Laramide Tectonics and Deposition of the Ferris and Hanna Formations, South-Central Wyoming[1]

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The Upper Cretaceous–lower Tertiary Ferris and Hanna formations in south-central Wyoming constitute an interval of continental rocks that contain principal coal beds in the Hanna and Carbon intermontane basins. The interval in the Hanna foreland basin consists of plane-bedded arkosic and lithic conglomerate with sandstone and mudstone interpreted as piedmont slope deposits. They wedge southward into central basin planar and trough cross-bedded sandstone and coeval parallel bedded sandstone and siltstone, dark-colored mudstone and shale, and coals interpreted as fluvial and floodplain deposits. The adjacent Carbon basin contains the fluvial and floodplain deposits. Deposition occurred in a syncline situated between systems of uplifts that resulted from compressional deformation. Upper Cretaceous sediments were derived mostly from uplifts to the south, and Paleocene and lower Eocene sediments were derived mostly from north of the Hanna basin. Lower Eocene and older rocks were folded into the footwalls of large, east-west-trending middle Eocene uplifts that were thrust southward over the northern Hanna basin margin.

Increased structural complexity from Late Cretaceous through middle Paleocene to middle Eocene time resulted from increasing uplifts and associated counterclockwise rotation from east-west- to north-south-directed couple stresses. This rotation paralleled the movement of the North America plate as it overrode the Farallon plate. The north-south couple stresses produced thrusting of middle Eocene uplifts surrounding the basins, separation of the Hanna and Carbon basins, and thrusting that was at about right angles to Late Cretaceous thrust patterns. Crustal shortening was followed by extensional deformation and general regional uplift.

INTRODUCTION

The Upper Cretaceous–Paleocene Ferris Formation and the Paleocene–Eocene Hanna Formation contain the principal coal beds of the Hanna coal field in south-central Wyoming. Mineable coal beds of these formations occur in the Hanna and Carbon intermontane basins where the formations represent vestiges of a greater area of continental sedimentation that existed during the Laramide orogeny. The two basins have a combined area of slightly less than 1200 mi^2 (3100 km^2). These structural basins lie between the Medicine Bow–Sierra Madre mountains and the Granite–Seminoe–Shirley mountains (Figure 1).

This study was undertaken to determine the geologic history of the structural deformation and how it affected the deposition of Ferris and Hanna coal beds and their confining sediments in the Hanna and Carbon basins. In the Hanna basin, the Ferris and Hanna formations constitute a coal-bearing interval that is as much as 16,000 ft (4900 m) thick. In contrast, this coal-bearing interval is less than 4200 ft (1300 m) thick in the Carbon basin. The record of Laramide tectonism is more comprehensive in the Hanna basin.

Precambrian crystalline rocks of the Hanna basin apparently subsided to great depths during Laramide tectonism. These rocks are now more than 31,000 ft (9450 m) below mean sea level datum. Similar Precambrian rocks are now exposed more than 7300 ft (2200 m) above mean sea level datum in the uplift that has been thrust faulted over the north edge of the Hanna basin (Figure 2). The areal relationship of the Hanna basin to the surrounding major uplifts is shown on Figure 3. Though relatively small, the Hanna basin has undergone the same geologic events that formed the larger Wind River and other deep, asymmetric, thrust-fault-bounded basins in the Wyoming foreland.

The significance of Laramide compressional structures in the Wyoming foreland was not understood until Berg (1962) described the magnitude and form of the southwest thrust fault of the Wind River uplift. Gries (1983a) demonstrated that compressional deformation was common to the large Laramide uplifts in the foreland. Blackstone (1983) thoroughly described the numerous structures formed by Laramide compressional deformation in southeastern Wyoming.

[1]Publication authorized by the Director, U.S. Geological Survey.

