Geologic Setting

The geologic units that contain aquifers for which water-quality characteristics are presented are described in this section from oldest to youngest. The oldest geologic units in the study area are the Precambrian crystalline (metamorphic and igneous) rocks (fig. 2), which form a basement under the Paleozoic, Mesozoic, and Cenozoic rocks and sediments. The Precambrian rocks are exposed in the central core of the Black Hills. These Precambrian rocks range in age from 1.7 to about 2.5 billion years, and were eroded to a gentle undulating plain by the beginning of the Paleozoic Era (Gries, 1996). The Precambrian rocks are highly variable, but are composed mostly of metasediments, such as schists and graywackes. The Paleozoic and Mesozoic rocks were deposited as nearly horizontal beds. Subsequent uplift during the Laramide orogeny and related erosion exposed the Precambrian rocks in the central core of the Black Hills with the Paleozoic and Mesozoic sedimentary rocks exposed in roughly concentric rings around the core. Deformation during the Laramide orogeny contributed to the numerous fractures, folds, and other structural features present throughout the Black Hills. Tertiary intrusive activity also contributed to rock fracturing in the northern Black Hills where numerous intrusions exist.

Surrounding the crystalline core is a layered series of sedimentary rocks including limestones, sandstones, and shales. The distribution of hydrogeologic units in the Black Hills area is shown in figure 3. The bedrock sedimentary units typically dip away from the uplifted Black Hills at angles that can approach or exceed 15 to 20 degrees near the outcrops, and decrease with distance from the uplift to less than 1 degree (Carter and Redden, 1999a, 1999b, 1999c, 1999d, 1999e) (fig. 4).

The oldest sedimentary unit in the study area is the Cambrian- and Ordovician-age Deadwood Formation, which is composed primarily of brown to light-gray glauconitic sandstone, shale, limestone, and local basal conglomerate (Strobel and others, 1999). These sediments were deposited on the generally horizontal plain of Precambrian rocks in a coastal- to near-shore environment (Gries, 1975). The thickness of the Deadwood Formation increases from south to north in the study area and ranges from 0 to 500 feet (Carter and Redden, 1999e). In the northern and central Black Hills, the Deadwood Formation is disconformably overlain by Ordovician-age rocks that include the Whitewood and Winnipeg Formations. The Winnipeg Formation is absent in the southern Black Hills, and the Whitewood Formation has eroded to the south and is not present south of the approximate latitude of Nemo (DeWitt and others, 1986). In the southern Black Hills, the Deadwood Formation is unconformably overlain by the Devonian- and Mississippian-age Englewood Formation because of the absence of the Ordovician-age sequence. The Englewood Formation is overlain by the Madison Limestone.

The Mississippian-age Madison Limestone, deposited as a marine carbonate, is a massive, gray to buff limestone that is locally dolomitic (Strobel and others, 1999). The thickness of the Madison Limestone increases from south to north in the study area and ranges from almost zero in the southeast corner of the study area (Rahn, 1985) to 1,000 feet east of Belle Fourche (Carter and Redden, 1999d). The Madison Limestone was exposed above land surface for approximately 50 million years. During this period, significant erosion, soil development, and karstification occurred (Gries, 1996). Numerous caves and fractures occur within the upper part of the formation (Peter, 1985). Because the Madison Limestone was exposed to erosion and karstification for millions of years, the formation is unconformably overlain by the Minnelusa Formation.

The Pennsylvanian- and Permian-age Minnelusa Formation consists mostly of yellow to red cross-stratified sandstone, limestone, dolomite, and shale (Strobel and others, 1999). In addition to sandstone and dolomite, the lower part of the formation consists of shale and anhydrite (DeWitt and others, 1986). The upper part of the Minnelusa Formation also may contain anhydrite, which generally has been removed by dissolution at or near the outcrop areas, forming collapse features filled with breccia (Bowles and Braddock, 1963). The thickness of the Minnelusa Formation increases from north to south and ranges from 375 feet near Belle Fourche to 1,175 feet near Edgemont in the study area (Carter and Redden, 1999c). On the southwest side of the study area, there is a considerable increase in thickness of clastic units as well as a thick section of anhydrite. In the southern Black Hills, the upper part of the Minnelusa Formation thins due to leaching of anhydrite. The Minnelusa Formation is disconformably overlain by the Permian-age Opeche Shale, which is overlain by the Minnekahta Limestone.

The Permian-age Minnekahta Limestone is a fine-grained, purple to gray laminated limestone with thicknesses ranging from 25 to 65 feet in the study area (Strobel and others, 1999). The Minnekahta Limestone is overlain by the Triassic- and Permian-age Spearfish Formation.

