

INTRODUCTION

Numerous widespread subbituminous and lignite coal deposits occur in the Powder River Basin in southeastern Montana, principally within the Fort Union Formation. Many of the coal beds are less than 250 feet (76.2 m) below land surface and are, therefore, mineable by surface methods. Individual coal beds commonly are 20-30 feet (6.1-9.1 m) thick, but may be as much as 80 feet (24 m). These factors, coupled with the low-sulfur content of the coal, make it attractive as a major energy resource.

The Fort Union Formation generally consists of discontinuous sandstone and coal beds separated by shale. The coal beds are important aquifers, supplying water to many domestic wells, stock wells, and springs. Although the yields of wells and springs are small, the supplies are necessary to the agricultural economy of the area. Increased development of the coal resources not only will locally remove part of the aquifer, but may also cause dewatering of the coal and overlying beds around the mine site and cause changes in the chemical quality of the ground water.

PURPOSE AND SCOPE

This report has resulted from a continuing detailed hydrologic investigation of the shallow ground-water system, generally less than 4,500 feet (1,370 m) below land surface in the northern Powder River Basin (see index map). The purpose of the overall investigation is to develop an understanding of the hydrologic system, document geologic conditions prior to coal mining, and predict the regional effects of coal mining and related activities on the system. Owing to the time requirement and cost of collecting field data, geologic concepts will be used where possible to extend ground-water data in space. Thus, a principal requirement in understanding the hydrologic system is definition of the geologic framework.

The purpose of this report is to describe the geologic framework in terms of lithology, formational contacts, and stratigraphic relationships of the geologic units. The results of this study, which was cooperatively funded in part by the Montana Bureau of Mines and Geology and the U.S. Bureau of Land Management, will be used as a foundation for future hydrologic modeling and reports.

The geology was reviewed, modified, and where necessary remapped in the field during the summer and fall of 1975, with the aid of aerial photographs of most of the area. A horizon, which is shown on the geologic maps where its thickness is 5 feet (1.5 m) or more, was mapped from the valley edge to the center of the stream course along the project boundary.

About 650 geophysical logs were examined during the preparation of the structure contours for the Bearpaw Shale shown on the geologic map. Of these, 410 were within and 240 were adjacent to the mapped area. Use of the data points adjacent to the study area provided a better interpretation near project boundaries than had they not been considered. Some structure contours in the southwestern and southeastern parts of the map have been omitted for clarity where their inclusion would unduly congest the map.



INDEX MAP SHOWING LOCATION OF STUDY AREA

PREVIOUS INVESTIGATIONS

Numerous geologic studies have been conducted in selected parts of the report area during the past 67 years, principally for the purpose of coal-bed definition and correlation. These various studies (see index to geologic mapping) were used as guides for the present mapping. Work by Thom, Hall, Wegmann, and Moulton (1933) was used for the geology represented in this report, and the location within the boundaries of the Crow and Northern Cheyenne Indian Reservations.

Acknowledgments

Residents of the area were very cooperative in allowing access to and providing information about their property.

Construction of the structure contours and geologic sections was facilitated by information obtained from various types of geophysical logs on file at the Montana Oil and Gas Conservation Commission in Billings.

DEVELOPMENT OF POWDER RIVER BASIN

Geologic units within the study area consist of massive deposits of the Parkman Sandstone, Bearpaw Shale, and Fox Hills Sandstone of Late Cretaceous age and continental deposits of the Hell Creek Formation, Fort Union Formation, Wasatch Formation, terrace deposits, and alluvium of Late Cretaceous to Holocene age (see geologic map). Gill and Cobban (1973) indicate that the marine units consist of eastward-thinning wedges of regressive deposits of the Parkman and Fox Hills Sandstones that enclose westward-thinning wedges of fine-grained predominantly transgressive deposits of the Bearpaw Shale.

The Parkman Sandstone is composed of fine- to coarse-grained massive sandstone interbedded with silt to carbonaceous shale on the west side of the basin. The Parkman is representative of a bracket to fresh-water near-shore depositional environment associated with a withdrawing sea (Baker, 1971). Lower Parkman beach, sandbar, and distributary-channel sediments were deposited in deltas. The upper beds of these sediments were subsequently reworked during late Parkman deposition into a successive series of bars and shoreline sands (Glaze and Keller, 1965).

