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Regional Topography, Physiography, and Geology of the Northern Great Plains

By

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Illustrations

[In pocket]

REGIONAL TOPOGRAPHY, PHYSIOGRAPHY, AND GEOLOGY OF THE NORTHERN GREAT PLAINS

By

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Introduction

This report was prepared as part of the Northern Great Plains Resources Program. Its primary purpose is to provide general descriptions of the topography, physiography (land forms), and geology of the Northern Great Plains region and adjoining areas in northeastern Wyoming, eastern Montana, western North Dakota, and northwestern South Dakota. The discussions focus chiefly on the Powder River and Williston basins, which are the principal geologic features and contain the bulk of the coal, oil, gas, uranium, and other resources in the 146,000 square mile (378,000 sq. km) study area.

Topography and Physiography

The Northern Great Plains region lies almost wholly within the Great Plains physiographic province (plate A-1; Fenneman, 1931, p. 1-91). Elements of the Middle Rocky Mountains, Wyoming Basin, and Southern Rocky Mountains provinces are included along the west and southwest margins and a segment of the Central Lowland province is included along the northeast margin. Except for the extreme northeast corner, which is drained by the northward-flowing Souris River, the entire region is within the drainage basins of the eastward- and southeastward-flowing Missouri River and a principal tributary, the northeastward-flowing Yellowstone River. The North Platte River, near the south edge, flows eastward into the main stem of the Platte River in central Nebraska, and thence into the Missouri River at the east edge of Nebraska.

The northeast corner of the Northern Great Plains study area, which is within the Western Lake Section of the Central Lowland province, is characterized by nearly flat plains surrounding the Souris River and Des Lacs River Valleys. Elevations rise from about 1,500 feet[1] above sea level along the valley floors to 2,000 feet at the margin of the Turtle Mountains on the northeast and to 1,700-2,000 feet along the foot of the Missouri Escarpment on the southwest. The Turtle Mountains are a group of hummocky hills generally less than 200 feet high; maximum elevations reach 2,400 to 2,500 feet above sea level in that area.

The boundary between the Great Plains and Central Lowland physiographic provinces is marked by the Missouri Escarpment, a conspicuous linear topographic feature extending northwest across the northeast part

[1]To convert feet to meters, multiply feet by .3048.

of the study area (plate A-1). The east-facing slope rises from elevations of 1,700-2,000 above sea level along the base to 1,900 to 2,200 feet at the top. Westward, the escarpment levels off onto the Missouri Plateau, which is the name commonly given to that part of the Great Plains province that lies within the Northern Great Plains study area (sometimes referred to also as the Upper Missouri Basin).

The eastern segment of the Missouri Plateau is a 15- to 25-mile wide strip of extremely irregular terrain which abounds with hills, lakes, ponds, and swamps indicative of the glacial origin of the landscape. This strip, cutting diagonally northwest across central North Dakota, is commonly referred to as the Coteau du Missouri (Hills of the Missouri). To the southwest, the terrain slopes downward to the valley of the Missouri River, an ice-marginal stream whose present position was determined by continental glaciers advancing from the north and northeast some 10,000-15,000 years ago.

The Missouri Plateau stretches westward and southwestward across western North Dakota and northwestern South Dakota into the broad plains region of eastern Montana and northeastern Wyoming, skirting the Black Hills in west-central South Dakota (plate A-1). The landscape is dominated by plains and low-lying hills and tablelands, interrupted here and there by entrenched river valleys and by isolated uplands, buttes, and mesas. Elevations rise gradually from about 2,000 feet above sea level at the east edge of the Missouri Plateau to 5,000-6,000 feet at the foot of the bordering mountain ranges along the west and southwest margins. Except for the areas covered by glacial deposits (see plate A-3), the surface rocks throughout are chiefly soft, easily eroded sandstones and shales.

Geologically, that part of the Northern Great Plains lying in western North Dakota, northwesternmost South Dakota, and easternmost Montana is referred to as the Williston basin, and that part lying in southeastern Montana and northeastern Wyoming (west of the Black Hills) is referred to as the Powder River basin (see plate A-4). Both features are major downfolds, separate and distinct from adjacent geologic structures. The Williston basin has little topographic or physiographic expression, but the Powder River basin is bounded by extensive uplands along parts of its east, south, and west margins. To the north and northeast, however, the terrain of the Powder River basin merges with, and cannot be distinguished from, the remainder of the Missouri Plateau.

The Black Hills are an isolated mountain range surrounded by other elements of the Missouri Plateau; only the north end of the range is included in the Northern Great Plains study area (plate A-1). Elevations range from 4,000 feet above sea level in the foothills to nearly 7,000 feet along the crest. The range exhibits a central core of irregularly dissected crystalline rocks flanked in the foothills areas by concentric ridges and valleys that have been eroded from an alternating sequence of resistant and non-resistant sedimentary rocks.

