Chapter HF

FRAMEWORK GEOLOGY OF FERRIS AND HANNA COAL IN THE HANNA AND CARBON BASINS

By R.M. Flores,[1] V.V. Cavaroc, Jr.,[2] and L.R. Bader[1]

in U.S. Geological Survey Professional Paper 1625-A

[1]U.S. Geological Survey

[2]North Carolina State University, Raleigh, North Carolina

Click here or on this symbol in the toolbar to return.

Contents

Figures

HF-14. Fluvial channels, floodplains, and swamps of the Columbia River in the Province of British Columbia, Canada.

HF-15. Crevasse splay of the Saskatchewan River in the Province of Saskatchewan, Canada.

HF-16. Structural cross section B-B' showing the Ferris 65 coal bed.

HF-17. Fluvial channel of the Beluga River, Alaska.

HF-18. Fluvial channel and associated crevasse splay of the Saskatchewan River in the Province of Saskatchewan, Canada.

HF-19. Structural cross section C-C' showing the Ferris 48-50 coal beds.

HF-20. Structural cross section D-D' showing the Hanna 77-78 coal beds.

HF-21. Structural cross section E-E' showing the Hanna 81 coal bed.

HF-22. Structural cross section F-F' showing the Hanna 78, 79, and 81 coal beds.

HF-23. Anastomosed fluvial channels and associated swamps of the Saskatchewan River in the Province of Saskatchewan, Canada.

HF-24. Structural cross section G-G' showing the Hanna 78-79 coal beds.

HF-25. Structural cross section H-H' showing the Hanna 78-81 coal beds.

HF-26. Structural cross section I-I' showing the Johnson-107 coal zone.

HF-27. Crevasse splays draining into floodplain lakes from anastomosed fluvial channels of the Columbia River in the Province of British Columbia, Canada.

HF-28. Structural cross section J-J' showing the Johnson-107 coal zone.

STRUCTURAL SETTING

- The Hanna and Carbon Basins are in Carbon County, south-central Wyoming (fig. HF-1).
- The Hanna Basin is the deeper of these basins and contains more than 30,000 ft of sedimentary rocks overlying crystalline basement (Knight, 1951).
- The Ferris and Hanna Formations (equivalent to the Fort Union Formation) are present in the central part of the Hanna Basin. Exposed at the margins of the basin are the Cretaceous Medicine Bow Formation, Fox Hills Sandstone, Lewis Shale, and the undifferentiated Mesaverde Group, and lower Cretaceous formations (Love and others, 1955; Lowry and others, 1973; Hansen, 1986)
- Ferris and Hanna rocks in the Hanna Basin occur over a 750 square mile area and are about 13,500 feet thick.
- These rocks are tightly folded into synclines and anticlines and faulted into normal and thrust faults particularly along the basin margins (Glass and Roberts, 1979). Unidentified Paleocene coal-bearing rocks steepen to vertical dips and overturn on the northern flanks of the basin as the rocks approach a major thrust fault that separates the basin from the Shirley Mountains to the north.
- Beds dip steeply, particularly along the northern flank of the Hanna Basin; however, beds in the central part of the basin dip an average of 5-15 degrees.
- The Carbon Basin to the east-southeast is separated from the Hanna Basin to the west by the large northeast-trending Saddleback Hills anticline (Ryan, 1977). The two basins have a combined area of approximately 1,200 square mile.
- Ferris and Hanna rocks in the Carbon Basin are present over a 50 square-mile area and are more than 9,600 ft in thickness.

• Coal beds in the Carbon Basin are primarily in the Hanna Formation, which is as much as 5,500 ft thick.

STRATIGRAPHIC SETTING

• The Ferris Formation is Late Cretaceous and early Paleocene in age, and the Hanna Formation is middle to late Paleocene and early Eocene in age (fig. HF-2 and fig. HS-3 in Chapter HS). These formations are conformable in the Hanna Basin and unconformable in the Carbon Basin. More than 2,000 ft of rock is missing at the contact of these formations in the Carbon Basin (Hansen, 1986). Biostratigraphic zonations of the formations include Zones P1-P6 (fig. HF-3).

• Only the Paleocene parts of the Ferris and the Hanna Formations were studied for this assessment. The Paleocene coal was about 0.5 percent of the total U.S. coal production in 1997; it will continue to supply energy fuel during the next few decades.

• The Ferris and Hanna Formations each may be divided into a sandstone-dominated lower interval and coal-bearing middle and upper intervals.

• The lower sandstone-dominated interval ranges from 2,000-2,300 ft thick.

• Coal beds in the Ferris Formation are as much as 25 ft thick and in the Hanna Formation are as much as 36 ft thick.

• Proprietary and non-proprietary data from 1,905 drill holes were used for the study of the Ferris and Hanna coal beds.

DEPOSITIONAL SETTING

• Depositional environments were primarily in fluvial systems such as braided, meandering, and anastomosed streams (Hansen, 1986; Cavaroc and others, 1992; Perry and Flores, 1994).

- Minor depositional environments in the upper part of the Hanna Formation represent lacustrine deltas and lake systems (Perry and Flores, 1994).
- Coal accumulated in peat swamps on fluvial floodplains, in abandoned fluvial channels, and in lacustrine environments.

COAL QUALITY

- Coal rank is predominantly subbituminous with minor bituminous (Glass and Roberts, 1979).
- Coal quality reflects low to intermediate sulfur and low to high ash contents (Glass, 1978).
- Concentrations of selected trace-elements of environmental concern are low.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF COAL-ASSESSMENT UNITS

STRATIGRAPHY

- The Paleocene part of the Ferris Formation is more than 6,500 ft thick (see fig. HS-3 in Chapter HS).
- The Ferris Formation is composed mainly of sandstone, siltstone, and mudstone and subordinately of carbonaceous shale and coal beds.
- Assessment units include the Ferris 23, 25, 31, 50, and 65 (Dobbin and others, 1929) in the Hanna Basin.
- Coal beds 23, 25, and 31 are in the middle part of the Ferris Formation and coal beds 50 and 65 are in the upper part of the formation.

- The Paleocene part of the Hanna Formation is about 7,000 ft thick.
- The Hanna Formation consists primarily of sandstone, siltstone, and mudstone, and subordinately of carbonaceous shale and coal beds.
- Sandstone makes up more than 50 percent of the Ferris and Hanna Formation. Based on outcrop investigations, the sandstone beds exhibit an erosional base and generally vary from 10 to 100 ft in thickness and were interpreted by Hansen (1986) and Cavaroc and others (1992) as fluvial channel deposits. Some of these deposits were interpreted by Ryan (1977) as braided stream deposits. Coarsening-upward sandstone sequences as much as three ft thick were interpreted by Hansen (1986) and Cavaroc and others (1992) as crevasse splay deposits. These characteristics were used as a guide when interpreting the fluvial depositional environments (fig. HF-4) in the subsurface.
- Assessment units include the Hanna 77, 78, 79, and 81 coal beds in the Hanna Basin and the Johnson-107 coal zone (Dobbin and others, 1929) in the Carbon Basin.
- These coal beds and zones (77-79, 81, and Johnson-107) are all in the middle to upper part of the Hanna Formation.

DEPOSITIONAL ENVIRONMENTS

- Ferris and Hanna coal beds accumulated in peat swamps in fluvial environments (Cavaroc and others, 1992). However, the Hanna coal beds were deposited primarily in peat swamps of fluvial-floodplain lacustrine environments.
- As can be seen in mine highwalls, the Ferris coal beds are interbedded with lenticular fluvial-channel sandstone bodies that grade laterally into floodplain, thin- to thick-bedded, crevasse-splay, silty sandstone, siltstone, and mudstone (fig. HF-5). The coal beds interbedded with floodplain-crevasse-splay and crevasse-channel

deposits suggest accumulation in low-lying swamps (fig. HF-6). Coal formed in a low-lying swamps contains detrital partings (see upper coal in fig. HF-7) indicating influx of sediments from a nearby fluvial channel. The channel sandstone, which overlies the coal with partings, indicates avulsion or shift of the fluvial channel into the low-lying swamp.

- As can be seen in mine highwalls, the Hanna coal beds are interbedded with fluvial-channel sandstone, crevasse-splay sandstone, and floodplain siltstone and mudstone (fig. HF-8). The tabular crevasse-splay sandstone bodies grade laterally into lens-shaped crevasse-channel sandstone (fig. HF-9). The coal is interbedded with carbonaceous shale and mudstone, suggesting accumulation in a low-lying swamp (fig. HF-10). Another indication of the low-lying nature of the swamp is the presence of lenticular fluvial-channel sandstone beds between coal beds, which merge as the sandstone pinches out (fig. HF-11).
- Fluvial environments developed in an eastward-flowing fluvial system that included braided, meandering, and anastomosed streams (Ryan, 1977; Perry and Flores, 1994).

DISTRIBUTION OF FERRIS AND HANNA COAL BEDS AND ZONES IN THE FERRIS, HANNA, AND SOUTH CARBON COALFIELDS

- The Ferris coalfield boundary (fig. HF-12) approximately follows the areal extent of the Seminoe mining district defined by Glass and Roberts (1979; 1980) which includes past and current mines that produced from the Ferris coal. The coalfield is bounded on the west and south by the outcrop of the Ferris coal and Seminoe Reservoir, on the north by the Medicine Bow River, and on the east by an arbitrary line (5 mi from the outcrop line) based on the distribution of control points (see fig. HS-1 in Chapter HS).

- The Hanna coalfield boundary (fig. HF-12) approximately follows the areal extent of the Hanna mining district as defined by Glass and Roberts (1979; 1980), which includes past and current mines that produced from the Hanna coal. The coalfield is bounded on the west, east, and south by the outcrop of the Hanna coal and on the north by the Medicine Bow River.
- The South Carbon coalfield boundary (fig. HF-12) approximately follows the southern area of the Carbon mining district as defined by Glass and Roberts (1979; 1980), which includes past and current mines that produced from the Hanna coal. The coalfield is bounded on the west, east, and south by the outcrop of the Hanna coal and on the north by the northern extent of the Johnson-107 coal zone, which is targeted for leasing (U.S. Bureau of Land Management, 1998).
- More than 60 Ferris coal beds are vertically distributed as closely spaced units separated by mudstone and thin sandstone beds in the Hanna Basin.
- More than 20 Hanna coal beds are distributed as widely spaced units separated by thin to thick sandstone beds and minor mudstone interbeds in the Carbon Basin.
- Most coal beds are in the subsurface of Carbon County and there is indication that the more persistent coal beds may thicken in the central areas of the Hanna and Carbon Basins (Glass and Roberts, 1980).
- Surface occurrences and minable deposits of the Ferris coal are in the western and southwestern parts of the Ferris coalfield.
- Most surface occurrences and minable deposits of the Hanna coal are in the eastern part of the Hanna coalfield and the southern part of the South Carbon coalfield.

STRATIGRAPHIC FRAMEWORK

- Ferris coal beds are interbedded with mudstone, carbonaceous shale, siltstone, and sandstone.

- Ferris coal beds 23 and 25 are within a 350-ft-thick interval, beds 31-39 are within a 400-ft-thick interval, and beds 50 and 65 are within a 1,500-ft-thick interval. Hanna coal beds 77-9 and 81 are within a 700-ft-thick interval, and the Johnson-107 coal zone is within a 200-ft-thick interval.
- Laterally these coal beds merge, split, and pinch out.
- Split coal beds are interbedded with mudstone, siltstone, and sandstone. Most split into two or more beds, gradually thin or pinch out or interfinger with other clastic rocks.
- Merged coal beds are interbedded with carbonaceous shale partings. Merging of two or more beds results in a single, thicker bed. Intervening clastic rocks thin or pinch out or interfinger with coal and carbonaceous shale.
- Rocks above and below the Ferris and Hanna coal beds consist of mudstone, siltstone, and sandstone. Sandstone is the most common rock type; it has a salt and pepper appearance that results from a mixture of quartz and rock fragments (Ryan, 1977).
- The sediments forming these rocks accumulated in channels and floodplains in a fluvial system (Cavaroc and others, 1992).
- The coal beds accumulated in peat swamps formed in distal floodplains, at the margins of floodplain lakes, and on abandoned fluvial-channel deposits.

