HYDROGEOLOGIC MAP OF CARBON AND STILLWATER COUNTIES, SOUTH-CENTRAL MONTANA

PAMPHLET TO ACCOMPANY MAP

Daniel D. Blythe and John I. LaFave

Montana Bureau of Mines and Geology

Montana Bureau of Mines and Geology

Cover: Looking north from the Dryhead overlook, near the top of East Pryor Mountain, southeast Carbon County.

HYDROGEOLOGIC MAP OF CARBON AND STILLWATER COUNTIES, SOUTH-CENTRAL MONTANA

PAMPHLET TO ACCOMPANY MAP

Daniel D. Blythe and John I. LaFave
Montana Bureau of Mines and Geology

October 2020

Ground Water Assessment Atlas 6 Map 2

Montana Bureau of Mines and Geology

TABLE OF CONTENTS

FIGURES

INTRODUCTION

The Montana Bureau of Mines and Geology (MBMG) conducted the Carbon–Stillwater groundwater characterization study as part of the Montana Ground Water Assessment Program. This report and the accompanying map are a part of Montana Ground Water Assessment Atlas 6, which documents groundwater resources in Carbon and Stillwater Counties. The hydrogeologic framework presented in this report and plate provide a stand-alone depiction of the hydrogeologic setting. Companion maps in Atlas 6 include a compilation of sites visited during these investigations (Carstarphen and Smith, 2007), a regional water table map (Blythe and Retien, 2015), and an assessment of groundwater quality (Carstarphen and LaFave, in review).

Carbon and Stillwater Counties encompass an area of about 3,900 mi^2, in south-central Montana (fig. 1A). Approximately 10,000 people live in each county (Montana Department of Commerce, 2014), and most households (about 77 percent) rely on groundwater as their potable water source; the rest depend on surface water. Where surface water or groundwater are unavailable, residents haul water to store in cisterns. Surface water is used for irrigation and stockwater purposes; however, where not available, ranchers and farmers depend on water pumped from wells (Cannon and Johnson, 2004).

The study area encompasses parts of the northern Rocky Mountains and the unglaciated Missouri Plateau section of the Great Plains physiographic provinces (Fenneman and Johnson, 1946). Mountain ranges and high plateaus characterize the Rocky Mountains, in contrast to the flat to rolling topography of the unglaciated Missouri Plateau. The Beartooth and Pryor Mountains lie within southern Carbon County, and the Lake Basin subarea, a prominent, internally drained depression, occupies northern Stillwater County (fig. 1B). High topographic relief and complex geologic structure distinguish the area near the Beartooth Mountains. In contrast, the region north of the mountain front is mostly flat-lying with less structure and low topographic relief, as illustrated along cross section A–A′ on the map.

The Yellowstone River enters Stillwater County near the town of Reed Point and splits the study area into northern and southern parts. Rock Creek and the Stillwater River (major tributaries of the Yellowstone River) drain the southern region between the Yellowstone River and the Beartooth Mountains (fig. 1A). The Clarks Fork of the Yellowstone flows north from Wyoming through Carbon County to its confluence with the Yellowstone River. The southeast corner of the study area, off the east flank of the Pryor Mountains, drains into Bighorn Lake.

The climate is semiarid, with cold winters and hot summers. Annual average precipitation is about 23 in; Belfry receives the least precipitation and Red Lodge the most. Monthly precipitation averages are lowest in winter; 1981–2010 January averages are: Belfry, 0.4 in; Absarokee and Rapelje, 0.5 in; and Red Lodge, 0.7 in (Montana Climate Office, 2019). Peak precipitation occurs in May [Belfry, 2.1 in; Lake Basin, 2.6 in; Absarokee, 2.9 in; and Red Lodge, 3.2 in (Montana Climate Office, 2019)]. Groundwater recharge typically occurs during spring and early summer runoff when snowpack melts and the ground is unfrozen. Irrigation diversions into unlined ditches and excess water applied to crops are also significant sources of groundwater recharge (Carstarphen and others, 2014).

MAP CONSTRUCTION AND DATA SOURCES

The major aquifers depicted on the Hydrogeologic Framework map were compiled from published geologic maps indexed on the map. The aquifer and confining units described in this framework include geologic formations that are named differently across 1:100,000-scale geologic map boundaries. The formations on the 1:100,000-scale maps were used to identify source aquifers for the water wells on file at the MBMG Ground-Water Information Center (GWIC, MBMG, 2019). Cross sections were compiled from geologic maps, formation top elevations, thicknesses derived from oil and gas well logs on file at the Montana Board of Oil and Gas Conservation database (MBOG, 2015), and lithologic data from GWIC water well logs.

GEOLOGY

Geologic conditions in the study area are well documented. Investigations include early reconnaissance mapping by Knappen and Moulton (1931) and 1:100,000-scale geologic mapping of the Harlowton

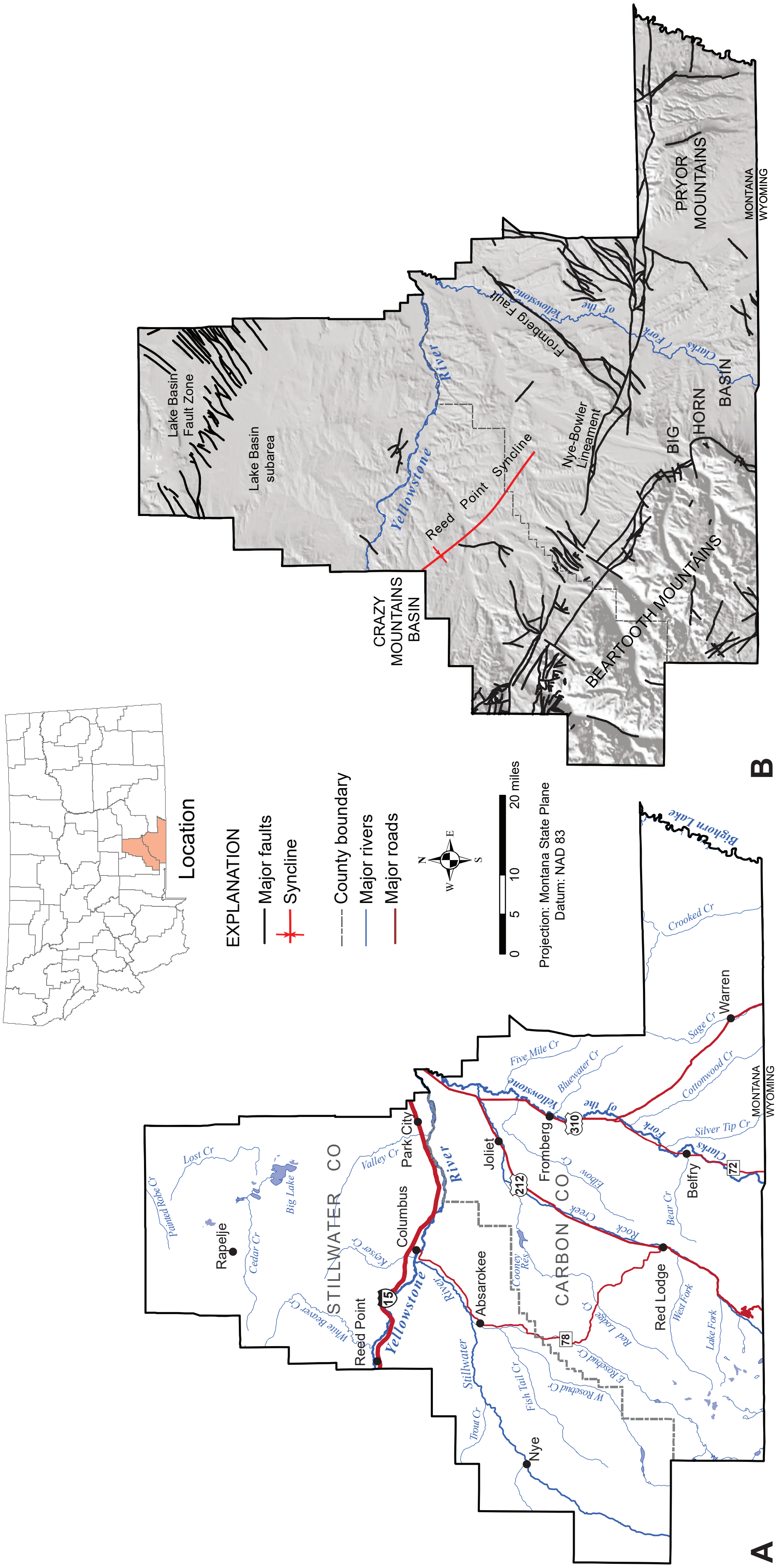

Figure 1. Carbon–Stillwater study area location and structural features.

(Wilde and Porter, 2001), Roundup (Wilde and Porter, 2000), Big Timber (Lopez, 2000a), Billings (Lopez, 2000b), Bridger (Lopez, 2000c), Gardiner (Berg and others, 1999), and Red Lodge (Lopez, 2001) quads. The terraces near Red Lodge and along the Beartooth front were described by Ritter (1967), and Big Horn basin structure and stratigraphy are described in Exum and George (1975), Flueckinger (1970), Fox (1993), Gill and Cobban (1973), and Jobling (1974).

Exposed bedrock in the Carbon–Stillwater area consists mostly of Tertiary and Cretaceous sedimentary rocks. In the south, older formations of Cambrian to Jurassic age are exposed on the flanks of the Beartooth Plateau and the Pryor Mountains. Cross sections A–A´ and B–B´ show that the Tertiary Fort Union Formation thickens near the Beartooth Plateau. Darlinton (1969) estimate a thickness of up to 8,500 ft for the Fort Union Formation. Cretaceous sedimentary rocks consist of alternating sandstone and shale. In the north, the internally drained Lake Basin subarea contains Quaternary stream and lake deposits. Quaternary alluvium occupies the valleys of the Yellowstone River and its tributaries, with an average thickness of 30 ft; alluvium thicknesses are slightly greater in the Clarks Fork of the Yellowstone Valley (Darlinton, 1969). Smaller valleys containing tributary streams to the Yellowstone and Clarks Fork also contain Quaternary alluvium. Terraces flanking the streams represent various changes of drainage patterns resulting from uplift. Terrace gravels range from 15 to 50 ft thick along Rock Creek and commonly range from 15 to 25 ft elsewhere (Darlinton, 1969). Ritter (1967) studied terrace gravels extensively near Red Lodge and along the northern flank of the Beartooth Plateau.