ERATHEM	SYSTEM	ABBREVIATION FOR STRATIGRAPHIC INTERVAL	STRATIGRAPHIC UNIT	THICKNESS IN FEET	DESCRIPTION
CENOZOIC	QUATERNARY & TERTIARY (?)	QTu	UNDIFFERENTIATED SANDS AND GRAVELS	0-50	Sand, gravel, and boulders
		Tw	WHITE RIVER GROUP	0-300	Light colored clays with sandstone channel fillings and local limestone lenses.
	TERTIARY	Tui	INTRUSIVE IGNEOUS ROCKS	--	Includes rhyolite, latite, trachyte, and phonolite.
MESOZOIC	CRETACEOUS	Kps	PIERRE SHALE	1,200-2,700	Principal horizon of limestone lenses giving teepee buttes. Dark-gray shale containing scattered concretions. Widely scattered limestone masses, giving small teepee buttes. Black fissile shale with concretions.
			NIOBRARA FORMATION	[1]80-300	Impure chalk and calcareous shale.
			CARLILE SHALE: Turner Sandy Member	[1]350-750	Light-gray shale with numerous large concretions and sandy layers.
			CARLILE SHALE: Wall Creek Member		Dark-gray shale
			GREENHORN FORMATION	225-380	Impure slabby limestone. Weathers buff. Dark-gray calcareous shale, with thin Orman Lake limestone at base.
			GRANEROS GROUP: BELLE FOURCHE SHALE	150-850	Gray shale with scattered limestone concretions. Clay spur bentonite at base.
			GRANEROS GROUP: MOWRY SHALE	125-230	Light-gray siliceous shale. Fish scales and thin layers of bentonite.
			GRANEROS GROUP: MUDDY SANDSTONE / NEWCASTLE SANDSTONE	0-150	Brown to light yellow and white sandstone.
			GRANEROS GROUP: SKULL CREEK SHALE	150-270	Dark gray to black siliceous shale.
		Kik	INYAN KARA GROUP: FALL RIVER FORMATION	10-200	Massive to slabby sandstone.
			INYAN KARA GROUP: LAKOTA FM: Fuson Shale	10-190	Coarse gray to buff cross-bedded conglomeratic sandstone, interbedded with buff, red, and gray clay, especially toward top. Local fine-grained limestone.
			INYAN KARA GROUP: LAKOTA FM: Minnewaste Limestone	0-25	
			INYAN KARA GROUP: LAKOTA FM: Chilson Member	25-485	
	JURASSIC	Ju	MORRISON FORMATION	0-220	Light-gray claystone and shale. Thin sandstone.
			UNKPAPA SS	0-225	Massive fine-grained sandstone.
			SUNDANCE FORMATION: Redwater Member, Lak Member, Hulett Member, Stockade Beaver Mem., Canyon Spr Member	250-450	Greenish-gray shale, thin limestone lenses. Glauconitic sandstone; red sandstone near middle.
			GYPSUM SPRING FORMATION	0-45	Red siltstone, gypsum, and limestone.
	TRIASSIC	TRPs	SPEARFISH FORMATION	375-800	Red sandy shale, soft red sandstone and siltstone with gypsum and thin limestone layers.
PALEOZOIC	PERMIAN		Goose Egg Equivalent		Gypsum locally near the base.
		Pmk	MINNEKAHTA LIMESTONE	[1]25-65	Thin to medium-bedded finely-crystalline, purplish gray laminated limestone.
		Po	OPECHE SHALE	[1]25-150	Red shale and sandstone.
	PERMIAN / PENNSYLVANIAN	PIPm	MINNELUSA FORMATION	[1]375-1,175	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limestone, dolomite, shale, and anhydrite. Red shale with interbedded limestone and sandstone at base.
	MISSISSIPPIAN	MDme	MADISON (PAHASAPA) LIMESTONE	[1]250-1,000	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.
	DEVONIAN		ENGLEWOOD FORMATION	30-60	Pink to buff limestone. Shale locally at base.
	ORDOVICIAN	Ou	WHITEWOOD (RED RIVER) FORMATION	[1]0-235	Buff dolomite and limestone.
			WINNIPEG FORMATION	[1]0-150	Green shale with siltstone.
	CAMBRIAN	OЄd	DEADWOOD FORMATION	[1]0-500	Massive to thin-bedded brown to light-gray sandstone. Greenish glauconitic shale flaggy dolomite and flat-pebble limestone conglomerate. Sandstone, with conglomeratelocally at the base.
PRECAMBRIAN		pЄu	UNDIFFERENTIATED METAMORPHIC AND IGNEOUS ROCKS		Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.

[1] Modified based on drill-hole data

Modified from information furnished by the Department of Geology and Geological Engineering, South Dakota School of Mines and Technology (written commun., January 1994)

Figure 2. Stratigraphic section for the Black Hills.

