Chapter HS

FERRIS AND HANNA COAL IN THE HANNA AND CARBON BASINS, WYOMING: A SYNTHESIS

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INTRODUCTION

Subbituminous and bituminous coal exist in the Paleocene parts of the Ferris and Hanna Formations in the Hanna and Carbon Basins (Dobbin and others, 1929; Berryhill and others, 1950; Glass and Roberts, 1979) in south-central Wyoming (fig. HS-1). These formations are stratigraphically equivalent to the Fort Union Formation in other Tertiary basins in the Rocky Mountains and northern Great Plains region. Ferris and Hanna strata make up the surface bedrock over much of the Hanna and Carbon Basins (fig. HS-2). These strata (fig. HS-3) are conformably underlain by the Upper Cretaceous part of the Ferris Formation and the Medicine Bow Formation, conformably overlain by the Eocene part of the Hanna Formation, and unconformably overlain by Quaternary deposits.

Coal in the Hanna Basin was first discovered by James C. Fremont along the North Platte River near the mouth of Sage Creek (Dobbin and others, 1929). Coal occurrences elsewhere along the Overland Trail were reported in Fremont's accounts of the "Expedition to Oregon and North California in years 1843-1844." In 1856, Lt. F.T. Bryan of the U.S. Army Topographic Corps and H. Engelmann, a geologist, reported the occurrence of coal along the North Platte River and north of the present town of Elk Mountain (fig. HS-1). In 1865, James Evans, who surveyed the proposed Union Pacific rail line, reported that coal was found from the North Platte River eastward to Rock Creek (23 miles east of Elk Mountain), which is east of the Carbon Basin (Gardner and Flores, 1989). The availability of significant amounts of coal along the Overland Trail as reported by Fremont and Evans, dictated the selection of the Union Pacific Railroad route to the West Coast. In 1868, the earliest geological investigation in the Hanna and Carbon Basins was made by Hayden (1873). He described the Tertiary formations and reported the

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presence of coal mines in the Hanna and Carbon Basins along the Union Pacific Railroad, west of Como Ridge. Here Hayden described "peculiar sands and sandstones and clays and numerous coal beds" within a 50-mile distance of the rail line. He also described the structural geology, noting that "rocks incline nearly southeast, or south and east." Plant fossils of the Tertiary formations were first examined and described by Lesquereux (1872) for the purpose of dating the rocks. Veatch (1907) prepared a reconnaissance geologic map of the Hanna and Carbon Basins and adjacent areas.

Bowen (1918) formally named the coal-bearing Tertiary formations as the Ferris and Hanna Formations. These formation names were retained, although F.H. Knowlton, T.W. Stanton, and J.W. Gidley later identified plant, invertebrate, and vertebrate remains in these rocks as typical "Fort Union" age (Dobbin and others, 1929). The coal beds and resources in the Ferris and Hanna Formations were investigated in detail by Dobbin and others (1929), who devised a comprehensive numerical nomenclature for the beds (Nos. 21-89, from bottom to top). Numbers 1-20 are found in the Cretaceous Medicine Bow Formation, which conformably underlies the Ferris Formation and outcrops along the flanks of the Hanna and Carbon Basins. The Medicine Bow coal beds were not studied because they are not potentially strippable, averaging 5-6 ft thick and dipping greater than 25 degrees (for example, in the Corral Creek mining district; see fig. HS-1; Glass and Roberts, 1979, 1980). The Hanna Formation was demonstrated by Knight (1961) to be conformable with the underlying Ferris Formation in the center of the Hanna Basin. However, the Hanna Formation rests unconformably on older formations along the basin margin and in the Carbon Basin. The Ferris and Hanna Formations exist over 600 square miles in the Hanna Basin. The Hanna Formation exists over 80 square miles in the Carbon Basin.

This study includes only the Paleocene parts of the Ferris and Hanna Formations in the Hanna Basin because associated coal beds (for example, Ferris 23, 25, 35, 50, 65, and others; Hanna 77-79, 81; see fig. HS-3) were mined and account for more than 3 million short tons of the 1998 U.S. total coal production (Resource Data International, Inc., 1998). The Hanna coal (Johnson-107 coal zone) in the Carbon Basin is a potentially minable deposit targeted for possible development (U.S. Bureau of Land Management and U.S. Office of Surface Mining, 1998). These coal beds and zones are expected to contribute fuel supplies for in-state and out-of-state electric generating power plants. The intensive exploration and development of the Ferris and Hanna coal during the early to mid 1900's by the Union Pacific Coal Company provided a number of data points for this study. Later exploration and development by other coal companies (for example, Arch Coal Incorporated, Energy Development Company, Medicine Bow Coal Company, Resource Exploration and Mining, Inc., Rosebud Coal Sales Company, and Cyprus Amax Coal Company) provided additional surface and subsurface stratigraphic information for our coal assessment of the Ferris and Hanna Formations. In addition, drilling and mapping programs by the U.S. Geological Survey (USGS) in the 1970's in the Hanna and Carbon Basins contributed stratigraphic information. Data from a total of 1,960 drill holes from these drilling activities are archived as digital records at the U.S. Bureau of Land Management in Rawlins, Wyoming, and in the USGS National Coal Resources Data System in Reston, Virginia (email: mdcarter@usgs.gov). Most of these data are proprietary.

HISTORY OF COAL MINING

Mining of the Ferris and Hanna coal in the Hanna and Carbon Basins began in 1868 near the town of Carbon, Wyoming. The production of the coal in these basins was intertwined with the establishment of a transcontinental railroad and subsequent expansion of the Union Pacific Railroad. The railroad benefited from the Pacific Railroad Act of 1862, which was modified by the Pacific Railroad Act of 1864, that stated the Union Pacific would be granted ten sections of land (6,400 acres) for every mile of track laid (Gardner and Flores, 1989). This land was distributed in alternating sections or "checkerboard" pattern in which the even-numbered sections were retained by the federal government and the odd-numbered sections were given to the railroad. (For an example of this checkerboard pattern, see the section on ownership maps in Chapter HM of this CD-ROM). The Pacific Railroad Act of 1864 liberalized trade and led to doubling the land grant to twenty sections per mile. The Union Pacific was given the mineral rights to the property received in the land grant. Thus, the railroad accumulated vast amounts of coal resources, monopolized the transport of coal from its mines, and produced additional coal from land leased from the government (Union Pacific Coal Company, 1940). The coal was a source of fuel for the Union Pacific steam locomotives, for heating fuel, and to fuel industries in western and midwestern cities.

Seven underground mines were ultimately opened by the Union Pacific Railroad in the town of Carbon, which produced about 4,680,000 tons of coal from 1868 to 1902 (Dobbin and others, 1929; Union Pacific Coal Company, 1940). Eventually these mines were abandoned when the main railroad line was shifted farther north to the present towns of Hanna. Five underground coal mines were opened in the town of Hanna in 1890 (Dobbin and others, 1929; Gardner and Flores, 1989). The mines were developed in Hanna Formation coal beds. The Hanna beds were sequentially identified by number according to the order in which the mines were opened. Only coal mine numbers 2 and 4, which produced about 2,200 tons of coal daily, were still active through the 1930's. Increased coal production was enhanced by mechanization of these underground mines during the 1920's and 1930's. Underground mine production was increased by transporting coal using electric locomotives instead of hauling coal using mules and horses and by utilizing modern coal mining equipment. Initial underground mining was by the room and pillar method, with longwall mining introduced in the 1980's. Even though strip mining was introduced in Wyoming in 1924 (Gardner and Flores, 1989), this method of mining was not used in the Hanna Basin until the 1960's and 1970's when draglines, trucks, and shovels were available to mine the steeply-dipping coal beds.