The broad, fault-bounded, and uplifted Beartooth Plateau dominates the southwest part of the study area. Thrust faults bordering the Beartooth Mountains represent nearly 5 mi of structural relief (Wise, 2000) and, as illustrated on the map, mark a major geologic transition from Precambrian crystalline rocks to Tertiary and Cretaceous sandstone and shale formations. The west–southwest dipping thrust plane that bounds the uplift is the major structural feature from Red Lodge to Nye (Foose and others, 1961). The north part of the Bighorn Basin extends into the study area between the Beartooth Plateau and the Pryor Mountains, with the axis of the basin trending northwest. The Nye–Bowler lineament marks the northern extent of the Bighorn Basin and the southeast extent of the Reed Point Syncline and the Crazy Mountains Basin (fig. 1B). Even though the Nye–Bowler lineament defines the boundary between two structural basins, it is topographically low compared to the high topographic relief of the nearby Beartooth Plateau and Pryor Mountains. Several northeast–southwest-trending tear faults extend from the Nye–Bowler lineament (Foose and others, 1961). Most notably, the Fromberg fault trends northeast from the Nye–Bowler lineament through Fromberg (fig. 1B).

HYDROGEOLOGY

Aquifers are permeable geologic units that store and transmit usable quantities of groundwater. Within the study area, unconsolidated sediments and bedrock formations form the primary aquifers. Based on over 9,200 records in GWIC, about half of all water wells are completed in unconsolidated sediments and half in various bedrock aquifers (fig. 2). Most wells are reportedly used for domestic (76 percent) and stockwater (16 percent) supplies (fig. 3). Wells are generally completed at depths less than 200 ft (fig. 4) and typically yield less than 40 gallons per minute (gpm; fig. 5).

Quaternary alluvial deposits occur in the modern floodplains of rivers and streams. Although too thin to depict in cross section, the map illustrates the aerial extent of the floodplain deposits and terrace gravels that flank modern alluvium and together form the alluvial aquifers.

Bedrock formations consist mostly of Tertiary and Cretaceous age sandstone and shale, and some Paleozoic sandstone and limestone units. The primary bedrock aquifers occur in the Tertiary Fort Union Formation, Cretaceous Hell Creek Formation, Judith River Formation, and Eagle Sandstone. The Cretaceous bedrock aquifers are separated by fine-grained shale layers that typically act as confining units; however, near outcrops or where there are transitional contacts with sandstone units, shale formations may yield small amounts of mineralized water. Minor bedrock aquifers between the Clarks Fork of the Yellowstone and the Pryor Mountains include the lower Cretaceous Kootenai Formation, Jurassic through Pennsylvanian sandstones and limestones, and the Mississippian Madison Limestone (Cross section B–B´). The bedrock aquifers in this area provide water to some high-yield wells and several springs, including the Bluewater Springs, the source water for the Bluewater Springs trout hatchery in eastern Carbon County.

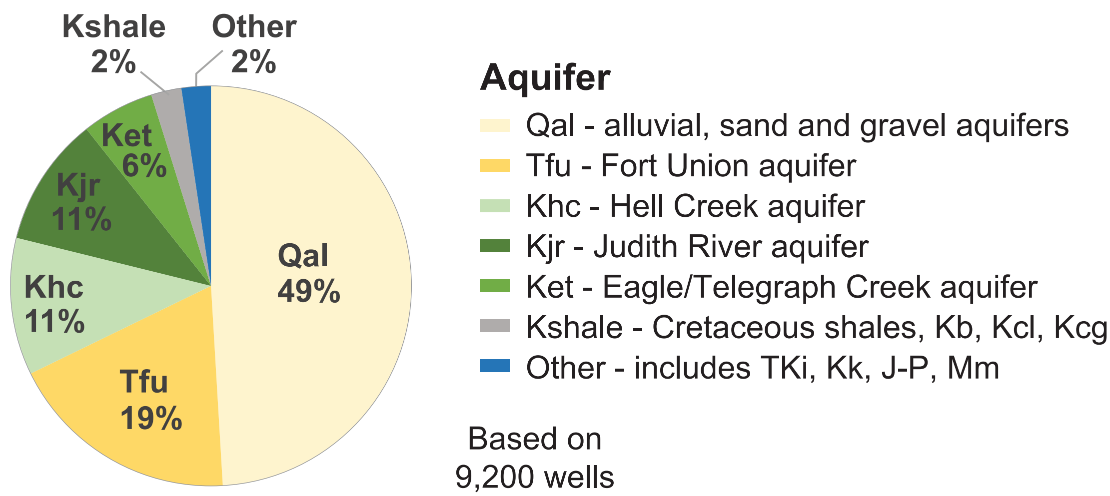

Figure 2. Percentage of water wells by aquifer in Carbon and Stillwater counties (based on records of 9,200 wells in GWIC).

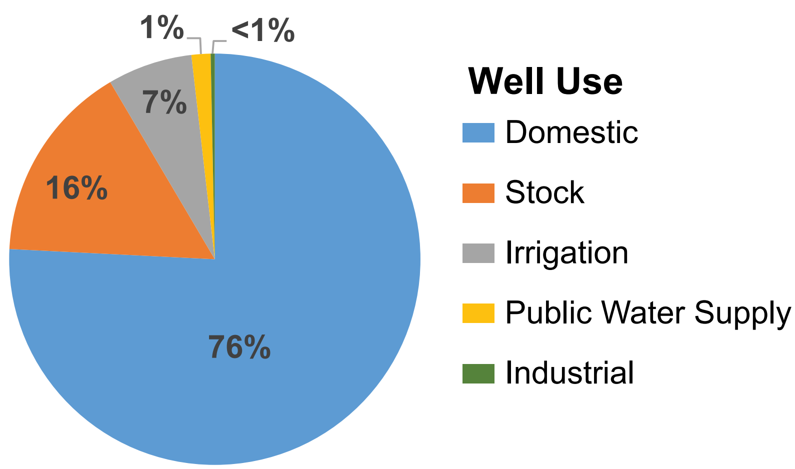

Figure 3. Percentage of wells by reported use in Carbon and Stillwater counties (based on records of 9,885 wells in GWIC).

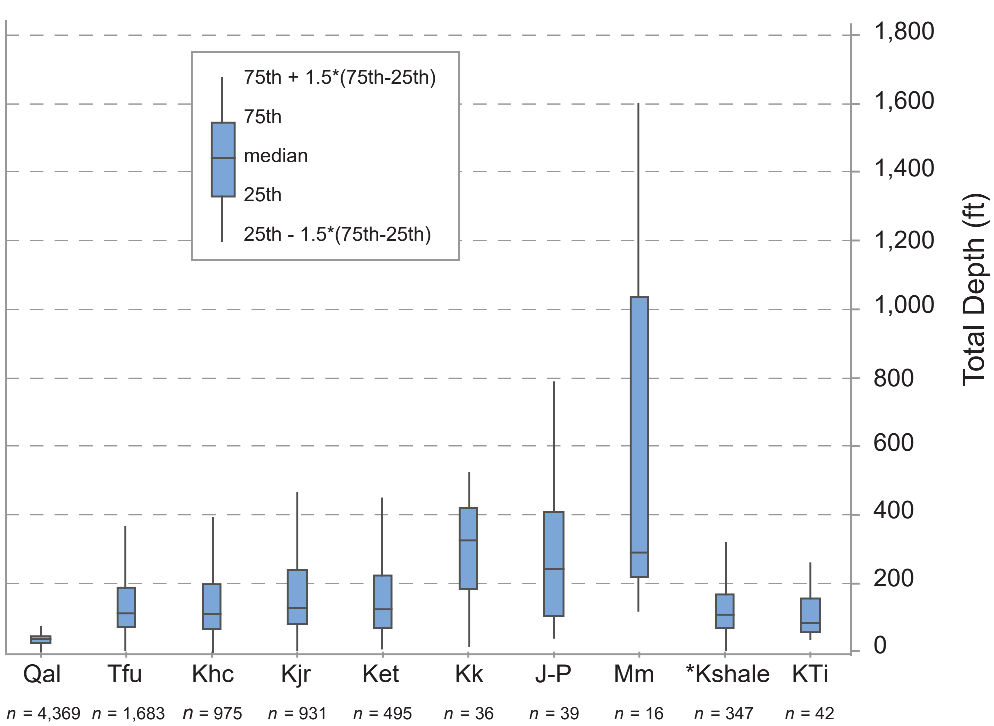

Figure 4. Box plots of driller-reported total depths by aquifer.