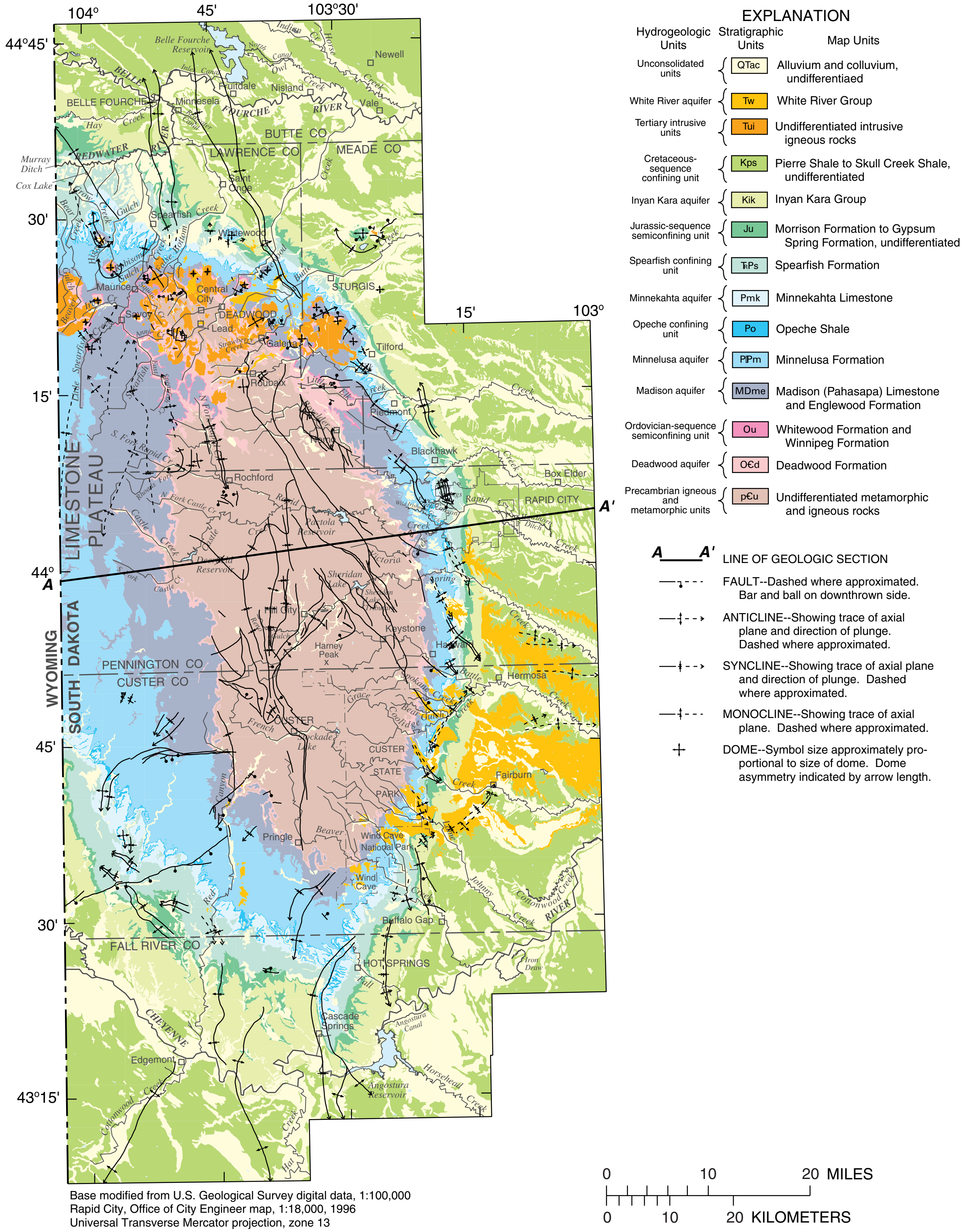

Figure 3. Distribution of hydrogeologic units in the Black Hills area (modified from Strobel and others, 1999).

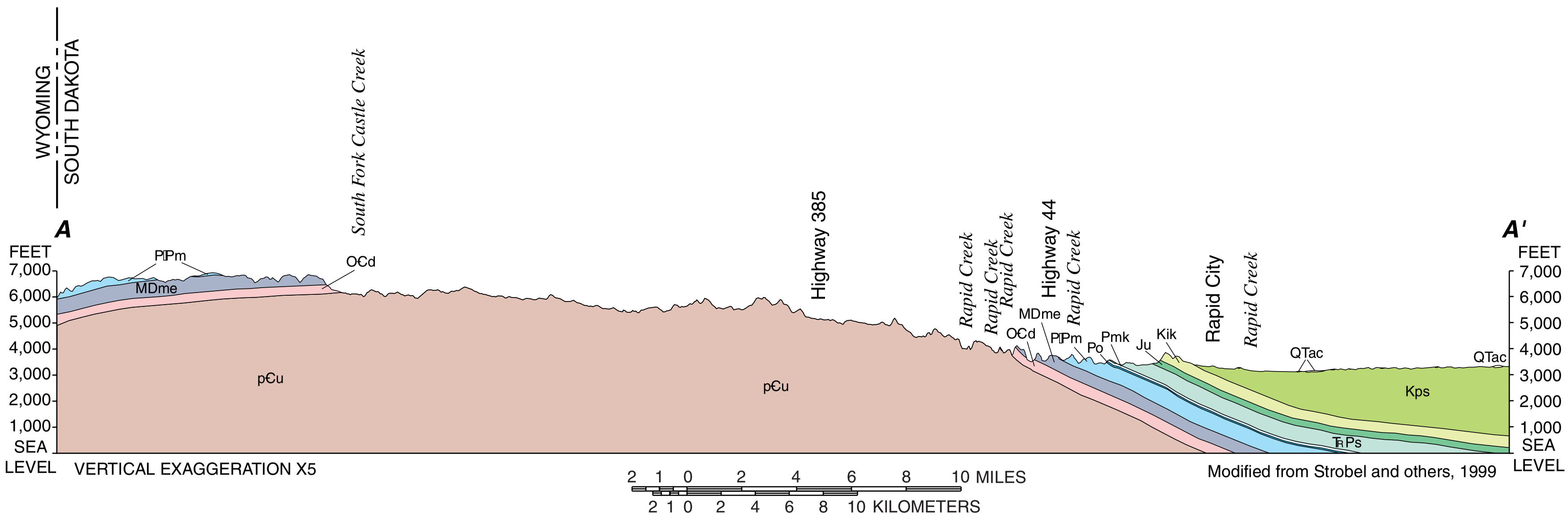

Figure 4. Geologic cross section A-A' (Location of section is shown in figure 3. Abbreviations for stratigraphic intervals are explained in figure 2.).

The Permian- and Triassic-age Spearfish Formation consists of red, silty shale interbedded with friable, red sandstone and siltstone, and sparse limestone layers (Strobel and others, 1999). The lower portion of the Spearfish Formation contains massive gypsum (Robinson and others, 1964). The thickness of the Spearfish Formation ranges from 375 to 800 feet (Gries and Martin, 1985).

Jurassic-age units consisting of shale and sandstone with some limestone and gypsum overlie the Spearfish Formation and include the Sundance and Morrison Formations. The Sundance Formation consists of reddish-gray to light-gray siltstone, sandstone, limestone, and glauconitic sandstone and shale (DeWitt and others, 1989) and is 250 to 450 feet thick in the study area (Strobel and others, 1999). The Morrison Formation is a light-gray siliceous claystone and shale (DeWitt and others, 1989) with a thickness that ranges from 0 to 220 feet (Strobel and others, 1999).

The Cretaceous-age Inyan Kara Group consists of the Lakota Formation and overlying Fall River Formation. The Lakota Formation consists of the Chilson, Minnewaste Limestone, and Fuson Shale members. The Lakota Formation consists of yellow, brown, and reddish-brown massive to thin-bedded sandstone, pebble conglomerate, siltstone, and claystone of fluvial origin (Gott and others, 1974); lenses of limestone and coal are present locally. The Fall River Formation is a brown to reddish-brown, fine-grained sandstone, thin bedded at the top and massive at the bottom (Strobel and others, 1999). The thickness of the Inyan Kara Group ranges from 135 to 900 feet in the study area (Carter and Redden, 1999a).

