Stratigraphic Framework of Lower and Upper Cretaceous Rocks in Central and Eastern Montana

By Steven M. Condon

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Foreword

Large accumulations of biogenic gas are known to exist in shallow (<3,000 ft deep) Cretaceous reservoirs of the Northern Great Plains (mainly Montana) and southeastern Alberta and southwestern Saskatchewan, Canada. The 1995 USGS National oil and gas assessment made a mean estimate of 1.15-1.18 x 10^{12} m^3 (41-42 trillion cubic ft) of potential additions to reserves of continuous-type (unconventional) gas in Cretaceous shallow biogenic gas plays of northern and central Montana (Rice and Spencer, 1995). About 90 percent of the 1995 gas estimate was in hypothetical plays. The controls on the boundaries of these plays were poorly understood at the time of the assessment in 1995. As a follow on to the 1995 assessment, a multidisciplinary project (Ridgley and others, 1999) was undertaken in order to better understand the controls on the gas accumulation and to better define the play boundaries. The focus of the project is on Cretaceous rocks from the top of the Mowry Shale to the base of the Judith River Formation, and within this geologic time slice the project will define the petroleum system of the shallow biogenic gas.

To achieve these goals, we are integrating geologic, structural, hydrologic, and engineering studies with known and new geochemical data on the gas and co-produced water to understand the controls on the spatial distribution of potential gas accumulations and to understand the origin and time of generation and migration of the gas. An additional focus of the project is to determine the controls on the sites of shallow biogenic gas in the large southeastern Alberta gas field in Canada. This gas accumulation is in rocks age-equivalent to those that host the shallow gas in the Northern Great Plains. Over one-half of the 1995 national oil and gas assessment was based primarily on similarity of the potentially productive facies in Montana to the facies that host large shallow biogenic gas resources in southeastern Alberta and southwestern Saskatchewan. We will determine if the Canadian analog is appropriate for the Northern Great Plains shallow gas system. We plan a series of topical reports that will provide the background information required for the next assessment of the shallow biogenic gas system in the Northern Great Plains in late 2000.

J.L. Ridgley
February, 2000

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Stratigraphic Framework of Lower and Upper Cretaceous Rocks in Central and Eastern Montana

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Introduction

This report summarizes the stratigraphic framework of Lower and Upper Cretaceous sedimentary rocks in the central and eastern part of Montana, and was written in support of U.S. Geological Survey studies of energy resources in Cretaceous rocks. The study was undertaken as a part of a larger project, under the direction of J.L. Ridgley, that investigated the occurrence of shallow biogenic gas in Upper Cretaceous rocks in north-central Montana and adjacent areas of Canada. The approach used here is to describe briefly the rock units and to show their thickness, distribution, and structural configuration using isopach maps, cross sections, and structure contour maps.

This report updates some stratigraphic nomenclature and relationships earlier discussed by Rice (1976c, 1981) in this same area. Other reports important in defining the stratigraphy of this area include Cobban (1951), Dyman and others (1995), Hearn (1976), Johnson and Smith (1964), Knechtel (1959), Lopez (1995), Porter and others (1993, 1997, 1998), and Schmidt and others (1964). A database of geologic names (Mac Lachlan and others, 1996) was invaluable as a source of historical background of the geologic units.

Cretaceous rocks of the Western Interior of North America were deposited in a large asymmetric foreland basin (deeper on the west side) that developed east of the Sevier orogenic belt and west of the stable cratonic interior. The development of the western Cordillera, its flanking foreland basin, and the sedimentary fill of the basin have been discussed and summarized by Armstrong and Ward (1993), Beaumont and others (1993), McGookey and others (1972), Roberts and Kirschbaum (1993), and (Vuke, 1984). Episodic tectonic activity in the orogenic belt shed coarse clastic rocks into the west side of the basin, while simultaneously, fine-grained mudrocks and calcareous marls were deposited farther eastward. Deposition in the foreland basin was also influenced by worldwide changes in sea level (Haq and others, 1987; Haq and others 1988) and by sea-level changes due to local tectonics. The interplay of these two main controlling processes led to the rock record we see preserved in central and eastern Montana today.

In the study area, within the central foreland basin setting, most deposition of Lower and Upper Cretaceous rocks was between the lithologic end members of very coarse terrigenous clastics and the open marine chalks. With few exceptions, Cretaceous rocks in the study area consist of fine- to medium-grained sandstone, siltstone, mudstone, and shale. Other rock types, such as conglomerate and limestone are relatively rare in the section. Bentonite beds, a result of ash falls from volcanic eruptions to the west, are volumetrically insignificant, but are important marker beds through much of the Cretaceous section.

This area of Montana is of special interest in stratigraphic studies because it was the site of nearly continuous marine deposition for much of the Cretaceous Period. As shown by Dolson and others (1991) and Porter and others (1998), a marine basin remained extant for much of the Early Cretaceous while areas marginal to the basin were exposed during sea-level lowstands. This pattern continued in the Late Cretaceous, as shown by Roberts and Kirschbaum (1995) and Dyman and others (1995). The significance of this long-lived depositional basin is that there is a more complete sequence of Cretaceous rocks here, unlike other areas where significant intervals of the rock record were removed by erosion.

Eighteen formations are described in this report; five formations of Early Cretaceous age and thirteen of Late Cretaceous age. The thickness of the entire Cretaceous section ranges between about 3,500 ft and 5,600 ft; within this range between 500 and 1,000 ft are Lower Cretaceous and the remainder are Upper Cretaceous. The entire section is thickest on the west, and thins eastward (Dyman and others, 1995).

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Geographic and structural setting

The study area is in the eastern half of Montana (fig. 1) within a rectangle roughly bounded by 104° west longitude on the east and 111.5° west longitude on the west, 46° north latitude on the south and 49° north latitude on the north. The area illustrated by isopach and structure maps extends from Township 3 North through Township 37 North, and from Range 11 East through Range 58 East. The northern border of the study area is the United States-Canada international boundary, and the eastern border is the Montana-North Dakota State line. The southern edge of the study area is along an east-west line just north of Billings, Montana. The western side of the study area is roughly defined by a line from Billings to Great Falls, Montana, and then north to the International boundary.

