Chapter 4
Geologic Setting

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The Platte River Basin drainage basin comprises approximately 24,106 square miles (15.43 million acres) in Wyoming, effectively covering the southeast corner of the state. The geologic setting for the basin is, therefore, both extensive and complex in that it encompasses 4 major Laramide structural basins, overlies small parts of five other Laramide basins and includes five mountain ranges of the southern Rocky Mountains as well as several smaller uplifts. So, a complete description of the geologic framework of the Platte River Basin must include summary accounts of the assemblages of geologic and hydrogeologic units and structural elements that define each of these major structures. To accomplish this, an extensive set of figures and maps, presented as plates, have been prepared for inclusion in this report:

- **Plate 1** illustrates the bedrock geology of the Platte River Basin in Wyoming, Colorado and Nebraska overlain on a base map that shows highway, township, state and county data. Inset maps present the elevations of the Precambrian basement and lineaments (linear geologic features). **Appendix A** contains detailed descriptions of the geologic units shown in **Plate 1**.
- **Plate 2** displays an outcrop map of hydrogeologic units in the Platte River Basin developed by correlating the geospatial data of hydrogeologic units with hydrostratigraphic nomenclature charts **(Plates J, K, M, S, T, and U; Figure 7-2).** The general hydrogeology of the Platte River Basin is discussed in **Chapter 7.** Individual Platte River Basin aquifers are discussed in detail in **Chapter 7, also**.
- Nineteen cross sections, contained in this chapter (**Figures 4-2** through **4-20**)**,** show typical subsurface structure in the Platte River Basin. Isopach maps with substantial coverage of the major aquifers in the Platte River Basin are not available.

4.1 General/historical geology

The Platte River Basin contains simple to complex stratigraphic and structural elements. The configuration of these elements and relationships among them influence the availability of groundwater. The geologic history relevant to groundwater resources of the Platte River Basin begins with the nonconformable deposition of transgressive marine sediments onto Precambrian basement rocks during Middle Cambrian time (Libra and others, 1981; Richter, 1981; Snoke, 1993). From that time forward, a general geologic history that describes the development of the stratigraphic and structural elements the Platte River Basin is as follows:

1. Paleozoic strata in the Platte River Basin were deposited in marine and nonmarine transgressive /regressive environments. Marine limestones and dolomites are the dominant lithologies of the Paleozoic sequence, with less extensive sandstones and shales that represent beach and near-shore environments. Deposition in the Paleozoic Era was broken by long periods of erosion, indicated in the geologic record by several regional unconformities.
2. The early Mesozoic Era was a time when shallow seas deposited interbedded layers (in decreasing abundance) of sandstone, siltstone, shale, carbonates, and evaporites. An emergent transition to a terrestrial environment during the Late Triassic and Early Jurassic Epochs resulted in the deposition of marginal marine, eolian, fluvial, and paludal sandstones and shales.
3. During the Early Cretaceous Epoch a thick section of interbedded shale, sandstone, siltstone, and claystone was deposited under terrestrial, shallow marine and deltaic conditions. Late Cretaceous transgressions and regressions resulted in a thick sequence of interbedded sandstone, siltstone, claystone, and shale deposited in marine, marginal marine, coastal plane, and deltaic environments. Crustal deformation associated with the Laramide Orogeny began in the Late Cretaceous; the Lance Formation recorded the final, eastward retreat of the Cretaceous seas followed by the deposition in terrestrial environments that would prevail

throughout the Tertiary Period.

4. Laramide compressional deformation continued through the early Eocene with large-scale reverse and thrust faults forming the basement-cored mountain ranges and uplifts that surrounded and separated the concurrently subsiding structural basins that make up the Platte River Basin. The uplifted areas were the source of several thousand feet of Tertiary sediments composed of Mesozoic, Paleozoic and Precambrian rocks that were eroded from the uplifts and filled the basins to the extent that all but the highest areas of the surrounding uplifts were buried. These strata are composed of conglomerates, sandstones, and claystones deposited primarily in fluvial, alluvial fan, and lacustrine environments.
5. Late Tertiary normal faulting concurrent with modest extension occurred throughout Wyoming. Uplift during the past 5 million years over a broad area that encompasses the Platte River Basin resulted in the erosion and removal of an enormous volume of Tertiary strata, exhuming the Laramide framework and sculpting the present physiography of the Platte River Basin
6. The youngest geologic units in the basin are unconsolidated Pliocene and Quaternary terrace deposits and Quaternary alluvial deposits of various thicknesses. These deposits, some as much as several hundred feet thick, are composed of conglomerate, gravel, sand, and finer-grained clastic material. The age and occurrence of these deposits have been correlated with recent glacial and interglacial periods by Mackin (1937).

4.2 Structural geology

The Laramide age basins, contained either wholly or partly within the Platte River drainage basins, are small (Carbon basin) to large (Denver basin) asymmetric intermontane structural basins formed during the Laramide Orogeny (Late Cretaceous-Eocene) that contain up to 35,000 feet (Richter, 1981) of Cenozoic, Mesozoic, and Paleozoic sediments deposited on Precambrian crystalline basement rocks (Libra et al., 1981; Richter, 1981). The structural basins are bordered by compressional uplifts cored by Precambrian granite and mantled by moderately to steeply dipping sedimentary formations (Libra et al., 1981). Paleozoic and Mesozoic formations exposed along the flanks of the mountain ranges surrounding the Platte River Basin were folded, faulted, and eroded from the highest areas of the uplifts during the Laramide Orogeny; they now dip basinward at angles ranging from approximately 5 degrees to vertical, and some are overturned. Strata of Paleocene through early Eocene age are also deformed around the perimeters of these structural basins but are mostly flat lying in the interior basin areas. Numerous anticlinal structures with associated faults that formed during the Laramide Orogeny crop out along the margins of the structural basins. **Section 5.4** discusses the substantial influence that structures, primarily those located around the basin perimeters, exert on groundwater recharge, flow and storage.

The topography of the Platte River Basin generally reflects the structure and topography of the Precambrian basement surface formed by uplift, folding, faulting, and erosion of the earth's crust under compressional stress during the Sevier and Laramide orogenies. Downwarping of the structural basins and upwarping and faulting of the uplifts were concurrent; and the upper strata within the basin interiors are composed of Tertiary-age sediment that was eroded from the adjacent uplifts. The structure contour map of the Precambrian basement surface in the Platte River Basin shown on the lower inset map on **Plate 1** shows a general northwest-southeast structural trend. The geologic cross sections on **Figures 4-2** through **4-20** show Precambrian basement rocks overlain by varying thicknesses of Paleozoic through Cenozoic formations, all deformed by large-scale folding and faulting.

The major Laramide structural elements of the Platte River Basin **(Figure 4-1)** comprise:

- The folded and faulted Precambrian basement
- The deeply buried downwarped areas of the Denver, Laramie, Hanna-Carbon,

Shirley, Wind River and Powder River basins

- The mountain ranges and uplifts that surround and separate the basins:
    - The Laramie, Medicine Bow and Sierra Madre/Park mountain ranges
    - Green Mountain, Ferris Mountains, Seminole, and Shirley Mountains
    - The Granite Mountains
    - The Casper Arch and Hartville Uplift
    - The Rawlins Uplift
    - The Wind River Range
    - The structural basins
        - Denver Basin
        - Laramie Basin
        - Shirley Basin
        - Hanna-Carbon Basin
        - Saratoga Valley
        - Great Divide Basin
        - Powder River Basin
        - Wind River Basin

There are many subsidiary structures within the Platte River Basin, some of which are or may be important elements of existing or potential sites for local groundwater development, but discussion of these features is beyond the scope of this study.

4.3 Basin stratigraphy

Geologic units within the structural basins of the Platte River drainage basin vary widely in lithology and distribution, and range in age from Precambrian crystalline rocks to recent alluvial and terrace deposits. The structural basins that compose the Platte River Basin contain up to 35,000 feet, of Cenozoic through Paleozoic sedimentary strata. The explanation on **Plate 1**identifies the geologic units present in the basin; the individual geologic units are described in **Appendix A**. The distribution of geologic units reflects several periods of deposition, uplift, erosion, volcanism, and reworking/re-deposition of older units as younger strata. The erosion of rocks exposed in upland areas and re-deposition in the basins is an ongoing process. Accordingly, the stratigraphic sections preserved in interior basin areas are most complete, and stratigraphic sections are less complete to non-existent at higher elevations in the surrounding mountain ranges. In some places Tertiary and Quaternary deposits directly overly Precambrian basement rocks.

4.4 Granite Mountains, Green Mountain, Ferris Mountains, Seminoe Mountains, Shirley Mountains and Freezeout Mountains (Lillegraven and Snoke, 1996; WSGS, 2013)

Together, these Rocky Mountain foreland features form the southern flank of the Sweetwater Arch which extends over 100 miles from the western edge of the Granite Mountains to the eastern Freezeout Mountains. This area separates the Wind River basin from the Great Divide and Hanna basins, and in a general sense connects the southern end of the Wind River Range with the northern Laramie Mountains.

4.4.1 Granite Mountains (Love, 1970; WSGS, 2013)

The *Granite Mountains,* (**Plate 1; Figures 4-1, 4-2**) which consist of massive pink granite shot through with black diabase dikes, form a number of landmarks such as Independence Rock, Devils Gate, Split Rock, and Sweetwater Crossing along the Sweetwater River. The rocks that form these features crop out in bald, stark knobs that stand above light-colored, flat-lying Tertiary aged sedimentary rocks.

The area of the Granite Mountains is unique because it was once a much higher mountain range, similar to other mountains in the state that formed during the Laramide Orogeny. For example, the Crooks-Green-Ferris-Seminoe-Shirley mountain complex that bounds the Granite Mountains on the south has structural features like those found on the flanks of other Laramide mountain ranges in Wyoming; however, the Granite Mountains lack a high central core of Precambrian terrane. Also like other Wyoming mountain ranges, sedimentary basins on both sides of the Granite

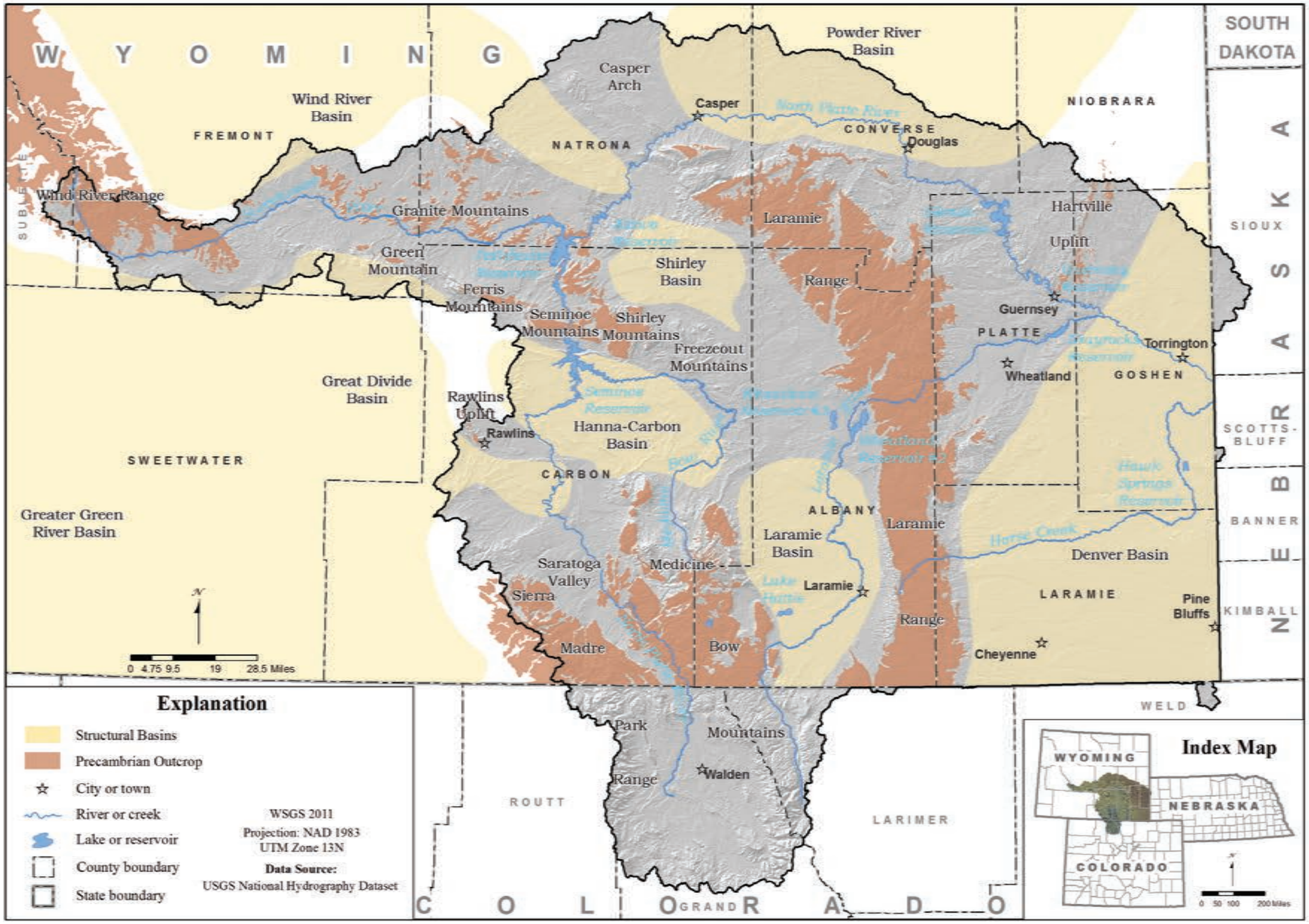
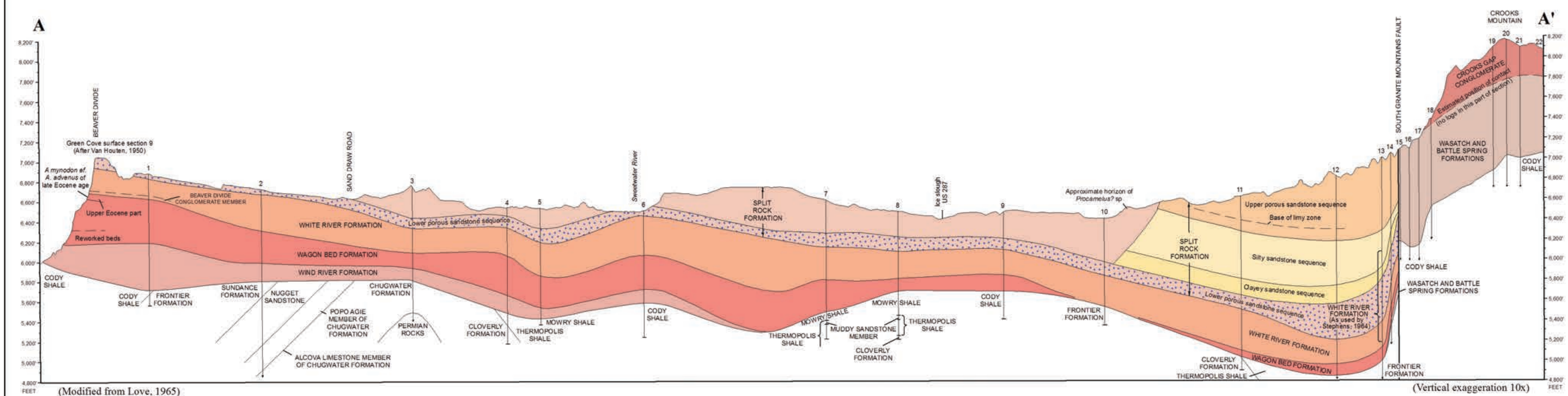
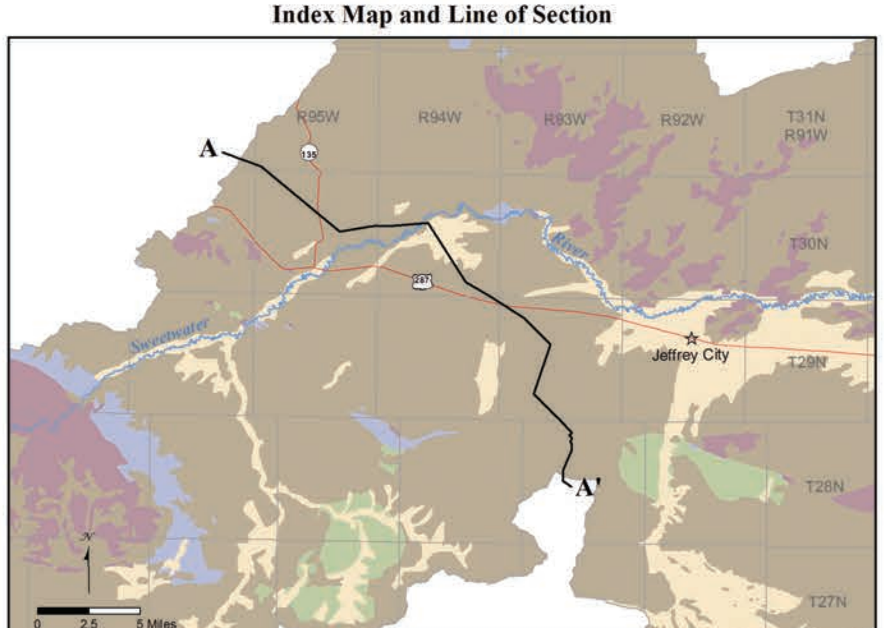


Figure 4-1. Major Laramide structural elements, Platte River Basin.