The Bearpaw Shale is represented in the western part of the basin by silty sandstone and thin interbedded shale resulting from numerous transgressive and regressive periods of deposition. To the east, however, the Bearpaw is composed of dark shaly claystone and shale deposited in an extensive stable sea.

Permanent withdrawal of marine water from the basin began after deposition of sediments forming the Bearpaw Shale (Gill and Cobban, 1973). This final withdrawal of the Late Cretaceous sea is represented by the fine- to medium-grained sandstone deposits of the Fox Hills Sandstone. Many geophysical logs within the study area depict upper and lower parts of the unit separated by thin shale. The Fox Hills Sandstone, then, represents two separate regressive phases. Gill and Cobban (1973) believe that these regressive phases represent an initial slow and regular withdrawal of the sea, an intervening small advance, and a final rapid withdrawal.

Some geologists have considered the repeated transgressions and regressions of the sea during Late Cretaceous time to be related to the beginning of the Laramide orogeny. However, the absence of coarse clastics in any of the units fails to support a theory of any marked uplift in the western cordillera. Broad regional uplift in central Montana is believed to have been the cause of the final withdrawal of the sea (Gill and Cobban, 1973). Vast amounts of continental deposits identified as the Hell Creek Formation were subsequently deposited in the Powder River Basin. These continental deposits are indicative of various fluvial and lacustrine depositional environments.

Existing at various periods throughout Late Cretaceous to Eocene time were extensive swamps, which are now represented by many coal beds of varying thicknesses and lateral extent in the Hell Creek, Fort Union, and Wasatch Formations. The thickest and most extensive coal units, however, occur in the Tongue River Member of the Fort Union Formation. Interbedded with the coal beds of these formations are deposits consisting primarily of heterogeneous, discontinuous mixtures of fine-lenticular sand, silty sandstone, siltstone, silty shale, and shale deposited in fluvial and lacustrine environments (Baker, 1971).

The Hell Creek Formation was deposited in the Powder River Basin in environments of coastal plains, meandering streams, and flood plains. These deposits are probably unconformable with the underlying shale and sandstone. During Hell Creek deposition, relatively strong subsidence of the basin was the first indication of the Laramide orogeny. During this time, a primary thrust of deposition existed in the southern part of the Powder River Basin in Wyoming (Glaze and Keller, 1965). The formation contains very little coarse-grained material, which suggests that adjacent uplands were relatively inactive at this time.

Tectonic events that occurred from Late Cretaceous through Pliocene time shaped the Powder River Basin into its present structure. During deposition of the Fort Union and Wasatch Formations, the Laramide orogeny was most pronounced.

Fort Union sediments were being deposited during the Paleocene as the Bighorn Mountains (Bighorn uplift) and the Black Hills (Black Hills uplift) began to rise, and large volumes of sediment were being transported into the swampy flood-plain environment of the newly formed Powder River Basin (see structural features map). The age of basin formation and local uplift is supported by Bekman (1962), Mepel (1958), and Robinson, Mepel, and Bergendahl (1964). Parker and Andrews (1939) state that the Tullock and Lebo Shale Members of the Fort Union Formation were deposited along stream courses and in temporary ponds and marshes over an area of low topographic relief. Locally, however, outcrops of the Tullock and Lebo Shale Members of the Fort Union Formation exhibit a vernal character in the northeast part of the basin, which is indicative of lacustrine deposition. Deposition was irregular and probably in none of the area was deposition continuous. The intervals of nondeposition allowed erosion of a limited amount of sediments and transportation elsewhere for redeposition. Such conditions are inferred from the lenticularity of the beds, the abrupt truncation of the Fort Union and Wasatch Formations, the Laramide orogeny was most pronounced.

The upper Parkman is represented in the depositional sequence in the basin by the Tongue River Member of the Fort Union Formation. This unit is alternating sandstone, siltstone, carbonaceous shale, coal, and clinker. Deposition was in an environment similar to that of the other members of the Fort Union Formation. Continental conditions prevailed with abundant accumulations of organic material in swamps, from which coal was later formed. Also, deposition was partly cyclic in nature and generally represented a period of alternating fluvial and lacustrine conditions (Baker, 1971).

