the Cloverly-Frontier Play were charged with gas and became saturated and over-pressured is uncertain. Burial and thermal reconstructions suggest that gas, generated from this interval may have begun during late Eocene time.

Traps— The depth of reservoirs within the play area is highly variable, ranging from 10,000 to 20,000 ft. Throughout most of the play area, the depth to the top of the Frontier is about 17,000 ft. Refer to the Southwestern Wyoming Continuous-Type Plays introduction for additional information.

Exploration status— Along the Moxa Arch (south of the Lander Planning Area), the play is mature and is currently experiencing a large amount of drilling. Elsewhere in the play area where drilling depths exceed 16,000 ft there are uncertainties concerning the quality of matrix and fracture permeability. However, with the advent and application of new drilling and completion techniques, reservoirs in the deeper parts of the play area may prove to be economically productive.

Resource Potential— The resource potential for this hypothetical play in the small area where it overlaps the Lander Planning Area is unknown.

4.2.2.2.2 GDB Greater Green River Basin Mesaverde Play (Hypothetical) (3741)

The play encompasses an area of about 8,200 sq miles in Wyoming and Colorado. Only the northeast corner of the play, encompassing about 160 sq. miles is contained within the Lander Planning Area.

The play area extends through the deeper parts of the Great Divide, Washakie, Sand Wash Basins and the northern part of the Green River Basin.

Reservoirs— The Mesaverde Play includes the stratigraphic interval from the base of the Rock Springs Formation and equivalent rocks to the top of the Almond Formation in the Great Divide, Washakie, and Sand Wash Basins. West of the Rock Springs Uplift, in the Green River Basin, the play includes the stratigraphic interval from the base of the Rock Springs Formation and equivalent rocks to the top of the Ericson (Mesaverde) Sandstone.

The thickness of the stratigraphic interval ranges up to 5,000 ft, and the cumulative thickness of individual reservoirs range from less than 750 to 2,000 ft. Individual reservoirs range in thickness from 10 to 75 ft.

Source rocks— The most likely source rocks are coal and carbonaceous shale within the play interval (Law, 1984).

Timing and migration— As previously discussed, the temporal relationships between gas generation, migration, and trap formation in basin-centered gas accumulations are not as important as they are in conventional gas accumulations. Gas began to be generated from the Mesaverde interval in late Eocene or Oligocene time. The charging and development of gas saturated, over-pressured reservoirs is not known.

Traps— Like all basin-centered gas accumulations, traps and seals as visualized in conventional hydrocarbon accumulations, are of secondary importance and are not of fundamental importance. For a detailed discussion of the boundaries of basin-centered gas accumulations refer to Meissner (1984), Law (1984), and Spencer (1989). Depth of occurrence: The depth to the top of reservoirs in the Mesaverde Play ranges from 8,000 to 18,000 ft.

Exploration status— The play is immaturely explored with the exception of the Almond Formation reservoirs in the Washakie Basin, where several fields produce gas from the uppermost part of the Almond. The Almond production represents "sweet spots" where the reservoir quality is much better than the rest of the Mesaverde reservoirs. Most of the Mesaverde Play remains unevaluated and it is likely that at least one accumulation larger than 1 MMBOE will be discovered.

Resource Potential— The resource potential for this hypothetical play in the small area where it overlaps the Lander Planning Area is unknown.

4.2.2.2.3 GDB Greater Green River Basin Lewis Shale Play (Hypothetical) (3742)

This play includes the stratigraphic interval of the Lewis Shale. The play area encompasses an area of about 3,900 sq mi and is restricted to the deeper parts of the Great Divide, Washakie, and Sand Wash Basins in Wyoming and Colorado. Only a portion of the northern part of the play encompassing approximately 89.6 sq. miles (57,345 acres) is contained within the Lander Planning Area. The western boundary of the play coincides with the western edge of the Lewis Shale transgression.

Reservoirs— Reservoirs in the Lewis occur as isolated sandstones bounded above and below by shale. The cumulative thickness of reservoirs in the play ranges from less than 200 ft to more than 600 ft and the median thickness is 400 ft. Individual sandstone reservoirs range in thickness from 10 to 100 ft.

Source Rocks— Sources of gas are from the marine shales of the Lewis Shale.

Timing and migration— As previously discussed, the temporal relationships between gas generation, migration, and trap formation in basin-centered gas accumulations are not so important as they are in conventional accumulations. Gas began to be generated from shales in the Lewis Shale in Oligocene time. The charging and development of gas saturated, over-pressured reservoirs is not known.

Traps— The depth to the top of reservoirs in the Lewis Play ranges from 8,000 to 14,000 ft. See discussion in introduction of Southwestern Wyoming Continuous-type Plays for more information.

Exploration status— The play is moderately explored. Several fields produce from low-permeability reservoirs within the play area.

Resource potential— A large area of this play is undrilled and untested. It is likely that at least one accumulation larger than 1 MMBOE will be discovered. The resource potential for this hypothetical play in the small area where it overlaps the Lander Planning Area is unknown.

4.2.2.2.4 GDB Greater Green River Basin Fox Hills-Lance Play (Hypothetical) (3743)

The play includes the stratigraphic interval from the base of the Fox Hills Sandstone to the top of the Lance Formation. In the Green River Basin, the play includes the interval from the top of the Ericson Sandstone (Mesaverde Group) to the top of the Lance Formation. The play area encompasses an area of about 4,100 sq mi in19the northern part of the Green River Basin and in the deeper parts of the Great Divide, Washakie, and Sand Wash Basins of Wyoming and Colorado. The majority of this play is generally linear in plan view and only a small portion of the east end of the play, encompassing about 103.6 sq. miles (66,313 acres), is contained within the Lander Planning Area.

Reservoirs— The reservoirs in the Fox Hills part of the play are represented by deltaic sandstones. In contrast, reservoirs in the Lance part of the play were deposited in fluvial dominated systems and are more lenticular than those in the Fox Hills. The cumulative thickness of reservoirs in the play ranges from less than 250 ft to greater than 1,500 ft, with a median thickness of 675 ft. Individual reservoirs range in thickness from 10 to 100 ft.

Source Rocks— Sources of gas are from coal and carbonaceous shale in the Fox Hills Sandstone and Lance Formation.

Timing and migration— See discussion of timing and migration in the introduction of Southwestern Wyoming Continuous-Type Plays for more information.

Traps— Depth of Occurrence: The depth to the top of reservoirs within the play area ranges from 8,000 to 12,000 ft. Through most of the area the depth is about 11,000 ft. See discussion of traps in the introduction of Southwestern Wyoming Continuous-Type Plays for more information.

Exploration status— The play is immaturely explored. Through nearly all of the play area, the reservoirs in the play interval have been very sparsely tested.

Resource potential— It is likely that at least one accumulation larger than 1 MMBOE will be discovered. However, the resource potential for this hypothetical play in the small area where it overlaps the Lander Planning Area is unknown.

4.2.2.3 Wind River Basin Coal-bed Natural Gas Play

Where otherwise not cited, the data presented in this section is found in Johnson and Rice (1995). The coal-bed natural gas (CBNG) potential of the Wind River Basin, central Wyoming has been evaluated by Rieke and Kirr (1984) and Johnson et al. (1993). The work by Johnson et al. (1993) is restricted to the Wind River Indian Reservation, which occupies part of the Wind River Basin.

In the basin, significant coal deposits are in the Upper Cretaceous Mesaverde and Meeteetse Formations and Paleocene Fort Union Formation. In a north-south trending belt in the west-central part of the basin, the cumulative thickness of Mesaverde coal, in beds 2 ft or thicker, is as much as 100 feet. East and west of this trend, the total thickness of Mesaverde coal thins to less than 20 ft. The Meeteetse Formation contains coal throughout the basin, but the cumulative thickness, in beds 2 ft or thicker, is generally less than 20 feet. However, as much as 40 ft of Meeteetse coal has been identified in the west-central part of the basin, near the thickest occurrence of coals in the underlying Mesaverde. The Fort Union Formation contains significant coal resources in a broad area along the southern flank of the basin. Cumulative thicknesses of Fort Union coal as much as 100 ft, in beds 2 ft or thicker, occur in two areas in the western and central parts of the basin. Jones and de Bruin (1990), however, consider Tertiary Fort Union coal in the Wind River Basin to be too deeply buried to be a target for coal-bed methane production.

The rank of Mesaverde and Meeteetse coal beds varies from lignite at or near the surface to anthracite at depths more than 18,000 ft along the deep-basin trough. The rank of Fort Union coal beds ranges from subbituminous C near the surface to high-volatile A bituminous at a depth of 11,000ft. Thermogenic coal-bed gas was probably generated while the basin was under maximum aggradation, about 35–10 million years BP.

The coal-bed gases consist mainly of methane, but also contain variable amounts of heavier hydrocarbon gases (as much as 4.6 percent) and CO2 (as much as 6.5 percent). Isotopic data indicate that the gases are a complex mixture of biogenic and thermogenic origin.

The Wind River Basin is a structural and sedimentary basin that is narrow and deep. The basin is more than 170 miles long, but only 60 miles wide at its widest place. The coal-bearing interval, which crops out along the western and southwestern flanks of the basin, plunges to depths greater than 19,000 ft in a distance less than 5 miles. These steep dips limit the area where coal beds occur at depths favorable for recovery of coal-bed gas (less than 6,000 ft). The basin contains numerous anticlinal structures, and limited information suggests that these structures may have enhanced cleat systems in the coal.

4.2.2.3.1 Wind River Basin–Mesaverde Play (3550)

The best potential for reserves of coal-bed gas in the Wind River Basin is from Mesaverde coal beds. The Meeteetse coals are generally too thin, but multiple-seam completions with Mesaverde coals may be possible in areas where coals in both formations are thick.

In the past, Fort Union coals have not been considered to be prospective because of their low rank, depth and anticipated low gas contents, although little data are available to support or refute this definitively (Jones and DeBruin, 1990).

Reservoir and Source Rocks— One coal-bed gas play is identified: the Wind River-Mesaverde Play (3550), and it occurs in the southwestern part of the basin where the Mesaverde coal beds are (1) at depths of 300 to 6,000 ft, and (2) at least 20 ft thick, but generally in the range of 30 to 50 ft thick. This is the area where coal-bed natural gas has been demonstrated. Early estimates of potential for reserves of coal-bed gas for this play are estimated to be fair to poor because the coals probably have low gas contents at significant depths. However, not much information is available on the coals at depths greater than 1,000 ft.