Index Map and Line of Section



Surface Geology
- Quaternary
- Tertiary
- Mesozoic
- Paleozoic
- Precambrian

Base Data
- ☆ City or town
- State or U.S. highway
- Township boundary
- River or creek

Explanation

Symbols

- Formation contact - dashed where approximately located
- Fault
- Well location and designation

Geologic Units

CENOZOIC
Tertiary

- Split Rock Formation - Upper porous sandstone sequence
- Split Rock Formation - Silty sandstone sequence
- Split Rock Formation - Clayey sandstone sequence
- Split Rock Formation - Lower porous sandstone sequence
- Split Rock Formation undivided
- White River Formation
- Wagon Bed Formation
- Crooks Gap Conglomerate
- Wasatch and Battle Spring Formations
- Wind River Formation

(Data on pre-Tertiary rocks is diagrammatic)

Well Information

Well/Core Hole #	API #	Well/Core Hole Name	Location (Section-Township-Range)	Elevation† (feet)	Depth (feet)	Bottom Formation	Spud Date
1	N/A	Atlantic CH 4	31-31N-95W	6,880	1,320	Frontier	N/A
2	49-013-05252	Govt Sweetwater Crs 1	8-30N-95W	6,737KB	2,835	Permian rocks	1957
3	49-013-05249	California Co. Govt 1	14-30N-95W	6,727KB	2,525	Madison Limestone	1954
4	N/A	Atlantic CH 2	13-30N-95W	6,547	1,354	Cloverly & Morrison, undiff.	N/A
5	49-013-08335	California Co. CH 1	18-30N-94W	6,532	1,159	Mowry Shale	N/A
6	N/A	Sinclair CH 2	16-30N-94W	6,510T	1,260	Cody Shale	N/A
7	49-013-08336	California Co. CH 6	35-30N-94W	6,600T	1,380	Thermopolis Shale	N/A
8	N/A	Sinclair CH 6	36-30N-94W	6,485T	1,270	Cloverly	N/A
9	N/A	California Co. CH 4	5-29N-93W	6,495G	1,072	Cody Shale	N/A
10	N/A	Sinclair CH 1	16-29N-93W	6,415T	1,061	Frontier	N/A
11	N/A	Sinclair CH 10	29-29N-93W	6,635T	1,725	Cloverly	N/A
12	49-013-05223	Govt 33-1	33-29N-93W	6,828KB	4,700	Chugwater	1953
13	49-013-05220	Happy Springs Unit 37	4-28N-93W	6,994KB	7,065	Madison Limestone	1955
14	49-013-05219	Happy Springs Unit 30	4-28N-93W	7,045T	6,378	Permian rocks	1954
15	49-013-05209	Happy Springs Unit 18	4-28N-93W	7,094T	4,527	Cloverly & Morrison, undiff.	1953
16	49-013-05204	Happy Springs Unit 13	4-28N-93W	7,110T	4,632	Cloverly & Morrison, undiff.	1952
17	49-013-05191	Happy Springs Unit 15	9-28N-93W	7,186G	4,760	Cloverly	1952
18	49-013-05177	Happy Springs Unit 28	9-28N-93W	7,391G	4,190	Frontier	1954
19	N/A	Happy Springs Unit 6	8-28N-93W	8,111G	6,625	Thermopolis Shale	N/A
20	49-013-05144	Happy Springs Unit 4	17-28N-93W	8,176G	6,954	Cloverly & Morrison, undiff.	1950
21	49-013-05133	Happy Springs Unit 5	17-28N-93W	8,099G	6,500	Mowry Shale	1951
22	49-013-05129	Happy Springs Unit 3	21-28N-93W	8,064G	6,675	Thermopolis Shale	1950

† T = Topographic Map; KB = Kelly Base on drill rig; G = Ground elevation at well site; no modifier = no data available or unknown

API # and **Spud Date** compiled from Wyoming Oil and Gas Conservation Commission website

Figure 4-2. Geologic cross section A-A'.

Mountains contain a thick sequence of lower Tertiary rocks, including thick conglomerate sequences that become coarser grained as they approach the Granite Mountains. The rock types found in the conglomerates, such as the giant boulders of Precambrian granitic rocks found in and on top of Green and Crooks Mountains south of the Sweetwater River, are exactly the same rock types found in the core of the Granite Mountains. During early Tertiary (Paleocene and especially early Eocene) time, there must have been high mountains in the area to produce these structural features and the conglomerates.

The south and north margins of the Granite Mountains are defined by an obvious system of east-west trending normal faults which preserve late Tertiary sedimentary rocks in the downdropped blocks. These rocks were almost completely removed by erosion elsewhere in Wyoming. At one time, all Wyoming basins were completely filled with these late Tertiary rocks, and only the highest mountain peaks stood above this fill. The granite knobs along the Sweetwater represent the buried crest of the central core of a mountain range that collapsed and subsided in the late Tertiary (mostly in the Pliocene Epoch). It is estimated that at least several thousand feet of the Granite Mountains collapsed along these normal faults into a downthrown trough (graben). This collapse was probably caused by crustal extension that affected other Laramide uplifts as well, but evidently not to the same extent it did the Granite Mountains. The proximity of early Tertiary volcanic rocks of the Rattlesnake Hills on the north edge of the Granite Mountains may also be a factor, and the debate continues as to why this entire mountain range collapsed.

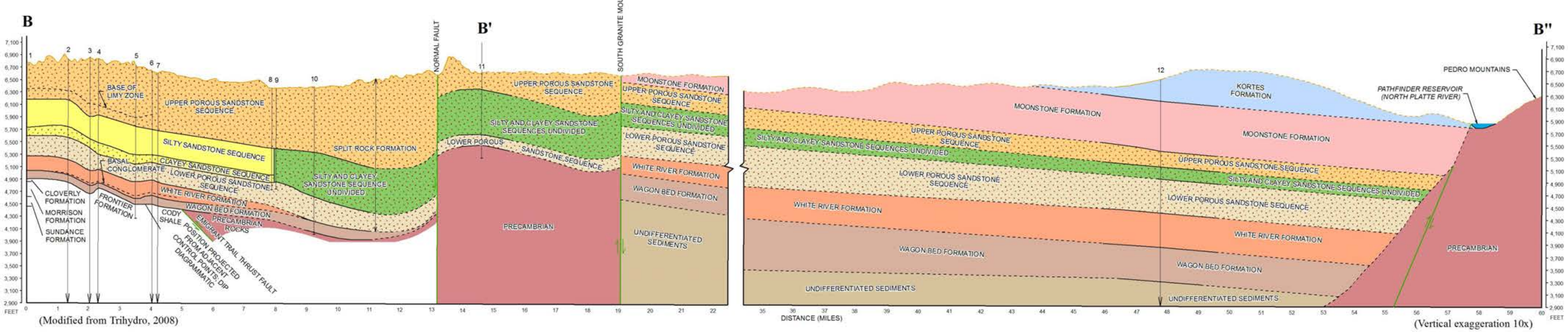
4.4.2 Crooks Mountain, Green Mountain, Ferris Mountains, Seminoe Mountains, Shirley Mountains (Lillegraven and Snoke, 1996)

The geology of these mountains (**Plate 1; Figures 4-1** through **4-3**), which parallel the Granite Mountains to the north, suggests that this structural complex constitutes the remnant of the foothills of the Granite Mountains prior to their collapse. A long system of thrust faults in the west and normal faults in the east, run along the northern flank of this mountain complex and separate it from the Granite Mountains. Crooks Mountain and Green Mountain are both low elevation features composed of Paleocene through Oligocene aged conglomerates containing giant Precambrian granite boulders that have the same composition as the granite knobs of the Granite Mountains.

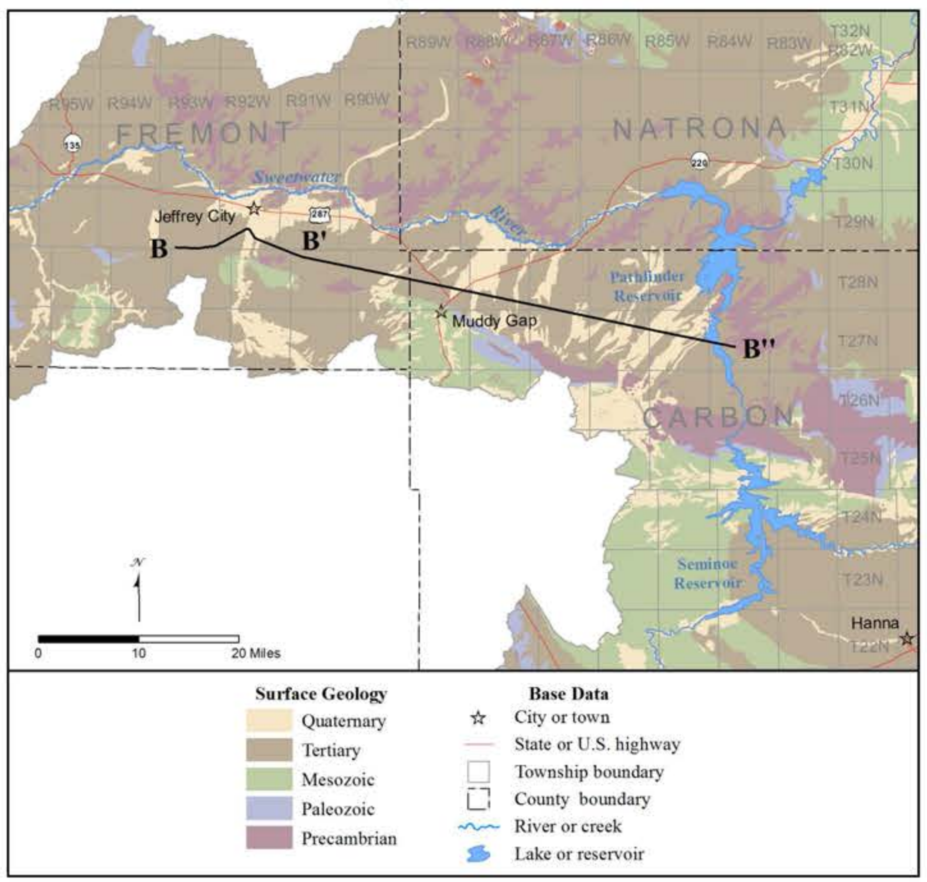
The Ferris Mountains, farther to the east are more rugged and over 2,000 feet higher in elevation. The mountains' flanks consist of an assemblage of upturned Cambrian – Upper Cretaceous sedimentary strata and the Precambrian granite core is exposed along the summit ridge. The most striking geologic features of the Ferris Mountains are the sub vertical exposures of resistant Mississippian Madison Limestone that form the flatirons along its southern flank.

The Seminoe Mountains (elevation 7,421 ft above MSL) have a similar geologic setting to the Ferris Mountains in that Paleozoic and Mesozoic sedimentary units cover its southern flank which also exhibits Madison Limestone flatirons along the mountains eastern half. The Precambrian core is more complex than the granite core of the Ferris Mountains, however. The core of the eastern two thirds of this small mountain range is Late Archean granite while the western third consists of Late Archean metavolcanic and metasedimentary rocks which contain iron and gold ores. Several small gold mines were in operation for a brief period in the late 1800s in this area but no large scale mining operation ever developed.

The Shirley Mountains constitute the easternmost part of the Green Mountains-Ferris Mountains-Seminoe Mountains-Shirley Mountains structural complex, which defines the southern part of the Granite Mountains uplift. The Shirley Mountains contain Precambrian rocks in its western core and a large anticlinal structure involving Paleozoic and Mesozoic rocks in the eastern part. The mountains separate the Shirley Basin to the north from the Hanna Basin to the south. The Shirley Mountains were thrust southward, overriding the deep synclinal axis of the Hanna Basin. The southeastern part of the Shirley Mountains that contains the large anticline draped with Paleozoic and Mesozoic rocks is sometimes called the Freezeout Mountains (or Hills).



Index Map and Line of Section



Explanation

Symbols

- Fault line
- Ground surface - dashed where inferred
- Formation line - dashed where inferred
- Surface water
- Approximate well location and designation
- Bottom of well
- Indicates depth of well continues beyond limits of cross section
- AMSL: above mean sea level

Geologic Units

CENOZOIC

Tertiary

- KORTES FORMATION
- MOONSTONE FORMATION
- SPLIT ROCK FORMATION - UPPER POROUS SANDSTONE SEQUENCE
- SPLIT ROCK FORMATION - SILTY AND CLAYEY SANDSTONE SEQUENCES UNDIVIDED
- SPLIT ROCK FORMATION - SILTY SANDSTONE SEQUENCE
- SPLIT ROCK FORMATION - CLAYEY SANDSTONE SEQUENCE
- SPLIT ROCK FORMATION - LOWER POROUS SANDSTONE SEQUENCE

Tertiary (cont.)

- WHITE RIVER FORMATION
- WAGON BED FORMATION
- UNDIFFERENTIATED SEDIMENTS

PRECAMBRIAN

- PRECAMBRIAN ROCKS

Well Information

Well/Core Hole #	API #	Well/Core Hole Name	Location (Section-Township-Range)	Elevation† (feet)	Depth (feet)	Bottom Formation	Spud Date
1	N/A	Sinclair, CH 19	32-29N-93W	6,780 T	2,326	Sundance	N/A
2	49-013-05223	Govt 33-1	33-29N-93W	6,828 KB	4,700	Chugwater	1953
3	49-013-05224	Govt 34-1	34-29N-93W	6,865 G	3,153	Cloverly & Morrison, undiff.	1953
4	49-013-05225	Govt 2	34-29N-93W	6,840 T	3,035	Cloverly & Morrison, undiff.	1956
5	49-013-60025	Sinclair, CH 6-B	35-29N-93W	6,738 G	2,470	Frontier	1956
6	49-013-08381	Sinclair, CH 4-B	36-29N-93W	6,640 T	2,620	Frontier	1956
7	49-013-08380	Sinclair, CH 2-B	36-29N-93W	6,615	2,660	Frontier	1956
8	N/A	Sinclair, CH 5-A	21-29N-92W	6,372 T	1,635	Split Rock	N/A
9	N/A	Sinclair, CH 5	21-29N-92W	6,375 T	1,635	Split Rock	N/A
10	N/A	Sinclair, CH 25	27-29N-92W	6,390 T	2,378	Precambrian	N/A
11	49-013-60062	Split Rock 1	5-28N-91W	6,620 T	1,350	Precambrian	1955
12*	49-007-07151	Test Boring SR-2	9-27N-86W	6,555 GPS	3,820	N/A	N/A

† T = Topographic Map; KB = Kelly Base on drill rig; G = Ground elevation at well site; GPS = Global Positioning System; no modifier = no data available or unknown

API # and Spud Date provided by Wyoming Oil and Gas Conservation Commission

* Data (except API #) from 2008 Split Rock Groundwater Development Project by Trihydro

Figure 4-3. Geologic cross section B-B'-B''.

4.5 Hanna-Carbon Basin and surrounding mountain ranges (Richter, 1981; WSGS, 2013)

This sedimentary basin consists of the larger Hanna Basin (**Plate 1; Figures 4-1, 4-4**) and the smaller, subsidiary Carbon Basin to the southeast, separated by the Simpson Ridge anticline. This basin is sandwiched between the Seminoe and Shirley Mountains to the north, the Medicine Bow Mountains to the south, and the Rawlins uplift to the west. It is separated from the Laramie Basin to the southeast by several folds in Cretaceous rocks. The Hanna Basin is quite small as intermontane basins go—only about 35 miles long by 20 miles wide—but it is unique because of the great depth to which the sedimentary rocks are depressed. The Precambrian floor beneath the sedimentary rocks in the deepest part of the basin north of Hanna lies approximately 30,000 feet below sea level. Structural relief ranges from 38,000 feet, measured from the highest point on the Shirley Mountains, to more than 41,000 feet, measured from the top of Elk Mountain (a horizontal distance of only 15 or 20 miles to the deepest part). The basins contain a thick sequence (up to 23,000 feet) of Upper Cretaceous and Tertiary clastic sedimentary rocks derived in part from adjacent uplands. Tertiary rocks in the northern part of the basin adjacent to the Shirley Mountains include a 10,000- to 15,000-foot-thick succession of vertically dipping conglomerates containing clasts eroded from nearly every sedimentary and Precambrian rock exposed in the surrounding uplifts. Overall, the thickness of the sedimentary section ranges up to 35,000 feet (Richter, 1981).

