3.0 DESCRIPTION OF MINERAL RESOURCES

Categorization of mineral resources as “locatable,” “leasable,” or “salable” is based upon provisions of the Act of May 10, 1872, otherwise known as the General Mining Law of 1872. The General Mining Law of 1872 declared “all valuable mineral deposits in lands belonging to the United States……to be free and open to exploration and purchase.” The federal regulations further defined a “locatable mineral” or a “valuable mineral” as being whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof.”

Whether or not a particular mineral deposit is locatable depends on such factors as quality, quantity, mineability, demand, and marketability. Over time, the number of locatable minerals originally authorized by the General Mining Law of 1872 has been substantially reduced by several subsequent acts, with two of the primary acts being as follows:

- the Mineral Leasing Act of 1920, as amended; and
- the Materials Act of July 31, 1947, as amended.

The Mineral Leasing Act of 1920, as amended, authorized that deposits of oil, gas, coal, potassium, sodium, phosphate, oil shale, native asphalt, solid and semi-solid bitumen, and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined or quarried, and the deposits of sulfur in Louisiana and New Mexico may be acquired only through a mineral leasing system.

The Materials Act of July 31, 1947, as amended by the Act of July 23, 1955, further excluded common varieties of sand, stone, gravel, pumice, pumicite, cinders and clay. However, *uncommon* varieties of sandstone, gravel, pumice, pumicite, cinders and clay remained as “locatable.” Those minerals considered non-locatable generally have a normal quality and a value for ordinary use, and include ordinary deposits of clay, limestone, fill material (e.g., sand and gravel), etc. (Maley, 1977).

The minerals occurrence and development potential for fluid minerals in the Rawlins RMPPA have been evaluated in the RFD report for oil and gas prepared by the Wyoming Reservoir Management Group in the BLM Casper Office. That information serves as the basis for related sections of this document.

The mineral resource potential for non-fluid minerals within the Rawlins RMPPA also has been evaluated in detail. A wide range of non-fluid minerals is present within the RMPPA, and such minerals, where present, occur within each of the classification categories to include leasable, locatable, and salable minerals.

In general, it can be stated that those non-fluid minerals of greatest economic significance within the RMPPA are coal, gypsum, limestone, aggregates, dimension, and decorative stone. While a number of other non-fluid mineral commodities are known to be present within the RMPPA, most occur in minor deposits. Other mineral types and occurrences are of sub-economic classification and as such are unlikely to be considered for development or exploitation within the projected planning period.

Coal has been a major mineral commodity within the RMPPA, largely being produced from Hanna Basin area mines. Historic production (of a limited scale) also has occurred elsewhere within the RMPPA.

Gypsum is produced in the Laramie area and utilized as a retarder in portland cement. Also, limestone is quarried from the Laramie area for utilization in the manufacture of cement.

Aggregate occurrences (though variable in quantity and type) are present throughout the RMPPA, and are subject to increasing consumptive demand as a result of expanding oil and gas development. This can generally be attributed to aggregate materials being utilized as roadway sub-base, base, and surfacing, with the increased demand being a result of the expanding infrastructure (collector, local, and resource roads) necessary to support the oil and gas industry.

Similarly, dimension, and decorative stone occurrences, while not of widespread occurrence, are being subjected to increasing demand for architectural and landscaping applications.

It also should be noted that prior to the early 1980s, when uranium markets took a significant downturn, Wyoming (inclusive of the RMPPA) was a major producer of uranium. There has been commercial-scale production of uranium from the Shirley Basin, and there are potentially economic deposits known to be present elsewhere within the area. Currently, there is no uranium production within the RMPPA, and that is not anticipated to change in the foreseeable future; however, uranium prices and demand are subject to fluctuating international demand and environmental/political factors, making future production estimates largely unpredictable.

3.1 Leasable Minerals

Leasable minerals are governed by The Mineral Leasing Act of 1920. The Mineral Leasing Act of 1920, as amended, authorized that specific minerals no longer be locatable; but instead shall be disposed of through a leasing system. Minerals designated as leasable under this law include:

- oil and gas;
- coal;

- native asphalt, solid and semisolid bitumen and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined;
- phosphate;
- sulfur (in the states of Louisiana and New Mexico); and
- chlorides, sulfates, carbonates, borates, silicates, or nitrates of potassium and sodium.

By far, the most significant leasable minerals known to be present within the RMPPA are oil and natural gas. Other leasable minerals are present, albeit to a significantly lesser degree. These other leasables include coal, oil shale, phosphate, sodium sulfate and other saline minerals.

3.1.1 Oil and Natural Gas

3.1.1.1 Origin, Occurrence, and Trapping of Oil and Natural Gas

Origin of Petroleum

Crude oil and natural gas are composed chiefly of hydrocarbon compounds and are found primarily in sedimentary rocks. The prevailing theory of the origin of petroleum hydrocarbons is that they are derived from organic matter. This is substantiated by the fact that the largest petroleum accumulations occur in sedimentary basins with widespread organic debris and that petroleum hydrocarbons have been found closely associated with organic matter. The organic matter accumulates in deposits that eventually become source rocks for petroleum. Source rocks are generally derived from organic-rich sediments that are deposited in an environment that precludes oxidation and this is normally in sedimentary basins or coal swamps. Potential source rocks are subjected to increasing temperature and pressure as they become buried by other sediments and by basin subsidence. Given high enough temperature and pressure, precursor petroleum compounds begin to form from the organic material in the rock. With increasing temperature and pressure, these organic compounds are thermally altered to form petroleum and natural gas. Hydrocarbons formed in this manner are termed *thermogenic* and are generated at temperatures above 200 degrees Farenheit (°F) (Wiese and Kvenvolden, 1993). The hydrocarbons mobilize and may migrate away from the source rocks into more porous and permeable rocks called reservoir rocks. Methane, a large component of natural gas, also can be formed from the bacterial decomposition of organic material in the absence of oxygen. This type of methane is termed *biogenic* and is found in the earth at low temperatures that preclude the killing of anaerobic bacteria below about 200°F.

Four essential physical elements of a petroleum reservoir are reservoir rock, connected pore spaces that are able to store hydrocarbons, the presence of hydrocarbon fluids or gases in the connected pore space that can be moved through the rock, and a trap that prevents the further migration of hydrocarbons (Levorson, 1967). Both source and reservoir rocks are widespread throughout the Rawlins RMPPA as evidenced by the oil and gas fields so far discovered and the evidence of hydrocarbons in much of the stratigraphic section of rocks found in the area. Important source rocks are the Phosphoria Formation and Cretaceous shales and coals.

Another element of a hydrocarbon reservoir can be stated thusly: A reservoir is “a rock from which oil or gas can be produced at a profit” (Berg, 1986, p. 33). This definition is important because in the history of petroleum exploration, known hydrocarbon-bearing strata have been bypassed or written off because either it was technologically or economically unfeasible to produce them. Later, such strata may invite renewed interest because of either more favorable commodity prices, changes in technology, or the existence of a transportation infrastructure (natural gas pipelines). An excellent example of this is coalbed methane (CBM) that was only recently recognized as a source of primarily gaseous hydrocarbons.

Trapping Mechanisms

The fourth fundamental element of a petroleum reservoir is the trap. Water is the dominant subsurface fluid and hydrocarbons are lighter than water. Therefore the tendency is for hydrocarbons to migrate vertically through the subsurface. Because of this tendency for vertical movement, any physical feature that impedes that movement will create a trap. There are three basic types of traps: structural traps, stratigraphic traps, and combination traps (Levorson, 1967). **Figure 3-1** portrays the most common trap types. Coal provides a fourth kind of trap where adsorption of the gas onto the coal constitutes the trapping mechanism and structural stressing or high pressure may increase the capacity of the coal to trap gas. Coal is both a source rock and reservoir rock.

One type of structural trap is formed as a result of the folding of reservoir strata. Hydrocarbons migrate into the reservoir and are held there by less permeable rock on top of the reservoir. Anticlines are a common form of structural trap. Exposed structures are readily apparent and have received the earliest and most extensive exploration effort. Buried, or subsurface structures are more difficult to locate, requiring detailed geophysical and geologic analysis. Anticlinal structures are common along the basin margins and many have yielded significant oil and gas resources. The central region of the Rawlins RMPPA has numerous examples of anticlinal traps. They are also found in the interbasinal areas such as the Rawlins Uplift, Wamsutter Arch, and Cherokee Arch.

Another common form of structural trap forms when a reservoir is sealed by movement of a fault that places less permeable strata opposite the reservoir or the fault itself is the sealing agent. This

Figure **3-1** Trap Types

presumes that the strata over the reservoir will not allow the hydrocarbons to escape. Anticlinal structures, possibly modified to some extent by faulting at depth, are common traps in the Rawlins RMPPA.

Another type of trap is the stratigraphic trap. Stratigraphic traps occur because of a lateral change in the physical characteristics of the reservoir or a change in the continuity of the rocks (Levorson, 1967). No matter what has caused the change in physical characteristic or change in continuity, ultimately it is the change of permeability that traps the hydrocarbons. Changes in permeability occur as a result of the complexity of the original depositional environment such as stream deposits or unconformities, which may result in the truncation of permeable strata with subsequent deposition of an overlying impermeable deposit. A change in permeability also may result from later alteration (diagenesis) that causes a reduction in pore sizes that decreases the potential flow paths through the reservoir to form a barrier to petroleum migration. Stratigraphic traps are not apparent at the surface as in the case of the surface anticlines, but in special cases may be indicated by geophysical data. The discovery of stratigraphic traps often depends upon detailed mapping of the subsurface using information derived from previously drilled wells to look for potential discontinuities or changes in rock types that may create traps. Under special conditions, modern geophysical methods also have the ability to identify changes in rock type that may be indicative of potential stratigraphic traps at depth. Sandstones that pinchout or are highly laterally variable have created numerous stratigraphic traps in the western portions of the RMPPA in the Great Divide and Washakie Basins.

Combination and Unconventional Traps

Many traps are not strictly structural or stratigraphic, but have elements common to both **(Figure 3-1)**. There are all gradations of traps and often it is difficult to precisely determine the primary trapping mechanism. Unconventional traps are those traps that may or may not possess some of the typical elements found in conventional traps. One type of unconventional trap with implications to the RMPPA is what is termed the “basin-centered” trapping of natural gas. In the basin-centered model, there is no obvious seal or permeability barrier and the traditional concepts of structural and stratigraphic trapping are of lesser importance (Law, 1995). Instead of a continuous seal, hydrocarbons are trapped in widespread low-permeability reservoirs. Other attributes of basin-centered accumulations of gas include the following: the accumulations cover large areas of the deepest parts of basins, there is no gas-water contact below the accumulation, there is little or no water production, abnormal pressures are present (higher or lower than expected gradient), the gas is the pressuring agent, the gas is sourced from immediately adjacent rocks, and the gas is thermogenic in origin.

3.1.1.2 Historical Development and Production

The Rawlins RMPPA has had a long history of oil and non-CBM natural gas production. Since the 1920s, the area has produced 525 million barrels of oil and 4.2 trillion cubic feet (TCF) of gas from a number of fields. A list of fields and units in the area is on **Table 3-1**. The following discussion summarizes the major producing areas in the RMPPA. Based on production figures through year 2,000, four of Wyoming's top 25 gas producing fields are within or partially within the RMPPA. The fields and year 2001 production rank are as follows: Echo Springs (12), Standard Draw (13), Wild Rose (14), and Wamsutter (15) (Wyoming Oil and Gas Conservation Commission [WOGCC] 2002a). In addition, the RMPPA contains two of the top 25 oil fields in the state; Lost Soldier (2) and Wertz (23).

Before an oil or gas well is drilled, the WOGCC must approve an Application for Permit to Drill (commonly referred to as an APD). A memorandum of understanding between BLM and WOGCC regulates this approval. In the case of wells drilled on BLM-managed lands, the WOGCC can only regulate the spacing and location of a well and provide a unique well identification number. The WOGCC also regulates underground injection, but the BLM regulates all aspects of drilling and surface use for wells drilling on BLM-managed lands. If the well will be on federal lands, an APD also must be approved by the BLM. Historically, federal applications to drill have been about 44 percent of the total number of applications filed in the Rawlins RMPPA. Not every approved application is actually drilled. Since 1987, about 70 percent of the approved applications in the RMPPA have actually been drilled. **Figure 3-2** shows the yearly total of new wells drilled since 1910. It does not include workovers (maintenance operations), recompletions (completion of zones not previously produced), or wells that were reentered and deepened. Records indicate that before 1910 only one well had been drilled. Note that **Figure 3-2** shows that there has been a pronounced upward trend in wells drilled.

Figure 3-3 shows the relative depths of wells drilled since 1990. “Percent of Wells Drilled” was used because some wells did not have readily available depth information. Seventy-four percent of the wells drilled were between 8,000 and 12,000 feet deep. The average total depth was 9,249 feet. As the number of wells drilled has increased during this period, the depth of the wells also has increased.

As new wells are drilled and completed, wells are being plugged and abandoned. The great majority of these are wells that are either unproductive (dry holes), or have become depleted and are no longer economic. **Figure 3-4** shows the wells drilled and wells abandoned since 1980. Abandonments have been 37 percent of the total number of wells drilled. The number of abandoned wells would be slightly greater than shown in **Figure 3-4** because about 12 percent of the wells reported as abandoned did not have an abandonment date and could not be plotted. The number of wells abandoned is more consistent year-to-year than the number of wells drilled. Historically, about 53 percent of the wells drilled have been abandoned (**Table 3-2**).

