2.0 DESCRIPTION OF GEOLOGY

2.1 Physiography

The RMPPA is primarily located in the extreme northern portion of the Greater Green River Basin (**Figure 2-1**), which is part of the Wyoming Basin Physiographic Province that includes much of southwestern Wyoming and part of northwestern Colorado. The province consists of a 40,000-square-mile area bounded by the Middle Rocky Mountains, the Southern Rocky Mountains, and the Great Plains Provinces (Howard and Williams, 1972). A small portion of the Wyoming Basin Province is bounded on the southwest by the Colorado Plateau. The Wyoming Basin Province is typified by topographic and structural basins that are either bounded by mountains in the adjacent provinces or bounded by ranges within the province. The major basins within this province include the Greater Green River, Wind River, Laramie, and Hanna Basins. Within each of the major basins, there are numerous sub-basins.

The RMPPA is essentially a triangular-shaped area bounded on the north and northeast by Gros Ventre and the Wind River Mountains, and on the west by the Wyoming and Hoback Ranges (**Figure 2-2**). Small portions of the RMPPA are in the Wind River and Wyoming Ranges, which are part of the Middle Rocky Mountain Province. A small portion of the Wyoming Range extends into the southwestern corner of the RMPPA and portions of the southwest flank of the Wind River Mountains are located in the RMPPA. The southern boundary of the RMPPA does not follow a readily discernible topographic boundary. Except along the edges of the mountain fronts, there is moderate relief in the RMPPA with elevations ranging from about 6,500 feet National Geodetic Vertical Datum (NGVD) in the southwestern corner to above 7,500 NGVD along the western and northern portions of the area. Along the mountain fronts, elevations range from 9,000 to 9,500 feet NGVD. Topographic relief features in the area include mesas and buttes. The RMPPA contains two major drainages, the Green River and the Hoback River. Most of the RMPPA is in the drainage of the Green River that begins in the northern Wind River Mountains and flows south and exits from the RMPPA south of the Town of La Barge. A very small portion of the northwest part of the RMPPA is in the drainage of the Hoback River that eventually drains to the Snake River at Hoback Junction about 60 miles northwest of Pinedale. The drainage divide between the Hoback and Green Rivers is a topographic feature referred to as “The Rim” (Lageson and Spearing, 1991). The drainage basin of the Hoback River also is referred to as the Hoback Basin (Dorr and Steidtmann, 1977).

Figure **2-1** Physiographic Provinces in Relation to the Wyoming Basin

Figure **2-2** Physiographic and Structural Elements of the Northern Green River Basin

2.2 Stratigraphy

The rocks in the RMPPA range in age from Precambrian to Recent (**Figure 2-3**). In the northern Green River Basin, the total thickness of sedimentary rock above the Precambrian is about 32,000 feet (Law, 1995). Rocks exposed at the surface are largely composed of Tertiary and Quaternary deposits although there are limited exposures of Precambrian, Paleozoic, and Mesozoic rocks. Precambrian Rocks are exposed on the southwest slope of the Wind River Mountains. Paleozoic and Mesozoic Rocks are exposed in the southwest corner of the RMPPA while Mesozoic Rock outcrops occur along the western boundary of the RMPPA. The following subsections provide general descriptions of the surface and subsurface rocks that occur in the RMPPA.

2.2.1 Precambrian Era

The Precambrian Rocks that are exposed on the western slope of the Wind River Mountains consist of igneous granodiorite and granite (Love and Christiansen, 1985). The Precambrian Rocks that form the basement (i.e., crust of the earth below sedimentary deposits) of the Green River Basin in the RMPPA also are presumed to be granitic type rocks (Simms and others, 2001; Gary and others, 1974). No wells are known to have penetrated the Precambrian Rocks in the deep basin portions of the RMPPA (IHS Energy Group, 2002), but several wells have been drilled into the Precambrian rocks along the southwestern flank of the Wind River Mountains. Precambrian rocks are covered with a thin veneer of Tertiary and Quaternary deposits along the southwestern flank of the Wind River Mountains, but may be over 30,000 feet deep in the deepest parts of the northern Green River Basin.

