Chapter 4

Geologic overview

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The Northeast River Basins (NERB) study area covers approximately 14.86 million acres in northeastern Wyoming, southeastern Montana, western South Dakota, and western Nebraska. The geologic setting of the NERB includes Precambrian-cored uplifts formed during the Laramide orogeny and adjacent basins filled with Phanerozoic clastic and carbonate rocks. The following information regarding the NERB study area is provided in this chapter:

- An overview of the geologic history
- A summary of the structural geology
- An outline of significant mineral and energy resources
- Geologic cross sections

4.1 GENERAL GEOLOGIC HISTORY

During the Paleozoic Era, the area that is now the NERB was located on the western margin of the North American craton in a shelfal environment. Although there is some evidence of minor movement along zones of weakness within the cratonic basement (Slack, 1981; Maughan and Perry, 1986; Dolton and others, 1990), the region was tectonically stable and only underwent minor deformation in the form of gentle upwarping and subtle depressions.

Sediments deposited during the Paleozoic Era indicate episodic sea level shifts along the edge of the craton. Consequently, Paleozoic rocks in the NERB range from terrestrial and near-shore marine sandstones to marine shales and carbonates. Episodic late Paleozoic uplift events associated with the formation of the Ancestral Rocky Mountains to the south further influenced deposition of sediments across Wyoming (Maughan, 1993).

In the early Mesozoic Era, sea level fluctuations continued to be a major control on sediment deposition. During most of the Triassic Period, the NERB was a coastal plain environment where deposition of red beds occurred and are now observed, particularly in the Chugwater Group (Spearfish Formation Equivalent; Cavaroc and Flores, 1991).

As the Sevier orogeny began uplifting sedimentary cover rocks to form the mountain ranges of present-day western Wyoming (Royse, 1993), the NERB area was submerged in the Cretaceous Interior Seaway. A thick succession of shales with interbedded sandstone, siltstone, and limestone were deposited, indicating numerous sea level fluctuations until the final retreat of the seaway in the Late Cretaceous.

The Laramide orogeny commenced in the Late Cretaceous and continued through the Early Eocene. Crustal shortening was accommodated by displacement of Precambrian crystalline basement rocks and the overlying sedimentary cover rocks (Brown, 1993). Basement-cored Laramide structures border the NERB on three sides: 1) the Bighorn Mountains to the west, 2) the Black Hills to the east, and 3) the Rattlesnake Hills and Hartville Uplift to the south (fig. 4-1).

The geologic setting of the NERB study area is illustrated on the bedrock geologic map in plate 1. This map also displays surface water, highways, political boundaries, and state and county data. Inset maps on plate 1 show the distribution of lineaments and a structure-contour map of the top of the Precambrian basement. Nine cross sections show subsurface structure in the NERB (figs. 4-2 through 4-11). Descriptions of the Precambrian- through Tertiary-aged stratigraphic units exposed in the study area are included in appendix A, and are not addressed specifically in this chapter.

4.2 STRUCTURAL GEOLOGY

The NERB study area includes the Powder River Basin, the easternmost edge of the Wind River Basin, and the northernmost tip of the Denver-Julesburg Basin. Significant uplift structures that bound these basins are also a part of the study area. These include the Bighorn Mountains, Black Hills Uplift, Rattlesnake Hills, Casper Arch, and the Hartville Uplift (fig. 4-1). These and other significant structural features are discussed below.

4.2.1 Powder River Basin (PRB)

The Powder River Basin is an elongate, north-northwest-trending sedimentary and structural basin in northeastern Wyoming and southeastern Montana. The basin is bounded by Laramide Precambrian-cored uplifts on three sides: 1) the Bighorn Mountains to the west, 2) the Black Hills Uplift to the east, and 3) the Casper Arch and Hartville Uplift to the south (fig. 4-1). Reverse and thrust faults are present along the flanks of some of these uplifts, occasionally with a strike-slip offset component (Clarey, 2009). The geometry of the basin is asymmetric, with a steeply dipping to overturned western limb and a gently dipping eastern limb. The synclinal axis is positioned adjacent to the Bighorn Mountains near the western margin of the basin (Ver Ploeg and others, 2008). The maximum thickness of Phanerozoic rocks in the basin is 18,000 ft (Beikman, 1962).

4.2.2 Wind River Basin (WRB)

The Wind River Basin is a structural and sedimentary basin in central Wyoming. A portion of the eastern end of the northwest–southeast-trending basin is included in the NERB study area. Within the NERB, the WRB is bounded to the southwest by the Rattlesnake Hills and to the northeast by the Casper Arch and Bighorn Mountains (fig. 4-1). The basin formed during Laramide deformation as the trough subsided and mountains adjacent to the basin were uplifted. As the uplift structures began to erode, sediments were shed into the basin, resulting in the deposition of an 18,000-ft-thick sequence of Phanerozoic sediments, including fluvial and lacustrine sediments (Keefer, 1970).

4.2.3 Denver-Julesburg Basin (DJB)

The northernmost edge of the Denver-Julesburg Basin is included in the southeastern corner of the NERB study area (fig. 4-1). The DJB is a north-south-trending asymmetrical Laramide-aged basin that covers more than 70,000 mi^2 (180,000 km^2) in parts of Colorado, Wyoming, Kansas, and Nebraska. In the NERB, the DJB is bounded to the north by the Hartville Uplift. Most of the subterranean strata preserved in the DJB was deposited during the Laramide orogeny and is Cretaceous aged (Drake and others, 2014), however, most surface exposures in the basin are Tertiary, which in the NERB consists of the Arikaree Formation.

4.2.4 Bighorn Mountains

The Bighorn Mountains formed during the Laramide orogeny in the Rocky Mountain foreland (fig. 4-1). They are cored by Precambrian plutonic and metamorphic rocks that extend in an arcuate fashion from southcentral Montana to the northern margin of the Wind River Basin in central Wyoming. The Bighorn Mountains were thrust to the east and are flanked in the NERB study area by steeply dipping to overturned Paleozoic and Mesozoic sedimentary rocks on the east.

4.2.5 Hartville Uplift

The Hartville Uplift is a north–northeast-trending Laramide structural uplift along the southern margin of the NERB (fig. 4-1). It is superimposed upon and predates the Hartville Arch, which is a northeast-southwest-trending structure between the Powder River and Denver-Julesburg basins. Iron and copper are among the minerals mined in the Hartville mining district.

4.2.6 Black Hills

The Black Hills of Wyoming are the northwestern continuation of the Black Hills in South Dakota (fig. 4-1). It formed in the late stages of the Laramide orogeny by the intrusion of an alkaline igneous complex. The exposed basement consists of Precambrian igneous and metamorphic rocks, and is overlain by Paleozoic and Mesozoic clastic and carbonate rocks.

4.2.7 Casper Arch

The Casper Arch is bounded to the southwest by a west-southwest vergent, large-displacement foreland thrust fault that in the subsurface offsets Precambrian rocks above younger sedimentary rocks in the adjacent Wind River Basin (Skeen and Ray, 1983; fig. 4-1). Although it is an uplifted area, it is not uplifted significantly enough to form a mountain range with an exposed core of Precambrian rock. Upper Cretaceous marine shales are exposed at the center of the arch, with rocks as young as Paleocene exposed on its flanks.

4.2.8 Rattlesnake Hills

The Rattlesnake Hills are a Laramide uplift structure located along the southern margin of the Wind River Basin (fig. 4-1). They are a northwest-trending anticlinal structure in which the crystalline-cored fold is overlain by Phanerozoic rocks. Alkaline intrusive rocks are also exposed in the southern Rattlesnake Hills, and were emplaced after Laramide folding (Hoch and Frost, 1993). These exposures are not a part of the NERB study area, but are similar in age and structural setting, and share mineralogical and geochemical signatures with the alkaline igneous complex exposed in the Black Hills region of the NERB (Hoch and Frost, 1993).

4.2.9 Pine Ridge

Pine Ridge is a northwest–southeast-trending topographic high on the eastern margin of the Casper Arch (fig. 4-1). It serves as a hydrologic divide between the Powder River and Cheyenne River hydrologic basins. This area is part of the Powder River Basin uranium district.

4.2.10 Pumpkin Buttes

Pumpkin Buttes are a group of large, orange-colored Wasatch sandstone mesas in the central Powder River Basin that are overlain unconformably by a 30- to 50-ft-thick cap of White River Formation (Sharp and others, 1964; fig. 4-1). A significant uranium deposit was discovered here in 1951.

4.2.11 Red Hills

The Red Hills are clinker deposits that formed due to naturally burning coal beds (fig. 4-1). They have burned since at least the early Pliocene (Heffern and others, 2007). About 1,600 mi^2 (4,100 km^2) of the Powder River Basin is dominated by clinker-controlled topography, which forms resistant reddish layers that cap hills and buttes. In the Red Hills, exposures of the Tongue River Member of the Fort Union Formation are capped by resistant layers of clinker (Heffern and others, 2007).