Table **3-1** Oil and Gas Fields and Cumulative Production in the Rawlins RMPPA

Figure **3-2** Number of New Wells Drilled, by Year, in the RMPPA

Figure **3-3** Well Depth Distribution for Wells Drilled Since 1990 in the RMPPA

Figure **3-4** Wells Drilled and Wells Abandoned in the RMPPA from 1980 to 2001

Within the RMPPA, 5,515 wells are present in five categories **Table 3-2**. To date, 59 percent of all wells have been drilled on federal lands, with the other 41 percent drilled on fee or state lands. Fifty-two percent of all wells have been abandoned. Wells have been abandoned because of the following:

- no hydrocarbons were encountered, or hydrocarbons were not present in economic quantities;
- the wells were initially capable of producing hydrocarbons, but they became uneconomic to produce at a latter date; and
- mechanical difficulties with a wellbore prevented economic hydrocarbon production.

Table 3-2
Rawlins RMPPA Well Status on April 1, 2002

	Federal	Fee or State	Total
P&A Wells	1,991	893	2,884
Dormant Wells	33	32	65
Completed Wells	1,123	1,231	2,354
Notices of Abandonment	31	40	71
Drilling Wells	69	72	141
Total Wells	**3,247**	**2,268**	**5,515**

Source: WOGCC, 2002a, Wyoming State Office RMG.

A map of the RMPPA **(Figure 3-5)** shows the locations of all wells drilled. For this map, wells were divided into two categories; active and abandoned. This map shows that drilling activity has been concentrated in three regions. The first and most heavily drilled region is in the eastern Green River Basin and includes the Great Divide Basin, Wamsutter Arch, Cherokee Arch, and Washakie Basin. This region is located in the westernmost part of the RMPPA. In spite of the heavy drilling in parts of these areas, there are some townships in this region that have been only lightly tested.

The two other regions of concentrated activity lie in the eastern part of the RMPPA and in a region across its center. These regions have been less heavily explored and developed than in the region on the west. Many townships within these two regions have been only lightly tested. Outside of these three regions, many townships have not been tested with even one well.

Figure 3-6 shows RMPPA production of natural gas by year, from 1974. Production was flat early on, but began a steady increase in 1978 that carried through 1981. After a period of fluctuation during 1982-1985, production increases resumed. During the 1986 through 1997 period, production increased at a nominal annual rate of 4.2 percent. Gas production was 7.5 times higher in 2001 than in 1974. The decline in production during 2000 and 2001 was mostly due to

Figure **3-5** Wells Drilled for Oil and Gas

Figure **3-6** Yearly Total Gas Production and Production from Federal, Private, and State Lands in the Rawlins RMPPA decline in production from private wells. Gas production from the RMPPA in 2001 was 11 percent of Wyoming's total gas production.

Figure 3-7 shows oil production from wells on federal, private, and state minerals, by year, from 1974. During the period from 1978 to 1995, production fluctuated around an annual rate of 8 million barrels. Beginning in 1990, annual production began declining and has declined at a nominal rate of 2.8 percent per year through 2001. About half the oil produced in the RMPPA during 2000 and 2001 was from the Lost Soldier-Wertz Fields near Bairoil, Wyoming. In 2001, only 7 percent of Wyoming's total oil production came from the RMPPA.

Producing oil and gas wells in the RMPPA have increased at a nominal rate of 3.1 percent per year between 1974 and 2001 (**Figure 3-8**). Forty-five percent of the producing wells are federal.

Rawlins Uplift Area

The Rawlins Uplift essentially provides a platform area that is between the Great Divide-Washakie Basins and the Hanna Basin. The fields in this area are generally anticlinal traps that produce out of multiple reservoirs. Oil was first discovered in the Rawlins RMPPA in 1916 at Lost Soldier Field when oil was produced from sandstones in the Frontier Formation (Skeeters and Hale, 1972). Lost Soldier Field is an anticlinal trap with seven producing zones from Cambrian to upper Cretaceous. Production has also been obtained from fractured Precambrian rock in this structure. Through February 2002, the field has produced over 251 million barrels of oil and 439.8 billion cubic feet of gas (BCFG) (WOGCC 2002b). Another early development in the RMPPA occurred at Hatfield Dome, 10 miles south of Rawlins. Significant gas was discovered at Hatfield Dome in 1915 when a Frontier Formation well flowed from 10 to 20 million cubic feet per day (Bauer, 1992).

Hanna Basin

There are only a few oil and gas fields discovered to date in the Hanna Basin, but development came relatively early. Allen Lake Field was discovered in 1918 and Simpson Ridge was discovered in 1923 (Skeeters and Hale, 1972). As of the present day, the oil and gas fields are concentrated around the edges of the basin in anticlinal traps. Since the Hanna Basin has a very thick sedimentary rock section (over 40,000 feet), the basin is relatively unexplored.

Laramie Basin

Oil production began in the Laramie Basin at Rock River field in 1918 (Skeeters and Hale, 1972). Quealy Dome, discovered in 1934 by the California Company, is notable because it was the first field in Wyoming that was discovered using seismic exploration techniques (Berg, 2002). The oil

Figure **3-7** Yearly Total Oil Production and Production from Federal, Private, and State Lands in the Rawlins RMPPA

Figure **3-8** Total Producing Wells and Federal, Private, and State Producing Wells in the Rawlins RMPPA, by Year fields in the Laramie Basin are primarily basin-margin structural traps located in anticlines on the west side of the basin.

Great Divide – Washakie Basins

Early production in these basins was found at Wamsutter Field, discovered in 1950 with production from upper Cretaceous reservoirs: Lewis Shale, Mesaverde, and Almond Formations (DeBruin, 2002; WOGCC 2002b). Within the Rawlins RMPPA, early production came from South Baggs and Savery Fields, both discovered in 1954. These fields have produced mainly out of upper Cretaceous sandstones, but South Baggs has Tertiary and Mississippian production as well. Although Table Rock Field is technically on the Rock Springs uplift and lies mostly in the Rock Springs Field Office area, part of it extends into the Rawlins RMPPA. It was discovered in 1946 and produces from Tertiary, Cretaceous, and Paleozoic reservoirs (DeBruin, 2002; WOGCC, 2002b). There were sporadic discoveries in the basins in the 1950s and 1960s, but in the 1970s, significant discoveries were made at Siberia Ridge (1975), Echo Springs (1975), Wild Rose (1975), Hay Reservoir (1976), and Standard Draw (1978). Much of the production is from low permeability upper Cretaceous stratigraphic traps. The Almond Formation is an important gas-producing unit as well as sandstones within the Lewis Shale. Many of the reservoirs in this area are considered tight-sands because of the low permeability and reservoirs below 9,000 or 10,000 feet may be over-pressured (Law and others, 1989).

Denver-Cheyenne Basin

The Denver-Cheyenne Basin encompasses a large area of northeastern Colorado, southeastern Wyoming, and southwestern Nebraska. The portion of the basin located in the Rawlins RMPPA is a relatively small part of the entire basin. In that portion of the basin within the RMPPA, oil was first discovered in 1922 at Butler Field (WOGCC, 2002b). The oil and gas resources are found in structural and stratigraphic traps and production is primarily from lower Cretaceous sandstones. Important structural traps are Horse Creek and Borie Fields, discovered in 1942 and 1949, respectively. These fields produce from lower Cretaceous reservoirs in anticlines along the east flank of the Laramie Mountains. An unconventional trap was discovered in 1981 at Silo Field when oil was found in fractured shale reservoir of the Niobrara Formation. Silo Field has produced nearly 10 million barrels of oil and nearly 8 BCFG (WOGCC, 2002b).

Deep Wells

Dyman and others (1990) characterized deep wells as those wells drilled to depths greater than 15,000 feet. **Figure 3-9** shows areas of the RMPPA that may contain potential reservoir rock below 15,000 feet and those that do not contain potential reservoirs at those depths. Only about 25 percent of the RMPPA has potential reservoir rock below 15,000 feet. These areas are in deeper parts of the Great Divide, Washakie, and Hanna Basins and along the Wamsutter Arch, Figure **3-9** Deep Wells (>15,000 feet) and Deep Reservoir Potential which separates the Great Divide and Washakie Basins. Seventy-five percent of the RMPPA, which includes the margins of the three deep basins, structural uplifts, and the Denver-Cheyenne, Laramie, and Shirley Basins, does not contain potential deep reservoir sediments. Data for the discussion of deep wells in the RMPPA was obtained from IHS Energy Group (2002) and WOGCC (2002a).

The Potential Gas Committee (PGC) (PGC, 2001) projected large amounts of total undiscovered natural gas resources in the conterminous 48 states, below 15,000 feet. For the entire Greater Green River Basin, the PGC estimated almost one-third (8.4 TCF of a total of 26 TCF of gas) of the potential resource lies below 15,000 feet. These potential resource estimates were projected for areas much larger than that of the RMPPA. Since the Denver-Cheyenne Basin does not contain potential deep reservoir rocks, their estimate of a potential gas resource of 3.70 TCF was just for shallower potential reservoirs. Information presented below will show where deep gas resources presently are known to exist within the RMPPA.

Deep wells drilled in the Rawlins RMPPA are shown on **Figure 3-9**. Information relating to these wells is presented in **Table 3-3**. Thirty-eight deep wells have been drilled. To date, 15 wells have been drilled between 15,000 and 16,000 feet, 11 have been drilled between 16,000 and 17,000 feet, 6 have been drilled between 17,000 and 18,000 feet, and 5 have been drilled between 18,000 and 19,000 feet. The deepest well, and only well drilled to a depth greater than 19,000 feet, was the Frewen Deep No. 1. That well was drilled to 19,299 feet in the Frewen Field, on the north edge of the Washakie Basin. The Frewen Deep No. 1 also is the deepest producing well in the RMPPA. It was originally completed as a Cretaceous Lakota Formation gas producer between 19,054 and 19,126 feet. This zone produced 168 million cubic feet of gas (MMCFG) and 8 barrels of oil before it was abandoned.

Two of the 38 wells have recently been drilled and they are considered suspended until testing has been completed and a final status is determined (**Table 3-3**). Twenty-seven of the 36 completed wells (75 percent) were originally completed as gas wells. Eighteen of those 27 wells (67 percent) produce from zones deeper than 15,000 feet. Production in these deep wells has been predominantly gas. Gas has been encountered in 10 different formations, with the Nugget productive in 8 wells. Oil has been produced in small amounts from deep zones in 9 of the 18 wells.

The following discussion describes the deep wells that have been drilled in the RMPPA.

Hanna Basin

Only 3 deep wells (Pass Creek Unit No. 1, St. Mary's Unit No. 1, and Seminoe Unit No. 1-25) have been drilled in the Hanna Basin (**Table 3-3**). All were drilled as part of federal exploratory unit agreements. None have been productive nor had hydrocarbon shows in zones deeper than

Table **3-3** Summary of Data for All Deep Wells (>15,000 Feet) Drilled in Rawlins RMPPA

15,000 feet. The Seminoe Unit No. 1-25 was completed as a shallower Lewis Shale gas producer. It was completed in 1983 and was the last deep well drilled in the Hanna Basin.

Wilson and others (2001) have reviewed the potential for a deep basin-centered gas accumulation in the Hanna Basin. Limited data indicates that a gas-charged, overpressured interval may occur along the southern and western margins of the basin. In this area, the Cretaceous Mowry, Frontier, and Niobrara Formations lie in this potential gas-charged overpressured interval, at depths below 10,000 feet. In the center of the basin, Wilson and others (2001) project possible gas-charged overpressuring at depths below 18,000 to 20,000 feet. The potential Niobrara, Frontier, and Mowry reservoirs have not yet been commercially productive in other known basin-centered gas accumulations.

Great Divide Basin

Seven deep wells were drilled (**Table 3-3**) in the east and north parts of the Great Divide Basin (**Figure 3-9**). Three of the 7 wells produce, although only two were completed as producers from reservoirs at depths greater than 15,000 feet. Production from these wells has been small.

The first deep test was the Bull Springs Rim No. 1-19. It is the deepest well drilled in the basin and it also produces from the greatest depth. The Cretaceous Niobrara Formation produces from 15,383 to 15,478 feet in this well.

To date, the oldest formation encountered was the lower Cretaceous Cloverly, in the Bull Springs Rim No. 1-19. The other six wells only drilled to upper Cretaceous aged sediments. All 7 wells were drilled in the 1975 to 1980 period.

Wamsutter Arch

The Wamsutter Arch occupies a small part of the Rawlins RMPPA and is a low relief anticlinal structure separating the Great Divide and Washakie Basins. Three deep wells have been completed on the crest of this structure (**Table 3-3**). These wells are productive, but from zones less than 15,000 feet deep. In the Sidewinder No. 1-H and No. 2-H wells, portions of the wells were horizontally drilled. All wells were drilled to lower Cretaceous formations, with the first completed in 1997.

Washakie Basin

Most of the deep wells (25 of 38 wells, **Table 3-3**) in the RMPPA are scattered across the Washakie Basin **(Figure 3-9)**. Twenty-one of these wells were drilled in the 1975 to 1996 period. Three new deep wells were drilled in 2001.

The first deep well in the Washakie Basin was the South Baggs Unit No. 8 drilled to 16,248 feet in 1960. It drilled completely through the sedimentary section into Precambrian basement rocks. The upper Cretaceous Lewis Shale was found to be productive at depths less than 15,000 feet in the well.