The Cretaceous-age Graneros Group includes the Skull Creek Shale, Newcastle Sandstone, Mowry Shale, and Belle Fourche Shale. The Skull Creek Shale is a dark gray to black siliceous shale and is 150 to 270 feet thick (DeWitt and others, 1989). The Newcastle Sandstone is 0 to 100 feet thick and is a gray to light-brown sandstone and siltstone that contains beds of bentonite and lignite (DeWitt and others, 1989). The Mowry Shale consists of light-gray siliceous shale with thin bentonite layers and is 125 to 230 feet thick (DeWitt and others, 1989). The Belle Fourche Shale is a dark-gray bentonitic shale that contains minor limestone lenses and large concretions and is 150 to 850 feet thick (DeWitt and others, 1989).

The Cretaceous-age Pierre Shale is a dark-gray to black shale containing minor limestone lenses and concretions. The thickness of the Pierre Shale ranges from 1,200 to 2,700 feet (Strobel and others, 1999).

For purposes of this report, alluvial deposits refer to Quaternary-age alluvium, gravel deposits, and windblown deposits and Tertiary-age gravel deposits. Generally, the thickness of these deposits ranges from 0 to 50 feet.

Hydrologic Setting

The hydrologic setting of the Black Hills area is schematically illustrated in figure 5. The major aquifers in the Black Hills area are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Aquifers in the Precambrian rocks also were considered as a major aquifer in this report because numerous wells are completed in this unit. In some local areas, wells are completed in strata that generally are considered semiconfining or confining units. These local water-bearing strata are referred to as minor aquifers in this report. This section describes the hydrologic setting for the major and minor aquifers considered in this report.

Major Aquifers

The Precambrian basement rocks generally have low permeability and form the lower confining unit for the series of sedimentary aquifers in the Black Hills area. Localized aquifers occur in Precambrian rocks at many locations in the central core of the Black Hills, where enhanced secondary permeability results from weathering and fracturing. These localized aquifers are referred to as the Precambrian aquifers in this report. In the Precambrian aquifers, water-table (unconfined) conditions generally prevail and land-surface topography can strongly control ground-water flow directions. Many wells completed in the Precambrian aquifers are located along stream channels.

Many of the sedimentary units contain aquifers, both within and beyond the study area. Within the Paleozoic rock interval, aquifers in the Deadwood Formation, Madison Limestone, Minnelusa Formation, and Minnekahta Limestone are used extensively. These aquifers are collectively confined by the underlying Precambrian rocks and the overlying Spearfish Formation. Individually, these aquifers are separated by minor confining layers or by relatively impermeable layers within the individual units. In general, ground-water flow in these aquifers is radially outward from the central core of the Black Hills. Although the lateral component of flow predominates, extremely variable leakage (vertical component of flow) can occur between these aquifers (Peter, 1985; Greene, 1993).

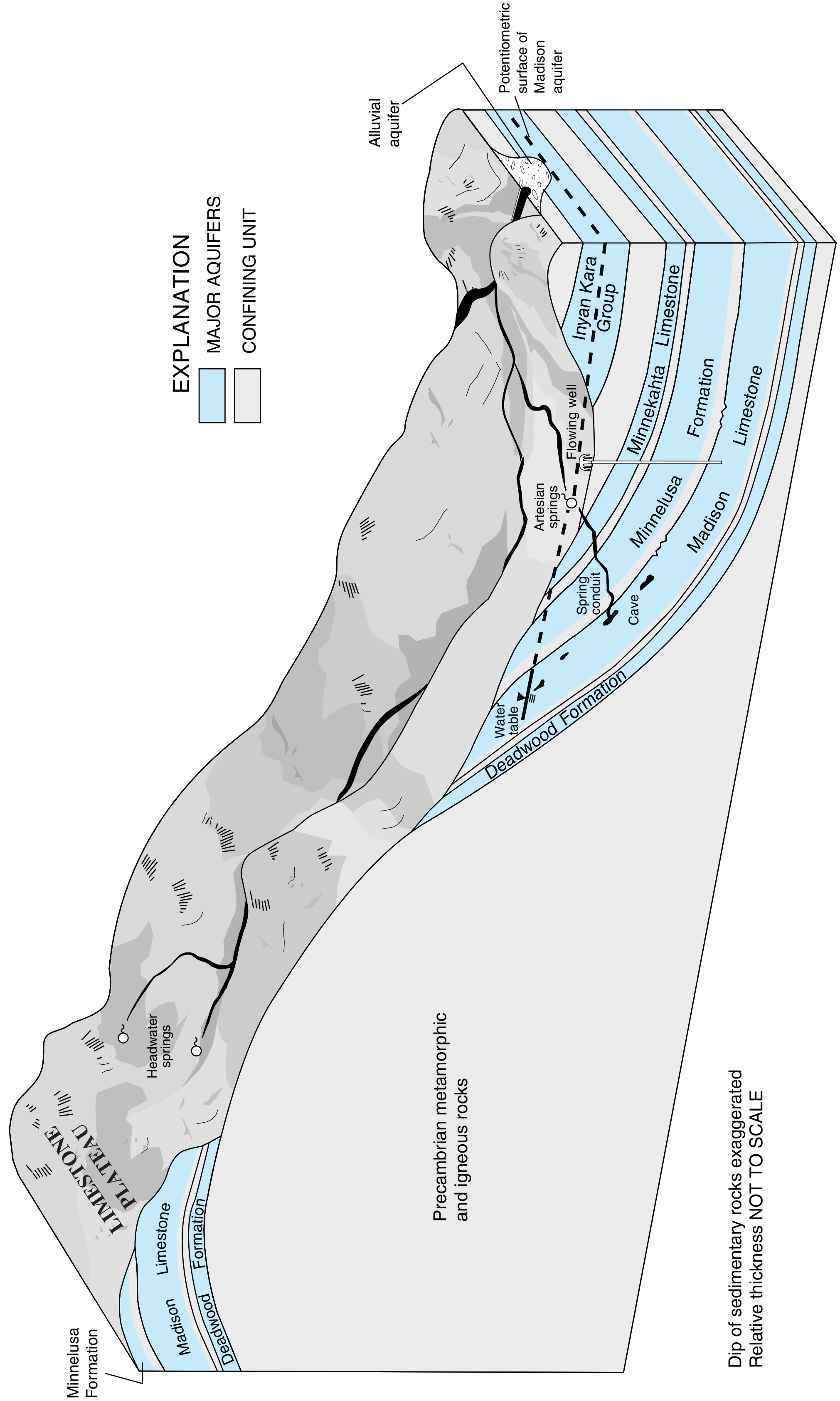

Figure 5. Schematic showing simplified hydrogeologic setting of the Black Hills area.