FERRIS 23-25 COAL BEDS: STRUCTURAL CROSS SECTION A-A’

- This structural cross section (fig. HF-13) shows the Ferris 23, 24, and 25 coal beds. These beds dip to the southeast. The cross section was drawn using data from 6 drill holes, which are not labeled on the cross section.
- The Ferris 23 coal bed is as much as 5 ft thick, the Ferris 24 coal bed is more than 20 ft thick, and the Ferris 25 coal bed is as much as 17 ft thick.

- The Ferris 23, 24, and 25 coal beds split locally; they thicken to the northwest where they merge into an interval as much as 48 ft thick.
- The Ferris 23-25 coal-bed interval to the southeast is as much as 75 ft thick.
- Interburden rocks between the thick Ferris 23, 24, and 25 coal beds and partings within these coal beds are dominated by mudstone (shown in green) with minor sandstone (shown in yellow).
- The Ferris 23, 24, and 25 coal beds and interburden or partings accumulated in peat swamps (fig. HF-14) that were intermittently overtopped by floodplain mud and crevasse-splay sand (fig. HF-15).
- Overburden rocks above the Ferris 25 coal bed consist mainly of mudstone (green), with subordinate sandstone (yellow) interbedded with minor coal beds more than 5 ft thick.
- The overburden rocks are interpreted to have formed in fluvial channels (sandstone) or on a floodplain (mudstone); the associated coal beds accumulated in peat swamps.

FERRIS 65 COAL BED: STRUCTURAL CROSS SECTION B-B’

- This structural cross section (fig. HF-16) shows the Ferris 65 and associated coal beds, which dip to the northeast. The cross section was drawn using data from 7 drill holes, which are not labeled on the cross section.
- The Ferris 65 coal bed is more than 7 ft thick and the associated coal beds vary from 2 to 8 ft thick.
- The Ferris 65 coal bed is locally split but maintains a uniform thickness throughout most of the 0.20-mi lateral extent of the cross section.
- Rock partings are composed mainly of mudstone (shown in green).
- The Ferris 65 coal bed and rock partings accumulated in peat swamps that were intermittently overrun by floodplain mud.

- The Ferris 65 coal bed is overlain by thick sandstone bodies (shown in yellow) that were deposited in large fluvial channels (fig. HF-17).
- Rocks above and below the Ferris 65 coal bed consist mainly of mudstone (green) and subordinate sandstone (yellow) interbedded with minor coal beds more than 2 ft thick.
- The rocks above and below the Ferris 65 coal bed are interpreted to have formed in small crevasse channels (sandstone) (fig. HF-18) or on a floodplain (mudstone); the associated coal beds accumulated in peat swamps.

FERRIS 48-50 COAL BEDS: STRUCTURAL CROSS SECTION C-C'

- This structural cross section (fig. HF-19) shows the folded Ferris 50 coal bed and associated Ferris 48 and 49 coal beds. The cross section was drawn using data from 6 drill holes, which are not labeled on the cross section.
- The Ferris 50 coal bed is as much as 15 ft thick; the associated Ferris 48 and 49 coal beds vary in thickness from 2 to 14 ft.
- The Ferris 50 coal bed is locally split by partings composed of mudstone (shown in green).
- The Ferris 50 coal bed and partings accumulated in peat swamps that were intermittently overrun by floodplain mud.
- The Ferris 50 coal bed is overlain by rocks composed of vertically stacked, thick sandstone bodies (shown in yellow) that were deposited in large, deep fluvial channels.
- Rocks below the Ferris 50 coal bed consist of mudstone (green) with subordinate sandstone (yellow) interbedded with minor coal beds (Ferris 48 and 49) that are less than 2 ft thick.

- Rocks below these coal beds are interpreted to have formed in small fluvial channels (sandstone) or on a floodplain (mudstone); the associated coal beds formed in peat swamps.

HANNA 77-78 COAL BEDS: STRUCTURAL CROSS SECTION D-D'

- This structural cross section (fig. HF-20) shows the Hanna 77 and 78 coal beds and associated rocks dipping to the northeast. The cross section was drawn using data from 4 drill holes, which are not labeled on the cross section.
- The Hanna 77 coal bed is as much as 20 ft thick and the Hanna 78 coal bed is as much as 22 ft thick.
- The Hanna 77 and 78 coal beds are locally split by sandstone partings (shown in yellow) and mudstone partings (shown in green).
- The Hanna 77 and 78 coal beds and partings accumulated in peat swamps that were locally overtopped by floodplain mud and crevasses-splay sand.
- Interburden rocks between the Hanna 77 and 78 coal beds consist of four thin to thick sandstone bodies (yellow) that were deposited in fluvial channels. This indicates reoccupation of the channels several times.
- The fluvial channel sandstone bodies are interbedded with mudstone (green) that was deposited in floodplain and overbank environments.

HANNA 81 COAL BED: STRUCTURAL CROSS SECTION E-E'

- This structural cross section (fig. HF-21) through the Hanna 81 coal bed shows rocks dipping to the northeast. The cross section was drawn using data from 8 drill holes, which are not labeled on the cross section.

- The Hanna 81 coal bed is as much as 18 ft thick and is locally split by mudstone partings (shown in green).
- The Hanna 81 coal bed and partings accumulated in peat swamps that were locally overrun by floodplain mud.
- The overburden rocks above the Hanna 81 coal bed consist of numerous thin to thick, laterally offset sandstone bodies (shown in yellow) that were deposited in fluvial channels that were reoccupied at least three times.
- The fluvial-channel sandstone bodies are interbedded with mudstone (green) that accumulated in floodplain and overbank environments.

HANNA 78, 79, AND 81 COAL BEDS: STRUCTURAL CROSS SECTION F-F'

- This structural cross section (fig. HF-22) across the basin axis (low spot of the cross section) shows steeply dipping rocks to the southeast and more gently dipping rocks to the northwest. (Dips are greatly exaggerated due to compressed horizontal scale.) Rocks include the Hanna 78, 79, and 81 coal beds and associated sandstone and mudstone. The cross section was drawn using data from 12 drill holes, which are not labeled on the cross section.
- The Hanna 78 coal bed is as much as 35 ft thick, and the Hanna 79 and 81 coal beds vary from 2 to 10 ft in thickness.
- The Hanna 79 and 81 coal beds are thin and laterally uniform in thickness throughout the cross section. The Hanna 79 coal bed is locally split by mudstone partings (shown in green) toward the northwest; it thins to the southeast.
- The Hanna 78, 79, and 81 coal beds and partings accumulated in peat swamps that were intermittently overtopped by floodplain mud.

- The interburden rocks between Hanna 78, 79, and 81 coal beds consist of stacked, thick and thin sandstone beds (shown in yellow). The thick sandstone beds were deposited in large, deep fluvial channels, and the thin sandstone beds were deposited in small, shallow fluvial channels (fig. HF-23).
- The fluvial channel sandstone bodies are interbedded with mudstone (green) deposited in floodplain and overbank environments.
- The basin axis contains vertically stacked, thick fluvial-channel sandstone bodies (yellow), indicating that it served as a depositional axis of the fluvial system.

HANNA 78-79 COAL BEDS: STRUCTURAL CROSS SECTION G-G'

- This structural cross section (fig. HF-24) shows the Hanna 78 and 79 coal beds and associated rocks dipping to the southeast and northwest. The cross section was drawn using data from 6 drill holes, which are not labeled on the cross section.
- The Hanna 78 coal bed is as much as 14 ft thick and the Hanna 79 coal bed is as much as 10 ft thick.
- The Hanna 78 coal bed is laterally uniform in thickness throughout the cross section but is locally split toward the northwest by a mudstone parting (shown in green).
- The Hanna 78 and 79 coal beds and partings accumulated in peat swamps that were locally overtopped by floodplain mud.
- The interburden rocks between the Hanna 78 and 79 coal beds consist of stacked, thick and thin sandstone bodies (shown in yellow). The thick sandstone beds were deposited in large, deep fluvial channels, and the thin sandstone beds were deposited in small, shallow fluvial channels.
- The fluvial-channel sandstone bodies are interbedded with mudstone (green) that accumulated in floodplain and overbank environments.

HANNA 78-81 COAL BEDS: STRUCTURAL CROSS SECTION H-H'

- This structural cross section (fig. HF-25) shows the Hanna 78-81 coal beds, which generally dip to the northwest. The cross section was drawn using data from 5 drill holes, which are not labeled on the cross section.
- The Hanna 78 coal bed is as much as 15 ft thick, the Hanna 79 coal bed is as much as 22 ft thick, and the Hanna 81 coal bed is as much as 10 ft thick.
- The Hanna 78 and 81 coal beds are laterally uniform in thickness throughout the cross section, and the Hanna 79 coal is locally split toward the northwest by mudstone partings (shown in green).
- The Hanna 78, 79, and 81 coal beds and partings accumulated in peat swamps that were intermittently overtopped by floodplain mud.
- The interburden rocks between the Hanna 78, 79, and 81 coal beds consist of stacked, thick and thin sandstone beds (shown in yellow). The thick sandstone beds were deposited in large, deep fluvial channels, and the thin sandstone beds were deposited in small, shallow fluvial channels.
- The fluvial channel sandstone beds (yellow) are interbedded with mudstone (green) that was deposited in floodplain and overbank environments.

JOHNSON-107 COAL ZONE: STRUCTURAL CROSS SECTION I-I'

- This structural cross section (fig. HF-26) through the Johnson-107 coal zone shows rocks dipping about ten degrees to the north and six degrees to the south. The cross section was drawn using data from 12 drill holes, which are not labeled on the cross section.

- The Johnson coal bed is as much as 20 ft thick and is the lowermost bed in the Johnson-107 coal zone. The Finch coal bed is as much as 20 ft thick and is above the Johnson coal bed. The 107 coal bed is as much 15 ft thick and is above the Finch coal bed and is the uppermost bed of the Johnson-107 coal zone (see cross section J-J' to see detail).
- The Johnson, Finch, and 107 coal beds are vertically closely spaced; however, they are split by sandstone partings (shown in yellow) and mudstone partings (shown in green).
- The Johnson coal bed and partings accumulated in peat swamps that were locally overrun by floodplain mud and crevasse-splay sand (fig. HF-27).
- The overburden rocks above the Johnson-107 coal zone consist of numerous, stacked, thin to thick, laterally offset sandstone bodies (yellow) that were deposited in fluvial channels that were reoccupied several times.
- The fluvial-channel sandstone bodies are interbedded with mudstone (green) that was deposited in floodplain and overbank environments.

JOHNSON-107 COAL ZONE: STRUCTURAL CROSS SECTION J-J'

- This structural cross section (fig. HF-28) through the Johnson-107 coal zone shows rocks dipping to the west and to the east. The cross section was drawn using data from 6 drill holes, which are not labeled on the cross section.
- The Johnson coal bed is as much as 25 ft thick and is locally split by sandstone beds (shown in yellow).
- The Johnson coal bed and partings accumulated in peat swamps that were locally overrun by floodplain mud (shown in green) and crevasse-splay sand (yellow).
- The Finch coal bed, which is the upper bed of the Finch-Johnson coal zone, is as much as 20 ft thick to the west and thins to the east.

- The Johnson and Finch coal beds, interburden rocks, and partings accumulated in peat swamps that were locally overrun by floodplain mud and crevasse-splay sand.
- The overburden rocks above the Johnson-107 coal zone consist of numerous, stacked, thin to thick, laterally offset sandstone bodies (yellow) that were deposited in fluvial channels that were reoccupied several times.
- The fluvial channel sandstone bodies are interbedded with mudstone (green) that accumulated in floodplain and overbank environments.
- The overburden rocks immediately above the Finch-Johnson coal zone include thin to thick coal beds. The coal beds are as much as 25 ft thick, but laterally they thin and pinch out into the laterally equivalent fluvial channel sandstone beds.