Deepest production is in the Frewen Deep No. 1. This well was completed as a lower Cretaceous Lakota Sandstone gas well in 1989. It produced in an interval from 19,054 to 19,126 feet and has since been abandoned.

Eleven deep wells have been drilled within that portion of the Table Rock field that lies within the RMPPA **Table 3-3**. Table Rock Unit No. 123 was recently drilled and is waiting on wellbore tests. The other 10 wells were all completed as deep producers; 8 in the Triassic Nugget Sandstone, and 1 each in the Pennsylvanian Weber Sandstone and Mississippian Madison Limestone. Most of the deep production in the RMPPA has come from these wells. Hydrocarbons are produced from an anticlinal structure at Table Rock field. Gas from the Weber and Madison contains about 2 percent hydrogen sulfide (Dickinson, 1992).

Formations productive at Table Rock field have not been found to be productive in other parts of the Washakie Basin. A number of different formations have been found to be productive outside Table Rock field. Those productive formations are: the Upper Cretaceous Lewis Shale, Mesaverde Group, and Niobrara Formation; the Lower Cretaceous Lakota Sandstone; and lower Pennsylvanian rocks.

Deep gas production in the RMPPA part of the Washakie Basin has totaled 93.953 BCFG to January 2002. Only a small amount of oil (11,098 barrels) has been produced from these wells.

Secondary and Tertiary Recovery Projects

Primary production includes the initial stages of reservoir production when the hydrocarbons can be fairly easily moved to the wellbore either by the natural forces in the reservoir or through artificial lift (pumping). Primary recovery sometimes only recovers a fraction of the hydrocarbons originally in place in the reservoir. In order to more efficiently extract the oil as the reservoir energy is depleted, oil and gas operators often conduct secondary recovery operations. Secondary recovery involves the injection of water, gas, or steam to help push the oil to production wells. Beyond secondary recovery, there are tertiary recovery methods that often involve the injection of miscible fluids to combine with the oil to try to move the oil to production wells. However, a point is reached at which no more oil can be recovered under existing technologies. There are a number of secondary and tertiary recovery projects in the RMPPA as listed on **Table 3-4**. A major tertiary recovery project in the RMPPA is at Lost Soldier Field where carbon dioxide (CO_2) gas is injected into various formations to enhance recovery of oil. The CO_2 is produced from the Madison Formation reservoirs in the Big Piney – La Barge area in Sublette County (DeBruin, 2001). After

Table **3-4** Secondary and Tertiary Recovery Units in the RMPPA processing and treatment at the Exxon/Mobile Shute Creek gas plant, the CO_2 is transported to Lost Soldier field via a 20-inch pipeline (DeBruin, 2002).

Pipelines, Natural Gas Storage, Natural Gas Processing

There is an extensive system for gas processing transportation within the Rawlins RMPPA as would be expected with the level of production. There are a number of gas gathering systems within the production areas that feed into transportation lines. Associated with the gas gathering pipelines are compressor and gas processing facilities. Compressors are used to move the gas through the pipelines and the processing facilities are used to remove liquid hydrocarbons (condensate and natural gas liquids) and excess water. Along the I-80, there are several major gas transportation pipelines up to 36 inches in diameter (DeBruin, 2002).

The WOGCC (2002b) lists three gas storage projects in the RMPPA at Bunker Hill, Mahoney Dome, and Wertz. The Wertz gas storage project is listed as inactive and the status of the other two projects was not indicated in the WOGCC statistics (2002b).

There are six natural gas processing plants in the RMPPA, the largest is located at Rawlins and has a capacity of 230 MMCFG per day.

Federal Unit Agreements

Non-CBM and CBM federal unit agreements lie within the Rawlins RMPPA boundaries. Sixty-five active (non-CBM) federal unit agreements lie within or partially within the RMPPA **(Figure 3-10)**. These units cover an area of 324,060 acres, or about 3 percent of the Field Office area. Companies operating these units are; Benson-Montin-Greer, BP America Production, Braden-Deem Inc., Cabot Oil & Gas Corp., Chevron Texaco, Coral Production Corp., Devon SFS Operation Inc., Double Eagle Petroleum Co., EOG Resources Inc., Ensign Operating, Goldmark Engineering Inc., Kaiser-Francis Oil Co., Hudson Group LLC, Marathon Oil Co., Merit Energy Co., Questar Exploration and Production, Richardson Production, RME Petroleum Co., Rock River Operating Co., Sonoma Energy Corp., Stanley Energy Inc., Stone Energy LLC, Tom Brown Inc., Westport Oil & Gas Co. Inc., Windsor Oil & Gas Inc., Wold Oil Properties Inc., Xeric Oil & Gas Corp., and Yates Petroleum Corporation.

Most of the units are located in the eastern greater Green River Basin area, with two in the Denver Basin, and three each in the Hanna and Laramie Basins. Nearly all of these units are at a mature stage of development. In recent years some new exploratory unit agreements have been proposed and approved in the Washakie Basin portion of the greater Green River Basin. These units are in early stages of exploratory activity.

Figure **3-10** Non-CBM Federal Unit Agreements

As of August 9, 2002, there are three established exploratory units for CBM and six others pending. There is one established unit in the Hanna Basin, two authorized and five pending units on the eastern side of the Washakie Basin, and one pending unit on the east side of the Wamsutter Arch. **Figure 3-11** shows the locations of CBM federal units in the RMPPA. A more detailed discussion of these units is in Section 3.1.1.4.

3.1.1.3 Origin and Occurrence of Coalbed Methane

The presence of methane in coal seams has long been recognized as a potential hazard in the mining of coal (Diamond, 1993). The extraction of methane from coal was originally practiced to provide a margin of safety for coal mining by removing as much methane as possible prior to mining. It was recognized that there was a potential significant gas resource in coals. In the early1980s, Congress considered CBM as an “unconventional” gas resource and enacted tax incentives for the production of gas from coal seams. The tax incentives were extended, but eventually expired in 1991. The tax incentive spurred industry to develop technologies to produce the resource and major coalbed producing areas resulted in the Black Warrior Basin of Alabama and the San Juan Basin in southwestern Colorado and northwestern New Mexico (Rice and others, 1993).

The methane in coal seams occurs as a result of the process that turns plant material into coal (DeBruin and others, 2001). The process of turning peat and other plant material into coal is called coalification. As accumulated plant material is buried and subjected to increasing temperature and pressure it is turned into varying ranks of coal. The coal rank is reflective of the amount of burial and therefore temperature and pressure to which a coal has been subjected. The gas in the coal can either be biogenic and thermogenic, depending on the particular circumstances of the burial and exhumation history of a coal seam. In addition to methane, other gases generated in the coalification process are nitrogen and CO_2. The nitrogen and CO_2 are generated under thermogenic conditions. Other heavier hydrocarbon gases and oil may be generated depending on the organic materials in a particular coal deposit (Rice and others, 1993; Garcia-Gonzalez and others, 1993).

The methane generated in the coalification process can be stored in several ways: as free gas in tiny pores and fractures in the coal, as a dissolved phase in interstitial water in the coal, or adsorbed onto the surface of the coal. Because most coals have abundant microfractures, or cleat, there is abundant surface area on which gas can be adsorbed. This feature of gas storage allows coals to store a much higher volume of gas than conventional gas reservoirs (Rice and others, 1993).

In order to extract the gas from the coal, it is necessary to lower the hydrostatic pressure in the coal. Lowering the pressure is accomplished by producing the water that is in the coal. Extraction of the gas often involves the pumping of large amounts of water in the initial stages of

Figure **3-11** CBM Unit Agreements

development. **Figure 3-12** shows a production profile for a typical CBM well showing relative production rates of gas and water over time. The highest initial water production rate for a CBM well in the Rawlins RMPPA was reported as 2,127 barrels of water per day (WOGCC, 2002a). However, water production rates are usually less than 1,000 barrels per day with maximum rates on the order of 600 barrels per day. Once wells reach economic production, water production rates decline substantially. Water quality can range from 380 milligrams per liter (mg/l) of total dissolved solids (TDS) to 2,720 mg/l with average TDS in the RMPPA of 1,246 mg/l. Water quality may be better in the coal seams that are closer to the surface, indicating potential recharge from meteoric water. Water disposal options, which are highly dependent on water quality and economics, can include discharge to the surface or subsurface injection into disposal wells or into aquifer recharge wells. Surface disposal options may require pre-treatment prior to disposal to meet discharge permit requirements. All disposal options require permits.

3.1.1.4 CBM and Production in the Rawlins RMPPA

Potential CBM-bearing formations in the RMPPA are the Mesaverde, Lance, and Fort Union Formations in the Washakie Basin and the Hanna, Medicine Bow, and Ferris Formations in the Hanna Basin (DeBruin and Jones, 1989). A detailed description of these coal-bearing units is in Section 3.1.3. Evidence for the presence of methane in coals came from “gas kicks” during drilling of exploration borings or gas explosions observed in coal mines in the Hanna Basin (DeBruin and others, 2001). Gas contents measured in coals from southwestern Wyoming range from 100 to 541 standard cubic feet per ton (Law, 1995).

Although there is substantial interest in CBM development in the RMPPA, there has been little production. Only 0.179 BCFG and 10.3 million barrels of water have been produced in the RMPPA (WOGCC, 2002a).

At present, two CBM exploratory unit agreements have been authorized and five are pending (**Figure 3-8 and Table 3-5**). Authorized and pending units cover an area of about 140,800 acres.

The Magic Unit has only recently been proposed and details about it are still confidential. This unit lies along the crest of the Wamsutter Arch, between the Great Divide and Washakie Basins.

The authorized and pending units are located along the east flank of the Washakie Basin. They are part of a larger proposal by Petroleum Development Corporation and others that are currently exploring the feasibility of developing gas resources in the coals of the Mesaverde Formation in an area between townships 13 to 20 north and ranges 89 through 92 west. A separate EIS is being prepared for this proposed project. Initial wells for pilot tests in the north and middle parts of the project area have been drilled and testing is planned to begin in 2002. The Sun Dog unit operator plans to drill wells for a pilot test in 2002.

Figure **3-12** Typical CBM Well Production Profile

Table 3-5
Rawlins RMPPA CBM Methane Unit Agreements

Unit Name	Operator	Size (acres)	Date Received	Date Approved
Blue Sky	Pet. Dev. Corp.	24,878.60	05/13/2001	11/13/02
Magic	Yates Pet. Corp.	15,980.29	02/25/2002	Pending
Muddy Mountain	Pet. Dev. Corp.	23,464.41	05/13/2001	Pending
Point Rocky	Pet. Dev. Corp.	19,030.06	05/13/2001	Pending
Sand Hills	Pet. Dev. Corp.	14,485.48	05/13/2001	Pending
Smiley Draw	Pet. Dev. Corp.	19,576.15	05/13/2001	Pending
Sun Dog	Pet. Dev. Corp.	23,468.74	05/13/2001	12/22/2001
	Total Acres	140,883.73		

Source: Rawlins Field Office, Wyoming State Office RMG.

3.1.2 Coal

There are six identified coalfields within the RMPPA. Of these, the Hanna Field has been the most significant in terms of historic (and projected) coal production (**Figure 3-13**). Most activity within the remaining fields has typically been of small-scale, or in some cases, the coal resource has yet to be economically exploited.

In recent years, there has been a contraction of the coal sector within the RMPPA's Hanna Coalfield. As of 1979, five mining companies were still active in the Hanna Field (Glass and Roberts, 1979), but by the year 2002, there are only two active coal mines in the Hanna Field. With the mid-2000 closure of the RAG Shoshone No. 1 Mine (underground), there remain only two operational Hanna Coalfield mines (the Seminoe No. II and the Medicine Bow mines), both of which are surface coal mines operated by Arch of Wyoming, Inc. It is indicated that remaining economic reserves (estimated at an aggregate 2 million tons) at these two mines will sustain production for an estimated 2 years.

Coal is classified by rank, in accordance with standard specifications of the American Society for Testing Materials (ASTM). Most of the Wyoming coals are of bituminous and sub-bituminous rank. The reader is referred to ASTM D-388 for detailed information regarding coal classification specifications and considerations. While it should be noted that there are minor variants on classification on the basis of certain physical properties, a brief synopsis of the classification system (in general decreasing order of rank) is as follows:

I. Anthracitic
   1. Meta-anthracite
   2. Anthracite
   3. Semi-anthracite

Figure **3-13** Wyoming Coalfields

II. Bituminous

1. Low volatile bituminous	(> 78 percent but < 86 percent Fixed Carbon)
2. Medium volatile bituminous	(> 69 percent but < 78 percent Fixed Carbon)
3. High volatile "A" bituminous	(> 31 percent but < 69 percent Fixed Carbon)
4. High volatile "B" bituminous	(> 13,000 but < 14,000 Btu/lb[1] moist)
5. High volatile "C" bituminous[1]	(> 11,000 but < 13,000 Btu/lb moist)

III. Sub-bituminous

1. Sub-bituminous "A"[1]	(> 11,000 but < 13,000 Btu/lb moist)
2. Sub-bituminous "B"	(> 9,500 but < 11,000 Btu/lb moist)
3. Sub-bituminous "C"	(> 8,300 but < 9,500 Btu/lb moist)

[1]British thermal units per pound.
[2]Classification varies on the basis of agglomerating and weathering properties.

Within the RMPPA there are five significant coalfields containing coal resources of sub-bituminous to bituminous rank (Berryhill and others, 1950), as follows:

- Hanna Coalfield;
- Great Divide Basin Coalfield;
- Rock Creek Coalfield;
- Kindt Basin Coalfield;
- Little Snake River Coalfield; and
- Goshen Hole Coalfield.

