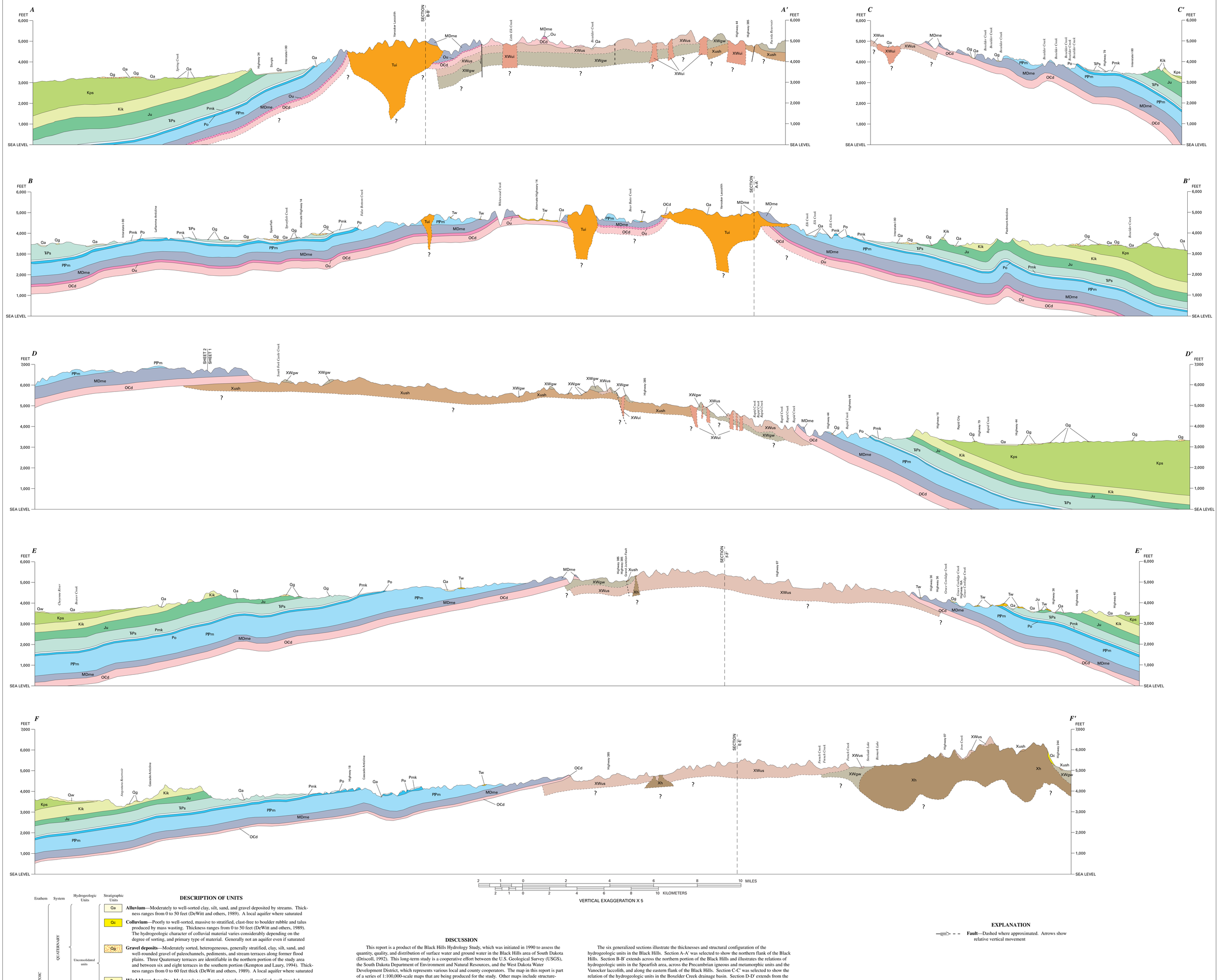
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
AND THE WEST DAKOTA WATER DEVELOPMENT DISTRICT