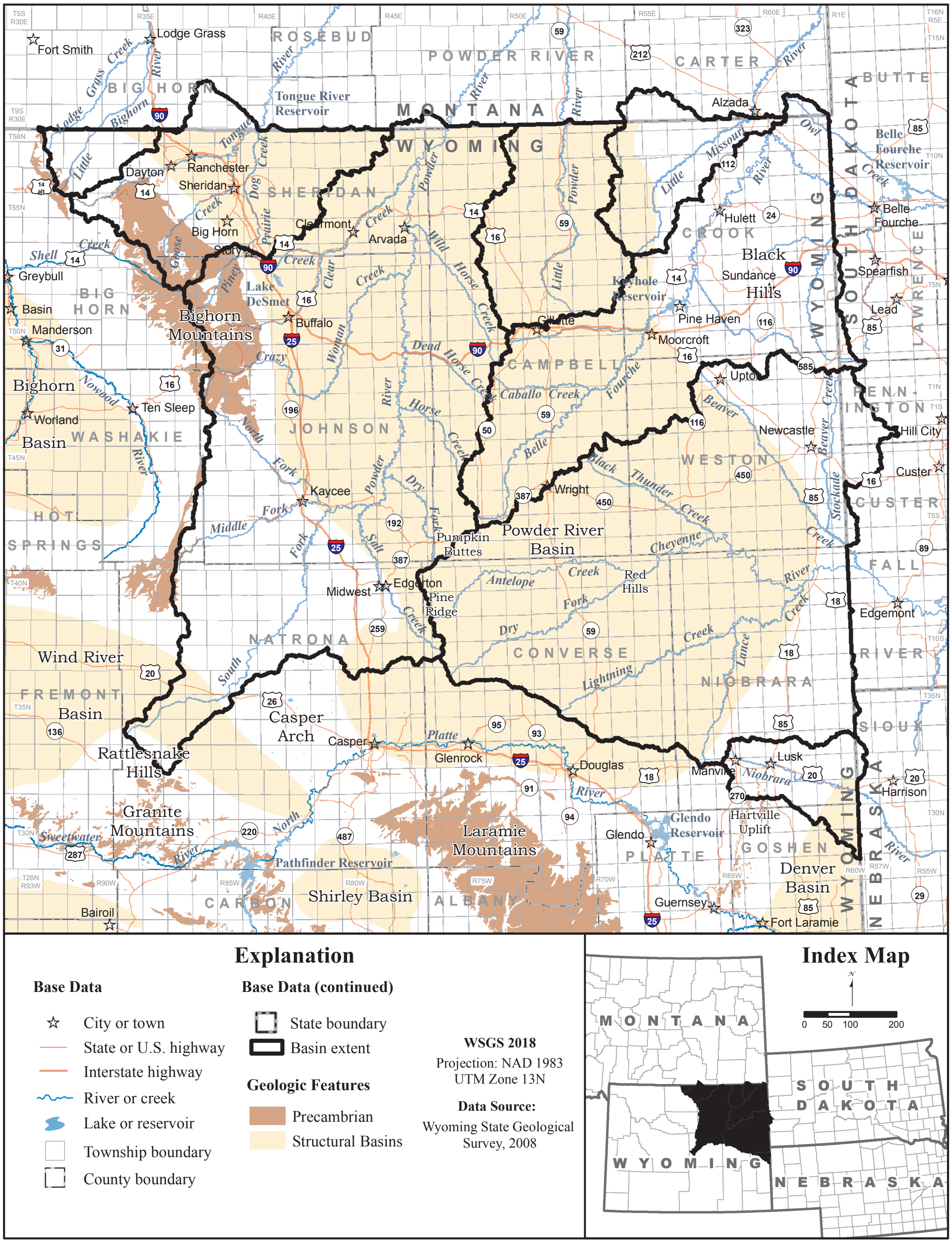


Figure 4-1. Geologic features in the NERB, Wyoming.

4.3 MINERAL AND ENERGY RESOURCES

The NERB is rich with various mineral and energy resources, including aggregate (clinker, limestone, and gravel), oil and gas (including coalbed methane), coal, gypsum, bentonite, and uranium (Harris and others, 1992). Iron and copper are mined in the Hartville mining district. Chapter 5 of this study identifies potential contamination sources related to the development of mineral and energy resources.

The most significant resources in the NERB are the near-surface coals mined in the Powder River Basin, which account for nearly half of all coal produced in the United States. Oil and gas, including coalbed natural gas, and uranium are also key resources in the NERB.

The following is a partial list of references that provide detailed information about the major mineral and energy resources in the NERB:

Powder River Basin

- Summary of mineral and energy resources in the Powder River Basin (Harris and others, 1992)
- Petroleum system assessment for the Powder River Basin (USGS, 2004; Anna, 2010)
- Uranium deposits in the Pumpkin Buttes area (Sharp and others, 1964)
- Coal geology and assessment of coal resources and reserves in the Powder River Basin (Luppens and others, 2015)

Wind River Basin

- Petroleum system assessment for the Wind River Basin (USGS, 2007)
- Mineral resources (Hausel and Holden, 1978)

Denver-Julesburg Basin

- Oil and gas in Denver-Julesburg Basin (USGS, 2007)

Black Hills

- Mineral resource potential (DeWitt and others, 1986)

4.4 GEOLOGIC CROSS SECTIONS

Plate 1 and fig. 4-2 show the locations of the geologic cross sections (figs. 4-3 through 4-11) provided in fold-out figures at the end of this chapter. The cross sections, adapted from USGS and WSGS studies, also illustrate the progression of stratigraphic nomenclature in northeastern Wyoming from the early 1900s until now. The WSGS digitized the original cross sections and added colors to the geologic units generally consistent with the Geologic Map of Wyoming (Love and Christiansen, 1985). Geographic extents within the NERB for individual cross sections are noted below:

Sections A-A', B-B', and C-C' (figs. 4-3 through 4-5) are from Lynds (2013). Section A-A' extends through the Tongue River and Powder River drainages. Section B-B' passes from the eastern Powder River drainage through the Little Powder River and Belle Fourche drainages. Section C-C' goes through the central part of the Powder River drainage.

Sections D-D', E-E', and F-F' (figs. 4-6 through 4-8) are by Darton (1906). Section D-D' goes from the crest of the Bighorn Mountains through the Little Bighorn River drainage into the Tongue River drainage. Sections E-E' and F-F' extend from the crest of the Bighorn Mountains into the Powder River drainage. Stratigraphy in theses sections does not match Love and others (1993). The Parkman, Piney, DeSmet and Kinsbury (sic) combined unit (Kpd) occupy an interval currently comprised of the Wasatch, Fort Union and Lance formations, and Foxhills Sandstone (Love and others, 1993). The "Colorado Shales" unit (Kc) refers to a stratigraphic interval that stretches from the Fall River Formation through the Niobrara Formation of Love and others (1993). The "Embar" Formation is an abandoned unit name, widely used in past oil exploration, that has been replaced by the Park City, Dinwoody, and parts of the Chugwater formations, and their stratigraphic equivalents (USGS Geolex, 2018).

Section G-G' (fig. 4-9), obtained from Keefer (1970), passes through a small part of the Wind River Structural Basin located in the Powder River drainage.

Section H-H' (fig. 4-10), from DeWitt and others (1989), extends from the crest of the Black Hills through the Belle Fourche drainage into the Little Missouri River drainage.

Section I-I' (fig. 4-11), from McLaughlin and others (2011), passes through southern parts of the Niobrara River drainage.

The maps and studies that contain the original cross sections are available on the USGS National Geologic Map Database (https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl) and the USGS Publications Warehouse website (https://pubs.er.usgs.gov/).

