INTRODUCTION

Numerous and widespread coal deposits occur in eastern Montana, principally within the Fort Union Formation. The prospect of large-scale development of the coal resources in this region has caused concern about the effects on the water resources. Surface mining of the coal will disrupt and locally remove certain aquifers of the Fort Union Formation and could cause changes in the quality of ground water. Furthermore, increases in population near coal-development areas could significantly increase demands for public water supply. These factors, in addition to the scarcity of alternative water supplies, make ground water an important aspect of the area hydrology that needs to be better understood for proper management.

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 below land surface, in the Fort Union coal region of eastern Montana (see index map of study area). The purpose of the overall investigation is to develop an understanding of the hydrologic system, document hydrogeologic conditions prior to large-scale coal development, and predict regional effects of coal mining and related activities on the system. The occurrence, movement, and quality of ground water are largely dependent on the hydrogeologic framework. Therefore, definition of this framework is a principal requirement to the understanding of the hydrologic system.

The purpose of this report is to delineate and describe the aquifers and confining layers that form the shallow ground-water system. The result of this work, which was prepared in cooperation with the U.S. Bureau of Land Management, will be used as a foundation for future hydrologic studies and reports.

Previous geologic maps and compilations were reviewed, modified, and, where necessary, remapped during the spring and summer of 1978. Alluvium is shown on the hydrogeologic map where its thickness is estimated to be 5 feet or more. Along the study area boundaries, alluvium was mapped from the valley edge to the center of the stream course.

Most of the hydrogeologic-unit boundaries correlate closely with established stratigraphic contacts. Only the upper boundary of the Fox Hills-lower Hell Creek aquifer had not been previously mapped. This boundary was easily recognized in most of the project area by field inspection. In poorly accessible areas the boundary was extended with the aid of aerial photographs and topographic maps. In the northern Powder River Basin (see map showing structural features) it was mapped by correlating the surficial geology of Lewis and Roberts (1978) with nearby subsurface geophysical data.

More than 500 geophysical logs from within and adjacent to the study area were examined for preparation of the structure contours and the hydrogeologic sections. Additional data from oil and gas appropriation files were useful where geophysical data were sparse. The structure contours in the northern Powder River Basin and near the Cedar Creek anticline (for location, see map showing structural features) were modified from previous investigations of Lewis and Roberts (1978) and Taylor (1968), respectively.

PREVIOUS INVESTIGATIONS

During the past 64 years, numerous studies have been conducted in parts of the project area, principally for the purposes of coal-bed identification and correlation and for ground-water evaluation. These various studies (see index to previous mapping; sheet 1) were useful guides for the present mapping. Except for the upper contact of the Fox Hills-lower Hell Creek aquifer, the geology of Lewis and Roberts (1978) was adopted for the hydrogeology in the northern Powder River Basin. The work by Bergantino (1977a, b, c, d), which is largely a compilation of and interpolation between previous detailed geologic mapping, was modified for this report.

ACKNOWLEDGMENTS

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

Construction of the structure contours and cross sections and interpretation of hydrogeologic boundaries were facilitated by information obtained from various types of geophysical logs on file at the Montana Oil and Gas Conservation Commission in Billings.

SELECTION OF HYDROGEOLOGIC UNITS

The hydrogeologic units mapped in this study (see hydrogeologic map; sheet 1) were selected primarily on the basis of the relative ability of the rocks to transmit water. The hydrogeologic units are separated into two basic categories: confining layers and aquifers. Confining layers are materials of low permeability that are stratigraphically adjacent to one or more aquifers; the materials restrict the vertical movement of water between aquifers and yield little or no water to wells and springs. Aquifers are saturated rocks or unconsolidated sediments that are sufficiently permeable and contain sufficient saturated material to yield significant quantities of water to wells and springs. Several heterogeneous and lenticular lithologies are present in the study area, particularly in the Tongue River, Tullock, and lower Fort Union aquifers. Within these aquifers are many thin, discontinuous, and alternating beds. Although individual beds have the properties of aquifers or confining layers on a local scale, the hydrogeologic units function as aquifers in terms of ground-water flow on a regional scale.