The northwestern part of the Laramie Mountains, which are an element of the Southern Rocky Mountains physiographic province, extends into the south edge of the study area (plate A-1). Elevations rise abruptly from 5,000 feet along the floor of the Powder River Basin and the valley of the North Platte River to nearly 9,000 feet along the crest of the range. The north- and northeast-facing slopes are deeply faceted by numerous tributaries of the North Platte. Casper Mountain, at the extreme northwest tip of the Laramie Mountains, stands 2,000 feet above the basin floor south of the city of Casper, and descends westward onto the plains of the adjacent Wyoming Basin province.

The dividing line between the Great Plains and Wyoming Basin provinces is not marked by any prominent topographic or physiographic feature. It is more readily defined, however, on the basis of geologic structure. Extending between the Laramie Mountains and the Bighorn Mountains to the northwest is a broad upfold known geologically as the Casper arch (see plates A-1 and A-4). This feature separates the downfolded Powder River basin on the east from the similarly downfolded Wind River basin (part of the Wyoming Basin Province) to the west. The crest of the arch is occupied in several places by sharply folded, smaller anticlines, and a northwest-trending line connecting these features is arbitrarily used as the boundary between the two major physiographic provinces. It should be noted that the Powder River heads west of this line in the easternmost part of the Wind River Basin. The terrain extending across the Casper arch, generally less than 6,000 feet above sea level, is flat to gently rolling, but locally it is eroded into prominent irregular "breaks" particularly near the south end of the Bighorn Mountains.

The Bighorn Mountains, one of the major ranges of the Middle Rocky Mountains physiographic province, extends northwest along the southwest edge of the Northern Great Plains study area for about 150 miles (plate A-1). Rising from 5,000-6,000 feet above sea level in the foothills areas to more than 13,000 feet at the crest, the Bighorns form an imposing mountain barrier between the Powder River Basin on the east and the Bighorn Basin on the west. In gross aspect, the range contains a massive core of crystalline rocks surrounded by gently to steeply inclined sedimentary rocks. The east slope, facing the Powder River Basin, is steep and rugged for the most part, and is cut by many deep, narrow canyons. Except for the middle third of the range, which is precipitous and highly glaciated, the upland surfaces extending across the top are flat to gently rolling. Near the north end, at the Wyoming-Montana state line, the Bighorn River has cut a gorge through the mountains and flows out of the Bighorn Basin onto the Great Plains; Yellowtail Dam and Reservoir are located within this gorge.

The Pryor Mountains are a small, detached mountain uplift which can be considered physiographically as the northwest continuation of the Bighorn Mountains. The uplift appears as a dissected plateau, with sedimentary rocks covering both the top and flanks. Elevations range from 5,000 feet around the base to nearly 9,000 feet in the higher parts.

North of the Bighorn Mountains and Pryor Mountains, and extending to the Canadian border, the landscape of the Northern Great Plains is dominated by broad to sharply entrenched river valleys (chiefly, the Yellowstone, Musselshell, and Missouri Rivers) and by extensive low, moderately to deeply dissected interstream divides. The Big Snowy Mountains, whose southeast-facing slopes rise abruptly 3,000 feet above the plains in the northwest corner of Golden Valley County, Montana, are the only uplands of consequence across this area.

A map prepared by Edwin H. Hammond (U.S. Geological Survey, 1970, p. 61-64; Hammond, 1964, p. 11-19) showing broad-scale land form characteristics in the United States was adapted for use in the present study to provide generalized information on two basic attributes of the landscape--slopes and local topographic relief--across the North Great Plains region (plate A-2). The boundary lines plotted on plate A-2 are essentially those published by Hammond on smaller scale maps; however, some modifications were made by the writer following visual inspection of the two-degree, 1:250,000 topographic maps of the region. The unit area chosen by Hammond as the basis for his classification was a six-mile square, which, in the case of the Northern Great Plains, corresponds to the area of an individual township.

Except where abrupt changes in slope angles and topographic relief are involved, such as juxtaposed plains and mountains, the differences between the various land form categories shown on plate A-2 are not great. The boundaries are therefore gradational in many places, and small areas exhibiting characteristics of one land form type may be included with another type. However, the categories as presently delineated are considered to be representative of much the greater parts of the land surface included within them. As expected, certain boundary lines on plate A-2 coincide closely to boundaries between major physiographic provinces and other large physical features as shown on plate A-1. The predominance of plains and tablelands is also evident throughout the region. Of particular note are the extensive areas classified as "open high hills" (labelled C4 on plate A-2), indicating rough, broken terrain where the land surface has suffered moderate to deep erosion as exemplified by the prominent badlands adjacent to the Little Missouri River in west-central North Dakota.

The classification of land forms has a variety of uses. It provides an index to general terrain conditions which may exert a significant influence on the cross-country "movement" of people and things, such as the construction of a transmission line. Knowledge of land forms likewise may be used in evaluating the degree of difficulty to be expected in re-shaping surface-mined land so that it will conform closely to the surrounding, undisturbed land surface. Deeply dissected badlands would be extremely difficult to reshape, for example, whereas irregular plains would be less difficult. The scenic or aesthetic values of a given area are, of course, directly dependent upon its landscape characteristics.