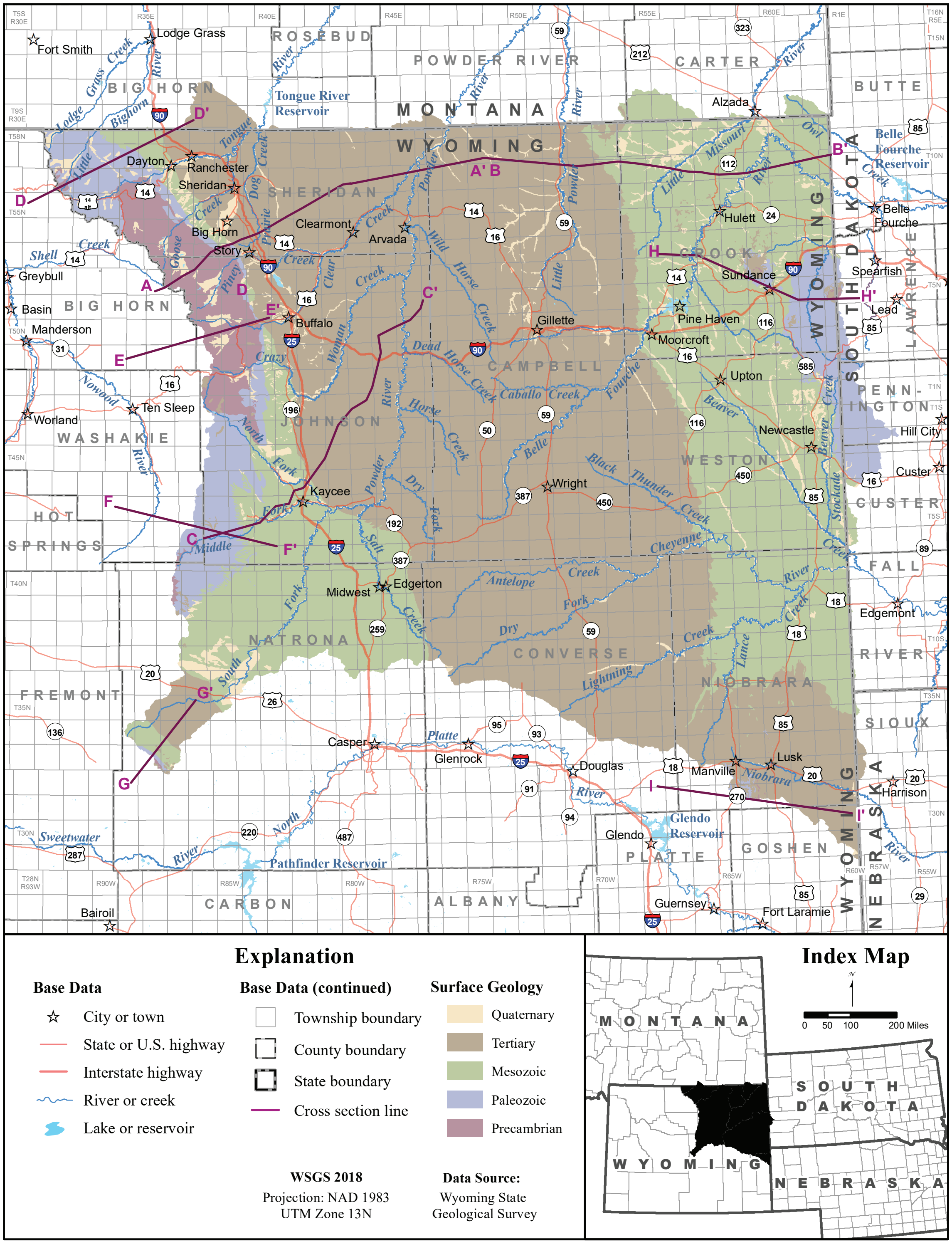
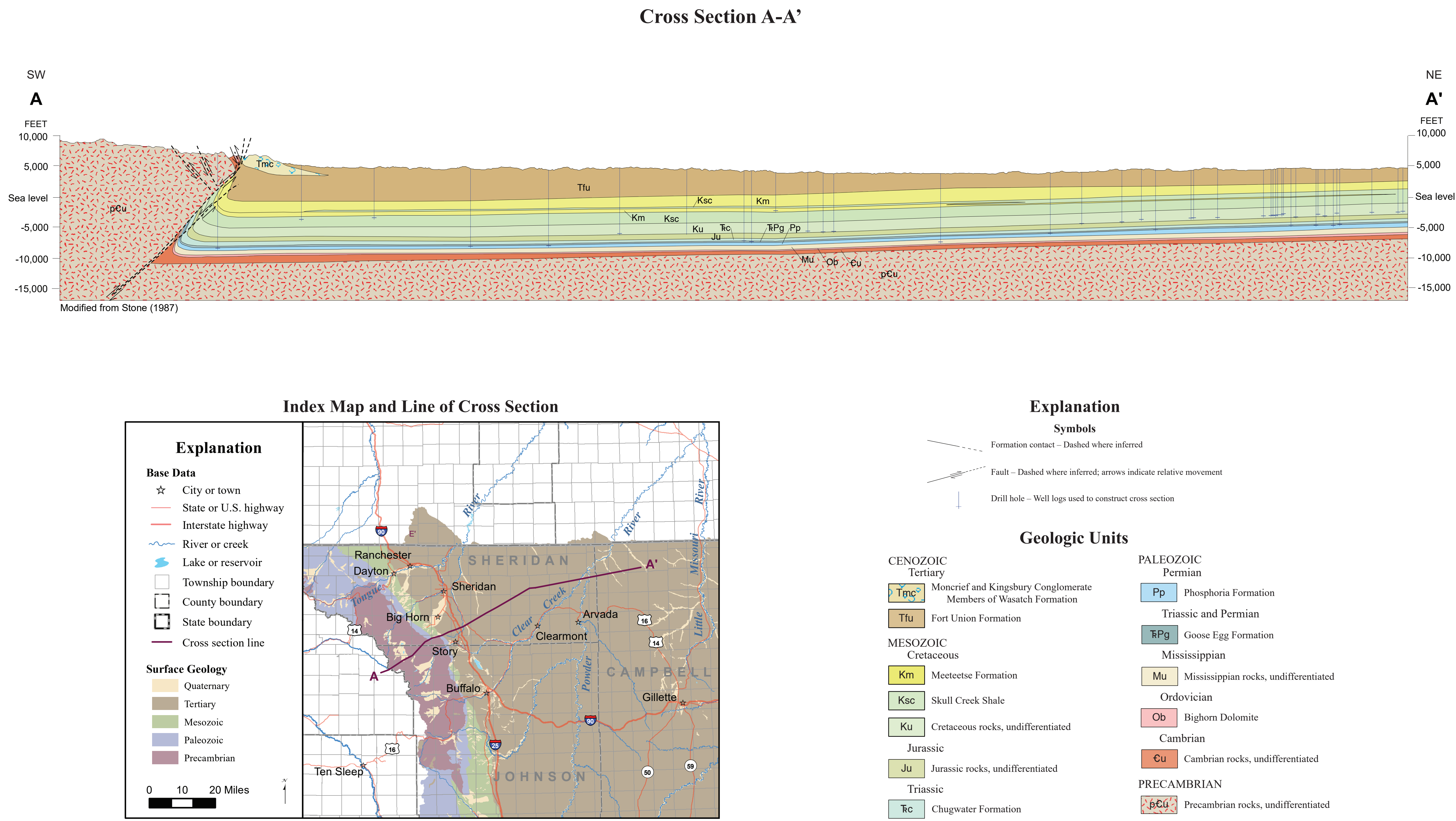


Figure 4-2. Locations of cross sections A-A' through I-I'.

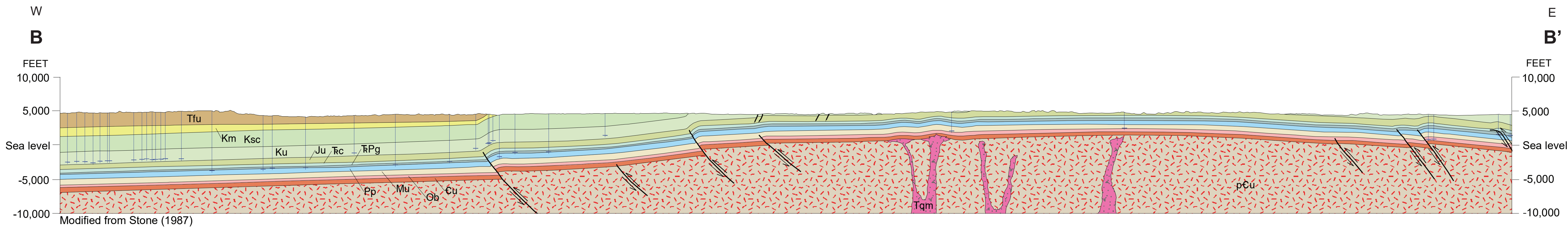


Adapted from:

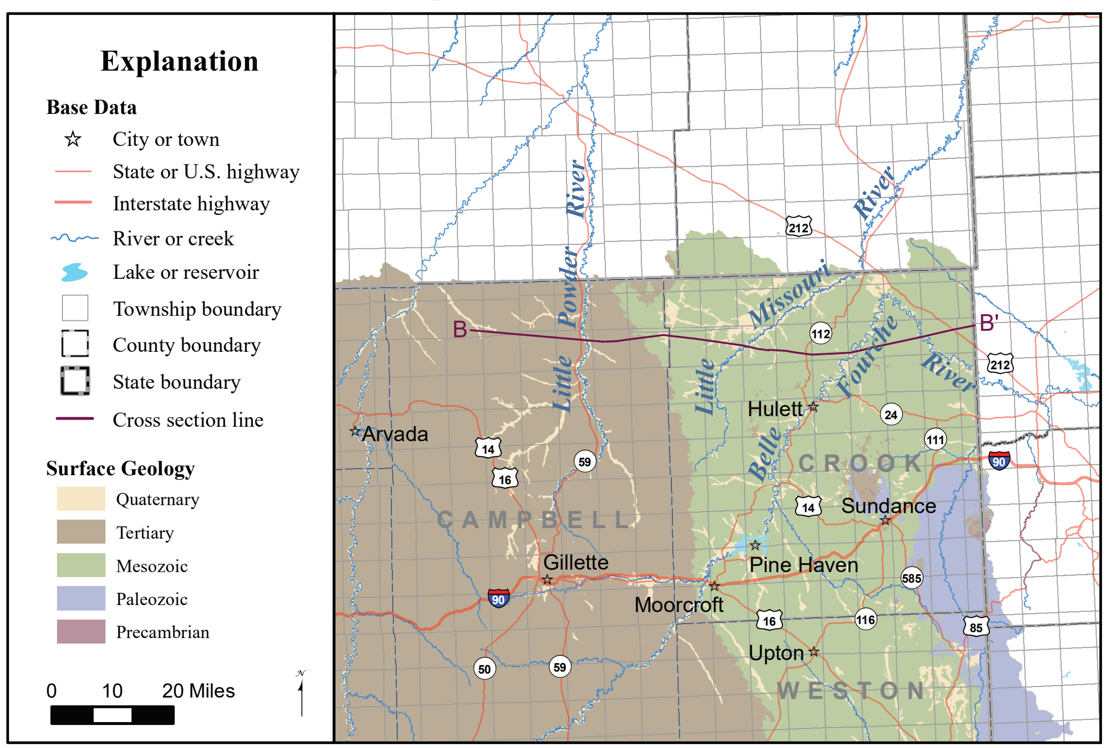
Lynds, R.M., 2013, Geologic storage assessment of carbon dioxide (CO_2) in the Laramide basins of Wyoming: Wyoming State Geological Survey Technical Memorandum 3, 200 p., 20 pls.

Figure 4-3. Geologic cross section A-A’.

Cross Section B-B’



Index Map and Line of Cross Section



Explanation

Symbols

Formation contact – Dashed where inferred

Fault – Dashed where inferred; arrows indicate relative movement

Drill hole – Well logs used to construct cross section

Geologic Units

CENOZOIC
Tertiary
- Tqm — Quartz monzanite intrusion
- Tfu — Fort Union Formation

MESOZOIC
Cretaceous
- Km — Meeteetse Formation
- Ksc — Skull Creek Shale
- Ku — Cretaceous rocks, undifferentiated

Jurassic
- Ju — Jurassic rocks, undifferentiated

Triassic
- Ʀc — Chugwater Formation

PALEOZOIC
Permian
- Pp — Phosphoria Formation

Triassic and Permian
- ƦPg — Goose Egg Formation

Mississippian
- Mu — Mississippian rocks, undifferentiated

Ordovician
- Ob — Bighorn Dolomite

Cambrian
- Ꞓu — Cambrian rocks, undifferentiated

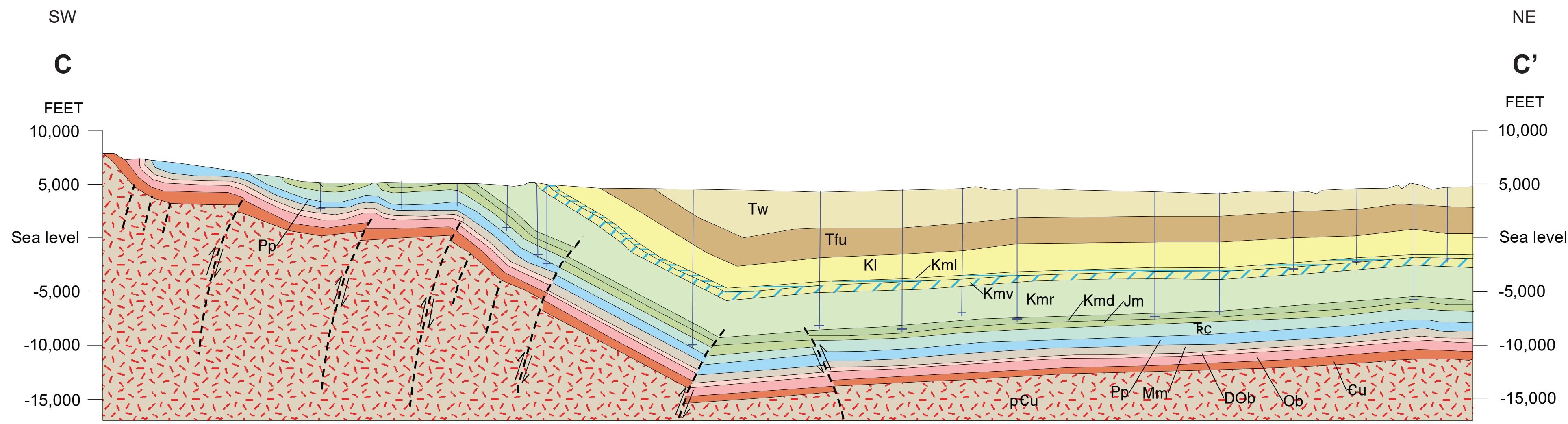
PRECAMBRIAN
- pꞒu — Precambrian rocks, undifferentiated

Figure 4-4. Geologic cross section B-B’.

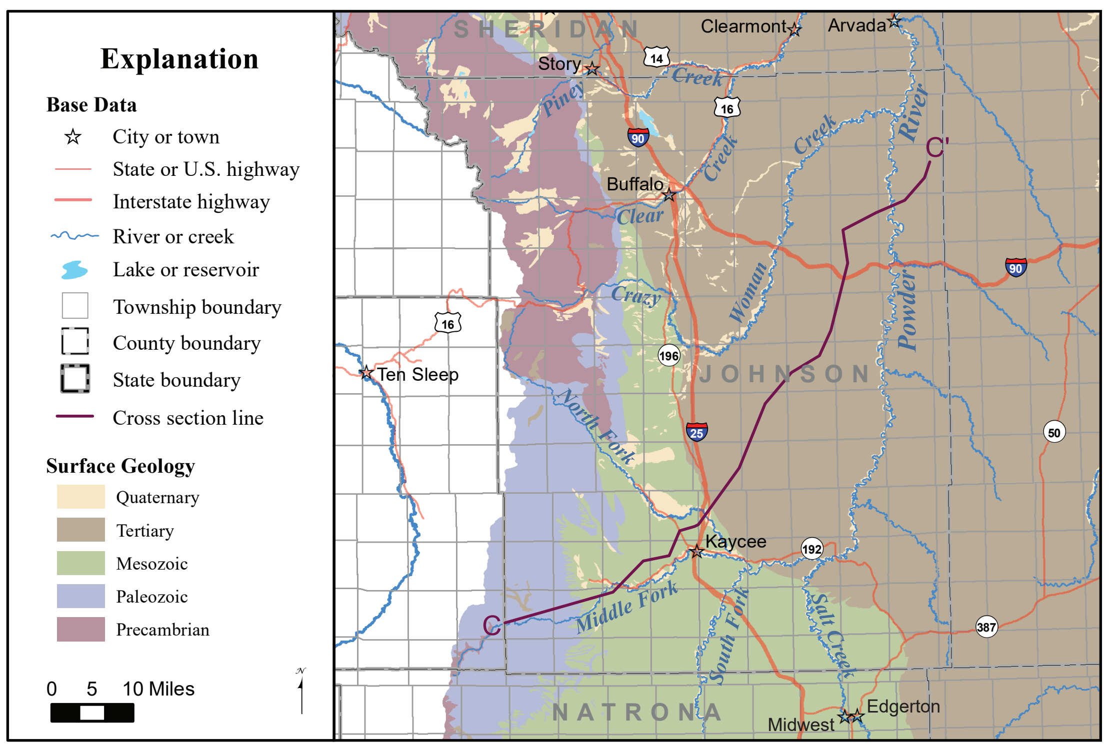
Adapted from:

Lynds, R.M., 2013, Geologic storage assessment of carbon dioxide (CO_2) in the Laramide basins of Wyoming: Wyoming State Geological Survey Technical Memorandum 3, 200 p., 20 pls.