Hydrologic anomalies exist for both categories of hydrogeologic units. Units mapped as aquifers may locally behave as confining layers, just as units mapped as confining layers may locally be aquifers.

Most aquifer boundaries in the area correlate within 100 feet of presently accepted stratigraphic contacts (see description of map units; sheet 1). Depending on local lithology, specific aquifer boundaries may be above or below stratigraphic contacts. Because these differences are relatively insignificant in a regional sense, many previously mapped geologic contacts were used in the present compilation. However, the position of the upper contact of the Fox Hills-lower Hell Creek aquifer is a major exception. In addition to the Fox Hills Sandstone and equivalent rocks, this aquifer can include from 0 to 600 feet of the overlying Hell Creek Formation. The variability in thickness is attributed to coincidental stacking of channel sands during deposition of the lower part of the Hell Creek Formation.

The Tullock aquifer and the Lebo confining layer were combined into one hydrogeologic unit, the lower Fort Union aquifer, in extreme eastern Montana. A line marking the approximate boundary between these units is shown on the hydrogeologic map (sheet 1). The boundary is based on a change in the gross lithologic character of the hydrogeologic units observed in the field and on geophysical logs. Rocks equivalent to the Tullock aquifer that are located east of the boundary appear to have a greater percentage of shale or less permeable beds than those to the west. Analogously, rocks equivalent to the Lebo confining layer that are located east of the boundary have greater percentages of sandstone than those to the west. Overall, the hydrogeologic units probably act as one regional-scale aquifer; inferior in terms of hydrologic properties to the overlying Tongue River aquifer and superior to those of the underlying upper Hell Creek confining layer. The lower Fort Union aquifer is essentially equivalent to the Ludlow Formation, as defined by Moore (1976), in southwestern North Dakota.

The Chadron-Arikaree aquifer was differentiated from underlying and overlying aquifers because of mineralogic differences. It is limited in areal extent to the extreme southeastern part of the region.

The terrace gravel aquifer is also limited in areal extent, and occurs primarily along upland areas and benches of the Yellowstone River. It was separated from underlying units for two reasons: its significantly greater permeability and its potential capability to facilitate recharge of water to underlying units.

The alluvial aquifer consists primarily of flood-plain deposits and terrace gravels of low lying benches along the major rivers and their tributaries. This aquifer has greater permeability than underlying units, and readily transmits water to or receives water from underlying units, depending on the hydrologic conditions present.

DISTRIBUTION AND CHARACTER OF OUTCROPS

All the major aquifers (those of large areal extent on the hydrogeologic map; sheet 1) occur in the Bull Mountains, western Williston, and northern Powder River structural basins. The most extensive subsurface aquifer is the Fox Hills-lower Hell creek aquifer. The Fox Hills Sandstone, however, is absent in many areas west of the Porcupine dome. The Lennep Sandstone, which is shown by Rice (1976a, b) to be the Fox Hills equivalent, is exposed in the extreme western part of the Bull Mountains Basin. Outcrops of the Fox Hills-lower Hell Creek aquifer commonly support much vegetation. The Tongue River aquifer, characterized by resistant sandstone bluffs that weather yellow, coal beds, and red clinker, has the greatest surface exposure, covering more than half the study area. The Tullock and lower Fort Union aquifers also form resistant bluffs that are typically darker colored. In contrast, the Bearpaw, upper Hell Creek, and Lebo confining layers erode to large flat plains where well cemented, and to badlands where less cemented; they commonly support sparse vegetation.