Exploration Status— In 1990, a gas well completed in a deeper zone was recompleted in Mesaverde coal beds at depths of about 3,200 to 3,840 ft. The well is located on the Riverton Dome in the southwest part of the basin, on the Wind River Indian Reservation. The well produced as much as 233 MCFG/day and was shut in after producing about 45 MMCFG and 52,000 billion barrels of water. This is the only known coal-bed gas well in the basin until a pilot project on the Wind River Indian Reservation was begun in 2005.

In 2007, a FONSI was issued for a 20-well pilot project in the Beaver Creek area. Five of the 20 authorized wells have been completed as of this writing. Following this, the proponents requested permission for an additional 200 wells involving 16,000 to 17,000 acres over a ten-year period. This additional proposal is being considered by the Lander Field Office under an EIS which was begun in 2008.

In 2008, the company responsible for the pilot project proposed up to 336 coal-bed methane wells and 20 conventional gas wells to be drilled over the next decade in the Riverton Dome formation on the Wind River Indian Reservation. The Bureau of Indian Affairs (BIA) has signed the record of decision for this project and it appears that the project is on track for commencement of operations in 2009. However the project is currently under appeal with no known timetable of resolution.

In 2008, an EIS was in preparation for the Beaver Creek CBNG Project in the Lander Planning Area. The Beaver Creek Project includes just over 200 CBNG wells and over approximately 16,000 to 17,000 acres of development during a 10-year time span. The decision record and FONSI for the 20-well pilot project phase of this development was signed in 2007 and is currently under way at the time of this writing.

Resource Potential— The Wind River Basin is a major gas-producing basin and the basic infrastructure is in place for the development of coal-bed gas. Johnson et al. (1993) presented data from USGS investigations on the Wind River Indian Reservation. It is assumed these data can be extrapolated to off-reservation areas in the Lander Planning Area underlain by similar geology. This study estimated that for Mesaverde and Meeteetse coals in the main part of the Wind River Basin in the 300 to 3,000 depth range, in-place gas resources range from a low of 110 BCF to a high of 604 BCF. For the 3,000 to 6,000 ft. depth range, in-place resources ranged from a low of 1.05 to 2.45 TCFG. For the 6,000 to 9,000 ft. depth interval, in-place resources were estimated at a low of 1.46 TCFG to a high of 3.14 TCFG. Further information is available in the USGS Resource Assessment Section of this report.

4.2.2.4 Great Divide Basin Coal-bed Natural Gas Play

As before, only the portion of the Great Divide Basin and the immediate surrounding region contained within the Lander Planning Area is considered here.

4.2.2.4.1 Great Divide Basin Fort Union CBNG Play

This play is currently exploratory in nature in the Lander Planning Area.

Reservoir and Source Rocks— The coal-beds of the Paleocene Fort Union Formation, underlying the Wasatch Formation, are the target for exploratory drilling.

Exploration Status— In 2008, an EIS was in preparation for an exploratory project at Pappy Draw to investigate this play. The Pappy Draw Project includes three units (Pappy Draw, North Pappy Draw North, and East Pappy Draw) which encompass approximately 48,350 acres. Only a small number of wells (16) are initially proposed to investigate the economic feasibility of a large-scale development project. The exact number of coal-beds in the Fort Union that would be targeted is unknown; however it is expected to be more than ten based on drilling logs from nearby conventional oil and gas wells.

Initial plans call for produced water to be injected into the Lance and Fox Hills Formations, which occur stratigraphically below the Fort Union Formation. The injection wells would penetrate to the bottom of the Fox Hills Formation, to the top of the Lewis Shale, to ensure adequate injection capacity. Injection wells would be adequately cased to isolate only the intended zone of injection.

4.2.3 USGS Oil and Gas Resource Assessments

The USGS assessed both undiscovered conventional oil and gas and undiscovered continuous (unconventional) oil and gas in the Lander Planning Area by considering resources contained in the Wind River Basin Province (USGS, 2005) and the Southwestern Wyoming Province (USGS, 2002). The assessments are 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). Within each TPS, various Assessment Units (AU) were defined, and undiscovered oil and gas resources were quantitatively estimated for each AU.

Continuous resources (including accumulations known as basin-centered gas, shale gas, tight gas, and coal-bed natural gas) were defined as those accumulations generally not trapped by hydrodynamic processes. According to the USGS, a continuous oil or gas accumulation may have some or all of the following characteristics:

(1) Accumulations are regional in extent;

(2) possess diffuse boundaries;

(3) existing “fields” commonly merge into a single regional accumulation;

(4) possess no obvious seal and trap;

(5) possess no well-defined, oil- or gas-water contact;

(6) hydrocarbons apparently not held in place by hydrodynamics;

(7) commonly are abnormally pressured;

(8) possess a large in-place resource volume, but a very low recovery factor;

(9) possess geologically controlled “sweet spots”;

(10) exhibit little free water production (except from coal-bed gas accumulations);

(11) contain water commonly found up dip from hydrocarbons;

(12) include few truly “dry” holes;

(13) have reservoirs generally in close proximity to source rocks;

(14) have reservoirs with very low matrix permeabilities;

(15) commonly exhibit natural reservoir fracturing; and,

(16) Estimated Ultimate Recovery (EUR) of oil or gas from wells is generally lower than EURs from wells in a conventional accumulation.

4.2.3.1 Wind River Basin Assessment

Using a geology-based assessment methodology, the USGS estimated a mean of 2.4 TCF of undiscovered natural gas, a mean of 41 million barrels of undiscovered oil, and a mean of 20.5 million barrels of undiscovered NGLs in the Wind River Basin Province of Wyoming. The area of this USGS assessment more or less represents the bulk of the Lander Planning Area, excepting the Granite Mountain area, and the northern portion of the Great Divide Basin which is included in the USGS assessment of the Southwestern Wyoming Province.

Using the geologic framework defined earlier, the USGS defined three conventional TPSs in the Wind River Basin Assessment Province: (1) Phosphoria TPS, (2) Cretaceous-Tertiary TPS, and (3) Waltman TPS. Within these systems, three AUs were defined and undiscovered oil and gas resources were quantitatively estimated within 10 of the 12 AUs.

The data are presented in the following Table 4-4 and Table 4-5. The data are presented by type of resource (conventional or continuous), followed by TPS and AU with oil, gas, and NGLs broken out separately. F95 represents a 95-percent chance of at least the amount tabulated. Other fractiles are defined similarly. As shown in these tables, conventional hydrocarbon resources are dominated by gas, and more so by natural gas liquids.

4.2.3.1.1 Wind River Basin Conventional Oil and Gas Resources

Oil and gas resources for the three conventional TPS and the associated AUs are presented in Table 4-4. CBNG resources are not included in the conventional resource tabulation.

Table 4-4 Total Undiscovered Conventional Oil and Gas Resources in Wind River Basin

Total Petroleum Systems (TPS) and Assessment Units (AU)	Field Type	Oil (MMBO)				Gas (BCF)				NGL (MBNGL)			
		F95	F50	F5	Ave	F95	F50	F5	Ave	F95	F50	F5	Ave
Phosphoria TPS													
Tensleep - Park City Conventional Oil & Gas AU	Oil	4	16	42	18	4	15	44	19	90	360	1090	440
	Gas					56	244	600	275	1040	4710	12550	5490
Cretaceous Tertiary TPS													
Cretaceous Tertiary Conventional Oil and Gas AU	Oil	3	10	23	11	10	35	84	40	230	820	2130	950
	Gas					30	92	190	99	230	720	1620	790
Waltman Shale TPS													
Upper Fort Union Sandstones Conventional Oil and Gas AU	Oil	3	11	25	12	6	21	54	24	330	1250	3370	1470
	Gas					0	0	0	0	0	0	0	0
Total Conventional Resources		10	37	90	41	106	407	972	457	1920	7860	20760	9140

Source: USGS (2005).

The data in Table 4-4 does not include two areas within the Lander Planning Area which are not considered in the Wind River Basin assessments. These areas are the northern part of the Great Divide Basin, and the Granite Mountain area, the latter of which contributes little if any to the total resources.

4.2.3.1.2 Wind River Basin Continuous Hydrocarbon Resources

Continuous hydrocarbon resources for the three TPS and the associated AUs are presented below in Table 4-5. CBNG resources are included in this table. The USGS defined two continuous TPSs in the Wind River Basin Assessment Province: (1) the Cretaceous - Tertiary TPS, and (2) the Waltman TPS. Within these two systems, nine AUs were defined and undiscovered oil and gas resources were quantitatively estimated for seven of the nine AUs. As before, F95 fractile represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly.

Table 4-5 Total undiscovered continuous hydrocarbon resources in Wind River Basin

Total Petroleum Systems (TPS) and Assessment Units (AU)	**Field Type**	**Gas (BCF)**				**NGL (MBNGL)**			
		F95	F50	F5	Ave	F95	F50	F5	Ave
Cretaceous Tertiary TPS									
Frontier Muddy Gas AU	Gas	198	430	934	481	110	320	970	400
Cody Sandstone Gas AU	Gas	48	103	224	115	10	30	10	40
Cody Fractured Shale AU	Oil	Not quantitatively assessed							
Mesaverde Meeteetse Sandstone Gas AU	Gas	163	345	732	383	360	960	2580	1150
LanceFort Union Sandstone Gas AU	Gas	373	668	1198	711	2670	7700	22250	9480
Mesaverde CBNG AU	CBNG	45	96	205	107	70	210	570	250
Meeteetse CBNG AU	CBNG	9	19	41	21	10	40	120	50
Fort Union CBNG AU	CBNG	49	106	228	118	10	20	70	30
Waltman Shale TPS									
Waltman Fractured Shale Oil AU	Oil	Not quantitatively assessed							
Total Continuous Resources		885	1767	3562	1936	3240	9280	26570	11400

Source: USGS (2005).

4.2.3.2 Southwestern Wyoming Province Assessment

The data presented for this section is limited to a summary of the discussion presented by USGS (2002) because of the great uncertainty in applying numerical data to the small portions of this province which intersect the Lander Planning Area.

The USGS Southwestern Wyoming Province for this assessment includes the Green River Basin, the Moxa arch, Hoback Basin, the Sand Bend arch, the Rock Springs uplift, the Wamsutter arch, Washakie Basin, Cherokee Ridge, Sand Wash Basin, and the Great Divide Basin. Only the Great Divide Basin is of interest here as it is partially contained within the Lander Planning Area.