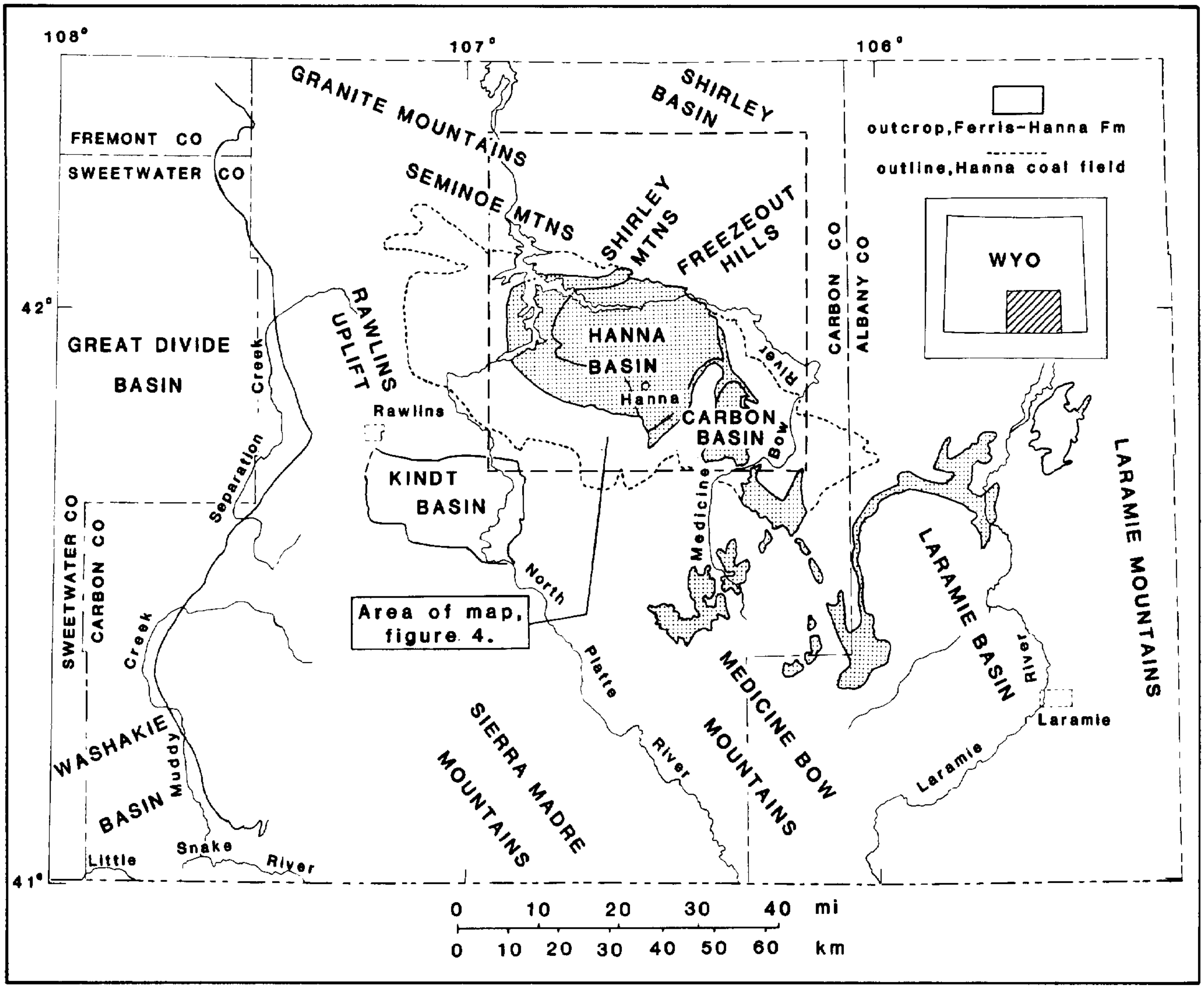


Figure 1—Location of the intermontane Hanna and Carbon basins, south-central Wyoming. In these basins the Ferris and Hanna formations contain the mineable coal beds of the Hanna coal field.

Another regional report by Gries (1983b) stressed the time and direction of the Laramide compressional deformation in the Wyoming foreland. The age of the different uplifts can be assigned by the direction they trend: (1) the Late Cretaceous structures trend north–south, (2) the Paleocene structures trend northwest–southeast, and (3) the Eocene structures trend west–east. Furthermore, the movements of the three ages of deformation have been equated by Gries (1983b) with movements of the North America plate. The movements of the plate were caused by the opening of the North Atlantic Ocean area during seafloor spreading in Late Cretaceous time and by the opening of the Arctic Ocean area during seafloor spreading in Paleocene to late Eocene time.