The hydrogeologic characteristics of the formations forming the major aquifers vary slightly across the study area. Sandstones and shales in the Bull Mountains Basin and extreme western part of the study area appear to be more indurated than those of the same formations to the east. Fractures are common and locally may be the principal zones of permeability for aquifers. Generally, with distance east from the Bull Mountains Basin, rocks composing the aquifers become progressively less indurated and contain greater percentages of shale. Therefore, aquifers in the extreme eastern parts of the study area are expected to have lower permeabilities.

The minor aquifers (those of small areal extent on the hydrogeologic map; sheet 1) consist of the alluvial, terrace gravel, and Chadron-Arikaree aquifers. The thickest and most extensive alluvial-aquifer deposits occur along the Missouri, Yellowstone, Powder, and Tongue Rivers. Significant deposits also occur along other perennial streams and their tributaries. The terrace gravel and Chadron-Arikaree aquifers occur principally as erosional remnants on buttes and drainage divides along the Yellowstone River and the eastern part of the study area.

SUBSURFACE IDENTIFICATION OF HYDROGEOLOGIC UNITS

Subsurface hydrogeologic boundaries were identified by the use of geophysical logs of oil and gas wells and other test holes. Electric logs were most abundant; however, gamma ray, borehole-compensated sonic, and compensated formation density (gamma-gamma) logs were also available for some wells and test holes.

The electric log is a recording of electric responses versus depth. It consists of a spontaneous-potential (SP) curve in the left column and generally one or more resistivity curves in the right columns. A curve for conductivity, which is the reciprocal of resistivity, is commonly shown along the right side of the log.

The SP curve reflects the difference in natural potential between the fluid in a borehole and the surrounding rock. Deflections of the SP curve are considered to be negative if to the left and positive if to the right. Sandstone and coal beds are generally recorded as negative deflections, and shale as a positive deflection. Mixtures of these lithologies such as siltstone or a shaly sandstone, are recorded in a position between that for sandstone and shale.

Resistivity curves indicate the electrical resistivity of rock materials in a borehole by application of a direct electric current. Resistivity increases to the right. Sandstone and coal are generally more resistive than shale and are shown at right deflections on the curve.

The responses shown by an electric log are partly dependent on borehole fluids, which have variable composition, and they are not always reliable as lithologic indicators. Where the electric logs were of poor quality, they either were not used or were verified by comparison with other types of logs from the same drill hole.

Representative electric logs show the general characteristics of subsurface units for which geophysical logs were available. The uppermost aquifer boundary shown on the logs was the base of the Tongue River aquifer. The location and depth below land surface of geologic contacts and hydrogeologic boundaries can be derived from the configuration of the curves. Two logs are used to show the correlation of the major aquifers mapped in the study area. The lower boundaries of major aquifers generally were chosen where the log deflections indicated a change from predominantly shale or silty shale (converging SP and resistivity curves) below to predominantly sandstone and siltstone (diverging curves) above. Conversely, the upper boundaries of major aquifers were placed where the log deflections indicated a change from predominantly sandstone to predominantly shale above.

The lower Fort Union aquifer and the Tongue River aquifer are not separated by a confining layer. They were differentiated on the basis that the lower Fort Union aquifer contains a greater percentage of shale than the overlying Tongue River aquifer.

CONFIGURATION OF TOP OF BEARPAW CONFINING LAYER

The Bearpaw confining layer is a thick unit of relatively consistent and lowly permeable shale that forms the base of the shallow aquifer system in the Fort Union coal region. It is also easily identified on electric logs. For these reasons, the top of the Bearpaw confining layer was chosen to show the structural configuration of the region (hydrogeologic map; sheet 1). A few structure contours have been omitted for clarity where their inclusion would unduly congest the map.

The contours reflect the general structure of the Bull Mountains Basin, northern flanks of the Powder River Basin, western flank of the Williston Basin, and principal structural features in and adjacent to these basins (see structural features map). The configuration shows that the Bull Mountains Basin, which is the smallest of the three basins, is asymmetrical. The greatest slope of the top of Bearpaw confining layer in the study area, approximately 2,000 ft/mi, is located along the northern edge of the Bull Mountains Basin.