REFERENCES

Cavaroc, V.V., Flores, R.M., Nichols, D.J., and Perry, W.J., 1992, Paleocene tectono-facies relationships between the Hanna, Carbon, and Cooper Lake basins, Wyoming [abs]: American Association of Petroleum Geologists Bulletin, v. 76, p. 1257.

Dobbin, C.E., Bowen, C.F., and Hoots, H.W., 1929, Geology and coal and oil resources of the Hanna and Carbon basins, Carbon County, Wyoming: U.S. Geological Survey Bulletin 804, 88 p.

Glass, G.B., 1978, Coal analyses and lithologic descriptions of five core holes drilled in the Carbon Basin of south-central Wyoming: Geological Survey of Wyoming Report of Investigations No. 16, 97 p.

Glass, G.B., and Roberts, J.T., 1979, Remaining strippable coal resources and strippable reserve base of the Hanna coal field in south-central Wyoming: Geological Survey of Wyoming Report of Investigations No. 17, 166 p.

_____1980, Coal and coal-bearing rocks of the Hanna coal field, Wyoming: Geological Survey of Wyoming Report of Investigations No. 22, 41 p.

Hansen, D.E., 1986, Laramide tectonics and deposition of the Ferris and Hanna Formations, south-central Wyoming, *in* Peterson, J.A., ed., Paleotectonics and Sedimentation in the Rocky Mountain Region, United States: American Association of Petroleum Geologists Memoir 41, p 481-495.

Knight, S.H., 1951, The Late Cretaceous-Tertiary history of the northern portion of the Hanna Basin—Carbon County, Wyoming, *in* Wyoming Geological Association Guidebook 6th Annual Field Conference, south-central Wyoming: Wyoming Geological Association, p. 45-53.

Love, J.D., Weitz, J.L., and Hose, R.K., 1955, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000.

Lowry, M.E., Rucker, S.J., Wahl, K.L., 1973, Water resources of the Laramie, Shirley, and Hanna Basins and adjacent areas, southeastern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-471, 4 sheets.

Perry, W.J., Jr., and Flores, R.M., 1994, Sequential Laramide deformation and deep gas-prone basins of the Rocky Mountain region, *in* Dyman, T.S., Rice, D.D., and Wescott, W.A., eds., Geologic Controls of Deep Natural Gas Resources in the U.S.: U.S. Geological Survey Bulletin 2146-E, p. 49-59.

Ryan, J.D., 1977, Late Cretaceous and early Tertiary Provenance and sediment dispersal, Hanna and Carbon Basins, Carbon County, Wyoming: Geological Survey of Wyoming, Preliminary Report No. 16, 16 p.

U.S. Bureau of Land Management, and U.S. Office of Surface Mining, 1998, Carbon Basin project environmental impact statement, Carbon County, Wyoming: TRC Mariah Associates, Inc,. Laramie, Wyoming, MAI Project 20241-01, 261 p.

Click here or on this symbol in the toolbar to return.

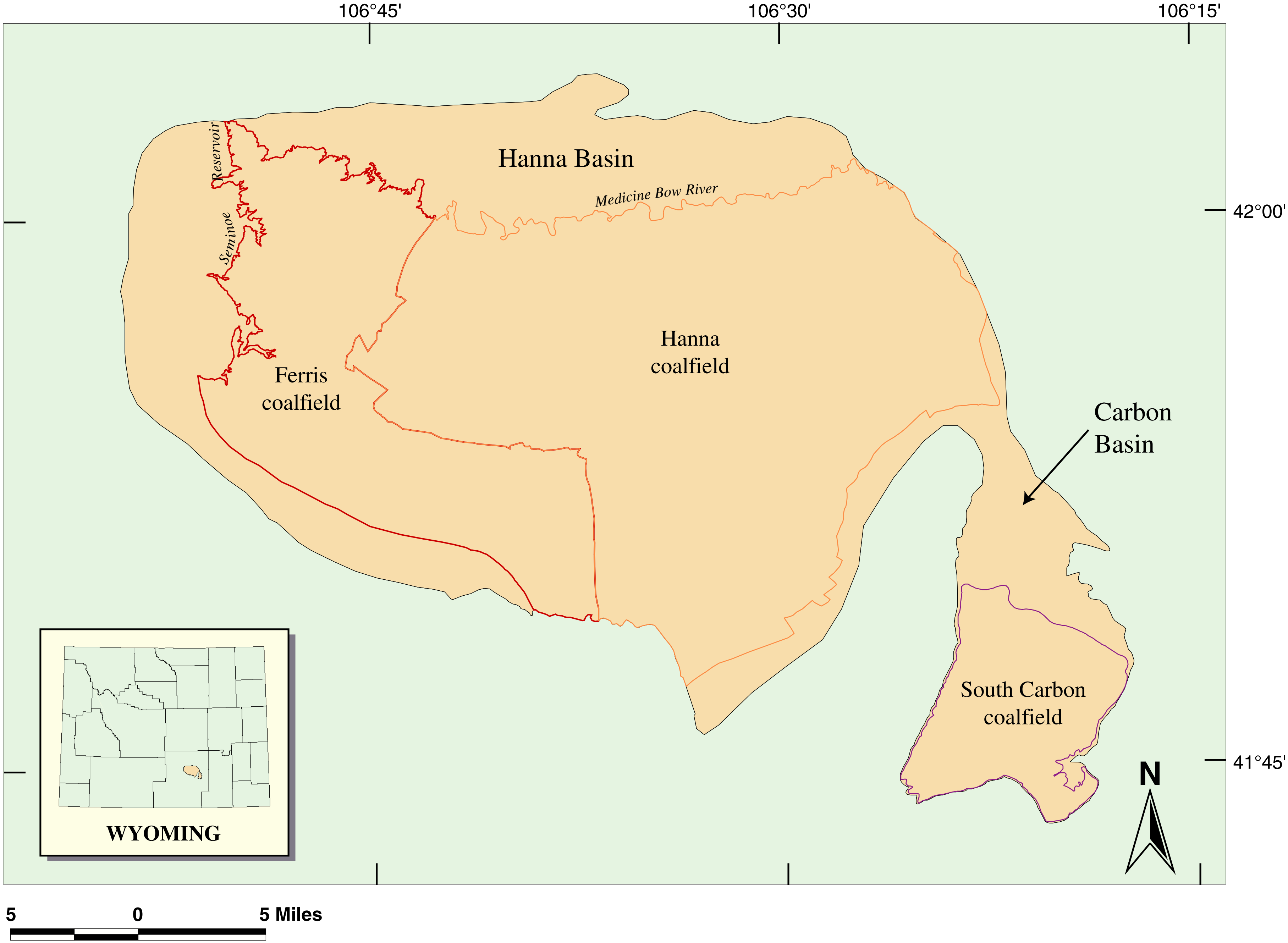

Figure HF-1. Location map showing coalfields in the Hanna and Carbon Basins.

USGS
science for a changing world

Click here or on this symbol
in the toolbar to return.

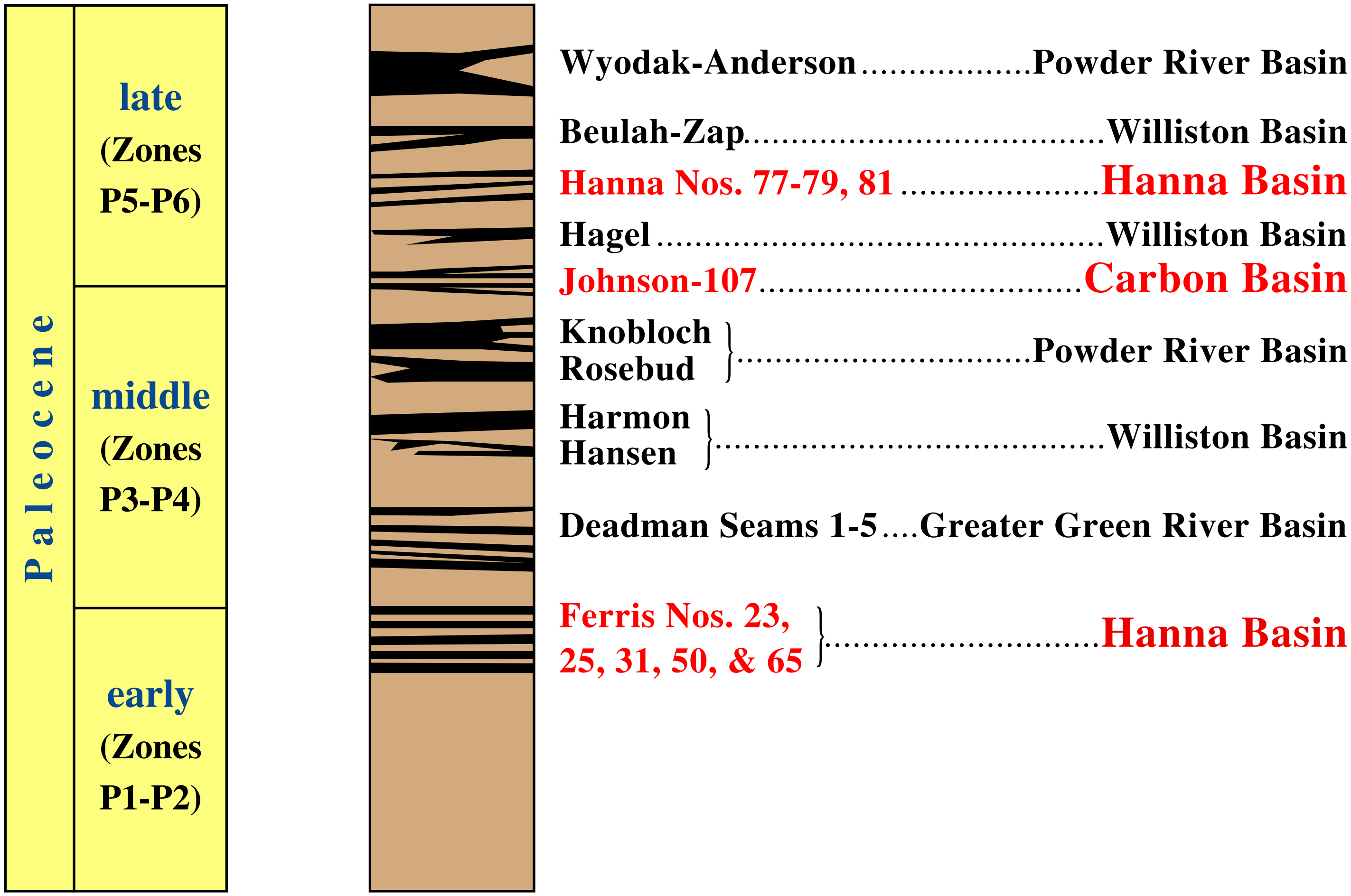

Figure HF-2. Composite stratigraphic section for the assessment region showing the studied coal beds and zones with age relationships based on palynology. Assessment units in the Hanna and Carbon Basins are highlighted in red.

Click here or on this symbol
in the toolbar to return.