The following sections provide brief descriptions of these coalfields. Information for these sections was primarily from Berryhill and others (1950) and Glass and Roberts (1979).

3.1.2.1 Hanna Coalfield

The Hanna Field is a structurally downwarped area of about 750 square miles (T21-24N, R79-86W) in the northern half of Carbon County, south-central Wyoming. The field is bounded on the north by the Shirley, Freezeout, Seminoe, and Ferris Mountains; on the west by the Rawlins Uplift; and on the south by the Medicine Bow Mountains. To the east, it merges with the Laramie Basin. The field is drained by the Medicine Bow River and several intermittent streams, all tributaries of the North Platte River, which flows in a northerly direction near the western edge of the field. The Union Pacific Railroad crosses the field from east to west, passing through the town of Hanna.

The topography in the central part of the field is of the "plains" type but is more rugged around the periphery. Along the southern side of the field, low ridges are prominent. In areas of T21N, R81W and northward a prominent ridge called Simpson Ridge (or the Saddleback Hills) extends north-northeasterly along an anticlinal axis. This ridge separates the largest coal-bearing area (Hanna Basin) on the west, from the smaller (Carbon Basin) to the east. Another small basin, the Walcott Basin, is southwest of the Hanna Basin.

The Mesaverde Formation (of upper Cretaceous age), which crops out at intervals around the edges of the field, is the oldest coal-bearing formation. Above the Mesaverde are the non-coal-bearing Lewis Shale and Foxhills Sandstone and the coal-bearing Medicine Bow, Ferris, and Hanna Formations. The Lewis Shale, Foxhills Sandstone, and the Medicine Bow Formations are upper Cretaceous. The basal part of the Ferris Formation also is considered to be of upper Cretaceous age, and the main part of the formation is considered to be of Paleocene. The Hanna Formation is Paleocene and lower Eocene.

A total of 130 coalbeds have been mapped in the four coal-bearing formations. Of this total, a third or more may lie at the same stratigraphic position as other numbered beds. The coal is of workable thickness at numerous places in the Hanna field, but as a rule the beds are not persistent for long distances. The highest-rank coal, high volatile “C” bituminous, occurs in the Mesaverde Formation; the thickest and most extensive beds are of sub-bituminous rank and occur in the Ferris and Hanna Formations. Throughout the field, many of the coal lenses cannot be traced because of poor exposures.

Description of the coals present within each formation is as follows.

Mesaverde Formation Coal

The Mesaverde Formation, which is 2,200 to 2,700 feet thick, crops out generally as ridges in the border areas of the field, where at places it also constitutes the central part of local anticlines. The formation consists of three members, each composed largely of sandstone and shale, but the middle member differs from the others in its fresh and brackish water invertebrate fossils, in its dominantly brown color, and in the large content of carbonaceous material. The coalbeds, which occur in the middle member of the formation and locally, in the upper member, are thin, irregular, and generally impure. At least four of the coalbeds are more than 3 feet thick. The maximum thickness of any bed is about 8 feet, as observed in T24N, R84W. The coal generally is of high volatile “C” bituminous rank. An analysis, on an as-received basis, of coal from the Mesaverde Formation in the Wissler mine indicates 10,290 Btu/lb heat value, 1.1 percent sulfur, and 7.8 percent ash.

Medicine Bow Formation Coal

The Medicine Bow Formation consists of 4,000 to 6,200 feet of shale and sandstone and numerous beds of coal that occur in a brown sandstone unit in the lower 1,500 feet of the formation. The unit contains at least 15 coalbeds that are more than 3 feet thick and attain a maximum thickness of about 11 feet. The beds are irregular in extent; at some places the unit contains no coal, whereas at others it has more than 12 beds. The coal is of sub-bituminous "A" rank. The average of two analyses, on an as-received basis, of coal from the Medicine Bow Formation indicates 11,050 Btu/lb heat value, 0.8 percent sulfur, and 3.8 percent ash.

Ferris Formation Coal

The Ferris Formation is about 6,500 feet thick and is composed of shale, sandstone, a basal conglomerate, and numerous thick beds of coal, which occur in the upper 5,400 feet of the formation above the basal conglomerate. A minimum of 20 beds in the formation are more than 3 feet thick, and as a rule the beds are thicker and more extensive than those in the Mesaverde and Medicine Bow Formations. Several beds are more than 5 feet thick, and the maximum thickness observed is 23.4 feet of clean coal, which is separated by 10 feet of shale near the middle and by 2 feet of shale near the top (T22N, R83W). The thickest bed extends at mineable thickness for about 7 miles along the outcrop, and, although it is generally separated into benches, at least one bench contains more than 5 feet of clean coal at most places. Others of the more than 18 beds of mineable thickness coal exposed in this township are thinner and less persistent and contain numerous partings. The beds in the general area dip about 10 degrees to 25 degrees northeast. The coal is of sub-bituminous rank.

Hanna Formation Coal

The Hanna Formation, which unconformably overlies the older rocks, consists of about 7,000 feet of alternating conglomerate, sandstone, and shale and contains numerous beds of coal. At least 30 coalbeds reach thickness greater than 3 feet, and the maximum thickness of clean coal is more than 30 feet. The thickest bed (seam) in the field is the Hanna No. 2, which crops out in the western part of T22N, R81W. At one exposure north of the town of Hanna, this bed contains more than 30 feet of coal without partings but north of the town its outcrop is generally burned. Southwest of the town the Hanna No. 2 seam is about 35 feet thick, including several shale partings each about 1-foot thick. But, 2 miles to the south the coal reportedly thins to 12 feet. It dips about 12 degrees to 20 degrees eastward. The coal is of sub-bituminous "A" rank; an analysis, on an as-received basis, of coal from the Hanna No. 2 seam (from within the Hanna No. 4 mine) indicates 11,200 Btu/lb, 0.5 percent sulfur, and 5.5 percent ash.

The Hanna field has been a major Wyoming coal producer, and total production ranked fourth behind that of the Rock Springs, Kemmerer, and Sheridan (Powder River Basin) fields. Its relative importance as a major coal producer has declined since the advent (late 1970s) of large-scale surface mining in the Powder River Basin.

Remaining Reserves – Hanna Field

The 1979 estimated remaining strippable resource and reserve base for the Hanna Coalfield was established at 648 million tons (Glass and Roberts, 1979). However, that may have been a liberal estimate, given that recorded production data (Lyman and Hallberg, 2000; Wyoming Coal Information Committee, 2002) and BLM estimates indicate that the following production occurred during the period 1975-2000. (Note: indicated tonnages are approximate and subject to rounding.

Mine	**Production (tons) 1975-2000**
Energy Development Company (3 mines)	8,000,000 (closed 1984)
Seminoe I (Arch)	18,200,000 (closed 1984)
Seminoe II (Arch)	33,500,000 (still operational)
Shoshone I (RAG)	43,000,000 (closed 2000)
Medicine Bow (Arch)	42,000,000 (still operational)
	144,700,000

[1]The Medicine Bow and Seminoe II mines remain operational with a projected 2-year mine life (based on an estimated aggregate of 2 million tons of recoverable reserves remaining).

In conjunction with the forthcoming closure of the Seminoe II and Medicine Bow mines, Arch of Wyoming, Inc. is apparently evaluating development of the nearby Carbon Basin coal project (Elk Mountain/Saddleback Hills Coal Lease – WYW139975). This lease tract contains an estimated 149.7 million tons of in-place federal coal resources, a portion of which is amenable to surface mining methods, while the remainder would be recoverable utilizing underground mining methods.

3.1.2.2 Great Divide Basin Coalfield

The Great Divide Basin field includes about 1,800 square miles in the northeastern part (T21-28N, R88-95W) of the Green River region.

The field is largely in Sweetwater County, but extends northward into Fremont County and eastward into Carbon County. It is bounded on the north by the Granite Mountains, on the east by the Rawlins Hills, and on the south by the Wamsutter Arch. The structure of the Great Divide Basin field is a broad downwarp overlain by flat-lying younger rocks. The oldest rocks in the basin crop out along the eastern edge of the downwarp; in this area the beds dip generally 25 degrees to 80 degrees westward, and in at least one place are overturned.

The Mesaverde Lance, Fort Union, and the Wasatch Formations contain coalbeds of mineable thickness in the field. The Mesaverde, which crops out along the eastern edge of the field, consists of about 2,000 feet of strata at the northern end of its outcrop and about 4,600 feet at the southern end. It is composed of alternating beds of sandstone and shale and is divided into three members, the upper two of which are coal bearing. The coal in these two members occurs in three zones: a lower zone at the base of the middle member, a middle zone at the base of the upper member, and an upper zone near the top of the upper member.

The lower coal zone contains four to six irregular beds of impure coal that are poorly exposed but apparently are not of mineable thickness. The coalbeds in the middle zone are generally thin in the few places where they are exposed, but they are believed to be thicker in the southeastern part of the field, where one bed contains 8.2 feet of clean coal and two 1-inch partings. The upper zone contains a minimum of four thin beds of coal, all of poor quality. Analyses of the coal in the Mesaverde are not available, but it is probably similar in rank to the high volatile “C” bituminous coal of nearby fields.

A sequence of shale, sandstone, and coal of the Lance Formation crops out in a north-trending belt in the eastern part of the Great Divide Basin field. It is separated from the Mesaverde Formation by the Lewis shale, which is 2,000 feet thick in the area. The coalbeds occur throughout the sequence and are especially numerous in the southern part of the field. The average thickness of 39 measured sections, located in all but one of the townships where the sequence is exposed, is 6.2 feet of clean coal. The maximum thickness of any bed is 12 feet, and the minimum is 10 inches. Some of the thicker beds are separated into benches by thick shale partings, but most sections show at least one bed of mineable thickness free of partings. A 1,800-feet measured section in the sequence (T25N, R89W) shows six coalbeds more than 2.5 feet thick, the thickest being 6 feet. An analysis, on an as-received basis, of weathered coal from the formation in the northeastern part of the field indicates 9,023 Btu/lb heat value, 0.3 percent sulfur, and 4.1 percent ash.

Rocks considered to be of Fort Union Formation unconformably overlie the Lance Formation in the eastern part of the field and crop out in a belt that trends generally north. This sequence consists of alternating beds of sandstone, shale, conglomerate, and coal. The lower 800 to 1,800 feet is composed of shale and conglomeratic sandstone and contains no coal. Above this lower barren unit coal occurs in two members that are separated by a non-coal-bearing member of soft shale and sandstone. In the southeastern part of the field both coal-bearing members contain workable beds. The lower member contains no coal in the northern part of the field, where it is the only part of the formation exposed. The average thickness of eight measured sections in both members, mostly in the southeastern part of the field, is 4.6 feet of clean coal. The maximum thickness is 20.7 feet.

The Eocene Wasatch Formation is flat-lying upon older dipping strata, crops out over a large part of the Great Divide Basin field. The Wasatch includes about 900 to 1,800 feet of sandstone, shale, conglomerate, and coal and includes a basal conglomerate that is thin in the southern part of the field where it is comprised of granite pebbles, but thickens northward and becomes coarse. The coalbeds are in a zone that overlies this basal member and are confined to the southern and western parts of the field. The average thickness of 12 measured sections is 5.1 feet of clean coal, the maximum being 16.1 feet. At many places along the outcrop the coal is burned.

3.1.2.3 Rock Creek Coalfield

The Rock Creek field covers about 450 square miles in the north-central part of the Laramie Basin, largely in Albany County but partly in Carbon County. The Union Pacific Railroad crosses the northeastern part of the field. The surface of the field is a gently rolling plain, which is covered with gravel over large areas. As a result, outcrops of the coal-bearing rocks are few in number and small in extent. The thickest and best-exposed coalbeds are in the northwestern part of the field (T20N, R76W and T19N, R77W) in the Mesaverde Formation and in the Hanna Formation. In these townships, the dips of the strata range from about 8 degrees to 20 degrees, generally to the southeast.

The Mesaverde Formation consists of 1,250 feet of sandstone, sandy shale, carbonaceous shale, and coal. The Pine Ridge sandstone at the top of the Mesaverde is about 80 feet thick in T20N, R76W and contains at least four coalbeds of “workable” thickness. The thickest coalbed exposed in the Pine Ridge sandstone member is in this township, where the coal attains a maximum thickness of 8 feet. The beds occur at several horizons in the sandstone, but they vary in thickness and probably are not continuous for long distances. Early mining operations (small, local operations) in the field were in coal ranging in thickness from about 4 to 7 feet.

The Hanna Formation, in the Rock Creek Coalfield, consists of sandy shale, sandstone, carbonaceous shale, conglomerate, and coal. One coalbed of mineable thickness crops out in places in the western part of T19N; R77W, where it reaches a maximum thickness of 9.5 feet, exclusive of several partings that total 2.2 feet. The coal is of sub-bituminous “B” rank, with representative analyses indicating 8,843 Btu/lb heat value, 0.9 percent sulfur, and 12.1 percent ash.

Coal is exposed locally in townships south and west of those discussed, but generally the gravel cover prevents determination of the thickness and extent of the beds. Mining within the Rock Creek field has been confined to small, local operations, and production has been limited.