The USGS defined nine TPSs and 23 AUs for this assessment, and quantitatively estimated undiscovered oil and gas resources within 21 of the 23 AUs.

The TPSs include the Phosphoria TPS, the Mowry Composite TPS, the Niobrara TPS, the Hilliard-Baxter-Mancos TPS, the Mesaverde TPS, the Mesaverde-Lance-Fort Union Composite TPS, the Lewis TPS, the Lance-Fort Union Composite TPS, and the Wasatch-Green River Composite TPS.

In summary, the USGS estimated a mean of 84.6 trillion cubic feet of gas, a mean of 131 million barrels of oil, and a mean of 2.6 billion barrels of natural gas liquids in nine TPSs. Nearly all (97 percent) of the undiscovered gas resource is continuous and distributed in six of the nine TPSs. Oil is mainly contained in two TPSs— the Niobrara and the Phosphoria.

4.2.4 Non-Coal-bed Hydrocarbon Occurrence Potential

The primary occurrence areas for non-CBNG hydrocarbons in the Lander Planning Area are in the Wind River Basin, and northern portion of the Great Divide Basin. All oil and gas plays defined by the USGS are considered to be areas of high occurrence potential. An estimated two-thirds of lands in the Lander Planning Area are in this category. A minority of the planning area (one-third) falls outside the USGS-designated play areas.

4.2.5 Non-Coal-bed Hydrocarbon Future Activity

This section summarizes reports from a variety of sources that describe potential future oil and non-CBNG 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 Lander Planning Area are expected to be completed by the BLM in fall of 2008.

4.2.5.1 Oil and Natural Gas Price Estimates

4.2.5.1.1 Crude Oil

The price of a barrel of oil is highly dependent on both its grade, determined by factors such as its specific gravity or API and its sulfur content, and its location. The vast majority of oil is not traded on an exchange but on an over-the-counter basis, typically with reference to a marker crude oil grade that is typically quoted via various pricing agencies. For the purposed of this analysis the price of petroleum means the spot price of WTI/Light Crude as traded on the New York Mercantile Exchange (NYMEX) for delivery in Cushing, Oklahoma.

At the time of this analysis, hydrocarbon prices experienced unprecedented fluctuations in price, as evidenced by a peak in light crude On July 11, 2008, when oil prices rose to a new record of $147.27 per barrel. Since that time, oil prices have witnessed a significant fall and had been trading around US$40 a barrel on December 6, 2008. On December 24, 2008, oil prices traded at US$35 per barrel. Without the benefit of prior knowledge of the aforementioned market behavior during 2008, the Energy Information Administration (EIA) raised the reference case path for world oil prices in the Annual Energy Outlook 2008 (AEO2008), although the upward adjustment is smaller than the last major adjustment, introduced in AEO of 2006.

The real world crude oil price in 2006 dollars, which for the purposes of AEO2008, is defined as the price of light, low-sulfur crude oil delivered in Cushing, Oklahoma. This price is predicted to move from current levels to $57 per barrel in 2016 ($68 per barrel in nominal dollars), as expanded investment in exploration and development brings new supplies to world markets. After 2016, real prices begin to rise as demand continues to grow and higher cost supplies are brought to market.

In 2030, the average real price of crude oil is estimated to be $70 per barrel in 2006 dollars, or about $113 per barrel in nominal dollars. Factors contributing to higher margins for liquid fuels include continued growth in the use of heavier and sourer crudes, growing demand for cleaner products, and the rising cost of refinery safety and emissions abatement. Alternative AEO2008 cases address higher and lower world crude oil prices (EIA 2008).

4.2.5.1.2 Natural Gas

Natural gas prices, as with other commodity prices, are driven by supply and demand fundamentals. These may include factors of demand such as weather, demographics, economic growth, fuel competition, storage and exports. Similarly, the supply for natural gas is driven such factors as pipeline capacity, storage, gas drilling rates, natural phenomena, technical issues, and imports. However, in comparison to the price of oil, there is less volatility in the natural gas marketplace, due to a well-established domestic market and distribution system.

The ability to transport natural gas from the well heads of the producing regions to the consuming regions affects the availability of supply in the marketplace. The interstate and intrastate pipeline infrastructure has limited capacity and can only transport so much natural gas at any one time. This has the effect of limiting the maximum amount of natural gas that can reach the market. The current pipeline infrastructure is quite developed, with the EIA estimating that the daily delivery capacity of the grid is 119 BCFG. However, natural gas pipeline companies may continue to expand the pipeline infrastructure in order to meet growing future demand. This is of particular concern in Wyoming, where lack of pipeline capacity to export product out-of-state results in lower prices for Wyoming producers.

AEO2008 projects higher prices for most energy fuels delivered to consumers. For example, in 2030, the average delivered price of natural gas (in 2006 dollars) is more than $1 per million Btu higher in the AEO2008 reference case than was projected in AEO of 2007. In part, the higher delivered prices result from higher prices paid to fossil fuel producers at the wellhead or mine-mouth; but they also result from updates made to assumptions about the costs to transport, distribute, and refine the fuels to make them more consistent with recent trends. For example, as a result of declining use per customer and the growing cost of bringing supplies from new regions to market, margins between the delivered and wellhead prices of natural gas are higher than previously projected.

The real wellhead price of natural gas (in 2006 dollars) declines from current levels through 2016, as new supplies enter the market. After some fluctuations through 2021, real natural gas prices rise to $6.63 per thousand cubic feet in 2030 ($10.64 per thousand cubic feet in nominal dollars). The higher prices in the AEO2008 reference case reflect an increase in production costs associated with recent trends that were discussed in AEO of 2007 but were not reflected fully in the AEO of 2007 reference case. The higher natural gas prices also are supported by higher oil prices.

4.2.5.2 Market Uncertainties

The economic uncertainties of the global financial system make accurate projections impossible if not highly unreliable. For example, rising demand for oil and gas from expanding Asian economics in the first seven years of this decade exceeded earlier consumption estimates. The precipitous drop in global demand (including the U.S. for the first time since the 1970s) in the latter part of 2008 is unprecedented.

Although price has fallen sharply, demand has not returned, due with little doubt to the national recession which began in the 4th quarter of 2007.

The implication for the supply of oil and gas from the time of the liquidity freeze starting in the 3rd quarter of 2008 and continuing through the date of this writing, coupled with the current price of crude is an undermining of exploration and development activities for a period which cannot be determined.

4.2.5.3 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.

Appendix A of this document describes oil and gas leasing procedures.

4.3 4.3 Leasable Solid Minerals

4.3.1 Coal

Coal resources in the Wind River Basin have been identified as having low potential 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).

Demand for Wyoming coal is expected to increase annually. There is significant potential for increased production from mines outside of the Lander Planning Area if the demand should increase. In summary, the occurrence potential for coal in the Lander Planning Area is assigned a rating of M/C.

4.3.2 Solid minerals Leasing Regulations (other than coal or oil shale)

In general, the Mineral Leasing Act provides the Secretary of the Interior with the authority to issue prospecting permits and leases to citizens of the United States, or any corporation organized under the laws of the United States, if in his judgment, it is in the public interest to do so. The maximum size of any lease is 2,560 acres. Minimum lease rentals are set at 25 cents per acre for the first year, 50 cents per acre for the second and third years, and $1.00 per acre thereafter.

Fees are charged by the BLM for applications, extensions, assignments, and transfers, etc. per a published schedule and case by case basis as detailed in 43 CFR 3000.11-12.

The minimum royalty established is as presented in Table 4-6. The BLM determines the actual rate for each lease before offering it. Leases are issued for 20 years and so long thereafter as the lessee complies with the terms and conditions of the lease.

Table 4-6 Minimum mineral leasing royalty rates

Commodity	Minimum Royalty Rate
Phosphate	5 percent of gross value of the output of phosphates or phosphate rock and associated or related minerals
Sodium	2 percent of the quantity or gross value of the output of sodium compounds and related products at the point of shipment to market.
Potassium	2 percent of the quantity or gross value of the output of potassium compounds and related products at the point of shipment to market.
Sulfur	5 percent of the quantity or gross value of the output of sulfur at the point of shipment to market.
Asphalt	25 cents per ton (2000 lbs) of marketable production.
Gilsonite	No minimum royalty rate.
Hard rock minerals	No minimum royalty rate.

Source: 43 CFR 3504.21

Where prospecting or exploratory work is necessary to determined the existence or workability of leasable mineral deposits, prospecting permits may be issued for a period of two years and may be extended for an additional period not in excess of four years. If prior to the expiration of a permit, a valuable deposit of leasable mineral is discovered, the permittee is entitled to a lease for all or any of the lands embraced by the permit. The maximum acreage that may be held in permits and leases nationwide is 20,480 acres.

There is also provision for the issuance for exploration licenses. Such a license allows the holder to explore in areas with known deposits of a leasable mineral(s) to obtain data. With an exploration license, however, there is no preference or other right to a lease.

4.3.3 Phosphate

4.3.3.1 Historical Phosphate Development Activity

Subsequent to government investigatory work described previously in Section 3.2.4, and until very recently, little interest had historically been shown in phosphate save for one proposal where Lander Planning Area phosphate deposits were seriously considered for development during the 1960s – 1980s. During this period, extensive surveying, mapping, drilling, trenching, and sampling of phosphate deposits were made by Susquehanna Western, Inc.

This activity resulted in acquisition of lands under U.S. Phosphate leases, U. S. Prospecting Permits, Wyoming State Leases, and private leases from several land owners. Total lands under control by leases held by Susquehanna Western, Inc., amounted to 7145.39 acres. Eventually eight federal leases totaling 12,628 acres were issued and held by this company until 1985. Though exploration activities were conducted under prospecting permits before the issuance of the leases, no mining operations were ever conducted on the leases during their existence. Table 4-7 presents a summary of these lands.

Table 4-7 Status and acreage of Susquehanna Western exploration lands

Area	U.S. Phosphate Lease (acres)	U.S. Prospecting Permit (acres)	Wyoming State Lease (acres)	Private Lease (acres)
Little Popo Agie	320	2015.72	—	—
Twin Creek	360	2007.83	320	200
Stambaugh	—	1520	401.84	—

Source: Susquehanna Western, Inc.; BLM LR2000 Database. February, 2009.