The structure of the Hanna-Carbon Basin is complex. Even the Tertiary rocks that are relatively flat lying in most other Wyoming basins are complexly folded and faulted, especially on the edges of the basin. Only the western part of the basin is relatively undeformed, with the rocks dipping eastward off the Rawlins uplift. Near Hanna, where the basin is deepest, even the youngest (Eocene) part of the Hanna Formation is folded into a small syncline. In the northern part of the basin, Upper Cretaceous rocks are highly overturned and overlain unconformably by lower Tertiary rocks that may also have steep dips.

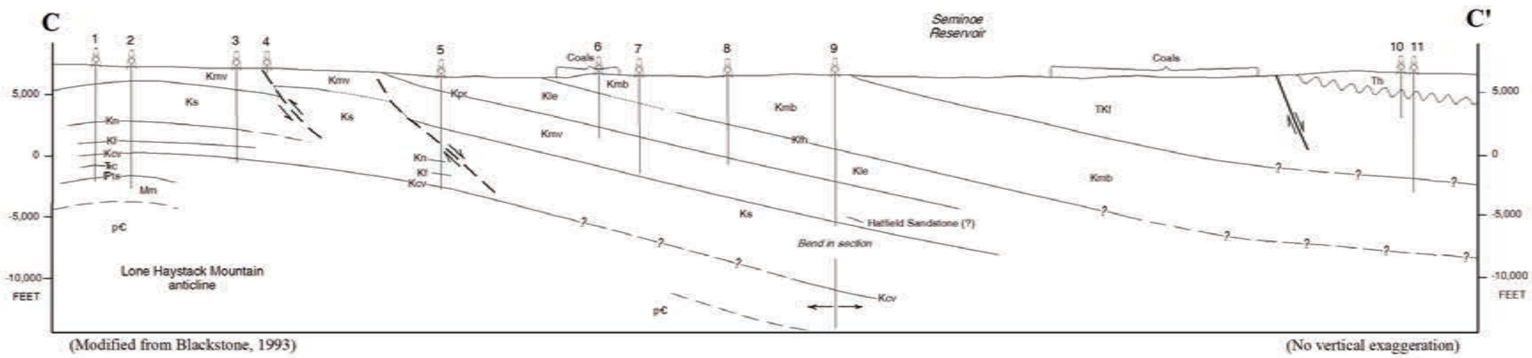
The Tertiary Hanna and Ferris formations contain thick coal beds in both the Hanna and Carbon basins. Coal was originally mined underground at old Carbon (now a ghost town) and later at Hanna, and was used to fuel steam locomotives on the Union Pacific Railroad. After the railroads switched from coal-fired to diesel-electric locomotives, coal mining practically ceased in the basin. Coal mining by both underground and surface methods resumed in the 1970s due to increased demand for coal to fuel electric power plants (brought about by passage of the Federal Clean Air Act). Today, most coal mining activity in the basin has once again nearly ceased because this coal must compete with the easily mined and much cheaper coal from the Powder River Basin.

4.6 Casper Arch (WSGS, 2013)

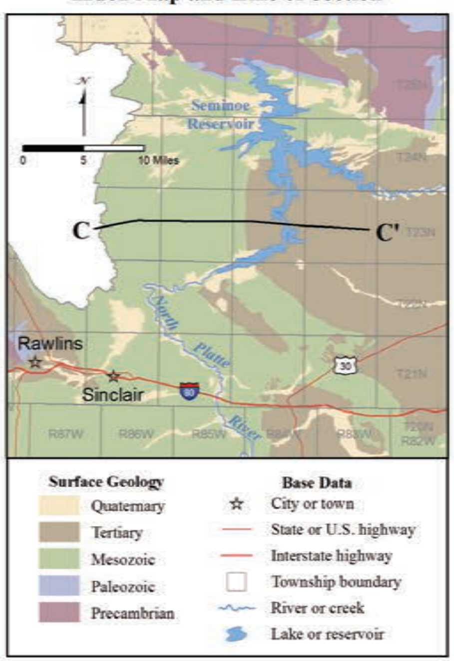
A structural arch represents a transitional area between Wyoming's basins and mountains. It is primarily an uplifted area, but the extent of uplift has not been enough to form a mountain range with an exposed core of Precambrian basement rocks. Relief is usually about the same as in the adjacent basins, but the uplift has exposed rocks older than those in the basins. The Casper arch (**Plate 1; Figures 4-1, 4-5**) is a large, northwest-trending asymmetric anticlinal structure that connects the Bighorn Mountains with the Laramie Mountains and separates the Powder River Basin (to the northeast) from the Wind River Basin (to the southwest). Rocks on the northeast flank dip gently into the Powder River Basin while steeply dipping rocks are thrust southwestward, overriding the synclinal axis of the Wind River Basin. Upper Cretaceous marine shale crops out in the center of the arch, with rocks as young as Paleocene on the flanks of the arch. Several large oil fields are found on the arch, including the Salt Creek/Teapot Dome, Pine Mountain/Poison Spider, and Tisdale Mountain anticlines, which expose older Cretaceous rocks in their cores.

4.7 Shirley Basin (WSGS, 2013)

The Shirley Basin (**Plate 1; Figures 4-1, 4-6**) is a small relatively undeformed depression



Index Map and Line of Section



Explanation

Symbols

- Kcv — Formation contact - symbol indicates formation top
- Inferred, projected, or restored formation contact or bedding planes
- Hypothetical formation contact
- Approximate position of formation or marker bed
- Fault - dashed where inferred; arrows indicate direction of relative movement
- Unconformity
- Mesaverde Group
- Well location and designation

Geologic Units

CENOZOIC
Tertiary
Th Hanna Formation
CENOZOIC and MESOZOIC
Tertiary-Cretaceous
TKf Ferris Formation
MESOZOIC
Cretaceous
Kmb Medicine Bow Formation
Kfh Fox Hills Sandstone
Kle Lewis Shale
Kmv Mesaverde Group
Kpr Pine Ridge Sandstone of Mesaverde Group
Ks Steele Shale

Cretaceous (cont.)
Kn Niobrara Formation
Kf Frontier Formation
Kcv Cloverly Formation (Dakota Sandstone)
Triassic
Tc Chugwater Group or Formation
PALEOZOIC
Pennsylvanian
Pts Tensleep Sandstone
Mississippian
Mm Madison Limestone
PRECAMBRIAN
pC Precambrian rocks

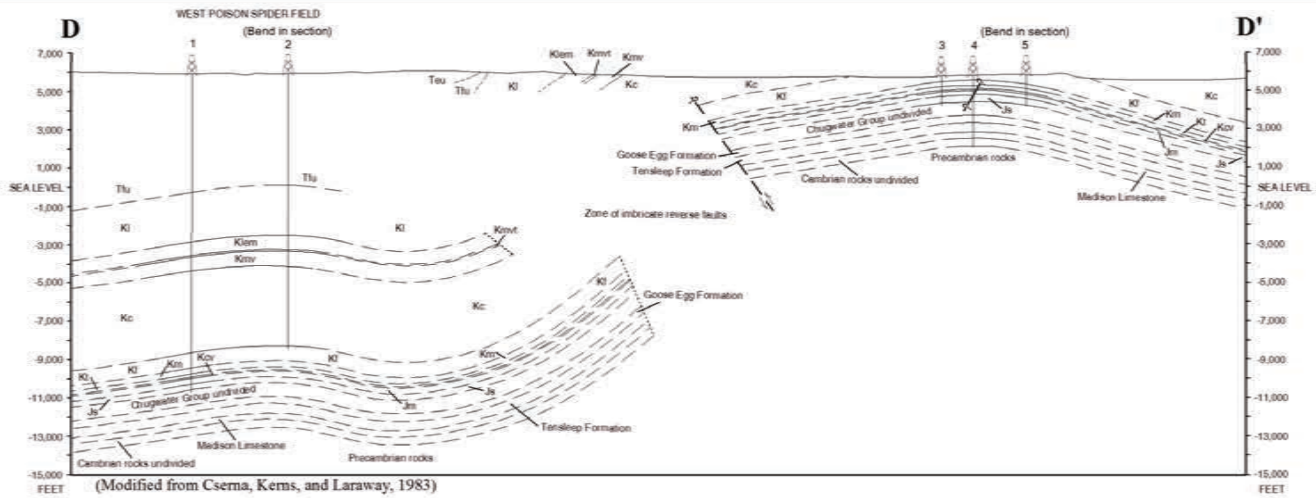
Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-007-20200	CHAMBERS-STATE 1-16	16-23N-86W	7,600 GR	9,240	Tensleep	1974
2	49-007-06036	UNIT HAYSTACK 33-16	16-23N-86W	7,294 KB	9,701	Madison Limestone	1960
3	49-007-05642	UNIT 1	14-23N-86W	7,377 KB	7,469	Morrison	1951
4	49-007-06930	GOVT-HAYSTACK 1-A	14-23N-86W	7,305 KB	721	Mesaverde	1966
5*	N/A	HAYSTACK UNIT	20-23N-86W	6,657	9,163	N/A	N/A
6	49-007-05637	UNIT 41-22	22-23N-85W	6,717 DF	4,924	Mesaverde	1963
7	49-007-05640	MILLER-CARSON 14-1	14-23N-85W	6,723 KB	7,910	Mesaverde	1956
8	49-007-20605	UPRR SANDSTONE RIDGE 1	13-23N-85W	6,607 GR	7,078	Mesaverde	1980
9	49-007-20336	SEMINOE RESERVOIR 1	17-23N-84W	6,567 GR	12,100	Mesaverde	1977
10	49-007-21144	HANNA UPRC 2-23	23-23N-83W	6,583 GR	3,046	Ferris	1989
11	49-007-20171	HANNA UNIT-CHAMPLIN 2	23-23N-83W	6,573 GR	8,623	Ferris	1973

GR = ground; DF = derrick floor; KB = kelly bushing

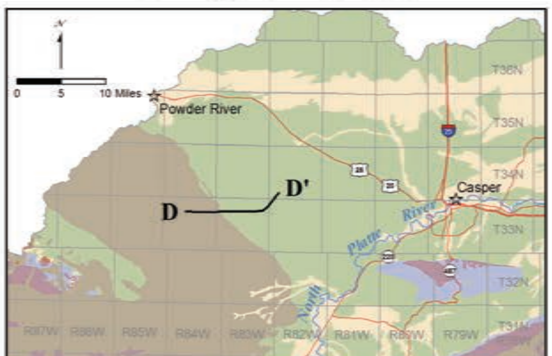
* Original data; no data was available from the Wyoming Oil and Gas Conservation Commission

Figure 4-4. Geologic cross section C-C'.



(Modified from Cserna, Kerns, and Laraway, 1983)

Index Map and Line of Section



Surface Geology
- Quaternary
- Tertiary
- Mesozoic
- Paleozoic
- Precambrian
- Volcanic

Base Data
- ☆ City or town
- Township boundary
- State or U.S. highway
- Interstate highway
- River or creek

Explanation

Symbols

Contact - long dashed where approximately located; short dashed where inferred

Fault - long dashed where approximately located; queried where inferred or unknown; arrows indicate relative movement where known

Well

Geologic Units

CENOZOIC
Tertiary
- Teu Eocene units, undivided
- Tfu Fort Union Formation

MESOZOIC
Cretaceous
- Kl Lance Formation
- Klem Lewis Shale and Meeteetse Formation, undivided
- Kmvt Teapot Sandstone Member of Mesaverde Formation
- Kmv Mesaverde Formation, undivided

Cretaceous (cont.)
- Kc Cody Shale
- Kf Frontier Formation
- Km Mowry Shale
- Kt Thermopolis Formation
- Kcv Cloverly Formation

Jurassic
- Jm Morrison Formation
- Js Sundance Formation

Triassic
- Chugwater Group, undivided

MESOZOIC and PALEOZOIC
Triassic-Permian
- Goose Egg Formation

Pennsylvanian
- Tensleep Formation

Mississippian
- Madison Limestone

Cambrian
- Cambrian rocks, undivided

PRECAMBRIAN
- Precambrian rocks

Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-025-05641	UNIT 3	10-33N-84W	5,936 DF	16,607	N/A	1949
2	49-025-05648	FEDERAL 1	11-33N-84W	5,937 GR	14,309	Frontier	1947
3	49-025-05661	FEDERAL T-8	12-33N-83W	5,758 KB	1,547	Alcova Limestone	1965
4	49-025-05671	GOVT T-6	12-33N-83W	5,771 KB	3,703	Precambrian	1964
5	49-025-05698	GOVT F2	01-33N-83W	5,823 TS	1,643	Sundance	1918

GR = ground; DF = derrick floor; KB = kelly bushing; TS = topo sheet

Figure 4-5. Geologic cross section D-D'.

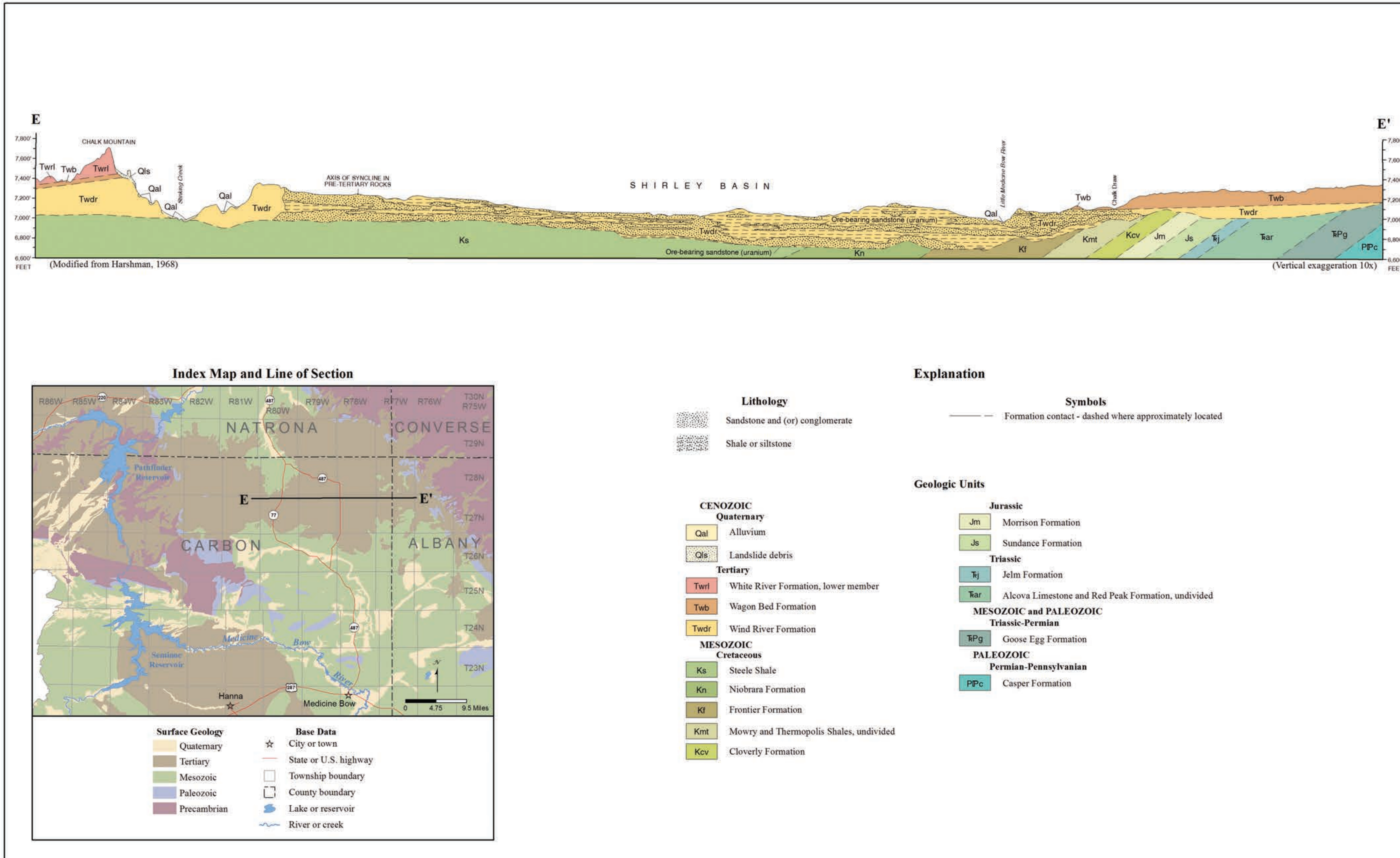


Figure 4-6. Geologic cross section E-E'.

between the Laramie Range and Freezeout or Shirley Mountains. Its floor is full of flat lying sandstones of the Eocene Wind River formation, which contain large deposits of uranium. Like other uranium deposits in Wyoming, the uranium leached from Precambrian granitic rocks and moved in percolating ground waters into porous sandstones of the Wind River formation. The Shirley Basin contains large reserves of uranium, which are minded from open pits. The north end of the Shirley Basin is covered by white, tuffaceous claystones and sandstones of the Oligocene White River formation, dated at 31 to 35 million years old. The basin contains 8,000 feet of Paleozoic and Mesozoic rock unconformably overlain by a Cenozoic section (Richter, 1981).