Figure 1 also shows some of the main structural features of eastern Montana. The study area is in a transitional region between the Cordilleran area of extensive thrust faulting and Laramide uplifts in western Montana, and the Williston basin and Cedar Creek anticline on the eastern border of the State. A series of low-amplitude anticlines, synclines, and domes exist along the northern border. The central part of the study area is complexly deformed, and the group of anticlines, synclines, and domes there are collectively referred to as the Central Montana uplift (fig. 1). Several centers of Tertiary intrusive or volcanic rocks are in the study area, including the Sweet Grass Hills, and the Bears Paw, Little Rocky, Highwood, and Judith Mountains. Cretaceous strata are domed upward around these centers, providing outcrops of the Cretaceous stratigraphic units. All of the structures are Laramide in age, or are Laramide and post-Laramide enhancements of pre-Laramide structures.

Plates 6, 7, and 8 are structure contour maps drawn on the top of the Morrison Formation, Greenhorn Formation, and Judith River Formation, respectively, which are at the base, middle, and near the top of the Cretaceous section. These maps also show some of the structural features displayed on figure 1. The Central Montana uplift is a prominent prong that extends eastward from western Montana for all the contoured horizons. In the northern part of the mapped area, the Bears Paw Mountains, Bowdoin dome, and Hogeland basin are evident. The Williston basin and Cedar Creek anticline are also structures apparent on all three contour maps. The parallelism of the three contoured intervals illustrates that the study area was structurally stable for much of the Cretaceous. This structural style contrasts with areas farther to the south in the Western Interior basin, which were more affected by Laramide tectonics and were segmented into discrete basins.

Methods

Data Sources And Map Generation

The source of data for the isopach and structure contour maps primarily is the Well History Control System (WHCS), a database maintained by Information Handling Services Group, Inc. Data for the wells, including operators, well names, completion information, and tops of formations were downloaded from the WHCS files and imported into GeoGraphix, a data management and digital mapping program. The data are current as of October, 1998. Data for 18,244 wells are in the database for the area of this study in central and eastern Montana, although only a small number of that set were used for any given map. Due to the proprietary nature of the data, locations of control points cannot be shown on the maps. See the explanations for individual maps for the number of control points used on each map.

In the WHCS data the formation tops were provided by well operators. The picks and names used for stratigraphic units can vary considerably among operators, so there is a lack of consistency in the database concerning tops of some formations. The large number of wells used made examination of all formation picks in all wells impossible, so the maps were constructed using the picks in the database. The maps were then examined for obvious problems with some picks, usually indicated by abnormally thick or thin areas centered on one well. These data points were then checked and removed, if necessary, and the data recontoured.

One result of computer mapping is that the contours are based on a mathematically constructed grid, not on actual data values. For mapping of unverified data, this process tends to average out bad data picks, which helps in gaining an understanding of regional trends. The data are also contoured in a repeatable fashion, and the contours are a result of the gridding algorithm, not a preconceived bias of how the map should look. However, it is important to remember that the isopach and structure maps in this report represent averages of data and not the actual data values.

Gridding parameters for all of the small-scale (1:1,000,000) maps are the same: the smallest feature that is resolved is 50,000 m (about 31 mi), resulting in 1996 grid columns and 740 grid rows for the mapped area. For the detailed maps at Bowdoin dome, a minimum feature size of 1,000 m was used (about 0.6 mi), with 149 grid columns and 154 rows. The minimum curvature method of gridding was used for all contour maps. Contour intervals were chosen to try to illustrate best the structural or depositional features of the mapped units.

In addition to the well database, a number of lithologic logs of cuttings or core descriptions were also examined for this study. Some of the descriptions were part of the drill-stem test data that is on file at the U.S. Geological Survey for each well, and other descriptions were from commercial well-logging companies. Only a few lithologic logs were located for the actual wells used for the cross sections, but other lithologic logs were available for nearby wells over most of the area. These logs were mainly of use in identifying sandy intervals.

Finally, a last source of data was cored intervals of some units that are stored at the U.S. Geological Survey Core Research Center in Denver, Colo. Parts of cores of the Eagle Sandstone, Bowdoin sandstone, Greenhorn Formation, and Phillips sandstone were examined.

Mapping Considerations

To facilitate regional mapping, certain formations were combined, or set equivalent to each other in the GeoGraphix database. Although current concepts of sequence stratigraphy suggest that some of the formations are not equivalent, for the stratigraphic resolution required for regional mapping purposes they can be combined, as was done by Dolson and others (1991). The best example of this is the Muddy Sandstone map, which includes equivalent reported tops for the Viking, Bow Island, and Newcastle Formations in various parts of the area. Other stratigraphic tops considered equivalent for this set of maps are the Mowry Shale and Fish Scale sandstone, the Carlile Shale and Bowdoin sandstone, the Mosby Sandstone Member of the Belle Fourche Shale and Phillips sandstone, and the Eagle Sandstone and Shannon Sandstone Member of the Gammon Shale.

Some Cretaceous formations could not be mapped at a regional scale due to a lack of data or insufficient data to make a meaningful map. These include the Hell Creek Formation, Fox Hills Sandstone, Mosby Sandstone Member, Shell Creek Shale, and Fall River Sandstone. In some cases there are few, if any, reported tops for the formations in the database.