A report by Susquehanna-Western, Inc. estimated that 15 million tons of strippable phosphate rock averaging 23.3 percent phosphorus pentoxide are available on the Twin Creek and Stambaugh areas with some possibility of some higher grade (perhaps 26 to 27 percent phosphorus pentoxide) in the Tweed Creek and Little Popo Agie areas (Susquehanna Western, Inc., 1963).

4.3.3.2 Recent Phosphate Development Activity

No additional phosphate development activity was proposed in the Lander Planning Area until 2008, when two companies approached the BLM with proposals for prospecting and leasing respectively. Both proposals focused on lands formerly held by Susquehanna Western, as well as lands north and south of these areas. The first company expressed interest in acquiring prospecting permits for lands formerly leased by Susquehanna Western, Inc. as well as numerous adjacent parcels.

As of early 2009, this prospecting proposal was under consideration by the Wyoming State Office for a determination of whether the issuance of prospecting permits are warranted versus requiring competitive leasing. However, no ultimate decision will be made on these proposals until final land use decisions are made through the current RMP effort. The second proposal was put forth by a company which expressed an interest in acquiring leases for lands in the Twin Creek Area. No official application regarding these leases has been received as of April 2009.

It is notable that the vast majorities of the lands under consideration by the two proposals are now, or have been in the past, lands classified as valuable for phosphate and in addition, the majority of the lands were subject to the original withdrawals made in the 1908 to 1914 timeframe. Therefore, in light of these facts, issuance of leases rather than prospecting permits is seen as a more likely outcome if the proposals move forward.

4.3.3.3 Phosphorus Market Outlook

In 2007, U.S. phosphate rock production fell below 30 million tons for the first time in more than 40 years, owing to lower production in Florida, and increased foreign production selling in markets in competition with the United States. Additionally, phosphate companies in Florida used a substantial amount of phosphate rock from stocks. One mine in Florida reopened after being closed for 18 months, but its output was offset by mine closures that occurred in 2006.

The United States remained the world's leading consumer, producer, and supplier of phosphate fertilizers; however, its share of the world market has been shrinking. Phosphate fertilizer production increasingly is being located in the large consuming regions of Asia and South America, reducing the need for imported fertilizers to these regions. China has surpassed the United States as the leading producer of phosphate rock in the world. U.S. exports of phosphate fertilizer to China and India, the two largest consumers of phosphate fertilizers, have dropped significantly since 2000 (USGS, 2008, p. 124125).

4.3.3.4 Phosphate Development Potential

In 1990, the US Bureau of Mines prepared datasets used for inventorying Federal mineral land in Wyoming and assessed the availability of this land for mineral exploration and development as affected by legal status and agency management practices (Anderson et al., 1990). In this effort, USBM also identified and ranked known mineral deposit areas (KMDAs)-i.e., areas having past or present mineral production and /or known mineral resources- and compared these areas spatially with availability of Federal mineral lands. Figure 4-1 presents the results of this analysis which categorized lands valuable for phosphate as high, moderate, or low.

Although transportation of mined material to processing facilities located elsewhere in the Western Phosphate field (Vernal, Utah, Soda Springs, Idaho, Pocatello, Idaho, etc.) is feasible, such infrastructure in the planning area is less developed. In addition, other factors are thought to currently make planning area phosphate deposits uneconomical to develop. First, the deposits are thin and on the lower end of the grade scale in comparison to other deposits in the Western Phosphate Field. In addition, costs associated with mine startup capitalization, permitting, increasing severance taxes, under-utilized phosphate capacity and a shift to foreign production creates a poor economic climate (USGS, 2008, p. 124125).

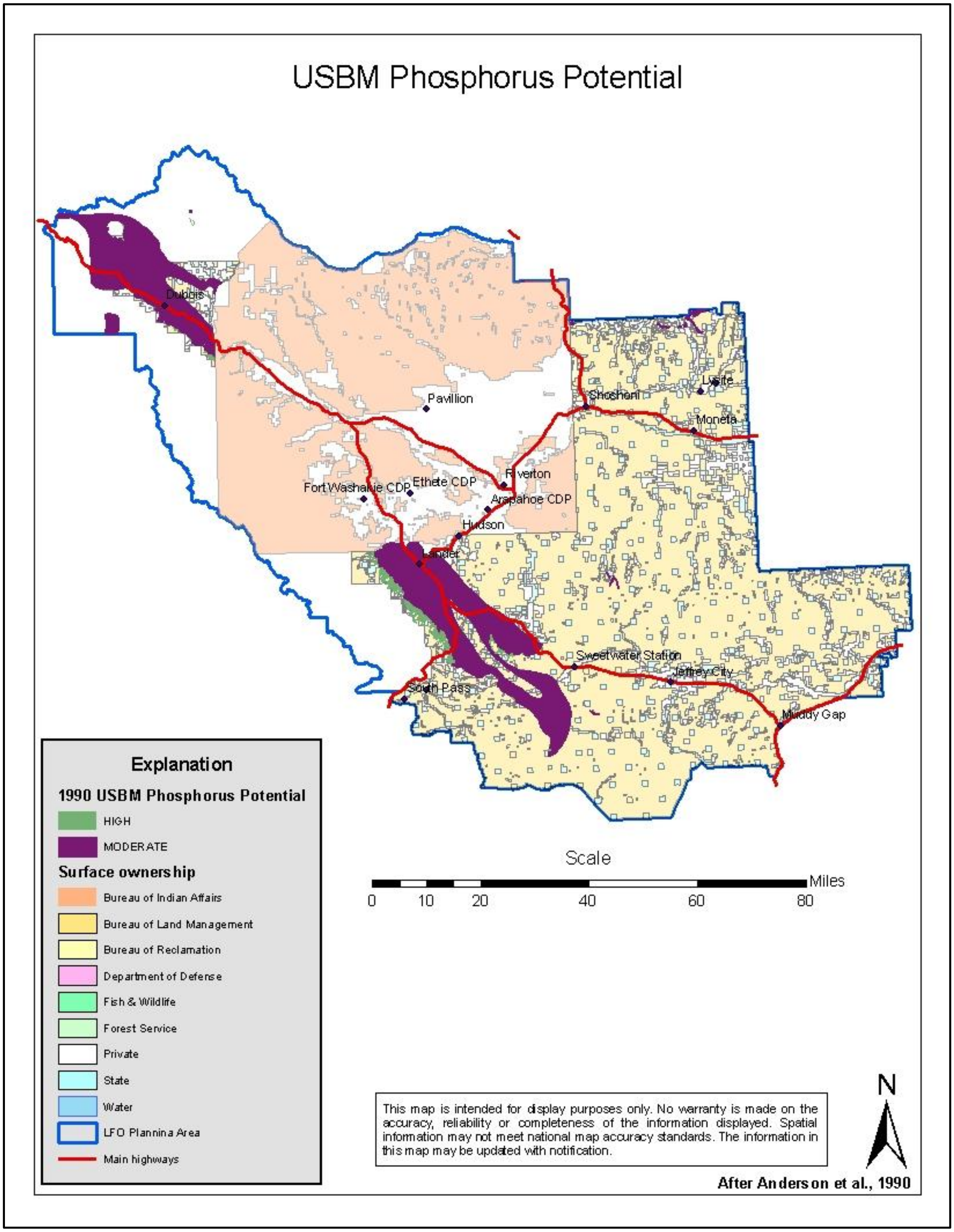
In summary, considering all the available data described in this report, the occurrence potential for phosphate in the Lander Planning Area is assigned a rating of H/D. However, the development potential for phosphate is assigned a rating of low for reasons detailed in the sections above.

4.4 Locatable Minerals

The majority of commercial locatable mineral activity in the Lander Planning Area centers on mainly on uranium and to a lesser degree, bentonite exploration. Currently, there are no uranium mines in operation in the planning area. Several uranium exploration projects have submitted plans of operations to the BLM and have made application to the NRC for a source materials license, which is a required precursor to a operating mine.

One bentonite mine in the planning area is currently permitted by the WYDEQ, and has an approved plan of operation. This mine is not yet in operation.

Figure 4-1 USBM 1990 Phosphorus Potential in the planning area



4.4.1 Uranium

Uranium is distributed worldwide. Australia has the world's largest uranium reserves — 40% of the planet's known supply — while Canada is currently the largest exporter of uranium oxide ("yellowcake"). There are also significant deposits in South Africa, Russia and Gabon. The immensely rich Canadian deposits, located around the rim of the Athabasca Basin in Alberta and Saskatchewan, range from 35-70% uranium oxide. However, these deposits have or will soon exhaust their reserves. Rich deposits are also being mined in Australia and Gabon, with lesser graded deposits being mined in South Africa and Namibia. U.S. deposits are all low-grade in terms of uranium oxide per ton, ranging from 0.5 to 2.0%.

Production from world uranium mines supplies only 62% of the requirements of power utilities. The balance comes from secondary sources. Secondary supply is essentially inventories of various types and includes inventories held by utilities and other fuel cycle companies, inventories held by governments, used reactor fuel that has been reprocessed, recycled materials from military nuclear programs and uranium in depleted uranium stockpiles. In 2005 eight producers provided approximately 80% of the estimated world production of 108 million pounds U_3O_8.

Worldwide uranium production from mining in year 2005 was 41,600 tons, about 63% of utilities annual requirements, which the United States provided 1039 tons (WNA 2008). Annual reactor requirements in year 2005 were estimated at 66,480 tons, of which the United States share amounted to 22,875 tons. The main contributors to fill the current supply gap is from secondary sources (e.g., the down-blending of highly enriched uranium obtained from dismantled nuclear weapons), and stockpiled uranium held by utilities (WNA 2008). The current down-blending contracts between the U.S. and Russia expire after 2013, so the supply gap may worsen considerably then. By the year 2020, an estimated 35,000 tons of unfilled demand will exist.

A complete analysis of the intricacies of world-wide supply and demand and primary and secondary sources is outside the scope of this document. However, it is generally accepted that only a very large addition of uranium mining and enrichment capacities can fill the looming supply gap. Table 4-8 summarizes projected world-wide uranium demand to the year 2050. The requirements of world-wide demand are compared to the market-based production requirements in the last column of this table. It is important to understand that market-based requirements are the estimate of production of uranium outside of the production of CIS countries (former Soviet bloc nations such as Kazakhstan and Ukraine), national programs (e.g., Czech Republic, France, Germany), and China.

Table 4-8 Summary of World-wide uranium demand

Uranium demand case	Requirements in cumulative requirements, Year 2050 (tons U)	Cumulative requirements, Year 2000 to 2050 (tons U)	Market-based production requirements to year 2050 (tons U).
Low	52,000	3,390,000	1,917,990
Middle	177,000	5,394,100	4,158,280
High	283,000	7,577,300	6,406,190

Source: IAEA (2001).