During the recession years in the 1920's and the depression years from 1930 to 1940, mine closures in Wyoming also affected coal mines in the Hanna and Carbon Basins. During World War II, coal mining was considered to be a critical industry in the war effort and coal production increased, only to decline again after the war with the advent of diesel locomotives. The railroads, with their steam locomotives, had influenced the coal market; however, the "dieselization" of the Union Pacific Railroad from the 1940's to the mid 1950's led to the closure of a majority of the mines in the Hanna and Carbon Basins (Union Pacific Coal Company, 1940; Gardner and Flores, 1989). The Union Pacific began to close their remaining mines in the Hanna Basin in 1953.

Coal mining again picked up from the 1960's to 1970's as a result of changes in the state severance tax structure and introduction of modern strip-mining methods. New power plants were built in-state and out-of-state to (1) satisfy increased demand for electrical power generation in general and (2) to burn low-sulfur coal in particular. This led to the resurrection of abandoned coal mines and opening of new ones in the Hanna Basin. The passing of the current severance tax by the Wyoming State Legislature eventually brought an economic boom to the state (Gardner and Flores, 1989). The idea behind the tax is to recapture part of the lost value of coal, a nonrenewable energy source, through excise tax on the mining of a natural resource. The Wyoming severance tax was levied on the coal industry at a steadily increasing rate through the 1970's and created a revenue source for the State of Wyoming. In the late 1970's, 98 percent of the coal production in the Hanna Basin was from strip mines equipped with modern draglines, truck shovels, and high-capacity haul trucks. Glass and Roberts (1979) estimated that at least 63.1 million tons of coal had been strip-mined by 1978.

At present, Arch Coal Incorporated is operating strip mines in the Ferris and Hanna coalfields. The Cyprus Coal Company operates an underground mine in the Hanna coalfield. The resources of the Ferris 23, 25, 31, 50, and 65, and Hanna 77-79 and 81 coal beds are assessed by this investigation in the Hanna Basin. In addition, the resources of the Johnson-107 coal zone is assessed in the Carbon Basin.

GEOLOGICAL SETTING

The Hanna and Carbon Basins are structural and sedimentary basins bounded on the south by the Medicine Bow uplift, on the north by the Sweetwater arch consisting of the Granite, Shirley, and Seminoe Mountains, and on the west by the Rawlins uplift (see fig. HS-1). The Hanna and Carbon Basins are separated by the northeast-trending Saddleback anticline, which was an emergent extension of the Medicine

Bow uplift during the early Paleocene (Knight, 1951; Glass and Roberts, 1980; Flores and Roberts, 1996; Perry and Flores, 1994). The basins are asymmetric subdivisions of an east-west trending structural trough that formed during the Laramide deformation. A total of more than 30,000 ft of sedimentary rocks accumulated on the Precambrian crystalline basement rocks (Dobbin and others, 1929; Knight, 1951). Rapid subsidence of the Hanna Basin is suggested by the combined thickness of the Ferris and Hanna Formations, which totals about 13,500 ft. Rocks of these formations are steeply dipping (greater than 25 degrees) along the basin margin and have moderate to low dips (5-15 degrees) in the basin center (Glass and Roberts, 1980). In addition, Glass and Roberts (1980) indicate that younger coal-bearing Paleocene rocks steepen to vertical dips.

Both basins were modified by folding and faulting (see fig. HS-1). High-angle, normal and thrust faults with displacements from a few feet to 0.5 mi or more (fig. HS-4) are common in the central part and along the flanks of the Hanna Basin (Glass, 1977; Perry and Flores, 1994). Cross-faults between northwest-trending faults are also present in the east-central part of the basin. Major faults along the basin margins developed from Late Cretaceous to early Paleocene time, during the Laramide deformation (Knight, 1951; Love, 1970). The Hanna Basin is divided into three synclines with axes almost perpendicular to each other along its northern and eastern parts (fig. HS-1); it also contains a few folds along the margins of the basin. In the Carbon Basin, several anticlines are present along the basin margins. Numerous northeast-trending faults dissect the basin.

The sedimentary infilling of the Hanna and Carbon Basins evidently was controlled by periodic tectonic movements of the uplifts surrounding the basins (Brooks, 1977; Ryan, 1977). This interpretation is based on the petrology and mineral composition of the Ferris and Hanna Formations in comparison to rocks of the surrounding uplifts. Early Paleocene uplift of the ancestral Park Range-Medicine Bow Mountains shed sediment from the south, which mostly formed the Ferris Formation. A minor amount of sediment was shed from the inactive Sweetwater arch (Granite, Seminoe, and Shirley Mountains) during this time. Middle to late Paleocene tectonic movements of the Sweetwater arch caused shedding of abundant sediment from the north to form the Hanna Formation. These sediments were transported and deposited by eastward-flowing braided and meandering rivers. Late Paleocene tectonic movement of the Rawlins uplift caused closure of the western margin of the Hanna Basin (Perry and Flores, 1994). The Carbon Basin developed as a depositional basin only from middle to late Paleocene time, and it was structurally separated from the Hanna Basin by late Paleocene or Eocene time (Perry and Flores, 1994).

The tectonic settings of the basins and adjacent areas imposed physical differences in the stratigraphy of the Ferris and Hanna Formations (see fig. HS-3). The lower 1,100 ft of the Ferris Formation consists primarily of conglomeratic sandstone beds composed of pebble fragments of quartzite, varicolored jasper, rhyolite, and porphyry (Dobbin and others, 1929). The remaining 5,700 ft of the Ferris Formation consists of interbedded sandstone, siltstone, mudstone, carbonaceous shale, and coal. The Hanna Formation consists of interbedded "packages" of thick conglomeratic to coarse-grained sandstone interbedded with sandstone, siltstone, mudstone, carbonaceous shale, and coal. The lowermost part of the formation consists of as much as 1,900 ft of conglomeratic sandstone composed primarily of pebble fragments derived from the Ferris conglomeratic sandstone together with granitic fragments. In addition, Hanna sandstone is more arkosic than the Ferris sandstone (Brooks, 1977; Ryan, 1977).

DEPOSITIONAL SETTING

The tectonic imprint on the physical stratigraphy of the Ferris and Hanna Formations is shown by differences in their depositional environments. Erosional bases of Ferris and Hanna conglomeratic sandstone beds (figs. HS-5, HS-6, and HS-7) probably reflect lowering of the base level due to uplifts or basin subsidence. These events permitted fluvial channels to downcut and form paleovalleys that were subsequently infilled during succeeding rises in base level. Major events of downcutting and subsequent infilling of paleovalleys occurred during early Ferris time and early Hanna time. Braided and meandering streams infilled these paleovalleys (Cavaroc and others, 1992). Intervening coal-bearing intervals consisting of sandstone, siltstone, mudstone, and coal (figs. HS-8 and HS-9) reflect base level rises during which alluvial plains were drained mainly by meandering and anastomosed rivers (see figs. HS-10 and HS-11; Perry and Flores, 1994). Thus, cyclic intervals of deposition of conglomeratic sandstone and coal-bearing rocks represent base-level fall and rise controlled by tectonism and basin subsidence. Provenance and sediment dispersal studies of the Ferris and Hanna Formations in the Hanna and Carbon Basins by Ryan (1977) suggested that clastic sediment was dispersed by three fluvial systems, two entering from the north and one entering from the south. These dispersal systems were influenced by uplift of the Medicine Bow Mountains to the south and subsequent uplifts of the Granite Mountains to the north. Uplift reversals controlled the dynamics of the fluvial systems, changing their styles from dominantly braided rivers to dominantly meandering and anastomosed rivers; the latter being overprinted more by changes in basin subsidence than by uplifts. The evolution of fluvial styles is indicated by the channel sandstone architecture (figs. HS-12, HS-13, and HS-14). These fluvial systems were probably

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fed from the mountains through alluvial fans (Hansen, 1986), exemplified by sandstone and conglomerate deposits (figs. HS-15 and HS-16).