Geology

General

A geologic map (plate A-3) and a structure contour map (plate A-4) portray the principal geological characteristics of the Northern Great Plains region. The geologic map is primarily a bedrock map, and, except for a few areas, does not show the narrow strips of surficial deposits (sand, gravel, silt, and clay) that commonly occur in river and other stream valleys. Glacial deposits are shown in a large area in the northeast corner of the study area, however, where they almost completely bury the bedrock units. Extensive deposits of glacial drift are also present in a 20- to 100-mile wide strip that lies to the southwest. Bedrock is only intermittently exposed within this strip, and formation contacts are inferred throughout much of it. Because of the small scale of the geologic map (1:1,000,000; 1 inch equals approximately 16 miles), two or more geologic formations have been combined into single units in many places for adequate map representation. The individual formations contained in each map unit are shown in the geologic map explanations (plate A-3), and general descriptions are given in Appendix A. Major stratigraphic and geologic time divisions are listed in Appendix B.

The structure contour map (plate A-4) reflects the major geologic structures of the region by means of contour lines drawn on top of the Fall River Formation in the Powder River Basin and adjacent areas in northeastern Wyoming and southeastern Montana, and on top of the Kootenai Formation or the equivalent Cloverly Formation elsewhere. All these formations are Early Cretaceous in age, but the Fall River occupies a stratigraphic position that is somewhat higher than either the Kootenai or the Cloverly. The contour interval is 1,000 feet, except locally where only 5,000-foot intervals are shown; contours above 5,000 feet have not been drawn.

The major geologic features in the Northern Great Plains region--the Williston and Powder River basins--are extensive downfolded structures which contain thick sequence of sedimentary rocks and the bulk of the mineral resources that are of special interest to the present study. In particular, these basins were the sites of accumulation of widespread coal deposits during the Paleocene and Eocene epochs of the Tertiary period (50-60 million years ago; see Appendix B), and the downwarping has preserved these deposits from subsequent erosion over most of both basin areas. A comparison of the structure contour map (plate A-4) with a coal map of the Northern Great Plains (Averitt, 1974) readily shows the influence of basin structure on the present distribution of coal deposits throughout the Northern Great Plains region.

Rocks

Rocks of all geologic systems occur in the Northern Great Plains region. The oldest are represented by the Precambrian crystalline rocks ("basement complex") in the cores of the Black Hills and Hartville uplift, and the Laramie, Granite, Bighorn, Pryor, and Big Snowy Mountains (plate A-3). Flanking the uplifts are layers of progressively younger sedimentary rocks which are upturned and eroded near the mountain fronts, but which flatten toward the basin interiors. These rocks range in age from Cambrian to late Tertiary. The strata forming the surface rocks over much of the Powder River and Williston Basins are early Tertiary (Paleocene and Eocene) in age. They were once covered by several thousands of feet of younger Tertiary rocks most of which have since been removed by erosion. The youngest sedimentary units in the region are the unconsolidated alluvial, glacial, and other surficial deposits.

Precambrian rocks exposed in the mountain areas are chiefly resistant, fine to coarsely crystalline igneous and metamorphic rocks. Granite and granite gneiss predominate; one exception is in the core of the Big Snowy Mountains of central Montana, where hard compact shales of the Precambrian Belt Supergroup are locally exposed. Igneous rocks of early Tertiary age occur in places in the Black Hills and along the north edge of the Granite Mountains.

A great variety of rock types comprise the sedimentary formations of the region (Appendix A). Individual formations also vary considerably in character from one place to another. In general, there is a gradual transition from the more resistant limestone, dolomite, and sandstone beds in the lower parts of the succession (Cambrian through Lower Cretaceous) to the less resistant sandstone and shale beds in the higher parts (Upper Cretaceous and Tertiary). Most of the sedimentary rock units that crop out along the west, south, and east margins of the Powder River Basin project beneath the basin without interruption. Maximum combined thickness of all strata is about 23,000 feet in the structurally deepest parts of the basin (Denson, oral commun., 1974). The sedimentary sequence occupying the Williston Basin has a maximum thickness of about 16,700 feet (Sandberg, 1962, p. 18), and contains several formations ranging in age from Late Ordovician to Early Mississippian that are not represented in surface exposures.

The Fort Union Formation of Paleocene age, which is the most widely exposed sedimentary rock unit in the Northern Great Plains region, is the principal coal-bearing formation. In many places it can be subdivided into two or more members for detailed geologic mapping and for more precise coal bed correlation and resource evaluation. Coal beds are generally thickest, most numerous, and most widespread in the upper part of the sequence. In the Gillette area of central Campbell County, Wyoming, for example, nearly a dozen coal beds, with combined thicknesses of more than 300 feet locally, have been identified in the upper 1,000-1,200 feet of the Fort Union and traced over several hundered square miles (Denson, Keefer, and Horn, 1973). The overlying Wasatch Formation of Eocene age also contains coal beds of economic interest in several parts of the Powder River Basin. Because of the slight inclination of the sedimentary strata along most basin margins (see following discussion of structure) several of the Fort Union and Wasatch coal beds remain close to the ground surface over wide areas.