The sum of these three production sources is added to the expected supply from secondary sources and then subtracted from the estimated demand categories to arrive at the figures for market-based production required to fill the demand gap (IAEA, 2001).

Market-based production requirements would therefore represent the remaining demand that any uranium production out of the Lander Planning Area would sell into. This scenario may change however, with transition to market conditions in CIS, China, and national program nations.

4.4.1.1 Current Uranium Market Conditions

Uranium prices reached an all-time low in 2001, costing just $7 per pound triuranium octoxide (U_3O_8). Triuranium octoxide comprises the bulk of modern yellowcake, typically about 70 to 90 percent by weight. The price peaked at over $130 per pound of U_3O_8, in 2007 and as of March 2008 the price was about $72 per pound. However, by the end of calendar year 2008 the spot price had dropped to approximately $53 per pound.

4.4.1.2 Uranium Development Potential

Foreseeable future locatable minerals activity with respect to uranium is projected to continue at levels similar to that of the mid-to-late 2000s, and possibly experience a moderate increase as hydrocarbon-based sources of energy give way to alternate fuels such as uranium. In addition, it is expected that a limited number of the prospects currently under development will eventually be permitted as ISR mines and little if any open-pit mine activity is expected due to the high cost of development and reclamation in comparison to the readily available ISR prospects.

However, in the near term, with the recent downward change in uranium prices, the Lander Planning Area is expected to experience a level of uranium mining activity somewhat lower compared with the level of activity occurring through the end of 2008. After the world-wide economic recession abates, conceivably during the next one to two years, exploration activity in the planning area would be expected to increase at that time.

In summary, the occurrence potential for uranium in the Lander Planning Area is assigned a rating of H/D. The development potential for uranium is assigned a rating of moderate to high, with a tendency to a high rating if market prices remain favorable.

4.4.2 Bentonite

4.4.2.1 Bentonite Exploration Activity

Based on the recent interest in Lander Planning Area bentonite deposits, the market factors associated with these deposits (e.g., grade, proximity to transportation, or processing facilities), and the fact that existing higher grade deposits elsewhere are becoming depleted, the BLM expects near-term bentonite mining activity in the Lander Planning Area, most likely in the Gas Hills at a location currently permitted by WYDEQ and possible one other location. Resource estimates indicate that enough bentonite will be mined to support two processing facilities (about 40 million tons).

4.4.2.2 Bentonite Market Conditions

Domestic production, export, and consumption have been on the rise in recent years as evidenced by the statistics presented in Table 4-9. Market price has also seen modest increase, ranging from $44 USD/ per ton in 2003 to $48 per ton in 2007.

Table 4-9 Domestic bentonite production statistics 2003 - 2007

Indicator	2003 (metric tons)	2004 (metric tons)	2005 (metric tons)	2006 (metric tons)	2007 (metric tons)
Production	3770	4550	4710	4940	5070
Export	721	915	847	1270	1460
Apparent consumption	3049	3635	3863	3670	3610

Source: USGS (2008).

Though use of bentonite was negatively impacted by the slowing of the U.S. economy and the decrease in housing starts in the mid-2000s, bentonite sales increased due to the strong demand from the drilling mud market. A declining U.S. dollar probably contributed to the slight increase in exports and a decline in imports in 2007. The future market for drilling mud is dependent upon future oil and gas activities.

In summary, the occurrence potential for bentonite in the Lander Planning Area is assigned a rating of M/C. This is based on the fact that the evidence existing thus far indicates some favorable geologic environments but little evidence to quantify how much is available and at what grade. The development potential for phosphorus is assigned a rating of moderate for reasons detailed earlier.

4.4.3 Gemstones and Lapidary Materials

4.4.3.1 Jade - Future Projection

Currently there are no authorized mining operations for jade in the Lander Planning Area, though there are numerous claimants still holding valid claims. Based on the recent history of jade activity, the BLM expects periodic recurring interest in developing jade claims on a case-by-case basis. This activity is expected at a rate of one notice-level operation every two years or so.

In summary, the occurrence potential for jade in the Lander Planning Area is assigned a rating of H/D. The development potential for jade is assigned a rating of low for reasons of lack of market and a lack of a known commercial accumulation of high-grade jade.

4.4.3.2 Opal - Future Projection

As of early 2008, there has been only notice currently authorized for opal exploration at Cedar Rim or elsewhere in the Lander Planning Area. The BLM expects that in the next five years, one to two notices (or plans) may be filed on the numerous opal claims on Cedar Rim on a case-by-case basis. This is speculation however, based solely on the sheer number of claims staked in the area, and high interest shown in this area when the discovery was announced in 2005.

In summary, the occurrence potential for opal in the Lander Planning Area is assigned a rating of M/B. The development potential for opal is assigned a rating of low for reasons of lack of market and a lack of a known commercial accumulation of high-grade, gem quality opal.

4.4.3.3 Agate - Future Projection

There is little information available that is sufficient to make an accurate projection. However, the occurrence potential for agate in the Lander Planning Area is assigned a rating of M/B. The development potential for agate is assigned a rating of low for reasons of lack of market and a lack of a known commercial accumulation of high-grade, gem quality opal.

4.4.4 Precious Metals - Future Projection

The mining of precious metals in the Lander Planning Area has had a long and varied past. As mentioned earlier, the vast majority of opportunities involving precious metals are gold prospects located on South Pass. These historical efforts have translated over the years to a fairly well-developed recreational and to a lesser degree, small profit-based mining prospects. The sheer numbers of recreational miners who work the South Pass area during the summer months are mostly on the level of casual use. However, the environmental effects of these gatherings have a larger cumulative effect.

The BLM could provide more education to the recreational miner community in order to help mitigate these impacts. One area that could be improved would be the dissemination of maps and other information detailing the areas where plans of operation are required (e.g., South Pass ACEC, or the historic trails corridor ACEC).

Another tool under consideration is to expand the special designation areas to encompass all the South Pass – Atlantic City – Lewiston mining districts in order to better coordinate with the organized mining groups (e.g., Wyoming Prospector’s Association or the Gold Prospector’s Association of America). Coordination with the LFO recreation management team may address these impacts through special recreation permits similar to those for trekkers on the National Historic Trails.

With the exception of the potential in the Rattlesnake Mountains, the BLM does not believe future development of precious metals resources in the Lander Planning Area to be differ much from the current level of prospecting at the recreational or amateur levels. As discussed above, the potential for a low-grade large tonnage gold operation in the Rattlesnake Mountains is apparently sufficient to attract investment. The drilling program conducted at Rattlesnake Mountains in 2008 in conjunction with future additional drilling under a plan of operations should reduce some of the uncertainty with respect to this deposit.

In summary, the occurrence potential for precious metals in the Lander Planning Area is assigned a rating of M/D. The development potential for gold is assigned a rating of moderate based on the data available from the Rattlesnake Hills district. Excluding the Rattlesnakes Hills, and considering the development potential of the remaining areas of the Lander Planning Area (generally the South Pass area and the Copper Mountains), the development potential would shrink to a rating of low, for reasons of a lack of a known commercial accumulation of gold.

4.4.5 Base and other Metals - Future Projection

The BLM does not believe that there is high probability of developing a base metal mining resource in the Lander Planning Area anytime during the foreseeable future. The known deposits are too low of grade and do not include much tonnage. World class deposits base metal deposits are usually found in different geologic settings and ore styles other than what is known to occur in the Lander Planning Area. It is possible that base metals might be produced as a byproduct of minor precious metal development, but that likelihood is not considered great.

In summary, the occurrence potential for base metals deposits in the Lander Planning Area is assigned a rating of L/C. The development potential for base metals is assigned a rating of low based on the data available.

4.5 Salable Minerals

Salable minerals discussed in this section are all assigned an occurrence potential and certainty rating of H/D. There are ample supplies of mineral materials throughout the Lander Planning Area with sufficient proximity to market that have historically been exploited with an expectation to continue to provide such resources in the future. Development potential is rated high.

4.5.1 Free-Use Permits

Of the salable minerals in the Lander Planning Area, FUPs for sand and gravel are likely to have the largest demand as these materials are fundamental to many construction projects, such as road construction and maintenance, and oil field development (roads and drill pads). The Lander Field Office currently manages numerous FUPs for municipal, county, state and federal entities.

The Lander Field Office anticipates occasional future 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.

There is no anticipated change in the level of demand for FUPs for the foreseeable future.

4.5.2 Other Mineral Material

Other salable minerals including riprap, clay, decorative stone, clinker, and the like will most likely see a growth rate similar to the growth of Wyoming’s economy. In addition, as further AML projects are planned and completed in the Lander Planning Area, the need for stabilization material (e.g., riprap, clay) will increase. Because salable minerals represent such an important resource for everyday life, it is likely that there will be a steady demand. Nonetheless, predicting exact future demand and is difficult.

4.5.3 Community Pit and Common Use Area Development

There is a need in the near future for additional development of mineral materials at the community pit or common use area level. Of the three identified common use areas for moss rock (the most popular material besides sand and gravel), one is nearly played out, one has poor road access, and the third has resources in place, but at the greatest distance from population centers (Lander, Riverton, etc.).

A replacement area for the Little Popo Agie pit needs to identified, or alternatively, the road into Red Bluff Canyon could be rehabilitated, and the required environmental assessment process completed.

The Lander Planning Area currently lacks a community pit for sand and gravel. Past efforts in addressing this need were met with challenges in either acquiring access over existing roads, or acquiring the necessary resources to build a road into identified sand and gravel deposits. The remaining challenge would be formulating a plan to address reclamation and trespass enforcement. Currently, BLM collects a reclamation fee when making individual sales, and these funds are placed into a special account to be tapped when the need for reclamation arises. In the past for whatever reason, these funds had been used for other reasons other than community reclamation. In addition, because any community pit would likely be located in remote areas in the Lander Planning Area, the issue of trespass would be of concern. Resources are limited for the purpose of trespass enforcement.

Potential pits would ideally be located in the Riverton vicinity, the Dubois vicinity, and the Lander vicinity. A central location such as Hudson could serve both the Lander and Riverton communities, as well as Hudson itself.

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APPENDIX A: OIL AND GAS OPERATIONS

The operations information in this appendix was prepared for the 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.

A.1 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.

A1.1 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.