Although coal facies data used to determine whether the Ferris and Hanna coal was formed in planar (low-lying) or domed (raised) swamps are limited, Pierce (1996) postulated that the swamps in which Hanna coal formed were low-lying. Based on the coal petrology and proximate analysis of the Hanna coal, Pierce suggested that large amounts of gelocollinite and high ash yields indicate accumulation of peat in low-lying mires or swamps. In addition, Pierce referred to unpublished palynological data of D.J. Nichols of the USGS that suggested angiosperms inhabiting the Hanna swamps provided a majority of the gelocollinite precursors. In contrast, the Ferris coal is composed of lesser amounts of gelocollinite and relatively more telinite (Pierce, 1996). Ferris coal also is dominated by pollen of woody taxodiaceous gymnosperms, which may have provided telinite precursors. Ferris coal probably developed in raised swamps. Thus, differences in swamp vegetation, as indicated by coal petrography and palynology, may have influenced the composition of the coal deposited in the Ferris and Hanna Formations.

Cavaroc and others (1992) and Perry and Flores (1994) suggested that basin subsidence may have controlled the nature of the swamps in the Hanna Basin; Pierce (1996) reached a similar conclusion. Perry and Flores (1994) indicated that subsidence may have occurred during the Paleocene in the northern part of the Hanna Basin at about 1.9 ft per 10^3 years for decompacted Ferris and Hanna rocks or 1.4 ft per 10^3 years uncorrected for compaction. Thus, this rapid rate of subsidence contributed to over-thickening (13,000 ft) of the Paleocene rocks and drowning of the basin by floodplain lakes and accompanying swamps. More importantly, subsidence influenced burial of the swamps by sediments. Thus, sedimentological evidence suggests that the Ferris and Hanna swamps were low-lying because they were prone to floods. It is suggested that the differences in vegetation between the Ferris and Hanna low-lying swamps and resulting coal macerals (Pierce, 1996) may be due to adaptability of plants to the tectonic conditions in the basin and to changing fluvial depositional environments, although effects of floral evolution cannot be discounted. It is possible that the Hanna swamps may have been more low-lying than the Ferris swamps, as indicated by greater degradation of Hanna peat. The similarity in tectonic conditions and depositional settings for both the Ferris and Hanna coal may explain the similarity in the thicknesses of assessed coal beds of the Ferris Formation (Ferris 23, 25, 31, 50, and 65), which range from 5 to 22 ft, and those in the Hanna Formation (Hanna 77-79 and 81), which range from 5 to 27 ft. Glass and Roberts (1980) indicated that thicknesses of Ferris coal ranges from 5 to 25 ft and Hanna coal ranges from 5 to 38 ft. In the Carbon Basin, which had a subsidence history similar to that of the Hanna Basin, the assessed coal beds (Johnson-107 coal zone; fig. HS-17) range from 5 to 25 ft thick.

COAL GEOLOGY

Seventy-seven coal beds are identified by Dobbin and others (1929) and Glass and Roberts (1980) in the Hanna and Carbon Basins, 47 coal beds are in the Ferris Formation, and 30 beds are in the Hanna Formation (see fig. HS-3). The interval containing coal beds in the Ferris Formation ranges from 25 to 400 ft thick, and that in the Hanna Formation from 30 to 1,100 ft thick (Dobbin and others, 1929). The thinner coal-bed interval in the Ferris Formation is composed primarily of interbedded mudstone, siltstone, and sandstone (see fig. HS-3). In contrast, the thicker coal-bed interval in the Hanna Formation is expanded by thick sandstone and conglomerate beds with minor mudstone and siltstone (see fig. HS-3). Except for these minor physical characteristics, the Ferris and Hanna Formations contain similar coal-bearing rocks. The biostratigraphy based on palynology (analysis of fossil spores and pollen) of the two formations utilizes the zonation of Nichols and Ott (1978); see also Nichols (1994), Nichols (1996), and Perry and others (1996). Paleocene Zones P1 through P6 are present in the Hanna Basin (see fig. HS-3; and Chapter HB in this CD-ROM). The Ferris Formation includes Zones P1 through P2 (lower Paleocene), and the Hanna Formation includes Zones P4 through P6 (middle and upper Paleocene). Zone P3 was not found; it may be either in the uppermost Ferris Formation or lowermost Hanna Formation. Palynology also shows that the lowermost part of the Ferris Formation is in the uppermost Cretaceous and the uppermost part of the Hanna Formation is in the lower Eocene. The coal stratigraphy of the Ferris and Hanna Formations in the Hanna Basin may be simplified by grouping the coal beds into bundles (see fig. HS-3; for example, F1 and H1) interbedded mainly with mudstone and siltstone and generally separated by intervals of conglomerate, sandstone, siltstone, and mudstone (see fig. HS-3). Similar coal-bed bundling is observed in the Carbon Basin (see fig. HS-3; for example, H6-H7). The Ferris coal beds in the middle part of the formation are vertically stacked. These stacked coal beds may be divided into four bundles of coal beds, each interbedded with abundant siltstone and mudstone, and subordinate sandstone, in intervals ranging from 20 to 60 ft thick (see fig. HS-3; F1-F4). The coal bundles range from 300 to 950 ft thick. The four coal bundles, from bottom to top, include: (F1) coal bed Nos. 21-24; (F2) bed Nos. 25-29; (F3) bed Nos. 30-50; and (F4) bed Nos. 51-59 (see fig. HS-3). Coal beds Nos. 60-65 are in intervals of varying thickness in the uppermost part of the Ferris Formation. The Hanna coal beds also are grouped in bundles throughout the formation; these coal bundles are vertically stacked on top of fining-upward intervals consisting of sandstone, siltstone, and mudstone ranging from 200 to 1,050 ft thick (see fig. HS-3; for example, H1, H2, H3, and H4). Four of the five Hanna coal bundles range from 100 to 800 ft thick, and are interbedded mainly with siltstone and mudstone and subordinate sandstone. The H5 coal bundle is over 1600 ft thick and is interbedded with sandstone, siltstone, and mudstone. The five coal bundles, from bottom to top, include: (H1) bed Nos. 67-69; (H2) bed Nos. 70-72; (H3) bed Nos. 73-76; (H4) bed Nos. 77-81; and (H5) bed Nos. 82-89 (see fig. HS-3).

The vertical and lateral variations in coal stratigraphy in the Ferris and Hanna Formations are controlled by the sedimentology and depositional environments of the rocks interbedded with the coal. In the Ferris Formation, coal beds may split and merge within short distances (within 0.1 mile; see cross sections in Chapter HF of this CD-ROM), forming a coal zone. The extent of this zone is controlled by the areal size and rate of sedimentation of the fluvial depositional systems that formed the deposits. Thus, a rapid rate of sedimentation in small, lobe-shaped depositional systems, such as crevasse splays, produced thin intervals of siltstone and mudstone and subordinate sandstone between coal beds. These sedimentary deposits formed short-lived swampy platforms on which thin peat deposits accumulated. Frequent autocyclic (lateral) shifts of these environments influenced the splitting and merging of the peat deposits; the resulting thick peat formed on these platforms. Stacking of the peat deposits and sediments related to autocyclic crevasse-floodplain depositional systems caused bundling or stacking of thin coal beds. The intervening intervals of sandstone, siltstone, and mudstone represent the fluvial-channel, overbank deposits of the fluvial systems.