The northern Powder River Basin is linked to the Bull Mountains Basin by a doubly plunging syncline, likely an extension of the Ashland syncline. The configuration of the Bearpaw in the Powder River Basin is uniform but slightly asymmetrical; slopes are greatest along the east flank of the Bighorn uplift and the west flank of the Black Hills uplift. The Bearpaw confining layer is deepest in this basin along the Montana-Wyoming border. The Porcupine dome, Miles City arch, and Black Hills uplift separate the Powder River Basin from the Williston Basin.

The western flank of the Williston Basin is areally the largest depressional feature shown in the study area. Along the western flank, the slope of the Bearpaw confining layer is as small as 7 ft/mi. The Weldon fault, indicated by a northeast-trending monocline, and the Cedar Creek anticline are the most significant structural features within the Williston Basin.

A structure-contour map of the Montana Plains drawn on the base of the Colorado Shale (Dobbin and Erdmann, 1955) indicates that the same general subsurface features are present at greater depth. A previously compiled tectonic map of eastern Montana (Osterwald and Dean, 1958) suggests that the western slope of the Cedar Creek anticline is faulted and downthrown on the west side.

THICKNESS OF UNITS IN THE SHALLOW AQUIFER SYSTEM

Three hydrogeologic sections, two east-west and one north-south, illustrate the relative thicknesses and stratigraphic relationships of principal hydrogeologic units above the Bearpaw confining layer.

Section A–A′ crosses the Williston Basin in Montana. Generally, the units thicken from west to east and become more uniform in thickness near the Montana-North Dakota border. An opposite trend is noticeable for the Tullock aquifer; its thickness is greatest to the west. The section crosses thin remnants (less than 70 feet) of the terrace gravel aquifer near the Yellowstone River.

Section B–B′ shows units in the Bull Mountains Basin (on the west) and along the northern edge of the Miles City arch (just east of center). The section also illustrates the Porcupine dome (just west of center) and Cedar Creek anticline (on the extreme east), features that interrupt the general configuration of the shallow aquifer system. The hydrogeologic units have a uniform thickness in the Bull Mountains Basin; the upper Hell Creek confining layer is thickest here. Units above the Fox Hills-lower Hell Creek aquifer thin slightly to the east. In this section, the thickness of the Fox Hills-lower Hell Creek aquifer is greatest east of the Porcupine dome. Abrupt changes in thickness of this aquifer east of center are a result of variable thickness of the lower part of the Hell Creek Formation.

Section C–C′, the only north-south section, crosses the northern flank of the Powder River Basin (on the south) and western flank of the Williston Basin (on the north). The composite thickness of all the units is greatest in the Powder River Basin. The Tongue River aquifer thickens in the Williston Basin between the Yellowstone and Missouri Rivers. The thickness of the Fox Hills-lower Hell Creek aquifer is variable, particularly to the south.

All three of the sections show that in the eastern part of the study area, the lower Fort Union aquifer tends to maintain the approximate combined thickness of the Lebo confining layer and the Tullock aquifer to the west.

The alluvial aquifer (flood-plain and terrace deposits) is thickest along the Missouri and Yellowstone Rivers, owing mostly to the inclusion of low-lying terraces. If only flood-plain deposits are considered, however, the thickness may be greater along their major tributaries than along the two rivers (Lewis and Roberts, 1978).