HYDROLOGIC INVESTIGATIONS ATLAS HA-743
Generalized sections —SHEET 3 OF 3



DESCRIPTION OF UNITS

Erathem	System	Hydrogeologic Units	Stratigraphic Units	
CENOZOIC	QUATERNARY	Unconsolidated units	Qa	**Alluvium**—Moderately to well-sorted clay, silt, sand, and gravel deposited by streams. Thickness ranges from 0 to 50 feet (DeWitt and others, 1989). A local aquifer where saturated
			Qc	**Colluvium**—Poorly to well-sorted, massive to stratified, clast-free to boulder rubble and talus produced by mass wasting. Thickness ranges from 0 to 50 feet (DeWitt and others, 1989). The hydrogeologic character of colluvial material varies considerably depending on the degree of sorting, and primary type of material. Generally not an aquifer even if saturated
			Qg	**Gravel deposits**—Moderately sorted, heterogeneous, generally stratified, clay, silt, sand, and well-rounded gravel of paleochannels, pediments, and stream terraces along former flood plains. Three Quaternary terraces are identifiable in the northern portion of the study area and between six and eight terraces in the southern portion (Kempton and Laury, 1994). Thickness ranges from 0 to 60 feet thick (DeWitt and others, 1989). A local aquifer where saturated
			Qw	**Wind-blown deposits**—Moderately to well-sorted, poorly to well-stratified, well-rounded, commonly calcareous, and frosted silt and fine to medium-grained sand. Thickness ranges from 0 to 50 feet thick (DeWitt and others, 1989). A local aquifer where saturated
	TERTIARY	White River aquifer	Tw	**White River Group**—Consists of the Brule and Chadron Formations. Sandstone, claystone, and siltstone with channel fillings and limestone lenses (Rahn, 1985). Thickness ranges from 0 to 300 feet (DeWitt and others, 1989). A minor aquifer where saturated
		Tertiary intrusive units	Tui	**Undifferentiated shallow intrusive igneous rocks**—Includes rhyolite, latite, trachyte, and phonolite (see DeWitt and others, 1989, for a more thorough description). The hydrogeologic characteristics of these rocks vary with the degree of fracturing
MESOZOIC	CRETACEOUS	Cretaceous-sequence confining unit	Kps	**Pierre Shale to Skull Creek Shale, undifferentiated**—Confining unit of shale, limestone, and sandstone containing the following formations listed with their thickness in feet: Pierre Shale, 1,200-2,700; Niobrara Formation, 80-300; Carlile Shale, 350-750; Greenhorn Formation, 225-380; Belle Fourche Shale, 150-850; Mowry Shale, 125-230; Newcastle Sandstone, 0-150; and Skull Creek Shale, 150-270; (modified from DeWitt and others, 1989). Where present, the Newcastle Sandstone is an aquifer if saturated
		Inyan Kara aquifer	Kik	**Inyan Kara Group**—Sandstone and other clastic rocks of the Fall River Formation and Lakota Formation. The Fall River Formation is 100-200 feet thick consisting of brown to reddish-brown fine-grained sandstone, thin-bedded at the top and massive at the bottom. The Lakota Formation is 35-700 feet thick consisting of yellow, brown, and reddish-brown massive to thin-bedded, sandstone, pebble conglomerate, siltstone, and claystone with local limestone, coal, and fossiliferous layers (DeWitt and others, 1989). A major regional aquifer
	JURASSIC	Jurassic-sequence semiconfining unit	Ju	**Morrison Formation to Gypsum Spring Formation, undifferentiated**—Semiconfining unit combines interbedded shale, sandstone, and gypsum of the following formations listed with their thickness in feet: Morrison Formation, 0-220; Unkpapa Sandstone, 0-225; Sundance Formation, 250-450; and Gypsum Spring Formation, 0-45 (modified from DeWitt and others, 1989) Sandstones of the Sundance Formation are locally productive aquifers where saturated (Kyllonen and Peter, 1987)
	TRIASSIC	Spearfish confining unit	TrPs	**Spearfish Formation**—Red silty shale interbedded with friable, red sandstone and siltstone, and sparse limestone layers. Lower portion contains massive gypsum (Robinson and others, 1964). Thickness ranges from 375 to 800 feet (Gries and Martin, 1985)