By Eocene time all of the major structural features of the area had been partly formed and Wasatch Formation sediments were being deposited. During early Eocene time, strata in the basin and surrounding areas were strongly folded and faulted (Glaze and Keller, 1965), forming most of the present-day structural features of southeastern Montana (see map). The environment of fresh-water lakes, stream channels, and swamps. During late Eocene time, the Tongue River Member of the Fort Union Formation, with sediments that later formed shale, sandstone, and coal of the Wasatch being deposited in an environment of fresh-water lakes, stream channels, and swamps. During late Eocene time uplift was renewed in the Black Hills (Robinson and others, 1964) and the basin was filled westward, creating an asymmetrical structure with the deepest part on the west side adjacent to the Bighorn uplift near the Montana-Wyoming border.

Following the Black Hills uplift, erosion created a mature landscape of reduced relief over much of the area. During Oligocene and Miocene time, the area is thought to have been buried by tuffaceous detritus from increased volcanic activity to the west (Glaze and Keller, 1965). Only the highest mountain ranges were left unburied by these ash deposits.

Near the end of Pliocene time, a major regional uplift took place (Glaze and Keller, 1965), with many of the structures near the basin, such as the Miles City arch, becoming more prominent. Extensive normal faulting occurred, altering structures to their present form. Examples of this faulting are the Vornado fault, a northeast-trending normal fault just north of the mapped area, and the Lake Basin fault zone to the west of the Powder River Basin (structural features map). Composed of a series of northeast-oriented extension faults, the Lake Basin fault zone bounds the northern extension of the Bighorn uplift and has a general west-northwest alignment.

Subsurface structure northwest of the basin is dominated by the gently southward-plunging Ashland syncline. This feature probably developed as a trough between the Bighorn uplift to the south and the Porcupine dome to the north during their formation. Subsequent subsidence within the Powder River Basin accompanying continued uplift of the Bighorn Mountains caused the syncline to plunge into the basin.

The major regional uplift near the end of Pliocene time caused streams to be rejuvenated and erode through the ash cover, uncovering buried mountains and re-excavating basins. Erosion continued until Pliocene time and formed most of the present landscape (Glaze and Keller, 1965).

Geologic units probably have been folded locally since the inception of the basin. However, local deformation generally associated with the burning of a coal deposit and subsequent baking of the overlying units is of a more recent age. Subsidence and slumping generally followed this process, which account for many small structural features in the study area, particularly in the Tongue River Member of the Fort Union Formation.

Many small, local faults in rocks of the Tongue River Member were undoubtedly associated with the variations in weight of overlying deposits created by deposition and erosion during the course of their formation. However, the faults visible at the land surface are also generally associated with the burning of a subsurface coal unit and subsequent related stresses and strains created by this process. Faulting of this type is probably expressed by randomly arranged fault patterns, such as those shown on the geologic map near Kirby, Coburn, and Olive.

Many local fault patterns have a more easterly orientation. The northeast-trending faults near Decker and eastward along the Montana-Wyoming border are oriented in such a manner to suggest that a deep-seated fracture system in the subsurface extends to the land surface. Existence of a subsurface fracture system is supported by a northeast-trending fault shown on the surface of the Bearpaw Shale (geologic map) in the basin by the Tongue River Member of the Fort Union Formation. This unit is alternating sandstone, siltstone, carbonaceous shale, coal, and clinker. Deposition was in an environment similar to that of the other members of the Fort Union Formation. Continental conditions prevailed with abundant accumulations of organic material in swamps, from which coal was later formed. Also, deposition was partly cyclic in nature and generally represented a period of alternating fluvial and lacustrine conditions (Baker, 1971).

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Resistivity curves reflect the electrical resistivity of rock materials in a borehole by direct application of an electric current. Resistivity is recorded as increasing to the right. Sandstone is generally more resistive than shale; coal beds exhibit high resistivities, which are generally greater than for sandstone, but may be less.

