2.0 DESCRIPTION OF GEOLOGY

2.1 Physiography

The Rawlins RMPPA is located in three major physiographic provinces: the Wyoming Basin, the Southern Rocky Mountains, and the Great Plains (Howard and Williams, 1972). **Figure 2-1** depicts the RMPPA in relation to the physiographic elements. The western and northwestern portions of the RMPPA are located in the Wyoming Basin, a 40,000-square-mile area that includes much of southwestern Wyoming and part of northwestern Colorado. 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 itself. There are several west-east trending mountain ranges in the north-central part of the RMPPA. The ranges are, from west to east, the Ferris Mountains, the Seminoe Mountains, and the Shirley Mountains. The Ferris Mountains are up to 10,000 feet national geodetic vertical datum (NGVD) while the Seminoe and Shirley Mountains peak about 9,500 NGVD.

Sub-basins of the Wyoming Basin within the RMPPA boundaries include the Washakie and Great Divide Basins of the eastern Greater Green River Basin, the Hanna Basin, Carbon Basin, Kindt Basin, Shirley Basin, and the Laramie Basin. In the basin areas the topography is typified by rolling plains dissected by badlands.

Elevations in the sub-basins of the Wyoming Basin portion of the RMPPA generally range from 6,500 to 7,500 feet (NGVD). The Great Divide Basin is bounded by branches of the Continental Divide and has no external drainage outlet. Major river drainages in the Wyoming Basin portion of the RMPPA are the North Platte River, Laramie River, and the Little Snake River. All of these rivers head in the Southern Rocky Mountains.

A small part of the Southern Rocky Mountains Province is in the south and south-central portions of the RMPPA. The Southern Rocky Mountains extends through northern New Mexico, Colorado, and southern Wyoming. Mountain ranges in the southern part of the RMPPA consist of the northernmost portions of the Southern Rocky Mountains. Those ranges are the Laramie Mountains, Medicine Bow Mountains, and the Sierra Madre (the northern extension of Colorado's Park Range). The portions of the planning area on the flanks of the mountains generally range from 7,500 to 8,000 feet NGVD with the highest point in the Rawlins RMPPA being Elk Mountain at 11,156 feet NGVD. In many places, hogback ridges mark the flanks of the mountain ranges.

The southeastern portion of the planning area is located in the Great Plains province in a sub-province called the High Plains (U.S. Geological Survey [USGS], 1970). The High Plains are characterized by nearly flat-lying Tertiary deposits with mesas and badland topography. A prominent physiographic feature in southeastern Wyoming is called the "Gangplank," so-called

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

because the Tertiary rocks form a long sloping surface up to the 7,000-foot level of the Laramie Range (Howard and Williams, 1972). Elevations in the High Plains portion of the RMPPA range from 7,000 feet at the east flank of the Laramie Range to less than 5,000 feet NGVD in northeastern Laramie County.

In this portion of the RMPPA, drainages head in the Laramie Range and flow from west to east. The important drainages from south to north include Crow Creek, Lodgepole Creek, Horse Creek, and Little Bear Creek. Crow Creek eventually empties into the South Platte River in Colorado and the others are in the North Platte River basin.

2.2 Stratigraphy

The rocks in the planning area range in age from Precambrian to recent deposits (**Figure 2-2**). In the eastern Green River Basin, at the western edge of the RMPPA, the total thickness of sedimentary rock above the Precambrian is about 30,000 in the Washakie Basin (Kent, 1972). The Hanna Basin contains a thick sequence of post Precambrian rocks which is estimated to be greater than 42,000 feet (Law, 1995). Precambrian rocks are generally exposed in the cores of the mountain ranges and smaller uplifts such as the Rawlins uplift. In southeastern Wyoming in the northwest portion of the Denver-Cheyenne Basin, the sedimentary rock section is slightly more than 10,000 feet thick (Kent, 1972). Paleozoic, Mesozoic, and Cenozoic rocks are exposed throughout the RMPPA.