A1.2 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.

A1.3 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 A.1-1 depicts the 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.

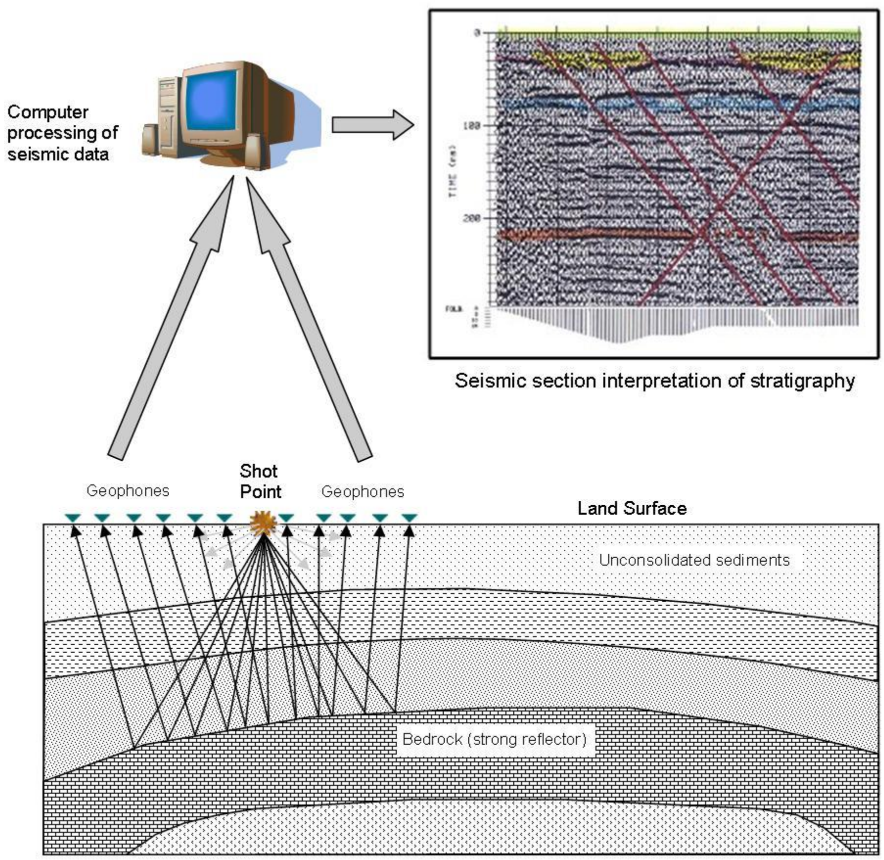
Usually four to five thumper trucks are used, each equipped with 4-foot-square vibrator pads. At a location called the source point, the trucks are spaced at specified intervals and the vibrator pads are simultaneously triggered to vibrate or thump on the ground. The thumping lasts for 10 to 30 seconds. 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 boreholes 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 borehole, covered, and detonated. In rugged topography, a portable drill is sometimes carried in by helicopter. Charges are placed in the borehole 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 1-to-2 mile grid spacing. Spacing of the lines is often changed to 0.25 mile on a1-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 data points and the closer spacing of the lines.

Figure A.1-1 Seismic Survey Process



Seismic section interpretation of stratigraphy

Typical surface geometry of seismic reflectance data acquisition equipment

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 areal extent. Three-dimensional 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 over-thrust blocks are more readily discernable.

A1.4 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.

A1.5 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.

A1.6 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.

A.2 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-coal-bed methane (i.e., non--CBNG) gas, and CBNG 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 non-competitive leases are issued for a term of 10 years. If the lessee establishes hydrocarbon production, the competitive and non-competitive leases can be held for as long as oil or gas is produced.

The federal government receives yearly rental fees on nonproducing leases. Royalty on production is received on producing leases, one half of which is returned to the State of Wyoming.

A.3 DRILLING PERMIT PROCESS

A3.1 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:

1. Notice of staking (NOS);
2. Application for permit to drill (APD), which includes a multipoint surface use and operations plan;
3. Sundry Notice, which is required for approval of subsequent operations;
4. Well abandonment;
5. Conversion to water well;
6. Responsibilities on privately-owned surface; and
7. Reports and activities required after well completion.

The permitting process for drilling is the same for oil, non-CBNG gas, and CBNG.

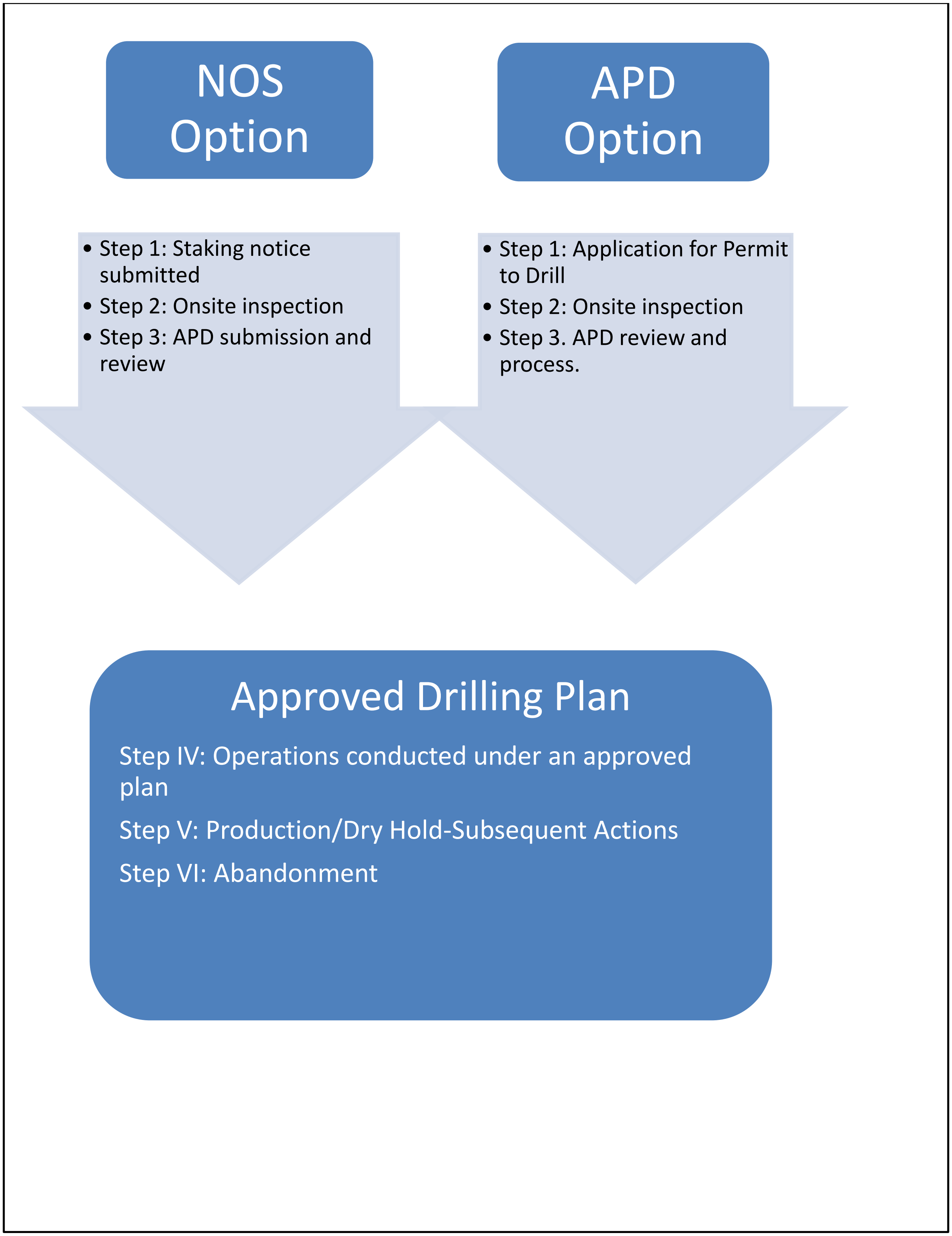
The lessee or operating company selects the location of a proposed drill site. The selection of the site is based on well location and spacing requirements, the subsurface geology as interpreted by the operator’s geoscientists, and the topography. Well location and spacing requirements are established 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 A.1-2 depicts the NOS and APD processes, and they are explained further below:

NOS procedure— 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.

Figure A.1-2 Federal Permitting Process



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 then submitted based on the findings of the inspection and review of potential conflicts.

APD procedure— 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 assessment 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 ground water 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.

A3.2 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-CBNG gas, and CBNG are similar, except the typical CBNG 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 cattle guards 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 CBNG well pads, the average would be 4.0 acres for a typical single well-pad layout, an average of 300 feet by 400 feet. The dimensions of a typical CBNG location are smaller than oil or non-CBNG gas locations because of the shallower drilling depths and smaller drilling rigs that are required. An average CBNG 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 un-compacted 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 re-vegetation 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 truckloads 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.

A3.3 Rights of Way

Rights of way are required for all facilities, tank batteries, pipelines, truck depots, power lines, and access roads that occupy federally owned land outside the lease or unit boundary. Facilities within the lease boundaries are authorized under the lease.

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.

A3.4 Drilling Operations

A1.1.1 Oil and Non-Coal-bed Natural Gas

A3.4.1.1 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 borehole. 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 borehole 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 borehole, through the bit, up the bore of the well, and finally to the surface. When the mud emerges from the borehole, 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 borehole, and bring the rock chips to the surface.

There are three common types of drilling fluids: water-based, oil-based, and synthetic. Water-based mud is the most common and is largely made up of water and bentonite clay that has special characteristics used to maintain proper viscosity and other properties over a wide range of drilling conditions. Freshwater 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 maybe 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 borehole 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 borehole in 60-foot or 90-foot sections (stands) until the bit is brought out of the borehole. 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 borehole 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.

A3.4.1.2 Casing and Cementing

Casing consists of steel pipe that is placed into the borehole to prevent the collapse of the borehole, 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 borehole 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 borehole 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 borehole). The cement holds the casing in place and protects potential shallow fresh water 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, and this depth is reviewed by the BLM geologist to ensure compliance with this requirement. 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 borehole 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 borehole while drilling deep wells, to control over-pressured zones, to protect hydrocarbon zones, to provide a point from which to drill a deviated borehole, 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 borehole when drilling deep wells.

A3.4.1.3 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 causes of over pressures are hydrocarbon generation and a sealing overburden.