In the Hanna Formation, coal beds split and merge over a few miles, forming a coal zone. This zone resulted from the rapid rate of sedimentation in wide alluvial plains that were drained by meandering and braided streams and accompanying crevasse splays. Avulsion and prolonged abandonment of these stream deposits led to the formation of extensive alluvial platforms on which swamps developed and very thick peat deposits accumulated. However, rapid successions of avulsion and abandonment of the fluvial depositional systems along the width of the alluvial plain led to coal-bed bundling. In addition, the vast expanse of abandoned platforms contributed to the extensive areal distribution of the peat deposits. This accounts for the widespread coal deposits of the Hanna Formation.

COAL RESOURCES AND COAL QUALITY

On the basis of strippable coal resources, the Hanna and Carbon Basins were subdivided into four mining districts by Glass and Roberts (1979; 1980). These mining districts include, from west to east, the Corral Creek, Seminoe, Hanna, and Carbon districts, with areas barren of near-surface coal serving to delimit one district boundary from another (see fig. HS-1). The Corral Creek mining district contains coal beds of the Cretaceous Medicine Bow Formation. The Seminoe mining district contains the Ferris coal beds, and the Hanna and Carbon mining districts contain the Hanna coal beds. Glass and Roberts (1979; 1980) reported that the weighted average thickness of the Ferris coal beds is 10 ft, based on strippable resources in the Seminoe mining district. These workers also reported that the weighted average thickness of the Hanna coal beds is 11-14 ft, based on strippable resources in the Hanna and Carbon mining districts. The thickening of minable deposits is enhanced by coalescing of individual coal beds from a coal zone into a single bed.

Dobbin and others (1929) estimated that the Hanna Basin contained 4.2 billion tons of coal from the surface to a depth of 3,000 ft and about 4 billion tons at greater depths. Berryhill and others (1950) reinvestigated the coal resources of the Hanna Basin using the data of Dobbin and others (1929) and calculated reliability categories based on thickness and depths. These investigators reported 3.9 billion tons for coal found at the surface to a depth of 3,000 ft. In a study instigated by the increasing demand for near-surface or strippable (0-200 ft depth) coal resources in the Hanna Basin, the U.S. Bureau of Mines (1971) estimated that 10 million tons of resources were in eight unnamed coal beds of the Hanna Formation. The U.S. Bureau of Mines assumed that 80 percent of this volume was recoverable and estimated 8 million tons as a strippable reserve.

Based on resource calculations provided by Berryhill and others (1950), Glass (1972) estimated about 313 million tons of strippable coal resources existed in the Hanna Basin for bituminous coals over 42 inches thick and subbituminous coal over 5 ft thick under less than 1,000 ft of overburden. In the Seminoe mining district, the U.S. Bureau of Land Management (1975) identified 41.21 million tons of strippable Ferris coal resources within a 9.6 square mile area under 0-200 ft of overburden. Glass and Roberts (1979) reported about 173 million tons of strippable coal resources underlie the townships that the U.S. Bureau of Land Management studied. A series of U.S. Geological Survey Open-File Reports prepared by Texas Instruments, Inc. (1978a-u), have provided the most detailed estimates for the Hanna Basin. However, these reports only provided figures for strippable resources of unleased federal mineral lands. Choate and Lent (1977) estimated coal resources of steeply dipping coal beds in the Hanna Basin to be about 240 million tons. Their estimates included beds 5 to 30 ft thick with dips greater than 20 degrees.

Glass and Roberts (1979; 1980) reported comprehensive coal resource estimates in the Hanna and Carbon Basins. These investigators estimated remaining strippable coal resources of the Ferris and Hanna coal beds and zones as of January 1, 1978, to be more than 657 million tons. About 299 million tons of this total are under 0-100 ft of overburden, and about 348 million tons are under 100-200 ft of overburden. Seventy-nine percent of these strippable coal resources are found in the Seminoe and Hanna mining districts. Prior to January 1, 1979, about 189 million tons of the strippable coal resources had been mined, and about 80 million tons of this coal resource were removed or lost by strip mining (Glass and Roberts, 1979; 1980). Another 110 million tons were removed or lost by underground mining prior to this date. Resource Data International, Inc. (1998) recorded a total of about 40 million tons that was produced by seven mines from 1989 to 1997. Thus, not including production from 1979 to 1989, approximately 218 million tons remain as strippable coal resources in the Ferris and Hanna coal beds and zones in the Hanna and Carbon Basins.

Estimates of coal resources of the Ferris, Hanna, and Johnson-107 coal beds and zones are presented in Chapter HN of this CD-ROM. Estimates of coal resources in beds thicker than 2.5 ft are: Ferris coal beds and zones—1.75 billion short tons; Hanna coal beds and zones—4.26 billion short tons; and Johnson-107 coal beds and zones—2.7 billion short tons; a total for the two basins—8.71 billion short tons (see Chapter HN). These coal resource estimates are broken down by thickness, overburden, ownership, and county (see Chapter HN). The methodology of calculating the resources of these coal beds and zones is discussed in Chapters DB and HN of this CD-ROM.

The apparent rank of the Ferris and Hanna coal beds varies from subbituminous A to high-volatile C bituminous. This variation in rank is not related to the age of the coal because Hanna coal has been reported as high-volatile C bituminous by Glass and Roberts (1979; 1980). These workers reported that the apparent rank of the Ferris coal is usually subbituminous A. The variations in coal rank between Ferris and Hanna coal may be explained by the location of the coal samples. That is, the Ferris coal samples were collected from the Seminoe mining district, or along the western margin of the Hanna Basin. In contrast, the Hanna coal samples were collected from the central part of the Hanna Basin and from the Carbon Basin. In general, the coal rank increases from west to east, ranging from 11,170 Btu/lb for the Ferris coal on the western part of the Hanna Basin to 11,590 Btu/lb for the Hanna coal in the east-central part of the Hanna Basin and 12,270 Btu/lb for the Hanna coal in the Carbon Basin to the east (Glass and Roberts, 1979). Glass and Roberts (1980) suggested that the spatial variation may be explained by variation in heat flow, which is higher and longer in duration in the east than in the west. However, the spatial variation in rank also may be explained by the difference in depth of burial, because the Hanna coal in the central and deepest part of the basin was buried deeper than the Ferris coal in the western part or margin of the Hanna Basin. Vitrinite reflectance of the Ferris coal ranges from 0.48 to 0.53 percent Ro and of the Hanna coal from 0.45 to 0.54 percent Ro in the Hanna Basin (fig. HS-18; Teerman, 1983). The vitrinite reflectance of the Hanna coal ranges from 0.51 to 0.54 percent Ro in the Carbon Basin (fig. HS-18; Teerman, 1983). The vitrinite reflectance of the Ferris and Hanna coal indicates no significant difference from the west to the east, suggesting that there is no relationship between coal rank and vitrinite reflectance (McCartney and Teichmuller, 1972).

The ultimate and proximate analyses of coal from the Ferris and Hanna Formations in the Hanna and Carbon Basins were reported by Lord (1913), Dobbin and others (1929), U.S. Bureau of Mines (1931; 1971), U.S. Bureau of Land Management (1975), Glass (1972; 1978), and Texas Instruments, Inc. (1978a; 1978c-h; 1978j-m;

1978o-s; 1978u). These analyses were summarized by Glass and Roberts (1979). The moisture, volatile matter, and fixed-carbon values (arithmetic mean; as-received basis) for the Ferris coal in the Seminoe mining district are 12.58, 34.30, and 45.19 percent, respectively. The sulfur and ash contents of the coal are 0.49 and 7.93 percent, respectively. In contrast, the moisture, volatile matter, and fixed carbon values (arithmetic mean; as-received basis) for the Hanna coal in the Hanna mining district are 12.76, 36.68, and 41.82 percent, respectively, and for the Hanna coal in the Carbon mining district are 10, 36.71, and 39.55 percent respectively. The sulfur and ash contents of the Hanna coal are 0.76 and 8.75 percent, respectively, and of the Hanna coal in the Carbon Basin are 2.72 and 13.74 percent, respectively. Our coal-quality investigation of the Johnson-107 coal zone indicates the following arithmetic mean values (on an as-received basis) for the coal not presently being mined or leased: ash yield—12.48 percent, total sulfur—0.96 percent, and calorific value—10,090 Btu/lb (see Chapter HQ of this CD-ROM for more detail).