2.2.1 Precambrian Era

The Precambrian rocks that are exposed in the mountain ranges are complex assemblages of igneous and metamorphic rocks (Houston, 1993). The Precambrian rocks that form the basement of the various basins within the RMPPA also are presumed to be similar to the rocks exposed in the mountain ranges (Simms and others, 2001).

2.2.2 Paleozoic Era

2.2.2.1 Cambrian System

Cambrian rocks are present in the west and northwest portion of the RMPPA (Boyd, 1993). The rocks consist of coarse-grained sandstone and conglomerate of the middle Cambrian Flathead Sandstone and sandy shale of the upper Cambrian Buck Springs Formation (Watson, 1980). The Cambrian rocks thin from west to east across the RMPPA from about 1,000 feet thick in the Washakie Basin to zero feet along a line trending from the north end of the Sierra Madre to the north end of the Laramie Range (Lachman-Balk, 1972). Cambrian rocks are not present east of this line.

Figure **2-2** Stratigraphic Nomenclature Chart

2.2.2.2 Ordovician, Silurian, and Devonian Systems

There are no widespread rocks representing Ordovician through Devonian; however, the Ordovician Bighorn Dolomite and Devonian Darby Formation are present further west in the Green River Basin (Boyd, 1993). There is evidence that rocks of the Ordovician and Silurian were present, but were eroded at a later time. In diatremes (diamond-bearing intrusive rocks) of the southern Laramie Mountains, blocks (xenoliths) of rocks containing fossils of Ordovician and Silurian age are present. The diatremes may be of Silurian or Devonian age.

2.2.2.3 Mississippian System

The Mississippian System is represented by the Madison Limestone and the Darwin Sandstone in the western portion of the RMPPA, but the Mississippian rocks thin from west to east until they are absent east of line from Centennial, Wyoming to northwest Laramie County (Boyd, 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). In the northwest portion of the RMPPA, the Madison consists of a lower coarse sandstone and an upper limestone unit (Watson, 1980). The Madison ranges from about 600 in the northeast Great Divide Basin to about 60 feet thick near Elk Mountain. It also is present in the Hanna, Shirley, and Laramie Basins but is mainly composed of limestone with thin sandstone at the base (Watson, 1980). The Darwin Sandstone is the basal member of the Amsden Formation and is white cross-bedded sandstone and may only be present in the northwest corner of the RMPPA (Craig and others, 1972; Boyd, 1993).

2.2.2.4 Pennsylvanian System

Pennsylvanian rocks in the RMPPA consist of the Amsden Formation, the Tensleep Sandstone, the Casper Formation, and the Fountain Formation. Aggregate thickness of Pennsylvanian rocks in the planning area is generally about 500 feet with appreciable thinning next to the mountain ranges (Mallory, 1972). In the southeastern portion of the area, Pennsylvanian age rocks may be up to 750 feet thick. The Amsden Formation occurs in the western portion of the planning area and consists primarily of shale but includes limestone, siltstone, dolomite, and anhydrite (Watson, 1980). Where the Darwin Sandstone Member of the Amsden Formation is present, it appears at the base of the shale in the Amsden and is probably upper Mississippian as discussed above. The Tensleep Sandstone is composed of fine-grained sandstone with minor limestone and dolomite beds (Watson, 1980). The Tensleep and Casper Formations are aeolian deposits of an extensive sand sea that covered most of Wyoming. These sandstones generally display massive bedding and relatively good porosity and permeability. These formations are good aquifers but are also productive of hydrocarbons in structural traps. In the eastern Washakie Basin, the Tensleep Sandstone is very well cemented and is considered a quartzite in places. In the Hanna, Shirley, and Laramie Basins the Casper Formation, equivalent to the Tensleep Sandstone, consists of

massive interbedded sandstone and dolomite (Watson, 1980). The sandstone is generally fine-grained and quartzitic. The Fountain Formation occurs in the Denver-Cheyenne Basin and portions of the southern Laramie Basin and is composed of coarse-grained to conglomeratic sandstone with interbedded shale and limestone lenses. The Fountain Formation is equivalent to the Casper Formation.