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 borehole (to kill the well) and allow drill pipe to move in and out of the borehole.

A3.4.1.4 Formation Evaluation

One of the primary activities that occur during the drilling of the well is the acquisition of down-hole information. Formation evaluation covers a variety of data gathering and retrieving methods that include mud logging, wire-line 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.

A3.4.1.4.1 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 borehole, 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 down-hole 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, wire line log data, gas readings, drilling data, and core and test intervals and descriptions.

A3.4.1.4.2 Wireline Well Logs

Wireline well logs (or geophysical well logs) are basic to formation evaluation. Open-hole (borehole 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 non-shale).

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 borehole 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.

A3.4.1.4.3 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 borehole 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 borehole 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 borehole 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.

A3.4.1.4.4 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 advancing the borehole by 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 presses 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

A3.4.1.4.5 Measurement While Drilling

Measurement by 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 data to be collected and preserved to guard against the case the borehole is lost before the wireline logs are run.

MWD is also useful 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 borehole attitude and direction.

A3.4.2 Coal-bed Natural Gas

A3.4.2.1 Drilling Procedures

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

A3.4.2.2 Casing and Cementing

Surface casing is required to be set in CBNG 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, utilizing an open borehole completion. Generally the open borehole under the casing is under-reamed by a bit that expands to a large diameter and drills a larger borehole.

A3.4.2.3 Blowout Prevention

Similar to conventional oil and gas wells, BOPs are required for drilling CBNG wells as required by Onshore Rule No. 2.

A3.4.2.4 Formation Evaluation

Wireline well logs are common formation evaluation tools for CBNG 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 desorbed from the coal. Desorption is accomplished by lowering the hydrostatic pressure on the coal by producing the water in the coal.

In CBNG formation evaluation, the amount of gas that can be desorbed 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 gastight 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 gastight 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.

A.4 FIELD PRODUCTION AND DEVELOPMENT

A4.1 Oil and Non-Coal-bed Natural Gas

A4.1.1 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 spacing 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 BLM field office 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, flow-lines, pipelines, tank batteries, or other production facilities) must be approved by the BLM.

Production from multiple wells on one lease may be carried by flow-lines 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 cattle guards, 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.

A4.1.2 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 power lines 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.

A4.1.3 Production Practices

A4.1.3.1 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 borehole. 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 (sized particles mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment) 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 resin-coated silica sand obtained from natural sandstone formations or may be derived from artificial materials such as ceramic material composed of sintered bauxite. 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.

A4.1.3.2 Well Production

The following describes typical production practices at non-coal-bed natural gas and oil wells.

A4.1.3.2.1 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 down-hole 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 casing head 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 are operated by gas combustion in order to facilitate separation of the fluids. The gas may be used to heat the fluids and is either provided from commercial propane or casing head gas. Emulsions are usually treated with chemicals for severe or difficult emulsion problems. The casing head 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 casing head 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 include 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.

A4.1.3.2.2 Natural Gas Wells

Production and processing equipment at a typical gas well location might consist of a wellhead (called a "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 which 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. 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. The intermitter is typically installed in the well and regulated to allow wide-open flow for short periods several times a day and then shut off. 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.

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).

After dehydration, the gas is moved into 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.

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 well site 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). NGLs can be classified as low (condensate), intermediate (natural gasoline) and high (liquefied petroleum gas) according to their vapor pressures. Natural gas liquids include propane, butane, pentane, hexane and heptane, but not methane and ethane, since these hydrocarbons require refrigeration in order to be liquefied. 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 and used in various applications such as hydrocarbon reservoir stimulation.

A4.1.3.2.3 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, and in fact the method recommended by Oil and Gas Offshore Order No. 7, is to re-inject the water into the producing formation to maintain pressure in the reservoir as part of a secondary recovery water flood. 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. Down-hole 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, and must be installed with deterrents to prevent wildlife from accessing the water surface. 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.

The disposal of these wastes are addressed by various procedures 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.

A4.1.3.2.4 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 offline 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, and 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 borehole. Rods and tubing are pulled out of borehole and stacked vertically within the mast.

A4.1.4 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 to treatment or production facilities. 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 maintaining reservoir pressure by injecting the gas into the existing gas cap, and by injecting the gas directly into the oil saturated zone, creating an immiscible or miscible (mixable) 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 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. Thermal-type enhanced recovery processes utilize heat introduced from the surface or developed in place in the subsurface reservoir.

In the thermal drive process, hot water or steam is injected from the surface. 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.

In addition, CO_2 can also be used in a secondary recovery process with CBNG 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.

A4.2 Coal-bed Natural Gas

A4.2.1 Field Development

Because a CBNG reservoir has some inherent differences from oil and non-coal-bed gas development, CBNG 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 de-pressured enough to determine if gas can be produced in commercial quantities. When federal managed lands are involved, new CBNG developments are analyzed under the NEPA usually by means of an EA, although sometimes an EIS is needed.

In initial CBNG 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 CBNG, 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 CBNG 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 CBNG 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 CBNG 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.

CBNG development in the Wind River Basin may differ from other CBNG development in Wyoming because of the generally deeper coal depths. For example, 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 CBNG, it is likely that surface uses would more closely resemble those of conventional oil and gas development. When deeper coal-beds are targeted for development, the establishment of a network of groundwater monitoring wells may be less of a concern as compared to shallower CBNG fields such as in the Powder River Basin.

A4.2.2 Unitization

The establishment of an exploration unit is advantageous for CBNG 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.

A4.2.3 Production Practices

A4.2.3.1 Well Completion

CBNG wells can either be open borehole completions or cased borehole completions. In open borehole completions, the production casing is set above the target coal zones. In cased borehole 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 borehole completion involves creating a cavity in the coal. The cavity that is created can be four to five 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 borehole 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 CBNG wells.

A4.2.3.2 Production Practices

A CBNG 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.

After completion of a CBNG well, all that remains on 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 consists 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 of produced water but are not effective for handling large amounts of water over long periods of time, especially in the State of 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 the case for oil and non-CBNG gas wells, workover operations are conducted for routine maintenance, failure of down-hole equipment (rods or pumps), or re-stimulation.

A.5 ABANDONMENT AND RECLAMATION

A5.1 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 to100 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.

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. If the cement cap is placed using a dump bailer, a minimum of 35 feet of cement is sufficient.

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 above ground, and embedded in cement. The well identity and location description 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.

A5.2 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 back-filled, and then the disturbed areas are re-vegetated with appropriate seed mixtures to enhance the reclamation of the area.

A.6 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 (1) computer power, speed and accuracy, (2) remote sensing and image-processing technology, (3) developments in global positioning systems, (4) advances in geographical information systems, (5) 3D and four-dimensional time-lapse imaging technology that permit better interpretation of subsurface traps and characterization of reservoir fluid, (6) improved borehole logging tools that enhance our understanding of specific basins, plays, and reservoirs, and (7) 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 reduced 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.

A6.1 Drilling and Completion

Advanced Resources International, Inc. 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 (1) Smaller footprints (less surface disturbance), (2) reduced noise and visual impact, (3) less frequent maintenance and workovers with less associated waste, (4) reduced fuel use and associated emissions, (5) enhanced well control for greater worker safety and protection of groundwater, (6) less time on site with fewer associated environmental impacts, (7) lower toxicity of discharges, and (8) better protection of sensitive environments and habitat.

A6.1.1 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.

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.

The capability to directionally drill has been useful in avoiding sensitive surface features. 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 (1) fewer wells and surface disturbance, (2) Lower waste volume, and (3) protection of sensitive environments.

A6.1.2 Slimhole Drilling and Coiled Tubing

The slimhole technique refers to a borehole (and associated casing program) which is significantly smaller than a standard approach, commonly resulting in a wellbore less than 6 in. in diameter. 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 including:

(1) lower waste volumes,

(2) smaller surface disturbance areas,

(3) reduced noise and visual impacts,

(4) reduced fuel use and emissions, and

(5) protection of sensitive environments.

A6.1.3 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.

A6.1.4 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 down-hole pressures and in fluid-sensitive formations. It is an important tool in drilling horizontal wells. This type of drilling significantly reduces waste and surface disturbance, shortens drilling time, and decreases power consumption and emissions.

A6.1.5 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:

(1) lower waste volumes,

(2) reduced maintenance and workovers,

(3) reduced fuel use and emissions,

(4) less noise,

(5) less time on site, and

(6) enhanced well control.

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

A6.1.6 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 sand slurry into the fractures which props open the fractures, allowing hydrocarbons to enter the wellbore. Improvements such as CO2-sand fracturing, new types of additives, and fracture mapping promise more effective fractures and greater ultimate hydrocarbon recovery.

A6.2 Production

This section summarizes technologies and efficiencies that have helped reduce production costs and reduce impact on the environment.

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.

A6.2.1 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.

A6.2.2 Artificial Lift Optimization

Artificial-lift technologies include any system that adds energy to the fluid column in a wellbore with the objective of initiating and improving production from the well. Artificial-lift systems use a range of operating principles, including rod pumping, gas lift and electric submersible pump. Improvements have enhanced production, lowered costs, and lowered power consumption, which reduces air emissions.

A6.2.3 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.

A6.2.4 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. As an example, in 1998, this type of produced water facility was constructed for McMurray Oil Company (now Shell Oil) at the 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) were 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 re-use in near-surface wellbore applications. The brine (66,900 mg/l dissolved solids) was suitable for re-use 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.

A6.2.5 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.

A6.2.6 Down-hole 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.

A6.2.7 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.

A6.2.8 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.

GLOSSARY

allogenic: Formed or generated elsewhere; a term specifically used to describe rocks or minerals that were derived from preexisting rocks and transported to their present depositional site.

Agate: Cryptocrystalline quartz, typically displaying colors in stripes or bands, often mixed with opal.

Analcime: A sodium-alumina-silicate zeolite mineral, $NaAlSi_2O_6 \cdot H_20$.

anticline: A structural fold, generally convex upward, whose core contains the stratigraphically older rocks.

Archean: A term which refers to the age of rocks which comprise the early part of the informally named Pre-Cambrian "supereon." The Archean is a geologic eon before the Proterozoic, unofficially beginning 3.8 billion years B.P., and ending at 2.5 billion years B.P. Instead of being based on stratigraphy, this date is defined chronometrically.

arkose: A feldspar-rich sandstone, typically coarse-grained and pink and reddish in color, that is composed of angular to sub-angular grains that are either poorly or moderately well-sorted, and is usually derived from the rapid disintegration or granite or granitic rocks.

basic: A term which refers to igneous rock having a relatively low silica content, perhaps between 44 to 52%, e.g., basalt or gabbro. Basic rocks are relatively rich in iron, magnesium and/or calcium.

bbls: Barrels, a volumetric term used in measurement of oil and gas liquids, equivalent to 42 US gallons.