The trace elements of environmental concern in Ferris and Hanna coal, which can impact coal utilization and reclamation, include arsenic, mercury, selenium, and uranium. Glass and Roberts (1979) reported that the Ferris coal in the Seminoe mining district contains 4.6 ppm arsenic, 0.08 ppm mercury, 0.67 ppm selenium, and 2.4 ppm uranium (n=34-35, arithmetic mean, on a whole coal, as-received basis). In comparison, the Hanna coal in the Hanna and Carbon mining districts contains 3.3-25 ppm arsenic, 0.08-0.20 ppm mercury, 0.79-3.2 ppm selenium, and 1.8-3.9 ppm uranium (n=15-19, arithmetic mean, on a whole-coal, as-received basis). Stricker and others (1998) reported no significant difference in the arithmetic means for contents of arsenic (4.4 ppm), mercury (0.07 ppm), selenium (0.80 ppm), and uranium (1.9 ppm) (n=14, arithmetic mean, on a whole-coal, as-received basis) of the Ferris and Hanna coal in the Hanna and Carbon Basins. These workers

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suggested that the higher sulfur, ash, and trace-element contents (see Chapter HQ of this CD-ROM for more detail) of the Ferris and Hanna coal beds and zones compared to other basins in the Rocky Mountains and northern Great Plains region were controlled by the source rocks in the surrounding uplifts, the intensity of the tectonic activity in these uplifts, and the low-lying swamps associated with the fluvial depositional settings.

CONCLUSIONS

The Ferris and Hanna coal beds represent a significant energy resource in the Hanna and Carbon Basins in south-central Wyoming. The mining history and development spans about 130 years and continues to support local and national consumers. The most important use of this high-rank coal resource is fuel for electric power generating plants. Presently, open-pit mines produce from the Ferris coal beds and zones, and underground and open-pit mines produce from the Hanna coal beds and zones. Production from these coal mines supports seven in-state electric power plants and one degasification plant. Coal production in 1998 from three mines was more than 3.1 million short tons (Resource Data International, Inc., 1998).

In order to evaluate subbituminous A to high-volatile C bituminous coal needed for electric power plants during the next century, assessment of Ferris and Hanna coal in the Hanna and Carbon Basins in Wyoming concentrated on the compliant coal beds of the Ferris 23, 25, 31, 50, and 65, Hanna 77-79, 81, as well as the Johnson-107 coal beds and zones. Estimates of coal resources in these coal beds and zones of the Hanna and Carbon Basins total 8.71 billion short tons. These coal deposits are as much as 30 ft thick and have low sulfur, ash, and trace-element contents. The Ferris and Hanna coal beds and zones contain approximately 218 million tons of remaining strippable coal resources under less than 200 ft of overburden in the Hanna and Carbon Basins.

The Ferris coal beds may have been deposited in raised swamps and the Hanna coal beds in low-lying swamps, all associated with fluvial depositional systems. The variable vertical and lateral distribution of these coal beds and zones reflect accumulation in dynamic fluvial settings controlled by basin subsidence and tectonic uplift of the adjoining ancestral mountains. These fluvial environments and tectonic conditions also influenced the coal quality (for example, rank, ash, sulfur, and trace elements) of the Ferris and Hanna coal beds and zones. These coal beds will be a clean and compliant energy resource during the next few decades.

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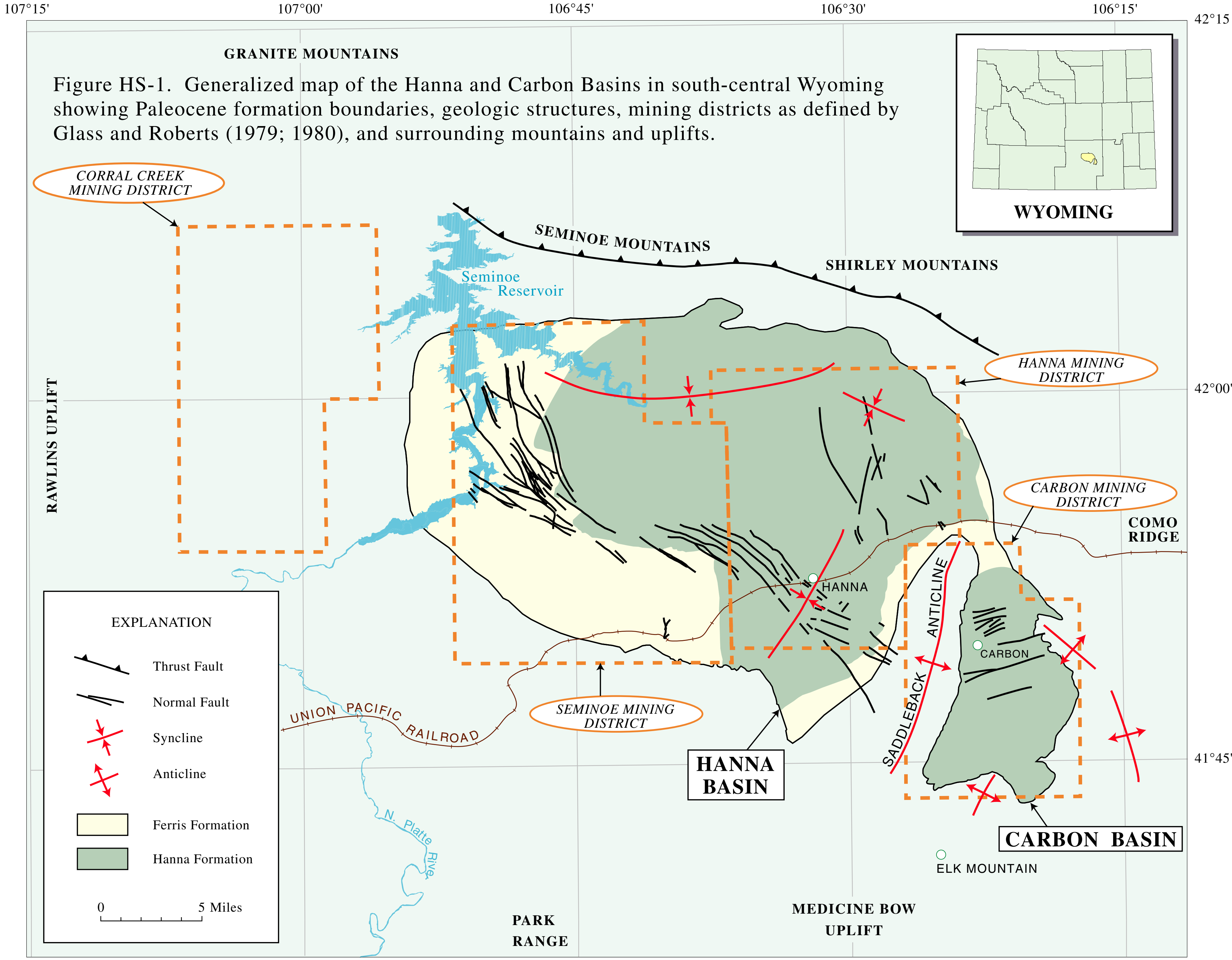

Figure HS-1. Generalized map of the Hanna and Carbon Basins in south-central Wyoming showing Paleocene formation boundaries, geologic structures, mining districts as defined by Glass and Roberts (1979; 1980), and surrounding mountains and uplifts.