2.2.2.5 Permian System

In the western part of the RMPPA, Permian rocks are represented by the Phosphoria Formation and the Goose Egg Formation. In the Washakie Basin, the Phosphoria consists of about 250 feet of limestone, dolomite, interbedded chert, and minor shale (Watson, 1980; Peterson, 1984). Further east in the Hanna, Laramie, and Shirley Basins the Phosphoria equivalent Goose Egg Formation consists of red shale and siltstone with thin beds of anhydrite and dolomite (Watson, 1980). The Goose Egg thickens from about 350 feet in the Shirley Basin to over 500 feet in the Laramie Basin. In the Denver-Cheyenne Basin, the Permian rocks are represented by the Satanka Shale and the Forelle Limestone (Love and others, 1993). The Satanka Shale is composed of red shale and siltstone and evaporite deposits (Watson, 1980). Permian rocks may exceed 1,000 feet in thickness in eastern Laramie County (Rascoe and Baars, 1972).

2.2.3 Mesozoic Era

2.2.3.1 Triassic System

The Dinwoody Formation, Chugwater Group, and the Nugget Sandstone represent Triassic rocks in the western and northern parts of the RMPPA. The Dinwoody consists of dolomite that grades southward to red shale and anhydrite (Watson, 1980). The Chugwater Group is composed of members that consist of red shale, limestone, and sandstone (Watson, 1980). The Nugget Sandstone is present in the western part of the RMPPA but thins to the east and may interfinger with the upper member of the Chugwater Group. In the Denver-Cheyenne Basin, the Triassic rocks are referred to as the Chugwater Formation. The Chugwater is similar to the Goose Egg Formation and consists of red shale, limestone, and sandstone (Watson, 1980).

2.2.3.2 Jurassic System

The Jurassic Formations in the planning area consist of the Nugget Sandstone Sundance Formation, and Morrison Formations. The total aggregate thickness of the Jurassic rocks across the area is 350 feet or less and thins to the south (Peterson, 1972). The Nugget Sandstone also is lower Jurassic and is not present east of the Rawlins area (Love and others, 1993). The middle Jurassic Sundance Formation consists of sandstone and shale. The Canyon Springs Sandstone in the lower part of the Sundance Formation is fairly widespread across the area. The Canyon

Springs often consists of a calcareous, oolitic sandstone with well-rounded and frosted quartz grains (Watson, 1980). Generally, the upper portion of the Sundance Formation has more shale.
The Morrison Formation, which is upper Jurassic, is characterized by shale of various colors (often red, green, and purple) with interbedded sandstone, siltstone, and conglomerate (Watson, 1980). In the eastern Hanna Basin at Como Bluff, outcrops of the Morrison Formation have yielded abundant dinosaur bones (Mears and others, 1986).

2.2.3.3 Cretaceous System

When describing Cretaceous rocks, they are usually divided into upper and lower Cretaceous. The thickness of lower Cretaceous rocks in the planning area ranges from about 500 feet in the northwestern portion of the planning area to about 250 feet in the southeastern corner of Wyoming (McGookey and others, 1972). Upper Cretaceous rocks may be up to 16,000 feet thick in the Hanna Basin and in other parts of the planning area range from 8,000 to 10,000 feet thick.

2.2.3.4 Lower Cretaceous

The lower part of the lower Cretaceous are sandstones that are loosely correlated and referred to as the Lakota Sandstone, and Fall River Sandstone. The Lakota and Fall River are sometimes indistinguishable, but the Lakota is often conglomeratic. The sandstones are occasionally separated by a shale called the Fuson Shale, but it is often not present (McGookey and others, 1972; Watson, 1980). These sandstones are sometimes referred to as the Cloverly Formation in the western and northern parts of the planning area (Love and others, 1993). Above the Lakota and Fall River Sandstones is the Thermopolis Shale that is a black marine shale. In the Denver-Cheyenne Basin, this shale has been called the Skull Creek Shale. Above the Skull Creek and Thermopolis Shales is the Muddy Sandstone, a widespread sandstone of variable composition. In the Denver-Cheyenne Basin, the Muddy Sandstone is referred to as the “J” Sandstone, a subsurface terminology (Watson, 1980).