Four maps posed particular problems due to inconsistencies in the data. (1) The top of the Greenhorn Formation is represented by over 5,000 points in the database, which allows construction of a tightly controlled structure contour map (Plate 7), but calculating a thickness for the unit was much more problematic. As shown on the cross sections (Plates 1-5), the base of the Greenhorn is the top of the underlying Mosby Sandstone Member of the Belle Fourche Shale. However, the Mosby (or equivalent Phillips sandstone) is poorly represented in the database, except in the Bowdoin dome area. The top of the Belle Fourche Shale is the next commonly available formation top in the database, so it was used as the base of the Greenhorn for the Greenhorn isopach map. (2) The Belle Fourche isopach map was constructed by calculating the difference between the top of the Belle Fourche and the top of the Mowry, but it does not include the Mosby Sandstone Member of the Belle Fourche. (3) The Shell Creek Shale has not been used as a formal stratigraphic unit in U.S. Geological Survey reports in Montana, and is not a formation in the WHCS database; it therefore could not be mapped as a separate unit. The Mowry Shale isopach map includes the Shell Creek and extends from the top of the Mowry to the top of the underlying Muddy Sandstone and equivalent units. This usage is common in the literature, including the cross sections of Rice (1976c). (4) The Skull Creek Shale consists of an upper shale unit and a basal silt unit; in the WHCS database many operators report the lower silt unit as the 'Dakota silt.' This pick was used as the dividing point between the two parts of the Skull Creek for the isopach maps presented in this report. However, the top of the Fall River Sandstone is not common in the database of well tops, so the top of the Kootenai Formation was used as the base of the basal silt unit of the Skull Creek. This interpretation has resulted in the Fall River Sandstone being included with the basal silt unit of the Skull Creek, but allowed me to construct a regional map. Details of these and other maps are discussed in the descriptions of individual units below.

Cross Sections

The cross sections were constructed from a set of geophysical logs that were scanned from microfiche film records. The image quality of these logs is dependent on the original quality of the photographed log, and the quality varies quite substantially. The cross sections were laid out and correlation lines and text were added in Adobe Illustrator. An indication of the variations in picks of formation tops in the WHCS database is shown on the cross sections. For each pick that differed substantially from that made by me, the operator's picks are also shown as a footnote to the log. The updated picks, made by me, were used in constructing the isopach and structure maps. Information on drill-stem-tests and on producing intervals is also shown for each log where data were available.

A datum of the top of the Greenhorn Formation was chosen for two reasons. (1) The Greenhorn is a widespread carbonate or calcareous shale unit that is usually evident on geophysical logs and is well represented in the WHCS database. It is relatively thin, and represents a close approximation of a time-line through the study area. (2) Formations higher in the section, such as the Bearpaw Shale or Judith River Formation, are not present in all areas, or are partially eroded in some areas. The Greenhorn is present in nearly all the wells used for these cross sections, and therefore provided a consistent datum horizon for the whole area.

Plate 1 also includes a set of restored stratigraphic diagrams for each of the cross sections. These diagrams have the wells spaced proportionately to their actual positions, as opposed to the cross sections, which have wells spaced evenly because of size considerations. The restored stratigraphic diagrams give a better representation of the thickness changes of some formations over the study area, and also provide the reader with a thumbnail view of the larger, detailed sections.

Descriptions of Stratigraphic units

Nomenclature

The nomenclature of Cretaceous rocks in the study area has undergone many changes in the past and is currently in flux for some units. In addition to early research in the Bears Paw Mountains, Little Rocky Mountains, and Central Montana uplift, correlations were made from the Black Hills and from Wyoming, and names used there were introduced into Montana. In addition, common use of some names by drillers has led to acceptance of names that may not have always been appropriate (for instance, use of the name Dakota in central Montana). A single set of names had to be used for this report, but it is recognized that other names for the same stratigraphic units may be just as useful, depending on the requirements of the reader. In the descriptions of units that follow, other common names for the units described are noted. Figure 2 shows the nomenclature of this report.

The Montana Bureau of Mines and Geology does not currently use some nomenclature adopted by the U.S. Geological Survey, and this nomenclature will be discussed briefly here. As a result of regional stratigraphic studies in the northern Great Plains, Rice (1976a, 1976b) made several changes to Cretaceous nomenclature. Those changes that most impact the current study include: (1) The Muddy Sandstone was raised to formation rank in Montana; (2) The Greenhorn Formation was recognized in north-central and central Montana; and (3) The Thermopolis Shale and Cloverly Formation were abandoned in Montana. Further studies prompted Rice and others (1982) to make more changes. Of main importance for the current report was that the Mosby Sandstone Member (and its subsurface equivalent, the Phillips sandstone) was removed from the Greenhorn Formation and assigned as an upper member of the Belle Fourche Shale.

Recent geologic mapping and stratigraphic studies by the Montana Bureau of Mines and Geology and the U.S. Geological Survey has reinstated usage of some units and introduced new terms to the nomenclature of the study area. For example, Porter and Wilde (1993) mapped Thermopolis Shale in the Little Rocky Mountains area, and Porter and others (1997, 1998) recognized the Thermopolis Formation at several localities in northern and central Montana. These studies include several members in the Thermopolis that were considered to be of formation rank by Rice (1976a). In addition, Porter and others (1997) did not use the Muddy Sandstone as a stratigraphic unit at all in Montana, but did recognize the Shell Creek Shale as the upper member of the Thermopolis. Previous reports, such as Rice (1976a, c), did not use the name Shell Creek in Montana, although the U.S. Geological Survey recognizes the unit in Wyoming (Mac Lachlan and others, 1996). Rice (1976a, c) included the Shell Creek interval in the Mowry Shale.

These differing systems of nomenclature posed certain problems in writing the current report. On one hand, I wish to use current nomenclature that is in accord with ongoing geologic

Geographic distribution: The Fall River Sandstone, and equivalent units, are recognized throughout the study area.

Depositional environment or facies: The Fall River is a transgressive sandstone, deposited during a rise of the Early Cretaceous sea in the study area. Depositional environments include shallow marine shelf, tidal flats, and, farther to the southeast, shoreface and deltaic coal swamps.

Gas/oil production/potential: The Fall River, or First Cat Creek sandstone of subsurface usage, produces oil in the Cat Creek anticline area (Johnson and Smith, 1964); oil was also produced from the Fall River on the west flank of the Black Hills uplift (Bolyard and McGregor, 1966).

Other comments: The Fall River is the upper formation of the Inyan Kara Group in the Black Hills. Stratigraphically equivalent rocks include the Flood Member of the Blackleaf Formation, First Cat Creek sandstone, or 'Dakota sand' (Suttner, 1969; Bolyard and McGregor, 1966). The Fall River is the basal unit of the Colorado Group, which extends to the base of the Eagle Sandstone (fig. 2).