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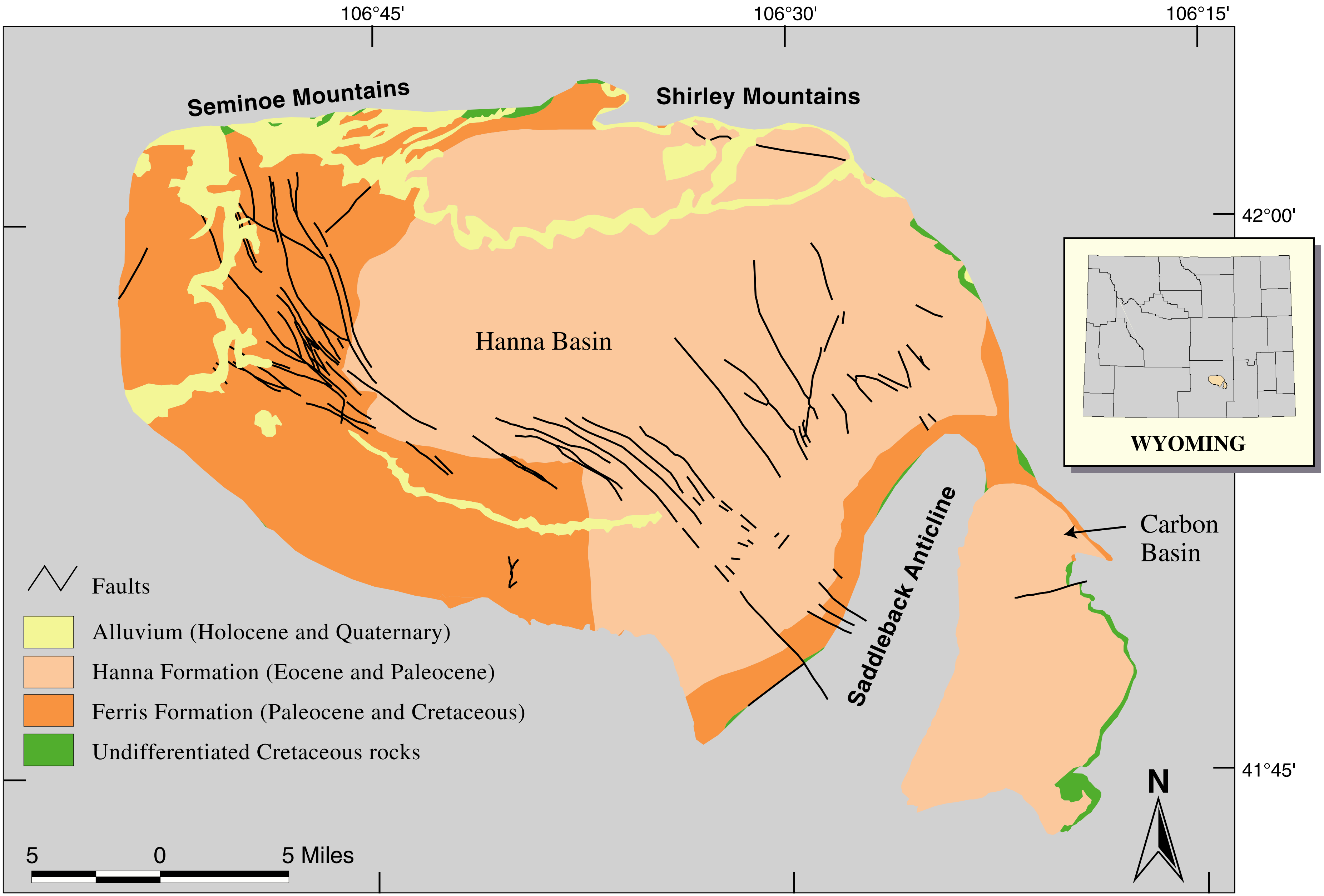

Figure HS-2. Geologic map of the Hanna and Carbon Basins showing areal distribution of Tertiary, Quaternary, and Holocene rocks (adapted from Green and Drouillard, 1994).

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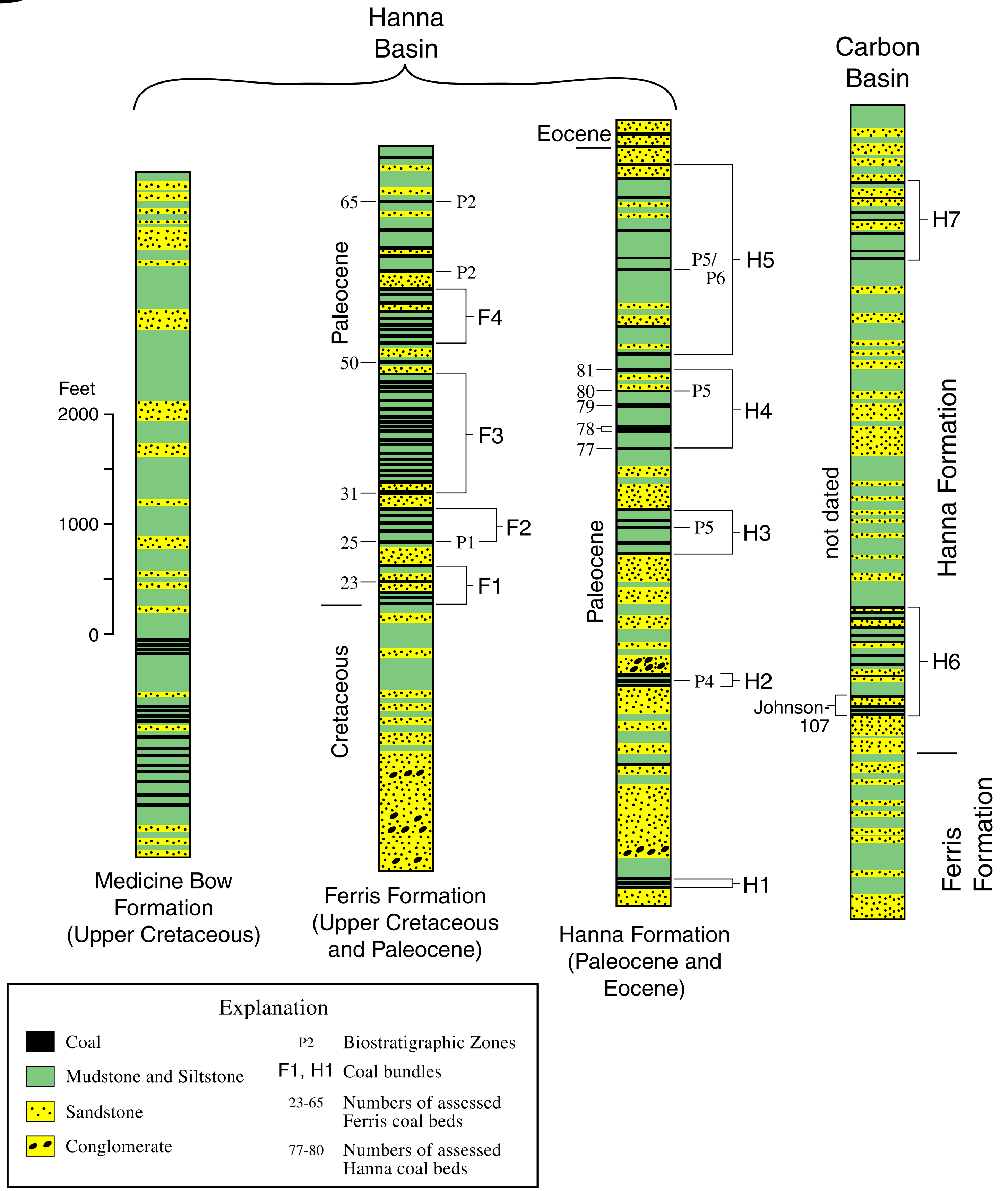

Figure HS-3. Stratigraphic subdivisions of the Cretaceous Medicine Bow Formation and Paleocene Ferris and Hanna Formations in the Hanna and Carbon Basins. Paleocene biostratigraphic zones (P1 through P6) of coal beds in the Ferris and Hanna Formations in the Hanna Basin are also shown. Ferris coal bundles are F1 through F4. Hanna coal bundles are H1 through H7. Stratigraphy and coal bed names were adapted from Dobbin and others (1929).