SUMMARY

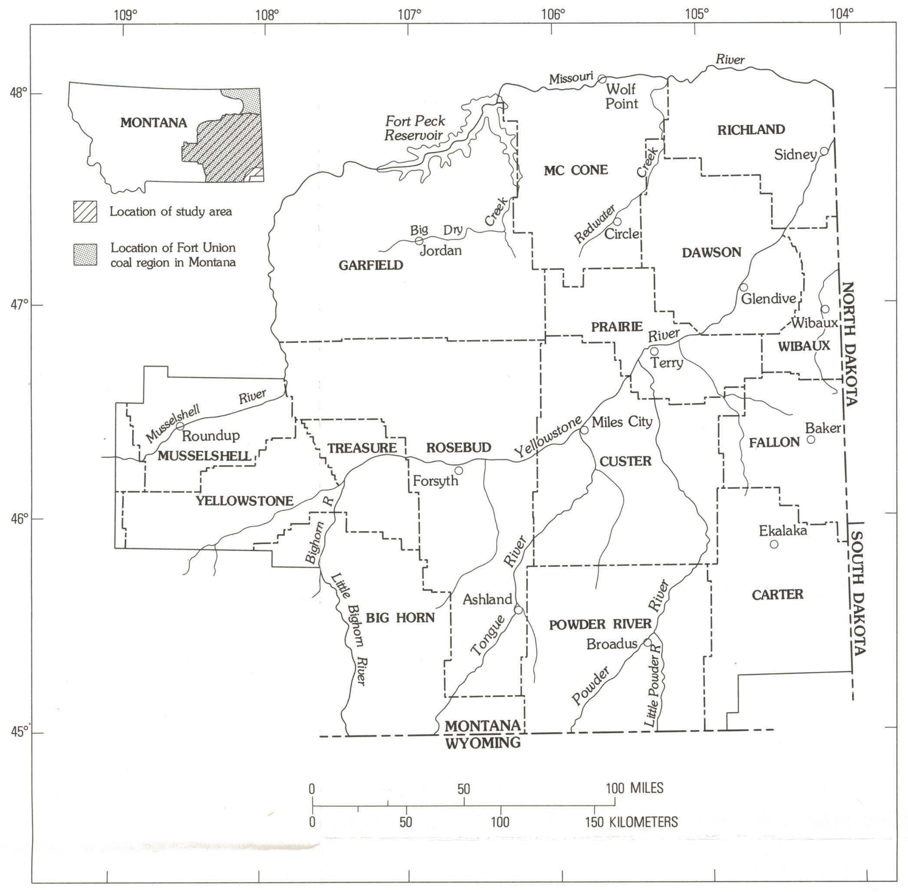
Hydrogeologic units that form the shallow ground-water system of the Fort Union coal region of eastern Montana lie above the Bearpaw confining layer (Bearpaw or Pierre Shale). Major aquifers are, in ascending order, Fox Hills-lower Hell Creek aquifer, Tullock aquifer (or lower Fort Union aquifer in extreme eastern Montana), and Tongue River aquifer. Confining units that are stratigraphically between the major aquifers include the Bearpaw, upper Hell Creek, and Lebo confining layers. Other hydrogeologic units, which are of lesser importance as sources of water, include the Chadron-Arikaree, terrace gravel, and alluvial aquifers. The names of the aquifers and confining layers correspond to respective geologic formation or member names.

The boundaries of the hydrogeologic units were chosen at prominent changes in ability of the rocks to transmit water. With the exception of the Fox Hills-lower Hell Creek aquifer, all the aquifer boundaries correlate within 100 feet of established stratigraphic boundaries. The upper boundary of the Fox Hills-lower Hell Creek aquifer may range from 0 to 600 feet above the base of the Hell Creek Formation. Because of regional trends in lithology, the Tullock aquifer and the Lebo confining layer were combined to form the lower Fort Union aquifer in extreme eastern Montana. Regionally, this unit is inferior in terms of hydrologic properties to the overlying Tongue River aquifer.