3.1.2.4 Kindt Basin Coalfield

The Kindt Basin field is an eastward extension of the Green River (coal) region. The Green River region comprises approximately 15,400 square miles in southwestern Wyoming, and extends into Carbon County, being generally bounded on the east by the Rawlins Uplift and the Sierra Madre. The Kindt Basin field occupies approximately 200 square miles, mostly in T19-20N, R84-87W in west central Carbon County. The field is immediately south of the Union Pacific Railroad and southeast of the Town of Rawlins. The coal-bearing Mesaverde Formation crops out over most of the field, the limits of its outcrop determining the northern and southern boundaries. Along the eastern side of the basin Tertiary rocks conceal the Mesaverde Formation. To the west, the Kindt Basin adjoins the Little Snake River field.

In the Kindt Basin Coalfield, the Mesaverde Formation ranges in thickness from about 2,700 to 3,600 feet and consists of three members composed mostly of alternating beds of sandstone and shale. The lowest member, about 700 feet thick, contains no coal; the middle and upper members contain coal at irregularly spaced intervals. The coalbeds are lenticular and may show at least one shale parting that is variable in thickness. The coalbeds, exclusive of partings, are 2 to 6 feet thick. On the north side of the Kindt Basin field the coalbeds dip at 45 degrees to 75 degrees southward; on the south side the dip is about 11° northward.

The coal is of high volatile "C" bituminous rank. An analysis, on an as-received basis, from the Dillon mine indicated 11,010 Btu/lb heat value, 0.5 percent sulfur, and 8.4 percent ash.

3.1.2.5 Little Snake River Coalfield

The Little Snake River field, which is south of the Great Divide Basin field, includes more than 1,500 square miles in parts of T12-20N, R87-95W. The field is in the southeastern part of the Green River region, south of the Red Desert and west of the Sierra Madre. It extends from the Colorado state line on the south to the Union Pacific Railroad on the north. The strata generally dip westward toward the central part of the Green River region at angles ranging from nearly horizontal to as much as 35 degrees west.

The Mesaverde Formation and two overlying upper Cretaceous and Tertiary units contain workable coalbeds, many of which, especially the two higher units, are burned at the outcrops. The Mesaverde Formation consists of about 2,000 feet of strata, and is composed mainly of sandstone and shale. It crops out in a general north-trending band along the eastern edge of the field and is divided into three members, of which the middle and upper contain coal of mineable thickness. At the southern end of the field, several sections (probably in the middle member) show workable coalbeds that contain 2.8 to 12.2 feet of coal with no partings. The coalbeds in the middle member decrease in number and become thinner toward the north where the coal is of poor quality.

The upper portion of the Mesaverde contains several coalbeds in its area of outcrop in the Little Snake River Coalfield. In a measured section (T17-18N, R90W) the member contains four beds 5 to 11 feet thick. In the southern part of the field three measured sections each show more than 5 feet of clean coal.

The exposures of coal in the Mesaverde Formation are not continuous, and the beds are believed to be lenticular. However, where one bed thins, another is likely to thicken, and as a result the total thickness of the coal may remain fairly consistent over considerable areas. The coal is of high volatile “C” bituminous rank. Available analyses of coal in the Mesaverde from this field are of weathered samples; analyses on an as-received basis indicate 10,492 Btu/lb heat value, 0.9 percent sulfur, and 7.0 percent ash.

Rocks of the Lance Formation, separated from the Mesaverde Formation by about 1,600 feet of Lewis Shale, include about 3,500 feet of sandstone and shale and small amounts of coal. The coalbeds are poorly exposed, are covered in many places by surficial material, and generally occur between beds of shale that weathers rapidly. One measured section of a coalbed (T12N, R90W) which is probably in this sequence in the southern part of the field, shows 6.5 feet of clean coal. A bed about 5 miles to the north contains only 2 feet of coal, but two beds measured still farther north show a minimum of 5 feet and one shows 8.2 feet. At least some of the coal in the formation is of sub-bituminous “B” rank. The only available analyses (from the northeastern part of the field) indicate on an as-received basis, 9,722 Btu/lb heat value, 0.3 percent sulfur, and 3.8 percent ash.

The Tertiary (Paleocene) Fort Union Formation in the Little Snake River field is about 5,000 feet thick and consists of sandstone, shale, clay, and some conglomerate. It isdivided into three members, the lower and upper of which are coal bearing. Sandstone, some of which is conglomeratic, is abundant in the lower and upper members; conglomeratic sandstone and, locally conglomerate occur at the base of the formation. The non-coal-bearing middle member generally consists of clay shale, sandy clay, and local beds of sandstone. The sequence, which probably contains more coal than any other in the field, crops out extensively in the northern part of the field, but because of overlap by younger rocks the exposed part decreases southward to a narrow band.

The lower member of the Fort Union Formation, as measured in T17-18N, R91W, includes (within an interval of about 160 feet) a minimum of three workable coalbeds averaging 8, 5, and 3.5 feet in thickness. South of the locality, some coalbeds in the lower member are more than 5-feet thick and are possibly continuous for long distances. In the upper member, one zone (T18N, R92W) contains within an interval of about 60 feet several layers of shaley coal but only about 3 feet of good coal. This member is largely concealed in the western part of the field by younger coal-bearing rocks.

The coal in the sequence ranges in rank from sub-bituminous “C” to “A.” The average of five analyses, on an as-received basis (weathered samples from the lower member) indicates 8,789 Btu/lb heat value, 0.9 percent sulfur, and 8.3 percent ash.

3.1.2.6 Goshen Hole Coalfield

The Goshen Hole field includes approximately 250 square miles (T19-23N, R60-64W) in southern Goshen County in an area underlain by the Lance Formation. The area is about 75 miles southeast of the southern end of the Powder River Basin.

The coal bearing rocks in the Goshen Hole field are exposed in a topographic basin. Most of the coal outcrops are along Horse Creek, where several mines have been opened in the past. No coal more than 2.5 feet thick is known to occur in the field, though it is reported that a well near Meriden, in the southern part of Goshen County, penetrated once coalbed 4 to 5 feet thick and several thinner beds, all within 1,000 feet of the surface.

Because of the thickness (thinness) of the coalbeds at the surface, no resource/reserve data has been obtained representative of the Goshen Hole field. No analyses of coal from the field are available, but the coal is presumably of sub-bituminous rank like coal of the same age and geologic relationships elsewhere in Wyoming.

3.1.3 Oil Shale

The USGS estimates Wyoming's oil shale resource at 320 billion barrels in rock yielding fifteen gallons per ton or more within the Green River Basin and Washakie Basin (Brobst and Pratt, 1973).

The Green River Formation (Eocene age) is host to oil shale occurrences within the Luman Tongue, Fontenelle Tongue, Tipton Tongue, Tipton Shale Member, and Laney Shale Member. Presence of the oil shale bearing rock (with no implication as to yield or quality inferred) has been confirmed (Bradley, 1964; Love and Christensen, 1985).

In general, the oil shale occurrences occupy an extensive portion of the Washakie Basin (centered on the Adobe Town area), and there are discontinuous or intermittent occurrences present in the northwest portion of the Great Divide Basin.

These two areas encompass the following townships (listed in a general west-to-east sequence):

<u>Washakie Basin Oil Shale Occurrence</u>
T12-17N, R99-100W
T12-18N, R98W
T12-19N, R94-97W
T13-17N, R92-93W

Green River Basin Oil Shale Occurrence
T25N, R94-96W
T23N, R96W
T23N, R95W

3.1.4 Phosphate

Phosphate rock is the source for calcined phosphate compounds, roughly 90 percent of which are used as the major component of fertilizer. The remaining 10 percent of phosphate production is used to produce industrial chemicals such as elemental phosphorous or phosphoric acid (Stowasser, 1989).

Primary phosphate production in the United States (U.S.) centers in southeastern Idaho, where phosphatic ores are mined from the Permian Phosphoria Formation. The formation is estimated to encompass an area in excess of 175,000 square miles, and extends easterly (at significant depth) into the Great Divide – Washakie Basin areas of the RMPPA where it grades into the Goose Egg Formation. The Phosphoria Formation is not present in the central or eastern portions of the RMPPA.

The Phosphoria Formation consists of oolitic, phosphatic limestones and shales with interbedded shales, mudstones, and dolomitic limestones. The deposits are typically overlain by a cherty member, and underlain by either a limestone or a quartzite. The formation varies in thickness from a few to as much as 200 feet in some localities. Commercial grade phosphate is usually restricted to a comparatively narrow bed either near the top or bottom of the formation (Cochran, 1950).

Phosphate rock is classified by grade, on the basis of tri-calcium phosphate [$Ca_3(PO_4)_2$], or bone phosphate of lime (BPL) content, as follows: "low grade" (30 to 49.9 percent BPL); "medium grade" (50 to 69.9 percent BPL); or "high grade" (70 percent or greater BPL). Phosphate beds containing over 65 percent BPL content are generally considered to be of potential commercial grade.

The principal constituents of phosphate rock are lime, phosphate, silica, CO_2, organic matter, magnesia, alumina, iron oxide, and fluorine (listed in approximate order of abundance). In addition, appreciable quantities of vanadium are found in thin beds within the Phosphoria Formation. Investigation by the Geological Survey of Wyoming has determined that the phosphatic shales can contain as much as 0.01 percent to 0.02 percent U_3O_8 (uranium oxide) (Cochran, 1950; McKelvey, 1946).

3.1.5 Other Leasables

A number of saline minerals categorized as leasable minerals are present within the RMPPA, including sodium sulfate and potash. These minerals are typically present as evaporite deposits in Quaternary playas (i.e., sodium sulfate), or in bedded deposits in sedimentary rocks (i.e., potash) of Pennsylvanian age.

3.1.5.1 Sodium Sulfate

Sodium sulfate is an industrial chemical used in soap and detergents, in pulp and paper treatment, and in glass and other products (Kostick, 1989). Pure sodium sulfate is found in nature as the mineral thenardite (anhydrous). Hydrous sodium sulfate (mirabilite) is produced in Wyoming at the Pratt sodium sulfate deposit near Natrona in Natrona County. Other sodium sulfate rich soda lakes are found throughout Wyoming (Harris and others, 1985). Although none are being mined at the present time, known locations of soda lakes or soda salt deposits within the RMPPA include the following:

Within T22N, R96W	Red Desert Basin (west edge of RMPPA)
Within T20N, R95W	About 6 miles west-northwest of Wamsutter
Within T21N, R94W	About 9 miles northwest of Wamsutter
Within T24N, R95-96W	Lost Creek Lake
Within T25N, R88-89W	About 3 miles north-northeast of Separation Point
Within T22N, R84W	Midway between Fort Steele and Seminoe Reservoir
Within T15N, R75W	Soda Lake (Harmony vicinity, north of Laramie River)

3.1.5.2 Potash

Potash (K_2O, or potassium carbonate) is an evaporite mineral product used almost exclusively in fertilizer. Beds of potash are present in the subsurface in Goose Egg Formation equivalent rocks (Permian in age) in eastern Wyoming.

One indicated potash occurrence deposit (which is within the RMPPA) generally encompasses areas extending east-to-west (from the Wyoming-Nebraska state line) to approximately R67W, and, extending from the N½ of T16N to include all of T17-19N. Oil wells have penetrated this section, and a few cores of potash-rich rock have been recovered.

Although New Mexico currently produces most of the potash consumed in the U.S. and potash has not been produced from Wyoming in the past, these beds may be an economically viable resource of potash (Harris and King, 1986).

3.1.5.3 Geothermal Resources

According to the Geothermal Steam Act of 1970 as amended, (84 Stat, 1566; 30 U.S.C. 1001-1025), geothermal resources are: 1) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; 2) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; 3) heat or other associated energy found in geothermal formations; and 4) any byproduct derived from them. The Act provides the Secretary of the Interior with the authority to lease public lands and other federal lands, including National Forest lands, for geothermal exploration and development in an environmentally sound manner. This authority has been delegated to the BLM. BLM implements the Act through the regulations contained in 43 Code of Federal Regulations (CFR) Part 3200.

Geothermal leases are issued through competitive bidding for federal lands within a known geothermal resource area (KGRA), or noncompetitively for federal lands outside of a KGRA. There are no KGRA's within the RMPPA. The Rawlins Field Office will authorize exploration and development activities on geothermal leases. The Wyoming State Engineer regulates all water resources and the necessary permits would have to be obtained from this agency prior to development.

Geothermal energy in the RMPPA is the heat energy that is available from deep basin centered reservoirs or shallower hydrothermal convective systems that are connected to the deep basin reservoir systems. With aquifer flow from the deeper parts of the basin, shallower areas along the basin margins may access the geothermal energy of the moving water as a hydrothermal convective system. Beyond the basin margins, the aquifers are generally too deep to be economically drilled for the available low to moderate temperature geothermal resources (Heasler, 1983). Water quality as related to the TDS, pH, and reactivity or hardness could have wide ranges from different aquifers. Flow rates are also widely variable but some reservoirs have good productivity. Because of the low to moderate temperatures, water quality and flow rates will be a big factor in the economic viability of this resource. Water quality and flow rates affect the capture of the energy from the water and subsequent disposal of the effluent. Water flow rates and quality in the RMPPA has a large range from very good to poor (Heasler, 1983).

In the Rawlins RMPPA, only one geothermal resource has been documented (James, 1979). The Saratoga geothermal resource consists of a number of springs flowing from the Miocene North Park Formation along the North Platte in the downtown area of the town of Saratoga. The main spring and adjacent pool was originally used by Indians before white pioneers "discovered" the spring and later named the town Saratoga after the hot springs in New York State (James, 1979). Several wells have also tapped this resource and all are used for hot water supply to swimming pools (James, 1979). The report by James (1979) suggests that this geothermal resource would be used for district heating of municipal buildings and homes in the town of Saratoga. The City Clerk of the Town of Saratoga states that this project was never initiated.