2.2.3.5 Upper Cretaceous

In the western parts of the RMPPA, the upper Cretaceous consists of the Mowry Shale, Frontier Formation, Niobrara Formation, Steele (Baxter) Shale, the Mesaverde Group, the Lewis Shale, and the Lance Formation. The Frontier Formation is composed of sandstone, dark shale, and local coals (Watson, 1980). The Mowry Shale overlies the Muddy and is composed of black siliceous shale characterized by numerous bentonite beds. The Niobrara Formation and Steele Shale are composed of gray to black marine shale. The top of the Niobrara is often composed of limestone or calcareous shale (McGookey and others, 1972). Overlying the Steele Shale is the Mesaverde Group that consists of the Haystack Mountain Formation, Allen Ridge Formation, the Pine Ridge Sandstone, and the Almond Formation (Love and others, 1993). The Mesaverde Group is a designation for widespread upper Cretaceous sedimentary rocks in the Greater Green

River Basin consisting of sandstone, carbonaceous shale, and coal (Ver Ploeg, 1992). After the Mesaverde is the Lewis Shale, which is a dark gray marine shale that contains isolated sandstone bodies and siltstone beds. Bentonite beds also are present in the lower part of the Lewis. Overlying the Lewis Shale in the western part of the planning area is the Fox Hills Sandstone. The uppermost Cretaceous in the western part of the planning area is the Lance Formation. The Lance is made up of carbonaceous shale, sandstone, siltstone, and coal (Watson, 1980). In the Hanna, Shirley, and Laramie Basins the last upper Cretaceous units are the Medicine Bow and Ferris Formations that are composed of carbonaceous shale, coal, and sandstone.

In the Denver-Cheyenne Basin portion of the planning area, the lowest upper Cretaceous units in ascending order are the Graneros Shale, Greenhorn Formation, Carlile Shale, and Niobrara Formation. The aforementioned units consist largely of limestone, shale, chalk, and occasional sandstone. Above the Niobrara Formation is a dark gray marine shale called the Pierre Shale. Within the middle part of the Pierre are a number of sandstones that in the Denver-Cheyenne Basin are referred to as the Hygiene and Terry sandstones (Watson, 1980). These sandstones are correlative to the Parkman and Teapot Sandstones of the Powder River Basin. Overlying the Pierre Shale is the Fox Hills Sandstone. The Lance Formation overlies the Fox Hills Sandstone in the northern part of the Denver-Cheyenne Basin (Lilligraven, 1993).

2.2.4 Cenozoic Era

2.2.4.1 Tertiary System

The earliest Tertiary rocks (Paleocene Series) in the western portions of the planning area are in the Paleocene Fort Union Formation that is composed of sandstone, conglomerate, shale, and coal (Watson, 1980). In the Hanna, Shirley, and Laramie Basins the Paleocene is represented by the Ferris and Hanna Formations. The Ferris, which also may be upper Cretaceous in part, consists of carbonaceous shale, sandstone and conglomerate, and numerous coalbeds (Love and others, 1993; Watson, 1980). The Hanna Formation is later Paleocene and is similar in lithology to the Ferris Formation. Love and Christiansen (1985) indicate that large quartzite boulders are present in the Hanna Formation in areas near the Medicine Bow Mountains. There are no lower Tertiary rocks in the Denver-Cheyenne Basin (Lilligraven, 1993).

Eocene Series rocks in the western part of the RMPPA are the Wasatch and Green River Formations which attain a thickness of 4,500 to 5,000 feet in the Great Divide Basin and Washakie Basins (Roehler 1992). The Wasatch and Green River Formations thin rapidly to the east and are generally not present at the eastern boundary of the Green River Basin. The Wasatch Formation is generally described as being composed of mudstone, red sandstone, carbonaceous shale, and sub-bituminous coal (Watson, 1980). The main body of the Green River Formation is further west of the RMPPA and occupies the central and southwest portion of the Green River Basin. The Green River Formation is composed of numerous members that are

generally composed of shale, oil shale, marlstone, and occasional sandstone and some members of the Wasatch and Green River Formations are interbedded (Roehler, 1992).