Figure HS-4. Normal faults showing displacement of Ferris coal beds in the highwall of the Medicine Bow coal mines. Photograph by R.M. Flores.

Figure HS-5. Basal Ferris sandstone showing large-scale trough crossbeds exposed in the southwestern part of the Hanna Basin. Photograph by R.M. Flores.

Figure HS-6. Pebble fragments in the conglomeratic sandstone at the basal Ferris Formation exposed in the southwestern part of the Hanna Basin. Photograph by R.M. Flores

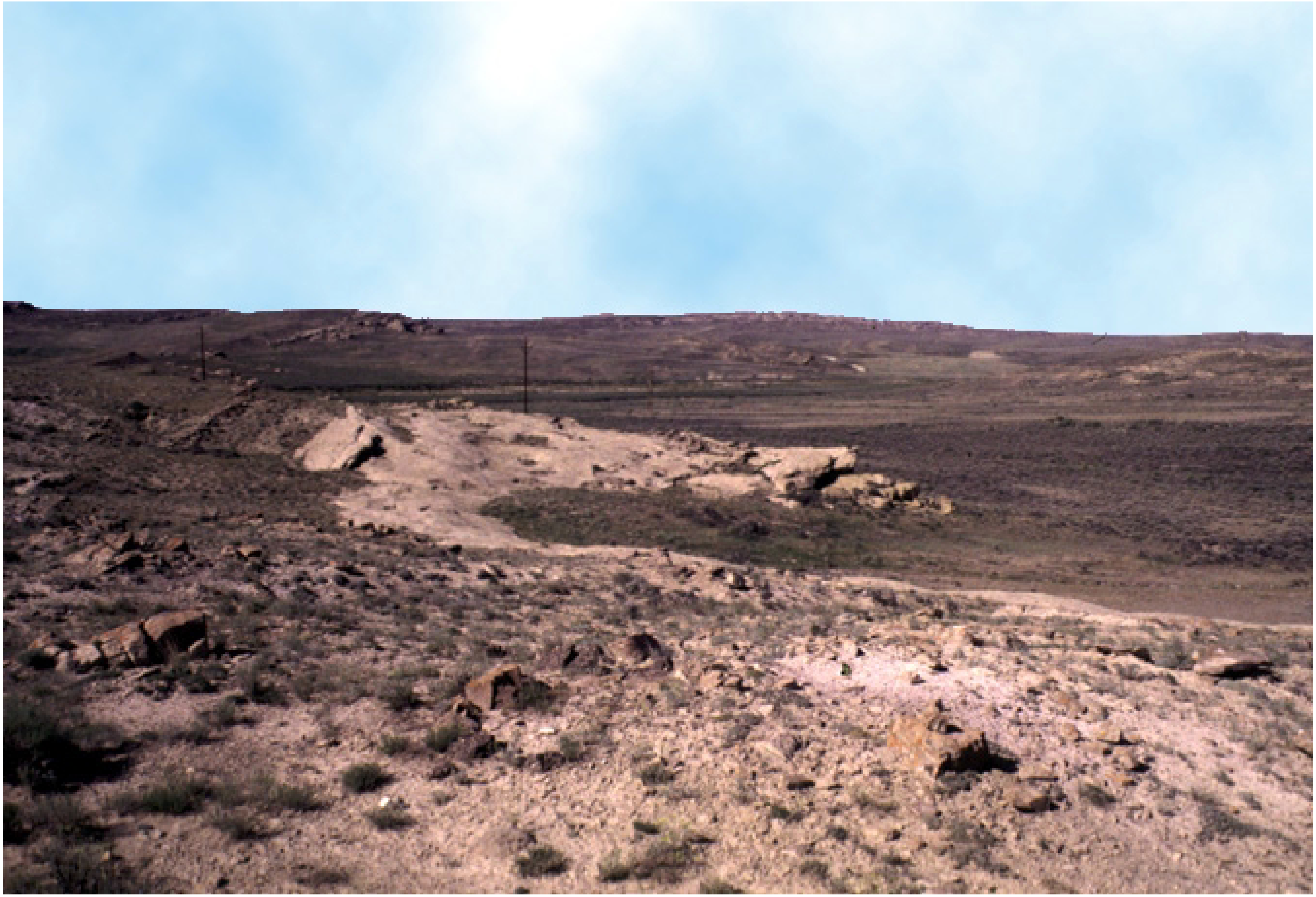

Figure HS-7. Laterally extensive basal conglomeratic sandstone of the Hanna Formation exposed along the central part of the Hanna Basin. Photograph by R.M. Flores.

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Figure HS-8. Interbedded coal, mudstone, siltstone, and sandstone in the Ferris Formation. The buff sandstone on the upper right is a lens-shaped, fluvial channel deposit. Photograph by R.M. Flores.

Figure HS-9. Thick coal and carbonaceeous shale overlain by tabular crevasse splay sandstone in the Hanna Formation. Photograph by R.M. Flores