Potential geothermal resources in the Rawlins RMPPA are restricted to basin margins of the deeper basins and areas in which Paleozoic reservoirs allow an aquifer of adequate capacity and high quality water. Only the Paleozoic time period have the necessary widespread and high quality reservoirs with the Tensleep (Casper) Sandstone and Madison Limestone being the primary formations. Reservoirs of other geologic ages are generally much more limited, have poor reservoir characteristics and would probably have poor water quality.

The Denver Cheyenne Basin in the eastern portion of the RMPPA has neither the depth nor the Paleozoic or other relatively continuous reservoirs to have potential geothermal resources. The Shirley Basin has the necessary reservoir rock but is not deep enough to generate the geothermal resource. There is some evidence that would suggest a hydrothermal convective system in the Laramie basin (Hinckley and Heasler, 1984) but the resource would have to be pumped and the economics would not be attractive. The Hanna Basin has anomalous geothermal gradients (Hinckley and Heasler, 1984) on its margin, which suggests a hydrothermal convective system. The basin margin of the shallow Kindt Basin has the only known geothermal resource in the RMPPA with the Saratoga Hot Springs and this is probably a hydrothermal convective system from the adjacent deep basins. It is unlikely that any new resource will be developed in the Kindt Basin unless an oil and gas well discovered a geothermal resource and it was completed for geothermal use. The deep Great Divide and Washakie Basins with their associated shallow margins and arches may have geothermal resource potentials but again it is unlikely that commercial ventures could be economically justified due to the relative isolation and limited application of the resource.

3.2 Locatable Minerals

Wyoming is a uranium province. Uranium was discovered in the Powder River and Wind River Basins during the 1950s, and continued exploration for uranium resulted in discovery of additional sedimentary uranium deposits in the major basins of central and southern Wyoming. The Rawlins RMPPA contains its share of sedimentary uranium deposits in the Shirley Basin, the Great Divide Basin, the Red Desert area, and around Baggs in the Poison Buttes area. In addition to uranium, the Rawlins RMPPA encompasses deposits of titaniferous magnetite, stratabound gold, copper-gold deposits, and diamonds hosted in kimberlite pipes (**Figure 3-14**). Commercial development of the sedimentary uranium and the titaniferous magnetite deposits has occurred over the past 50 years. The other locatable mineral deposits have seen only limited production and sporadic exploration. Locatable mineral deposits in the Rawlins RMPPA are summarized in **Table 3-6** and plotted on **Figure 3-15**, with locations summarized in **Table 3-7**.

Figure **3-14** Potential Mineral Resources

Table **3-6** Locatable Minerals Deposits in the Rawlins RMPPA

Figure **3-15** Locatable Minerals

Table **3-7** Locatable and Salable Minerals Deposit Location Index

3.2.1 Sedimentary Uranium Deposits

In the Rawlins RMPPA, sedimentary uranium deposits are found in the Shirley Basin, the Great Divide Basin, the Red Desert, and in the Poison Buttes and Ketchum Buttes areas near Baggs and Saratoga, respectively. Sedimentary uranium deposits in Wyoming are epigenetic sandstone-hosted deposits formed by groundwater movement in paleochannels along the margins of major depositional basins, most of which are Tertiary in age.

Groundwater carrying uranium moved downward and towards the basin center from either volcanic or Precambrian basement sources. This relatively oxidized groundwater followed old alluvial channels (paleochannels) formed when the basin was subsiding. As the groundwater moved basinward, it encountered more reducing conditions and the uranium in the groundwater is reduced and deposited as pitchblende, uraninite, and coffinite in a “roll-front” type setting within the paleochannel. These roll-front settings are relatively easy to identify in outcrop and in drill cuttings because of the rapid transition from oxidizing conditions characterized by iron oxides to reducing conditions characterized by clay alteration, a dark color or stain, and a noticeable increase in radioactivity.

3.2.1.1 Shirley Basin Deposits

Shirley Basin is a major uranium district in Wyoming located about 32 miles north of Medicine Bow. Commercial production of uranium began in the 1950s and continued until the early 1980s. In 1965, the Atomic Energy Commission estimated the reserve in Shirley Basin to be about 50 million pounds of U_3O_8 at $8/lb. This was approximately one-sixth of the known uranium reserve in the U.S. at that time (Harshman, 1972b). Production has come from mines owned or operated by Kerr McGee, Petrotomics, Utah Construction and Mining, and Pathfinder (Harshman, 1972a). These sedimentary uranium deposits are hosted in the Tertiary Wind River Formation. The deposits are in “stacked paleochannels” formed in alluvial/lacustrine sedimentary environments that developed as the Shirley Basin subsided and was filled with fluvial and lake-bed sediments during the Tertiary.

There are three major zones of altered and mineralized sand extending over a depth range of about 400 to 1,500 feet. These zones are vertically stacked and form a linear trend 6 miles long extending northwest down the approximate center of the basin. The largest of these zones is 5 miles long, 3 miles wide, and 70 feet thick. Mining grades during the 1950s and 1960s ranged from 0.1 to 0.7 percent U_3O_8. Grades in drill intercepts ranged up to 20 percent U_3O_8. Uranium is associated with copper, selenium, and vanadium minerals in the ore zones. The age of the deposits is approximately 18 to 20 million years before present (Harshman, 1972a). Published past production is 9.3 million pounds of U_3O_8 as of 1969 (Crew, 1969). It is estimated that about 10 million more pounds of U_3O_8 were produced in the 1970s and early 1980s, before the collapse of uranium prices. The mines are currently shut down and undergoing reclamation because of the low price of uranium. Should the price of uranium return to levels comparable to those found in the mid to late 1970s, uranium mining could resume. Future extraction could employ in-situ solution mining of the uranium, rather than the open-pit mining that characterized the 1950s and 1960s. It is estimated that about half of the estimated resource of 50 million pounds of U_3O_8 still remains in Shirley Basin.

3.2.1.2 Poison Buttes Deposits

The Poison Buttes deposits are found in the Tertiary Browns Park Formation west of Baggs, Wyoming. These are disseminated epigenetic uranium deposits formed in the tuffaceous eolian sands of the Browns Park Formation. Mineralization consists of autunite, uranophane, and schroeckinite in the upper oxidized portions of the deposit and coffinite in the lower parts of the deposit (Hausel, 1982; Harshman, 1968). During the 1970s, Urangesselschaft identified a major deposit containing a reserve of 8 to 15 million pounds of U_3O_8 and planned a mine with 2,000 tons per day production capacity. The sharp drop in uranium prices in the 1980s put the development of this deposit on hold. Past production in the district has been estimated at about 176,000 tons of ore during the period from 1954 to 1967 (Hausel, 1982).

3.2.1.3 Red Desert Deposits

These sedimentary uranium deposits are not commercially viable because of their low grade. Uranium is associated with lignite coal deposits in the Wasatch and Green River Formations. Disseminated uranium in the lignite beds has grades ranging from 0.003 to 0.007 percent U_3O_8. Estimated resources of uranium are 24,000 tons (Wyant and others, 1956).

3.2.1.4 Great Divide Basin Mineralization

Uranium mineralization in the Great Divide Basin consists of sandstone-hosted and evaporative epigenetic uranium shows or prospects scattered throughout the Tertiary Battle Spring, Green River, and Bridger Formations. No resources have been identified. The strongest showing of uranium is the evaporative mineralization at the Lost Creek Schroeckinite deposit, where uranium grades range from 0.013 to 0.28 percent U_3O_8 in the Green River Formation. The Battle Spring and Bridger Formations are found farther north, outside of the Rawlins RMPPA, in the Green Mountain-Crooks Gap area of Wyoming, where they are host to major uranium deposits. The evaporative deposits in the Great Divide Basin are due to uranium-rich waters migrating to the surface and evaporating in areas of groundwater seeps and pools. Larger, more economic deposits of uranium may exist at depth.

3.2.1.5 Sedimentary Uranium Prospect Areas

Exploration for uranium in the Rawlins RMPPA during the 1950s and again in the 1970s uncovered a number of areas with strong uranium showings. These areas are dotted with uranium prospects, but have no identified resources. Notable areas of uranium showings include: 1) the Ketchum Buttes area north of Encampment, Wyoming, where disseminated and roll-front uranium mineralization have been found in the Tertiary Browns Park Formation; 2) the Desert Rose area southwest of Laramie, Wyoming, where sandstone uranium prospects are found in the Cretaceous Cloverly Formation; 3) the Miller Hill area near Rawlins, Wyoming, where disseminated uranium is found in the Tertiary Browns Park Formation; and 4) the area around Encampment and Riverside, Wyoming, where sandstone-hosted uranium prospects are found in the Tertiary Browns Park Formation.

3.2.2 Titaniferous Magnetite Deposits

3.2.2.1 Iron Mountain District

Titaniferous magnetite deposits are found in the Laramie Range and within the Precambrian Laramie Anorthosite, located northeast of Laramie, Wyoming. This intrusive mass contains layers and lenses of titaniferous magnetite formed as magmatic segregations when the igneous mass cooled. Subsequent folding and deformation of the intrusive mass have resulted in the layers of magnetite being distributed along the anticlinal axis of the intrusive in the Iron Mountain District of the Laramie Range (Hausel, 1990). The magnetite is associated with ilmenite, olivine, and anorthisite feldspar. Past production has come from the Shanton, Iron Mountain, and Sybille mines. Past operators have been Anaconda and the Union Pacific Railroad and production to 1968 has been estimated at 1.1 million tons of magnetite ore (Hausel, 1990). Estimated reserves are 30 million tones of massive magnetite ore averaging 45 percent iron and 20 percent TiO_2. Disseminated ore is estimated at 148 million tons at 20 percent iron and 9.7 percent TiO_2.

The Iron Mountain District encompasses 350 square miles and contains both massive and disseminated ore in 30 identified mines and prospects (Hausel, 1990). Besides ilmenite, pyrrhotite, chalcopyrite, pyrite, and sphalerite are found in the ore zones. Vanadium grades in the ore zones range from 0.03 to .75 percent V_2O_5. Three main mines with proven resources have been identified. The Iron Mountain Mine (T19N, R71W) has a past production of 674,000 tons of ore (1963-1966). Massive ore is found along an antiform for a distance of 1,700 feet and to a thickness of 200 feet. The identified resource is 30 million tons at 16 to 23 percent TiO_2 and 0.5 percent V_2O_5. The Shanton Mine (T18N, R71W) has two massive ore zones 400 by 60 feet and past production of 14,500 tons (1972-1974). Titanium grades are 15 to 21 percent TiO_2. The Strong Creek Deposit (T19N, R72W) is a disseminated deposit rich in sulfides that has a proven resource of 300 million tons at 13 to 45 percent iron and 5 to 30 percent TiO_2 (Hausel, 1990).

3.2.2.2 Sheep Mountain Black Sandstones

This deposit is found in sandstones of the upper Cretaceous Mesaverde Formation at the north end of Sheep Mountain in section 10, T15N, R77W. The sandstone outcrop extends for 4,300 feet with an exposure width of 50 feet. The maximum exposed thickness is 17 feet. The sandstones contain 67 percent heavy minerals of which 28 percent are titaniferous magnetite. Samples of the unit have averaged 15.6 percent TiO_2, 40.4 percent Fe, and 0.0015 percent U_3O_8 (Houston and Murphy, 1962). No resources have been identified and there is no past production.

3.2.3 Stratabound Gold Deposits

Stratabound gold deposits within the Rawlins BLM district are found in the Ferris Mountains and the Seminoe Mountains. Both of these areas are Laramide-age uplifts where Precambrian metasedimentary rocks are exposed. No resources have been delineated, but older mines with limited past production and exploration during the 1980s have uncovered similarities to stratabound gold deposits in Canada that are known to host considerable reserves of gold.

3.2.3.1 Ferris Mountains

The stratabound gold deposits in the Ferris Mountains have been described as “vein-like” deposits and beds in Precambrian metasediments and granites” (Lovering, 1929; Hausel, 1980). The “veins” in the metasediments are actually exhalative iron-formation jasperoid gold and copper beds that have been deformed by many periods of folding. Gold is disseminated in the oxide iron-formation jasperoid-rich beds; the copper is found in chalcopyrite zones within these exhalative beds. The Spanish Trail Mine is the only mine in the Ferris Mountains developed on these beds for the purpose of extracting gold. The past production is not known, but is probably not considerable, given the size of the mine workings. Numerous prospects and pits are found throughout the area.

3.2.3.2 Seminoe Mountains

The Seminoe Mountains constitute an uplifted Archean metamorphic province (Precambrian) containing amphibolite – grade metasedimentary rocks, exhalative banded iron-formation beds containing basalts with copper and gold. The district was discovered in 1871. Early ore grades from the Desert Treasure and King Mines were in the range of 5 to 12 ounces/ton gold. By 1886, the Desert Treasure Mine had 200 feet of workings and a 10-stamp mill. By 1896, the King Mine had reached 700 feet of workings. Development of the area was hindered by frequent Indian raids (Hausel, 1994).

The Penn Mine at Bradley Peak has been studied in some detail because it is the largest mine developed on these iron-formation gold-bearing beds. This mine encompasses the old King Mine.