2.2.2 Paleozoic Era

2.2.2.1 Cambrian System

The Cambrian Formations in the RMPPA include the Flathead Sandstone, Gros Ventre Formation, and the Gallatin Limestone (Love and others, 1993). The Cambrian rocks consist of coarse-grained sandstone, shale, and limestone that may be as thick as 1,500 feet (Lachman-Balk, 1972). One well of record, located near La Barge, Wyoming, in the southwestern part of the RMPPA, was drilled to 15,350 feet and Cambrian rocks were reportedly encountered at total depth (TD) (IHS Energy Group, 2002). Cambrian rocks also are exposed in the mountain front west of La Barge.

Figure **2-3** Stratigraphic Nomenclature Chart

2.2.2.2 Ordovician System

The Ordovician System in the RMPPA is represented by the Bighorn Dolomite and may be between 250 and 500 feet thick (Foster, 1972). The Bighorn Dolomite and equivalent rocks are important hydrocarbon (i.e., oil, natural gas) producers outside of the RMPPA in the Big Horn Basin of Wyoming and in the Williston Basin of Montana and North Dakota.

2.2.2.3 Silurian System

There are no rocks of the Silurian System in the area (Boyd, 1993).

2.2.2.4 Devonian System

The Darby Formation is of the upper Devonian System and consists of brown dolomite and limestone overlain by siltstone and shale (Love and Christiansen, 1985). In the RMPPA, the Darby Formation ranges from less than 10 feet to 40 feet in thickness (Baars, 1972).

2.2.2.5 Mississippian System

The Mississippian System is represented by the Madison Limestone (Love and others, 1993). The Madison Limestone and equivalents are extensive in the Rocky Mountain region from northern Arizona to Montana and North Dakota (Craig and others, 1972). The Madison ranges from less than 500 feet thick to over 1,000 feet thick in the RMPPA and largely consists of massive limestone and dolomite (Love and Christiansen, 1985). The Madison Limestone is an important producer of carbon dioxide gas (DeBruin, 2001).

2.2.2.6 Pennsylvanian System

Rocks of the Pennsylvanian System consist of the Amsden Formation and Tensleep Sandstone. The age of the Amsden also may be associated with upper Mississippian (Love and others, 1993). The Amsden Formation consists of limestone, sandstone, and conglomerate (Love and Christiansen, 1985). The Tensleep Sandstone is a widespread sandstone that also contains minor limestone and dolomite beds (Watson, 1980). The Amsden Formation and the Tensleep Sandstone together vary from about 1,000 feet in thickness in the western part of the RMPPA to around 400 feet thick in areas closer to the Wind River Mountains (Peterson, 1984). The Tensleep Sandstone is an important oil producing sandstone in other parts of Wyoming, but is not listed among active producing formations in the RMPPA (Wyoming Oil and Gas Conservation Commission [WOGCC], 2002a).

2.2.2.7 Permian Period

In the RMPPA, the Phosphoria Formation is about 250 feet thick and consists mainly of black organic-rich, phosphatic shale (Peterson, 1984). The Phosphoria Formation is an important phosphate source outside of the RMPPA. However, the Phosphoria may be an important source rock for petroleum.

2.2.3 Mesozoic Era

2.2.3.1 Triassic System

In the western part of the RMPPA, the Triassic rocks consist of the Dinwoody Formation, Woodside Formation, Thaynes Limestone, and the Ankareh Formation that grade to the east into the Chugwater Formation (Love and others, 1993). The Dinwoody Formation consists of dolomitic siltstone; the Woodside Formation is composed of red and maroon shale; the Thaynes Limestone is largely limestone with some limey siltstone; and the Ankareh is composed of dark red to maroon shale, siltstone, and sandstone (Love and Christiansen, 1985; Watson, 1980). The thickness of the Triassic section in the RMPPA may range from 2,000 to 3,000 feet, with these rocks becoming progressively thicker to the west. The Thaynes Limestone thins to the east and grades into the shale of the Chugwater Formation (Love and others, 1993). The Chugwater Formation in the northern Green River Basin consists of red siltstone and shale.