Cross Section C-C’



Index Map and Line of Cross Section



Explanation

Symbols

Formation contact – Dashed where inferred

Fault – Dashed where inferred; arrows indicate relative movement

Drill hole – Well logs used to construct cross section

Geologic Units

CENOZOIC
Tertiary

- Tw — Wasatch Formation
- Tfu — Fort Union Formation

MESOZOIC
Cretaceous

- Kl — Lance Formation
- Kml — Lewis Shale
- Kmv — Mesaverde Formation
- Kmd — Muddy Sandstone
- Kmr — Mowry Shale

Jurassic

- Jm — Morrison Formation

Triassic

- Ꞅc — Chugwater Formation

PALEOZOIC
Permian

- Pp — Phosphoria Formation

Mississippian

- Mm — Madison Limestone

Devonian and Ordovician

- DOb — Devonian rocks and Bighorn Dolomite, undifferentiated

Ordovician

- Ob — Bighorn Dolomite

Cambrian

- Ꞓu — Cambrian rocks, undifferentiated

PRECAMBRIAN

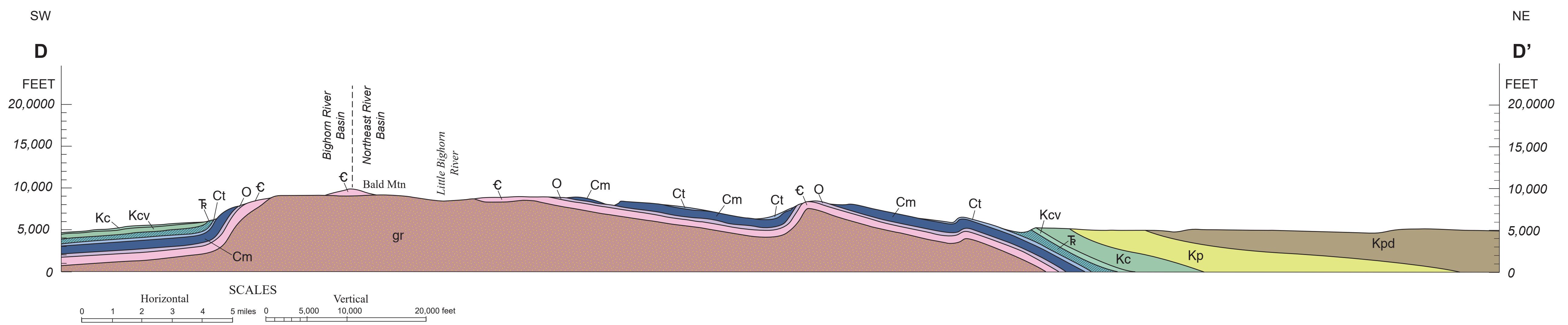
- pCu — Precambrian rocks, undifferentiated

Figure 4-5. Geologic cross section C-C’.

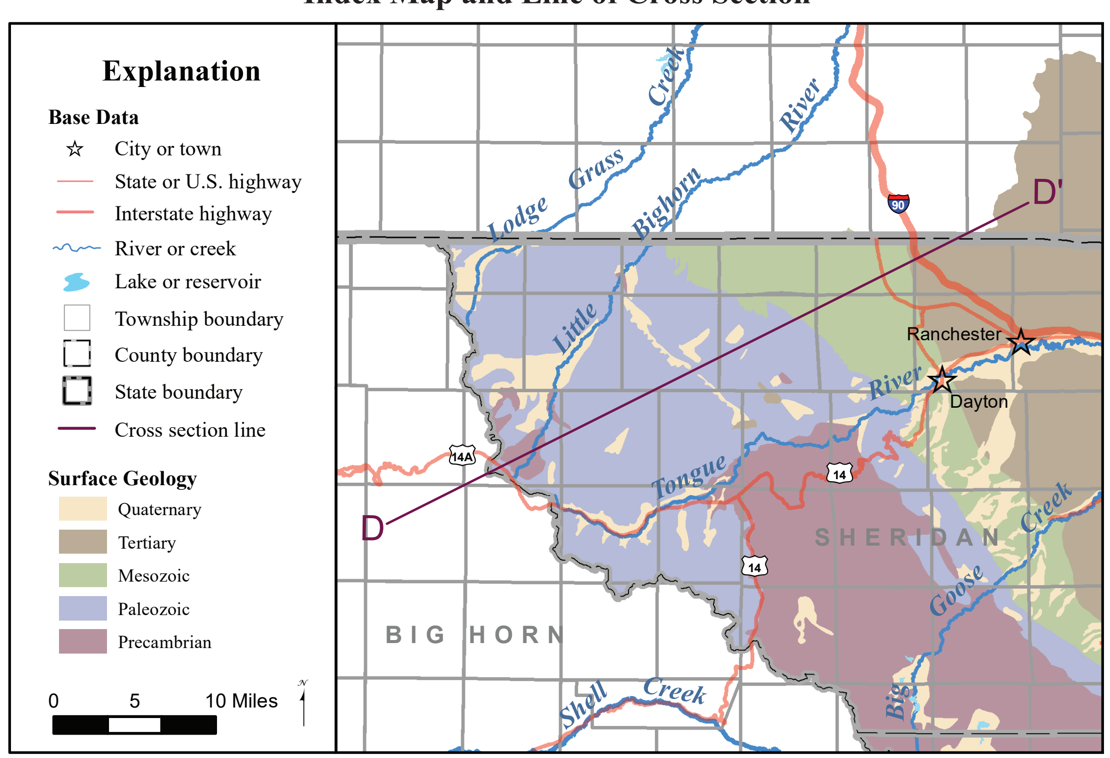
Adapted from:

Lynds, R.M., 2013, Geologic storage assessment of carbon dioxide (CO_2) in the Laramide basins of Wyoming: Wyoming State Geological Survey Technical Memorandum 3, 200 p., 20 pls.

Cross Section D-D’



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Geologic Units

CENOZOIC–MESOZOIC
Tertiary–Cretaceous

- Kpd — Parkman, Piney, and De Smet formations and Kinsbury Conglomerate

MESOZOIC
Cretaceous

- Kp — Pierre Shale
- Kc — Colorado shales

Cretaceous–Jurassic

- Kcv — Cloverly-Sundance formations

Triassic

- ₮ — Chugwater red beds

PALEOZOIC
Permian–Cambrian

- Ct — Tensleep, Embar, and Amsden formations
- Cm — Madison Limestone
- O — Bighorn Dolomite
- Є — Deadwood Formation

PRECAMBRIAN

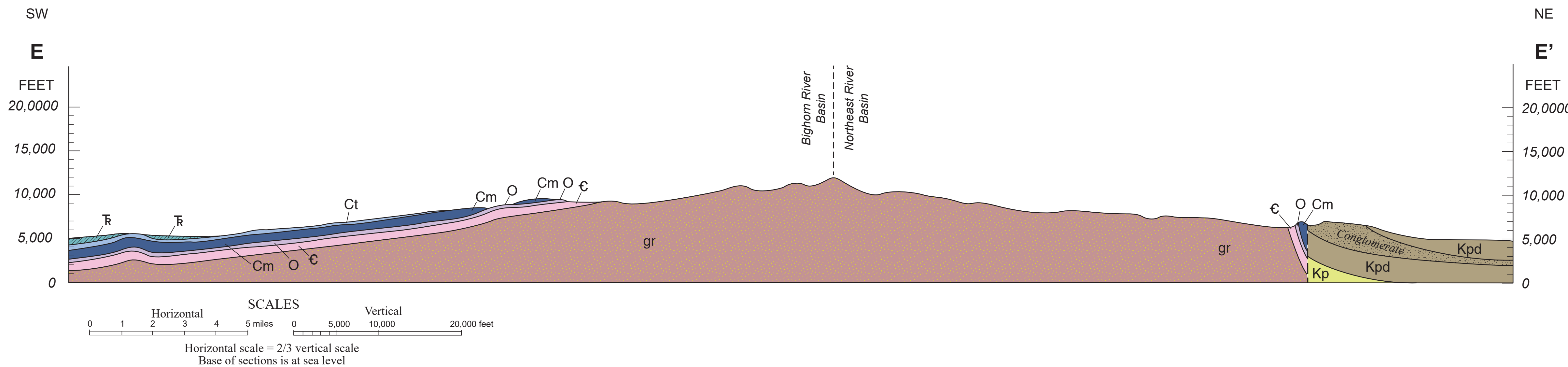
- gr — Granite

Figure 4-6. Geologic cross section D-D’. Stratigraphy does not match Love and others (1993)