The Deadwood Formation contains the Deadwood aquifer, which overlies the Precambrian rocks. In general, the Deadwood aquifer serves as a source of water mainly for domestic and municipal users near its outcrop area. There may be some hydraulic connection between the Deadwood and the underlying weathered Precambrian rocks, but regionally the Precambrian rocks act as a lower confining unit to the Deadwood aquifer. Where present, the Whitewood and Winnipeg Formations act as a semiconfining unit overlying the Deadwood aquifer (Strobel and others, 1999). These units locally may transmit and exchange water with the Deadwood aquifer, but regionally are not considered aquifers. Where the Whitewood and Winnipeg Formations are absent, the Deadwood aquifer is in contact with the overlying Englewood Formation, which Strobel and others (1999) included as part of the Madison aquifer.

The Madison aquifer generally occurs within the karstic upper part of the Madison Limestone; however, Strobel and others (1999) included the entire Madison Limestone and underlying Englewood Formation in their delineation of the aquifer. Numerous fractures and solution openings in the Madison Limestone provide extensive secondary porosity in the aquifer. The Madison aquifer generally is confined by low permeability layers in the overlying Minnelusa Formation.

The Minnelusa aquifer occurs within layers of sandstone, dolomite, and anhydrite in the lower portion of the Minnelusa Formation and sandstone and anhydrite in the upper portion. The Minnelusa aquifer has primary porosity in the sandstone units and secondary porosity from collapse breccia associated with solution of interbedded evaporites and fracturing. The Minnelusa aquifer is confined by the overlying Opeche Shale and by low-permeability layers within the Minnelusa Formation.

The Minnekahta aquifer, which overlies the Opeche Shale, typically is very permeable, but well yields are limited by the aquifer thickness. The overlying Spearfish Formation acts as a confining unit to the aquifer.

Within the Mesozoic rock interval, the Inyan Kara Group contains an aquifer that is used extensively. As much as 4,000 feet of Cretaceous shales act as the upper confining layer to the Inyan Kara aquifer.

Artesian (confined) conditions generally exist within the aforementioned aquifers where an upper confining layer is present. Under artesian conditions, water in a well will rise above the top of the aquifer in which it is completed. Flowing wells will result when drilled in areas where the potentiometric surface is above the land surface. Flowing wells and artesian springs that originate from confined aquifers are common around the periphery of the Black Hills.

Numerous headwater springs originating from the Paleozoic units at high elevations on the western side of the study area provide base flow for many streams. These streams flow across the central core of the Black Hills, and most streams generally lose all or part of their flow as they cross the outcrops of the Madison Limestone (Rahn and Gries, 1973; Hortness and Driscoll, 1998). Karst features of the Madison Limestone, including sinkholes, collapse features, solution cavities, and caves, are responsible for the Madison aquifer's capacity to accept recharge from streamflow. Large streamflow losses also occur in many locations within the outcrop of the Minnelusa Formation (Hortness and Driscoll, 1998). Large artesian springs occur in many locations downgradient from these loss zones, most commonly within or near the outcrop of the Spearfish Formation. These springs provide an important source of base flow in many streams beyond the periphery of the Black Hills (Rahn and Gries, 1973; Miller and Driscoll, 1998).

Minor Aquifers

In addition to the major aquifers, many other aquifers, such as the Newcastle and alluvial aquifers, are used throughout the study area. In addition, many of the semiconfining and confining units shown in figure 3 may contain local aquifers. These other and local aquifers are considered minor aquifers in this report. This section provides a brief overview from Strobel and others (1999) of the minor aquifers for which water-quality data are available.

Local aquifers may exist in the Spearfish confining unit where gypsum and anhydrite have been dissolved, increasing porosity and permeability; these aquifers are referred to as the Spearfish aquifer in this report. The Jurassic-sequence semiconfining unit consists of shales and sandstones. Overall, this unit is semiconfining because of the low permeability of the interbedded shales; however, local aquifers do exist in some formations such as the Sundance and Morrison Formation. These aquifers are referred to as the Sundance and Morrison aquifers in this report.

The Cretaceous-sequence confining unit mainly includes shales of low permeability, such as the Pierre Shale; local aquifers within the Pierre Shale are referred to as the Pierre aquifer in this report. Within the Graneros Group, the Newcastle Sandstone contains an important minor aquifer. Because water-quality characteristics are very different between the Newcastle aquifer and the other units within the Graneros Group, water-quality data are presented for the Newcastle aquifer separately from the other units within the Graneros Group, known as the Graneros aquifer in this report.

Gravel deposits of Tertiary age and unconsolidated units of Quaternary age, including alluvium, colluvium, gravel deposits, and wind-blown deposits, all have the potential to provide water where these units are saturated. In this report, these units are collectively referred to as alluvial aquifers.

Previous Investigations

Numerous reports from previous investigations contain information on the water quality of ground and surface water in the Black Hills area. The investigations described in this section are not exhaustive, but rather are those that either provide regional water-quality information or were done as part of the Black Hills Hydrology Study.