Past production has been estimated at 530 ounces of gold (Hausel, 1994). There is an estimated 100 million tons of iron ore at 28 to 68 percent iron as a resource in the Bradley Peak area. Gold values from samples taken in the outcrop of the iron-formation beds range up to 2.7 ounces per ton gold. Gold in the banded iron-formation beds is associated with pyrite and chalcopyrite. Nephrite jade also is found in the Precambrian metasedimentary rocks. Registered mines in the district include the Penn, Charlie's Glory, the Star, Hope, and Sunday Morning mines. No gold resource has been identified to date.

3.2.4 Copper-Gold Deposits

Copper-gold veins, disseminated ore, and mineralized shear zones are found in the Jelm Mountain District, the Cooper Hill District, and the Silver Crown District. All three areas have seen past mining, but only the Silver Crown District has a proven resource of copper and gold.

3.2.4.1 Jelm Mountain District

The Jelm Mountain District lies southwest of Laramie, Wyoming, and consists of oxidized copper-gold-silver-arsenic-bismuth "veins" in a tightly folded Precambrian amphibolite schist (Hausel, 1980). The Annie Mine has 3 to 30 percent copper and up to 0.1 ounce per ton gold. The Wyoming Queen has three shafts to depths of 250 feet. The past production records from both mines are not available. Similar "vein-like" gold and copper deposits are known from the Precambrian of Canada, where they are the source of major gold production.

3.2.4.2 Cooper Hill District

The Cooper Hill District lies southeast of Medicine Bow, Wyoming. Geologically, it is similar to the Jelm Mountain district with mineralized "veins" and shears in folded Precambrian metasedimentary rocks (Hausel, 1994). Three mines, the Charlie, the Emma G, and the Albion Mine have past production, with 30 tons of ore at grades of 0.85 ounces per ton gold recorded for the Albion Mine. Ore grades in samples range up to 0.7 ounce/ton gold and 12.2 ounces/ton silver (Hausel, 1994). The district was discovered in 1896, originally as a placer gold district. A 10-stamp mill was constructed to serve the mines. The quartz-pyrite-chalcopyrite-galena-gold veins are conformable to the folded bedding. Cross-cutting later quartz veins are barren. Adits and shafts were developed on at least seven separate mines in the district (Hausel, 1994). Recorded gold grades from past production range from 0.2 to 1.0 ounce/ton gold. The Rip Van Winkle Mine has a reported ore grade of 31 ounces per ton gold. The remaining gold resources in the district are not known.

3.2.4.3 Silver Crown District

The Silver Crown District lies southwest of Laramie, Wyoming, and consists of a mineralized Precambrian quart monzonite intrusive within the Nash Fork-Mullen Creek Shear Zone. This is a disseminated copper and gold deposit formed during Precambrian island arc volcanism. The Copper King deposit has a proven resource of 35 million tons of ore at 0.2 percent copper and 0.02 ounce per ton gold. The deposit will eventually be mined, when commodity prices for gold and copper increase to levels comparable to those found in the 1980s.

3.2.5 Kimberlite Pipes and Diamonds

Wyoming has two known diamond districts, the Iron Mountain District (Hausel and Roberts, 1984) in the Laramie Range and the Stateline District (Hausel and others, 1985) south of Laramie, Wyoming. Both districts have identified kimberlite pipes, some with diamonds, but neither district has had any production of diamonds. The diamonds are mainly of industrial quality. In the Stateline District, diamond grades range from 0.5 to 1.0 carat per 100 tons of rock. Exploration for diamonds in southern Wyoming is ongoing and a commercial deposit may be found in the next few years.

3.2.5.1 Stateline District

This district lies along the Colorado-Wyoming border and encompasses about 80 square miles. It is associated with the Virginia Dale Ring Dike complex. Kimberlite pipes of Silurian/Devonian age intrude the Sherman Granite, which is Precambrian in age. Forty kimberlite diatremes (or pipes) have been identified and 15 of these carry diamonds (Hausel and others, 1985). The district was discovered in 1975. Although most of the district lies in Colorado, Wyoming is host to many of the diamond-bearing pipes. The longest of the pipes is 1,800 feet in length. The potential for discovery and development of a commercial deposit is considered very good.

3.2.5.2 Iron Mountain District

This area of kimberlite pipes lies about 4 miles northeast of the Iron Mountain Titaniferous Magnetite District. The kimberlite pipes are Silurian/Devonian in age and intrude the Precambrian Sherman Granite. The kimberlite pipes form a northeast trend about 5 miles in length. To date, 57 pipes have been identified, but none are known to carry diamonds. The erosional level of the pipes may be too deep for diamond occurrences (Hausel and others, 1985).

3.2.6 Rare Earth Elements and Yttrium

Wyoming has deposits of rare earth elements and yttrium located in the northwestern and southeastern sections of the state (King and Hausel, 1991). The deposits are generally small, but can be high grade and economic if mined on a small scale. The deposits in northwestern Wyoming are in Tertiary carbonatite intrusions in the southern Bear Lodge Mountains and in Cambrian placer deposits in the Bighorn Mountains. In southeastern Wyoming, the deposits are associated with Precambrian pegmatites in Carbon County and in the Tie Siding area south of Laramie.

The common rare earth elements are lanthanum, cerium, and neodymium. These are often called the Cerium Group, or Light Rare Earth Elements. The Yttrium Group of elements are often considered as Heavy Rare Earth elements and yttrium is usually associated with the Cerium Group elements. Common minerals that carry the rare earth elements and yttrium are allanite, euxenite, samarskite, columbite and tantalite, and monazite. The rare earth elements and yttrium are used in superconductive materials, electronic components including television and computer monitor screens, ceramics, lasers, and as catalysts for distillation of petroleum products. The world supply of known rare earth element deposits is limited, with most mines being found in Russia, China, southeast Asia, California, Canada, and South Africa. Thus, the potential for small but economic deposits of rare earth elements in Wyoming is of considerable interest.

3.2.6.1 Tie Siding Pegmatites

These are Precambrian pegmatities located in T12N, R71W and R72W, and in T13N, R72W in Albany County. The pegmatites are highly radioactive and are found as pod-like masses in the Sherman Granite (King and Hausel, 1991). Pyrochlore, allanite, and zircon have been identified and assays for rare earth elements have ranged up to 1,000 mg/l for lanthanum and niobium, with yttrium at 200 mg/l and ThO_2 assays at 4.1 percent. Seven large pegmatites are known. There has been no reported production.

3.2.6.2 Red Mountain Syenite

This Precambrian intrusive mass is associated with the Laramie Range Anorthosite complex and is found in the eastern half of T22N, R71W. The syenite contains 1.5 to 3.6 percent disseminated allanite that carries rare earth elements. Assays contain up to 731 mg/l neodymium, 119 mg/l samarium, and 754 mg/l cerium (King and Hausel, 1991). No production has been recorded, but the potential size of the deposit makes this area a potential low-grade but open-pit mineable deposit.

3.2.6.3 Big Creek Pegmatite

The Big Creek pegmatite area is located in Carbon County in T13N, R80W and in T13N, R81W. The main pegmatite carrying rare earth elements is the Platt pegmatite found in Section 3 of T13N, R81W. This pegmatite was mined for rare earth elements and produced 10,000 pounds of euxenite between 1956 and 1958 (Houston, 1961). Other minerals in the pegmatite complex are columbite-tantalite, allanite, and monazite. There are many similar pegmatites found throughout the Precambrian terrain located south of Encampment, Wyoming, that contain rare earth elements and have not been adequately explored (King and Hausel, 1991).

3.2.6.4 Fox Creek Pegmatites

The Fox Creek pegmatites are located in T13N, R78W sections 13, 24, and 32 of Albany County. These pegmatites are rich in columbite and tantalite (Harris and King, 1987). The pegmatites have known lengths of 1,300 to 2,100 feet with widths of 50 to 200 feet. The depths are not known, but are at least in the range of 70 to 100 feet based on the shafts and pits that remain in the mined areas. Past production from these pegmatites has been estimated at 85 pounds of high grade, hand sorted columbite-tantalite (Harris and King, 1987).

3.2.7 Alumina Deposits

The Laramie anorthosite complex (situated in the central Laramie Range) contains plagioclase feldspar, an aluminosilicate of calcium-sodium rich feldspar. Anorthosite is an igneous rock composed almost entirely of plagioclase feldspar. The Laramie anorthosite complex is exposed over approximately 350 square miles and crops out along Rogers Canyon Ninth Street Road, about 11 miles northeast of Laramie. Specimens also have been noted along Highway 34 in Sybille Canyon north of Laramie (Housel, 1986).

3.3 Salable Minerals

Salable minerals disposition is addressed under the Materials Act of July 31, 1947, as amended by the Acts of July 23, 1955 and September 28, 1962. These Acts authorized that certain mineral materials be disposed either through a contract of sale or a free-use permit. This group of mineral materials, commonly known as “salable minerals” includes, but is not limited to common varieties of sand, stone, gravel, pumice, pumicite, cinders, clay, and petrified wood in public lands of the U.S. (Maley, 1977).

Salable minerals known to be present within the RMPPA include, but are not necessarily limited to, aggregate, silica sand, dimension stone, vermiculite, pumice and scoria, common clay, and decorative stone (e.g., moss rock, garden boulders, flagstone, etc.). To the extent petrified wood may be present within the RMPPA, it has been considered a paleontological resource rather than a mineral resource. Known deposits of salable minerals are shown in **Figure 3-15**.

3.3.1 Aggregates (Sand and Gravel)

By far, the most significant salable mineral (both in terms of occurrence and demand) within the RMPPA is aggregates, or sand and gravel. Aggregate resources typically occur in one or more of the following forms:

- natural gravel deposits (unconsolidated gravel or loosely or partially cemented gravel that can be removed without benefit of blasting or cutting);
- alluvial sand and gravel deposits (stream channel and flood plain deposits);
- terrace sand and gravel deposits (braided stream and sheet flood deposits of glacial and non-glacial materials derived from mountain ranges);
- glacial gravels;
- older gravel deposits (conglomerate); or
- windblown (dune) deposits.

Within the RMPPA, the aggregates resource base is relatively widespread with respect to sand-like materials (generally present as windblown, terrace, and alluvial deposits); however, coarser (gravel-type) materials are present to a somewhat lesser degree. Where gravel is present, it is generally as an older gravel (conglomeratic) deposit, oftentimes situated beneath surficial deposits.

Former gravel and aggregate deposits within the RMPPA are noted as having been present near Fort Steele (T21N, R85W), near Elmo (T22-23N, R81W), near Creston Junction (T21N, R92W), and in the Red Desert Basin (T21-23N, R95-97W).

Identification of the known aggregate deposits (by type and general location) is provided in the following sections. Due to the variability in gradational attributes, individual deposits will likely require site-specific determinations as to suitability for potential uses.

3.3.1.1 Terrace Deposits – Sand and Gravel

Mapped occurrences of terrace deposits are noted to be present at the following general locations. While mapping (Harris, 1996) indicates the presence of "sand and gravel" deposits at these locations, limited reconnaissance-level field examination indicates a predominance of gradation as sand, rather than gravel, at most locations. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T25N, R95-86W	North of Lost Creek Basin
T22N, R95-96W	Northeast flank of Red Desert Basin
T20-21N, R92W	Creston Junction area
Carbon County	
T26N, R87W	South flank of Ferris Mountains
T24-25N, R83-86W	Surrounding Seminoe Reservoir
T24-25N, R81-82W	West flank of Shirley Mountains
T19-20N, R80W	Elk Mountain area south of I-80
T24-25N, R78W	North of Medicine Bow, either side of Highway 487
T24N, R77W	TB Flat, between Muddy Creek and Little Medicine Bow River
T22N, R77-78W	Medicine Bow area, south of Highway 287
T20-21N, R77-78W	West of Rock Creek
Albany County	
T22N, R77W	Medicine Bow area, south of Highway 287, west of Wilcox
T20-21N, R77W	Rock River area, west of Rock Creek
T20N, R75-76W	Southeast of Rock River, south side of Highway 30
T21N, R74W	6 miles southwest of Wheatland Reservoir
T18N, R74-75W	Bosler/Cooper Lake area
T17N, R75-76W	West of Laramie River, both sides of I-80
T16N, R74-76W	West of Laramie along Highway 130 extending to Hatton
T14N, R75-76W	North of Highway 230, Harmony/Woods Landing area
T13N, R74-75	Antelope Creek area, south of Highway 230 and West of Highway 287
T13-16N, R73W	Intermittent deposits along either side Highway 287
Laramie County	
T18N, R61-62W	Meriden to Tremain
T12-15N, R60-63W	I-80 corridor Burns to Pine Bluffs south to state line

3.3.1.2 Alluvial Deposits

Mapped occurrences of alluvial deposits are noted to be present at the following general locations. While mapping (Harris, 1996) indicates the presence of "sand and gravel" deposits at these locations, limited reconnaissance level field examination indicates a predominance of sand, rather than gravel, at most locations. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	General Locational Description
Sweetwater County	
T24N, R96W	East of Hay Reservoir
T24N, R95W	Mouth of Eagles Nest Draw
T19N, R93W	Echo Springs area southeast of Wamsutter
T25-26N, R89-90W	Bairoil/Lamont area
Carbon County	
T23-24N, R88-89W	Separation Creek area, either side Highway 287
T23-24N, R87W	Separation Lake – Dry Lake area
T22N, R86W	Area north of Sinclair
T12-17N, R91-92W	Along extent of Muddy Creek, east side of Baggs Road
T15-18N, R83-85W	North Platte River and tributaries in Saratoga Area
T19-20N, R83W	Pass Creek, valley extending north-south
T26N, R81W	Grinnell Lake area northeast of Shirley Mountains
T22N, R78W	East of Medicine Bow
T19-20, R78W	McFadden area (Rock Creek/Pierce Reservoir)
Albany County	
T15N, R78W	Centennial area
T25-26N, R77W	Big Charley Lakes/Sheep Creek area
T25N, R74-75W	Laramie Range, headwaters North Laramie River
T17-21N, R73-74W	W of Laramie Range, Wheatland Reservoir to Laramie
T16N, R76W	Little Laramie River, north of Millbrook
T14-15N, R74-76W	Laramie River, Woods Landing to Laramie
T15N, R73-74W	South of Laramie, east of Highway 287