Name: Basal silt unit of Skull Creek Shale

Age: Early Cretaceous, late Albian

Contacts: Conformably overlies the Fall River Sandstone; conformably underlies the upper part of the Skull Creek Shale.

Lithology: Light-to dark-gray, calcareous, sandy shale and siltstone and thin beds of very fine to fine-grained, ferruginous sandstone.

Thickness. A thickness of about 200 ft is the maximum shown on the cross sections. The unit is thickest in the central part of the study area and thins westward. Plate 10 also indicates some thinning to the east, but the data do not extend far enough east to see a definite trend. It appears that the basal silt unit thins over Cedar Creek anticline. Note that the Fall River Sandstone is included on this map because of insufficient data to make an isopach map of the Fall River.

Geographic distribution: The basal silt unit is present throughout the study area; it grades into the Inyan Kara Group in the Black Hills region (Bolyard and McGregor, 1966).

Depositional environment or facies: This unit represents the deepening water of the Skull Creek marine basin and is transitional between the transgressive deposits of the underlying Fall River Sandstone and the deeper marine shale of the overlying upper Skull Creek.

Gas/oil production/potential: Only seven wells of the over 18,000 wells in the database show any production from this interval. Otherwise, no hydrocarbon production is documented from this interval.

Other comments: This part of the Skull Creek Shale is commonly referred to as the 'Dakota silt' in the petroleum industry. It is useful as a marker because of a distinctive geophysical log response, which can be seen on the cross sections.

Name: Upper part of Skull Creek Shale

Age: Early Cretaceous, late Albian

Contacts: Conformably overlies the basal silt unit of the Skull Creek Shale; conformably underlies some Muddy Sandstone beds and equivalents, but unconformably underlies Viking Formation or Newcastle Sandstone and equivalents where these nonmarine units exist.

Lithology: Medium-gray to black or bluish-gray, fissile shale; includes thin, lenticular, fine-grained sandstone beds and impure bentonite near the top.

Thickness: Ranges from about 50 ft to about 625 ft in the study area (pl. 11). The upper part of the Skull Creek is thinnest in a north-south region through the center of the study area. The thinnest area of the map is over the Central Montana uplift, and the unit also thins along a northeast trend toward the Williston basin. Thicker areas are to the southwest of the Rocky Boys Indian Reservation, and over the trend of the Cedar Creek anticline.

Geographic distribution: This unit is present in all areas of eastern Montana and surrounding states (McGookey and others, 1972).

Depositional environment or facies: Marine shale

Gas/oil production/potential: No hydrocarbon production is documented from this interval. The organic content of the formation suggests that it has potential as a source rock for hydrocarbon accumulations.

Other comments: The Skull Creek seaway was the first marine innundation of the Cretaceous Western Interior foreland basin. The sea transgressed from both the north and south (McGookey and others, 1972; Dolson and others, 1991); the study area was influenced mainly by the transgression from the north.

Name: Muddy Sandstone and equivalents

Age: Early Cretaceous, late Albian

Contacts: Lower and upper contacts vary, depending on the position of the interval with respect to one or more unconformities within the section.

Lithology: Light-gray, yellowish-gray, and greenish-gray, fine- to coarse-grained, massive to thin-bedded sandstone; contains glauconite or chert and quartzite pebbles at some localities. Also consists of light- to dark-gray, sandy, bentonitic shale; minor amounts of siltstone, carbonaceous shale, and coal.

Thickness: The Muddy interval is relatively thin and tabular over much of the study area. Rocks of the whole interval range from less than 50 ft to about 550 ft thick (pl. 12). A thick area in the northwest represents input from the Bow Island Sandstone. The thin area in the center of the map reflects this area's position in a sediment-starved marine basin during deposition of the Muddy. Some areas in the east may be thin due to erosion during a sea level lowstand (Dolson and others, 1991).

Geographic distribution: Rocks of diverse origins exist at the top of the Skull Creek Shale over the entire study area and in surrounding areas.

Depositional environment or facies: Three main depositional environments are represented: (1) The oldest units coarsen upward and transitionally overlie the Skull Creek Shale. They are progradational, or regressive, sandstone units that were deposited during the highstand of the Skull Creek seaway and *underlie* a regional unconformity formed during a subsequent lowstand. (2) Valley-fill sandstone (Newcastle, Viking) that was deposited within incised drainages during the subsequent rise of the Shell Creek-Mowry seaway and *overlie* the regional unconformity. (3) Transgressive marine sandstone that was deposited and reworked along shorelines and on shallow shelves as the Shell Creek-Mowry sea continued to deepen and advance landward.

Gas/oil production/potential: The Muddy Sandstone, and equivalent units, has been an important oil- and gas-producing interval in many areas in the Western Interior (Dolson and others, 1991), although only the Bow Island is a productive unit in the study area.

Other comments: This sandstone interval is probably the most complex of any interval in Lower or Upper Cretaceous rocks in the study area, which has led to a confusing array of names. The interval contains one or more regional unconformities (Wulf, 1962; McGookey and others, 1972; Donovan, 1995; Porter and others, 1998) which separate regressive units, below, from valley-fill or transgressive units, above. Units generally below the unconformity have been called the Muddy Sandstone, Birdhead sandstone, sandy member of the Colorado Shale, sandy member of the Thermopolis Shale, and Bow Island Sandstone. Units generally above the unconformity have been called the Newcastle Sandstone, Dynneson Sandstone, Viking Formation, and Cyprian Sandstone Member of the Thermopolis Shale. In some areas a named stratigraphic unit, especially the Muddy and Newcastle Sandstones, may straddle the unconformities.

Name: Shell Creek Shale

Age: Early Cretaceous, late Albian

Contacts: Conformably overlies the Muddy Sandstone or equivalent rocks in the study area; may unconformably overlie the Muddy in other areas; conformably underlies the Mowry Shale.

Lithology: Medium-to dark-gray, fissile to blocky shale and medium- to olive-gray, very fine grained, thin-bedded, platy sandstone.