Glacial deposits, consisting of gravel, sand, silt, and clay, occur in ground and end moraines and in outwash plains. The deposits are 100 to 200 feet thick over much of the glaciated area, but locally they attain thicknesses of 500 to 600 feet along buried, preexisting stream channels (Bluemle, 1971; U.S. Geological Survey and others, 1973, p. 42).

Structure

The Williston and Powder River basins, as mentionedpreviously, are broad regional downfolds which dominate the geologic structure of the Northern Great Plains. The Williston basin is a nearly symmetrical, elliptically shaped basin whose limbs are inclined very gently (50 to 65 feet per mile) toward a central, structurally low area in northwestern North Dakota (marked by the minus 3,500-foot contour on plate A-4; Sandberg, 1962, fig. 4). In contrast, the Powder River basin is an elongate, markedly asymmetrical feature with a gentle east limb (150 feet per mile) and a relatively steep west limb (500 to 600 feet per mile) dipping toward a deep trough line that lies near the west basin margin (marked by the minus 9,000-foot contours on plate A-4). Other large structural downfolds in the Northern Great Plains study area include the Bull Mountains basin in central Montana and the southeast arm of the Wind River basin in central Wyoming.

The 5,000-foot structure contour lines outline the mountain ranges and other major uplifts of the region (plate A-4). In some places the structural relief between adjacent mountain and basin structures is enormous, such as between the crest of the Bighorn Mountains and the trough line of the Powder River basin where it exceeds 25,000 feet.

Many subsidiary geologic structures--anticlines, synclines, and faults--occur throughout the region; only a few are labelled on plate A-4. Nesson and Cedar Creek anticlines are prominent features on the northeast and southwest flanks of the Williston basin, respectively. Except along the west limb of Cedar Creek anticline, where dips range from 4 to 30 degrees (and locally exceed 30 degrees), the sedimentary strata flanking the folds are inclined generally less than 3 degrees (Sandberg, 1962, p. 116). As the west side of the basin, Poplar and Bowdoin domes are also gently folded features. All the anticlines mentioned above are locally oil- and gas-bearing.

The south and southwest limbs of the Sheep Mountain and Blood Creek synclines are considered to form the southwest edge of the Williston basin (Sandberg, 1962, fig. 1). Adjoining features include Porcupine Dome and a broad, structurally positive area extending northwest from the Black Hills. The latter, sometimes called the Miles City arch (Mallory, 1972, p. 37), forms the boundary between the Williston and Powder River basins. Porcupine Dome and the Big Snowy Mountains to the west are part of what is commonly referred to as the Central Montana uplift.

Anticlines and synclines occur in considerable numbers across the Powder River basin, but the small scale and generalized character of the structure contours shown on plate A-4 do not reflect them in detail in most cases. Many of the oil and gas fields in the basin are located on anticlinal structures. However, numerous large petroleum accumulations have been discovered in recent years along the gentle east flank of the basin where stratigraphic conditions in Lower Cretaceous sandstones (most notably, the Muddy Sandstone Member of the Thermopolis Shale) form the trapping mechanism rather than anticlinal folding.

The Casper arch is the structural boundary between the Powder River basin and the Wind River basin to the southwest. The southwest margin of this feature is marked by an extensive fault zone. Prominent fault zones also extend along the north edge of the Laramie Mountains, in places along the east flank of the Bighorn Mountains, and on the southwest side of Cedar Creek anticline. Faults of lesser magnitude occur in many other parts of the region, but only a few are plotted on plates A-3 and A-4. Most faults are inactive at the present time.

Geologic History

Pre-uppermost Cretaceous sedimentary rocks originated primarily in broad, relatively shallow epicontinental seas which advanced and retreated across the present site of the Northern Great Plains many times during the Cambrian and ensuing geologic periods. Beginning with the deposition of the Lance and Hell Creek Formations in latest Cretaceous time, however, there was a shift from predominantly marine to predominantly nonmarine sedimentation which coincided with the advent of major mountain-building movements throughout much of the Rocky Mountain chain. Many of the major structural features of the Northern Great Plains and adjoining regions to the west commenced to form at this time, and structural deformation continued through the early part of the Tertiary period in most places.

As deformation proceeded, vast amounts of clastic material were eroded from the rising mountains and deposited in the intervening, subsiding basins. The basin floors remained close to sea level, and subtropical conditions prevailed during most of the Paleocene and early Eocene epochs. At times large segments of the basins were covered by extensive swamps supporting lush growths of vegetation, resulting in the widespread coal deposits not present in the Fort Union and Wasatch Formations.