The Nugget Sandstone is of uncertain age and has been divided between upper Triassic and lower Jurassic (Love and Christiansen, 1980). The Nugget Sandstone and equivalents is widespread throughout southwestern Wyoming, northwestern Colorado, and Utah. The thickness of the Nugget Sandstone may vary from 500 to 1,000 feet from east to west across the RMPPA (MacLachlan, 1972). This sandstone has excellent porosity and is a well-known hydrocarbon producer in Wyoming and Utah. The Nugget produces oil and gas from several fields in the Big Piney-LaBarge area (WOGCC, 2002b).

2.2.3.2 Jurassic System

Formations of the Jurassic System, which are younger than the Nugget Sandstone in the RMPPA, include the Twin Creek Limestone, Preuss Formation, Stump Sandstone, Gypsum Springs Formation, Sundance Formation, and Morrison Formation (Love and others, 1993). The total aggregate thickness of Jurassic rocks in the RMPPA may be 1,500 to 2,500 feet (Peterson, 1972). The Twin Creek Limestone is an oolitic limestone; the Preuss Formation consists of red and brown siltstone and sandstone; and the Stump Sandstone is a sandy and shaley calcareous sandstone (Watson, 1980). The Twin Creek, Preuss, and Stump grade to the east into the Gypsum Springs and Sundance Formations (Love and others, 1993). The Gypsum Springs consists of marine redbeds and gypsum and the Sundance Formation is composed of red and gray sandstone and shale (Love and Christiansen, 1985). The upper Jurassic is represented by the Morrison Formation composed of variegated shale, conglomerate, and sandstone (Watson, 1980).

2.2.3.3 Cretaceous System

When describing Cretaceous rocks, they are often divided into upper and lower Cretaceous. The total aggregate thickness of lower Cretaceous Rocks in the RMPPA may be about 2,000 feet (McGookey and others, 1972). Upper Cretaceous Rocks are at least 11,500 feet thick (Law and Johnson, 1989).

Lower Cretaceous

The lower Cretaceous is comprised of the Gannett Group, Bear River/Cloverly Formations, Thermopolis Shale, and Muddy Sandstone. The Gannett Group consists of claystone, sandstone, conglomerate, and freshwater limestone (Watson, 1980). The Bear River Formation consists of sandstone, conglomerate, black shale, and freshwater limestone. The Bear River Formation is used locally in the Wyoming Range area, while further east, equivalent rocks in this interval are the Cloverly Formation, Thermopolis Shale, and Muddy Sandstone (Love and others, 1993). The Bear River Formation and Muddy Sandstone produce oil and gas from fields in the Big Piney-LaBarge area (WOGCC, 2002b).

Upper Cretaceous

In the RMPPA, the upper Cretaceous consists of the Aspen Shale, Frontier Formation, Baxter (or sometimes referred to as the Hilliard) Shale, and Mesaverde Group (Love and others, 1993). The Aspen Shale is a dark gray silty shale with bentonite beds. The Frontier Formation may vary from 1,500 to 2,000 feet thick and is composed of sandstone, dark shale, and local coals (McGookey and others, 1972; Watson, 1980). The Baxter Shale may be up to 3,000 feet thick and consist of gray shale with silt and sand progressively increasing higher in the section (Law and Johnson, 1989). The Mesaverde Group is a designation for widespread upper Cretaceous sedimentary rocks in the Greater Green River Basin that consist of sandstone, carbonaceous shale, and coal. The units that compose the Mesaverde Group are the Blair Formation, Rock Springs Formation, Ericson Sandstone, and Almond Formation (Ver Ploeg, 1992). The Mesaverde Group present within the RMPPA is estimated to be 4,800 feet thick (Law and Johnson, 1989). The uppermost Cretaceous unit is the Lance Formation and it is composed of sandstone, siltstone, shale, and mudstone and is about 5,500 feet thick. The Frontier and Lance Formations are important hydrocarbon-producing zones in the RMPPA. The Mesaverde Group contains coal seams that may be prospective for coalbed methane (CBM) production.