Thickness: An isopach map of the Shell Creek Shale alone could not be made because it is not a recognized formation in the WHCS database of formation tops. On the cross sections it maintains a fairly constant thickness of 350-400 ft from south to north and it thins from about 350 ft to less than 100 ft from west to east. Plate 13 is a map of the combined Mowry and Shell Creek Shales. This map suggests that the thickest area of Shell Creek is in the south-central part of the study area, in the area of the Central Montana uplift; however, the combined unit is relatively thick in most of the central study area.

Geographic distribution: The Shell Creek can be recognized throughout the study area. It extends to adjacent areas to the southeast and south.

Depositional environment or facies: Marine shale. The Shell Creek is the basal marine shale unit deposited during the rise and landward transgression of the Shell Creek-Mowry sea.

Gas/oil production/potential: No hydrocarbon production is documented from this interval; its organic content indicates potential as a hydrocarbon source rock.

Other comments: This shale interval was called the Nefsy shale member of the Graneros Shale (Collier, 1922) in the Black Hills region. That name was abandoned by Ruby (1931) and the unit was included in the Mowry Shale. Eicher (1960) redefined the unit as the Shell Creek Shale in the Bighorn Basin of Wyoming, separating it from what had been considered Thermopolis Shale in that area. Porter and others (1998) considered the Shell Creek to be a member of the Thermopolis Shale or Formation in central Montana. The Shell Creek has not been used as a formal stratigraphic unit in Montana in U.S. Geological Survey reports (Mac Lachlan and others, 1996), and was included in the basal part of the Mowry Shale in the study area by Rice (1976c). Donovan (1995) recognized a transgressive surface of erosion at the base of the Shell Creek in the Powder River basin of Wyoming; in the study area the base may be conformable with the underlying Muddy Sandstone and equivalents.

Upper Cretaceous rocks

Name: Mowry Shale

Age: Late Cretaceous, early Cenomanian

Contacts: Conformably overlies the Shell Creek Shale; conformably underlies the Belle Fourche Shale.

Lithology: Dark-gray, siliceous, fossiliferous shale; weathers to distinctive light-gray to silver hard clay chips. Contains numerous bentonite beds, including the regionally widespread Clay Spur Bentonite Bed at the top and Arrow Creek Bentonite Bed at the base. Fish scales, and locally, fish bones and teeth, are abundant constituents, but other fossils are scarce. In some areas the formation contains beds of olive- to brownish-gray, fine-grained sandstone. It contains progressively more sandstone from east to west across the study area (Cobban, 1951; Lopez 1995).

Thickness: Plate 13 is a map of the combined Mowry and Shell Creek Shales. Most of the mapped interval consists of the Shell Creek Shale. As shown on the cross sections, the Mowry is a relatively thin, tabular unit that is between about 30 and 100 ft thick across the study area.

Geographic distribution: The Mowry is recognized throughout the study area.

Depositional environment or facies: Marine shale. The Mowry Shale represents a continuation of the expansion of the epicontinental sea that flooded the Western Interior foreland basin.

Gas/oil production/potential: No hydrocarbon production is documented from this interval.

Other comments: Wulf (1962) noted that the name was originally applied to just the silvery-gray-weathering siliceous interval, but that later usage expanded it to include all shale between the Clay Spur Bentonite Bed and the Muddy Sandstone. Current usage by Porter and others (1998) in Montana has again restricted it to just the upper siliceous interval bounded by the Clay Spur Bentonite Bed and Arrow Creek Member of the Colorado Shale, where it is considered early Cenomanian (Cobban and Kennedy, 1989).

Name: Belle Fourche Shale (main body)

Age: Late Cretaceous, middle Cenomanian

Contacts: Conformably overlies the Mowry Shale; conformably underlies the Greenhorn Formation. Where the Mosby Sandstone Member is present, the main body conformably underlies the Mosby.

Lithology: Grayish-black, noncalcareous, locally sandy, fissile shale, interlaminated with light-gray, very fine grained sandstone and bentonite beds. Iron and limestone concretions are present locally. In the Bears Paw Mountains there is a sequence, 5-10 ft thick, composed of arkose, mudstone, and sandstone with chert pebbles (Schmidt and others, 1964). A friable sandstone bed is also present near the middle of the formation in the Little Rocky Mountains area (Knechtel, 1959). The Belle Fourche is distinguished from the Mowry Shale by being darker and less resistant in outcrops.

Thickness: Due to the inclusion of the Mosby Sandstone Member in the Greenhorn Formation, the isopach of the Belle Fourche (pl. 14) is representative of the main body of the unit. It is over 300 ft thick in the southeast part of the study area, and thins northward and westward to less than 150 ft. A prominent thick lobe extends northward into the Glasgow area. In most of the northern part of the area, the Belle Fourche is less than 200 ft thick.

Geographic distribution: The Belle Fourche is recognized throughout the study area and in adjacent areas to the north, east, and southeast. It grades westward into the Frontier Formation.

Depositional environment or facies: Marine shale and shelf sandstone beds deposited during a continuation of marine flooding by the Shell Creek-Mowry sea.

Gas/oil production/potential: No hydrocarbon production is documented from this interval in the WHCS database.

Other comments: In the Little Rocky Mountains area this unit was previously called the lower shale member of the Warm Creek Shale; the name was formally abandoned by Rice (1976b). In the Central Montana uplift area, Porter and others (1993) noted the presence of cobbles at the base and top of a sandstone about 70 ft above the base of the formation. They interpreted this to be evidence of a lowstand erosional surface (sequence boundary) in the marine basin. This interval may correspond to the sandstone noted above in the Bears Paw and Little Rocky Mountains areas.

Name: Mosby Sandstone Member of Belle Fourche Shale (Phillips sandstone)

Age: Late Cretaceous, late middle Cenomanian

Contacts: Conformably overlies the main body of the Belle Fourche Shale; conformably underlies the Greenhorn Formation.

Lithology: Yellowish-gray to light-gray, very fine to fine-grained, calcareous, thin-bedded sandstone that contains partings of sandy shale; interlaminated with medium- to dark-gray or light-brownish-gray noncalcareous sandy shale. Limestone and calcareous sandstone septarian concretions are common, as are marine gastropods and pelecypods. Cores of this interval from the Bowdoin dome area consist mainly of dark-gray fissile shale with thin interbeds of very fine grained sandstone.