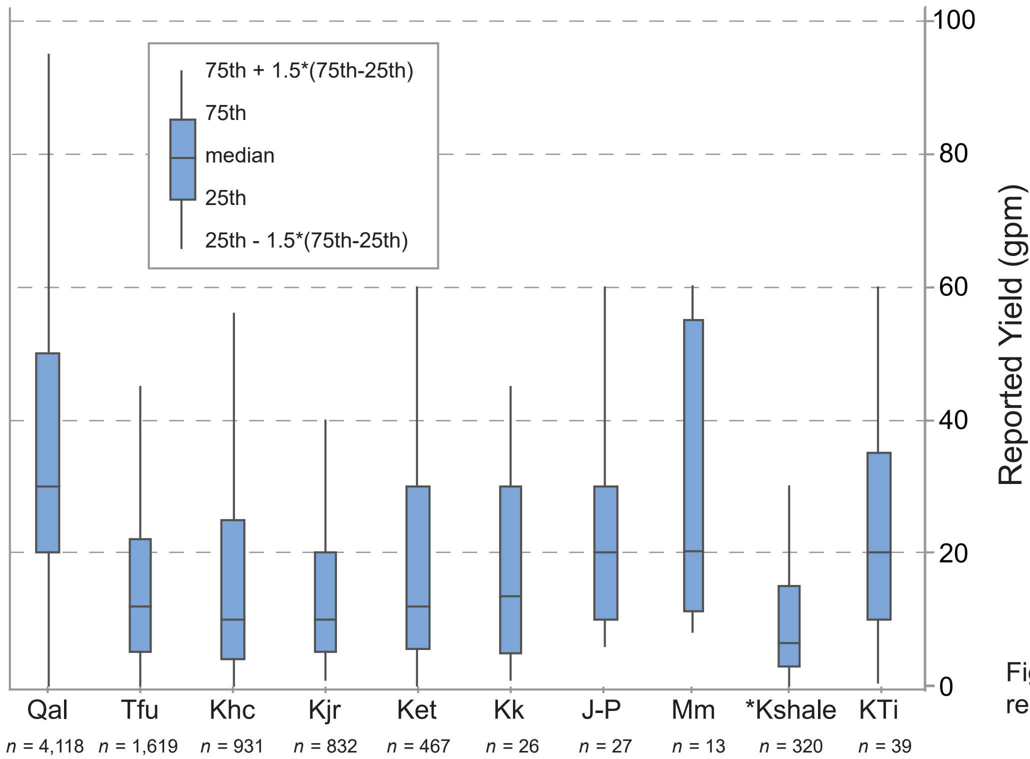

Figure 5. Box plots of driller-reported well yield by aquifer.

Alluvial Aquifers (Qsc, Qsf)

The Yellowstone River and its tributaries drain the southern part of the study area (fig. 1A). The alluvium associated with these streams and rivers comprises the most productive aquifers (fig. 6); it is a heterogeneous mix of interbedded sand, gravel, silt, and clay with a typical thickness of about 30 ft. In the Clarks Fork Valley the aquifer is about 45 ft thick (Darlinton, 1969; GWIC). Prominent terraces flank Rock Creek near Red Lodge, with thicknesses ranging from 15 to 50 ft (Lopez, 2005). Groundwater from these terrace gravel aquifers is used extensively near Red Lodge, where it is recharged by irrigation return water and canal leakage from Rock Creek surface-water diversions (Carstarphen and others, 2014).

About half of the wells in the study area are completed in the alluvial aquifers (fig. 2). Total depths range up to 72 ft with a median value of 38 ft (fig. 4). Yields from the alluvium range up to 2,000 gpm; several public water supply wells (Red Lodge, Columbus, and Bridger) and irrigation wells report yields of more than 500 gpm; the median reported yield is 30 gpm (fig. 5).

Fort Union Aquifer (Tfu)

The Tertiary Fort Union Formation, primarily exposed south of the Yellowstone River (fig. 7), was deposited by eastward-flowing streams across central and eastern Montana during uplift of the Rocky Mountains (Cherven and Jacob, 1985). Stream-channel sandstone, mud-rich floodplain deposits, and coal seams characterize the formation. The Fort Union has three members. The uppermost Tongue River Member is a fine- to medium-grained sandstone, shale, and mudstone with coalbeds. The middle, Lebo Shale Member, composed of dark gray shale and mudstone, is considered a confining unit; although it may yield small quantities of water near outcrops, drillers typically advance through it to the underlying Tullock member, which has lithology similar to the Tongue River.

Nineteen percent of the wells in the study area are completed in the Fort Union aquifer (figs. 2, 7). Total depths range from 10 to 360 ft with a median value of 118 ft (fig. 4). Yields range up to 45 gpm with a median yield of 12 gpm (fig. 5).

Hell Creek Aquifer (Khc)

In this hydrogeologic framework, the Hell Creek aquifer is made up of the Hell Creek Formation, Lance Formation, and Fox Hills Sandstone. The Hell Creek Formation consists of fine-grained sandstone and pale gray mudstones. It crops out north and east of Red Lodge. Thickness ranges from 900 to 1,000 ft (Lopez, 2001). The Lance Formation is as much as 350 ft thick. It contains fine-grained massive sandstone with

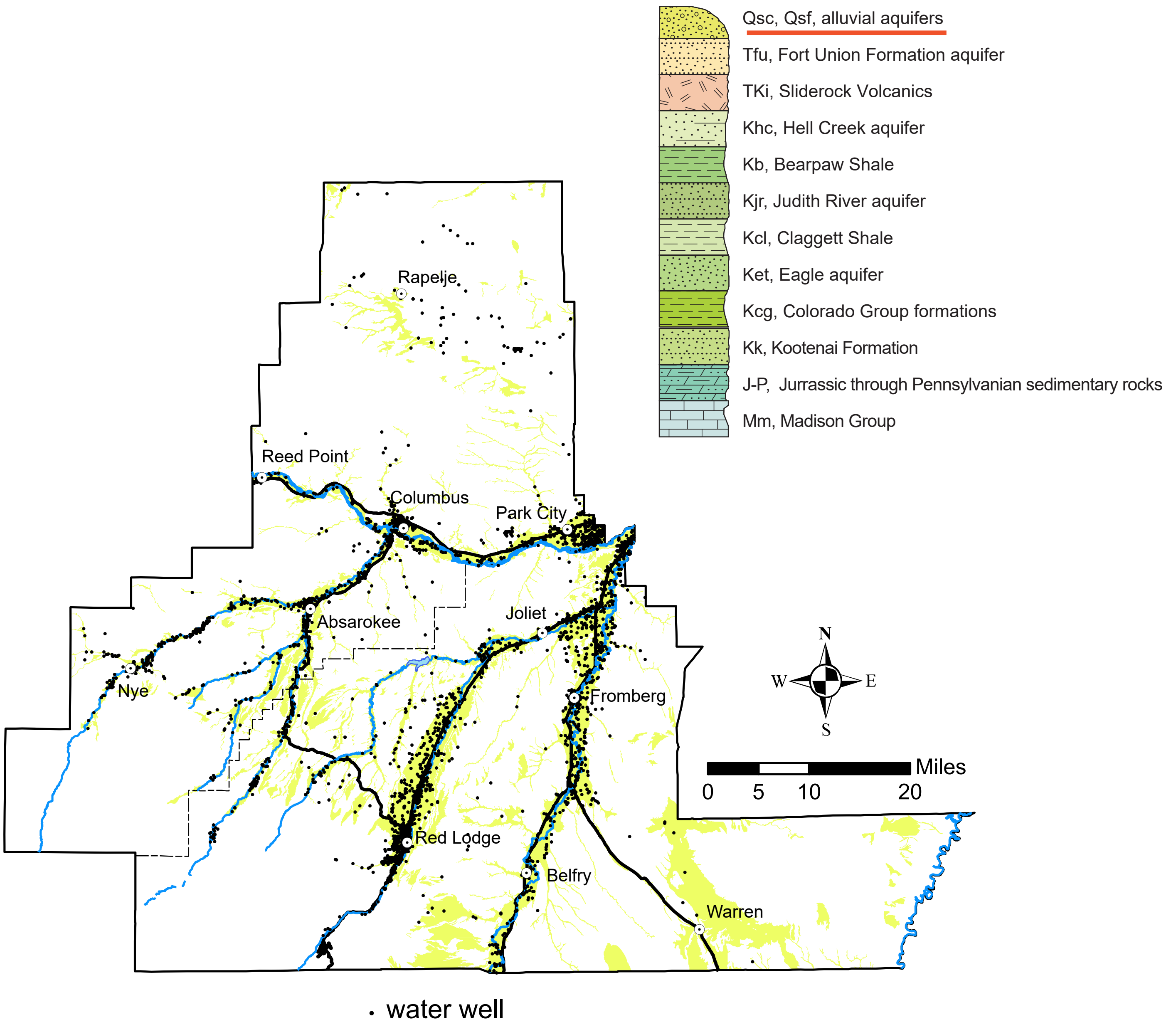

Figure 6. Distribution of water wells in the alluvial aquifers.

interbeds of shale and a few thin coals (Lopez, 2000a), and was deposited in stream channels and floodplains. The Fox Hills Sandstone is a poorly consolidated, sandstone-dominated unit with interbeds of siltstone and shale; it ranges from about 10 to 110 ft thick (Feltis, 1982a). In the study area, outcrops of the Fox Hills Sandstone are limited to northeastern Stillwater County, along the Lake Basin fault zone (Wilde and Porter, 2001).

The Hell Creek aquifer hosts about 11 percent of the wells in the study area (figs. 2, 8). Total well depths range from 4 to 392 ft with a median value of 110 ft (fig. 4). Yields range up to 56 gpm with a median of 11 gpm (fig. 5).

Judith River Aquifer (Kjr)

The Judith River aquifer consists of eastward-thinning wedges of non-marine shoreline sediments and marine shallow-water deposits. North of the Lake Basin fault zone it thins from 700–1000 ft to about 500 ft (Lopez, 2000a; Feltis, 1982b). The aquifer includes fine-grained sandstone and sandy shale. Most individual sandstones layers are about 10 ft thick, and a massive cliff-forming sandstone resembling the Eagle Sandstone exists near the base (Lopez, 2000b). The upper sandstones are easily eroded and may not be present in outcrop. The Judith River Formation grades into the underlying Claggett Shale (Lopez, 2000b).