A representative electric log for shallow formations in the Powder River Basin shows the general characteristics of geologic units. The log gives the location of geologic contacts interpreted from the configuration of the curves, and their relative depths below land surface, starting at the bottom of the surface casing at about 240 feet (73 m). The contacts were chosen in the following manner:

Bearpaw Shale: Upper contact is placed where SP curve makes a negative deflection from the relatively straight line below, and the resistivity abruptly increases. The log represents a change from predominantly shaly sandstone above. A transition zone of about 20 feet (6.1 m) of siltstone and silty sandstone at the top of the Bearpaw commonly conceals the contact. In this situation, the contact was placed near the base of the transition zone, keeping the permeable zones within the Fox Hills Sandstone.

Fox Hills Sandstone: Unit consists of upper and lower sandstone divisions separated by thin silty shale. Upper contact is placed where SP and resistivity curves converge for silty shale and siltstone overlying the upper sandstone.

Hell Creek Formation: Upper contact is placed where the deflections of the SP and resistivity curves are more symmetrical and become more closely spaced vertically. Both curves also converge slightly toward the center of the log in the interval above the contact. The pattern indicates a change from massive channel sandstone and shale in the Hell Creek to even-bedded fine-grained sandstone, siltstone, shale, and coal beds above.

Tullock Member of Fort Union Formation: Upper contact placed where SP and resistivity curves indicate a change from predominantly fine-grained sandstone and siltstone to predominantly massive shale and thin-bedded siltstone above.

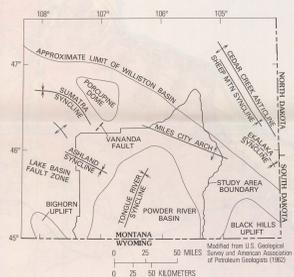
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CONFIGURATION OF TOP OF BEARPAW SHALE

The Bearpaw Shale as a thick unit of relatively consistent lithology that is easily interpreted on electric logs. It also forms the base of the overlying shallow ground-water system throughout most of the northern Powder River Basin. For these reasons, the top of the Bearpaw was selected to show the structural configuration of the basin.

The slope of the Bearpaw Shale surface increases southward from about 15 ft/m (2.8 m/m) in the north-central part of the basin to about 200 ft/m (38 m/m) at the Montana-Wyoming border (see geologic map). In the southern half of the mapped area the east and west flanks slope toward the deepest part of the basin in Montana. The asymmetrical aspect of the basin (axis to the west of center) is illustrated by the structure contours. The contours indicate a slope



MAP SHOWING STRUCTURAL FEATURES OF SOUTHEASTERN MONTANA

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The last phase of the geologic chronology of the Powder River Basin is Pleistocene and Holocene deposition, and, more importantly, erosion. During Pleistocene time, deposition of continental detritus was restricted to areas associated with glaciation, where features in areas of low relief, alluvial deposits along small streams, and lacustrine sediments in low-lying areas. More recent deposition has been alluvial deposition on flood plains of all sizes, some collier deposits, and limited amounts of lacustrine sediments. Recent erosion has stripped most of the Pleistocene deposits from the area.

PRESENT-DAY APPEARANCE OF GEOLOGIC UNITS

The regional dip of geologic units in most of the mapped area ranges from horizontal to a few degrees. The low dip results in the topographically controlled outcrop pattern shown on the geologic map.

The erosional characteristics of the geologic units and the type of vegetation growing on the units are distinctive. The sandy silt of Parkman Sandstone, Hell Creek Formation, Tullock and Tongue River Members of the Fort Union Formation, and the Wasatch Formation, in many instances, to resistant bluffs and commonly support a prolific growth of pine and juniper trees. The Bearpaw Shale and Lebo Shale Member of the Fort Union Formation, on the other hand, erode to large flat plains where vegetation is low-lying areas. Topography where less well cemented, they support little vegetation and virtually no trees. Pleistocene deposits appear principally as erosional remnants remaining as veneers on bluffs and perhaps the highest terraces along the Yellowstone River (see geologic map).

SUBSURFACE IDENTIFICATION OF GEOLOGIC UNITS

Geophysical logs of oil and gas wells and test holes drilled in the area were the principal sources of information used for identifying subsurface geologic contacts. Most available logs were electric logs; however, borehole-compensated sonic, gamma-ray, compensated formation density (gamma-gamma), and continuous downhole logs were available for many wells and test holes.