Thickness: An isopach map of this unit was not prepared because of a lack of data. There are many picks in the WHCS database for the top of the Mosby Sandstone Member and equivalent Phillips sandstone, but there are few wells in which data exist for both the top of the Mosby and the top of the underlying shale unit of the Belle Fourche, so a thickness could not be calculated. On the cross sections the Mosby is a generally tabular unit, ranging from about 100 to 220 ft thick.

Geographic distribution: The isopach map of the Belle Fourche Shale (pl. 14) shows the distribution of the Mosby Sandstone Member as interpreted by Rice (1984). The Mosby forms a lobe extending southward from Canada into Montana that thins to the west, south, and east within the study area.

Depositional environment or facies: Marine shelf sandstone deposited on a storm-dominated shelf (Rice, 1984). The sands were transported southward along the west coast of the marine basin by longshore currents.

Gas/oil production/potential: The Mosby is known as the Phillips sandstone on Bowdoin dome, near Saco, Montana, where it is an important source of shallow biogenic gas. It is not known to produce in other parts of the study area, but was considered as part of a widespread continuous gas accumulation in the 1995 oil and gas assessment (Gautier and others, 1995).

Other comments: Correlative beds in southern Canada are called the second white specks sandstone.

Name: Greenhorn Formation

Age: Late Cretaceous, late Cenomanian to early Turonian

Contacts: Conformably overlies either the main body or Mosby Sandstone Member of the Belle Fourche Shale; conformably or unconformably underlies the Carlile Shale, depending on location.

Lithology: In the study area the Greenhorn consists of gray to black calcareous shale that weathers light gray to white, and beds of blue-gray to brown, silty to sandy, thin-bedded limestone. Marine invertebrates and fish scales are common.

Thickness: Plate 15 shows that the Greenhorn is thinnest on the western side of the study area. In much of eastern Montana the Greenhorn displays a pattern of thick areas and thin areas, rather irregularly distributed. A thin area corresponds to the Central Montana uplift area, and another thin area trends southeasterly from about Bowdoin dome to the Miles City arch and over part of the Cedar Creek anticline. Thicker areas are in the Powder River and Williston Basins, and in the Coburg and Blood Creek synclines. The Greenhorn ranges from less than 50 ft to over 250 ft thick in the study area. The thick area from Malta to Mosby may be due to inclusion of the Mosby Sandstone Member of the Belle Fourche Shale on this map.

Geographic distribution: The Greenhorn is widely distributed throughout the study area and adjacent region.

Depositional environment or facies: Marine shale and limestone deposited during the highest marine transgression within the Cretaceous foreland basin.

Gas/oil production/potential: The Greenhorn is a gas-productive unit at Bowdoin dome, and was considered to contain part of a widespread continuous gas accumulation in Montana (Gautier and others, 1995).

Other comments: The Greenhorn represents the culmination of marine transgression that began with deposition of the upper part of the Muddy Sandstone and extended through Shell Creek, Mowry, and Belle Fourche time. Plate 16 is a detail of the structure contour map drawn on the top of the Greenhorn Formation at Bowdoin dome. Rice and others (1990) described an unconformity at the base of the Greenhorn at Bowdoin dome, which has not been recognized in other areas of northeastern Montana. This may indicate pre-Greenhorn structural movement at the dome. Correlative beds in southern Canada are called the second white specks, due to small whitish specks on bedding planes that are coccoliths.

Name: Carlile Shale (Bowdoin sandstone)

Age: Late Cretaceous, middle to late Turonian

Contacts: Conformably or unconformably overlies the Greenhorn Formation; unconformably underlies the Niobrara Formation.

Lithology: Dark-gray to bluish-gray, noncalcareous, fissile shale with lenses of gray limestone and layers of bentonite; interlaminated in some areas with lenses of very fine to fine-grained sandstone. Rice and Shurr (1980) mapped regional facies of the Carlile, which are shown on plate 17. They indicated that most of the study area consists of shelf sandstone facies and siltstone and shale facies. The name Bowdoin sandstone refers to a sandy facies of the Carlile at Bowdoin dome in the northern part of the area. At Bowdoin dome the entire Carlile is referred to as Bowdoin sandstone.

Thickness: The Carlile map (pl. 17) displays a somewhat irregular pattern of thick and thin areas; however, in general it is thickest in the southeast corner of the map and thins northward and westward. A local thick area is over the Central Montana uplift near Mosby. The thin area in the northeastern part of the map may be due to gradation to a more basinward facies that was starved of sediment in comparison with areas farther westward.

Plate 18 is a detailed isopach map showing the Bowdoin sandstone at Bowdoin dome. This map shows that the Bowdoin is generally between 225 and 300 ft thick over most of the dome area, with thin areas in the north, along the Canadian border, and in the southeast. Thickening exists in the west-central part of the dome, and south of Saco, off the main structure.

Geographic distribution: The Carlile is present throughout the study area and in adjacent areas.

Depositional environment or facies: Marine shale and shelf sandstone.

Gas/oil production/potential: The Carlile is an important gas-producing unit at Bowdoin dome, where it consists of a shaley shelf sandstone facies that is generally referred to as the Bowdoin sandstone.

Other comments: Rice and Shurr (1980) noted that the productive shelf sandstone units at Bowdoin dome are equivalent to the Cardium sandstone of Alberta, Canada, and the Turner Sandy Member of the Carlile in the Black Hills area. Dyman and others (1995) showed a regional unconformity at the base of the Turner Sandy Member, which may have had an influence on the distribution of facies favorable for gas production in the study area.

Name: Niobrara Formation

Age: Late Cretaceous, late Coniacian to early Santonian

Contacts: Unconformably overlies the Carlile Shale; conformably underlies the combined Eagle Sandstone and Telegraph Creek Formation, or the Gammon Shale.

Lithology: Bluish-gray to light-olive-gray, sandy, calcareous to noncalcareous shale and shaley sandstone that contains beds of bentonite and limestone. The lower contact with the Carlile is marked by a prominent zone of calcareous concretions.