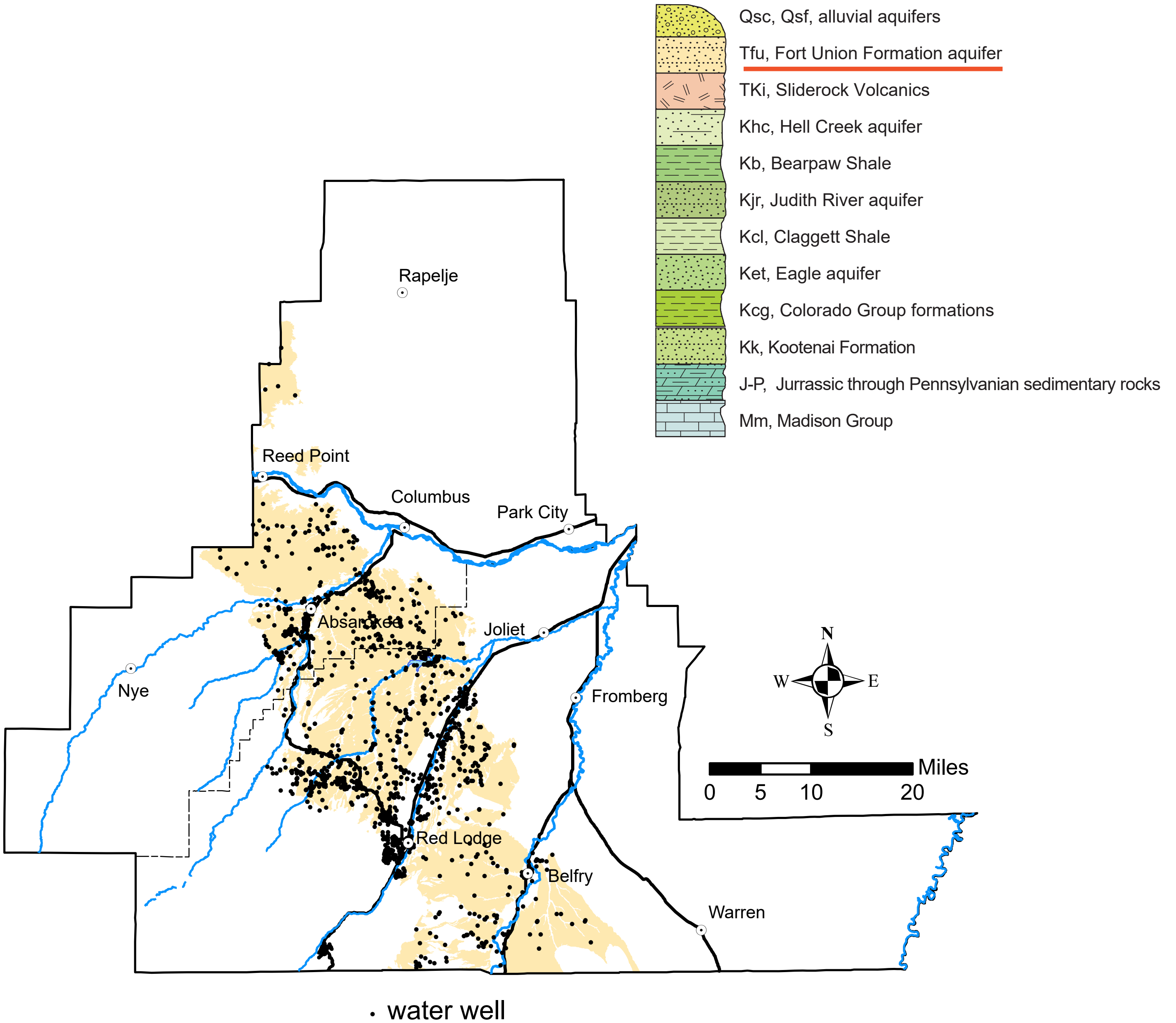

Figure 7. Distribution of wells in the Fort Union aquifer (Tfr).

About 11 percent of wells in the area are completed in the Judith River aquifer (figs. 2, 9). Total depths range from 8 to 455 ft with a median value of 130 ft (fig. 4). Yields range up to 40 gpm with a median yield of 10 gpm (fig. 5).

Eagle Aquifer (Ket)

The Eagle Sandstone and the underlying Telegraph Creek Formation form the Eagle aquifer. The Eagle Sandstone consists of a single eastward-thinning wedge (Feltis, 1982c). The transition from the Eagle Sandstone to the Telegraph Creek is gradational, and these two formations are considered hydraulically connected. The Eagle aquifer is about 500 ft thick near Red Lodge and nearly 900 ft thick in the Lake Basin subarea. The aquifer is between 400 and 500 ft thick along the eastern flank of the Beartooth Mountains (Feltis, 1982c).

About 6 percent of the wells in the study area are completed in the Eagle aquifer (figs. 2, 10). The aquifer underlies much of the study area; however, in most places it is greater than 1,000 ft below land surface. Total depths of wells range up to 455 ft with a median value of 125 ft (fig. 4). Yields range up to 60 gpm with a median yield of 10 gpm (fig. 5).

Kootenai Aquifer (Kk)

The Kootenai Formation is the basal Cretaceous unit; equivalent units include the subsurface Lakota,

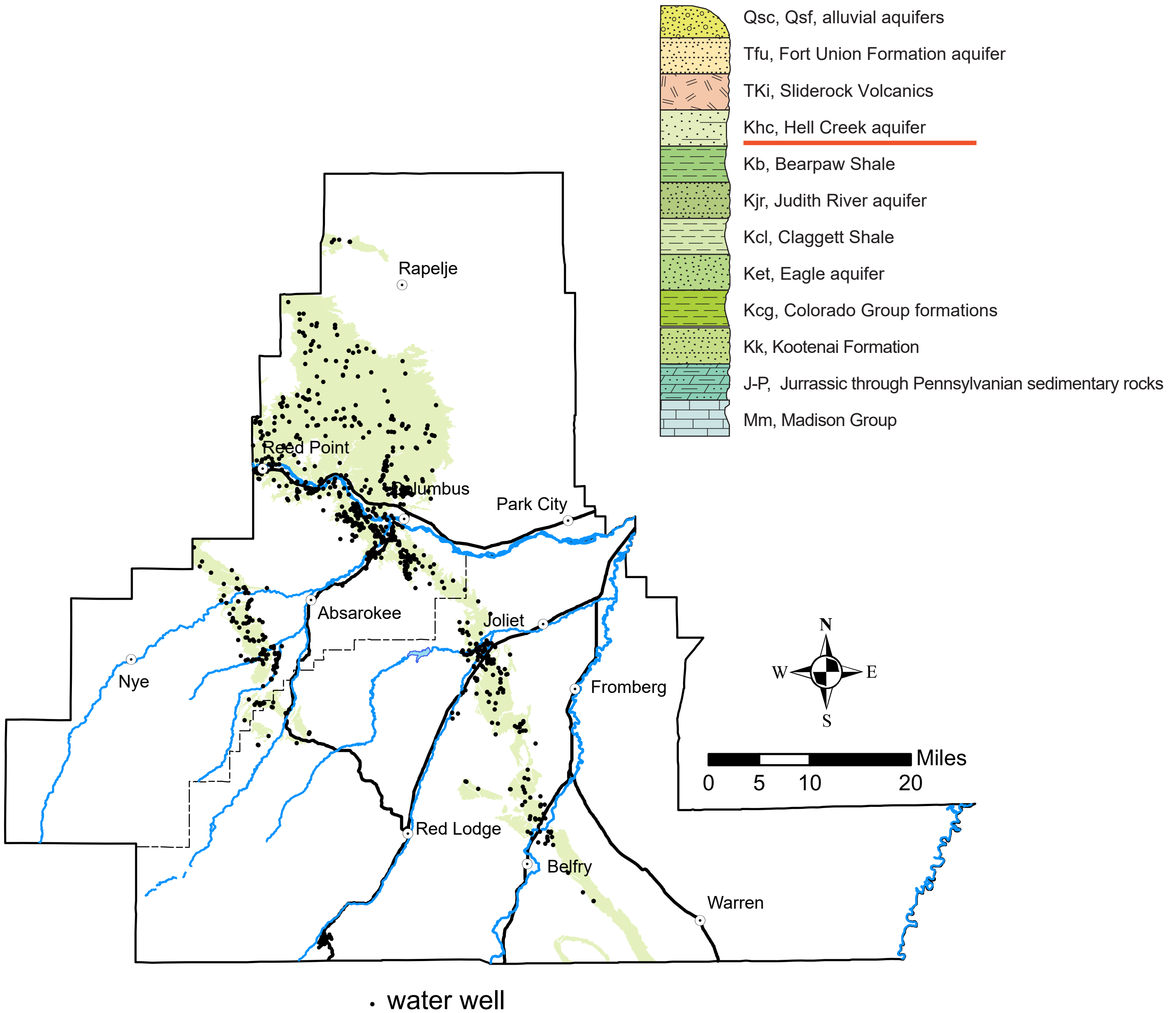

Figure 8. Distribution of wells in the Hell Creek aquifer (Khc).