2.2.4 Cenozoic Era

2.2.4.1 Tertiary System

Paleocene Series

The earliest Tertiary rocks in the RMPPA are found in the Paleocene Fort Union Formation (Love and others, 1993). The Fort Union Formation in the area is comprised of interbedded conglomerate, sandstone, siltstone, and mudstone (Law and Johnson, 1989), but does not contain abundant coal that is common to the Fort Union in other areas. On the west side of the RMPPA, in the Big Piney – La Barge area, the lowest Tertiary is called the Almy Formation. According to Law and Johnson (1989), there is an unnamed older Tertiary unit in the Pinedale Anticline area. The unit is reported to be about 1,300 feet thick and is composed of fluvio-deltaic derived sedimentary rocks. The Almy Formation is an important oil and gas producing zone in the Big Piney-LaBarge area (WOGCC, 2002b).

Eocene Series

The Eocene is represented by the Wasatch and Green River Formations. The Wasatch Formation progressively thickens from south to north in the RMPPA from 3,000 feet at La Barge to around 9,000 feet thick in the Pinedale area (Roehler, 1992). The Wasatch Formation is generally described as being composed of green and red mudstone and interbedded variegated sandstone. Weathering and erosion of the Wasatch Formation has resulted in the formation of buttes and badlands with distinctive red and green colors of the strata and generally form the buttes and mesas characteristic of the topography of the area. The Fontennelle Tongue, Farson Sandstone, Wilkins Peak, and Laney Shale Members of the Green River Formation are found in the southern portions of the RMPPA (Love and Christiansen, 1985). The main body of the Green River Formation is further south and occupies the central and southwestern portion of the Green River Basin. The Fontennelle Tongue consists of oil shale, marlstone, and limestone. The Farson Sandstone Member is composed of mainly tan and gray lacustrine sandstone. The Laney Shale Member consists of sandstone, marlstone, and oil shale (Watson, 1980). The Wilkins Peak Member consists of sandstone, marlstone, and trona. The Green River Formation is not present in most of the RMPPA, but is approximately 500 feet thick in the southern part of the RMPPA (Roehler, 1992). Portions of the Wasatch and Green River Formations are contemporaneous and some members of each interfinger with another. Another Eocene Formation that is present in the northern portion of the RMPPA is the Pass Creek Formation. It is present immediately south of the

Gros Ventre Range and consists of conglomerate that is gold-bearing (Love and Christiansen, 1985).

Oligocene-Miocene-Pliocene Series

The Oligocene through Pliocene Tertiary Series are not represented in the RMPPA (Love and Christiansen, 1985).

2.2.4.2 Quaternary System

Unconsolidated Quaternary deposits consist of alluvium, terraces, colluvium, gravels, pediments, and glacial deposits (Love and Christiansen, 1985). Alluvial deposits are generally associated with alluvial valleys of the Green River and tributaries. In the northwestern portion of the RMPPA, terrace deposits are widespread between the river valleys (Oriel and Platt, 1980). The terrace deposits are composed of coarse to fine gravel and can be as much as 300 feet thick. Glacial deposits are found along the southwestern flank of the Wind River Mountains and are largely composed of boulders, cobbles, and fine materials that were scoured from the mountains by the glaciers. The alluvial and terrace deposits contain gravel resources that are mined in various parts of the RMPPA.

2.3 Structural Geology and Tectonics

The northwestern extension of the greater Green River Basin lies between two major structural features, which include the Wind River Mountains and the Wyoming Range (**Figure 2-2**). The Wind River Mountains to the east are composed of Precambrian rocks that have been uplifted by a low-angle reverse fault (**Figure 2-4**). The vertical scale on the cross-section (**Figure 2-4**) has exaggerated the dip of the fault, which is actually 30° or less. The Wind River Mountains are typical of the nature of the predominant structural style found in many of the mountain ranges of Wyoming, Colorado, Utah, and Beartooth Mountains of Montana. The cores of the ranges contain Precambrian rocks that have been uplifted many thousands of feet through movement on low-angle to high-angle reverse faults. These mountain ranges are unique to the Western Hemisphere in structural style (Grose, 1972). The nature of the faulting on the western flank of the Wind River Mountains was first postulated by Berg (1961). He described the main fault as a low-angle reverse fault or thrust fault based on seismic records. The exact geometry of the thrust is more complicated than the first proposed model and the Precambrian wedge on the west flank of the mountain range is probably highly fractured (Berg, 1983).