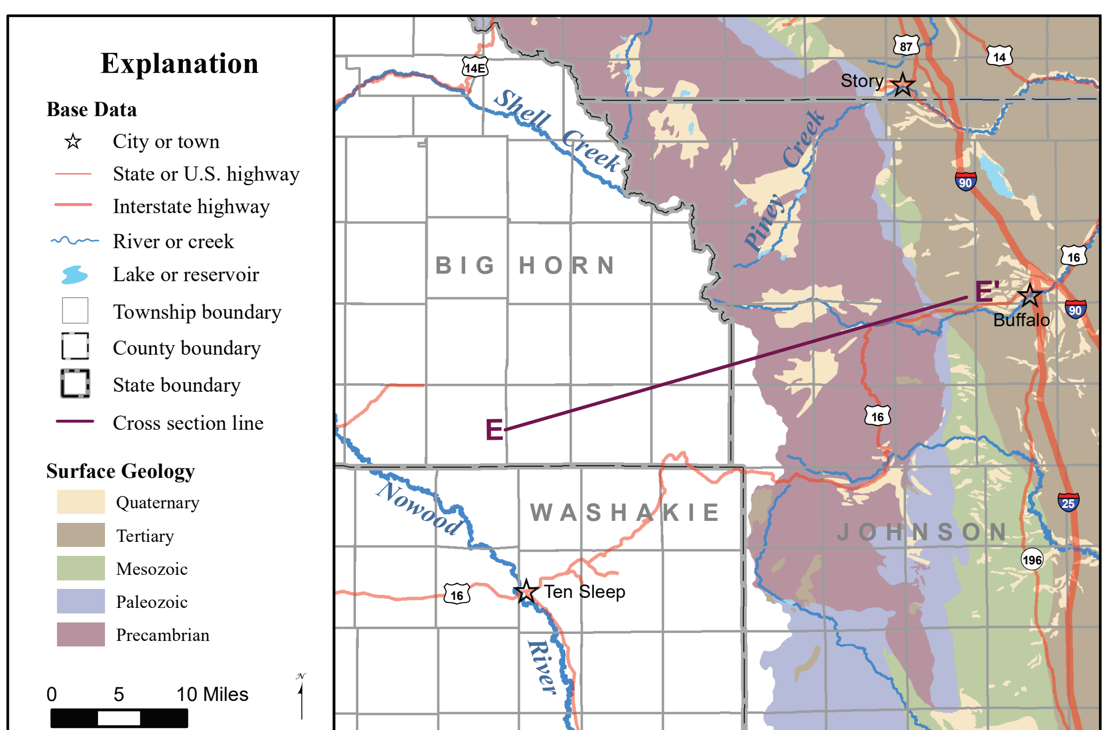
Adapted from:

Darton, N.H., 1906, Geology of the Bighorn Mountains: U.S. Geological Survey Professional Paper 51, 129 p., 5 maps, scale 1:125,000.

Cross Section E-E’



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Fault-dashed where approximately located

Geologic Units

CENOZOIC–MESOZOIC
Tertiary–Cretaceous

Kpd — Parkman, Piney, and De Smet formations and Kinsbury Conglomerate

MESOZOIC
Cretaceous

Kp — Pierre Shale

Triassic

₮ — Chugwater red beds

PALEOZOIC
Permian–Cambrian

Ct — Tensleep, Embar, and Amsden formations

Cm — Madison Limestone

O — Bighorn Dolomite

€ — Deadwood Formation

PRECAMBRIAN

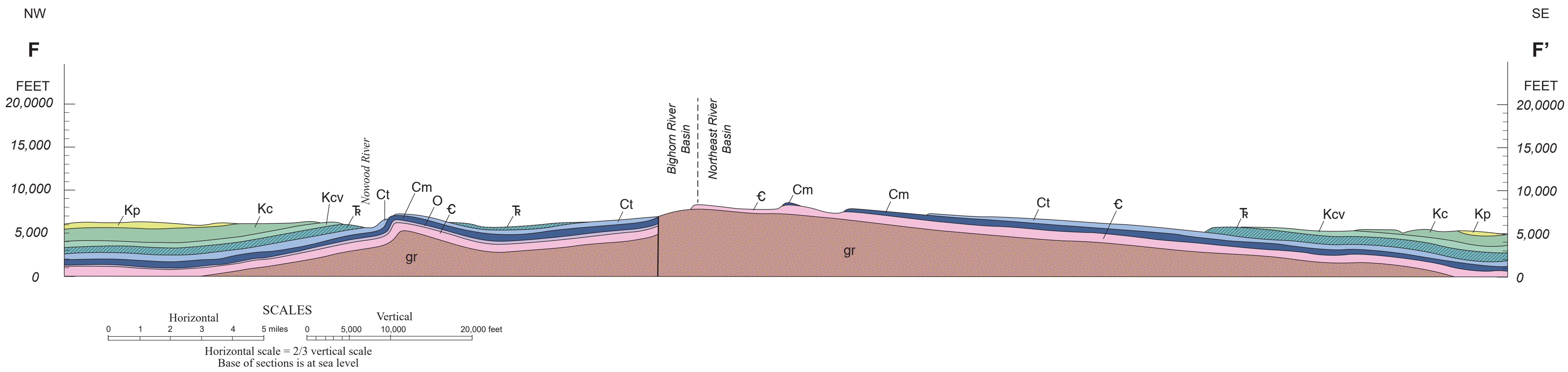
gr — Granite

Adapted from:

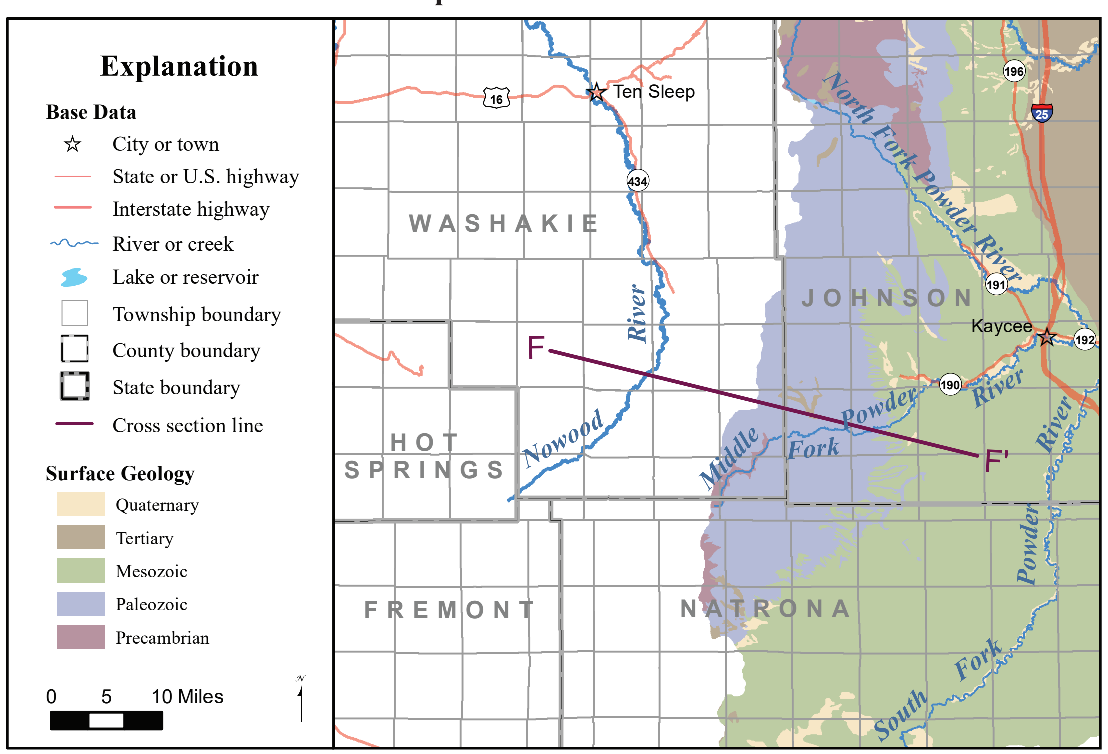
Darton, N.H., 1906, Geology of the Bighorn Mountains: U.S. Geological Survey Professional Paper 51, 129 p., 5 maps, scale 1:125,000.

Figure 4-7. Geologic cross section E-E’.

Cross Section F-F’



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Fault

Geologic Units

MESOZOIC

Cretaceous

Kp	Pierre Shale
Kc	Colorado shales

Cretaceous–Jurassic

Kcv	Cloverly-Sundance formations

Triassic

Ꞧ	Chugwater red beds

PALEOZOIC

Permian–Cambrian

Ct	Tensleep, Embar, and Amsden formations
Cm	Madison Limestone
O	Bighorn Dolomite
Ꞓ	Deadwood Formation