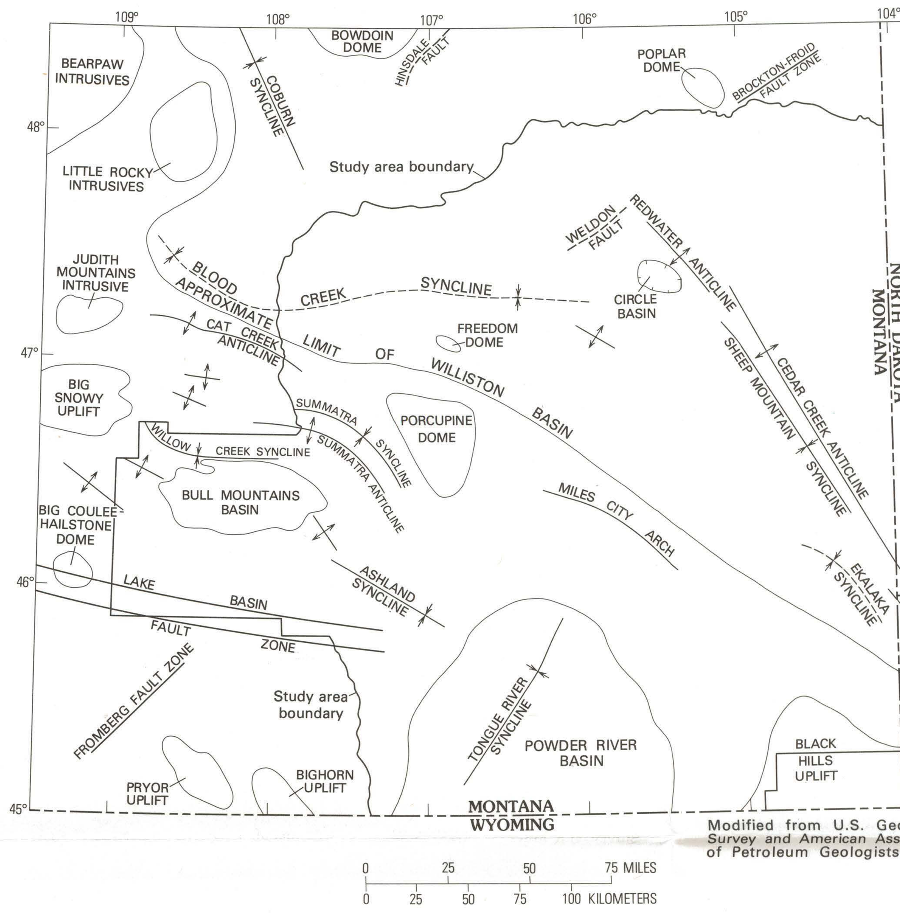
The aquifers comprise most of the hydrogeologic units that crop out in the study area. The Tongue River aquifer is exposed in more than half the area. The Fox Hills-lower Hell Creek aquifer, however, is the most extensive aquifer in the subsurface. The alluvial aquifer is thickest and most extensive along the Missouri, Yellowstone, Powder, and Tongue Rivers. Significant deposits also occur along other perennial streams and their tributaries. The Chadron-Arikaree and terrace gravel aquifers are limited in areal extent.

The configuration of the top of the Bearpaw confining layer reflects the structure of all or parts of three structural basins: Bull Mountains Basin, Powder River Basin, and Williston Basin. The configuration also indicates principal structural features in and adjacent to these basins.