In the Shirley and Laramie Basins, the Eocene is represented by the Wind River and Wagon Bed Formations. The Wind River Formation is described as being composed of sandstone, conglomerate, mudstone, carbonaceous shale, and minor coal (Watson, 1980). The Wagon Bed Formation consists of bentonitic claystone and conglomerate (Love and Christiansen, 1985). In the RMPPA, the Wind River Formation is only found in the Shirley and Laramie Basins. In the Denver-Cheyenne Basin, there are no Eocene rocks (Love and others, 1993).

Oligocene White River Formation is present in the western part of the RMPPA and in the Hanna, Shirley, and Laramie Basins. The White River consists of bentonitic mudstone, sandstone, and altered and unaltered volcanic debris (Watson, 1980). The Bishop Conglomerate, which is equivalent to the White River, is found in the Washakie Basin and is composed of quartzite, chert, and limestone clasts in a sandstone matrix (Love and Christiansen, 1985). The White River Formation in the Denver-Cheyenne Basin is composed of the Chadron and Brule Members. The Chadron is highly variable and consists of sandstone and clay. The Brule is composed of calcareous clay and silt and volcanic ash. The White River in the Denver-Cheyenne Basin may contain vertebrate fossils in isolated localities (Watson, 1980).

In the western parts of the RMPPA, the Miocene is represented by the Browns Park Formation and Split Rock Formations and are composed of tuff (material derived from volcanic eruptions), tuffaceous sandstone, mudstone, and quartzite (Love and Christiansen, 1985). The base of the Browns Park usually has a conglomeratic zone (Watson, 1980). An upper Miocene unit, the North Park Formation is limited to the Saratoga Valley and is composed of tuffaceous sandstone, siltstone, claystone, and conglomerate. In the Denver-Cheyenne Basin, the Miocene Ogallala Formation covers the surface in most of Laramie County (Love and Christiansen, 1985). The Ogallala is composed of tuffaceous mudstone, sandstone, and conglomerate. In northeastern Laramie County, the upper Oligocene and Miocene Arikaree Formation is present and is composed of soft sandstone, tuffaceous claystone, and siltstone.

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 major rivers and tributaries. Glacial deposits are limited to the Medicine Bow Mountains and Sierra Madre and are largely composed of boulders, cobbles, and fine materials that were scoured from the mountains by the glaciers.

2.3 Structural Geology and Tectonics

Figure 2-3 shows the major structural elements of the RMPPA. The Laramie and Medicine Bow Mountains and Sierra Madre are composed of Precambrian rocks that have been uplifted by low-to high-angle reverse faults. **Figure 2-4** shows a diagrammatic cross-section across the RMPPA. These major mountain ranges are typical of the nature of the predominant structural style found in 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. The nature of the faulting in these mountain ranges was first postulated by Berg (1961) on the structure of the Wind River Mountains. 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). These mountain ranges are unique to the Western Hemisphere in structural style (Grose, 1972).

In addition to the major mountain ranges, there are smaller scale uplifts with Precambrian cores within the RMPPA such as the Ferris, Seminoe, Shirley Mountains, and the Rawlins Uplift. The Rawlins Uplift is an asymmetric anticline bounded by a reverse fault on the west. An anticline is a geologic structure in which the rocks have been folded in a convex upward shape (Gary and others, 1974). The Ferris, Seminoe, and Shirley Mountains are uplifted Precambrian blocks that were originally part of the Sweetwater Uplift that also was uplifted during the Laramide Orogeny. The Laramide Orogeny involved basement core uplifts along low- to high-angle reverse faults that began at the end of Cretaceous. Later in Tertiary time the uplift subsided (Blackstone, 1971). The Ferris and Seminoe Mountains are bounded on the north by normal faults that mark the boundary of the south side of the Granite Mountains, remnants of the subsided Sweetwater Uplift (Mears and others, 1986). This type of subsided block is called a graben.