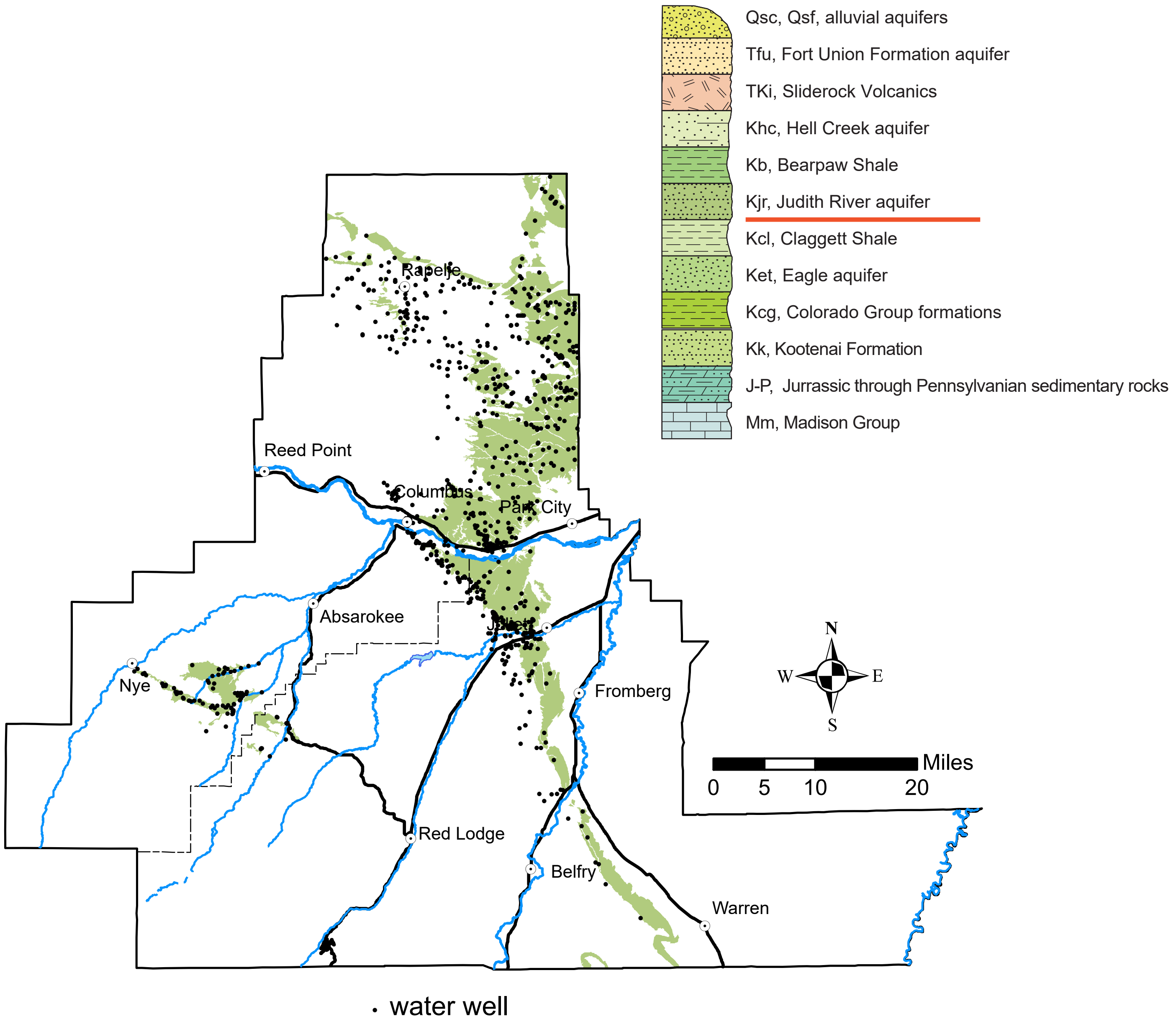

Figure 9. Distribution of wells in the Judith River aquifer (Kjr).

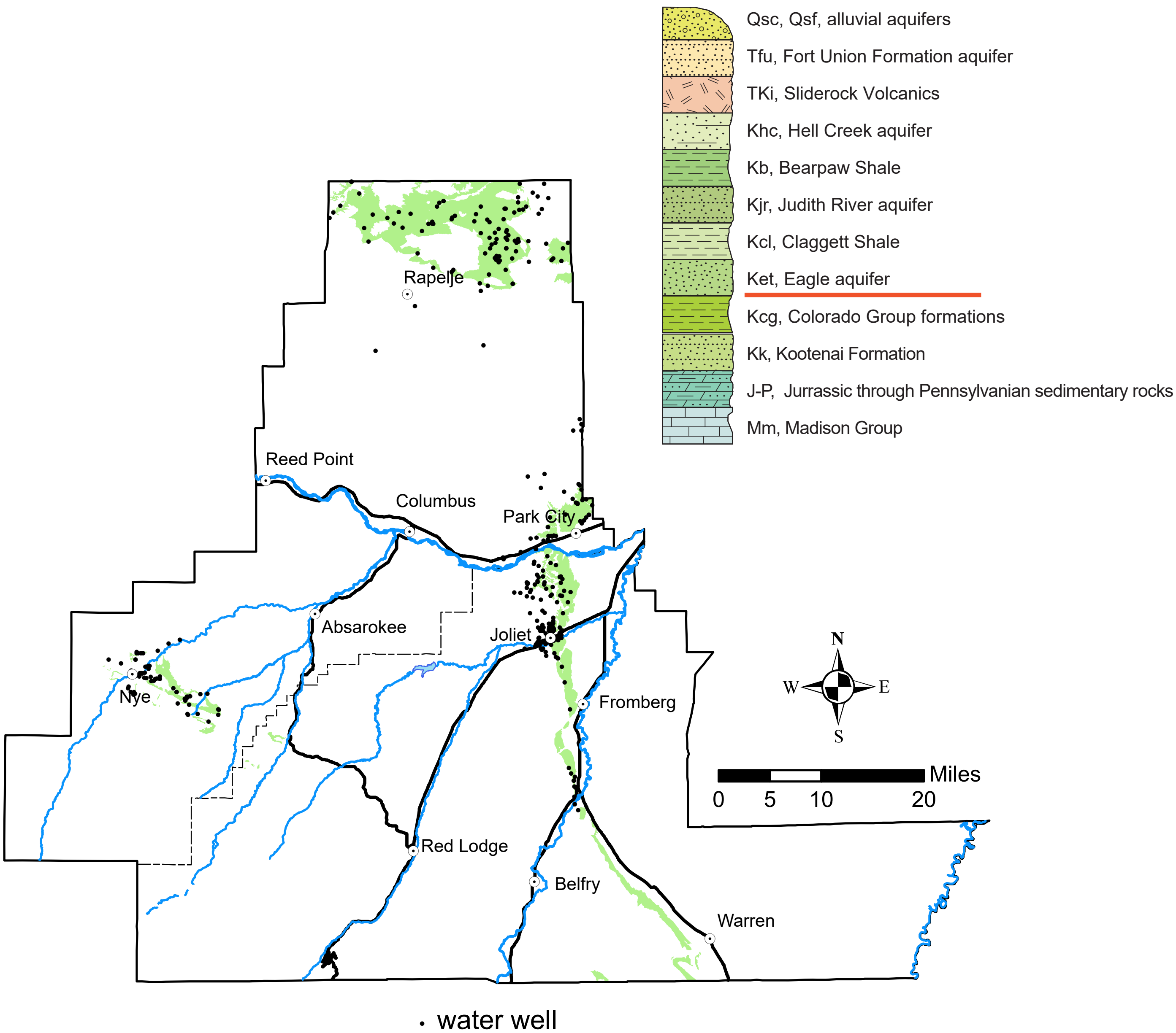

Figure 10. Distribution of wells in the Eagle aquifer (Ket).

Fusion, and Cloverly Formations. The Kootenai is composed of lenticular fluvial or conglomeratic sandstone, siltstone, limestone, and shale; these materials were deposited on an eroded Jurassic surface in a fluvio-deltaic environment. The Kootenai's thickness ranges from 100 to 600 ft (Lopez, 2000c).

The Kootenai is divided into three informal units. The lower (basal) unit, referred to as the Pryor Conglomerate, is marked by a hard, coarse-grained arkosic sandstone and chert–pebble conglomerate. It ranges from 20 to 60 ft in thickness. The middle unit, informally called the Second Cat Creek sandstone, is a brown-gray sandstone interbedded with siltstone and shales. The upper unit is a variegated argillaceous member, composed of red to grayish-green shale and siltstone with a few thin beds of light gray friable sandstone (the Greybull Sandstone).

The Kootenai is exposed as a thin band along the west flank of the Pryor Mountains between the overlying Colorado Group shales and the underlying Jurassic–Pennsylvanian rocks (fig. 11). Records from 34 wells completed in the Kootenai have total depths ranging up to 2,700 ft, with a median value of 345 ft (fig. 4). One irrigation well reportedly yields 2,300 gpm, but of the 26 reported well yields, most fall between 10 and 45 gpm, with a median of 18 gpm (fig. 5).

Jurassic–Pennsylvanian (J-P) Rocks

Below the Kootenai Formation, a sequence of mudstones, sandstones, limestones, and shales yield