PRECAMBRIAN

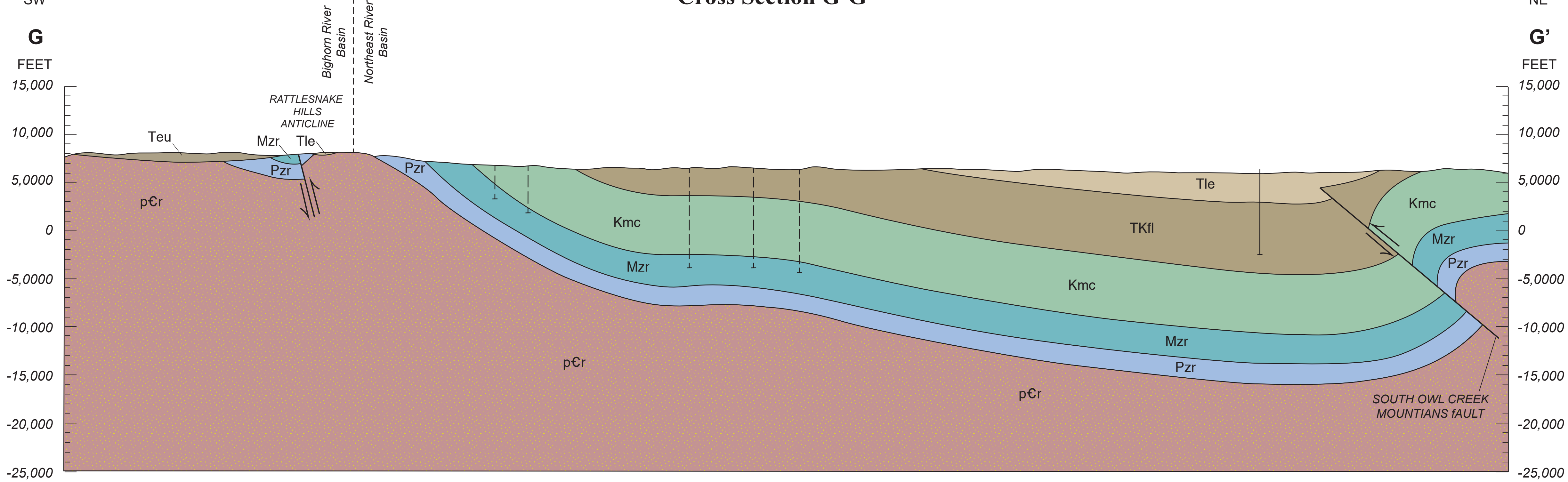
gr	Granite

Adapted from:

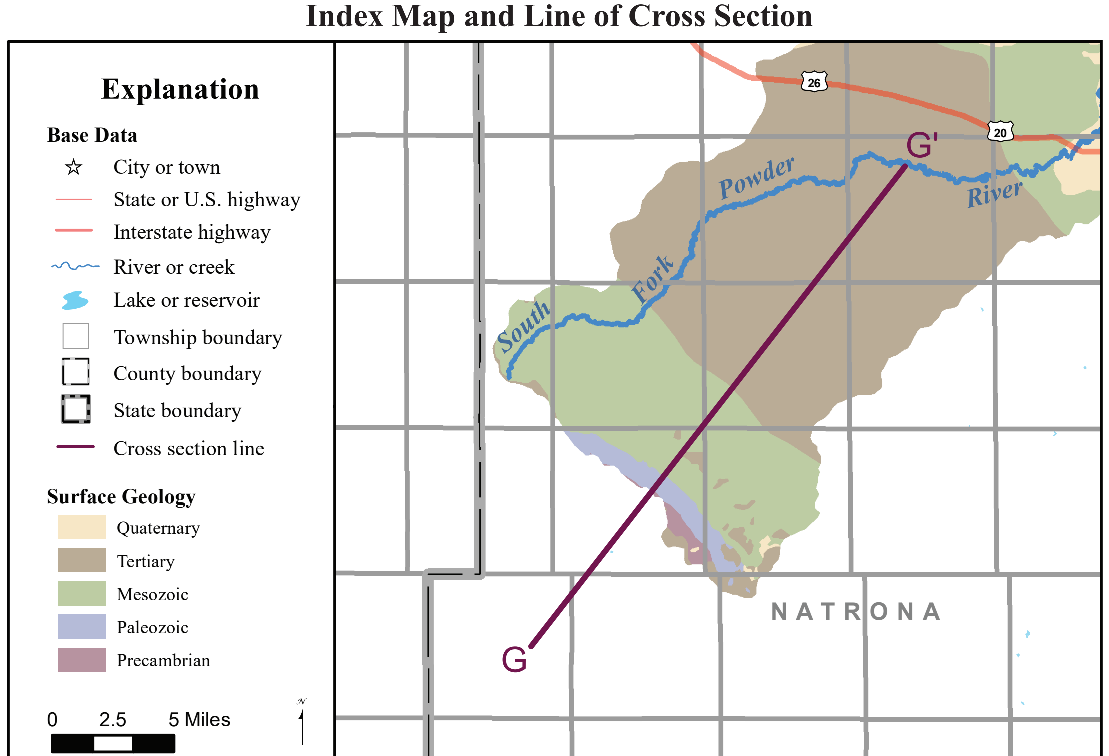
Darton, N.H., 1906, Geology of the Bighorn Mountains: U.S. Geological Survey Professional Paper 51, 129 p., 5 maps, scale 1:125,000.

Figure 4-8. Geologic cross section F-F’.

Cross Section G-G’



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Fault—arrows show sense of displacement

Well locations—solid if in line of section, dashed if projected into line of section

Geologic Units

NOTE: *Quaternary deposits not shown*

CENOZOIC
Tertiary

- Teu — Lower Eocene and younger Tertiary rocks, undivided
- Tle — Lower Eocene rocks

CENOZOIC–MESOZOIC
Tertiary–Cretaceous

- TKfl — Fort Union and Lance formations

MESOZOIC
Cretaceous

- Kmc — Meeteetse, Lewis, Mesaverde, and Cody formations
- Mzr — Pre-Cody Mesozoic rocks

PALEOZOIC
Permian–Cambrian

- Pzr — Paleozoic rocks

PRECAMBRIAN

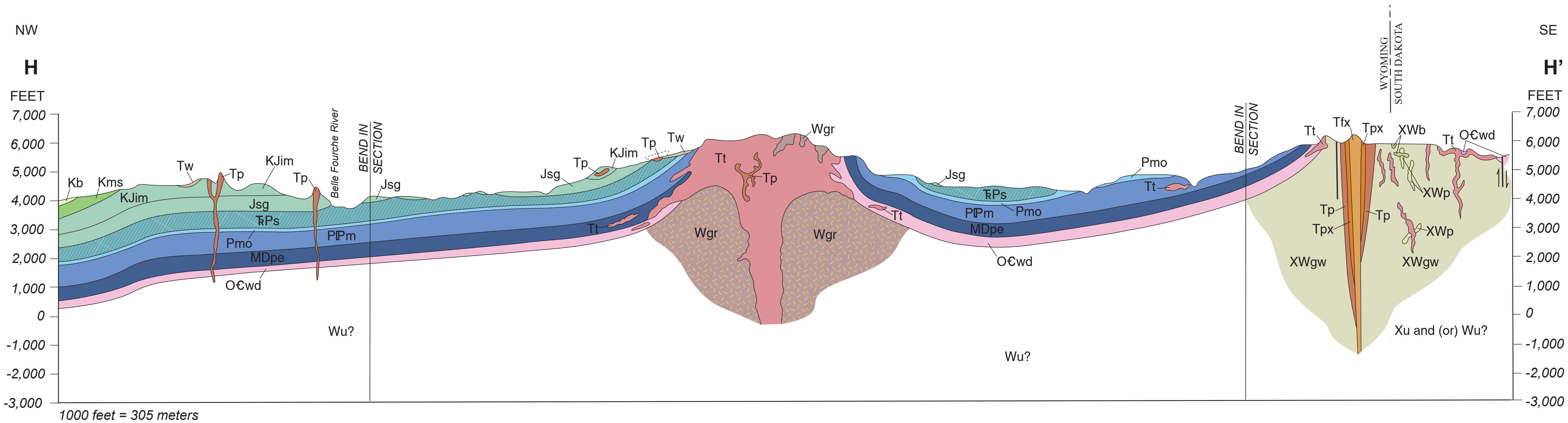
- p€r — Precambrian rocks

Figure 4-9. Geologic cross section G-G’.