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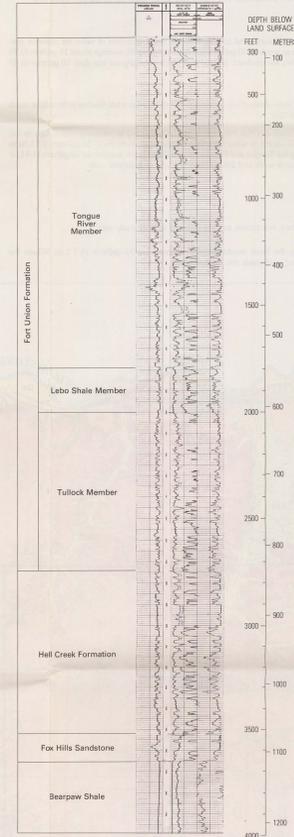
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The slope of the Bearpaw Shale surface increases southward from about 15 ft/m (2.8 m/m) in the north-central part of the basin to about 200 ft/m (38 m/m) at the Montana-Wyoming border (see geologic map). In the southern half of the mapped area the east and west flanks slope toward the deepest part of the basin in Montana. The asymmetrical aspect of the basin (axis to the west of center) is illustrated by the structure contours. The contours indicate a slope



REPRESENTATIVE ELECTRIC LOG SHOWING CHARACTERISTICS OF GEOLOGIC UNITS

The general thinning trend of the alluvium downward may be due to a change in altitude of a temporary base level, which is now the Yellowstone River. Several processes that could temporarily raise the base level are: continued uplift of the Porcupine dome and Miles City arch during Quaternary time; continued subsidence of the Powder River Basin south of the study area during Quaternary time; isostatic adjustments in land surface owing to removal of continental ice sheets to the north, causing a relative upward movement; or removal of large amounts of sedimentary deposits in the northern part of the study area by erosion, causing isostatic adjustment.

SUMMARY

Geologic units mapped in the Powder River Basin of southeastern Montana are of marine and continental origin. The Parkman Sandstone, Bearpaw Shale, and Fox Hills Sandstone of Late Cretaceous age are the result of deposition during transgressive and regressive phases of extensive seas. Overlying units are the result of continental deposition.

Extensive swamps existed at various periods throughout Late Cretaceous to Eocene time. Material deposited in the swamps formed the massive coal beds now present in the Hell Creek, Fort Union, and Wasatch Formations. The bulk of the thickest and most extensive coal beds is restricted to the Tongue River Member of the Fort Union Formation.

Tectonic events that occurred from Late Cretaceous through Pliocene time shaped the Powder River Basin into its present form. Large volumes of sediment were transported into the swampy flood-plain environment during the Paleocene, accompanied by the rise of the Bighorn Mountains and the Black Hills. During early Eocene time, strata in the basin were strongly folded and faulted, forming most of the structural features of southeastern Montana. Near the end of Pliocene time, major regional uplift and extensive faulting altered structures to their present form.

at a maximum of about 800 ft/m (150 m/m) near the outcrop on the west flank and a maximum of about 200 ft/m (38 m/m) on the east flank.

The contactal relief regional features (see map) of the area. Northwest-trending V-shaped contours in the northwestern part of the area depict the southeast-plunging Ashland syncline. Widely spaced and open contours in the north-central part of the area are evidence for the northeast-trending Miles City arch. Closely spaced contours in the southwest show the eastward limb of the Bighorn uplift. Moderately spaced contours in the southeast are a result of Black Hills uplift. Other structure contour maps for the northern Powder River Basin drawn on the base of the Colorado Shale (Dobbin and Erdmann, 1955) and on a basement map below the Greenhorn Shale (Robinson and others, 1964) show the same general subsurface structural features as are present at a greater depth.

THICKNESS OF UNITS ABOVE BEARPAW SHALE

Three geologic sections, two perpendicular and one parallel to the axis of the Powder River Basin, illustrate the thicknesses and relationships of the bedrock units above the Bearpaw Shale.