The west side of the RMPPA is bounded by the easternmost faults of the Wyoming Thrust Belt. These faults mark the eastern boundaries of the Wyoming and Hoback Mountain Ranges. The

Figure **2-4** Schematic Geologic Cross Section mountains were formed by generally north to south trending thrust faults that involved large-scale movement of Paleozoic and Mesozoic rocks. This style of faulting and deformation extends into eastern Idaho. The thrusting did not involve Precambrian rock as in the Wind River Mountains. The major thrust faults that extend into the RMPPA are the Darby Thrust and Prospect Thrust Faults (Blackstone, 1977). Several other thrust fault zones border the western boundary of the area. Other major structural features in the RMPPA include the La Barge Platform and Pinedale Anticline. The La Barge Platform is the northern extension of a structural feature referred to as the Moxa Arch. The Moxa Arch – La Barge Platform is a structural high that extends from southwestern Wyoming north to the La Barge area where it has been truncated by thrust faulting from the west. The Pinedale Anticline is found in the northeastern part of the area and generally parallels the Wind River Thrust Fault. An anticline is a geologic structure in which rocks have been folded in a convex upward shape (Gary and others, 1974). The anticline is 35 miles long and 6 miles wide and was probably formed by compression due to uplift on the Wind River Thrust Fault (Law and Johnson, 1989). The anticline is asymmetric (steeper on the west side) and may be bounded at depth by a reverse fault (Figure 2-4). The axis of the northern Green River Basin is parallel or coincident with the trend of the Pinedale Anticline. The axis represents the deepest part of the basin where depth to Precambrian basement may be over 30,000 feet.

2.4 Geophysics and Geochemistry

No information on geophysics and geochemistry was obtained for this report.

2.5 Historical Geology

2.5.1 Precambrian Era

The ancient Precambrian Rocks form the basement upon which later sedimentary rocks were deposited. The Precambrian Rocks represent portions of small continents that accreted to form the original continent (Lageson and Spearing, 1991).

2.5.2 Paleozoic Era

2.5.2.1 Cambrian to Mississippian Periods

During Paleozoic time, present-day Wyoming and much of the Rocky Mountain west were located along a fairly stable continental shelf with the land areas to the east (Lageson and Spearing, 1991). The area was generally inundated by shallow seas and fluctuations in sea level, which resulted in the deposition or erosion of sediments. The rocks that were deposited on this shallow continental shelf were the result of numerous changes in sea level referred to as transgressions (relative rise in sea level); or regressions (relative falling of sea level or movement of coastlines seaward). Changes in sea level also caused many deposits to be eroded resulting in unconformities (or gaps) in the rock record. The limestone, dolomite, and shale deposited from Cambrian to Mississippian are typical rocks that were originally deposited in a shallow marine environment. There is evidence that Silurian rocks may have been deposited, but were subsequently eroded (Boyd, 1993).

2.5.2.2 Pennsylvanian-Permian Periods

The sandstones of the Pennsylvanian represent an influx of sediment due to the uplift of the ancestral Rocky Mountains. Erosion from the uplifts resulted in the deposition of the Tensleep Sandstone and equivalents across the Rocky Mountain region. Permian rocks indicate a return of a shallow marine environment to the region. The black organic-rich shale of the Phosphoria Formation that was deposited during this time is a major potential source rock for petroleum (Peterson, 1984).

2.5.3 Mesozoic Era

2.5.3.1 Triassic-Jurassic Periods

Jurassic deposition reflects several transgressions and regressions in which marine deposits are interbedded or grade into rocks of more continental origin. Conditions at the end of the Triassic changed greatly when the continental conditions predominated and the shelf was emergent (Picard, 1993). The Nugget Sandstone was deposited as eolian (wind-blown) sand dunes in beach or arid desert environments. The Nugget Sandstone is characterized by well-sorted sand grains and has characteristics exhibited by large present-day sand dunes.