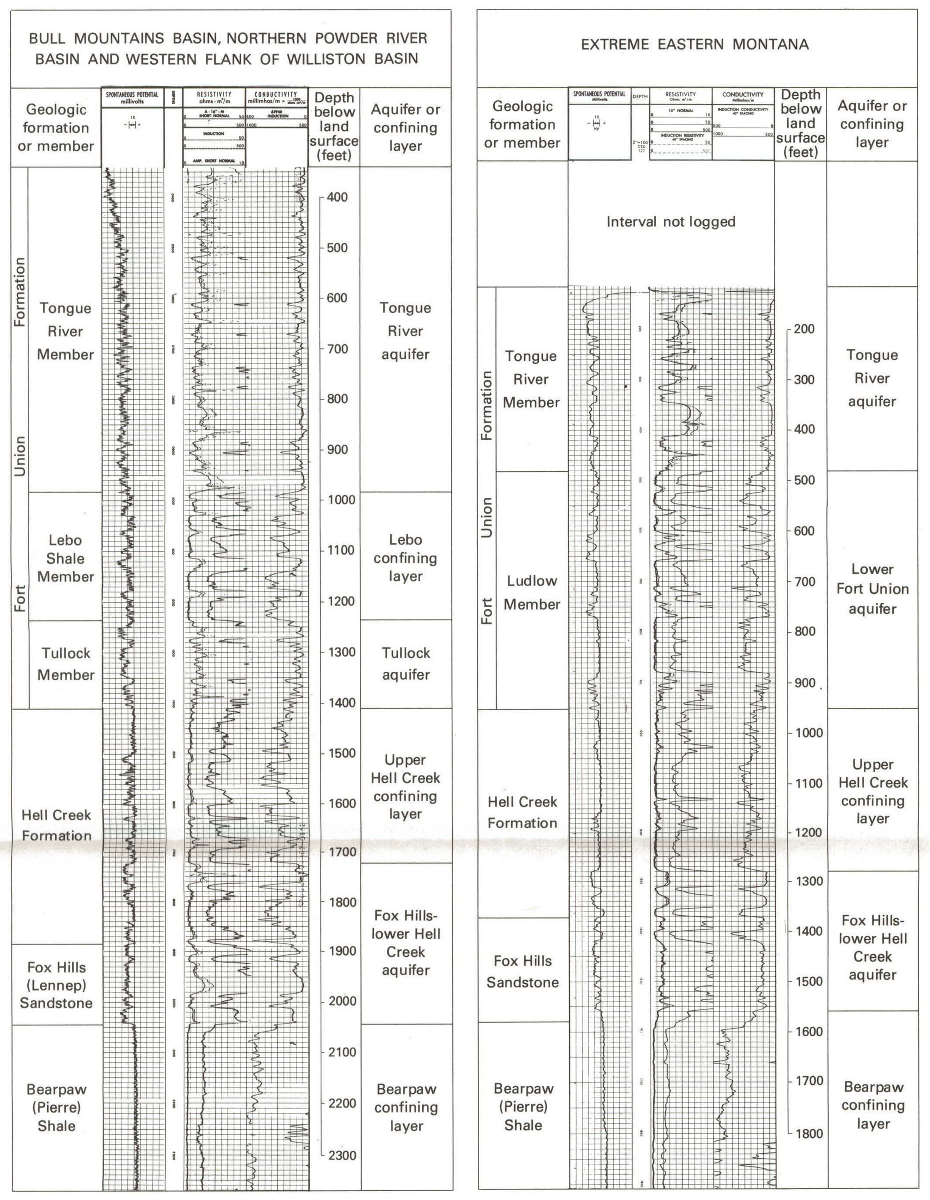
Thicknesses of the hydrogeologic units vary slightly across each of the major structural basins. Units are generally thickest near the basin centers and thinnest toward basin edges. The thickest composite section occurs in the Powder River Basin along the Montana-Wyoming border. Local abrupt changes in thickness of the Fox Hills-lower Hell Creek aquifer occur throughout the study area.



LOCATION OF STUDY AREA AND FORT UNION COAL REGION



STRUCTURAL FEATURES OF EASTERN MONTANA



REPRESENTATIVE ELECTRIC LOGS SHOWING CORRELATION BETWEEN SELECTED GEOLOGIC AND HYDROGEOLOGIC UNITS

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METRIC CONVERSION TABLE

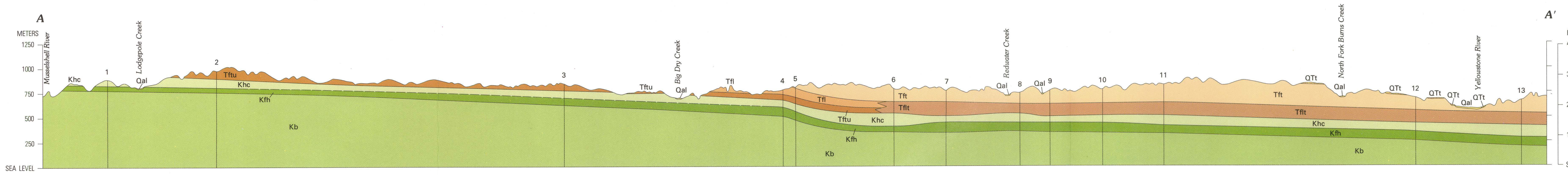
The following factors can be used to convert inch-pound units published herein to the International System (SI) of metric units.