Various investigations have addressed the quality of ground water in the Black Hills area. Water-quality data collected from the Inyan Kara aquifer in the southern Black Hills were presented by Gott and others (1974). Radium concentrations collected from wells completed in the Madison aquifer in western South Dakota were presented by Carda (1975). Numerous water-quality data were collected in western South Dakota during the National Uranium Resource Evaluation (NURE) Program established by the U.S. Department of Energy. Some of the NURE data collected in the Black Hills area were presented by Union Carbide Corporation (1979, 1980). Water-quality data collected from the Madison aquifer in Montana, South Dakota, and Wyoming were presented in Busby and others (1983). The quality of ground water in western South Dakota was summarized for 17 aquifers by Meyer (1984), and ground-water pollution problems were summarized in Meyer (1986). Summaries of water-quality samples collected from the Inyan Kara, Minnelusa, and Madison aquifers were presented by Peter (1985) for the Rapid City area and by Kyllonen and Peter (1987) for the northern Black Hills of South Dakota and Wyoming. Water-quality data with emphasis on selenium in the Inyan Kara aquifer in the Black Hills were presented by Behal (1988). Water-quality data with emphasis on radionuclides for the Deadwood aquifer in the Black Hills were presented by Rounds (1991). Major ion and isotope data for the Madison aquifer in Montana, South Dakota, and Wyoming were presented by Busby and others (1991).

Many investigations on the quality of surface water have been conducted. The general water quality of streams within South Dakota has been reported every 2 years in 305(b) assessment reports prepared by the South Dakota Department of Environment and Natural Resources (1975-99). Water-quality data and results from the Rapid City National Urban Runoff Program were presented by Harms (1983), Harms and others (1983), and Goddard and others (1989). The water-quality effects of contaminated sediments on Whitewood Creek and the Belle Fourche and Cheyenne Rivers were addressed by Cherry and others (1986a, 1986b, 1986c), Goddard (1988, 1989a, 1989b, 1990), and Fuller and others (1988, 1989). Water-quality data, including major ions, properties, trace elements, and pesticides, that were collected during 1988 as part of irrigation drainage programs were presented by Greene and others (1990) for the Angostura Reclamation Unit and by Roddy and others (1991) for the Belle Fourche Reclamation Project. The water quality of streams in Custer State Park following the Galena Forest Fire was presented by Gundarlahalli (1990). Freeman and Komor (1991) presented a compilation of water-quality data along Rapid Creek for the period 1946-90, and Williamson and others (1996) presented data on selected trace elements in Rapid Creek. Additional summaries of sources of water-quality data in the Rapid Creek Basin were presented by Zogorski and others (1990). Information about arsenic loads and concentrations in Spearfish Creek were presented by Driscoll and Hayes (1995). Water-quality impacts on surface water from mining were presented by Rahn and others (1996).

Several reports contain water-quality data that were specifically collected as part of the Black Hills Hydrology Study. Water-quality data for selected wells, streams, and springs have been published by Driscoll and Bradford (1994), Driscoll and others (1996), and Driscoll, Bradford, and Moran (2000). Water-quality data for selected streams in Lawrence

County were presented by Torve (1991), Williamson (1999), and Williamson and Hayes (2000). Nutrient, chloride, and bacteria data collected during 1988-90 for the Spearfish Creek Basin in Lawrence County were presented by Johnson (1992). Water-quality data from large-discharge springs and selected wells completed in the Madison and Minnelusa aquifers in the southern Black Hills were presented by Whalen (1994) and in northwestern Lawrence County by Klemp (1995). Water-quality data with emphasis on field properties of selected headwater springs in the Black Hills were presented by Wenker (1997).

Acknowledgments

The authors acknowledge the efforts of the West Dakota Water Development District for helping to develop and support the Black Hills Hydrology Study. West Dakota's coordination of various local and county cooperators has been a key element in making this study possible. The authors also recognize the numerous local and county cooperators represented by West Dakota, as well as the numerous private citizens who have helped provide guidance and support for the Black Hills Hydrology Study. The South Dakota Department of Environment and Natural Resources has provided support and extensive technical assistance to the study. In addition, the authors acknowledge the input and technical assistance from many faculty and students at the South Dakota School of Mines and Technology.

WATER-QUALITY CHARACTERISTICS

Data from the USGS National Water Information System (NWIS) water-quality database, QWDATA, were examined to characterize the water quality of aquifers, streams, and springs in the Black Hills area. QWDATA stores data primarily collected and analyzed by USGS. The data also are transferred to the U.S. Environmental Protection Agency (USEPA) water-quality database, STORET.

Data summarized in this report include samples collected from October 1, 1930, to September 30, 1998. A selection criterion for including a sample as part of this analysis was to have a cation/anion balance within 10 percent. Tables of individual results are not presented in this report, only summaries. Site specific data can be requested from the USGS or USEPA. For some of the constituents summarized in this report, multiple laboratory reporting limits were used, resulting in censored values at various levels. If the majority of detectable levels were less than some of the censored values, those censored values were removed because they do not provide additional information for describing the data set. For the censored data, boxplots and summary statistics were estimated using a log-probability regression procedure (Helsel and Gilliom, 1985).

Sampling Sites and Methods

Ground-water and surface-water samples collected as part of studies along Whitewood Creek have been summarized in previous reports (Goddard, 1988, 1989a; Fuller and Davis, 1989; Fuller and others, 1988, 1989; Goddard and others, 1989) and are not included in this summary. In addition, samples from wastewater treatment plant effluents, some miscellaneous measurement sites, and samples from sites obviously affected by abandoned mines are not included. Sampling locations for ground water and surface water are presented in figures 6 and 7, respectively. The location of selected surface-water sites in the Rapid Creek Basin is presented in figure 7a. Lists of the ground-water and surface-water sampling sites are presented in tables 15 and 16 in the Supplemental Information section at the end of the report.

For the majority of the samples collected prior to the Black Hills Hydrology Study and for all samples collected during the study, all water-sampling equipment was presoaked in a Liquinox solution, thoroughly scrubbed, rinsed with tap water, and then rinsed with deionized water prior to sampling. Samples were collected using acceptable methods at the time; most methods are described by Hem (1985) and Ward and Harr (1990). Field measurements of streamflow, air and water temperature, pH, dissolved oxygen, and specific conductance usually were collected. When more than one site was sampled on a given day, equipment cleaning between sites consisted of a deionized water rinse and thoroughly rinsing with well or stream water. After samples were collected, filtered and preserved, if applicable, they were shipped to the USGS National Water Quality Laboratory (NWQL) for analysis.