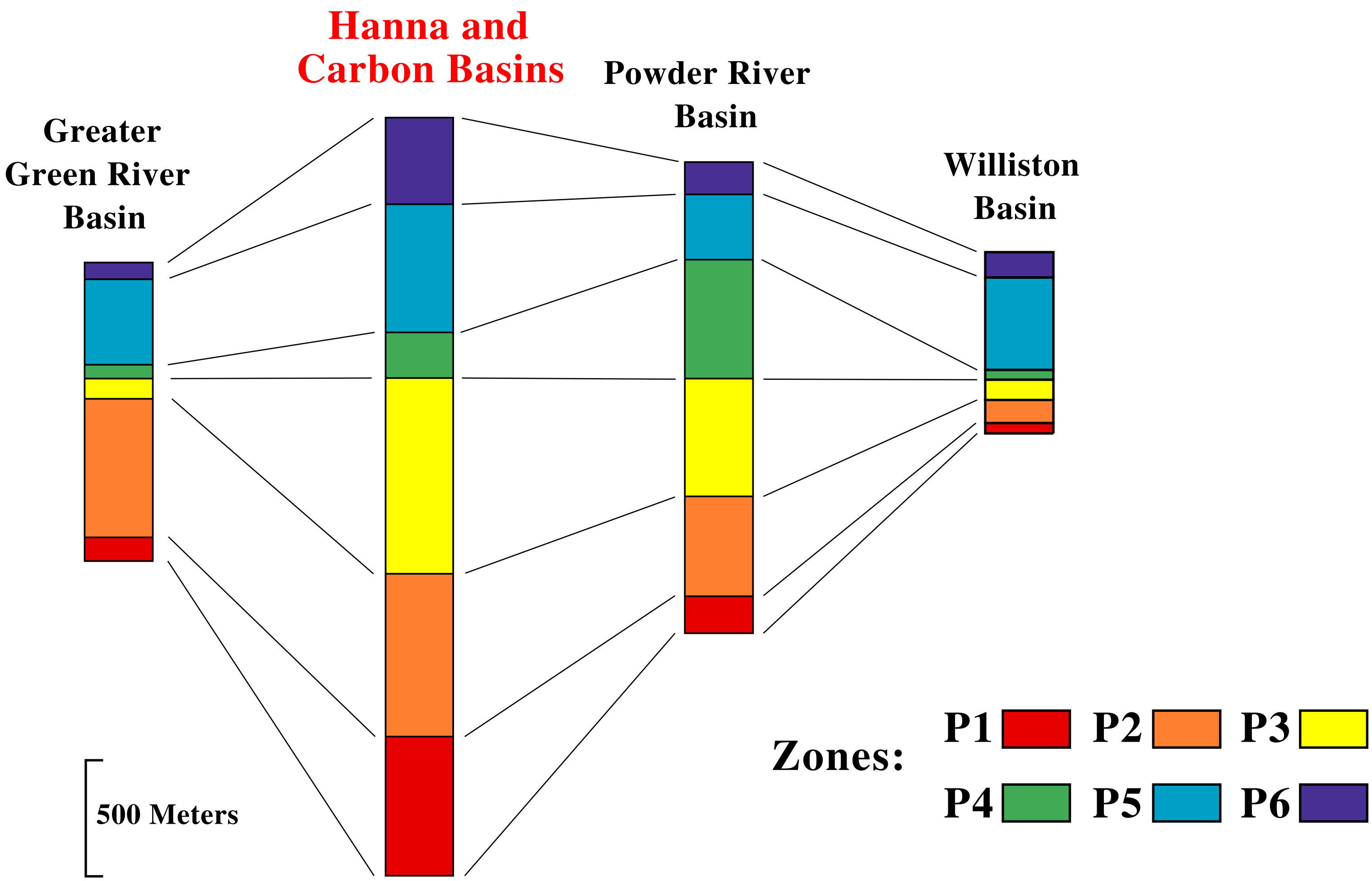

Figure HF-3. Composite correlation of Paleocene sections based on palynostratigraphy.

USGS
science for a changing world

Figure HF-4. Braided, meandering, and anastomosed channels of the Tanana River in Alaska.
Photograph by R.M. Flores.

Figure HF-5. Sandstone interbedded with siltstone, mudstone, and coal in the Medicine Bow mine. Photograph by R.M. Flores.

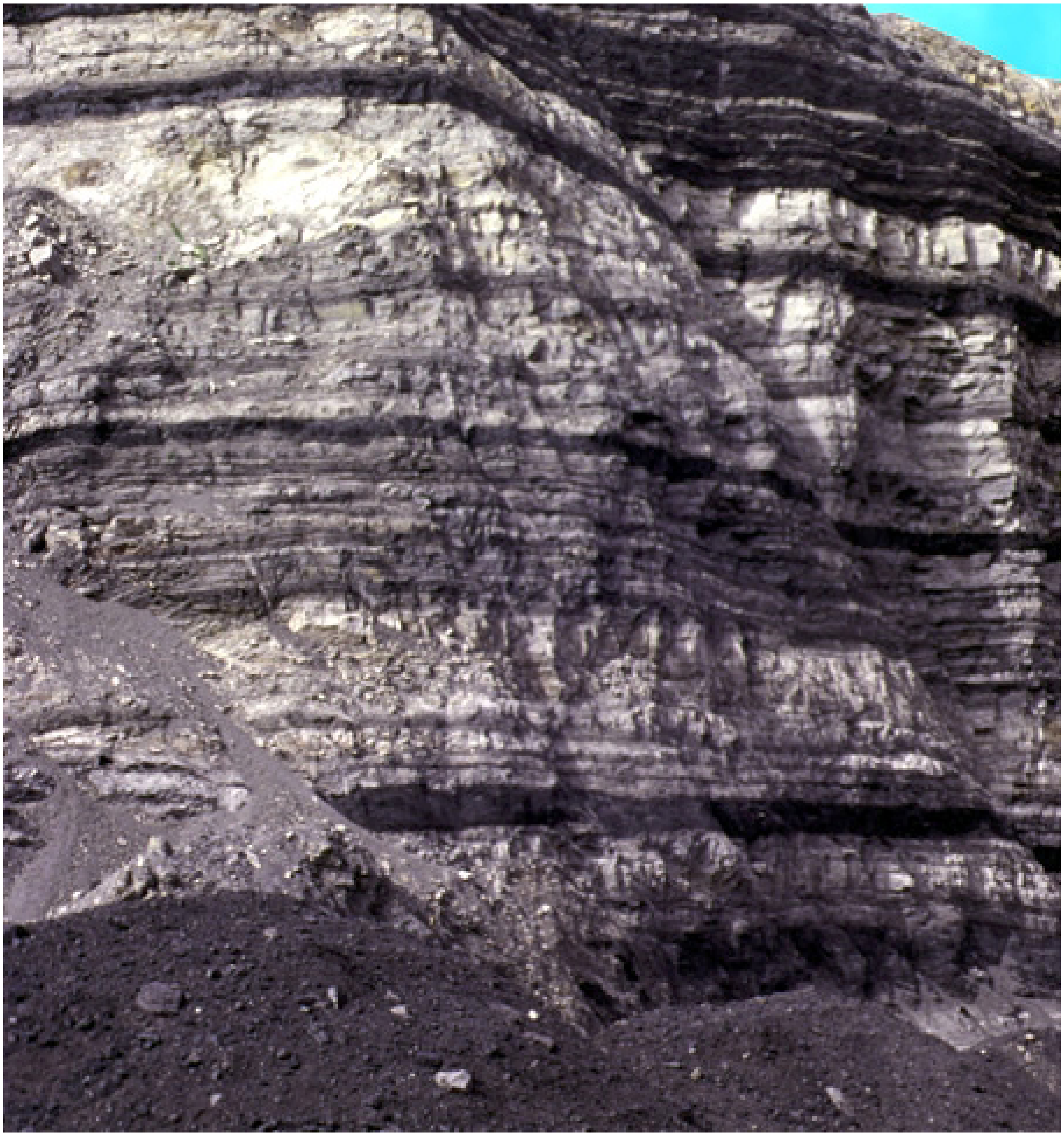

Figure HF-6. Siltstone and mudstone interbedded with minor sandstone and coal in the Medicine Bow mine. Photograph by R.M. Flores.

Click here or on this symbol
in the toolbar to return.

Figure HF-7. Coal (upper part of picture) with siltstone and mudstone partings in the Medicine Bow mine. Note normal fault on the right side of the picture. Photograph by R.M. Flores.

Figure HF-8. Coal interbedded with sandstone, siltstone, and mudstone in a mine north of the town of Hanna. Photograph by R.M. Flores.

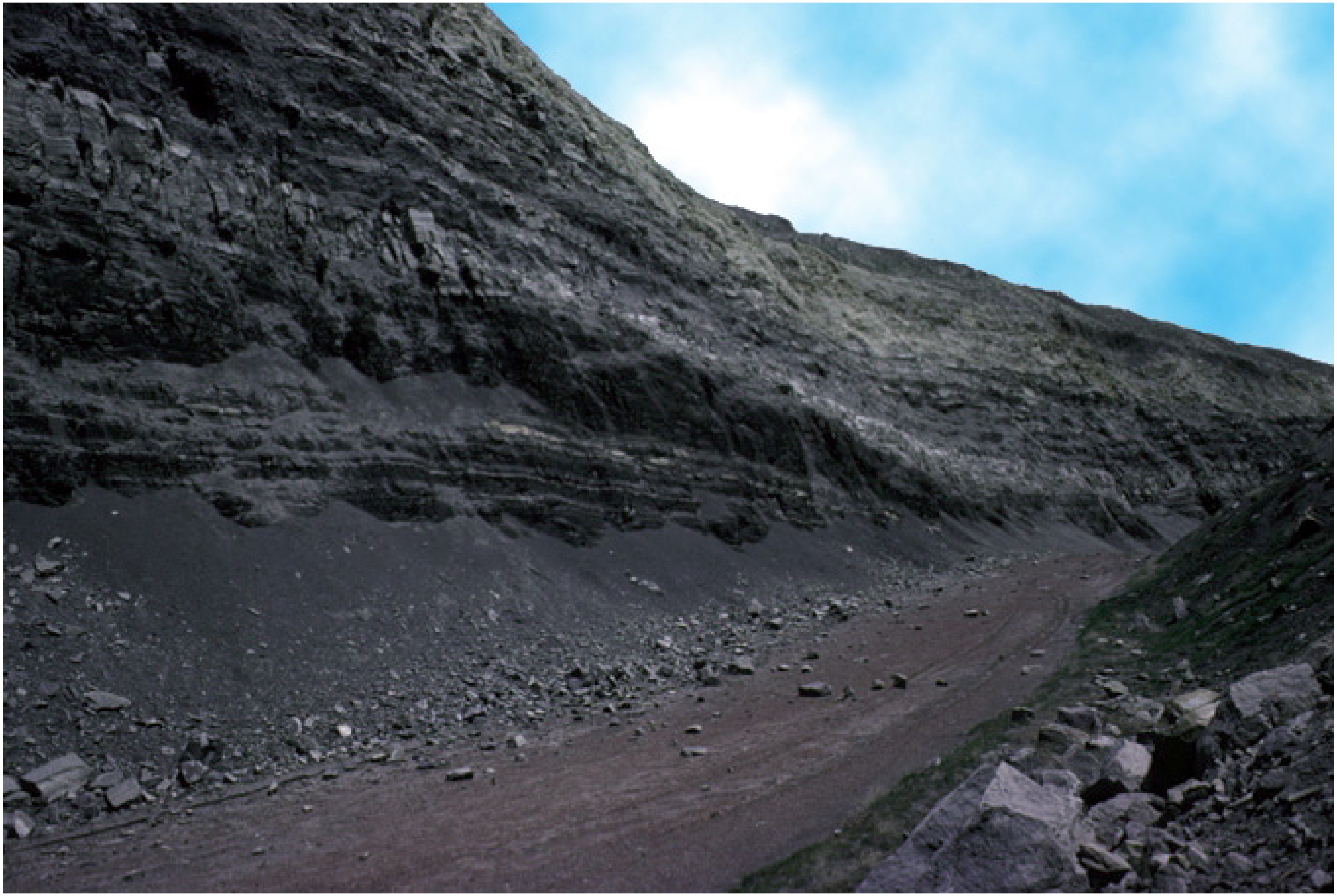

Figure HF-9. Interbedded sandstone, siltstone, and mudstone on a mine highwall north of the town of Hanna. Photograph by R.M. Flores.

Figure HF-10. Thick coal and carbonaceous shale interbedded with siltstone and mudstone, which in turn, are overlain by sandstone in a mine north of the town of Hanna. Photograph by R.M. Flores.

Figure HF-11. Coal and carbonaceous shale interbedded with sandstone, siltstone, and mudstone in an abandoned mine north of the town of Hanna. Photograph by R.M. Flores.