Section A-A' shows that the units in general thin from east to west and thicken over the Miles City arch near Mizpah Creek. The Lebo Shale Member of the Fort Union Formation, however, has a reverse trend and is thickest over the arch, probably as a result of deposition in a large lake that is believed to have existed over the arch during Paleocene time (Glaze and Keller, 1965). The Fox Hills Sandstone is fairly constant in thickness until it pinches out to the west.

Section B-B' shows that the Tongue River and Lebo Shale Member thicken toward the basin axis from both east and west flanks. The difference in slope between the upper and lower contacts of the Tongue River Member indicates two periods of regional uplift to the west or subsidence to the east one before initial deposition of the Wasatch and one after deposition. The Tullock Member of the Fort Union Formation and the Hell Creek Formation thicken slightly from the west flank into the basin, but become much thicker on the gently sloping east flank. The Fox Hills Sandstone becomes slightly thicker in the basin from the east flank but thins greatly on the steep westward flank and intertongues with the Bearpaw Shale in the western edge of the section.

Section C-C' shows a general thickening of all units southwest from the gently sloping Miles City arch. This trend continues well into the Wyoming part of the basin (Robinson and others, 1964). The exception to this pattern is the Lebo Shale Member, which is thickest near the arch. However, the Lebo does thicken slightly near the southern edge of the section.

Sections D-D' and E-E' illustrate the relationships of bedrock to the alluvium along the Yellowstone River in the north-central and northeastern parts of the study area, respectively. These sections, along with test holes exposed in valleys, indicate that major streams in the northern (downstream) part of the study area have produced valleys of wide and moderately thin alluvium accompanied by varying terrace deposits. In the southern (upstream) part of the study area, the major streams and their tributaries have a somewhat thicker and narrower alluvial fill. The decreasing thickness of alluvium in a downstream direction occurs in valleys of both the Powder and Tongue Rivers.

The Little Powder River, a major tributary of the Powder River, has a maximum thickness of alluvium of about 50 feet (15 m) near the Montana-Wyoming boundary (Robinson and others, 1964), north of Powderville, the alluvium has thinned to a maximum of 35 feet (11 m) along the Powder River (Parker and Andrews, 1939). Further thinning of the alluvium in a downstream direction is indicated by a maximum thickness of 21 feet (6.4 m) in test holes exposed near Locos, and 19 feet (5.8 m) in test holes near the confluence with the Yellowstone River.

The Tongue River has a maximum alluvium thickness of about 75 feet (23 m) near Ashland (Hopkins, 1973). 36 feet (11 m) in test holes exposed near Brandenburg, and 32 feet (9.8 m) in test holes near the confluence with the Yellowstone River.

This general thinning trend of the alluvium downward may be due to a change in altitude of a temporary base level, which is now the Yellowstone River. Several processes that could temporarily raise the base level are: continued uplift of the Porcupine dome and Miles City arch during Quaternary time; continued subsidence of the Powder River Basin south of the study area during Quaternary time; isostatic adjustments in land surface owing to removal of continental ice sheets to the north, causing a relative upward movement; or removal of large amounts of sedimentary deposits in the northern part of the study area by erosion, causing isostatic adjustment.

Geologic units mapped in the Powder River Basin of southeastern Montana are of marine and continental origin. The Parkman Sandstone, Bearpaw Shale, and Fox Hills Sandstone of Late Cretaceous age are the result of deposition during transgressive and regressive phases of extensive seas. Overlying units are the result of continental deposition.

Extensive swamps existed at various periods throughout Late Cretaceous to Eocene time. Material deposited in the swamps formed the massive coal beds now present in the Hell Creek, Fort Union, and Wasatch Formations. The bulk of the thickest and most extensive coal beds is restricted to the Tongue River Member of the Fort Union Formation.

Tectonic events that occurred from Late Cretaceous through Pliocene time shaped the Powder River Basin into its present form. Large volumes of sediment were transported into the swampy flood-plain environment during the Paleocene, accompanied by the rise of the Bighorn Mountains and the Black Hills. During early Eocene time, strata in the basin were strongly folded and faulted, forming most of the structural features of southeastern Montana. Near the end of Pliocene time, major regional uplift and extensive faulting altered structures to their present form.

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