In addition to major faults at the boundaries of the mountain ranges and smaller uplifts, there is a major shear zone in the RMPPA called the Cheyenne Belt **(Figure 2-3)**. The Cheyenne Belt is a series of southwest to northeast trending fault blocks that cut through the Precambrian rocks of the Sierra Madre, the Medicine Bow Mountains, and the Laramie Mountains (Houston, 1993). The Cheyenne Belt separates metamorphic sedimentary rocks on the north side from largely igneous rocks to the south of the belt.

On the west side of the RMPPA are sub-basins on the eastern edge of the Greater Green River Basin called the Washakie and Great Divide Basins. The Washakie and Great Divide Basins are separated by a structural high called the Wamsutter Arch that generally trends from west to east paralleling Interstate 80 (I-80). The Washakie Basin is bounded on the south by another west to east trending structural high called the Cherokee Arch. The Cherokee Arch lies generally along the Wyoming-Colorado state line and separates the Washakie Basin from the Sand Wash Basin

Figure **2-3** Major Structural Elements of the Rawlins RMPPA

Figure **2-4** Diagrammatic Cross-section of Southeastern Wyoming

in northwest Colorado (Law, 1995). Other smaller basins entirely within the RMPPA are the Hanna, Shirley, and Laramie Basins. In the eastern part of the RMPPA is the Denver-Cheyenne Basin that occupies northeast Colorado, southwest Nebraska, and southeastern corner of Wyoming. Within these basins are anticlines commonly along the basin margins. These anticlines are generally asymmetric and faulted at depth and provide traps for hydrocarbons.

2.4 Geophysics and Geochemistry

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

2.5 Historical Geology

2.5.1 Cambrian through Mississippian Periods

During Paleozoic time, present-day Wyoming and much of the Rocky Mountain west were located along a fairly stable continental shelf (Lageson and Spearing, 1991). The area was generally inundated by shallow seas, and fluctuations in sea level 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 of rocks that were originally deposited in a shallow marine environment. In the RMPPA, sedimentary Ordovician and Silurian rocks are present only as xenoliths in diatremes that may been emplaced in Silurian or Devonian time (Boyd, 1993).

2.5.2 Pennsylvanian-Permian Periods

The sandstones of the Pennsylvanian represent an influx of sediment from an aeolian (wind-blown) sand sea to the west of a north-south seaway along the eastern border of Wyoming. The geological setting was similar to the Persian Gulf at present with Wyoming no more than 15 degrees north of the Equator (Trotter, 1984). Erosion from the uplifts resulted in the deposition of the Tensleep Sandstone and equivalents across the Rocky Mountain region. Locally, in the Laramie and Denver-Cheyenne Basins, the Fountain Formation is composed of clastic debris shed from the Ancestral Rockies. The Permian rocks indicate alternating shallow marine to continental environments as indicated by the shale, limestone, and anhydrites in the Phosphoria and Goose Egg Formations and Satanka Shale (Boyd, 1993).

2.5.3 Triassic-Jurassic Periods

Shallow marine conditions appear to have been predominant in early Triassic with deposition of the Dinwoody Formation, however without the organic-rich material as was available during deposition of the Phosphoria Formation. Conditions in the later Triassic changed greatly compared with earlier Triassic. During much of the late Triassic and Jurassic Periods, the Wyoming shelf was emergent and much of the deposits laid down were terrestrial in origin typified by the red beds and evaporites of the Chugwater Group (Picard, 1993). In the western part of the RMPPA, the Nugget was deposited in late Triassic-early Jurassic mainly in an aeolian environment as sand dunes. The Sundance Formation deposits are representative of a transgressive-regressive sequence during later Jurassic. This seaway incursion was the first advance of the Western Interior Seaway from the north. The Canyon Springs Sandstone Member was deposited during the advance of the sea onto the Wyoming shelf (Picard, 1993). At the end of the Jurassic terrestrial conditions predominated resulting in the Morrison Formation which is characterized by stream deposits that were laid down on an alluvial plain.