Thickness: Plate 19 shows that the Niobrara ranges from less than 100 ft to over 600 ft thick in the study area. The thickest areas are in the southwest part of the region, northwest of Billings, and in a broad area from Glasgow to south of Glendive. In the north-central and northeast parts of the study area the Niobrara is thinnest.

Geographic distribution: The Niobrara is present throughout all of the study area and adjacent areas.

Depositional environment or facies: Marine shale.

Gas/oil production/potential: There is no documented production from this shale interval.

Other comments: Correlative beds in southern Canada are called the first white specks, due to small masses of calcite on bedding planes. Locally, a sandstone in about the middle of the Niobrara has been identified as the Martin sandstone, and has had shows of gas, but is not a producing unit (Rice and others, 1990). A productive unit correlative to the Martin in southern Canada is the Medicine Hat sandstone. One or more unconformities at or near the base of the Niobrara are regionally significant and mark a major Late Cretaceous sequence boundary (Dyman and others, 1995; Larue, 1995). The Niobrara is the top formation of the Colorado Group.

Name: Telegraph Creek Formation and Eagle Sandstone, combined

Age: Late Cretaceous, late Santonian to early Campanian

Contacts: Conformably overlies the Niobrara Formation; disconformably underlies the Claggett Shale.

Lithology: Telegraph Creek Formation consists of dark-gray to black shale and mudstone, concretions of limestone and calcareous sandstone, and beds of light-gray to brown, very fine to fine-grained, thin-bedded, silty sandstone. The sandstone beds increase in thickness upward in the formation. On the western side of the study area, the Eagle Sandstone consists of yellowish-brown to white, very fine to fine-grained, carbonaceous sandstone; dark-gray to brownish-gray, silty mudstone; gray to yellowish-brown siltstone; and minor coal beds. Rice (1980) noted chert gravel and sharks teeth in the upper beds of the Eagle. These rock types thin and pinch out eastward, at about the longitude of Bowdoin dome, into the Gammon Shale.

Thickness: The combined Telegraph Creek Formation and Eagle Sandstone ranges from less than 200 ft to about 500 ft thick (pl. 20). Thinnest areas are over the Bears Paw and Little Rocky Mountains uplifts in the northwest part of the map. East of roughly longitude 108° plate 20 shows the thickness of the Gammon Shale.

Geographic distribution: The Eagle Sandstone is confined to the western half of the study area. The Telegraph Creek is only recognized where the Eagle is present. Both formations grade eastward into the Gammon Shale.

Depositional environment or facies: The Telegraph Creek is shallow marine; the Eagle Sandstone was deposited in a wide range of environments, ranging from nonmarine on the west side of the study area to marine shelf sandstone in the central part (Rice and Shurr, 1983).

Gas/oil production/potential: The Telegraph Creek has produced minor amounts of gas in the study area; the Eagle Sandstone is an important gas-producing formation throughout the region. Tiger Ridge and Bullwacker fields, south of Havre, Montana, are producing areas.

Other comments: The Telegraph Creek and Eagle form a continuous progradational parasequence. On the west end of cross section A-A' the Eagle consists of an informal upper member and the Virgelle Member at the base. The Eagle transitionally overlies the Telegraph Creek at a contact that is not distinct, in areas where the Virgelle Member is not well developed. The Shannon Sandstone Member, which consists of sandstone lentils within the Gammon Shale, is equivalent to the Eagle Sandstone. The Telegraph Creek marks the base of the Montana Group (fig. 2).

Name: Gammon Shale

Age: Late Cretaceous, early Campanian

Contacts: In places, unconformably overlies the Niobrara Formation; disconformably underlies the Claggett Shale.

Lithology: Dark- to light-gray, silty, sandy, noncalcareous shale; contains abundant iron concretions and bentonite beds. Much of the upper part of the formation consists of interbedded silty shale, mudstone, and siltstone laminae (Gautier, 1981).

Thickness: The Gammon is shown on the eastern side of plate 20. It ranges from about 400 ft, in the central part of the study area, to over 1,200 ft thick, in the southeast part of the study area. It thins abruptly southeastward toward the Black Hills (Robinson and others, 1964).

Geographic distribution: The Gammon is only recognized east of about 108° west longitude; west of there, equivalent rocks are the Telegraph Creek Formation and the Eagle Sandstone.

Depositional environment or facies: Marine shale and marine shelf sandstone.

Gas/oil production/potential: The Shannon Sandstone Member is an important gas-producing interval. Other intervals of silty and muddy shale are potential reservoirs (Gautier, 1981).

Other comments: The Shannon Sandstone Member, which consists of sandstone lentils within the Gammon Shale, is equivalent to the Eagle Sandstone. In the Black Hills region, the Gammon is considered to be a member of the Pierre Shale.

Name: Claggett Shale

Age: Late Cretaceous, middle Campanian

Contacts: Disconformably overlies the Eagle Sandstone or Gammon Shale; conformably underlies the Judith River Formation.

Lithology: Shale and siltstone that are dark gray to black, weather brown. Basal beds consist of sandy shale containing chert pebbles. Bentonite beds are common near the base of the formation, and are known collectively as the Ardmore Bentonite Beds. Limestone concretions exist in the upper part of the Claggett.

Thickness: The Claggett thins from over 500 ft to less than 200 ft thick west to east across the study area (pl. 21). It is thickest north of the Rocky Boys and Fort Belknap Indian Reservations, and is thinnest over a wide area east of about west longitude 107° 30'. A thin area in the Bears Paw uplift may be due to faulting in that structurally complex area.

Geographic distribution: The Claggett is recognized throughout the study area. It grades eastward into the Pierre Shale where the overlying Judith River Formation pinches out.

Depositional environment or facies: Marine shale

Gas/oil production/potential: There is no documented production from this shale interval.

Other comments: The disconformity at the base of the Claggett represents a transgressive surface of erosion, or ravinement surface.

Name: Judith River Formation

Age: Late Cretaceous, late Campanian

Contacts: Conformably overlies the Claggett Shale, disconformably underlies the Bearpaw Shale.