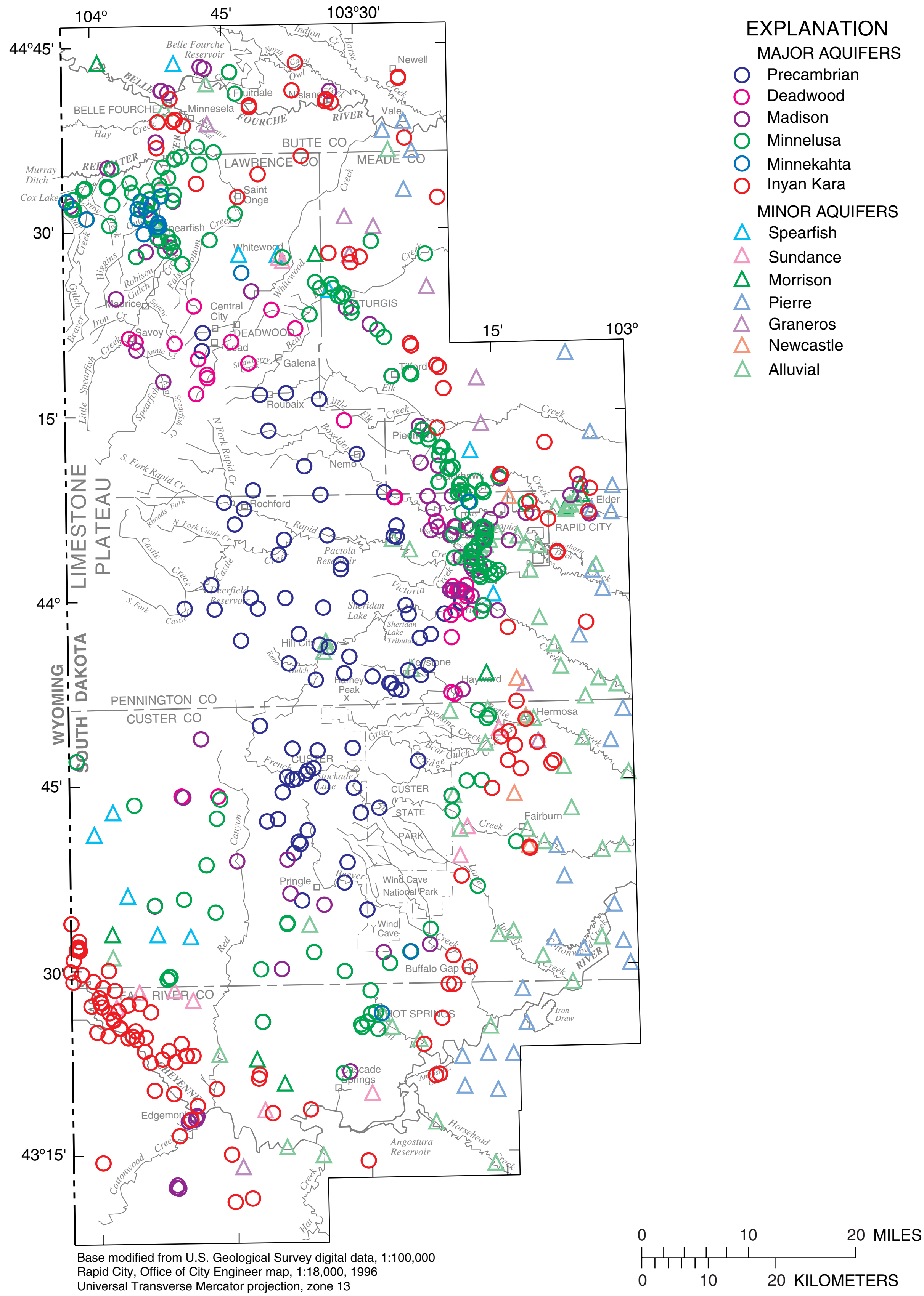

Figure 6. Location of ground-water sampling sites.