	PERMIAN	Minnekahta aquifer	Pmk	**Minnekahta Limestone**—Fine-grained, purple to gray laminated limestone. Thickness ranges from 25 to 65 feet (modified from DeWitt and others, 1989). Unit is locally fractured and brecciated due to solution collapse (Gries and Martin, 1985). A major aquifer in the study area
		Opeche confining unit	Po	**Opeche Shale**—Red siltstone and sandy shale, with local gypsum and anhydrite near the top. Thickness ranges from 25 to 150 feet (DeWitt and others, 1989)
PALEOZOIC	PENNSYLVANIAN	Minnelusa aquifer	PPm	**Minnelusa Formation**—Variably colored but generally yellow to red cross-stratified sandstone, limestone, dolomite, and shale of the Minnelusa Formation. Thickness ranges from 375 to 1,175 feet (modified from DeWitt and others, 1989), most commonly between 400 to 750 feet of the formation. Where anhydrite has dissolved, collapse-formed secondary permeability creates the most productive aquifer. Interbedded limestone and shale in the lower part of the formation forms a confining zone (Kyllonen and Peter, 1987). A major regional aquifer
	MISSISSIPPIAN AND DEVONIAN	Madison aquifer	MDme	**Madison (Pahasapa) Limestone and Englewood Formation**—Gray to buff and lavender limestone that is locally dolomitic. The Madison Limestone is 250 to 1,000 feet thick, and the Englewood Formation is 30 to 60 feet thick (modified from DeWitt and others, 1989). Generally massive, upper third is karstic with caves, solution collapse and enlarged conduits resulting in extensive secondary permeability and creating the potentially most productive aquifer in the Black Hills (Kyllonen and Peter, 1987). The lower portion of the Madison Limestone and the Englewood Formation form a lower confining zone (Greene, 1993). A major regional aquifer
	ORDOVICIAN AND CAMBRIAN	Ordovician-sequence semiconfining unit	Ou	**Whitewood Formation and Winnipeg Formation**—Undifferentiated semiconfining unit consists of limestone and dolomite of the Whitewood Formation, thickness ranges from 0 to 235 feet, and shale with interbedded siltstone of the Winnipeg Formation, thickness ranges from 0 to 150 feet (modified from DeWitt and others, 1989). The unit is found in the northern and western portion of the study area
		Deadwood aquifer	OCd	**Deadwood Formation**—Brown to light-gray glauconitic sandstone, shale, limestone, and local basal conglomerate. Thickness ranges from 0 to 500 feet (modified from DeWitt and others, 1989). A major aquifer in the study area
EARLY PROTEROZOIC AND LATE ARCHEAN	EARLY PROTEROZOIC	Precambrian igneous and metamorphic units	Xh	**Harney Peak Granite**—Pink and tan coarse-grained and pegmatitic muscovite granite. Characterized geochemically from other granites in the area by high concentrations of boron, beryllium, lithium, and uranium (DeWitt and others, 1989)
			Xush	**Undifferentiated metamorphosed phyllite and schist**—Locally carbonaceous and tuffaceous. Geochemical and geophysical signatures vary with the tuffaceous zones having an anomalously high copper concentration and a magnetic nature (DeWitt and others, 1989)
			XWui	**Undifferential igneous rocks**—Geochemical signature and geophysical nature vary depending on protolith (see DeWitt and others, 1989 for additional information)
			XWgw	**Metamorphosed graywacke**—Primarily a medium- to dark-gray siliceous mica schist and impure quartzite (DeWitt and others, 1989)
			XWus	**Undifferentiated metamorphosed sedimentary deposits**—Includes conglomerate, quartz sandstone, siltstone, and dolomite protoliths. Parts are characterized geochemically by anomalously high uranium, chromium, and gold concentrations and other parts by anomalous gold, silver, and arsenic concentration. The latter zones are magnetic in nature (DeWitt and others, 1989)