Deposition of the Nugget Sandstone continued into the Jurassic Era, but conditions changed in the middle Jurassic Era from a continental environment to shallow marine with the deposition of the Twin Creek Limestone and the marine shale and sandstone of the Preuss and Sundance Formations (Peterson, 1972; Picard, 1993). The Gypsum Springs may be a clastic equivalent of the Twin Creek Limestone. The upper Jurassic Morrison Formation represents deposition under non-marine continental conditions

2.5.3.2 Cretaceous Period

During Creatceous time, a feature known as the Western Interior Seaway developed from the Gulf of Mexico to the Arctic Ocean (McGookey and others, 1972). During the Cretaceous Period, there were numerous episodes of transgressions and regressions that resulted in the deposition of thousands of feet of sedimentary rock. The Gannett Group and Bear River Formation were deposited in fluvial (river) environments on the western shore of the seaway (Law, 1995). The rocks of the Gannett Group and Bear River Formation are made of deposits of clastic material derived from uplift to the west. The uplift is known as the Sevier Orogeny (McGookey and others, 1972). From west to east, the lower Cretaceous rocks grade from continentally-derived clastics to marine and marginal marine rocks of the Cloverly Formation, Thermopolis Shale, and Muddy Sandstone. At the close of the lower Cretaceous, sea level rose and the Mowry shale was deposited. The Frontier Formation resulted from several transgression-regression cycles and from west to east grades from fluvial to marine. After the Frontier Formation was deposited, another transgression resulted in the deposition of the marine Baxter (Hilliard) Shale (McGookey and others, 1972). Following the Baxter Shale, a regressive sequence represented by the Mesaverde Group was deposited in non-marine and marginal marine environments.

Near the end of the Cretaceous, mountain building began again west of the Green River Basin in the area of the western Wyoming-eastern Idaho Thrust Belt. As the mountains were uplifted, erosion occurred and sediment was shed into the shallow Cretaceous seaway. The uppermost Cretaceous unit is the Lance Formation and it is composed of alluvial plain deposits and marked the end of the Cretaceous. Also at the end of the Cretaceous and the beginning of Tertiary time, another episode of mountain building was occurring to the east and southeast of the area. This episode of mountain building is referred to as the Laramide Orogeny and involved the uplift of the Precambrian basement in the structural style described above (Lageson and Spearing, 1991).

2.5.4 Cenozoic Era

2.5.4.1 Tertiary Period

The uplifted blocks of basement rock were eroded and the sediment was deposited in the basin resulting in the Fort Union, Wasatch, and Pass Creek Formations. As mountain building subsided, the Green River Basin became a large lake. Sediments associated with this lake are represented by the Green River Formation. The Green River Formation contains abundant fossils and organic-rich rock referred to as oil shale. In Oligocene and Miocene time, large volcanic eruptions occurred to the west and north of the area (Lageson and Spearing, 1991). Prevailing winds carried the ash aloft over an extensive area and thick layers of ash were deposited as a result of these eruptions. Also in later Tertiary time, one more episode of uplift occurred, again resulting in the deposition of material in the basins.

2.5.4.2 Quaternary Period

The late Tertiary deposits were subjected to erosion and by the end of Tertiary time and the beginning of Quaternary time, the present-day topography began to emerge typified by mesas and benches composed of the erosional remnants of the rocks deposited during Tertiary time. It is likely that the later Tertiary deposits were largely eroded from the RMPPA. The Oligocene-age White River Formation and equivalents are composed of volcanic ash material that are evidence of the Tertiary volcanic activity are not present in the RMPPA, but are widespread over other basins in Wyoming (Love and Christiansen, 1985). During Quaternary time, there were several episodes of glaciation. Evidence of the several glaciations is exhibited in the Wind River Mountains. Several periods of glaciation have been identified as occurring from more than 200,000 years ago to about 12,000 years ago. The glacial deposits consist of lateral moraines, end moraines, and glacial outwash deposits that were laid down during successive glacial episodes. Prominent glacial lakes were formed along the southwestern flank of the Wind River Mountains by glaciers that carved out canyons. The end moraines left by the melting glaciers dammed the canyons and lakes formed behind the end moraines (Lageson and Spearing, 1991).