Click here or on this symbol
in the toolbar to return.

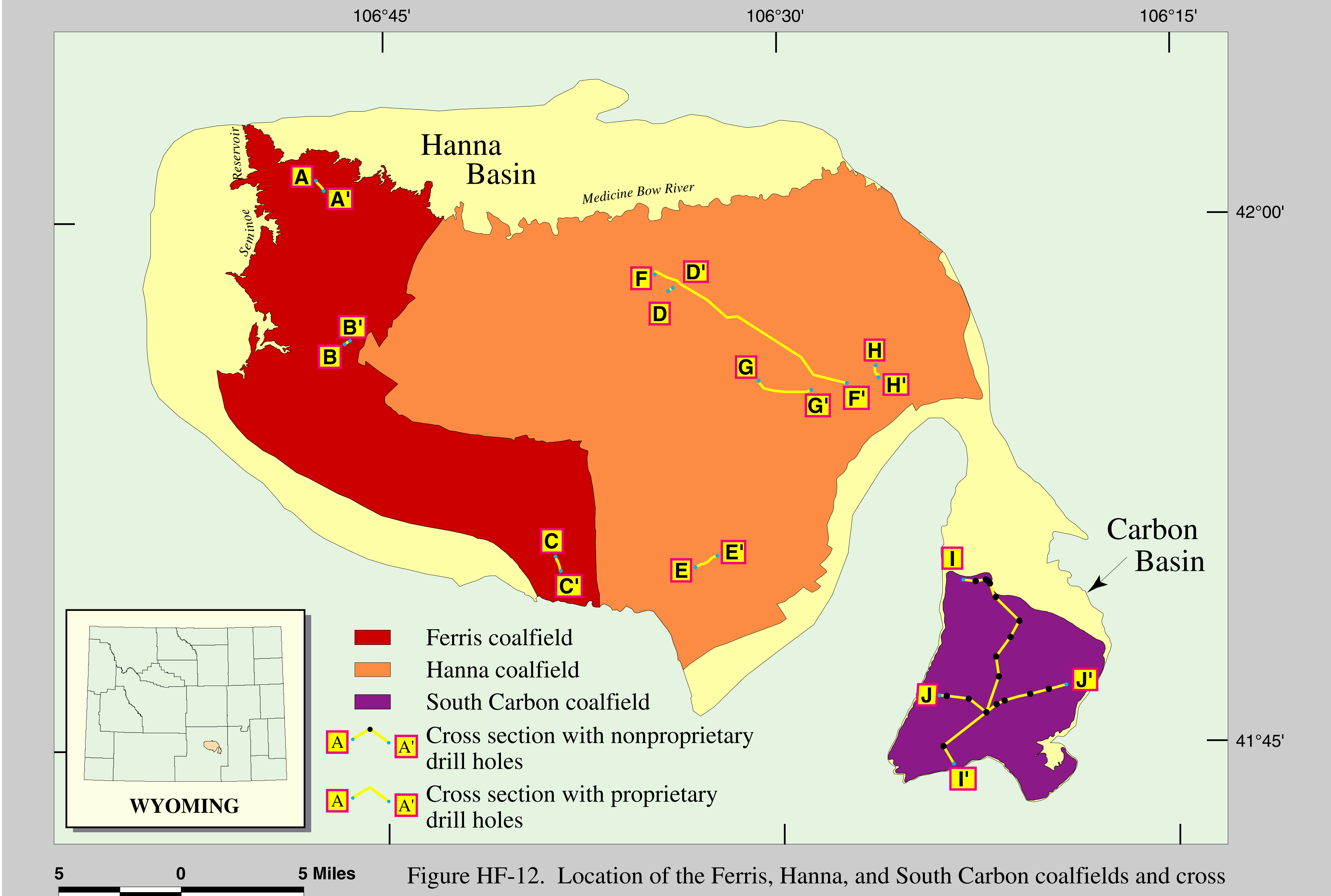

Figure HF-12. Location of the Ferris, Hanna, and South Carbon coalfields and cross sections in the Hanna and Carbon Basins.

Click here or on this symbol
in the toolbar to return.

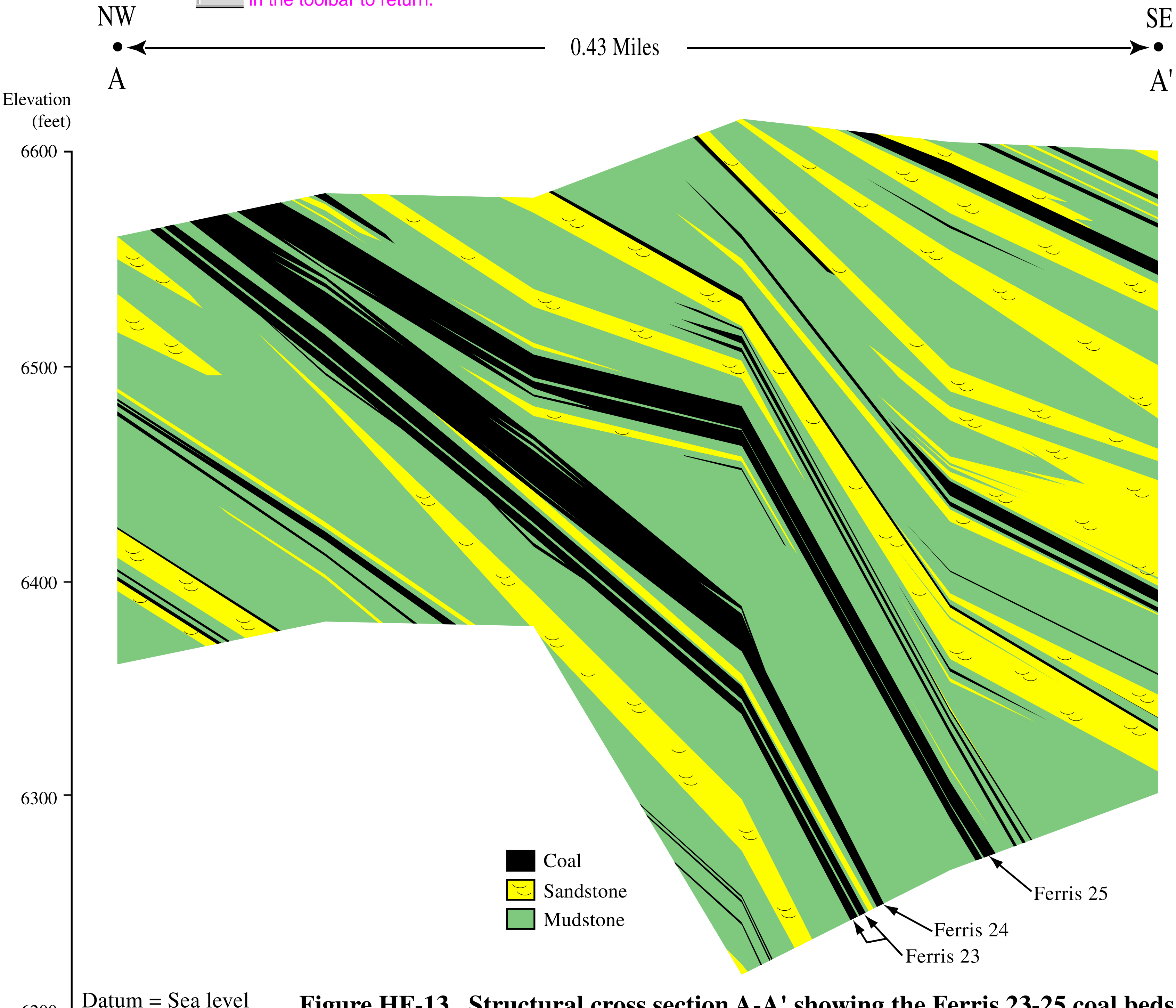

Figure HF-13. Structural cross section A-A' showing the Ferris 23-25 coal beds.

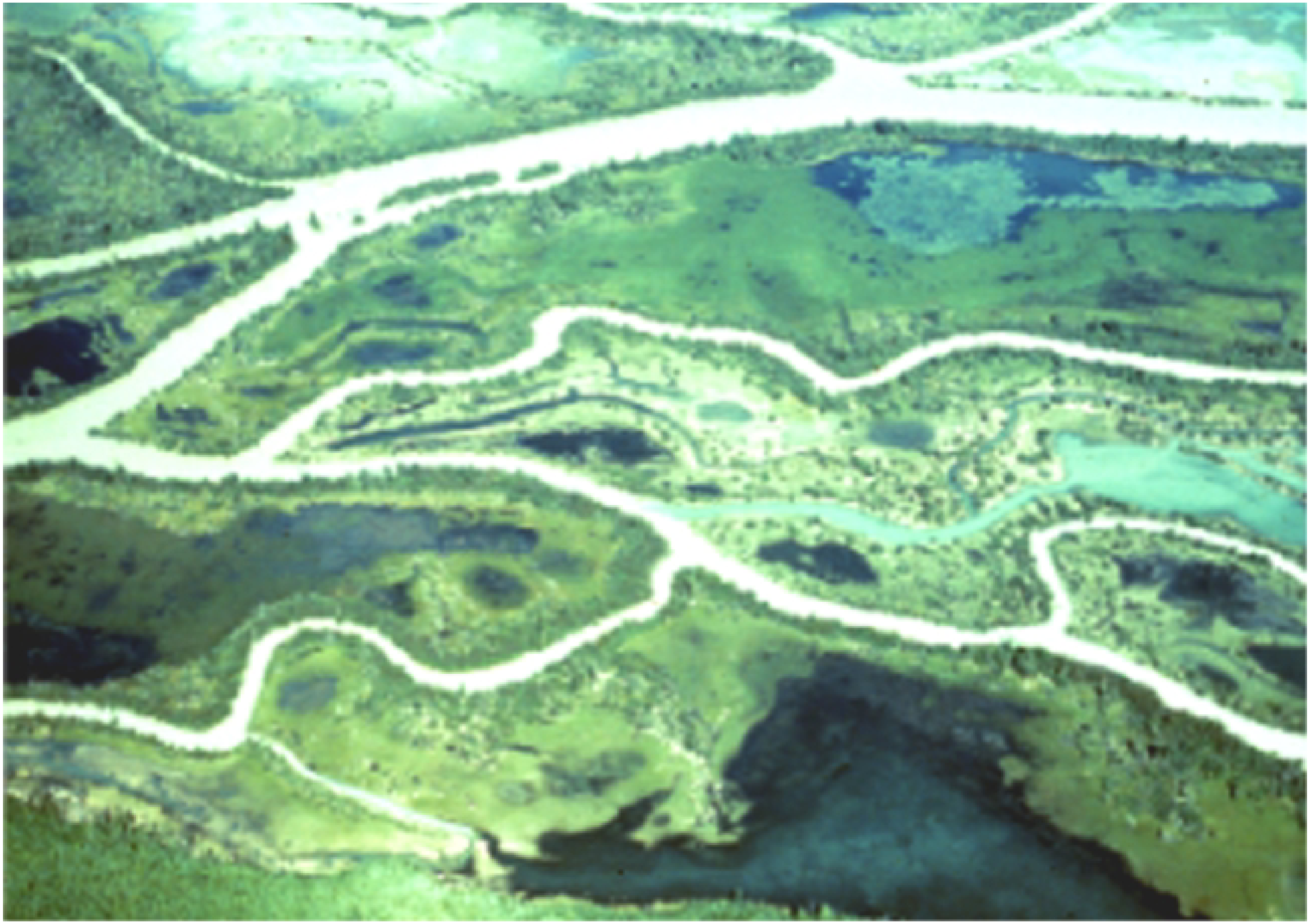

Figure HF-14. Fluvial channels, floodplains, and swamps of the Columbia River in the Province of British Columbia, Canada. Photograph by D. Smith.

Figure HF-15. Crevasse splay of the Saskatchewan River in the Province of Saskatchewan, Canada. Photograph by N. Smith.