The basins continued to fill with sediments during middle and late Tertiary time, but large parts of these deposits were removed by erosion prior to the close of the period. Continental glaciers advancing from the north and northeast spread blankets of glacial debris across the northeastern part of the Northern Great Plains in Quaternary time.

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APPENDIX A

SEDIMENTARY FORMATIONS IN THE NORTHERN GREAT PLAINS

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
A. NORTHEASTERN MONTANA			
Sources of data: Collier (1917); Jensen and Varnes (1964); Witkind (1959).			
Alluvium----------------	10±	Sand, gravel--------------------	Unconsolidated.
Glacial deposits--------	15±	Clay, silt, sand, gravel--------	Do.
Flaxville Formation-----	20±	Sand, gravel--------------------	Generally unconsolidated.
Fort Union Formation----	2,000+	Sandstone, siltstone, claystone-	Many thin lignite beds.
Hell Creek Formation----	250±	Claystone, siltstone, shale, sandstone.	
Fox Hills Sandstone-----	35-145	Claystone, siltstone, and sandstone at base overlain by massive sandstone.	
Bearpaw Shale-----------	800-1,140	Shale---------------------------	Many thin bentonite beds.
Judith River Formation--	400	Sandstone, claystone------------	
Claggett Shale----------	750	Shale---------------------------	
B. BIG SNOWY MOUNTAINS, BULL MOUNTAINS BASIN, AND ADJACENT AREAS IN CENTRAL MONTANA			
Sources of data: Foster (1956); Gardner (1950); Mallory (1972); Reeves (1931); Wolsey, Richards, and Lupton (1917).			
Alluvium----------------	10±	Sand, gravel, silt--------------	Unconsolidated.
Terrace deposit---------	10±	---do---------------------------	Do.
Fort Union Formation----	1,900	Shale, claystone, sandstone-----	Many coal beds.
Hell Creek Formation----	700-1,500	Sandstone, claystone, shale-----	Locally includes Lennep Sandstone at base.
Bearpaw Shale-----------	1,000+	Shale---------------------------	Some thin bentonite beds.
Judith River Formation--	200-400	Sandstone, siltstone, shale-----	
Claggett Shale----------	200-600	Shale---------------------------	Some thin bentonite beds.
Eagle Sandstone---------	200-525	Sandstone, shale----------------	
Colorado Shale----------	2,250	Shale, sandstone----------------	Many thin bentonite beds.
Kootenai Formation------	230-500	Shale, sandstone, limestone-----	Structure contour horizon (plate A-4).
Morrison Formation------	125-200	Shale, claystone, siltstone, sandstone.	
Ellis Group-------------	130-400	Limestone, shale, sandstone-----	Some gypsum.
Quadrant Formation------	0-50	Limestone, shale----------------	
Amsden Formation--------	100-200	Limestone, dolomite, shale------	
Big Snowy Group---------	800	Shale, sandstone----------------	
Madison Group-----------	1,600	Limestone-----------------------	
Snowy Range Formation---	425	Limestone, shale, siltstone-----	
Pilgrim Limestone-------	225	Limestone, shale----------------	
Wolsey and Park Shales--	300	Shale, limestone----------------	
Flathead Sandstone------	175	Sandstone, conglomerate---------	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
C. BIGHORN MOUNTAINS, PRYOR MOUNTAINS, AND WESTERN POWDER RIVER BASIN			
Sources of data: Hose (1955); Keefer and Van Lieu (1966); Mallory (1972); Mapel (1959); Richards and Rogers (1951); Thom and others (1935); Denson, N. M., oral communication (1973); Sandberg, C. A., oral communication (1973).			
Alluvium	10±	Sand, gravel, silt	Unconsolidated.
Moncrief Conglomerate	0-2,000	Conglomerate	
Arikaree Formation	200±	Sandstone	
White River Formation	200±	Claystone, siltstone, conglomerate.	
Wasatch Formation	1,000+	Sandstone, shale, conglomerate	Many coal beds.
Fort Union Formation	2,000-4,000	Sandstone, siltstone, shale	Do.
Lance Formation Hell Creek Formation.	600-2,200	Sandstone, shale	
Bearpaw Shale	200-865	Shale, sandstone	Some thin bentonite beds.
Judith River Formation	250-350	Sandstone, shale	Equivalent rocks termed Parkman Sandstone near Montana-Wyoming state line.
Claggett Shale	365-650	Shale	
Cody Shale	2,600-3,670	Shale, sandstone	Some thin bentonite beds; includes Telegraph Creek Formation north of Montana-Wyoming state line.
Frontier Formation	260-515	Sandstone, siltstone, shale	Some thin bentonite beds.
Mowry Shale	335-525	Shale	Several thin bentonite beds.
Thermopolis Shale	625	---do	Several thin bentonite beds; basal part termed the Skull Creek Shale and Newcastle Sandstone in places south of Montana-Wyoming state line.
Cloverly Formation	150-240	Sandstone, siltstone, claystone, shale.	Structure contour horizon (plate A-4).
Morrison Formation	180-280	Shale, claystone, siltstone, sandstone.	
Sundance Formation	285	Sandstone, shale, limestone	Sundance and underlying Gypsum Spring are termed the Ellis Group in places north of Montana-Wyoming state line.
Gypsum Spring Formation	0-190	Shale, claystone, limestone	Some gypsum beds.
Chugwater Formation	355-810	Siltstone, shale, sandstone	
Goose Egg Formation	180-250	Shale, limestone, siltstone	Some gypsum beds.
Tensleep Sandstone	0-420	Sandstone	
Amsden Formation	200-300	Dolomite, limestone, sandstone, shale.	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
C. BIGHORN MOUNTAINS, PRYOR MOUNTAINS, AND WESTERN POWDER RIVER BASIN--Continued			
Madison Limestone--------	330-735	Limestone, dolomite-------------	
Jefferson Formation-----	0-255	Dolomite------------------------	
Souris River Formation--	0-16	Limestone-----------------------	
Beartooth Butte Formation.	0-140	Dolomite------------------------	
Bighorn Dolomite--------	0-365	Dolomite, limestone-------------	
Gallatin and Gros Ventre Formations.	380-740	Shale, limestone, sandstone-----	
Flathead Sandstone------	215-345	Sandstone-----------------------	