3.3.1.3 Wind-Blown Deposits

The RMPPA has extensive wind-blown deposits of sand, as exhibited by dune formations present south of the Ferris Mountains and west of Seminoe Reservoir, and by surficial deposits in the southwest (Cow Creek) and extreme southwest (Adobe Town) portions of the area. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	**General Locational Description**
Sweetwater County	
T21-23N, R95-96W	Red Desert Basin, southwest of Lost Creek Basin
T13-17N, R94-97W	Intermittent/scattered deposits – Adobe Town area
T16-17N, R93-94W	Vicinity of Barrel Springs Draw(s)
T16-17N, R90-91W	Cow Creek – Muddy Creek area, south of Sulphur
T24-26N, R84-89W	Ferris Mountains – Seminoe Reservoir area (dunes)
T27-28N, R85-86W	North of Ferris Mountains, west of Pathfinder Reservoir
T22N, R86W	North of Sinclair (scattered deposits)
T23N, R85W	Southwest end of Seminoe Reservoir
T22N, R84W	8 miles northeast of Fort Steele (scattered deposits)

3.3.1.4 Conglomeratic or Consolidated Gravels

Includes selective areas of poorly consolidated to consolidated gravels and conglomerates in rocks of Late Cretaceous to Pleistocene age. In some cases, the deposits are likely overlain by thin surficial deposits. These deposits, listed by county, and in a general west-to-east sequence, include the following:

Township/Range	**General Locational Description**
Sweetwater County	
T25N, R95-96W	Great Divide Basin, north and east of Wamsutter
T23-25N, R94W	Contiguous extension of above
T22-26N, R92-93W	Contiguous extension of above
T21-26N, R90-91W	Contiguous extension of above
Carbon County	
T28N, R81-83W	Extending 8-22 miles east of Pathfinder Reservoir
T27N, R82W	Extending 10-15 miles east of Pathfinder Reservoir
T16-19N, R 79-81W	Kennaday Peak, Medicine Bow River, south of Elk Mountain
T19-20N, R79W	North of I-80 between Elk Mountain and Arlington
T18-19N, R78W	East of Arlington extending south to Sevenmile Creek
Albany County	
T16-17N, R77W	Area south and east of Sevenmile Creek, south of I-80

3.3.1.5 Baked and Fused Shale (aka "Scoria")

Although more properly classified as a salable mineral under the category of "common clay," the baked/fused shale or "scoria" has been included under the category of aggregates. This is because surface outcrops of baked and fused shale (locally referred to as "scoria" or "klinker," but not technically a true volcanic-derived scoria) are important sources of aggregate (as a substitute when economically obtainable aggregate is not readily available) throughout Wyoming. Typically, this material is present in association with coal outcrop or burn lines, and as such, is abundantly present within and around the Hanna Basin coal mines, where it is utilized in the construction of haul roads. In addition, it is present at other locations exhibiting similar coal outcrop or burn lines, including several large deposits in the area stretching from Creston Junction to Baggs. Known, mapped locations of this type of scoria are indicated as follows:

Township/Range	General Locational Description
Sweetwater County	
T20N, R94W	4 miles northwest of Wamsutter, north of I-80
T20N, R94W	2.5 miles northeast of Wamsutter along I-80

3.3.2 Silica Sand

Silica sand of very pure quality is used in making glass and ceramics. In the Rawlins RMPPA, there are two areas of silica sand resources. One area is south of the Shirley Basin in the Freezeout Mountain area (T25N, R79W). The other is the Plumbago Creek deposit in Albany County (T20N, R73W). Both of these are orthoquartzite sands with greater than 70 percent SiO_2 that can be cleaned and purified to 90 to 95 percent SiO_2 by grinding and washing. The proven resource at Plumbago Creek is 64 million tons (Harris, 1988). As with most industrial minerals, production is dependent on local demand.

3.3.3 Limestone and Dimension Stone

Limestone can be quarried for dimension stone, for aggregate, or for industrial uses as lime. Dimension stone can include granite, marble, and certain sandstones suitable for quarrying and use in buildings. In the Rawlins RMPPA, limestone is mined north of Laramie along the west slope of the Laramie Range for use in cement, and dimension stone is quarried from around Rawlins in the Rawlins Uplift (Harris, 1991). Limestone has been quarried along the east and west flanks of the Laramie Range for years (Hagner, 1953) from the Paleozoic Casper Formation. Two limestone quarries are operated north of Rawlins, along the crest of the Rawlins uplift. These quarries are operated by the Wyoming Department of Transportation and Pete Lich and Sons and mainly used for aggregate production. The locations of former and active limestone and dimension stone quarries in the Rawlins RMPPA are shown on **Figure 3-16**.

Figure **3-16** Salable Minerals

3.3.4 Vermiculite

Vermiculite is a name given to a group of hydrated magnesium aluminosilicate minerals that expand when heated. Vermiculite is a family of related minerals; the term also is used for the expanded product in industrial applications (Harris, 1991). Vermiculite is formed by the hydrothermal alteration of biotite and hornblende. Thus, it occurs only in areas of igneous activity and is associated with high temperature fluids. Vermiculite is used as a lightweight aggregate, a soil conditioner in agricultural applications, and in selected industrial applications. The largest resources of vermiculite in Wyoming are in the Encampment area.

The Baggot Rocks vermiculite deposits are located near Riverside, Wyoming, in T15N, R83W. These deposits were formed by the hydrothermal alteration of hornblende and biotite schists adjacent to intrusive Precambrian pegmatites. The two main deposits in this area are the Platte Ranch and Paine vermiculite pits. No resource has been identified, but about 1,000 tons of vermiculite have been mined from the Platte Ranch pit (Hagner, 1944).

3.3.5 Pumice and Scoria

Pumice and scoria are volcanic rocks made of glass and usually full of holes called vesicles. Pumice is used as an abrasive, as a filler in concrete block, and for aggregate. Scoria can be used as a substitute for pumice in most industrial applications. It differs from pumice primarily in its angularity (sharpness) and dark color. Deposits of pumice are found at Sportsman Lake (T13N, R73W) in Albany County, near Creston (T20N, R92W) in Sweetwater County, and near Seminoe Dam (T25N, R84W) and Buzzard Ranch (T26N, R85W) in Carbon County (Harris and King, 1986).

As indicated earlier, there is another type of "scoria" (technically not a scoria since it is not volcanic in origin, but rather a baked and fused shale that is locally referred to as "scoria") present within the RMPPA. The reader is referred to Section 3.3.1 for discussion of this type of deposit.

3.3.6 Common Clay

Clay minerals are hydrous aluminosilicate minerals with a sheet-like structure. Common clay is an industrial classification (by use) of clay, and it consists of clay or clay-like material that is sufficiently plastic to permit molding (Ampian, 1985). It is composed of the minerals illite, smectite, and kaolinite (Patterson and Murray, 1983). Common clay was produced in almost every county in Wyoming during the early years of statehood, typically for the manufacture of bricks that were used locally (Harris, and King, 1987). Occasionally, clay pits are opened for an immediate local need (e.g., landfill or lagoon liner material, etc.).

There are three former clay sites in Albany County at the Idealite deposit (T14N, R74W, S4), the Hutton Lake deposit (T14N, R74W, S34 and 27) and near Laramie (T16N, R74W, S36). The Cretaceous Frontier and Cloverly Formations and the Jurassic Morrison Formation are the principal sources of clay in Albany County. These former deposits were mined from shallow pits and are now inactive.

In Carbon County, there is a carbonaceous clay deposit in the Mesaverde Formation near Rawlins (T21N, R88W, S25) and clay deposits in the Hanna area (T22N, R81W, S3, 10, and 16) and near Sinclair (T21N, R86W, S21). These clays were used as lightweight aggregate and for brick clay.

Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. In certain areas of Wyoming (generally in association with coal outcrops or burn lines), baked and fused shales are present. Locally, this material is referred to as “scoria” (although not a true “scoria” since it is not of volcanic origin). This material if oftentimes utilized locally as an aggregate substitute. The reader is referred to Section 3.3.1 for discussion of this type of deposit.

3.3.7 Decorative Stone

Decorative stone is any rock product (exclusive of aggregate) that is used for its color or appearance. Although color and appearance are important criteria in selecting decorative rock, the rock must frequently meet strength, durability, and other specifications. These specifications can include the absence of sulfides or minerals that could oxidize and stain or discolor the rock.

A number of decorative rock products are produced from within the RMPPA. A predominant number of decorative stone locales (i.e., marble, quartzite, granite, etc.) are situated within the Medicine Bow National Forest, in areas of the Sierra Madre and Medicine Bow Mountains (not included below). General classifications and locations (Harris, 1996) of other deposits are shown in **Table 3-8**.

Additional decorative rock products that are present within the RMPPA include moss rock and boulders. These rock products are typically utilized for structural, architectural, or landscaping applications.

A sizeable outcrop of moss rock (sandstone) is present in the southwest portion of the RMPPA (T12N, R98W), in the vicinity of the Colorado state line (north of the Powder Wash, Colorado, residence camp). Although BLM mineral disposal sales have occurred in this area, there is evidence to suggest that significant trespass and theft activity also has occurred.

Table 3-8
Locations of Decorative Stone

Rock Product/Classification	Township/Range	General Locational Area
Alabaster	T25N, R80W	East end Shirley Mountains
Decorative Stone	T14N, R78W	3-4 miles west of Lake Owen
Dec. Stone (Leopard Rock)	T22N, R71W	10 miles east of Wheatland Reservoir
Decorative Stone	T28N, R71W	5 miles southeast of Estabrook
Decorative Aggregate	T17N, R78W	6 miles southwest of Morgan
Decorative Aggregate	T14N, R78W	4 miles southwest of Lake Owen
Feldspar (Potassium)	T12-14N, R71-72W	10-15 miles east of Laramie
Feldspar (Potassium)	T15-16N, R70W	12-15 miles east of Laramie
Feldspar (Potassium)	T20, R72W	14 miles northeast of Bosler Junction
Granite, Orbicular	T27N, 87W	Ferris Mountains
Marble	T18N, R78W	West of Morgan
Marble	T20N, R72W	12 miles northeast of Bosler Junction
Marble	T19-20N, R71-72W	10 miles northeast of Bosler Junction
Marble	T24-25N, R70-71W	18 miles west of Curtis
Mineral Pigments (Fe Oxide)	T22N, R88W	4 miles north of Rawlins
Mineral Pigments (Fe Oxide)	T21N, R87W	2 miles north of Rawlins
Mineral Pigments (Fe Oxide)	T22N, R78W	5 miles east of Medicine Bow
Sandstone (“Rawlins”)	T20N, R87W	4 miles southeast of Rawlins
Quartzite	17N, R79W	8 miles northeast of Medicine Bow

3.3.8 Epsomite

Epsomite ($MgSO_47H_2O$) also is known as epsom salt. It has been used in relatively small quantities in the past for industrial chemicals and medical products.

In the early years of the 20th century, at Rock Creek Lakes in Albany County and at Poison Lake in Converse County, small plants were constructed to produce epsomite. Small resources of epsomite remain present at these and other sites within the RMPPA.

Epsomite deposits in the Rawlins BLM district can be found in the Red Desert Basin (T22-23N, R96-99W), the Boggy Meadows area near Bairoil (T25N, R88-89W), Taylor Draw near Medicine Bow (T22N, R76W), Rock Creek Lakes (T23N, R76W), Chain Lakes (T23N, R93W), and near Elkhorn Draw in the Laramie Peak area (T24N, R75W). Deposits also are found at Union Pacific Lakes and Downey Lakes south of Laramie (T13N, R75W). The Downey Lakes occupy a wind-excavated depression in the Triassic Chugwater Formation (Harris, 1987). The lakes cover about 100 acres and are up to 12 feet deep. The Rock Creek Lakes are north of Laramie and are a group of saline lakes and playas in a closed depression in the Chugwater Formation. The Union Pacific lakes are located 13 miles south of Laramie adjacent to Highway 230. Production was active in this area during 1885 (Harris, 1987). Epsomite resources in Wyoming are small, but capable of supplying a local market if demand should rise. Currently, there is no active epsomite production in Wyoming (Harris, 1991).

In addition, “saline” mineralization (not defined) mineralization (Harris, 1996) is indicated to be present in two small deposits located within T17N, R73-74W, in the vicinity of the town of Howell (west of Highway 287).

3.3.9 Petrified Wood

Petrified wood is organic woody material that has been replaced by microcrystalline quartz or opal. Most Wyoming petrified wood formed 30 to 40 million years ago, a result of trees being buried under volcanic ash. It is mainly considered to be of value to specimen collectors. While it is technically a salable mineral (obtainable subject to limitations under a free-use designation), it has no significant commercial value. It is, however, considered a paleontological resource, and collection is subject to terms and conditions consistent with the preservation of significant deposits as a public recreational resource. The only known concentration of petrified wood in the RMPPA occurs in the Shirley Basin.