Lithology: A heterogeneous mixture of sandstone, siltstone, mudstone, shale, and coal. Sandstone beds are light to dark brown, yellow, and light gray, coarse to very fine grained, and contain iron concretions. Siltstone, mudstone, and shale beds are light green to dark gray, in part carbonaceous and gypsiferous. Coal or lignite beds are present at outcrops in the Sweet Grass Hills (Lopez, 1995) and as far east as the Little Rocky Mountains (Knechtel, 1959). In the Bears Paw Mountains a massive sandstone, as much as 60 ft thick, is at the base of the formation (Schmidt and others, 1964). This sandstone probably correlates with the Parkman Sandstone Member.

Thickness: Plate 22 shows that the Judith River thins eastward across the study area, from over 600 ft to less than 100 ft thick. It is thickest in the southwestern part of the contoured area, and is thinnest in the eastern third of the area and also in the Sweet Grass Hills region. It generally thins to the east as a result of gradation into marine shale.

Geographic distribution: The Judith River is recognized throughout most of the study area. It thins eastward and grades into the Pierre Shale.

Depositional environment or facies: Generally transitional from nonmarine on the west to marginal marine on the east in a progradational parasequence. The upper part is composed of transgressive systems tract sandstones (Rogers, 1993).

Gas/oil production/potential: The Judith River produces gas from several fields in the study area.

Other comments: A basal marginal-marine sandstone was defined as the Parkman Sandstone Member (Knechtel and Patterson, 1956). Detailed descriptions of the facies changes from continental to marine are in Shurr and others (1989), Monson (1989), and Rogers (1993). Much of the geological literature about the Judith River concerns its diverse fossil vertebrate fauna. Fish, turtles, crocodiles, dinosaurs, and mammals have been recovered in large numbers.

Name: Bearpaw Shale

Age: Late Cretaceous, late Campanian to early Maastrichtian

Contacts: Disconformably overlies the Judith River Formation; conformably underlies the Fox Hills Sandstone.

Lithology: Dark-gray to black, weathers to light-gray and brownish-gray, fissile shale; thin beds of yellowish-brown to brownish-gray, fine- to medium-grained sandstone; and numerous bentonite beds, limestone concretions, and iron concretions.

Thickness: Plate 23 shows that the Bearpaw ranges from less than 200 ft to over 1,100 ft thick in the study area. The northwestern quarter of the isopach map only shows an incomplete thickness of the formation because it is exposed and partly eroded at the surface over wide areas. Thickest contoured areas are in the Central Montana uplift and Williston basin. Thinnest areas in the Bears Paw and Bowdoin dome areas are probably due to erosion over those structures.

Geographic distribution: The Bearpaw is recognized throughout the study area. It grades eastward into the Pierre Shale in areas where the underlying Judith River Formation is absent.

Depositional environment or facies: Marine shale

Gas/oil production/potential: There is no documented production from this shale interval.

Other comments: --

Name: Fox Hills Sandstone

Age: Late Cretaceous, early Maastrichtian

Contacts: Conformably overlies the Bearpaw Shale, conformably underlies the Hell Creek Formation.

Lithology: Light-yellowish-gray to olive-gray, very fine to medium-grained sandstone; contains iron concretions throughout, carbonaceous material on bedding planes, and thin intervals of gray to olive-gray shale and siltstone.

Thickness: Due to a lack of control points in the WHCS database, an isopach map of the Fox Hills could not be constructed for the study area. In the Mosby area it is about 60-140 ft thick (Schmidt and others, 1964), and in the Bears Paw Mountains area it is 60-100 ft thick (Hearn, 1976).

Geographic distribution: The Fox Hills is widely distributed throughout the northern Cretaceous Interior foreland basin.

Depositional environment or facies: Marginal marine (shoreface) sandstone.

Gas/oil production/potential: There is no documented gas or oil production from the Fox Hills in the WHCS database within the study area.

Other comments: The Fox Hills is the uppermost formation of the Montana Group in the study area.

Name: Hell Creek Formation

Age: Late Cretaceous, late Maastrichtian

Contacts: Conformably overlies the Fox Hills Sandstone, unconformably underlies the Fort Union Formation.

Lithology: Yellowish-gray, olive-gray, brownish-black, carbonaceous and bentonitic shale and siltstone; local gray to light-brown, fine- to medium-grained, calcareous sandstone and minor amounts of sandstone- and shale-pebble conglomerate; coal beds in the Bears Paw Mountains.

Thickness: Due to extensive Quaternary erosion, an isopach map of the Hell Creek Formation was not prepared. It is about 400-500 ft thick in the Bears Paw Mountains (Hearn, 1976), and a partial thickness is estimated as about 300 ft in the Mosby area (Schmidt and others, 1964). Tops for this formation in the eastern part of the study area are also poorly represented in the WHCS database.

Geographic distribution: Eroded remnants along and near the Missouri River indicate that the Hell Creek was once widespread over at least the northern part of the study area, and was probably once present over all of eastern Montana (McGookey and others, 1972).

Depositional environment or facies: Nonmarine; fluvial channel, floodplain, and lacustrine.

Gas/oil production/potential: There is no documented production from the Hell Creek.

Other comments: The Hell Creek is the uppermost Cretaceous formation in the study area. It represents the continental deposits of a regressive parasequence that began with the Bearpaw Shale and extended through deposition of the Fox Hills Sandstone. Like the Judith River, the Hell Creek is well known for its abundant fossil fauna.

Overlying rocks

In the western part of the study area the overlying Tertiary Fort Union Formation is eroded and Cretaceous rocks are exposed at the surface. Remnants of the Fort Union exist in the Bears Paw Mountains where coal was mined locally (Hearn, 1976). The Fort Union is widely exposed in the eastern part of the study area (Stoner and Lewis, 1980) and consists of nonmarine sandstone, siltstone, and shale beds. Some of the shale beds are carbonaceous, and coal is present in thin beds. Robinson (1972) indicated that the Fort Union and equivalent strata were once present over all of the study area. Gries and others (1992) noted a regional unconformity that separates Tertiary from Cretaceous rocks in most areas of the Rocky Mountain foreland.

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