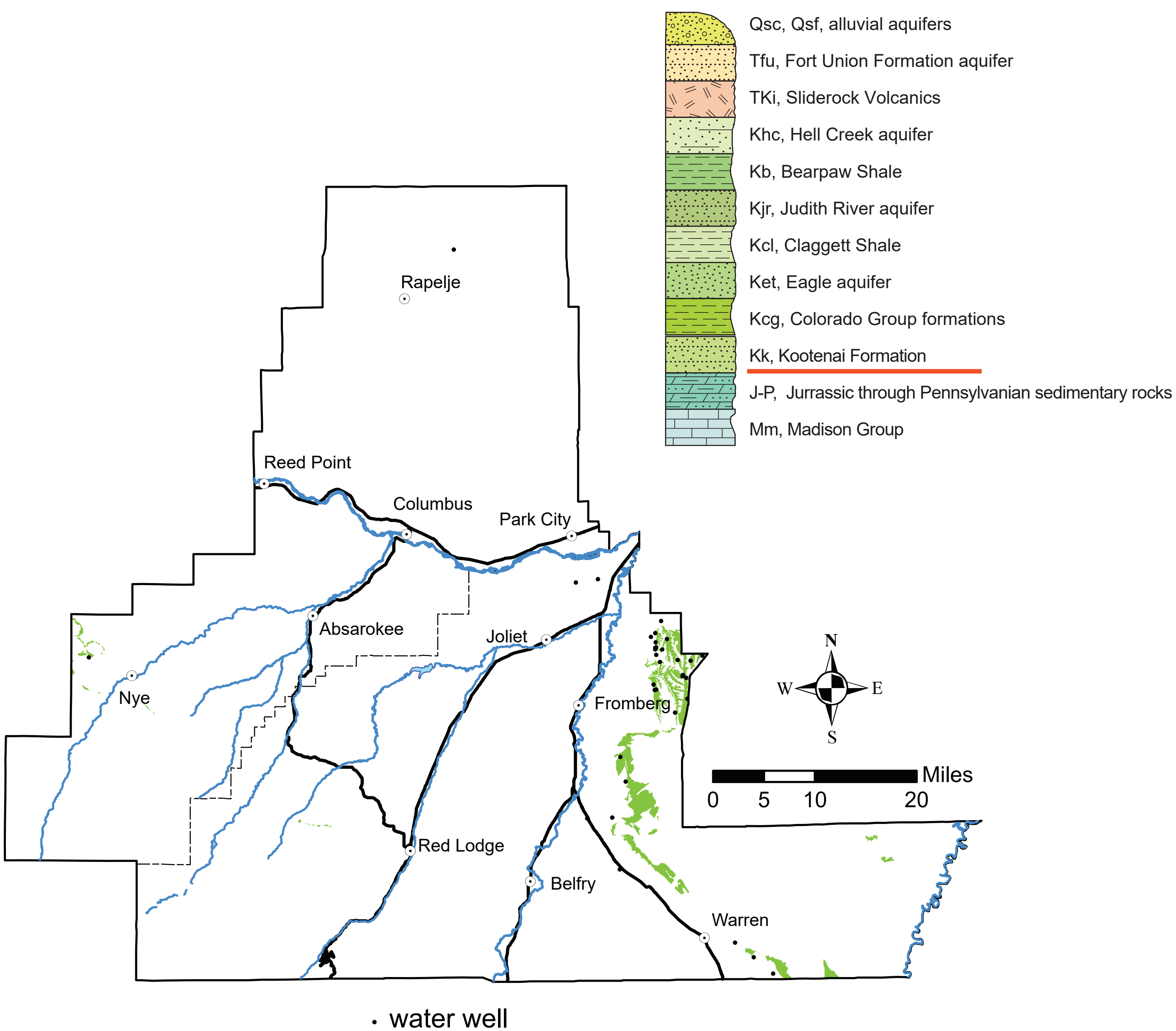

Figure 11. Distribution of wells in the Kootenai aquifer (Kk).

water to wells and springs along the western flank of the Pryor Mountains. These units range from Jurassic to Pennsylvanian in age and are combined in this framework as a single hydrogeologic unit (J-P) (fig. 12). The Morrison Formation, a mudstone with some sandy interbeds, is about 300 ft thick and marks the uppermost part of the J-P unit; it confines the underlying aquifers. Water-bearing sandstones and limestones occur in the Ellis Group, the Chugwater Formation, and the Tensleep Sandstone. The Amsden Formation, composed of a distinctive red mudstone, limestone, and siltstone, marks the base of the J-P unit.

Records of 39 wells completed in the J-P unit, including two industrial wells that are reportedly about 3,600 ft deep, have a median well depth of 230 ft (fig. 4). Well yields are recorded for 27 of these wells, and one irrigation well reportedly yields 3,720 gpm. Most wells yield between 10 and 30 gpm, with a median of 20 gpm (fig. 5).

Madison Limestone (Mm)

The Mississippian Madison Limestone is exposed in the core of the Pryor Mountains and dips westward into the Big Horn Basin (fig. 13). It is overlain by the Amsden Formation and composed of a light brownish gray dolomitic limestone about 800 to 1,000 ft thick (Lopez, 2000c). The Madison aquifer is characterized by secondary permeability attributed to solution-enhanced fractures, and joints; collapse features and caves distinguish the upper portion of the aquifer (Darlinton, 1969). Although relatively few wells are

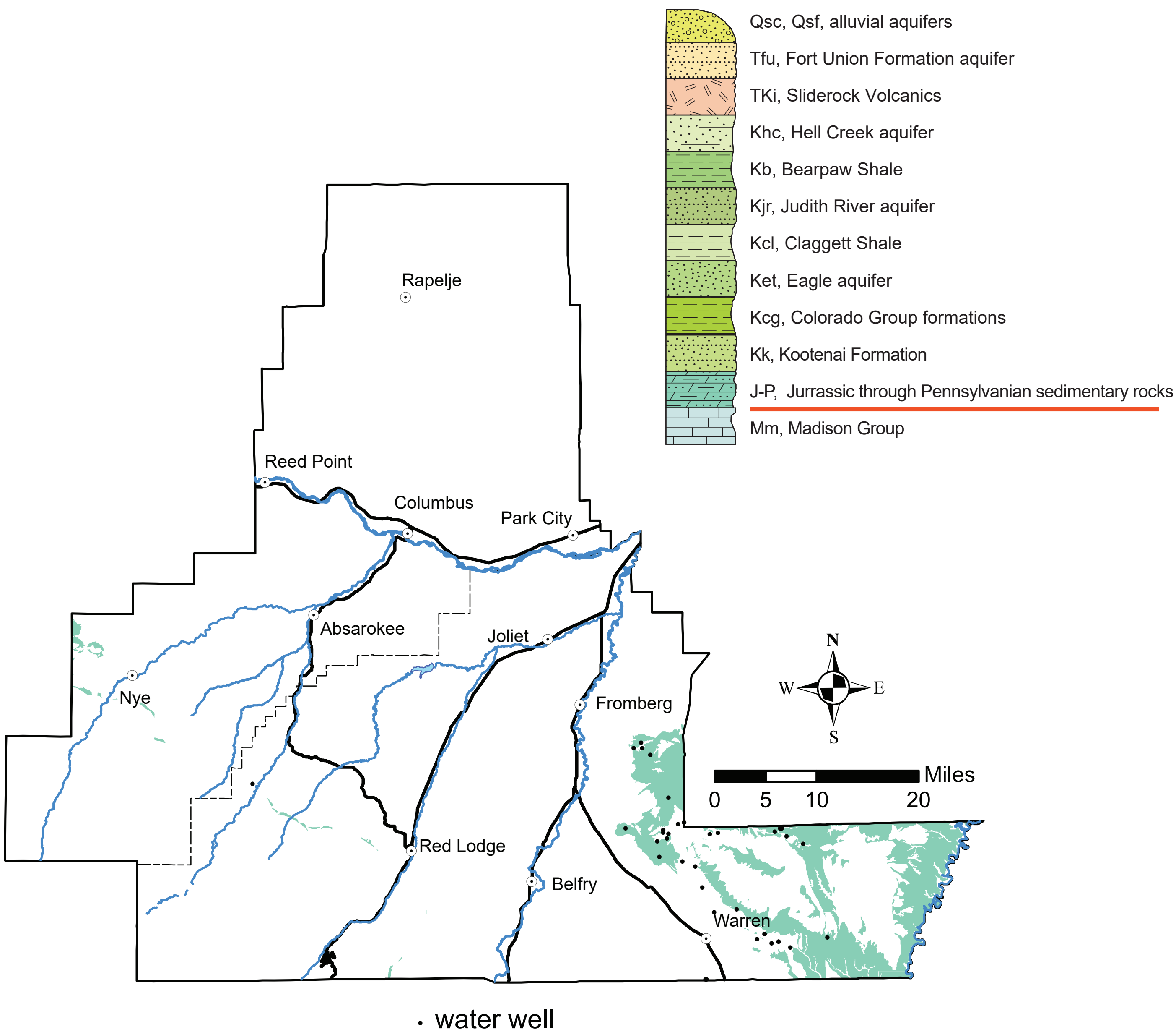

Figure 12. Distribution of wells in the Jurassic–Pennsylvanian aquifer system (J-P).