NOTE: Some thickness ranges given above are from the sources listed and from data on file at the U.S. Geological Survey, Rapid City, South Dakota

DISCUSSION

This report is a product of the Black Hills Hydrology Study, which was initiated in 1990 to assess the quantity, quality, and distribution of surface water and ground water in the Black Hills area of South Dakota (Driscoll, 1992). This long-term study is a cooperative effort between the U.S. Geological Survey (USGS), the South Dakota Department of Environment and Natural Resources, and the West Dakota Water Development District, which represents various local and county cooperators. The map in this report is part of a series of 1:100,000-scale maps that are being produced for the study. Other maps include structure-contour maps (altitudes of the tops of formations) for five formations that contain major aquifers in the study area, and potentiometric maps for these five major aquifers (the Inyan Kara, Minnekahta, Minnelusa, Madison, and Deadwood aquifers).

The study area consists of the topographically defined Black Hills and adjacent areas located in western South Dakota. The Black Hills area is an elongated, dome-shaped feature, about 125 miles long and 60 miles wide, which was uplifted during the Laramide orogeny (Feldman and Heimlich, 1980). The oldest geologic units in the study area are Precambrian metamorphic and igneous rocks, which are exposed in the central core of the Black Hills. Surrounding the Precambrian core is a layered series of sedimentary rocks including limestones, sandstones, and shales that are exposed in roughly concentric rings around the uplifted flanks of the Black Hills. The bedrock sedimentary units typically dip away from the uplifted Black Hills at angles that approach or exceed 10 degrees near the outcrops, and decrease with distance from the uplift. Many of the sedimentary units contain aquifers, both within and beyond the study area. Recharge to these aquifers occurs from infiltration of precipitation upon the outcrops and, in some cases, from infiltration of streamflow (Hortness and Driscoll, 1998). Artesian conditions generally exist within these aquifers where an upper confining layer is present. Flowing wells and artesian springs that originate from confined aquifers are common around the periphery of the Black Hills.

The map in this report shows outcrops of stratigraphic units for the northern (sheet 1) and southern (sheet 2) parts of the Black Hills area. Generalized sections showing the subsurface occurrence of these units also are presented. The map was compiled at 1:100,000 scale from other published and unpublished geologic maps that ranged in scale from 1:24,000 to 1:500,000, but mostly at scales equal to or larger than 1:100,000. The primary sources for mapping the distribution of the hydrogeologic units were supplemented by additional site specific maps (see index to sources of geologic data) and field work that focused on the smaller areas covered by the smaller scale maps.

The stratigraphic units provide the basis for designating the hydrogeologic units, which are based on similarity in hydraulic properties. The hydrogeologic units include aquifers, semiconfining units, and confining units. Aquifers are units that commonly are used as sources of ground water. Semiconfining units contain some layers with low permeability. Confining units consist mainly of layers with low permeability. Both semiconfining and confining units may contain rocks that are local aquifers, but these generally are not of regional importance.

The unconsolidated units include alluvium, colluvium, gravel deposits and wind-blown deposits of Quaternary age, and gravel deposits of Tertiary age. All have the potential to be local aquifers where they are saturated. The White River aquifer consists of various discontinuous units of sandstone and channel sands along the eastern flanks of the Black Hills, which may produce water where saturated. The Tertiary intrusive units are restricted to areas in the northern Black Hills, and generally are relatively impermeable. Intrusive sills can increase bedding plane fracturing and often are associated with "perched" ground water.

Rocks of Mesozoic age include the Cretaceous-sequence confining unit, Inyan Kara aquifer, Jurassic-sequence semiconfining unit, and the upper part of the Spearfish confining unit. The Cretaceous-sequence confining unit mainly includes shales of low permeability, such as the Pierre Shale and Carlile Shale, but may contain minor aquifers, such as the Newcastle Sandstone. The Inyan Kara aquifer consists of sandstones in the Fall River and Lakota Formations and is a major aquifer in the Black Hills. The Jurassic-sequence semiconfining unit consists of shales and sandstones of the Morrison Formation, Unkpapa Sandstone, Sundance Formation, and Gypsum Spring Formation. The overall unit is semiconfining because of the low permeability of the interbedded shales; however, minor local aquifers do exist. The Spearfish confining unit consists of sandy shale, sandstone, and siltstone, with gypsum and local limestone layers. Local aquifers may exist where gypsum and anhydrite have been dissolved.