4.8 Laramie Basin (Richter, 1981; WSGS, 2013))

Between the Laramie Mountains and the Medicine Bow Mountains is a complexly downfolded area, the trend of which roughly parallels the sweeping arc of U.S. Highway 30 and the Union Pacific Railroad from Laramie to Rawlins. The area is comprised of the Laramie and Hanna-Carbon Basins. The Laramie basin (**Plate 1, Figures 4-1** and **4-7** through **4-11**) is a small (60 miles north to south by 30 mile) trapezoidal shaped asymmetrical Laramide structural basin located in the southern part of this downwarped area. The Laramie Basin is bounded on the northeast and east by the Laramie Mountains, on the south and west by the Medicine Bow Mountains and is open to the northwest. The Laramie Basin contains a maximum thickness 12,000 feet of Cenozoic through Paleozoic sediments near the basin axis.

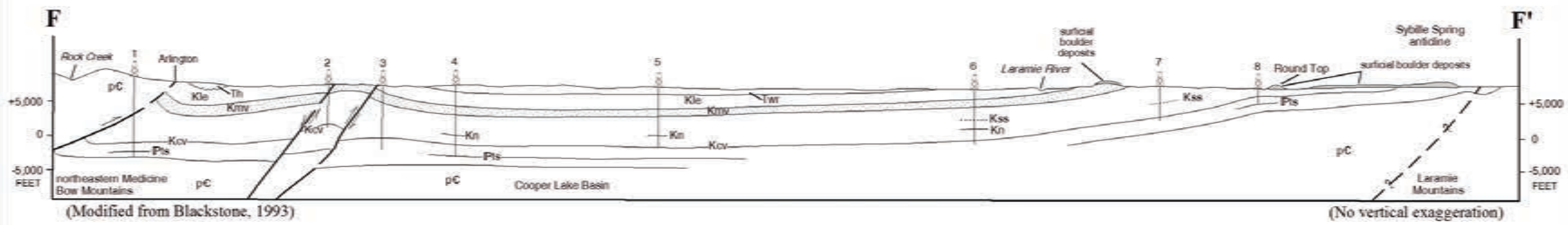
The surface geology consists of nearly horizontal unconsolidated Quaternary deposits which overlay Tertiary units that lie unconformably on Mesozoic and Paleozoic rocks downfolded into a large trough. The structure contour map **(Plate 1, inset)** of the Precambrian basement surface shows that the synclinal axis of the Laramie Basin is located along the west side of the basin and trends generally north-south along the arc of the mountain front of the thrust/reverse faulted Medicine Bow Mountains. Maximum structural relief between the deepest area of the basin and the highest area of the uplifts is about 16,000 feet defined by the difference between elevations in the deepest part of the structural basin, approximately 4,000 feet below sea level and on Medicine Bow Peak at 12,006 feet above sea level in the Snowy Range Mountains (Blackstone, 1993).

4.9 Laramie, Medicine Bow and Sierra Madre Mountain Ranges (WSGS, 2013)

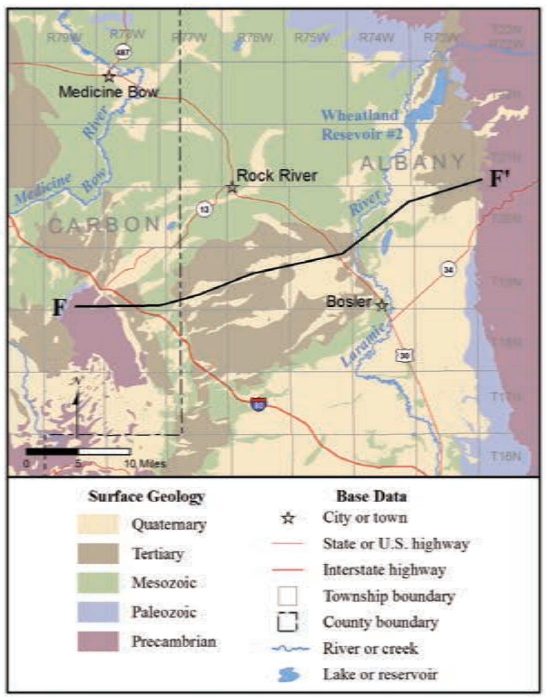
Just south of the Colorado-Wyoming boundary, the mountain masses of the Colorado Front Range of the Southern Rocky Mountains divide into three prongs that extend northward into Wyoming. These three prongs are known, from east to west, as the Laramie Mountains, the Medicine Bow Mountains, and the Sierra Madre. The Laramie Mountains (**Plate 1, Figures 4-1,** and **4-12** through **4-16**) are most closely related to, and are an extension of, the Colorado Front Range. In Wyoming, they separate the Denver Basin and Hartville uplift to the east from the Laramie and Shirley basins to the west. Casper Mountain, a northern salient of the Laramie Mountains, borders the Casper arch on the south. The northeastern Laramie Mountains borders the Powder River Basin on the south.

The *Laramie Mountains* are a moderately high (8,000 – 9500 feet above sea level) mountain range. The high relief landscape in the northern part of the range is capped by Laramie Peak (elevation 10,274 feet), a famous landmark well known to emigrants traveling westward along the Oregon Trail. Farther south, near the border between Wyoming and Colorado, the Laramie Mountains have been reduced by erosion to low relief. The basic geologic structure of the range is of a large asymmetric arch, steepest on the east. Precambrian rocks are extensively exposed in its core, which is flanked by sedimentary strata.

Crossing the Laramie Mountains between Cheyenne and Laramie, Interstate 80 and the Union Pacific Railroad first traverse a relatively flat surface of late Tertiary sedimentary rocks called the "Gangplank," finally reaching the Precambrian core of the mountains and a rolling upland of low relief at about 8,000 feet above sea level called the Sherman surface. The Gangplank



Index Map and Line of Section



Explanation

Symbols

- Formation contact, symbol indicates formation top
- Inferred, projected, or restored formation contact or bedding planes
- Approximate position of formation or marker bed
- Fault - dashed where inferred; queried where hypothetical or unknown; arrows indicate direction of relative movement
- Unconformity
- Mesaverde Group
- Surficial deposits
- Well location and designation

Geologic Units

CENOZOIC
Tertiary
Th Hanna Formation
Twr Wind River Formation
MESOZOIC
Cretaceous
Kle Lewis Shale
Kmv Mesaverde Group
Kss Shannon Sandstone
Kn Niobrara Formation
Kcv Cloverly Formation (Dakota Sandstone)
PALEOZOIC
Pennsylvanian
Pts Tensleep Sandstone
PRECAMBRIAN
pC Precambrian rocks

Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-007-21086	ROCKY MOUNTAIN STATE 1-44-3(	36-19N-79W	8,640 GR	11,677	Precambrian	1985
2	49-007-05202	STATE OF WYO-J 1	36-19N-78W	7,553 KB	6,027	Morrison	1964
3*	N/A	#1 HERRON	30-19N-77W	7,436	7,959	N/A	N/A
4	49-001-20101	COOPER 34-27	27-19N-77W	7,310 GR	10,336	Tensleep	1985
5	49-001-20027	DOLEZAL-STATE 1	16-19N-76W	7,122 KB	8,532	Dakota Sandstone	1971
6	49-001-20040	SCHMALE 11-1	1-19N-75W	7,054 GR	7,069	Morrison	1974
7*	N/A	1-15 LONG LAKE	15-20N-74W	7,034	5,010	N/A	N/A
8	49-001-05200	GOVT 1	12-20N-74W	7,016 GR	2,080	Morrison	1960

GR = ground; KB = kelly bushing

* Original data; no data was available from the Wyoming Oil and Gas Conservation Commission

Figure 4-7. Geologic cross section F-F'.

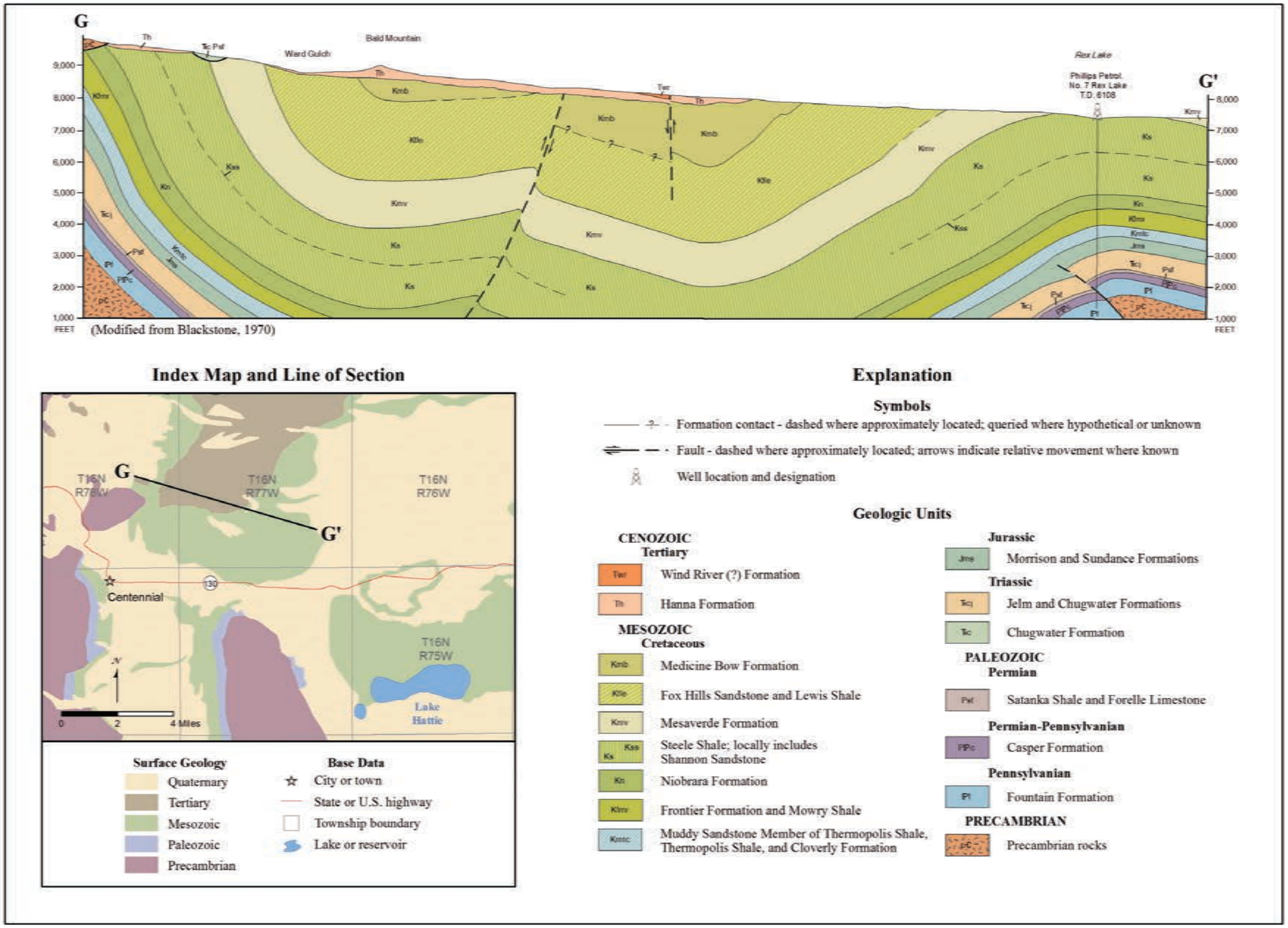


Figure 4-8. Geologic cross section G-G'.

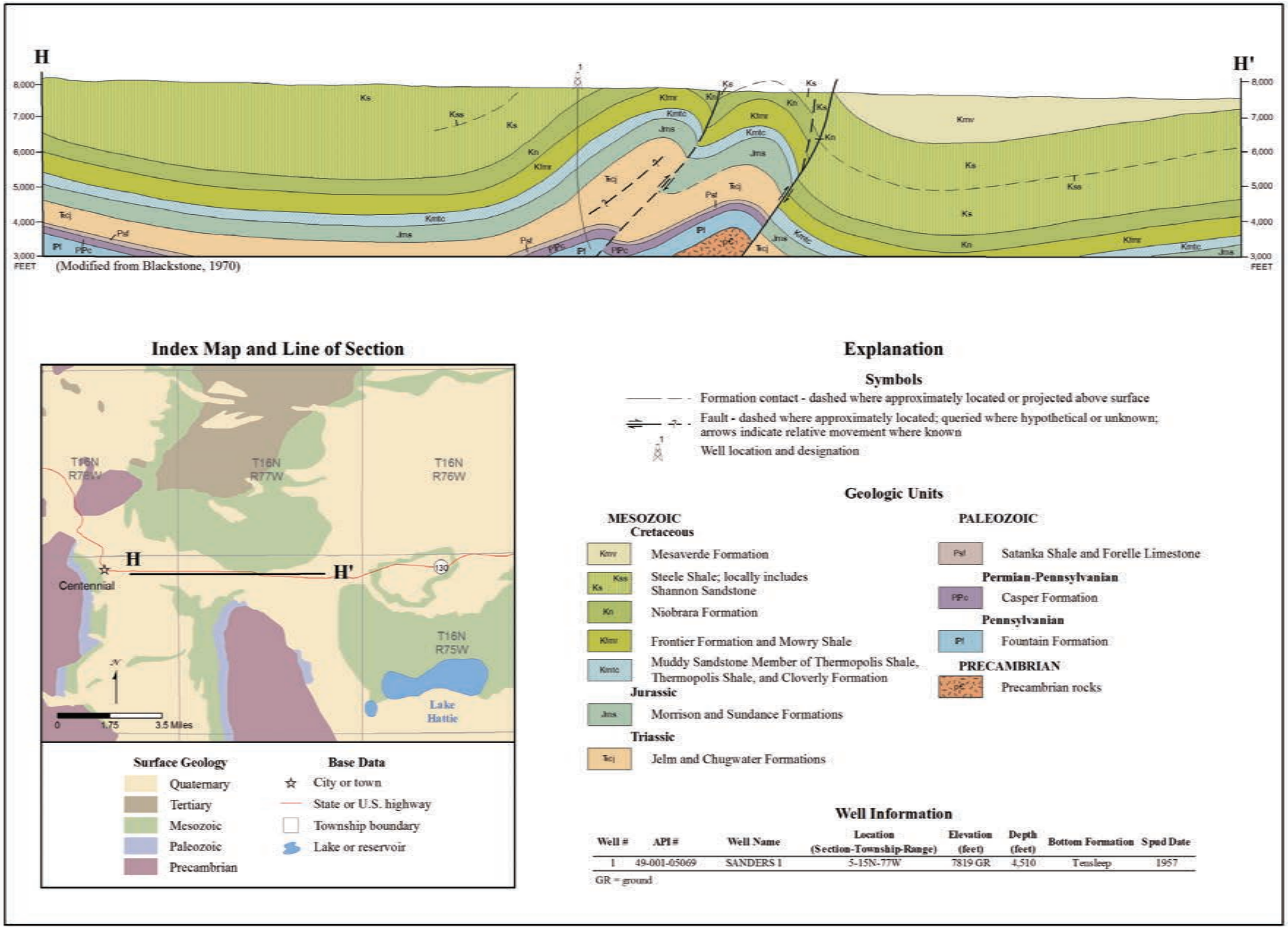


Figure 4-9. Geologic cross section H-H'.