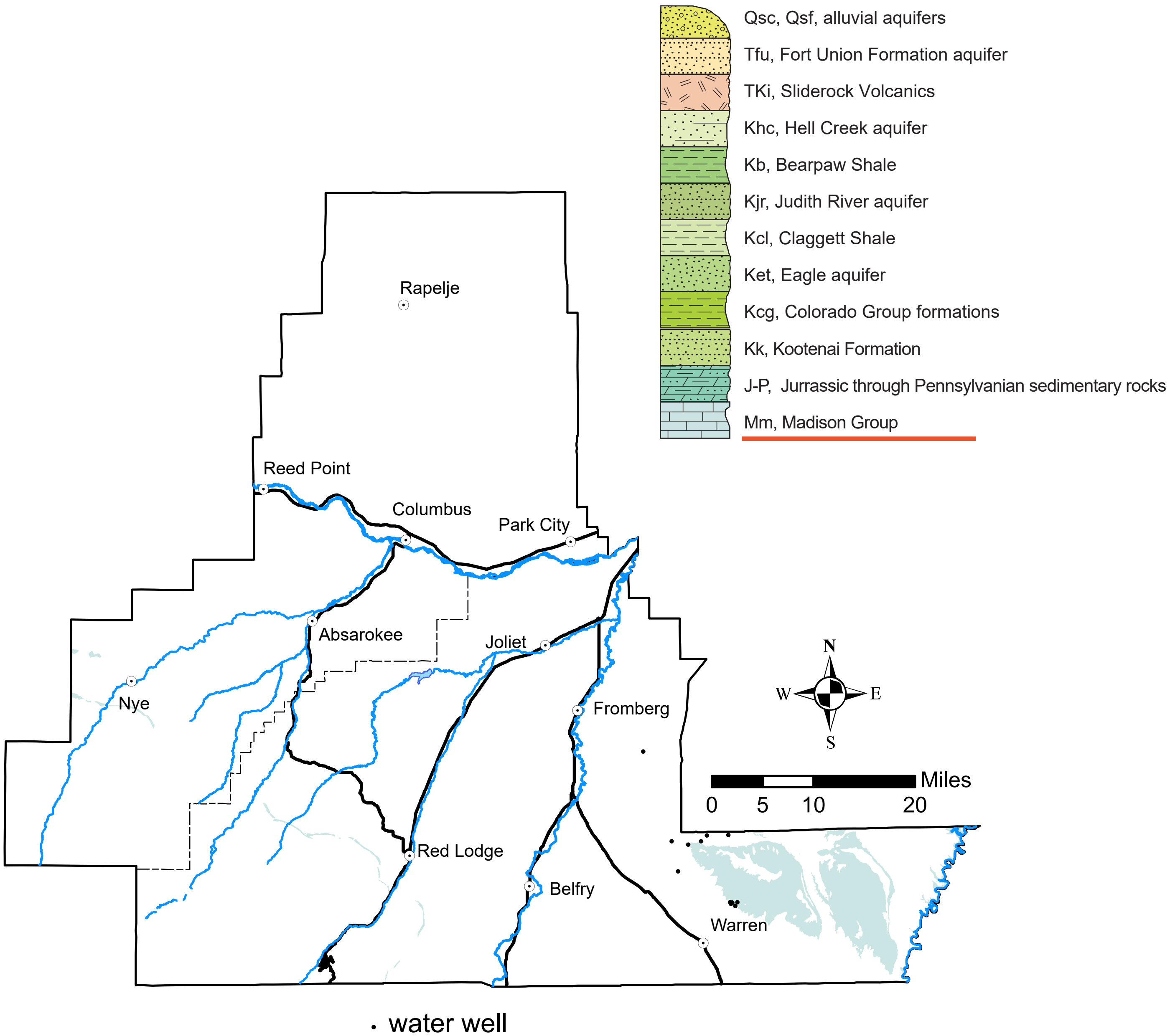

Figure 13. Distribution of wells in the Madison Limestone aquifer (Mm).

completed in the aquifer, it is the source of several large springs in the Pryor Mountains area.

Based on records of 18 wells completed in the Madison, well depths range up to 2,800 ft (fig. 4), with a median of 290 ft. Two irrigation wells have reported yields 2,300 gpm; however, the median reported yield is 20 gpm (fig. 5).

Other Water-Bearing Units

In some areas, thin sandy layers within Cretaceous shale units produce water to wells; the yields are generally low and the water mineralized. These units include the Bearpaw Shale, Claggett Shale, and Colorado Group Shale Formations (fig. 14); although these units are stratigraphically distinct, the discussion of well characteristics is grouped below and shown as Kshale in figures 4 and 5.

The Bearpaw (Kb) Shale forms a series of westward-thinning wedges of fine-grained sediments. The dark gray to black shale contains bentonitic clay beds. Sandstone interbeds (<10 ft) occur locally and may yield water to wells. Well reports indicate that less than 2 percent of wells are completed in the Bearpaw Shale. The Judith River Formation separates the Bearpaw from the underlying Claggett Shale.

In the study area, the Claggett Shale (Kcl) consists of 100–300 ft of brownish gray, thin-bedded, fissile

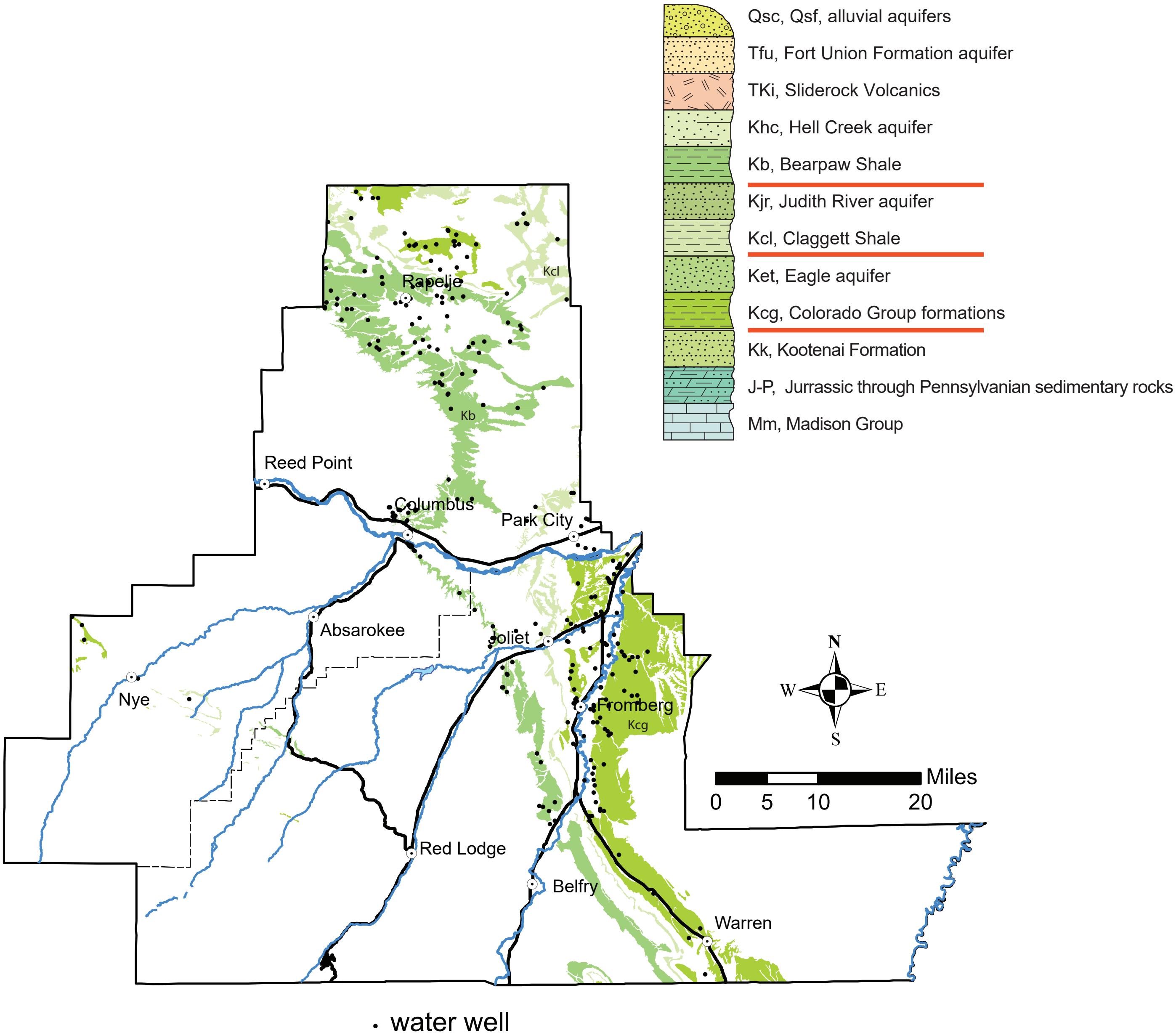

Figure 14. Distribution of wells in the Cretaceous shale units, includes the Bearpaw Shale (Kb), the Claggett Shale (Kcl), and the Colorado Groups Formations (Kco).

shale with zones of calcareous concretions and bentonite beds. Near its top, there may be sandstones transitional to the overlying Judith River Formation (Lopez, 2000c); however, the Claggett is generally a confining unit. Less than 1 percent of the wells in the area are completed in the Claggett Shale. The Eagle–Telegraph Creek Formations separate the Claggett from the underlying Colorado Group shales.

The Colorado Group (Kcg) consists of seven regionally extensive shale-dominated formations that underlie the Telegraph Creek Formation. In descending order, these include the Niobrara Shale, Carlisle Shale, Greenhorn Formation, Frontier Formation, Belle Fourche Shale, Mowry Shale, and Thermopolis Shale. Together, these units are about 2,600–2,800 ft thick (Lopez, 2000c). These shales are generally confining units, and less than 1 percent of the wells in the area are completed in the Colorado Group.

Grouping together these Cretaceous shale units, reported well depths range up to 310 ft with a median value of 110 ft (fig. 4). Yields range up to 30 gpm with a median yield of 7 gpm (fig. 5).

East of Absarokee, wells completed in Cretaceous Sliderock (TKi) volcanics yield water from fractures (fig. 15). The volcanic rocks of the Sliderock stratovolcano occur locally near Absarokee and Nye in Stillwater County. These rocks are resistant to weathering