2.5.4 Lower Cretaceous Period

During Cretaceous 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 there were numerous episodes of transgressions and regressions that resulted in the deposition of thousands of feet of sedimentary rock. The lower part of the Cloverly Group (Lakota Conglomerate) was deposited in alluvial fan and fluvial environments on the western shore of the seaway (Steidtmann, 1993). Following the deposition of the Dakota Conglomerate, the first major Cretaceous transgression began resulting in the deposition of the marginal marine Fall River Sandstone then the Thermopolis-Skull Creek Shales. A regression followed that resulted in the deposition of the widespread Muddy Formation.

2.5.5 Upper Cretaceous-Tertiary Periods

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 (Steidtmann, 1993). The near shore and transitional marine deposits of the Frontier Formation in the western parts of the RMPPA grade to the east into the Graneros Shale and Greenhorn Limestone which represent shallow marine conditions. After the Frontier, the Niobrara transgression resulted in the deposition of the marine Carlile Shale, Niobrara Formation, Steele Shale sequence (McGookey and others, 1972). Following the Niobrara Transgression, a regressive sequence composed of sandstone and shale was deposited in near-shore and marginal marine environments (Steidtmann, 1993). In the western part of the RMPPA, this regressive sequence is called the Mesaverde Group. However, to the east, the Mesaverde equivalents, the Pierre shale and associated sandstones, are marine in origin. The

last major Cretaceous transgression resulted in the deposition of the Lewis Shale. Within the Lewis Shale are sandstones and siltstones that were deposited in marine and transitional marine environments (Van Horn and Shannon, 1989).

Throughout the Cretaceous, mountain building occurred west of the Green River Basin in the area of the western Wyoming-eastern Idaho Thrustbelt. As the mountains were uplifted, erosion occurred and sediment was shed into the shallow Cretaceous seaway. In the RMPPA, the uppermost Cretaceous unit are the Lance Formation and Medicine Bow Formations which are composed of alluvial plain deposits marking the end of the Cretaceous (Lilligraven, 1993). Also at the end of the Cretaceous and the beginning of Tertiary time, another episode of mountain building was occurring in the area. This episode of mountain building is referred to as the Laramide Orogeny (Lageson and Spearing, 1991). The uplift of the Precambrian basement occurred in the structural style described above; movement of Precambrian basement blocks along low- to high-angle reverse faults. This period of mountain building resulted in the mountain ranges of the Southern and Middle Rocky Mountains. The uplifted blocks of basement rock were eroded and the sediment was deposited resulting in the Fort Union, Wasatch, Ferris, Hanna, and Wind River Formations. As mountain building subsided, the area of the Green River Basin became a large lake. Sediments associated with this lake are represented by the Green River Formation in the western part of the RMPPA. The Green River Formation contains abundant fossils and organic-rich rock referred to as oil shale.

In later Tertiary (Oligocene-Miocene), large volcanic eruptions occurred to the west and north of the area. Prevailing winds carried the ash aloft over an extensive area and thick layers of ash were deposited as a result of these eruptions. These ash deposits are found in the White River Formation. Also in later Tertiary time, one more episode of uplift occurred, again resulting in the deposition of material in the basins resulting in the Browns Park, North Park, Ogallala, and Arikaree Formations. Erosion of the Tertiary deposits by the end of Tertiary and the beginning of Quaternary resulted in the emergence of the present-day topography. The “Gangplank” in Laramie County is an erosional remnant of Tertiary rock and is evidence that by late Tertiary, the Rocky Mountains were nearly buried in debris that was shed from them (Blackstone, 1996). Erosion along the mountain fronts has removed the mantle of Tertiary deposits in most places resulting abrupt changes in elevation along the mountain fronts.

2.5.6 Quaternary Period

During Quaternary, there were several episodes of glaciation. Evidence of the several glaciations is exhibited in the Medicine Bow Mountains and Sierra Madre. Valley glaciers and icecaps over the mountain ranges probably began to recede about 15,000 years ago (Knight, 1990). The glacial deposits consist of lateral moraines, end moraines, and glacial outwash deposits that were laid down during successive glacial episodes. Small glacial lakes were formed in the Snowy Range in the core of the Medicine Bow Mountains. Continued erosion of the mountain ranges has resulted in the deposition of alluvial and terrace deposits in the basins.