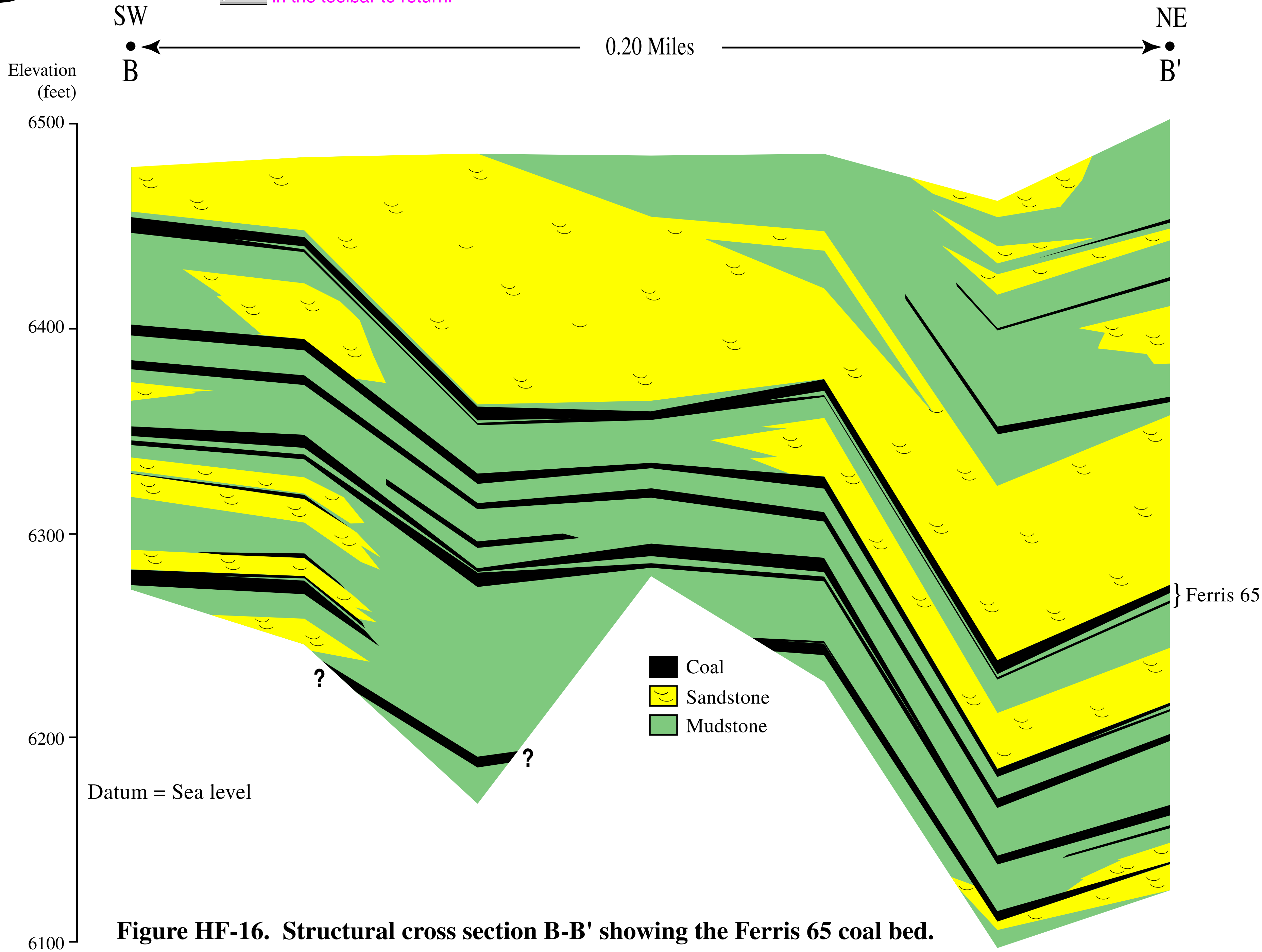

Figure HF-16. Structural cross section B-B' showing the Ferris 65 coal bed.

Figure HF-17. Fluvial channel of the Beluga River, Alaska. Photograph by R.M. Flores.

Figure HF-18. Fluvial channel and associated crevasse splay of the Saskatchewan River in the Province of Saskatchewan, Canada. Photograph by N. Smith.

Click here or on this symbol
in the toolbar to return.

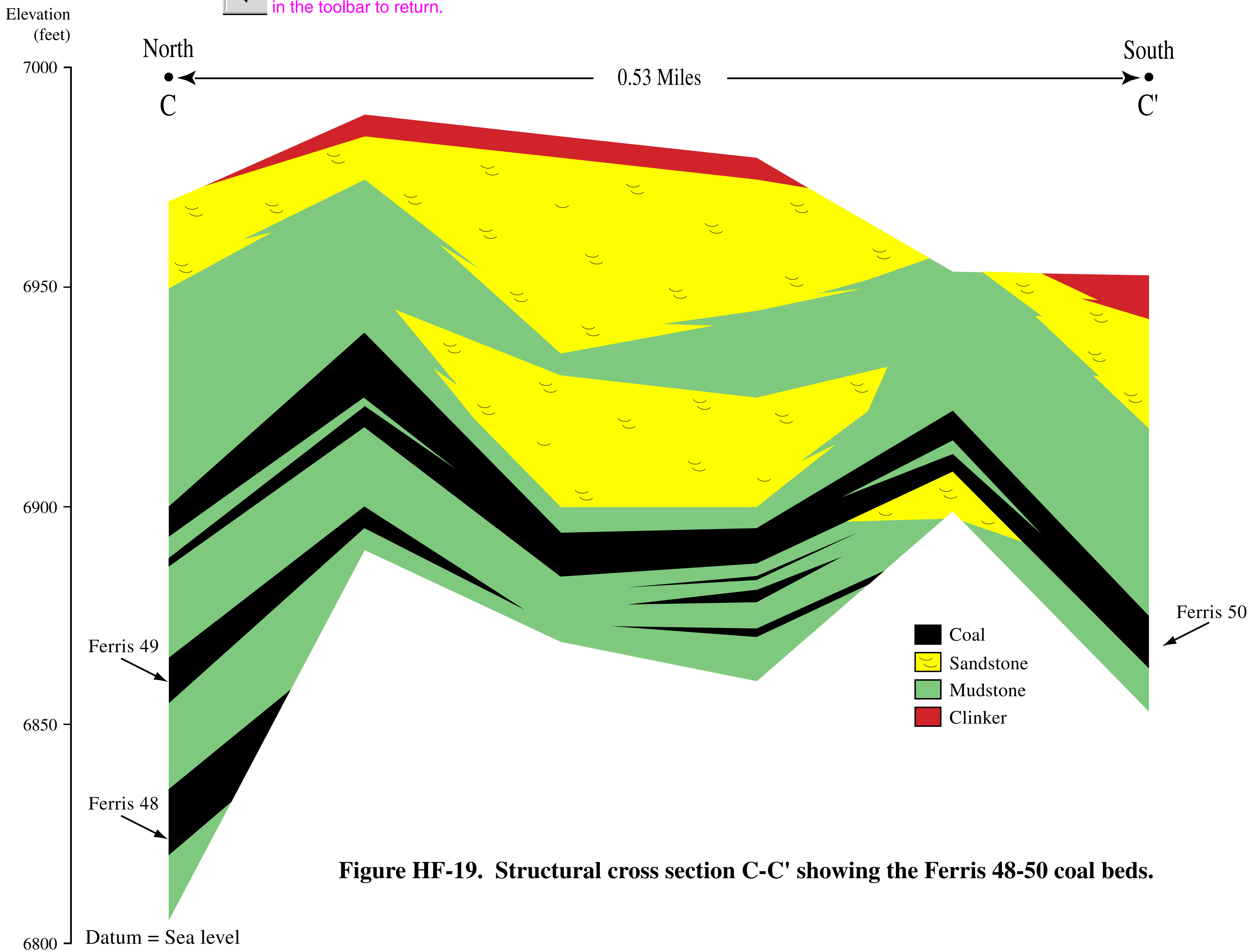

Figure HF-19. Structural cross section C-C' showing the Ferris 48-50 coal beds.

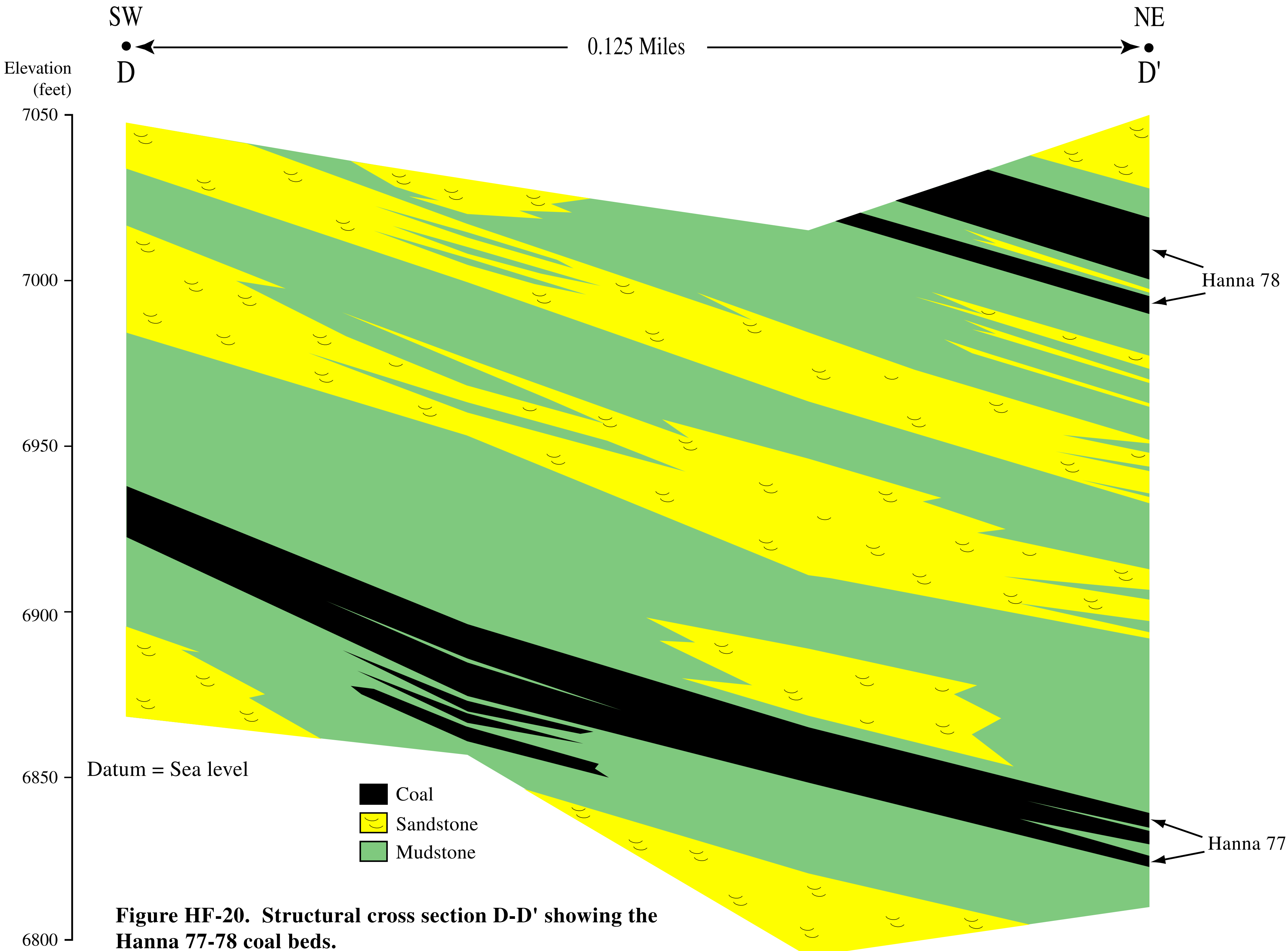

Figure HF-20. Structural cross section D-D' showing the Hanna 77-78 coal beds.