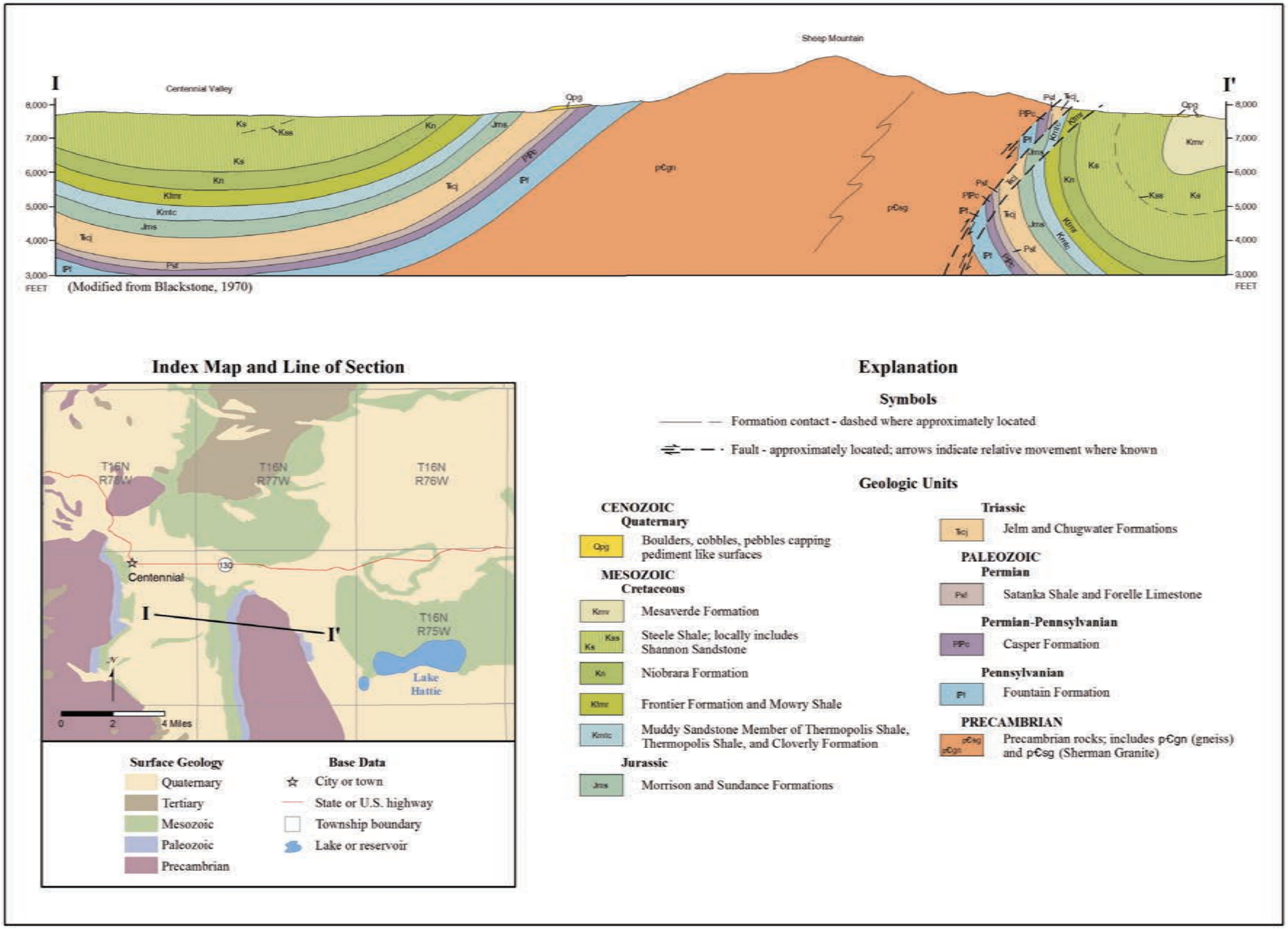


Figure 4-10. Geologic cross section I-I'.

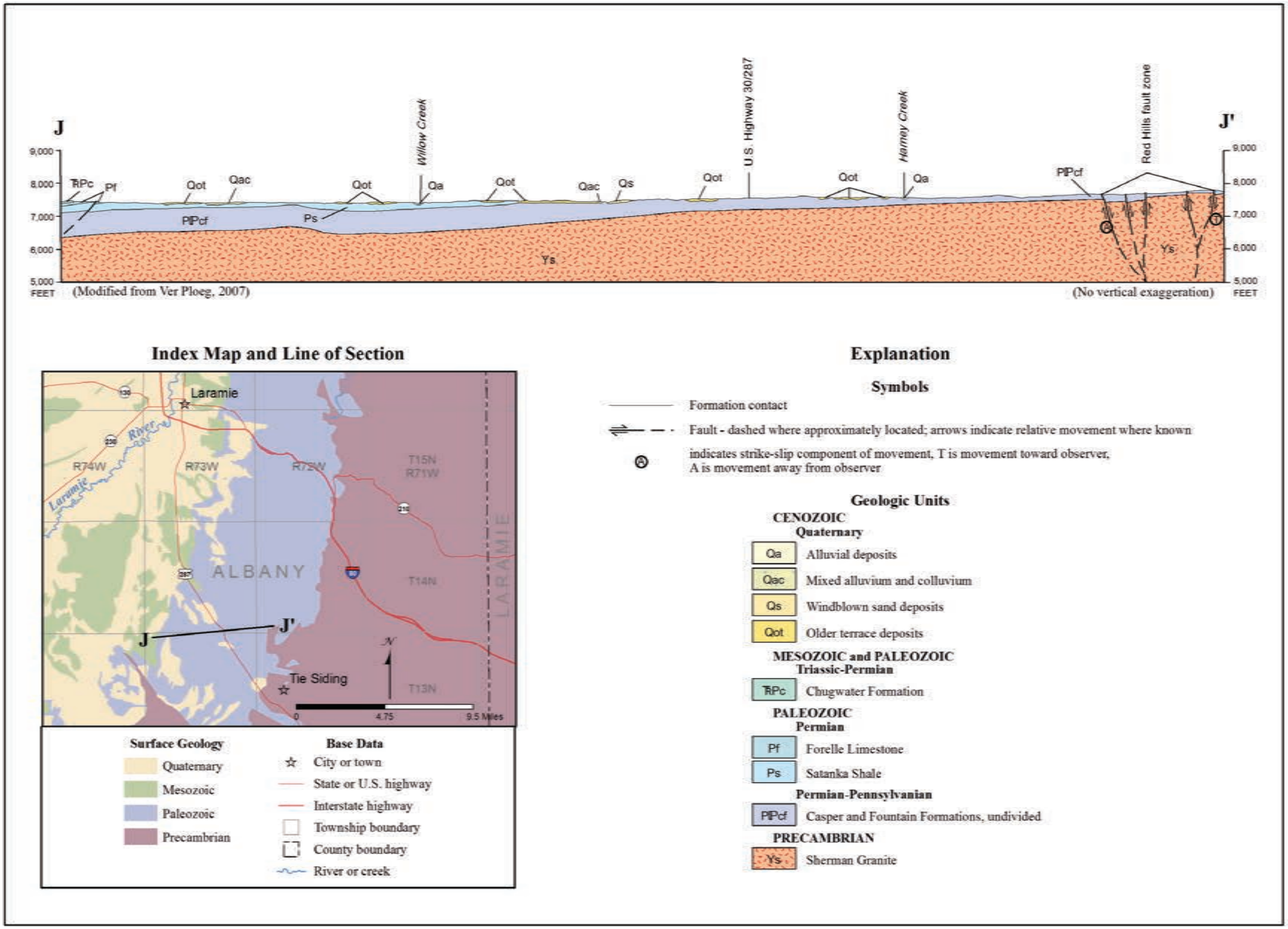


Figure 4-11. Geologic cross section J-J'.

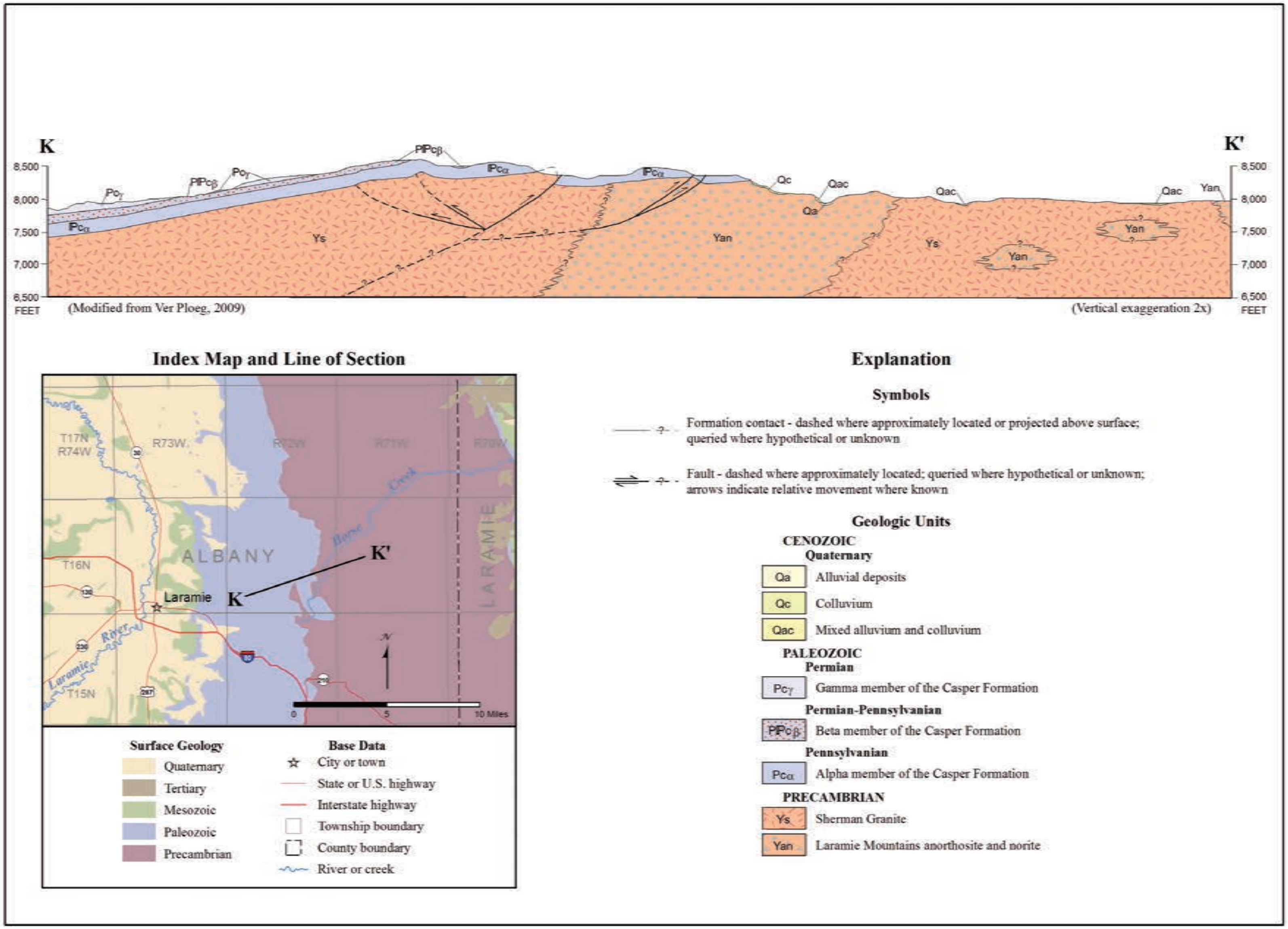


Figure 4-12. Geologic cross section K-K'.

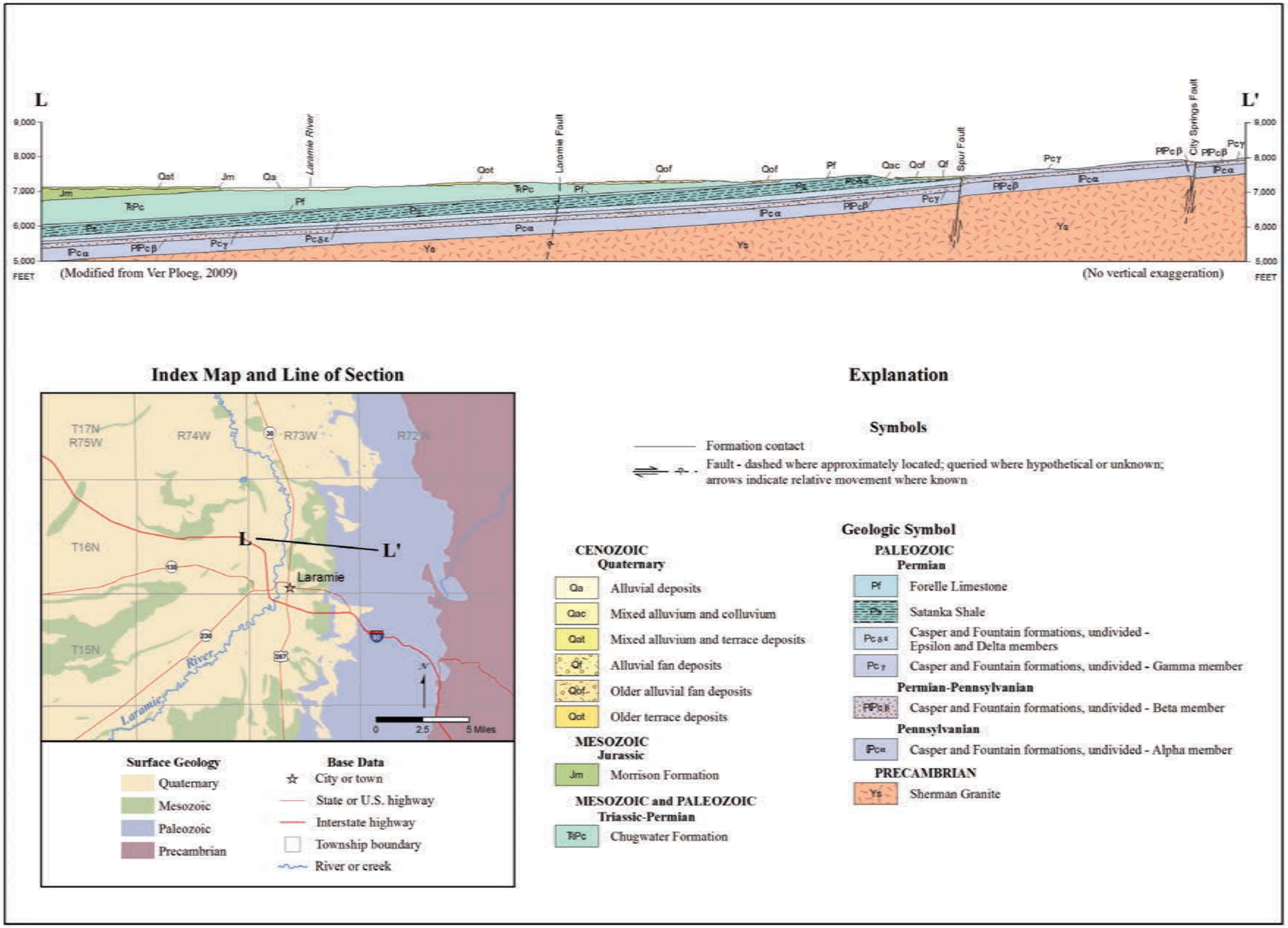


Figure 4-13. Geologic cross section L-L'.