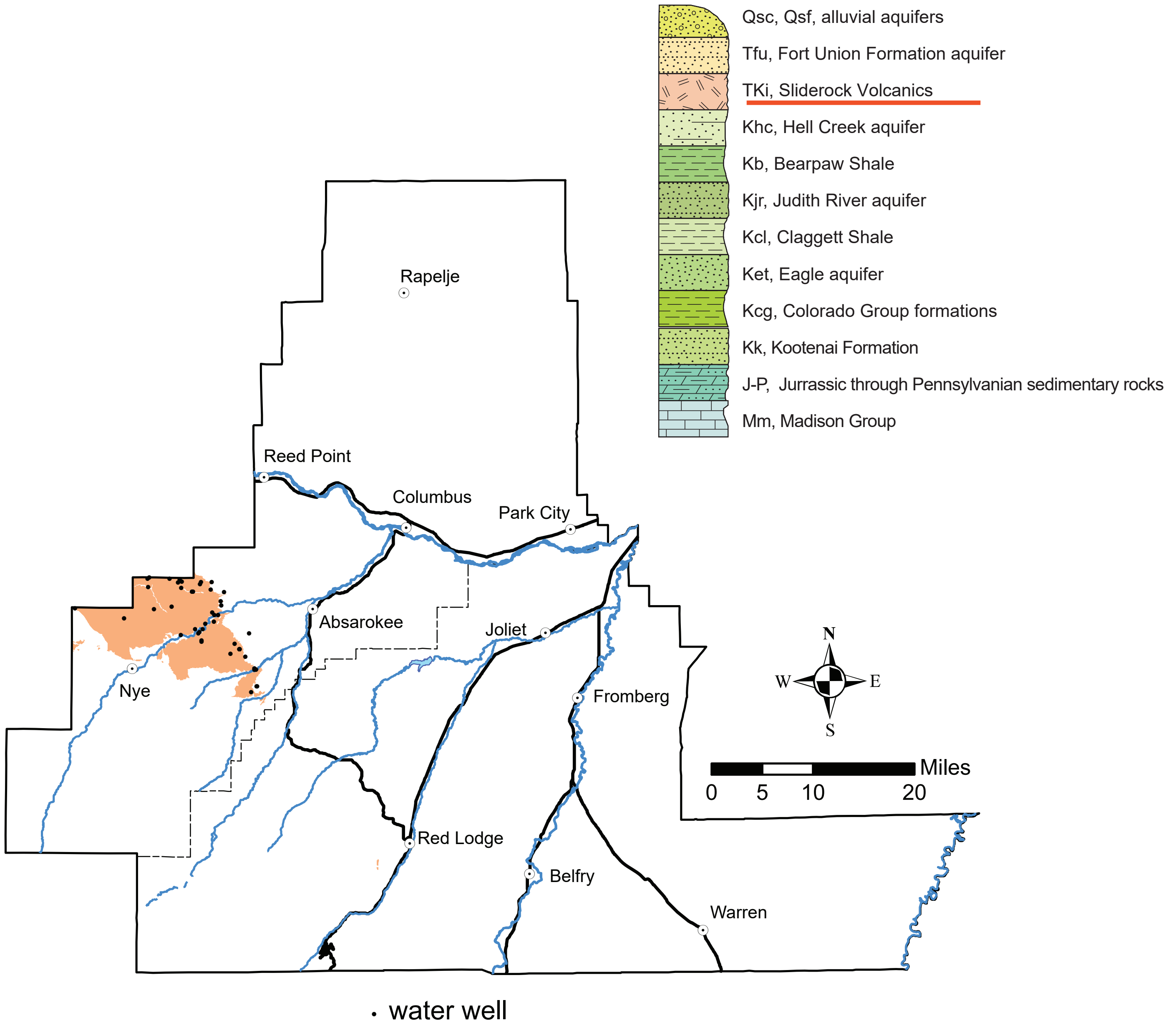

Figure 15. Distribution of wells in the Sliderock Volcanic aquifer (TKi).

and generally cliff-forming. Well depths and yields are variable and can change over short distances, reflecting the variable fracture permeability. Less than one percent of wells are completed in the local Sliderock volcanics (fig. 2). Total depths range from about 38 to 300 ft with a median value of 110 ft (fig. 4). Yields range from 0.5 to 60 gpm with a median of 20 gpm (fig. 5).

MAP USE AND LIMITATIONS

Descriptions of aquifers and confining units are based on the mapped geology and characteristics of water wells producing from these units as reported on drillers' logs. Some errors may exist due to variations in the quality and precision of driller-reported data. However, the large number of well records in this study area support the reliability of information on well and aquifer characteristics presented here.

Water well and borehole records are continuously updated in GWIC. The records shown in this map largely reflect the GWIC database on December 15, 2019. Current water well information can be accessed to supplement the data shown here at: http//mbmgg-wic.mtech.edu.

ACKNOWLEDGMENTS

Special appreciation is expressed to the landowners who allowed MBMG researchers to collect site information and sample their wells; reviews by Jon

Reiten, Ronald Breitmeyer, Tom Osborne, and Bob Bergantino greatly improved the readability and clarity of the text and figures. Map production and layout assisted by the help and direction of Susan Smith and Susan Barth.

REFERENCES

Berg, R.B., Lonn, J.D., and Locke, W.W., 1999, Geologic map of the Gardiner 30’ x 60’ quadrangle, south-central Montana: Montana Bureau of Mines and Geology Open-File Report 387, 9 p., 2 sheets, scale 1:100,000.

Blythe, D.D., and Reiten, J.C., 2015, Shallow groundwater altitude in bedrock units of the Carbon–Stillwater Study, Carbon and Stillwater Counties, Montana: Montana Bureau of Mines and Geology Montana Ground-Water Assessment Atlas 6-03, 1 sheet.

Cannon, M.R., and Johnson, D.R., 2004, Estimated water use in Montana in 2000: U.S. Geological Survey Scientific Investigations Report 2004-5223, 50 p.

Carstarphen, C.A., and Smith, L.N., 2007, Data for sites visited during the Carbon-Stillwater groundwater characterization study: Montana Bureau of Mines and Geology Montana Ground-Water Assessment Atlas 6-01, 1 sheet, scale 1:250,000.

Carstarphen, C., Patton, T., and LaFave, J.I., 2014, Water levels in the Upper West Bench alluvial aquifer, Red Lodge, Montana: Montana Bureau of Mines and Geology Information Pamphlet 8, 8 p.

Cherven, V.B., and Jacob, A.F., 1985, Evolution of Paleogene depositional systems, Williston Basin, in response to global sea level changes, in Flores, R.M., and Kaplan, S.S., eds., Cenozoic paleogeography of west-central United States: Denver, Colo., Rocky Mountain Section of SEPM, v. 3, p. 127–170.

Darlinton, E.V., 1969, Groundwater Inventory, Carbon County, Montana: Helena, Montana Water Resources Board, 40 p.

Exum, F.A., and George, G.R., eds., 1975, Geology and mineral resources of the Bighorn Basin: Casper, Wyoming Geological Association 27th Annual Field Conference Guidebook, 302 p.

Feltis, R.D., 1982a, Map showing total thickness of the Fox Hills–Lower Hell Creek Aquifer, Montana: U.S. Geological Survey Water-Resources Investigations 82-4042, scale 1:1,000,000.

Feltis, R.D., 1982b, Map showing total thickness of the Judith River Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4028, scale 1:1,000,000.

Feltis, R.D., 1982c, Map showing total thickness of the Eagle Sandstone and Telegraph Creek Formation, Montana: U.S. Geological Survey Water-Resources Investigations 82-4033, scale 1:1,000,000.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey map prepared in cooperation with the Physiographic Commission: U.S. Geological Survey, 1 sheet, scale 1:7,000,00,000.

Flueckinger, L.A., 1970, Stratigraphy, petrography, and origin of Tertiary sediments off of the front of the Beartooth Mountains, Montana–Wyoming: State College, Pa., Pennsylvania State University, Ph.D. dissertation, 249 p.

Foose, R.M., Wise, D.U., and Garbarini, G.S., 1961, Structural geology of the Beartooth Mountains, Montana and Wyoming: Geological Society of America Bulletin, v. 72, p. 1143–1172.

Fox, J.E., 1993, Stratigraphic cross sections showing electric logs of Upper Cretaceous and older rocks, Powder River basin, southeastern Montana and northeastern Wyoming: U.S. Geological Survey Oil and Gas Investigations Chart, OC-135 to OC-138, 4 sheets, Sections A–A’ through F–F’; G–G’ through L–L’; M–M’ through R–R’; S–S’ through V–V’.

Gill, J.R., and Cobban, W.A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: U.S. Geological Survey Professional Paper 776, 37 p.

Jobling, J.L., 1974, Stratigraphy, petrography, and structure of the Laramide (Paleocene) sediments marginal to the Beartooth Mountains, Montana: State College, Pa., Pennsylvania State University, Ph.D. dissertation, 102 p.

Knappen, R.S., and Moulton, G.F., 1931, Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone and Stillwater Counties, Montana: U.S. Geological Survey Bulletin 822-A, 70 p.

Lopez, D.A., 2000a, Geologic map of the Big Timber 30’ x 60’ quadrangle, south-central Montana: Montana Bureau of Mines and Geology Open-File Report 405, 1 sheet, scale 1:100,000.

Lopez, D.A., 2000b, Geologic map of the Billings 30’ x 60’ quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 59, 1 sheet, scale 1:100,000.

Lopez, D.A., 2000c, Geologic map of the Bridger 30’ x 60’ quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 58, 1 sheet, scale 1:100,000.

Lopez, D.A., 2001, Preliminary geologic map of the Red Lodge 30’ x 60’ quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Open-File Report 423, 1 sheet, scale 1:100,000.

Lopez, D.A., 2005, Geologic map of the Red Lodge area, Carbon County, Montana: Montana Bureau of Mines and Geology Open-File Report 524, 15 p., 1 sheet, scale 1:48,000.

Montana Board of Oil and Gas Conservation, Montana Department of Natural Resource and Conservation, 2015, http://www.bogc.dnrc.mt.gov/WebApps/DataMiner/ [Accessed December 2015].

Montana Bureau of Mines and Geology, 2019, Ground Water Information Center: http://mbmggwic.mtech.edu/ [Accessed December 2019].

Montana Climate Office, 2019, https://climate.umt.edu/atlas/precipitation/default.php [Accessed May 2019].

Montana Department of Commerce Census and Economic Information Center, 2014, http://ceic.mt.gov/Population/PopProjections_AllCountiesPage.aspx [Accessed January 3, 2014].

Ritter, D.F., 1967, Terrace development along the front of the Beartooth Mountains, southern Montana: Geological Society of America Bulletin, v. 78, p. 467–484.

Wilde, E.M., and Porter, K.W., 2000, Geologic map of the Roundup 30’ x 60’ quadrangle, central Montana: Montana Bureau of Mines and Geology Open-File Report 404, 14 p., 1 sheet, scale 1:100,000.

Wilde, E.M., and Porter, K.W., 2001, Geologic map of the Harlowton 30’ x 60’ quadrangle, eastern Montana: Montana Bureau of Mines and Geology Open-File Report 434, 1 sheet, scale 1:100,000.

Wise, D.U., 2000, Laramide Structures in basement and cover of the Beartooth Uplift near Red Lodge, Montana: AAPG Bulletin, v. 84, no. 3, p. 360–375, doi: https://doi.org/10.1306/C9EBCDF1-1735-11D7-8645000102C1865D