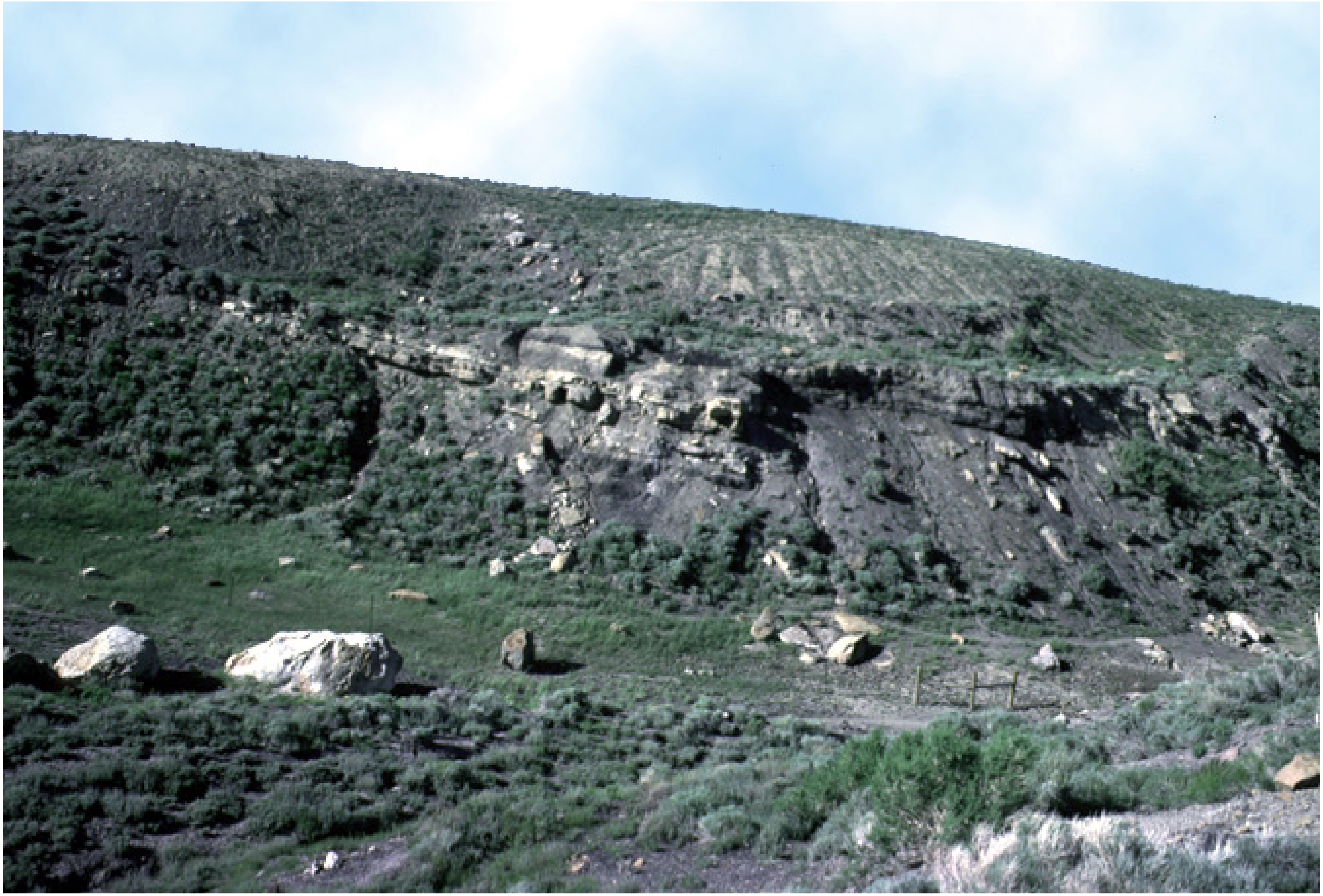

Figure HS-10. Lens-shaped, narrow fluvial channel sandstone (light) bounded by coal, mudstone, and siltstone in the Hanna Formation. Photograph by R.M. Flores.

Figure HS-11. Laterally extensive fluvial channel sandstone (buff) showing pinch out on the left and bounded by mudstone, siltstone, and coal in the Ferris Formation. Photograph by R.M. Flores.

Figure HS-12. Thick, stacked, multi-erosional sandstone deposited in braided streams of the basal Hanna Formation. Photograph by R.M. Flores.

Figure HS-13. Thin to thick, laterally offset, erosional-based sandstone deposited in meandering streams of the Hanna Formation. Photograph by R.M. Flores.

Figure HS-14. Laterally contemporaneous fluvial channel sandstone flanked by flat-bedded crevasse splay sandstone, siltstone, and mudstone representing anastomosed stream deposits of the Ferris Formation. Photograph by R.M. Flores.

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Figure HS-15. Trough crossbedded fluvial channel sandstone overlain by conglomerate deposited in alluvial fans of the Hanna Formation exposed along the northern flank of the Medicine Bow Mountains. Photograph by R.M. Flores.

Figure HS-16. Boulder to pebble conglomerate deposited in alluvial fans of the Hanna Formation exposed along the northern flank of the Medicine Bow Mountains. Photograph by R.M. Flores.

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Figure HS-17. Outcrop of the Johnson coal in the south Carbon coalfield. Photograph by R.M. Flores.

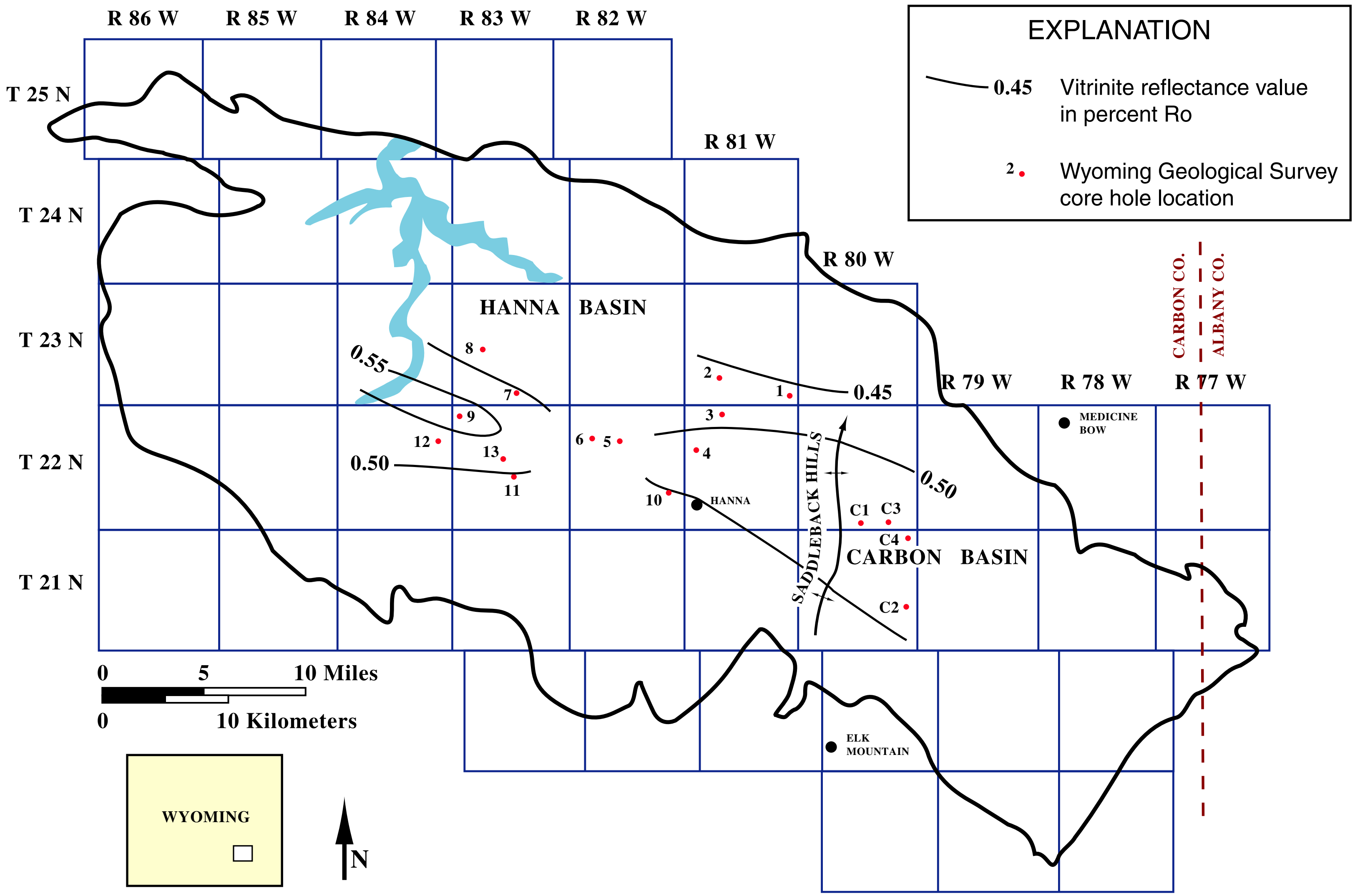

Figure HS-18. Map showing variations in vitrinite reflectance of the Ferris coal in the western part of the Hanna Basin and the Hanna coal in the eastern part. Modified from Teerman (1983).