D. SOUTHWESTERN POWDER RIVER BASIN, CASPER ARCH, AND SOUTHEASTERN WIND RIVER BASIN

Sources of data: Crist and Lowry (1972); Hares (1946); Keefer (1972); Keefer and Van Lieu (1966); Mallory (1972); Olson (1954); Denson, N. M., oral communication (1973); Pipiringos, G. N., oral communication (1973).

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
Wind-blown sand---------	0-200	Sand----------------------------	Unconsolidated.
Ogallala Formation------	0-800	Siltstone, sandstone, conglomerate.	Unconsolidated in part.
Arikaree Formation------	0-1,000	Sandstone, limestone, tuff, conglomerate.	
White River Formation---	0-1,465	Sandstone, siltstone, conglomerate.	
Wagon Bed Formation-----	0-1,000	Mudstone, sandstone, conglomerate.	Present in Wind River Basin only; Wind River Formation equivalent in Powder River Basin is Wasatch Formation.
Wind River Formation----	0-7,000	Claystone, shale, sandstone, conglomerate.	
Fort Union Formation----	0-8,000	Sandstone, siltstone, claystone, shale.	Many coal beds in Powder River Basin.
Lance Formation---------	250-5,000	Sandstone, shale, siltstone-----	
Fox Hills Sandstone-----	0-1,000	Sandstone, shale----------------	
Lewis Shale-------------	200-600	Shale, sandstone----------------	
Mesaverde Formation-----	850-1,365	Sandstone, shale----------------	Some thin coal beds in Wind River Basin.
Cody Shale--------------	3,000-5,000	Shale, sandstone----------------	
Frontier Formation------	625-1,000	Sandstone, shale----------------	
Mowry Shale-------------	200-300	Shale---------------------------	Many bentonite beds.
Thermopolis Shale-------	100-200	---do---------------------------	Muddy Sandstone Member at top.
Cloverly Formation------	150-300	Sandstone, claystone, conglomerate.	
Morrison Formation------	150	Sandstone, claystone------------	
Sundance Formation------	225-365	Shale, sandstone, siltstone, limestone.	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
D. SOUTHWESTERN POWDER RIVER BASIN, CASPER ARCH, AND SOUTHEASTERN WIND RIVER BASIN--Continued			
Jelm Formation----------	120-395	Siltstone, sandstone------------	
Red Peak Formation------	600-700	Shale, siltstone----------------	
Goose Egg Formation-----	150-380	Shale, siltstone, limestone-----	Some gypsum beds.
Tensleep Sandstone------	250-280	Sandstone-----------------------	
Amsden Formation--------	140-200	Shale, sandstone, limestone-----	
Madison Limestone-------	250-325	Limestone-----------------------	
Gallatin Limestone, Gros Ventre Formation, Flathead Sandstone.	200-800	Sandstone, shale----------------	
E. LARAMIE MOUNTAINS AND SOUTHERN POWDER RIVER BASIN			
Sources of data: Denson and Bottinelly (1949); Denson and Horn (1972); Keefer and Van Lieu (1966); Mallory (1972); Olson (1954); Pipiringos, G. N., oral communication (1973).			
Ogallala Formation------	0-400	Claystone, siltstone, sandstone, conglomerate.	
Arikaree Formation------	600±	Sandstone, siltstone, limestone-	
White River Formation---	0-1,100	Siltstone, conglomerate, limestone.	
Wasatch Formation-------	0-1,800	Sandstone, siltstone, shale-----	Several coal beds.
Fort Union Formation----	2,700-4,300	Sandstone, siltstone, claystone, shale.	Do.
Lance Formation---------	2,000-3,000	Shale, sandstone----------------	Several thin coal beds in lower part.
Fox Hills Sandstone-----	500-800	Sandstone, shale----------------	
Lewis Shale-------------	400	Shale, sandstone----------------	
Mesaverde Formation-----	900	Sandstone, shale----------------	
Cody Shale--------------	3,000-3,600	Shale, sandstone----------------	
Frontier Formation------	850-900	---do---------------------------	
Mowry Shale-------------	200-300	Shale---------------------------	Several thin bentonite beds.
Thermopolis Shale-------	75-250	Shale, sandstone----------------	Includes Muddy Sandstone Member.
Cloverly Formation------	65-320	Sandstone, claystone, shale, conglomerate.	
Morrison Formation------	130-220	Claystone, shale, sandstone, limestone.	
Sundance Formation------	220-480	Shale, sandstone, siltstone, limestone.	
Jelm Formation----------	0-45	Siltstone, sandstone------------	
Red Peak Formation------	580-610	Siltstone, shale, sandstone-----	Some gypsum beds.
Goose Egg Formation-----	380-410	Shale, limestone, sandstone-----	Several gypsum beds.
Casper Formation--------	525	Sandstone, limestone------------	Hartville Formation (900-1,225') in southern Niobrara County.