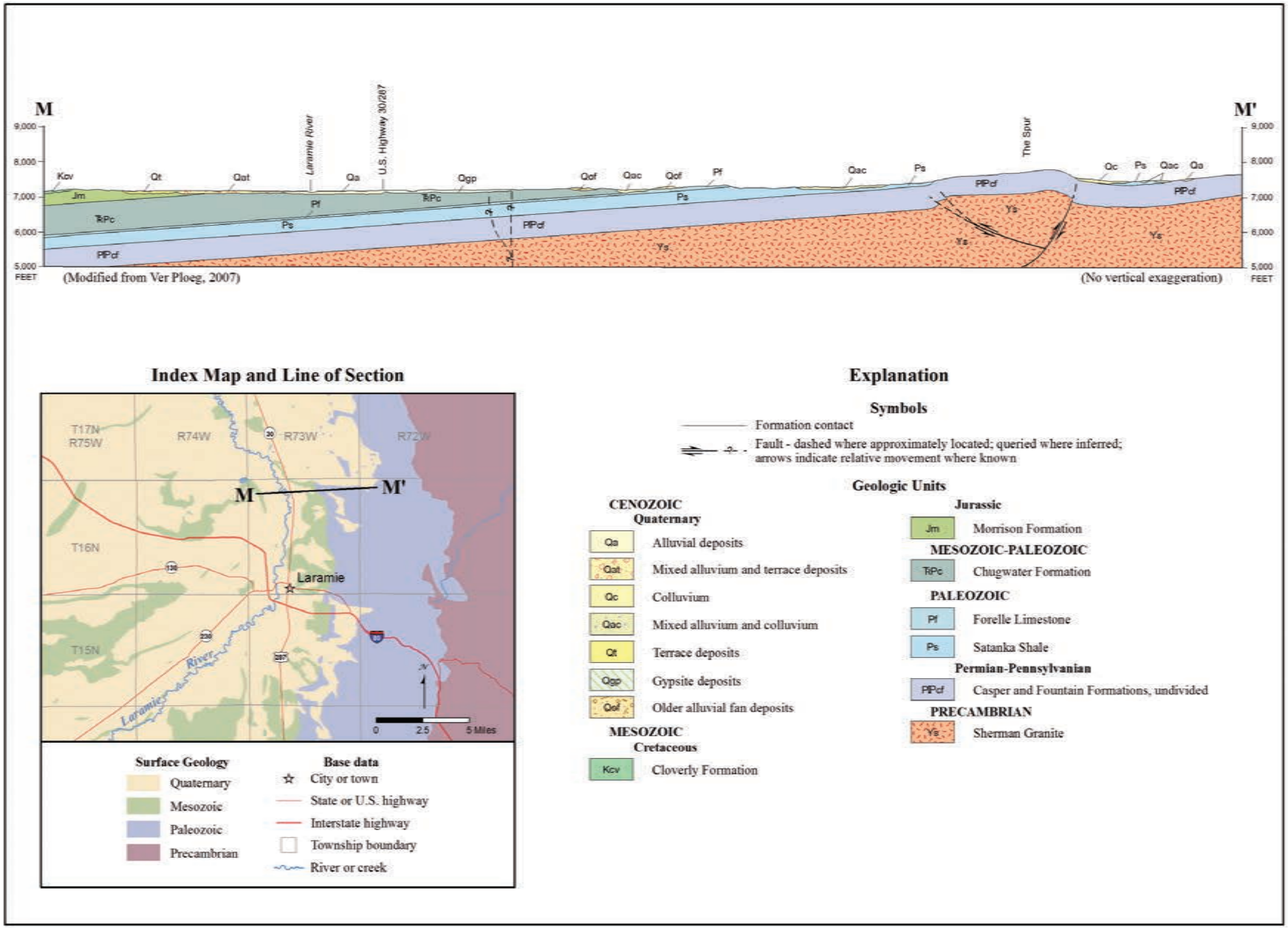
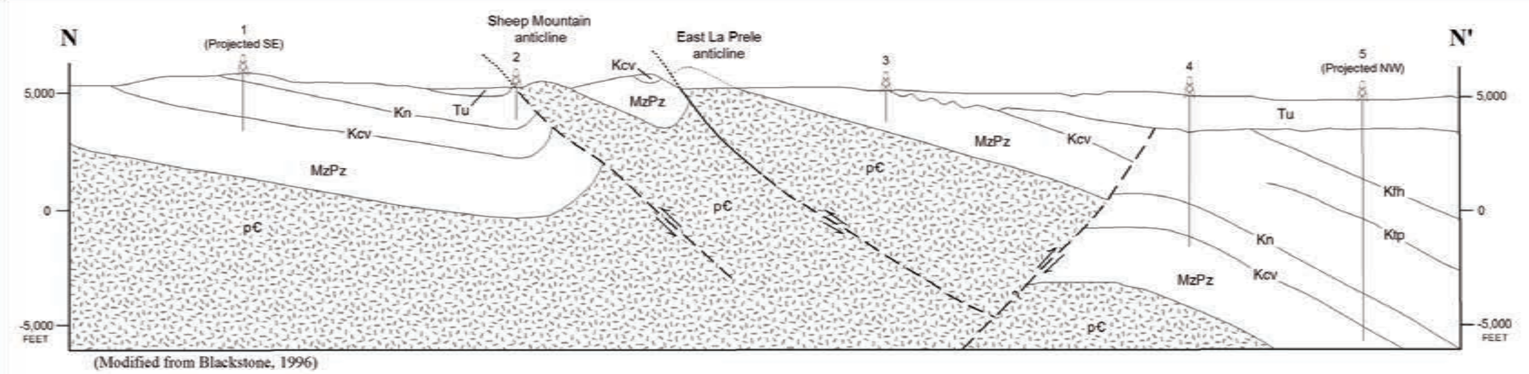
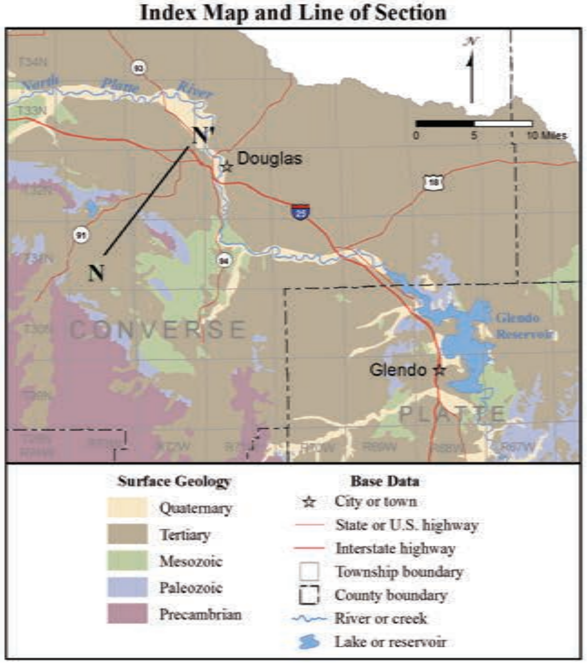


Figure 4-14. Geologic cross section M-M'.



Index Map and Line of Section



Explanation

Symbols

- Formation contact - dotted where projected above surface
- Fault - dashed where inferred; queried where hypothetical or unknown; dotted where projected above surface; arrows indicate direction of relative movement
- Unconformity
- Well location and designation

Geologic Units

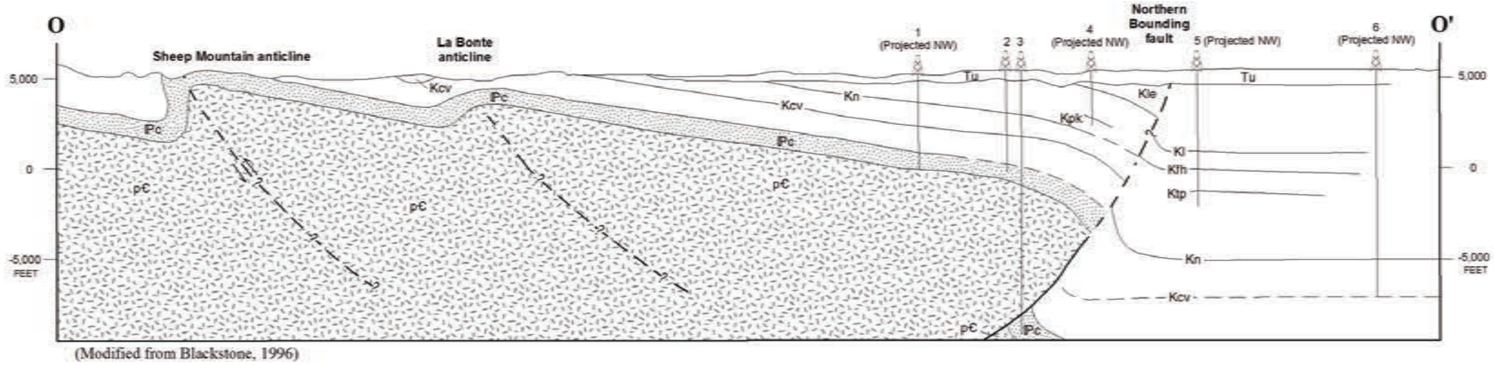
CENOZOIC
Tertiary
Tu Tertiary rocks, undifferentiated
MESOZOIC
Cretaceous
Kfh Fox Hills Sandstone
Ktp Teapot Sandstone Member of the Mesaverde Formation
Kn Niobrara Formation
Kcv Cloverly Formation
MESOZOIC and PALEOZOIC
MzPz Mesozoic and Paleozoic rocks, undifferentiated
PRECAMBRIAN
pЄ Precambrian rocks

Well Information

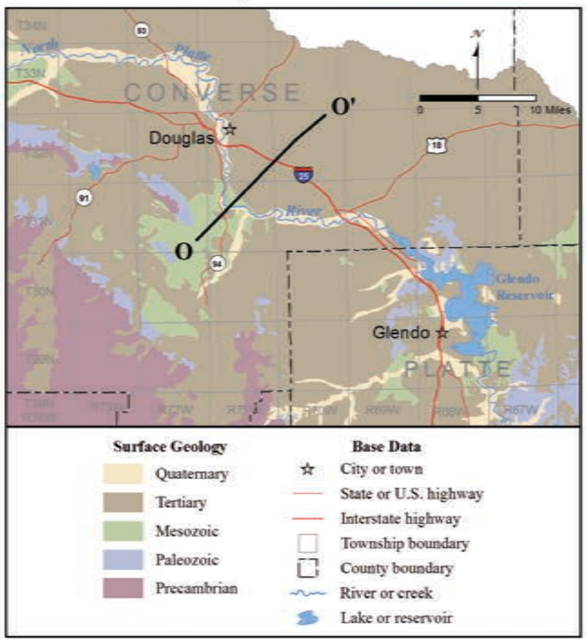
Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-009-05045	CROSS RANCH 1	10-31N-73W	6,013 GR	2,415	NA	1961
2	NA	NA	NA	NA	NA	NA	NA
3	49-009-60040	GIBB 1-20	20-32N-72W	5,470 KB	1,160	NA	1984
4	49-009-05203	WHITTEN 1	10-32N-72W	5,045 KB	6,754	Sundance	1958
5	49-009-21979	CZAR WEST 1-1	1-32N-72W	4,882 GR	10,953	Morrison	1981

GR = ground; KB = kelly bushing

Figure 4-15. Geologic cross section N-N'.



Index Map and Line of Section



Explanation

Symbols

Formation contact - dashed where inferred or poorly known

Fault - dashed where inferred; queried where hypothetical or unknown; arrows indicate direction of relative movement

Unconformity

Well location and designation

Geologic Units

CENOZOIC
Tertiary
Tu Tertiary rocks, undifferentiated

MESOZOIC
Cretaceous
Kl Lance Formation
Kfh Fox Hills Sandstone
Kle Lewis Shale
Ktp Teapot Sandstone Member of the Mesaverde Formation
Kpk Parkman Sandstone Member of the Mesaverde Formation
Kn Niobrara Formation
Kcv Cloverly Formation

PALEOZOIC
Pennsylvanian
IPc Casper Formation

PRECAMBRIAN
pC Precambrian rocks

Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-009-07008	GOVT-PARTRIDGE 1	32-32N-70W	4,952 KB	5,273	Minnelusa	1962
2	49-009-05115	FEDERAL F-14-1	19-32N-70W	5,244 KB	5,711	Leo (Minnelusa)	1957
3*	49-009-22649-0101	SCOTT 34-19	19-32N-70W	5,162 GR	15,200	Casper	1993
4	49-009-06577	MORTON RANCH 1	20-32N-70W	5,252 KB	2,987	Parkman Sandstone	1967
5	49-009-20031	WYOMING STATE-F 1	16-32N-70W	5,156 KB	7,952	Parkman Sandstone	1968
6	49-009-21829	MORTON 1	10-32N-70W	5,172 KB	13,146	Lakota	1980

GR = ground; KB = kelly bushing
* Data from WSGS records

Figure 4-16. Geologic cross section O-O'.

is the only place along the entire eastern mountain front where the Tertiary rocks that once buried the Laramie Mountains are still preserved and are in contact with the Precambrian core of the mountains. Further erosion during later Tertiary time left a few higher granite boulder knobs such as the spectacular area at Vedauwoo. Sherman Pass, at the summit of the Laramie Mountains on Interstate 80, is the highest point (8,640 feet above sea level) on this transcontinental highway. The Pennsylvanian Permian Casper formation outcrops along the western flank of the Laramie Mountains from Sherman Pass to the city limits of Laramie and its heavily fractured alternating limestone-sandstone strata can be seen in the road cuts along I-80.

The Medicine Bow Mountains are the middle prong of the Front Range that projects into Wyoming, and the northward extension of the Never Summer Range in Colorado. This mountain range is separated from the Laramie Mountains by the Laramie Basin, a structural basin underlying the Laramie plains. The mountains are characterized by a rather broad, rolling upland surface approximately 9,000 feet above sea level, above which rise two areas of higher relief. The highest part of the Medicine Bow Mountains, the Snowy Range, consists of a thick sequence of metasedimentary rocks, including a thick, very resistant white quartzite that culminates in Medicine Bow Peak at 12,006 feet.

The Medicine Bow uplift contains an excellent geologic record of two major ages of Precambrian rocks in the western United States: the older Archean (more than 2.5 billion years old) and the younger Proterozoic (2.5 billion to 540 million years old). A thick series of Proterozoic metasedimentary rocks is in fault contact along a major shear zone (or suture) with an older sequence of Archean-age metamorphic rocks. Stromatolites occur within 1.7 billon-year-old metasedimentary rocks. Stromatolites are fossil remains of blue-green algae, among the oldest and earliest forms of life known. They resemble giant cabbage heads and can be seen along the road to Lewis Lake en route to the Sugarloaf Recreation Area.

The *Sierra Madre* is the name applied in Wyoming to a section of mountainous terrain that is continuous with a mountain mass in Colorado called the Park Range. The Sierra Madre Range is the western prong of the Colorado Front Range that projects into Wyoming. This uplift separates the Saratoga Valley from the Washakie Basin, and may be structurally connected to the Rawlins uplift to the north. The Continental Divide runs along the crest of the Sierra Madre, and the highest point is Bridger Peak (11,007 feet). Drainages on its west flank flow to the Colorado River by way of the Little Snake River; drainages on its east flank flow to the North Platte River.

Geologically, the Sierra Madre are quite similar to the Medicine Bow Mountains, but lack the broad upland surface of the latter. The same major shear zone (or suture) that cuts across the Medicine Bow Mountains is also present in the Sierra Madre. This suture, called the Cheyenne belt, separates the oldest Archean rocks of what is known as the Wyoming Province to the north from younger igneous and metamorphic rocks to the south. Attached to the rocks north of the Cheyenne belt are some younger Early Proterozoic metasedimentary rocks similar to those in the Medicine Bow Mountains to the east. The Archean rocks of the Wyoming Province extend northward from the Sierra Madre to form the Precambrian cores of nearly all Wyoming mountain ranges. South of the Cheyenne belt in the Sierra Madre are well-preserved metamorphosed volcanic and sedimentary rocks (including basalt, andesite, and rhyolite flows and tuffaceous rocks, shales, and greywackes), as well as some younger granitic intrusions approximately 1.7 and 1.4 billion years old.

4.10 Rawlins Uplift (WSGS, 2013)

The Rawlins Uplift defines the eastern margin of the Great Divide Basin, the western end of southeastern Wyoming, and the beginning of the desert basin of the west. It is a small Laramide Uplift that has many of the characteristics of larger Wyoming ranges. Precambrian basement rocks are exposed in the core of the uplift, and its flanks are composed of outwardly-dipping Paleozoic and Mesozoic strata. A thrust fault dips beneath the uplift along the west and south sides. Rawlins lies at its south end.

4.11 Saratoga Valley (WSGS, 2013)

This area is a northwest-trending structural low between uplifts of the Medicine Bow Mountains to the east and the Sierra Madre to the west. The North Platte River flows north through this valley. Rocks of Miocene age overlie (or are faulted against) Precambrian rocks in the southern Saratoga Valley near the Colorado border and progressively truncate Paleozoic and lower Mesozoic rocks in the subsurface to the north. Upper Cretaceous rocks crop out in the northern Saratoga Valley and form a small sub-area known as the Kindt Basin. The east-trending Grenville Dome and Fort Steele anticlines on the northern flank of the Kindt Basin approximately define the northern boundary of the Saratoga Valley, separating it from the Hanna Basin to the north, while the Rawlins uplift and Miller Hill anticline (the northern projection of the Sierra Madre) bound the valley to the northwest.

4.12 Great Divide Basin, Wind River Basin, Powder River Basin (WSGS, 2013)

The Platte River Drainage Basin contains small portions of the northern Great Divide, southeastern Wind River, southwestern Powder River and northeastern Green River structural basins. The Green River and Great Divide structural basins constitute two subbasins within the Greater Green River Basin.

4.12.1 Great Divide Basin

Geologically, the *Great Divide Basin* is one of the two eastern sub-basins within the Greater Green River Basin. It is bounded on the east by the Rawlins uplift; on the north by the Granite Mountains (and related Crooks Mountain-Green Mountain uplifts) and the southern Wind River Range; and on the west by the north plunge of the Rock Springs uplift. The deepest part of the basin lies along the steep east flank of the Rawlins uplift and the northern mountains. The Great Divide basin contains a thick sequence of marine Upper Cretaceous and continental early Tertiary rocks as well as lacustrine rocks related to the Eocene Green River Formation. A thick, early Eocene arkosic conglomerate called the Battle Spring Formation crops out in the northeast third of the basin and interfingers with finer-grained rocks in the rest of the basin. This conglomerate was derived from the Granite Mountains that once stood high above the northern part of the basin. The maximum thickness of the sedimentary units in that part of the Great Divide Basin located within the Platte River watershed exceeds 29,000 feet (Blackstone, 1993).

Because of its location at the top of the continent, and the fact that no high mountain masses exist to the west or the east, the Great Divide Basin presents no restriction to the westerly airflow pattern of western North America. This westerly flow is "funneled" through southwestern Wyoming between the mountain masses of the Overthrust Belt/Wind River Range in Wyoming and the Wasatch/Uinta mountains in Utah. In other words, the wind blows, and it blows a lot, in this part of Wyoming. Because southwestern Wyoming is a desert environment and many of the outcropping rocks are poorly consolidated and easily eroded, it is no coincidence that the Great Divide Basin is home to extensive sand dune fields. For example, the Killpecker dune field, which extends across the Great Divide Basin from near Farson to Seminoe and Pathfinder Reservoirs, is the largest continuous area of active sand dunes in the U.S. In the Platte River Basin, the Killpecker dune field extends eastward from the south side of Green Mountain across the northern Great Divide basin to Seminoe Reservoir, passing along the south side of the Ferris Mountains and Seminoe Mountains. Another arm of the dune field runs northeast past the west end of the Seminoe Mountains to Pathfinder Reservoir. Surrounding the areas of active sand dunes are even larger areas of stabilized or inactive dunes.