Beryl: A beryllium aluminum silicate mineral with the chemical formula of $Be_3Al_2(SiO_3)_6$. Gem varieties include aquamarine (blue) and emerald (green).

Biotite: A common potassium magnesium iron silicate rock-forming mineral of the mica group, generally black or dark brown in color, which has a highly perfect basal cleavage, and consists of flexible sheets which easily flake off, or can be easily peeled apart.

BO: barrels of oil.

BNGL: Barrels of natural gas liquids

B.P.: Abbreviation for "before present," usually referring to a time before present, such as years before present (B.P.).

Categorical exclusion: A categorical exclusion (CX) is an exemption to a full National Environmental Policy Act (NEPA) environmental assessment. Is is granted on the basis of pre-existing criteria commonly described out in various federal government agency manuals.

CBNG: Coal-bed natural gas. CBNG is natural gas or methane (CH_4) that occurs in coal beds and has been generated during the conversion of plant material to coal during the process known as coalification.

CFG: cubic feet of gas, a volumetric unit of measurement.

chert: a cryptocrystalline variety of silica which typically takes the form of a compact siliceous rock formed of chalcedonic and/or opaline silica, of organic or precipitated origin.

chronostratigraphic unit: A chronostratigraphic unit is a material unit and consists of the body of strata formed during a specific time span. The hierarchy of chronostratigraphic units in order of decreasing rank is eonothem, erathem, system, series, and stage.

coalification: The alteration or metamorphism of plant material into coal.

coffinite: A black mineral, $U(SiO_4)1\text{-}x(OH)_4$, an important ore of uranium.

diatreme: A vertically orientated breccia-filled volcanic pipe-shaped feature formed by a gaseous explosion.

disconformity: An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks, generally by a considerable interval of erosion or non-deposition, and usually marked by a visible and irregular or uneven erosion surface of appreciable relief.

dome: A geologic structure or deformational feature consisting of symmetrically plunging anticlines, such that its surface expression in circular or oval in shape. When eroded, the oldest rocks are found in the center with younger strata dipping progressively off toward the outside, a diagnostic feature in the field.

eolian: a term referring to processes resulting in the geologic deposition of material resulting from the action of the wind. Although water is much more powerful than wind, eolian processes are important in arid environments such as deserts.

eon: The second-largest division of geologic time. Eons are divided into eras, which are in turn divided into periods, epochs, ages, and chrons.

eonothem: A chronostratigraphic geologic term that refers to the complete rock strata deposited in the stratigraphy record during a certain eon. Eonothems have the same name as their corresponding eon, of which three are currently defined in the history of the Earth. Oldest to youngest these are: the Archean, the Proterozoic, and the Phanerozoic.

epoch: A geochronometric unit, representing the third smallest division of geologic time, above the divisions age and chron.

facies: A distinctive rock type broadly corresponding to a certain environment or mode of origin; environment of deposition.

feldspar: a category or family of related common rock-forming minerals, such as microcline, orthoclase, plagioclase, or anorthoclase.

fluviatile: Belonging to a river, or produced by river action.

fossiliferous: Containing fossils.

Garnet: a group of six related, relatively hard minerals, which exhibit similar crystal habits generally in the shape of a dodecahedron. Garnets species are found in many colors including red, orange, yellow, green, blue, purple, brown, black, pink and colorless, depending on chemical composition. The harder species are often used for abrasive purposed, and some garnets are considered gemstones when of sufficient purity.

geochronometric unit: Units established through the direct division of geologic time, expressed in years. Unlike chronostratigraphic units, they are not material units, but simply time divisions of convenient magnitude for the purpose for which they are established. Examples (in descending order of rank) include eon, era, period, epoch, age, and chron.

geosyncline: A mobile down-warping of the crust of the Earth, typically elongate or basin-like, measured in scores of kilometers, in which sedimentary and volcanic rocks accumulate to thicknesses of thousands of meters.

Glauconite: A dull-green earthy or granular mineral of the mica group.

greenstone: A field term applied to any compact dark-green altered or metamorphosed basic igneous rock (e.g., spilite, basalt, gabbro, diabase), that owes its color to the presence of chlorite, actinolite, or epidote.

igneous: a term affixed to rocks or processes resulting from or involving solidification of molten or partially molten magma.

jade: a general term to describe an ornamental rock, usually pale green, which actually applies to two different kinds of metamorphic rocks that are made of different silicate minerals. In the classic sense (i.e., "true" jade), this is taken to refer to jadeite, a rock consisting almost entirely of jadiete, a sodium- and aluminum-rich pyroxene mineral. In the case of Wyoming jade, the term refers to nephrite jade which consists of a microcrystalline interlocking fibrous matrix of a calcium-magnesium-iron rich amphibole mineral as opposed to pyroxene. The higher the iron content the greener the color.

jasperoid: A dense, usually grey to pale orange, chert-like siliceous rock, in which chalcedony or cryptocrystalline quartz has replaced the carbonate minerals of limestone or dolomite.

kerogen: The mixture of organic chemical compounds that make up a portion of the organic matter in sedimentary rocks

Laramide orogeny: A time of geologic deformation typically recorded in the eastern Rocky Mountains of the United States, whose several phases lasted from late Cretaceous until the end of the Paleocene.

mica: a mineral group consisting of platy sheet-like structures characterized by very perfect basal cleavage.

micritic: A descriptive term used for the semi-opaque crystalline matrix of some limestones.

Opal: a transparent to opaque mineral or mineral gel, composed of packed spheres of silica, with a chemical formula of $SiO_2 \cdot H_2O$, and typically displaying a characteristic iridescent play of colors.

pegmatite: An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dikes, lenses, or veins, especially at the margins of batholiths, the large crystal growth is considered to be the result of late-stage water-rich cooling of such a plutonic body. Compositionally, the chemistry of such rocks is generally equivalent to granites, though other rocks types are known. The chemistry may be simple or complex and may include rare minerals such as lithium, boron, fluorine, niobium, tantalum, uranium, and rare earth metals.

Quaternary: The Quaternary Period is the geologic time period after the Neogene Period, spanning 1.805 +/- 0.005 million years ago to the present. The Quaternary includes two geologic epochs: the Pleistocene and the Holocene Epoch. The use of the term is the subject of considerable debate as its status as an actual period of the Cenezoic Era, or alternatively a sub-period of the Neogene.

period: in the context of the geologic time, the period refers to a certain geochronometric division of time of convenient magnitude for the purpose for which they are established. Examples include such periods as the Cambrian, Triassic, or Paleogene.

Phanerozoic: That part of geologic time represented by rocks in which the evidence of life is abundant, i.e., Cambrian and later time, beginning 542 years B.P.

plutonic: a term used to describe a body of igneous rock that has formed beneath the surface of the Earth by consolidation of magma.

Proterozoic: The Proterozoic is a geological eon extending from 2500 to 542 million years B.P., which represents a period before the first abundant complex life on Earth.

pumicite: a rock composed of lithified pumice fragments, which are excessively cellular and glassy fragments of volcanic lava ejected during a volcanic eruption.

red bed: An informal term commonly used to describe sedimentary strata composed largely of sandstone, siltstone, and shale, with locally thin units of conglomerate, limestone, or marl, that are predominately red in color due to the presence of hematite (ferric oxide) usually coating individual grains, e.g., the Permian and Triassic sedimentary rocks of western United States. At least 60% of any given succession must be red before the term is appropriate.

Sapphire: Refers to the gem varieties of the mineral corundum, which is an aluminum oxide with chemical formula Al_2O_3. Corundum (and therefore sapphire) is well known for its extreme hardness, defined as 9 on a relative scale (10 is equal to diamond). Rubies is also a variety of gem-quality corundum, but this term is only used when the color is red.

stock: An igneous intrusion that is less than 40 sq. miles in surface exposure, and is usually, but not always discordant (.i.e., contact between the intrusion and the country rock is not parallel to the foliation or bedding planes of the country rock.

stromatolitic: Containing structures produced by sediment trapping, binding, and/or precipitation as a result of the growth and metabolic activity of micro-organisms, principally blue-green algae.

supereon: A term for the largest defined unit of geologic time. A supereon is composed of eons.

syncline: A structural fold of which the core contains the stratigraphic younger rocks; it is generally concave upwards.

system: In the context of chronostratigraphic nomenclature, a system refers to the actual layers of rock that correspond to a particular period of geologic time.

tectonic: Of or pertaining to the broad architecture of the outer part of the earth, in particular the regional assembling of the structural or deformational features.

Tertiary: A geologic period defining the time span of 65 million to 1.8 million years before present. It is generally used informally and has been replaced by the more exact terms, Paleogene and Neogene to describe that portion of the Cenezoic Era.

transgression: a geologic term referring to the gradual expansion of a shallow sea resulting in the progressive submergence of land, as when sea level rises or land subsides.

tuff: a rock composed of compacted volcanic fragments generally smaller than 4 mm. in diameter.

unconformity: A substantial break or gap in the geologic record where a rock is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary rocks, and often but not always marked by an absence of parallelism between the strata.

Uraninite: A black, steel grey or brown mineral essentially UO_2, but usually partly oxidixed. This mineral is strongly radioactive and an important ore of uranium.

USBM:, United States Bureau of Mines. A former bureau of the United States Department of Interior, the USBM operated from 1910 until its closing in 1996. It's functions were divided among the Department of Energy, the Geological Survey, and the Bureau of Land Management.

USGS: United States Geological Survey, a bureau of the United States Department of Interior.

Vitrinite reflectance studies: Vitrinite is one of the primary components of coals and most sedimentary kerogens. The study of vitrinite reflectance is a key method for identifying the temperature history of sediments in sedimentary basins and its sensitivity to temperature ranges largely correspond to those of hydrocarbon generation. Therefore, with calibration, vitrinite reflectance can be used as an indicator of maturity in hydrocarbon source rocks. Generally, the onset of oil generation is correlated with a reflectance of 0.5-0.6% and the termination of oil generation with reflectance of 0.85-1.1%.

WRB: Acronym referring to the Wind River Basin, a structural, physiographic, and hydrologic basin in west central Wyoming.

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