Click here or on this symbol
in the toolbar to return.

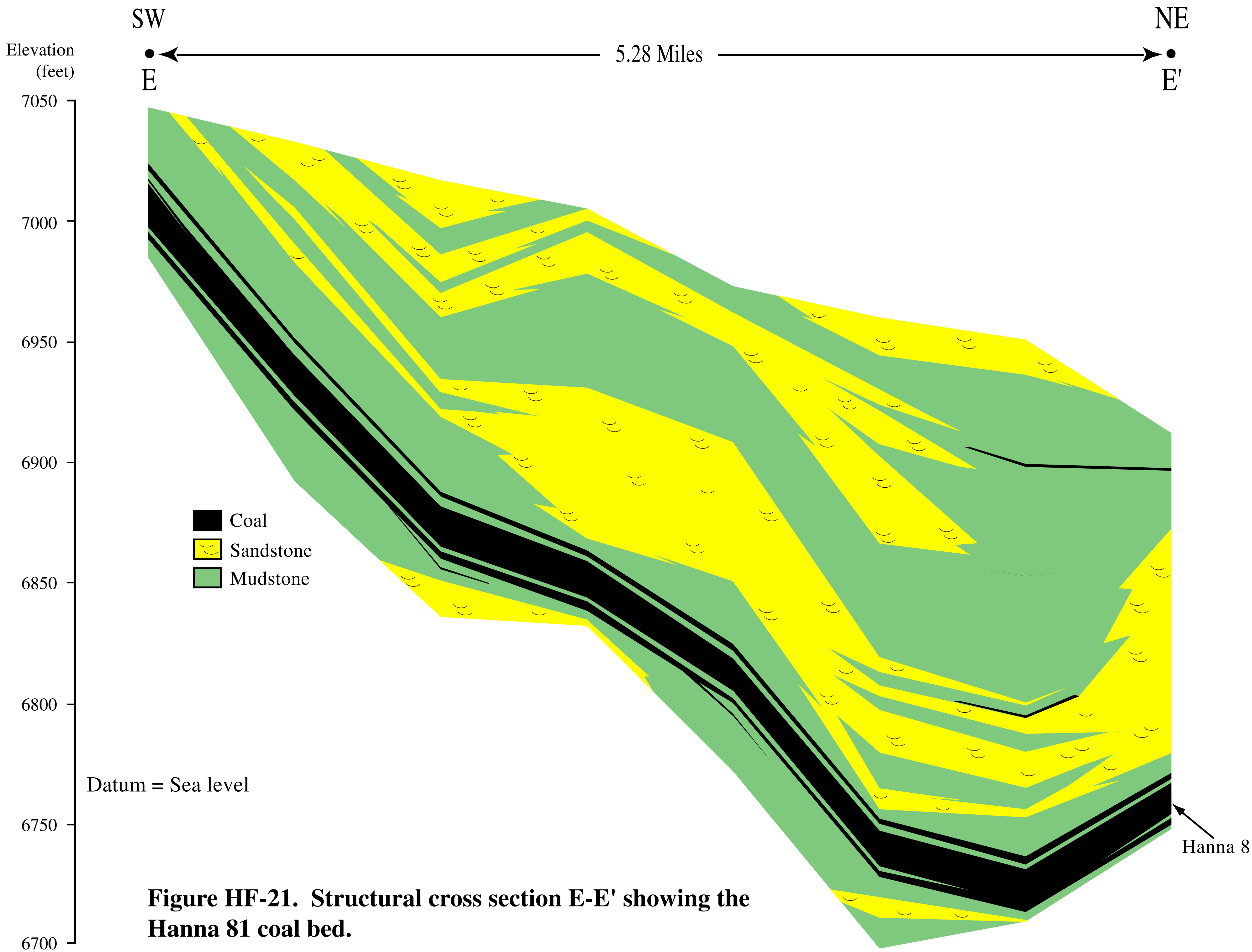

Figure HF-21. Structural cross section E-E' showing the Hanna 81 coal bed.

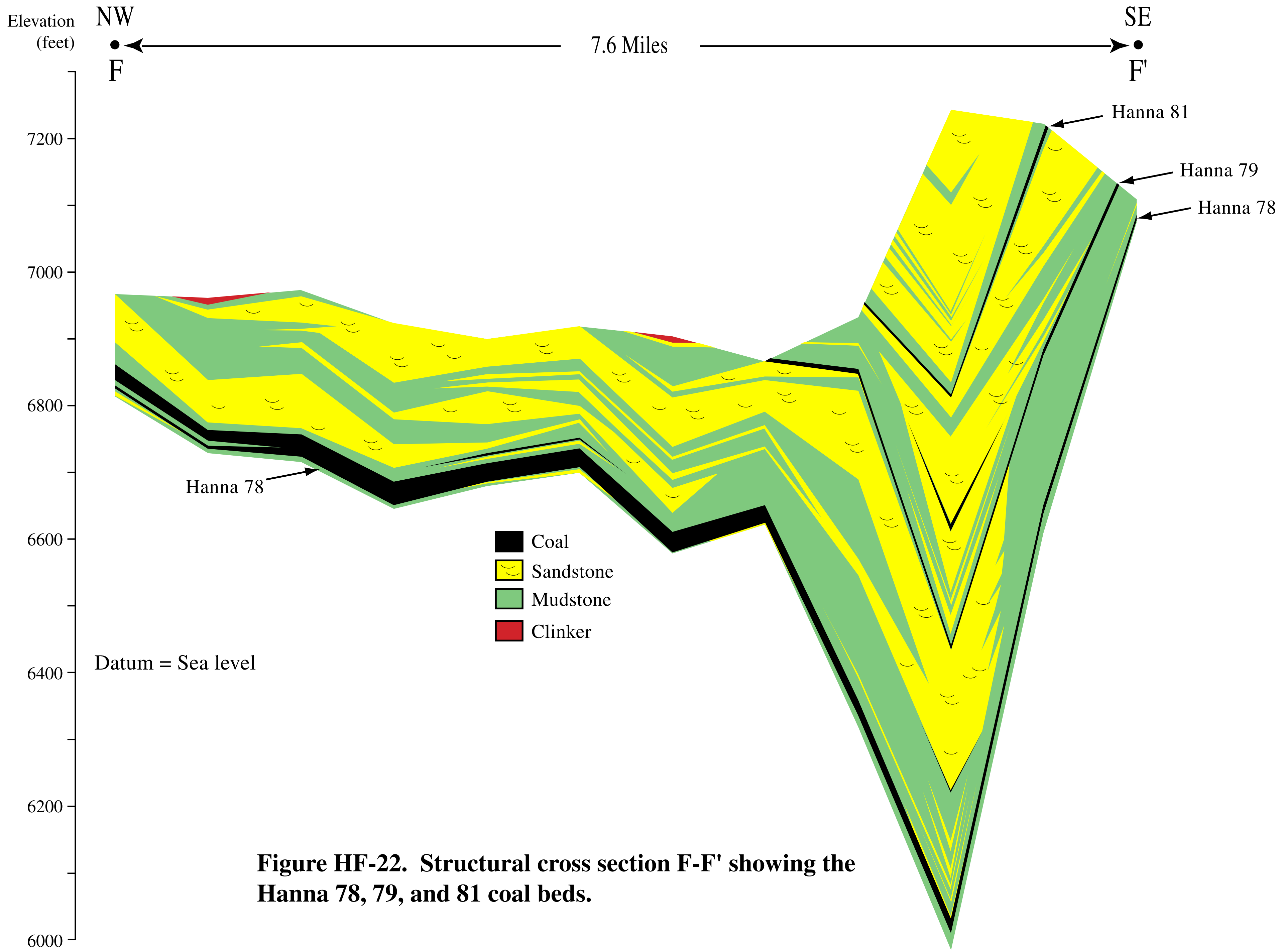

Figure HF-22. Structural cross section F-F' showing the Hanna 78, 79, and 81 coal beds.

Figure HF-23. Anastomosed fluvial channels and associated swamps of the Saskatchewan River in the Province of Saskatchewan, Canada. Photograph by N. Smith.

Click here or on this symbol
in the toolbar to return.

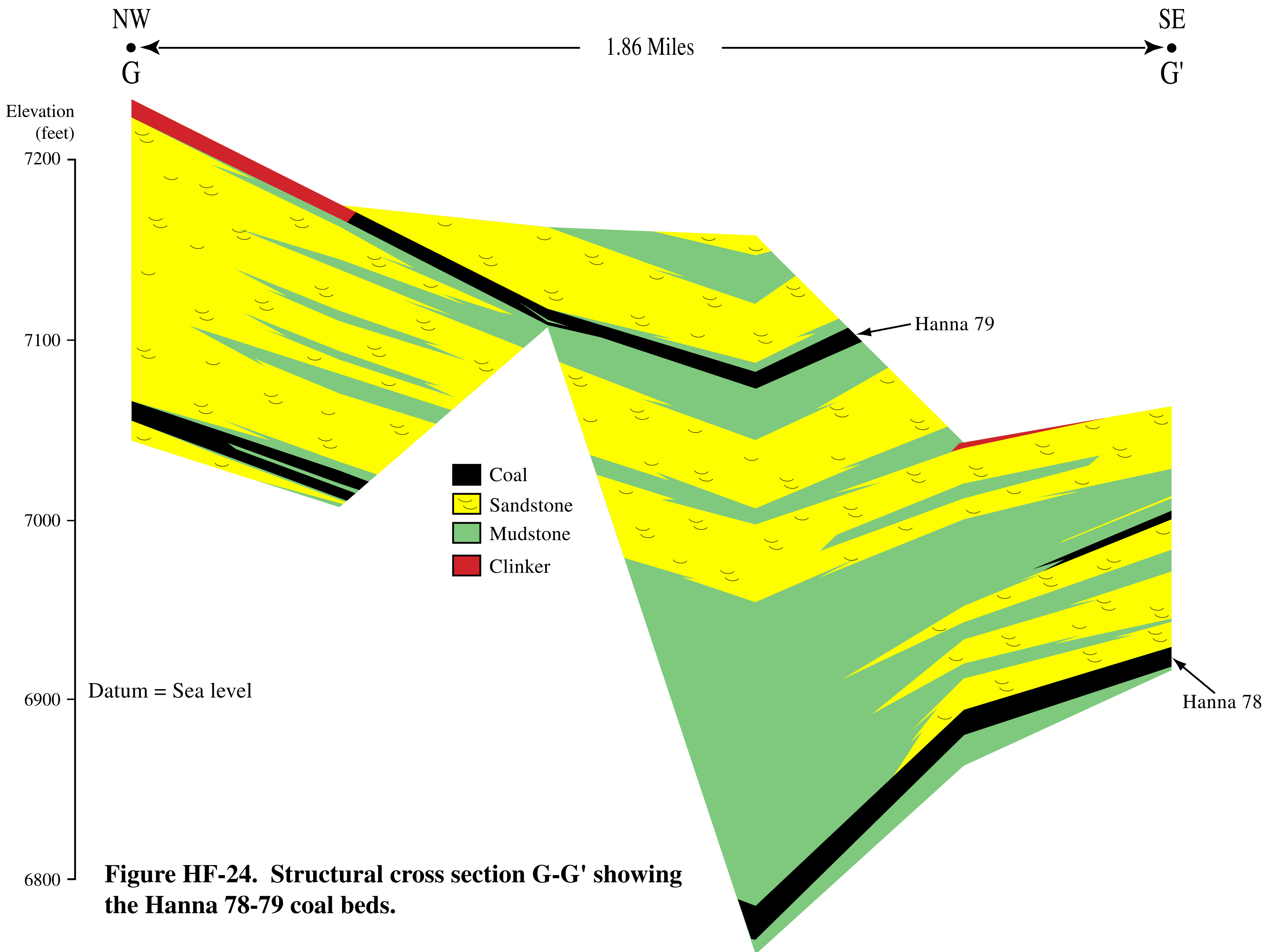

Figure HF-24. Structural cross section G-G' showing the Hanna 78-79 coal beds.