4.12.2 Wind River Basin

Almost exactly in the center of Wyoming is a rhomboidal topographic depression known as the Wind River Basin (**Plate 1, Figure 4-5**). Mountains and uplifts surround the basin, and nothing about the area is simple. The east and west sides of the rhomb are bounded by the northwest-trending Casper arch and Wind River Mountains, respectively; the north side is bounded by the Bridger-Owl Creek-Washakie ranges; and the south side is bounded by the Granite Mountains. In general, the basin is a highly asymmetrical syncline, with the basin axis nearest and parallel to the northern mountains and the Casper arch. The deepest part of the trough lies in the north, immediately adjacent to the Owl Creek Mountains, where the Precambrian basement may be displaced vertically more than 30,000 feet. The maximum thickness of the sedimentary units in that part of the Wind River Basin located within the Platte River watershed is nearly 24,000 feet (Blackstone, 1993) and occurs farther to the southeast along the basin axis.

The western boundary of the basin is the east-dipping flank of the Wind River Range, characterized by northwest-trending hogbacks of Paleozoic sedimentary rocks. Structurally, the southern boundary is the northern flank of the Granite Mountains, defined by a series of northwest-trending features including the Rattlesnake Hills, Conant Creek, and Alkali Butte anticlines. These anticlines lie north of the North Granite Mountains fault system. Topographically, most of the southern boundary is a north-facing escarpment of Middle Eocene, Oligocene, and Miocene rocks known as Beaver Rim and Shirley Rim, an erosional feature analogous to the Pine Ridge escarpment in eastern Wyoming and Nebraska.

The Casper arch, a broad upfold of sedimentary rock, forms the eastern boundary. Topographic relief is low, but the rocks are greatly elevated relative to their depth in the Powder River and Wind River Basins on opposite sides of the arch. Exploratory drilling revealed that the west side of the arch is in the hanging wall of a thrust fault with low dip to the east. There is more than 5 miles of westward movement on this hanging wall, and the fault has actually overridden the synclinal axis of the Wind River Basin. Oil and gas production in deep reservoirs has been established in the footwall of this thrust fault.

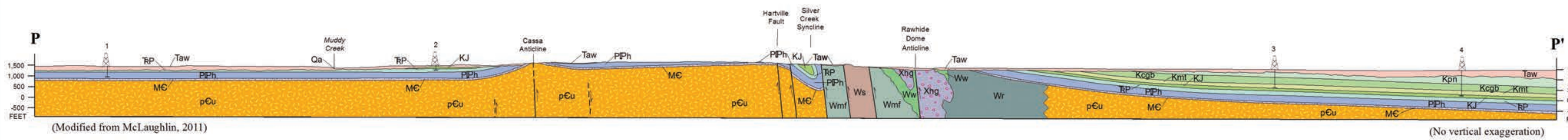
The first oil well in Wyoming was drilled southeast of Lander at Dallas Dome in 1884, and oil has been produced from this and a series of northwest-trending anticlines along the western and northwestern edges of the basin ever since. Extensive oil and gas development has occurred in nearly all parts of this basin, and reservoirs of nearly every age have produced. The basin contains a thick sequence of Upper Cretaceous and lower Tertiary sedimentary rocks that contain important reserves of coal, oil, and especially natural gas.

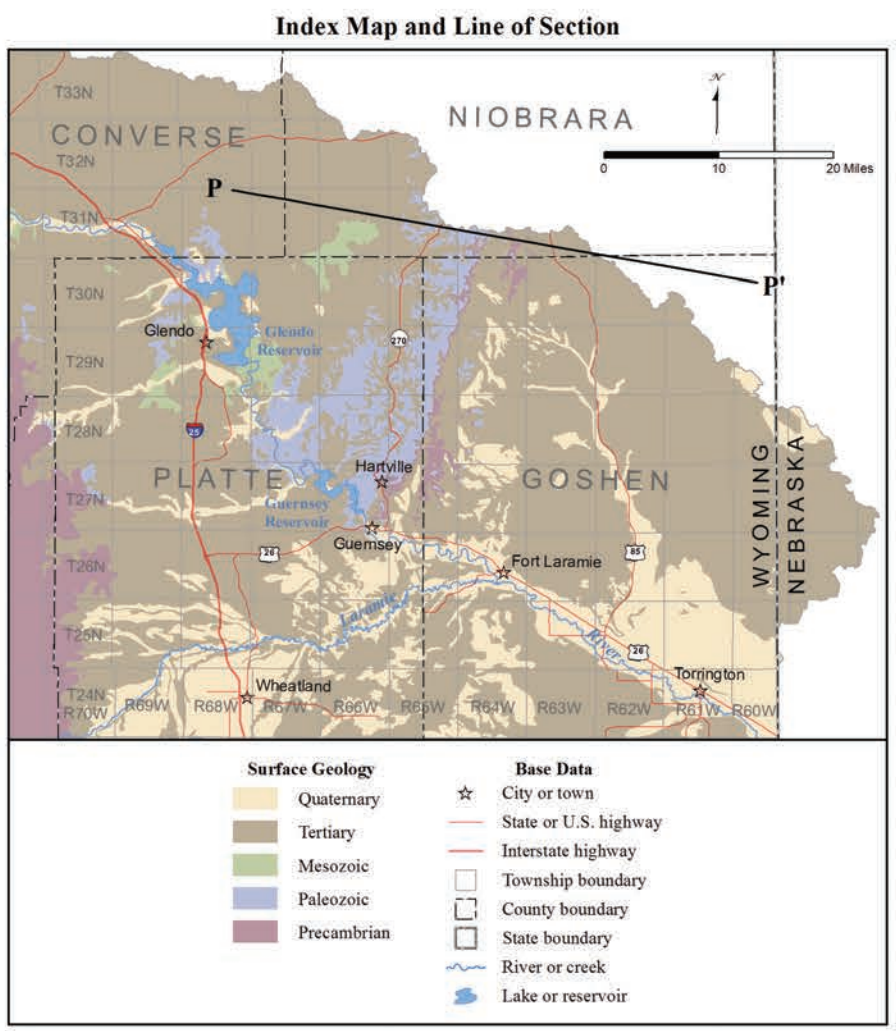
4.12.3 Powder River Basin

A very wide and moderately deep basin, the Powder River Basin (**Plate 1; Figures 4-1** and **4-17**) lies between the Black Hills and the Bighorn Mountains. It is separated from the Wind River Basin by the Casper arch and from the Denver Basin by the Hartville uplift. The basin is asymmetrical, with the steepest dips and the basin axis on the western side of the basin, near and parallel to the eastern Bighorn Mountain front. In several places along the western and southern edges, the basin has been overridden by thrust faults that place Precambrian and Paleozoic rocks against Tertiary rocks of the basin. The maximum thickness of the sedimentary units in that part of the Powder River Structural Basin situated within the Platte River watershed is almost 19,000 feet (Blackstone, 1993).

The basin edges are defined by a relatively thin band of Cretaceous marine sedimentary rocks; the basin interior is characterized by a wide expanse of lower Tertiary rocks, i.e., the Paleocene Fort Union Formation and the Eocene Wasatch Formation. In many places, the natural burning of thick coal beds initiated by lightning strikes, grass fires, and spontaneous combustion has baked the rocks overlying the coal beds in a manner similar to the action of a brick kiln. The resulting baked rock, known variously as clinker, red dog, or scoria, is usually red from oxidation of iron in the sediments; it is more resistant to erosion than the unbaked rocks below, and caps buttes and mesas over a large area of the basin where coal beds are at or near the surface.

This basin is one of the most important energy-producing areas in Wyoming (and the nation). Its vast coal resources are augmented by oil and natural gas resources, including natural gas produced from coal beds, and uranium deposits. Over broad areas, the Tertiary rocks contain extensive low-sulfur coal





Explanation

Symbols

- Formation contact
- Fault - dashed where approximately located; arrow indicates relative movement where known
- Well location and designation

Geologic Units

CENOZOIC

Quaternary

- Qa — Alluvial deposits

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

Cretaceous and Jurassic

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

Triassic and Permian

- ŦP — Chugwater and Goose Egg Formations, undivided

PALEOZOIC

Permian and Pennsylvanian

- PIPh — Hartville Formation, undivided

Mississippian, Devonian, and Cambrian (?)

- M€ — Mississippian, Devonian, and Cambrian (?) rocks, undifferentiated

PRECAMBRIAN

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

Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (Feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-009-22239	PICKINPAUGH 1-6	6-31N-68W	4,806 KB	1,472	Precambrian	1983
2	49-027-07025	BROOKS 1	14-31N-66W	5,112 KB	1,105	Opeche Shale	1951
3	49-015-20031	MARY S MOORE 1	1-30N-62W	4,932 KB	3,116	Morrison	1969
4	49-015-05087	STENGER 1-12	12-30N-61W	4,797 KB	4,239	Chugwater	1956

KB = kelly bushing

Figure 4-17. Geologic cross section P-P'.

deposits that are surface-mined near Gillette and Wright. Most of Wyoming's coal production comes from the Powder River Basin, and the state has been the leading coal producer in the U.S. since the late 1970s. The important Wyoming-type or "roll-front" uranium deposits were discovered at Pumpkin Buttes in the center of the basin in the 1950s, and led to the state's uranium boom.

4.12.4 Green River Basin (WSGS, 2013)

This is a large, complex intermontane area that covers much of southwestern Wyoming; it is used as a general term to include a number of separate structural arches and sedimentary basins as described below. Mountain ranges (uplifts) border the Greater Green River Basin on all but the western edge, where the Thrust Belt borders it. The Greater Green River Basin is bounded on the south by the Uinta Mountains and Cherokee Ridge; on the southeast, east, and northeast by the Sierra Madre, Rawlins uplift, Granite Mountains, and Wind River Range; and on the north by the Gros Ventre Range. Three major sedimentary basins are found within the Greater Green River Basin —the Green River, Washakie, and Great Divide basins. The Green River Basin occupies the western half of the Greater Green River Basin, and is separated from the Great Divide and Washakie basins in the east half of the Greater Green River Basin by the north-trending Rock Springs uplift. More specific details for each of these basins are described in their own separate sections. The Wamsutter arch, an eastward extension of the Rock Springs uplift, is a structural divide that separates the Washakie Basin from the Great Divide Basin.

The Greater Green River Basin is part of the Wyoming Basins geomorphic province; as one might expect, topographic relief within the Greater Green River Basin is much less than the surrounding mountains, with the lowest areas occupied by stream drainages and the higher areas by cuestas, mesas, and plateaus. Only a very small part (about 30 square miles) of the Green River Structural Basin falls within the Platte River drainage on the far western end of the watershed at the headwaters of the Sweetwater River. This upland area is overlain by undifferentiated Tertiary rocks.

4.13 Wind River Range (WSGS, 2013)

The Wind River Range is the largest and highest discrete mountain mass in Wyoming, containing most of the state's highest summit peaks, such as Gannett Peak (at 13,804 feet, the highest point in Wyoming), Fremont Peak (13,745 feet), and Wind River Peak (13,192 feet). Trending N 40° W from South Pass City on the south to Fish Lake Mountain on the north, the range is a major barrier between western and central Wyoming; it separates the Wind River Basin to the northeast from the Greater Green River Basin to the south and southwest. The northeast flank of the Wind River Range consists of a 96-mile-long, continuous band of Paleozoic sedimentary rocks exposed in a series of hogbacks and dip slopes that dip eastward into the Wind River Basin. The core of the range exposes an extensive area of some of the oldest Precambrian rocks in the state. The southwest flank of the range is characterized by an extensive thrust fault system, with Precambrian rocks thrust south and southwest onto relatively flat-lying Tertiary rocks in the Green River Basin. The fault system extends eastward where Precambrian rocks in the South Pass area were thrust over Tertiary rocks of the northern Great Divide Basin. A survey by the Consortium for Continental Reflection Profiling (COCORP) used reflection seismology across the southern Wind River Range along Wyoming State Highway 28 to gather new data on crustal structure. The data revealed that the thrust fault along the western boundary of the range dips to the east at an angle of 30° and extends to a depth of approximately 18.7 miles.

Glaciated peaks mark the high central region of the range; glaciers and permanent snowfields lie in the higher valley heads. U-shaped glaciated valleys issue from both the east and west sides of the Continental Divide, which forms the backbone of the range. On the west side of the range, a broad bench-like platform at about 9,400 feet above sea level is dotted by a myriad of glacial lakes. This high, relatively flat subsummit surface above timberline is dissected, as if by a biscuit cutter, by steep-sided glacial valleys. The range's highest peaks stand high above the subsummit surface. At the base of the mountain flanks, long, deep, morainedammed lakes—such as Fremont and New Fork on the west side and Dinwoody and Bull lakes on the east side—occupy valleys where glacial ice once flowed down from the higher regions onto the basin floor.

The South Pass area at the south end of the Wind River Range hosts a sequence of Archean (more than 2.5 billion years old) supracrustal metamorphic rocks called a greenstone belt that contains the state's principal gold deposits as well as iron ore deposits. Besides being an important point along the Oregon Trail, South Pass was also the site of extensive lode and placer gold mining in the 19th century and of a surface iron ore mine and mill in the 20th century. The area remains attractive for gold prospectors and has a rich and well-preserved history.

4.14 Hartville Uplift (WSGS, 2013)

The Hartville Uplift (**Plate 1; Figures 4-1** and **4-17** through **4-20**) and is a structural arch that separates the Denver Basin from the Powder River Basin. The arch extends from the northeast end of the Laramie Range to the south end of the Black Hills. Precambrian, Paleozoic, and Mesozoic rocks were raised along the arch during the Laramide orogeny, but were covered by the blanket of Cenozoic sediments. Today, there is very little topography to suggest that this is a structurally uplifted region. However, south of Glendo, to the east, Permian and Pennsylvanian-aged limestones, sandstones, and red shales poke through the blanket of Cenozoic strata to form tree-covered hills along the crest of the Hartville arch. These Paleozoic strata are also exposed in a large interstate highway roadcut at the north end of the Glendo Reservoir.

4.15 Denver Basin (Belitz and Bredehoeft, 1988, WSGS, 2013)

The Denver Basin (**Figures 4-1** and **4-20**), also known as the Denver Julesburg basin is a large (350 miles by 150 miles) oval shaped asymmetrical Laramide structural basin located in southeastern Wyoming, eastern Colorado, and western Nebraska. In Wyoming, the Denver structural basin is bounded on the north by the Hartville Uplift and on the west by the Laramie Mountains (Figure 3-2); the Cenozoic through Paleozoic sedimentary strata reach a maximum thickness of 12,000 feet near Cheyenne. The surface rocks here are nearly horizontal strata of Late Tertiary age, which lie unconformably on Paleozoic and Mesozoic rocks downfolded into a large trough. The trough extends southward from Cheyenne to Colorado Springs, Colorado. The axis of the trough lies a few miles east of the mountain front (Plate 1, inset). The maximum structural relief between the deepest area of the basin and the highest area of associated uplift in the Laramie Mountains exceeds 17,000 feet. This is the difference between elevations in the deepest part of the structural basin at approximately 7,000 feet below sea level near Cheyenne and at Laramie Peak, which is 10,274 feet above sea level.

4.16 Geothermal resources (Heasler and Hinkley, 1984; Hinkley and Heasler, 1986) - Figure 4-21

The geothermal resources of the Platte River Basin are of the low-temperature hydrothermal type, occurring where groundwater exists at anomalously elevated temperatures (relative to the average geothermal gradient). These elevated occurrences are not typically found at a depth where they can be put to beneficial use. Hydrothermal resources of the Platte River Basin are primarily suited to local, small-scale projects that utilize low-temperature waters for space-heating, de-icing, and recreational/ therapeutic applications (e.g., Saratoga Hot Springs).