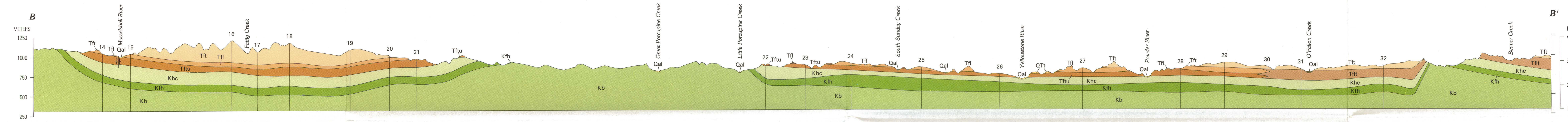
Multiply inch-pound units	by	To obtain metric units
foot (ft)	0.3048	meter (m)
inch (in)	25.40	millimeter (mm)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
mile (mi)	1.609	kilometer (km)

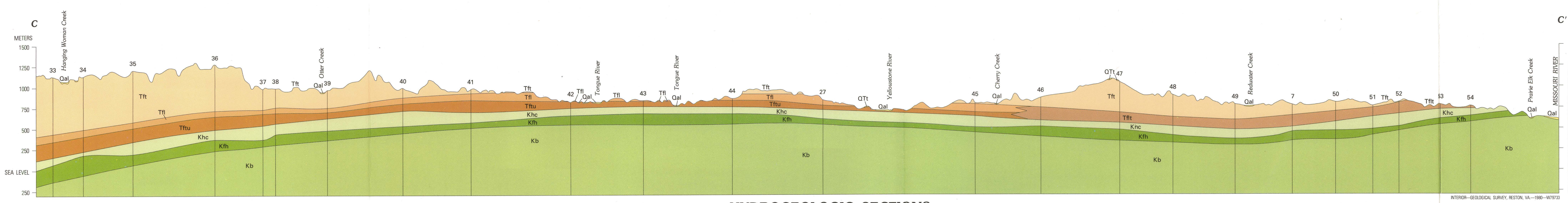
EXPLANATION

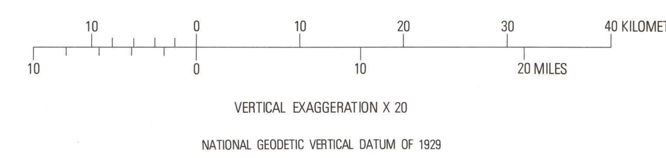
- Qal — ALLUVIAL AQUIFER—Minor thickness not shown
- QTt — TERRACE GRAVEL AQUIFER
- Tft — TONGUE RIVER AQUIFER
- Tflt — LEBO CONFINING LAYER
- Tftu — TULLOCK AQUIFER
- Tflt — LOWER FORT UNION AQUIFER
- Khc — UPPER HELL CREEK CONFINING LAYER
- Kfh — FOX HILLS-LOWER HELL CREEK AQUIFER
- Kb — BEARPAW CONFINING LAYER AND OLDER ROCKS, UNDIFFERENTIATED
- Aquifer boundary—Dashed where approximately located

Traces of hydrogeologic sections are shown on the hydrogeologic map (sheet 1)









HYDROGEOLOGIC SECTIONS

HYDROGEOLOGY OF THE FORT UNION COAL REGION, EASTERN MONTANA

By
Jeffrey D. Stoner and Barney D. Lewis
1980