Click here or on this symbol in the toolbar to return.

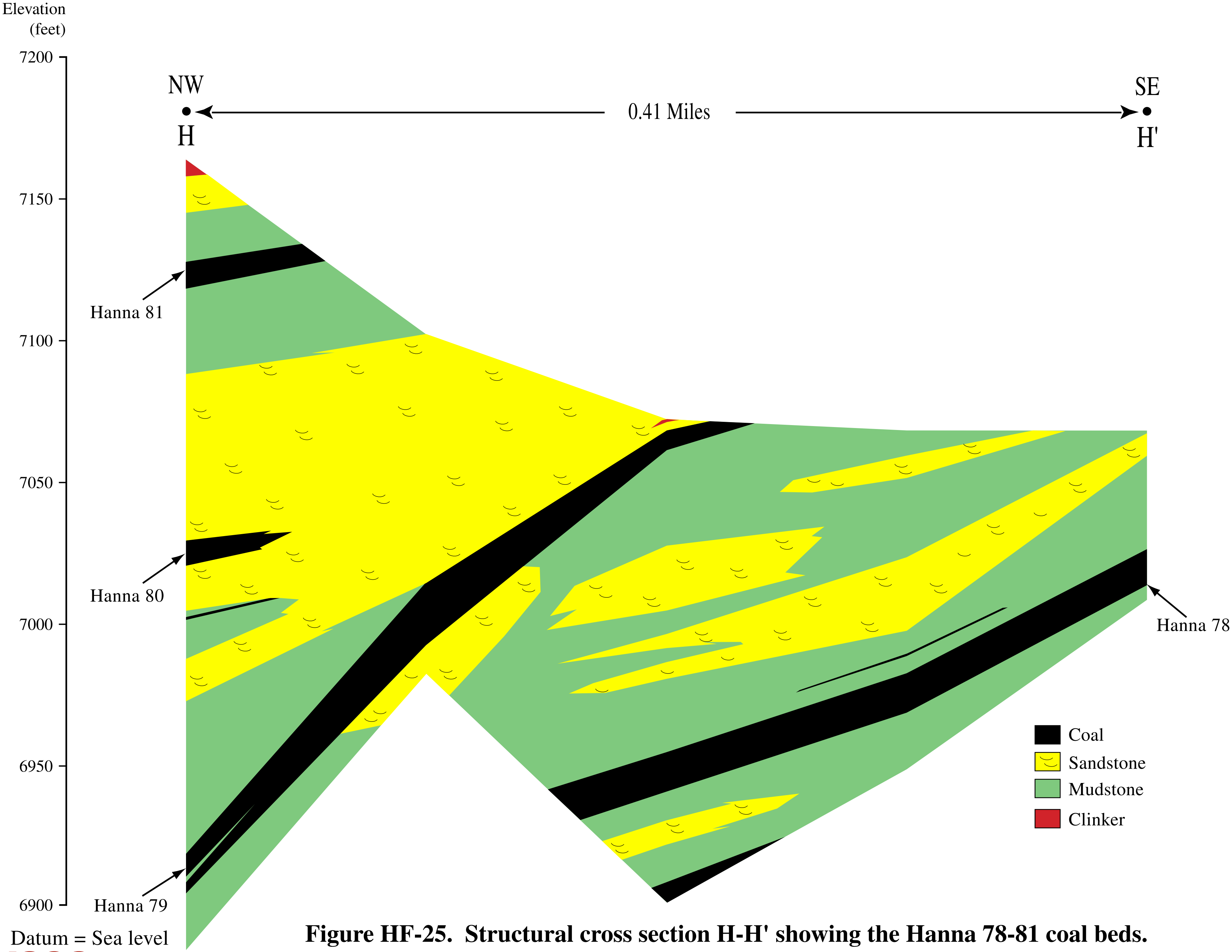

Figure HF-25. Structural cross section H-H' showing the Hanna 78-81 coal beds.

USGS
science for a changing world

Click here or on this symbol in the toolbar to return.

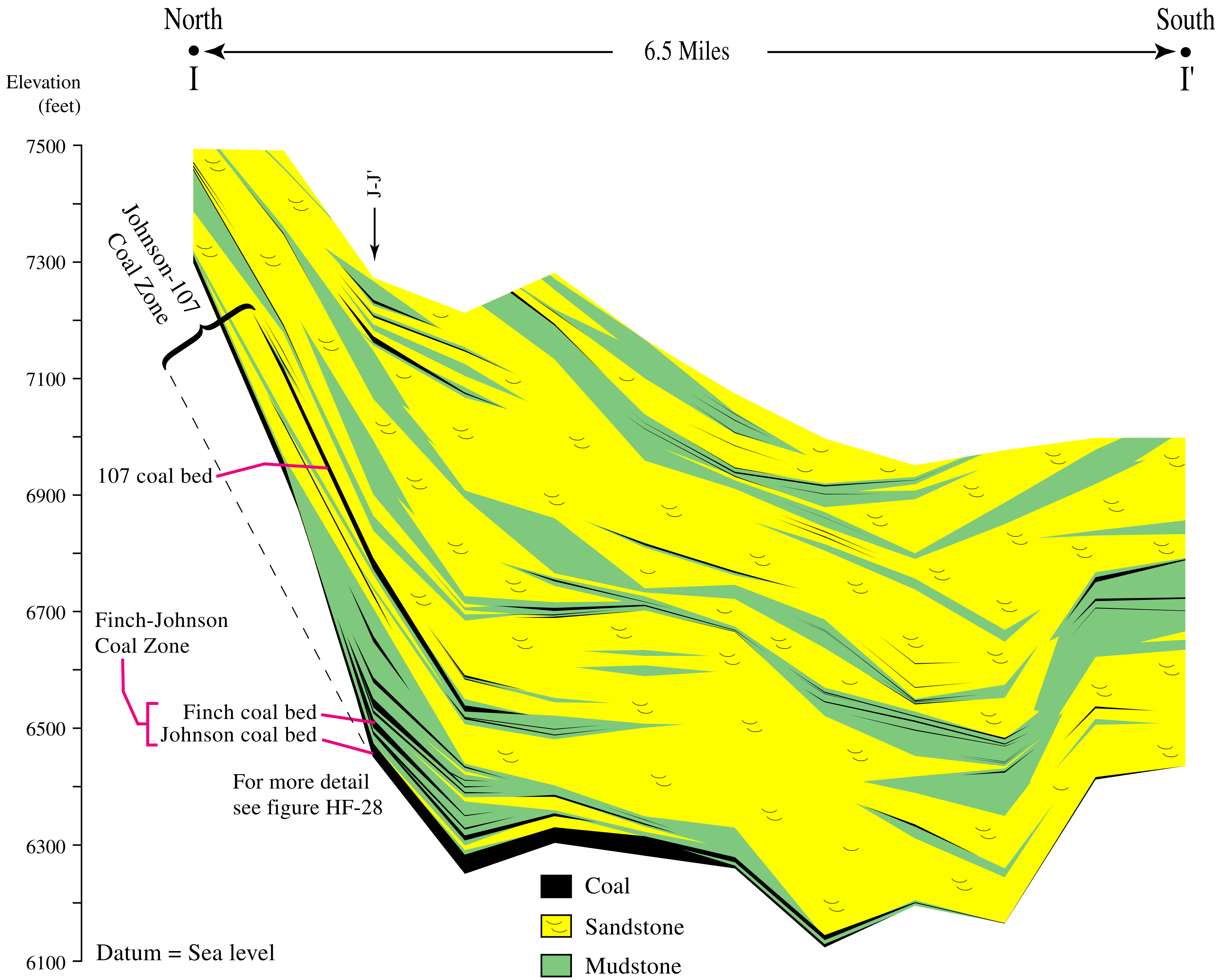

Figure HF-26. Structural cross section I-I' showing the Johnson-107 coal zone.

USGS science for a changing world

Figure HF-27. Crevasse splays draining into floodplain lakes from anastomosed fluvial channels of the Columbia River in the Province of British Columbia, Canada. Photograph by D. Smith.

Click here or on this symbol in the toolbar to return.

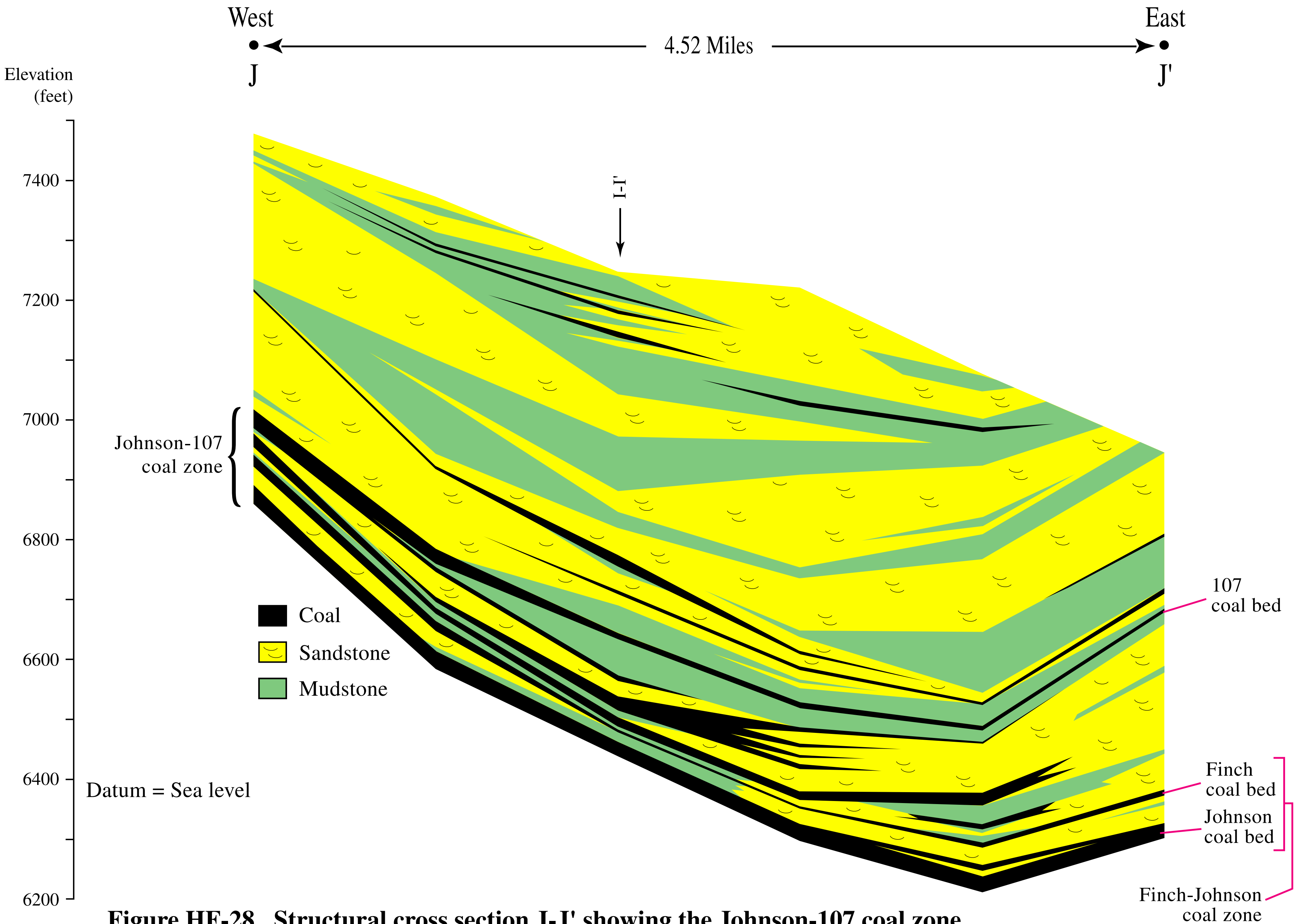

Figure HF-28. Structural cross section J-J' showing the Johnson-107 coal zone.

USGS
science for a changing world