Generally, groundwater is heated as it flows downdip into a structural basin in accord with the local geothermal gradient resulting from heat flow from deep in the earth toward the land surface. Platte River Basin hydrothermal resources occur primarily where the heated groundwater rises to shallower depth under artesian hydraulic pressures at velocities that preclude dissipation of the heat acquired at depth. This requires vigorous upward flow through permeable up-folded strata or up faults, fracture systems, or wells. In general, the conditions that control hydrothermal resources occur only within the more productive Mesozoic and Paleozoic aquifers in the Platte River Basin. The locations of known and potential areas of

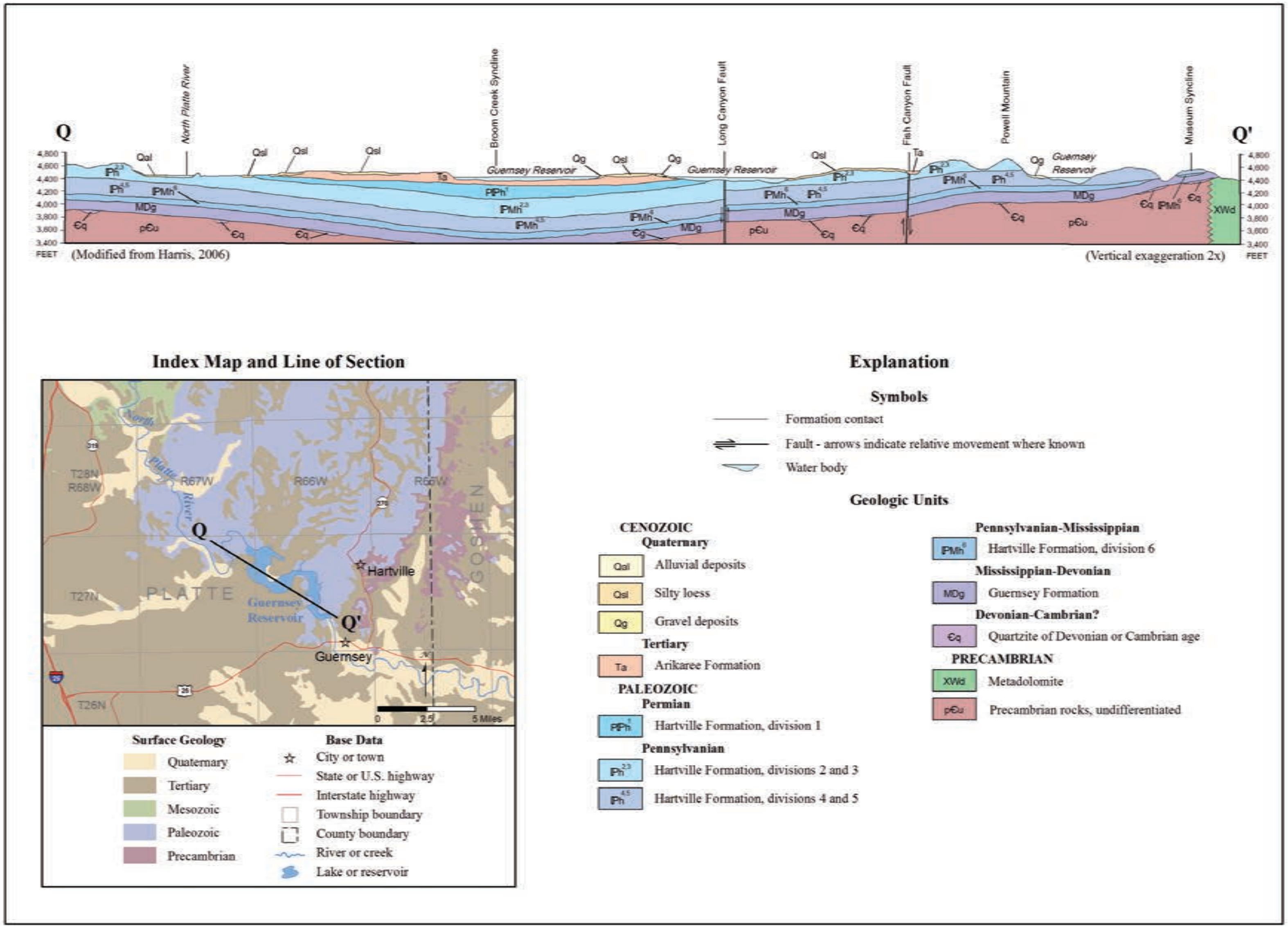


Figure 4-18. Geologic cross section Q-Q’.

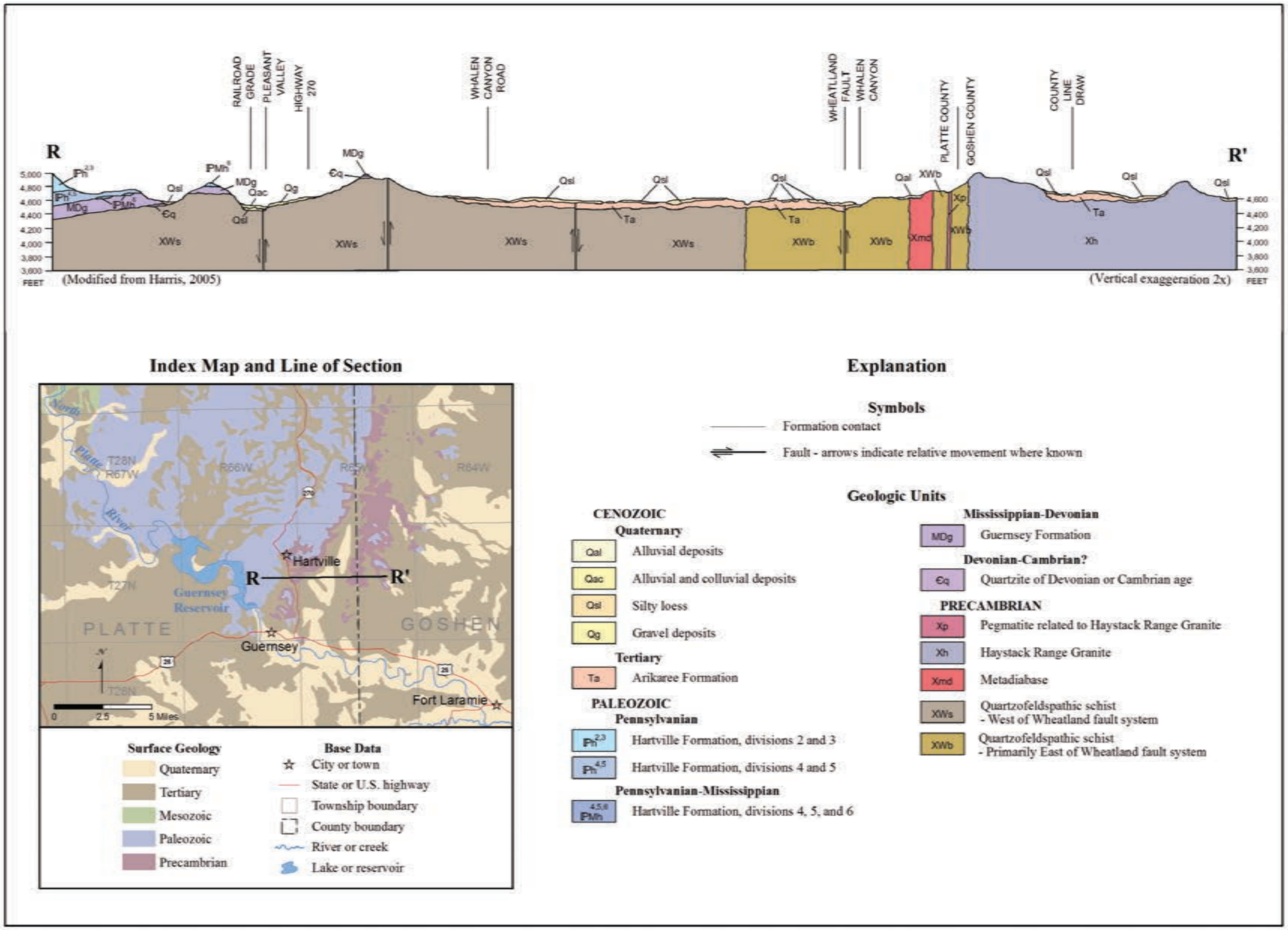
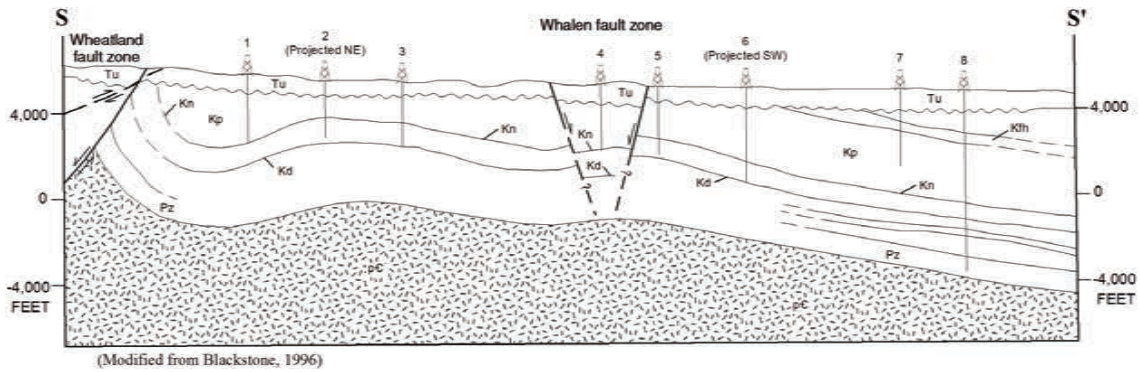
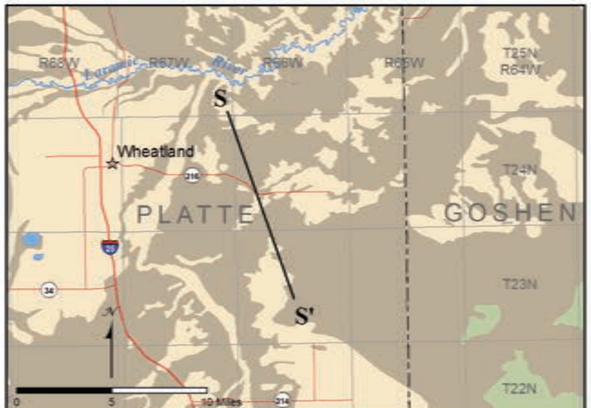


Figure 4-19. Geologic cross section R-R'.



Index Map and Line of Section



Surface Geology

- Quaternary
- Tertiary
- Mesozoic

Base Data

- ☆ City or town
- State or U.S. highway
- Interstate highway
- Township boundary
- County boundary
- River or creek
- Lake or reservoir

Explanation

Symbols

- Formation contact; symbol indicates formation top; dashed where inferred or poorly known
- Fault - dashed where inferred, queried where hypothetical or unknown; arrows indicate direction of relative movement
- Unconformity
- Well location and designation

Geologic Units

CENOZOIC

Tertiary

Tu Tertiary rocks, undifferentiated

MESOZOIC

Cretaceous

Kfh Fox Hills Sandstone

Kp Pierre Shale

Kn Niobrara Formation

Kd "Dakota" sandstone (Cloverly Formation)

PALEOZOIC

Pz Paleozoic rocks, undifferentiated

PRECAMBRIAN

p€ Precambrian rocks

Well Information

Well #	API #	Well Name	Location (Section-Township-Range)	Elevation (feet)	Depth (feet)	Bottom Formation	Spud Date
1	49-031-05009	PHIFER 1	18-24N-66W	4,631 KB	3,033	N/A	1956
2	49-031-20015	SHELL-FEDERAL 19-6	19-24N-66W	4,996 KB	2,740	Carlile Shale	1970
3	49-031-20031	SULLIVAN-JOHNSON 1	29-24N-66W	4,987 KB	3,208	Carlile Shale (Codell Sandstone)	1976
4	49-031-20004	GOVT 31-32	32-24N-66W	5,013 KB	3,080	Carlile Shale	1969
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	49-031-20022	JOHNSON 1	33-24N-66W	5,107 KB	4,520	Dakota	1975
7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	49-031-20038	BASS ASHENHURST FEE 16-31	16-23N-66W	5,142 GR	9,575	Precambrian	1982

GR = ground; KB = kelly bushing

Figure 4-20. Geologic cross section S-S'.

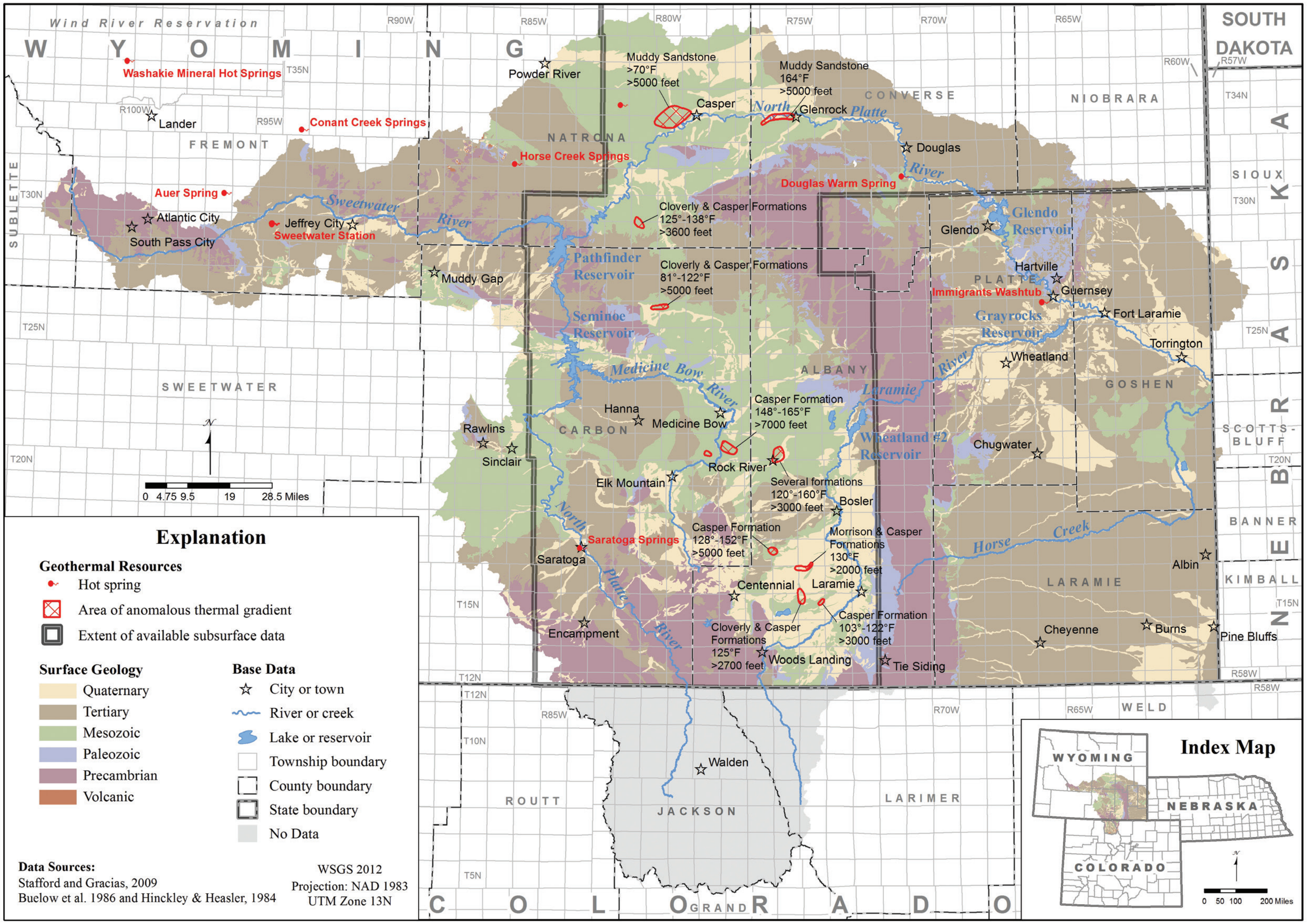


Figure 4-21. Geothermal resources, Platte River Basin.

hydrothermal resource development are shown on **Figure 4-21**.

4.17 Mineral resources

The development of mineral resources generally requires the use and proper disposal or surface discharge of groundwater and has a high potential to create avenues for groundwater contamination. **Figures 5-4, 5-7, 5-8, and 5-9** show the distribution of oil-and-gas operations and other active and historic mineral development locations within the Platte River Basin **(Section 5.7.2**). Even in areas without active mineral development, the presence of some naturally occurring minerals such as those that contain uranium, arsenic, and hydrocarbons, can, at significant concentrations, negatively impact groundwater quality. Some small communities in the northern part of the Platte River Basin have had to develop mitigation plans to address exceedances for naturally occurring radium, uranium and/or arsenic in their public water systems (WWC, 2011; Olsson Associates, 2008).

Significant quantities of oil and gas have been developed in the Platte River Basin primarily in the Casper Arch, High Plains and northern Great Divide Basin **(Figure 5-4)**. In the last few years, increased oil and gas exploration and production operations are focused on the Cretaceous Niobrara and Frontier Formations from Cheyenne north to Douglas. This trend has continued over the last year (June 1, 2012 to June 1, 2013) with over 140 Applications for Permit to Drill (APD) filed with the Wyoming Oil and Gas Conservation Commission (WOGCC) for wells in Converse County and 67 APDs approved for Laramie County. Again, most of these permits target the Niobrara Formation.

Substantial uranium and coal have been commercially developed in the Platte River Basin. Currently, there is no active coal mining in the Platte River Basin but uranium is mined by in-situ recovery extraction at the Smith Ranch-Highland operation 23 miles northwest of Douglas. Industrial minerals including sand, gravel, clay, limestone, dolomite, feldspar, shale, bentonite, and gypsum have been extensively mined within the Platte River Basin, and still are produced in many locales **(Figures 5-7, 5-8, and 5-9)**.

The Wyoming State Geologic Survey (WSGS) has evaluated many Wyoming sites for potential mineral development. These include precious metals (Hausel, 1989, 2002), gemstones (Hausel and Sutherland, 2000), base metals (Hausel, 1993, 1997), industrial minerals (Harris, 1992, 1996), decorative stones (Harris, 2003), coal (Jones and others, 2011), coal bed natural gas (WSGS, 2005) and oil and gas (Lynds, 2013). Although these reports and maps generally discuss groundwater, they do provide information on areas of future development that could create potential impacts on state groundwater resources. Mineral development in the Platte River Basin as a source of potential contamination to groundwater resources is further discussed in **Chapter 5.**