Rocks older than the Ferris and Hanna formations were folded into the basins and eroded off the nearby uplifts during Laramide time. Except for the Upper Cretaceous Medicine Bow Formation, the older formations are shown as combined units on the geologic map (Figure 4) and are listed in the explanation of map units. These Paleozoic and Mesozoic sedimentary rocks are about 22,000 ft (6700 m) thick, but Upper Cretaceous rocks are the major component of the succession. The Upper Cretaceous rocks form an interval about 18,500 ft (5700 m) thick directly below the Ferris Formation. This interval of marine and nonmarine sedimentary rocks apparently lies within a Late Cretaceous depocenter in the area of the Hanna and Carbon basins (Krumbien and Nagel, 1953). At the top of this interval the upper Medicine Bow Formation consists of coarse-grained sandstone of continental origin that is conformable with the overlying Ferris Formation.

Deposited during Laramide time, the Ferris and Hanna rocks are chiefly of alluvial origin. These formations, as defined by Bowen (1918), contain basal beds of conglomeratic sandstone and thin conglomerate. Other previous investigators (Veatch, 1907; Dobbin et al., 1929; Dorf, 1938) also regarded the occurrence of beds of conglomeratic sandstone and conglomerate as requiring a division of these terrestrial rocks into stratigraphic units. The lower contact of the Ferris Formation is conformable, as