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
E. LARAMIE MOUNTAINS AND SOUTHERN POWDER RIVER BASIN--Continued			
Madison Limestone-------	150-275	Limestone-----------------------	Guernsey Formation (140-260') in southern Niobrara County.
Flathead Sandstone------	0-90	Sandstone, conglomerate---------	
F. BLACK HILLS AND EASTERN POWDER RIVER BASIN			
Sources of data: Dobbin, Kramer, and Horn (1957); Mapel and Pillmore (1963); Robinson, Mapel, and Bergendahl (1964); U.S. Geological Survey and others (1964).			
White River Formation---	0-150	Sandstone, siltstone, claystone-	
Wasatch Formation-------	300±	Sandstone, shale----------------	Numerous coal beds.
Fort Union Formation----	1,200-2,270	---do---------------------------	Do.
Lance Formation, Hell Creek Formation.	500-2,500	---do---------------------------	
Fox Hills Sandstone-----	125-550	Sandstone, shale, siltstone-----	Colgate Sandstone Member at top.
Pierre Shale------------	945-3,100	Shale, claystone----------------	Several thin bentonite beds.
Niobrara Formation------	100-250	Shale---------------------------	Many thin bentonite beds.
Carlile Shale-----------	360-690	---do---------------------------	
Greenhorn Formation-----	70-370	Shale, limestone----------------	
Belle Fourche Shale-----	350-850	Shale---------------------------	
Mowry Shale-------------	180-230	---do---------------------------	Many thin bentonite beds.
Newcastle Sandstone-----	0-100	Sandstone, siltstone, shale, claystone.	Some thin coal and bentonite beds; equivalent to Muddy Sandstone Member of Thermopolis Shale.
Skull Creek Shale-------	160-270	Shale---------------------------	
Fall River Formation----	35-200	Sandstone, shale, siltstone-----	Structure contour horizon (plate A-4).
Lakota Formation--------	45-300	Sandstone, conglomerate, claystone.	Some thin coal beds.
Morrison Formation------	0-220	Claystone, shale, sandstone, limestone.	
Sundance Formation------	175-495	Shale, sandstone, siltstone, limestone.	
Gypsum Spring Formation-	0-125	Claystone, limestone------------	Abundant gypsum.
Spearfish Formation-----	450-825	Shale, siltstone, sandstone-----	Some gypsum beds.
Minnekahta Limestone----	30-50	Limestone-----------------------	
Opeche Formation--------	50-100	Sandstone, siltstone, shale-----	
Minnelusa Formation-----	650-1,000	Sandstone, limestone, dolomite--	Some gypsum and anhydrite.
Pahasapa Limestone------	500-600	Limestone-----------------------	
Englewood Limestone-----	50±	---do---------------------------	
Whitewood Dolomite------	50±	Dolomite------------------------	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
		F. BLACK HILLS AND EASTERN POWDER RIVER BASIN--Continued	
Winnepeg Formation------	50-100	Sandstone, shale, siltstone-----	
Deadwood Formation------	300-400	Sandstone, limestone, shale, siltstone.	
		G. SOUTHEASTERN MONTANA AND ADJACENT AREAS IN NORTH AND SOUTH DAKOTA	
		Sources of data: Denson and Gill (1965); U.S. Geological Survey and others (1973).	
Glacial deposits--------	0-600	Sand, gravel, silt---------------	Unconsolidated.
Flaxville Formation-----	20-200	Sandstone, conglomerate, tuff, mudstone.	Largely unconsolidated.
Arikaree Formation------	200-360	Sandstone, limestone, shale, conglomerate.	
White River Formation---	250±	Sandstone, claystone, shale, siltstone, conglomerate.	Some bentonite beds.
Golden Valley Formation-	0-175	Sandstone, siltstone, claystone-	Some thin beds of lignite.
Fort Union Formation----	1,250-2,300	Sandstone, shale, siltstone-----	Many lignite beds.
Hell Creek Formation----	400-575	Claystone, sandstone------------	Some thin lignite beds.
Fox Hills Sandstone-----	25-300	Sandstone, shale-----------------	
Pierre Shale------------	1,700-2,500	Claystone, shale-----------------	Some thin bentonite beds.