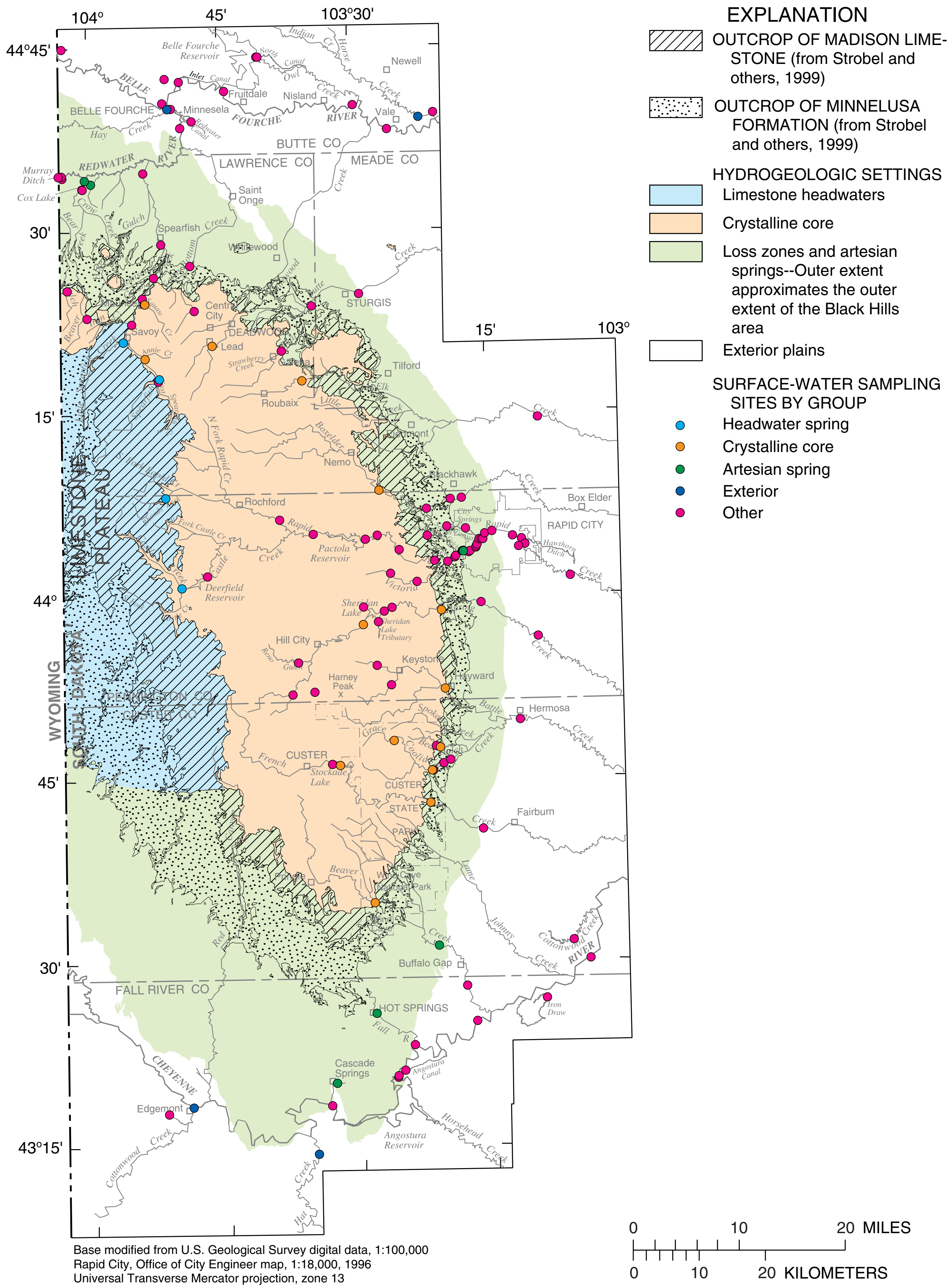

Figure 7. Location of selected surface-water sampling sites by group.

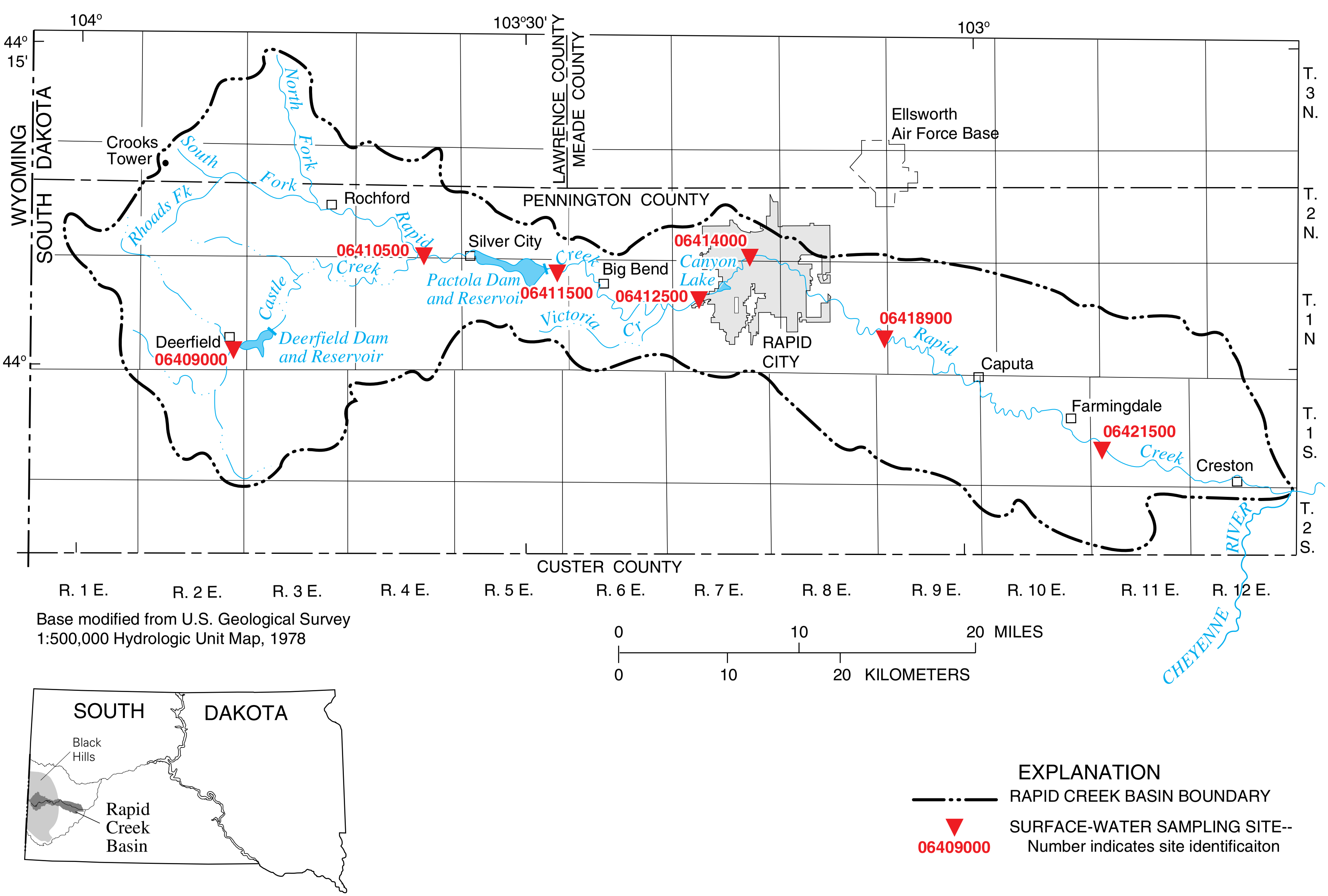

Figure 7a. Location of selected surface-water sampling sites in the Rapid Creek Basin.