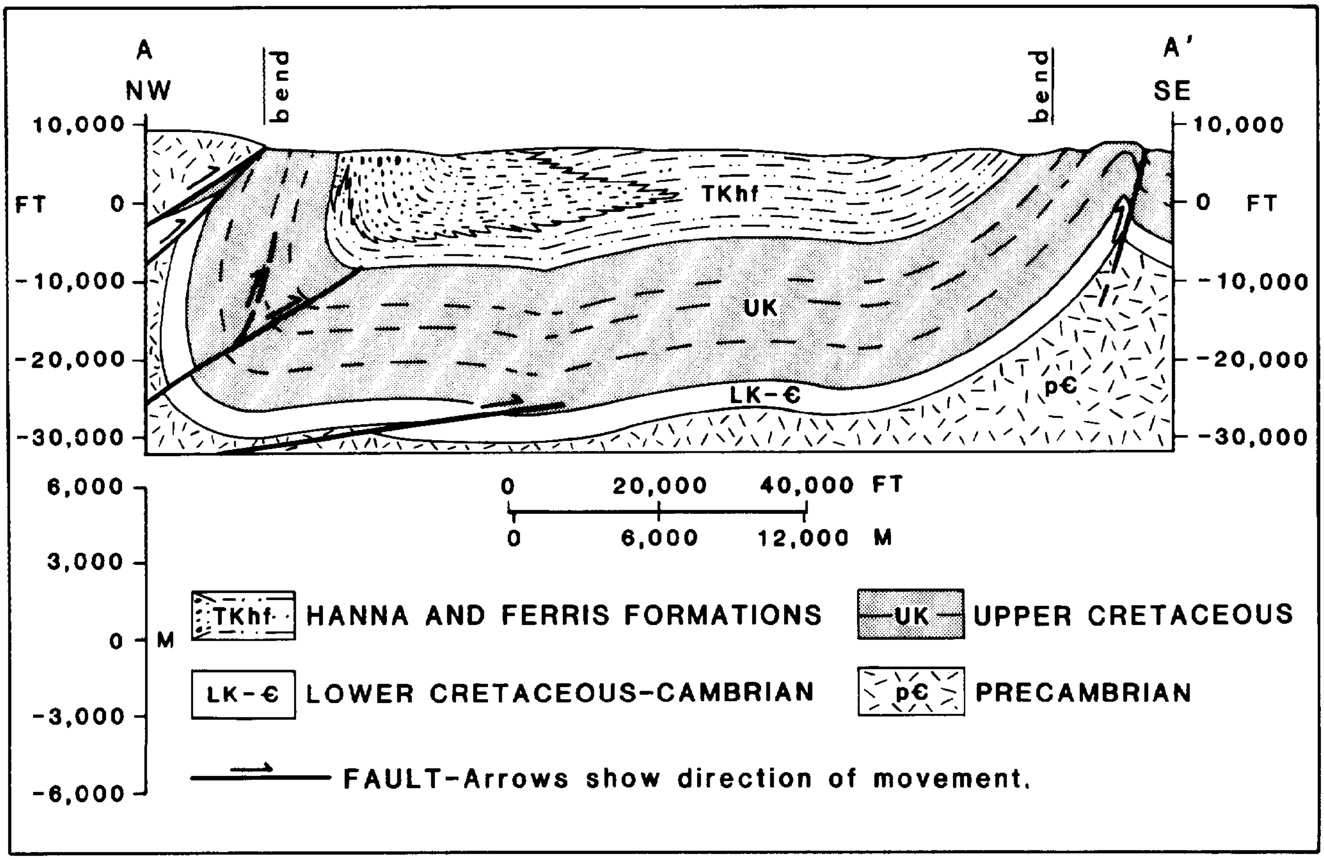


Figure 2—Schematic cross section A–A′ showing Laramide compressional deformation on the margins of the Hanna basin. This folded and thrust-faulted deformation is characteristic of the Wyoming foreland. Location of cross section is shown on geologic map in Figure 4.

previously mentioned. However, the Ferris–Hanna contact in the Carbon basin and along the eastern margin of the Hanna basin is unconformable and lies below conglomeratic sandstone of the basal Hanna. This relationship led Bowen (1918) and Dobbin et al. (1929) to the perception of a general unconformable Ferris–Hanna contact.

Except in the Carbon basin and along the eastern margin of the Hanna basin, the unconformable Ferris–Hanna contact mapped by Dobbin et al. (1929) does not exist. Along the western outcrops, the coal-bearing parts of the two formations show continuity, and the Ferris–Hanna contact is found to be conformable, as reported by Blanchard and Comstock (1980). Along the northern margin of the basin, the Ferris and Hanna formations also show continuity, and both formations grade laterally into the thick sequence of conglomerates that Knight (1951) measured. In the western and northern Hanna basin, these formations, as mapped in this report (Figure 4), together form a common rock interval consisting of the two general and distinct lithologic units that are outlined below.

STRATIGRAPHY OF THE FERRIS AND HANNA ROCK INTERVAL

The two distinct lithologic units are (1) northern Hanna basin conglomerate unit that wedges southward into (2) a central basin, coal-bearing mudstone and sandstone unit that is as much as 16,000 ft (4900 m) thick. These successions were deposited during Late Cretaceous–Eocene time, as shown in the stratigraphic columns (Figures 5 and 6). Upward increases of Precambrian rock fragments changed the aspect of the conglomerate and the coal-bearing rocks; this allowed the separation of the Ferris and Hanna formations (Bowen, 1918; Dobbin et al., 1929). But the important distinction is between the northern conglomerates and the coal-bearing mudstone and sandstone. These two distinct lithologies can be used to demonstrate how deposition of the rocks was affected by Laramide tectonism.

The general lithologies (conglomerate and coal-bearing mudstone and sandstone) can also be subdivided into units each showing a variation in aspect of the general lithology (Figure 7). The general lithologies and their subdivisions are mapped as areas having general boundaries (Figure 8), because the lateral contacts of the units are intertonguing and gradational. For the most part, the subdivisions contain intervals of rock that show variations of the principal rock types (Figure 9).

Coal-Bearing Mudstone and Sandstone

The coal-bearing rocks show a variation of color and of lithology. These rocks are subdivided into a basal dark-colored sandstone unit; units of thick coal; and units of thin coal, as previously illustrated. There are no mappable coal beds within the dark-colored sandstone unit and the thin