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APPENDIX B

MAJOR STRATIGRAPHIC AND TIME DIVISIONS

Subdivisions in Use by the U. S. Geological Survey			Age estimates commonly used for boundaries (in million years)[1]	
Era or Erathem	System or Period	Series or Epoch	(A)	(B)
Cenozoic	Quaternary	Holocene		
		Pleistocene	1.5-2	1.8
	Tertiary	Pliocene	ca. 7	5.0
		Miocene	26	22.5
		Oligocene	37-38	37.5
		Eocene	53-54	53.5
		Paleocene	65	65
Mesozoic	Cretaceous[3]	Upper (Late) Lower (Early)	136	
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	190-195	
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	225	
Paleozoic	Permian[3]	Upper (Late) Lower (Early)	280	
	Pennsylvanian[3]	Upper (Late) Middle (Middle) Lower (Early)	320[2]	
	Mississippian[3]	Upper (Late) Lower (Early)	345	
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	395	
	Silurian[3]	Upper (Late) Middle (Middle) Lower (Early)	430-440	
	Ordovician[3]	Upper (Late) Middle (Middle) Lower (Early)	ca. 500	
	Cambrian[3]	Upper (Late) Middle (Middle) Lower (Early)	570	
Precambrian	Time subdivisions of the Precambrian: Precambrian Z--base of Cambrian to 800 m.y. Precambrian Y--800 m.y. to 1,600 m.y. Precambrian X--1,600 m.y. to 2,500 m.y. Precambrian W--older than 2,500 m.y.			

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1/ Estimates for ages of time boundaries are under continuous study and subject to refinement and controversy. Two scales are given for comparison:

(A) Geological Society of London, 1964, The Phanerozoic time-scale; a symposium: Geol. Soc. London, Quart. Jour., v. 120, suppl., p. 260-262.

(B) Berggren, W. A., 1972, A Cenozoic time-scale--some implications for regional geology and paleobiogeography: Lethaia, v. 5, no. 2, p. 195-215.

In addition to these, a useful time scale for North American mammalian stages is given by:

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: Amer. Jour. Sci., v. 262, p. 145-198.

2/ From Table 1: Correlation chart for the Carboniferous of north-west Europe, Russia, and North America: Geol. Soc. London, 1964[1/], p. 222.

3/ Includes provincial series accepted for use in U. S. Geological Survey reports.

Terms designating time are in parentheses. Informal time terms--early, middle, and late--may be used for the eras, for periods where there is no formal subdivision into Early, Middle, and Late, and for epochs. Informal rock terms--lower, middle, and upper--may be used where there is no formal subdivision of an era, system, or series.

PROVINCIAL SERIES ACCEPTED FOR USE IN U.S. GEOLOGICAL SURVEY REPORTS

Series	Age	Region
Gulfian	Late Cretaceous	Texas, Louisiana, Oklahoma, Arkansas, Mississippi, and Alabama.
Comanchean	Early and Late Cretaceous	
Coahuilan	Early Cretaceous	Texas, Louisiana, Arkansas, Mississippi, and Alabama.
Ochoan	Late Permian	Texas and New Mexico.
Guadalupian	Early and Late Permian	Do.
Leonardian	Early Permian	Do.
Wolfcampian	Early Permian	Do.
Virgilian	Late Pennsylvanian	Arkansas, Oklahoma, Kansas, Missouri, Nebraska, and Iowa.
Missourian	do	
Des Moinesian	Middle Pennsylvanian	
Atokan	do	
Morrowan	Early Pennsylvanian	
Chesterian	Late Mississippian	Indiana, Kentucky, Tennessee, Illinois, Iowa, and Missouri.
Meramecian	do	
Osagean	Early Mississippian	
Kinderhookian	do	
Cayugan	Late Silurian	New York and Michigan.
Niagaran	Middle Silurian	Do.
Alexandrian	Early Silurian	Missouri, Illinois, and Michigan.
Cincinnatian	Late Ordovician	Ohio, Indiana, Kentucky, Tennessee, Michigan, Wisconsin, and Iowa.
Mohawkian	Middle Ordovician	New York, Michigan, Wisconsin, and Iowa.
St. Croixan	Late Cambrian	Iowa, Minnesota, Wisconsin, and Michigan.

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