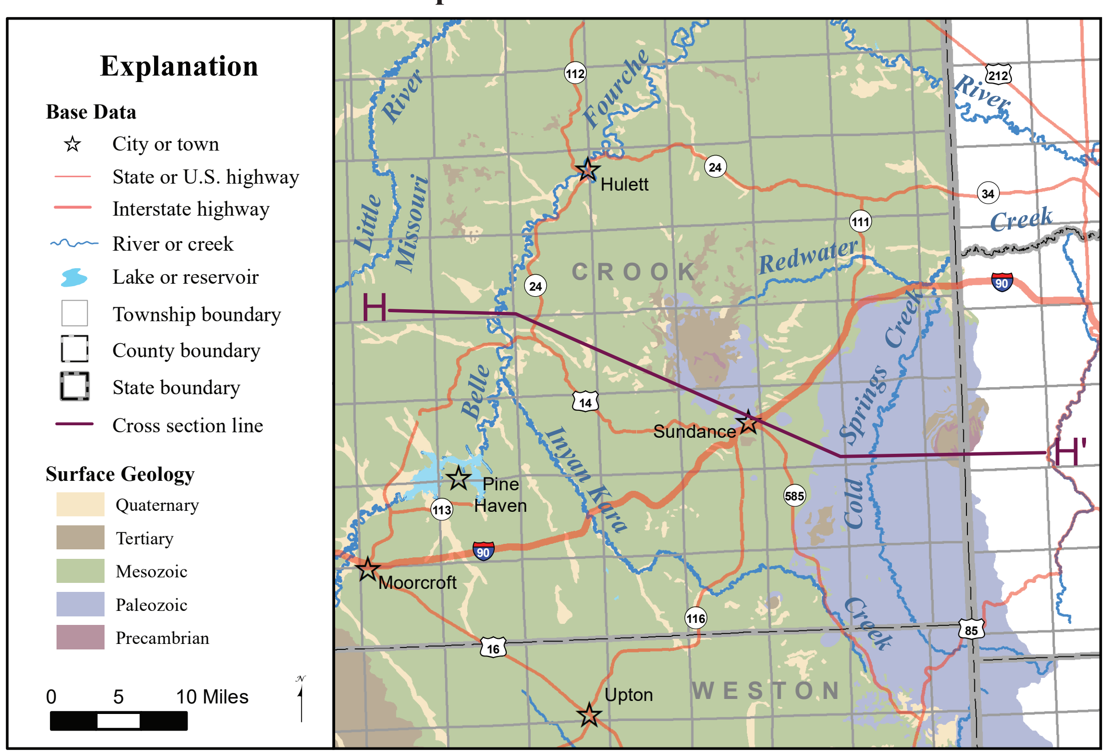
Adapted from:

Keefer, W.R., 1970, Structural geology of the Wind River Basin, Wyoming: U.S. Geological Survey Professional Paper 495, 35 p.

Cross Section H-H'



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Fault—arrows show sense of displacement

Geologic Units

CENOZOIC

Tertiary

- Tw — White River Group
- Tp — Phonolitic intrusive rocks
- Tt — Trachytic intrusive rocks
- Tfx — Feldspathoidal breccia
- Tpx — Pyroxenite

MESOZOIC

Cretaceous

- Kb — Belle Fourche Shale
- Kms — Mowry Shale, Newcastle Sandstone, and Skull Creek Shale

Cretaceous–Jurassic

- KJim — Inyan Kara Group and Morrison Formation and Unkpapa Sandstone

Jurassic

- Jsg — Sundance and Gypsum Spring formations

MESOZOIC–PALEOZOIC

Triassic–Permian

- TRPs — Spearfish Formation

PALEOZOIC

Permian

- Pmo — Minnekahta Limestone and Opeche Shale

Permian–Pennsylvanian

- PIPm — Minnelusa Formation

Mississippian–Devonian

- MDpe — Pahasapa Limestone and Englewood Formation

Ordovician–Cambrian

- OЄwd — Whitewood Dolomite, Winnipeg Formation, and Deadwood Formation

PRECAMBRIAN

Proterozoic

- Xu — Undifferentiated Proterozoic rocks

Proterozoic–Archean

- XWp — Pegmatite
- XWb — Metabasalt
- XWgw — Metagraywacke

Archean

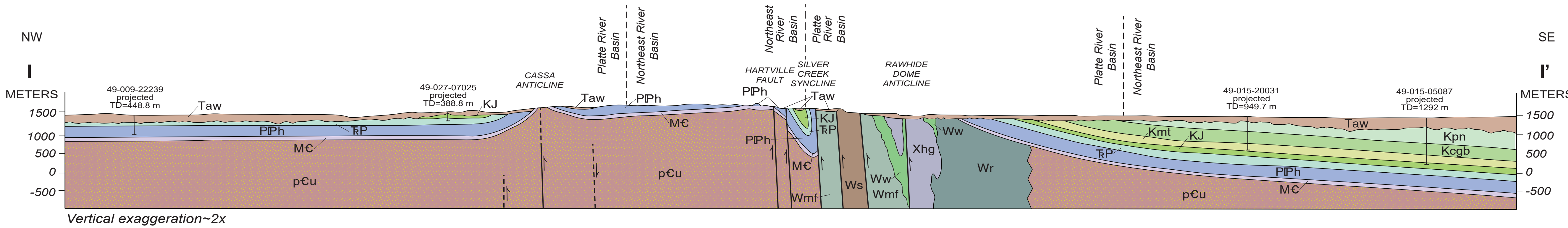
- Wgr — Granite
- Wu — Undifferentiated Archean rocks

Adapted from:

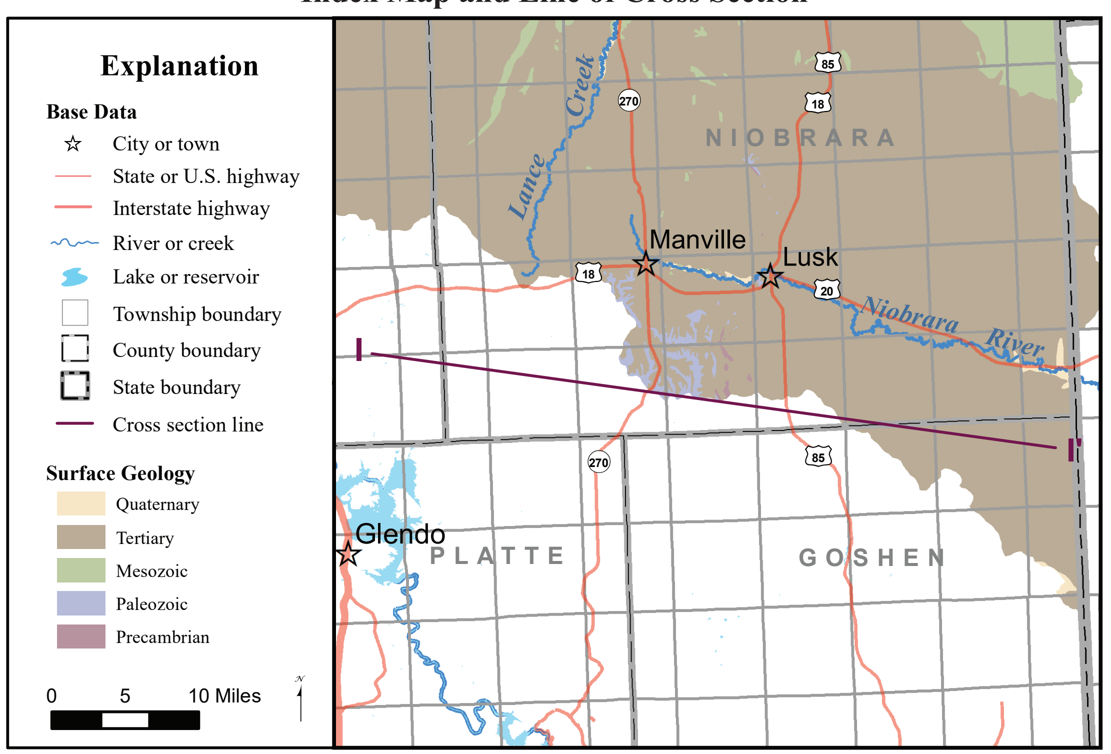
DeWitt, Ed, Redden, J.A., Buscher, D.P., and Wilson, A.B., 1989, Geologic map of the Black Hills area, South Dakota and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1910, scale 1:250,000.

Figure 4-10. Geologic cross section H-H'.

Cross Section I-I’



Index Map and Line of Cross Section



Explanation

Symbols

Contact

Fault—arrows show sense of displacement, and dashed where inferred

R-6 Well locations

Geologic Units

NOTE: *Quaternary deposits not shown*

CENOZOIC

Tertiary

- Taw — Arikaree and White River formations, undivided

MESOZOIC

Cretaceous

- Kpn — Pierre Shale and Niobrara Formation,undivided
- Kcgb — Carlile Shale, Greenhorn Formation, and Belle Fourche Shale, undivided
- Kmt — Mowry Shale, Muddy Sandstone, and Thermopolis Shale, undivided

Jurassic

- KJ — Cloverly, Morrison,and Sundance formations, undivided

Triassic

- TrP — Chugwater and Goose Egg formations, undivided

PALEOZOIC

Permian–Pennsylvanian

- PIPh — Hartville Formation, undivided
- M€ — Mississippian, Devonian, and Cambrian (?) rocks, undifferentiated

PRECAMBRIAN

Proterozoic

- Xhg — Gneissic phase of Haystack Range granite

Archean

- Wr — Rawhide Buttes Granite
- Ww — Wildcat Hills Formation
- Ws — Silver Springs Formation
- Wmf — Mother Featherlegs Metabasalt
- p€u — Precambrian rocks, undifferentiated

Adapted from:

McLaughlin, J.F., Stafford, J.E., and Harris, R.E., 2011, Geologic map of the Lusk 30’ x 60’ quadrangle, Niobrara, Goshen, Converse, and Platte counties, Wyoming, and Sioux County, Nebraska: Wyoming State Geological Survey Map Series 82, scale 1:100,000.

Figure 4-11. Geologic cross section I-I’.