Rocks of Paleozoic age include the lower part of the Spearfish confining unit, Minnekahta aquifer, Opeche confining unit, Minnelusa aquifer, Madison aquifer, Ordovician-sequence semiconfining unit, and Deadwood aquifer. The Paleozoic units include four of the five major aquifers for the Black Hills area. The Minnekahta Limestone consists of a laminated limestone. Although not particularly thick (25 to 65 feet), it is a reliable source of water around the perimeter of the Black Hills uplift. The Opeche confining unit is a silty to sandy shale that generally impedes ground-water movement between the Minnekahta and Minnelusa aquifers. The Minnelusa Formation is a thick (375 to 1,175 feet) unit of sandstone, limestone, dolomite, and shale. Sandstones in the upper part of the formation constitute a regionally important aquifer with relatively consistent yields. Larger yields can be obtained where secondary permeability results from fracturing or solution enhancement. The lower portion of the Minnelusa Formation contains interbedded limestone and shale, and is a lower confining zone within the unit. However, for mapping purposes, the entire unit was considered an aquifer.

The Madison aquifer is most productive in the karstic upper part of the Madison Limestone. Fractures and solution openings in the limestone and dolomite increase the secondary permeability of the aquifer. The Englewood Formation, a limestone at the base of the Madison Limestone, is included in this unit because of the hydraulic connection between the two units and relatively minor thickness of the Englewood Formation in outcrop areas. The lower portion of the Madison Limestone and the Englewood Formation generally may be confining zones.

The Ordovician-sequence semiconfining unit consists of the Whitewood Formation (Red River Formation) and Winnipeg Formation. The Whitewood Formation, where present, may contain a local aquifer, but seldom is used because of more reliable sources in the adjacent Madison or Deadwood aquifers. The shale layers of the Winnipeg Formation, where present, are confining zones in the unit. The Deadwood Formation, which consists of sandstone, limestone, basal conglomerate, and shale, is fractured in areas intruded by igneous sills and is missing in areas with massive igneous intrusions. Thus, the Deadwood aquifer is discontinuous in parts of the northern Black Hills where the maximum thicknesses also occur. The unit thins to the south, which limits its use in the southern Black Hills.

Igneous and metamorphic rocks of Precambrian age are exposed throughout the central Black Hills and consist of the Harney Peak Granite, other igneous rocks, and a variety of metamorphosed igneous and sedimentary rocks. These rocks are structurally complex and have a large variety of hydraulic properties. The Precambrian rocks constitute a lower confining unit to overlying sedimentary aquifers. However, fracturing and faulting has increased porosity and permeability in many outcrop areas. Numerous residents in the central Black Hills rely on these rocks for their water supply.

The six generalized sections illustrate the thicknesses and structural configuration of the hydrogeologic units in the Black Hills. Section A-A' was selected to show the northern flank of the Black Hills. Section B-B' extends across the northern portion of the Black Hills and illustrates the relations of hydrogeologic units in the Spearfish area, across the Precambrian igneous and metamorphic units and the Vanocker laccolith, and along the eastern flank of the Black Hills. Section C-C' was selected to show the relation of the hydrogeologic units in the Boxelder Creek drainage basin. Section D-D' extends from the western flank of the Black Hills, locally known as the Limestone Plateau, across the Precambrian igneous and metamorphic units, to the eastern flank of the Black Hills. Section E-E' extends from the southwest portion of the Black Hills area, across the Precambrian igneous and metamorphic units, to the eastern flank of the Black Hills. Section F-F' extends southward from the Precambrian igneous and metamorphic units in the central Black Hills to the southern flank of the Black Hills. These cross sections were constructed from published map information and well logs. Data to delineate the configuration of the Precambrian units, Tertiary intrusive units, White River aquifer, and unconsolidated units generally are very limited. These sections are provided mainly to illustrate the approximate conditions at depth. They should not be used to predict depth to aquifers at specific locations.

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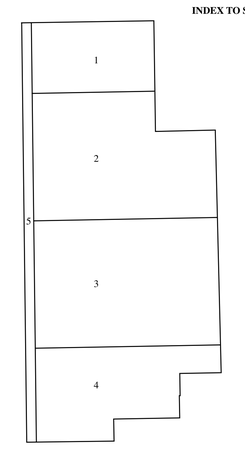
EXPLANATION

Fault—Dashed where approximated. Arrows show relative vertical movement

INDEX TO SOURCES OF GEOLOGIC DATA



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Distribution of Hydrogeologic Units in the Black Hills Area, South Dakota

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1999