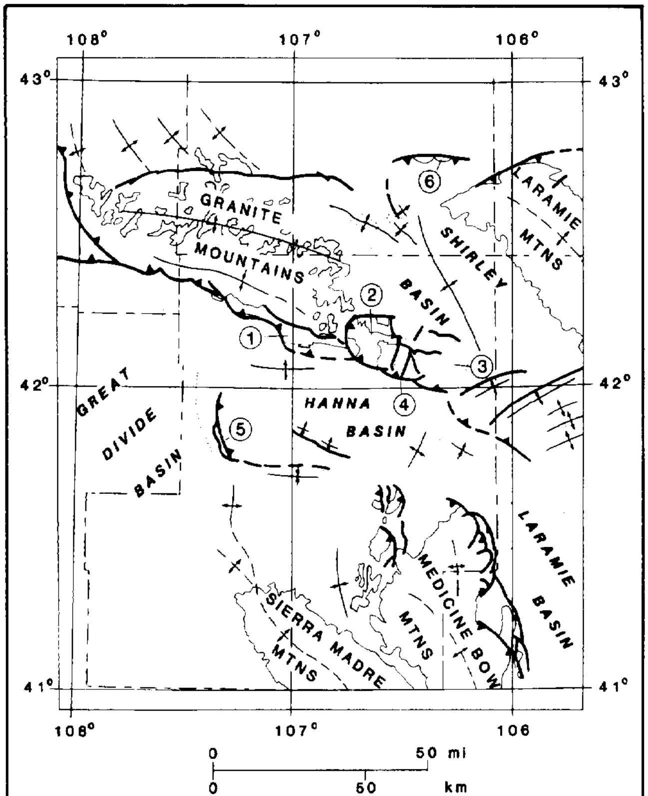


Figure 3—Location of Hanna basin and regional structures. Mountain uplifts show the regional trough aspect of the Hanna–Laramie basins. Shirley thrust fault system is on south side of Shirley Mountains–Freezeout Hills uplift. South Granite Mountains thrust fault system extends eastward along Seminoe Mountains. Dotted lines show Tertiary and Upper Cretaceous rocks that crop out and outline the uplifts and basins. General trends of synclinal and anticlinal forms are indicated by lines and arrows; barbs indicate upthrown side of thrust faults.

coal unit. The latter is mapped only in areas of thin, discontinuous, and impure coal beds.

Fossils associated with the coal-bearing rocks are invertebrates, including freshwater gastropods, bivalves, and ostracods (Glass, 1981); vertebrates, including bone fragments, turtle shell fragments, and fish remains; and plants, including common leaf imprints, branch fragments, tree trunks and stumps, and traces of roots.

Dark-Colored Sandstone

The dark-colored unit (lower Ferris Formation) consists of beds of conglomeratic sandstone; conglomerate; parallel-bedded sandstone; dark-gray and dark-brown siltstone, mudstone, and shale; carbonaceous shale; and minor coal. The unit is generally about 1000 ft (300 m) thick, but is as much as 1600 ft (490 m) thick in the northwestern Hanna basin.

The conglomeratic sandstone is dark gray and dark brown to yellowish brown and ferruginous, fine to coarse grained with granules and small pebbles, and trough and planar cross bedded. These sandstones can be classified as lithic arenites (Ryan, 1977). Sequences of beds of these conglomeratic sandstones are as much as 80 ft (25 m) thick in the upper part of the unit. The conglomerate is brown and consists chiefly of rounded pebbles of chert and quartzite rock fragments and rarer fragments of volcanic rocks (Bowen, 1918); the pebbles are generally less than 1 in. (2 cm) in diameter. The conglomerate occurs as pockets, lenses, and thin beds within the conglomeratic sandstone.

The parallel-bedded sandstone is dark brown, tan, and gray; and generally fine- to medium-grained. They are generally less than 4 ft (~1 m) thick. In places, the sandstone beds coarsen upward to include thin, plane-bedded conglomerate. The siltstone, shale, and mudstone beds are each generally less than 5 ft (1.5 m) thick, but their composite thickness can be as much as 12 m. The carbonaceous shale beds are thin (less than 1 ft, 0.3 m), and the impure coal beds are generally only a few inches thick, although one coal lens was found to be 2 ft (~0.5) m thick. Vertebrate remains occur in the conglomerate beds, and a few have been identified as *Triceratops* (Bowen, 1918). Plant remains are common; the microfossil assemblage from samples collected by Gill et al. (1970) is of Late Cretaceous age.

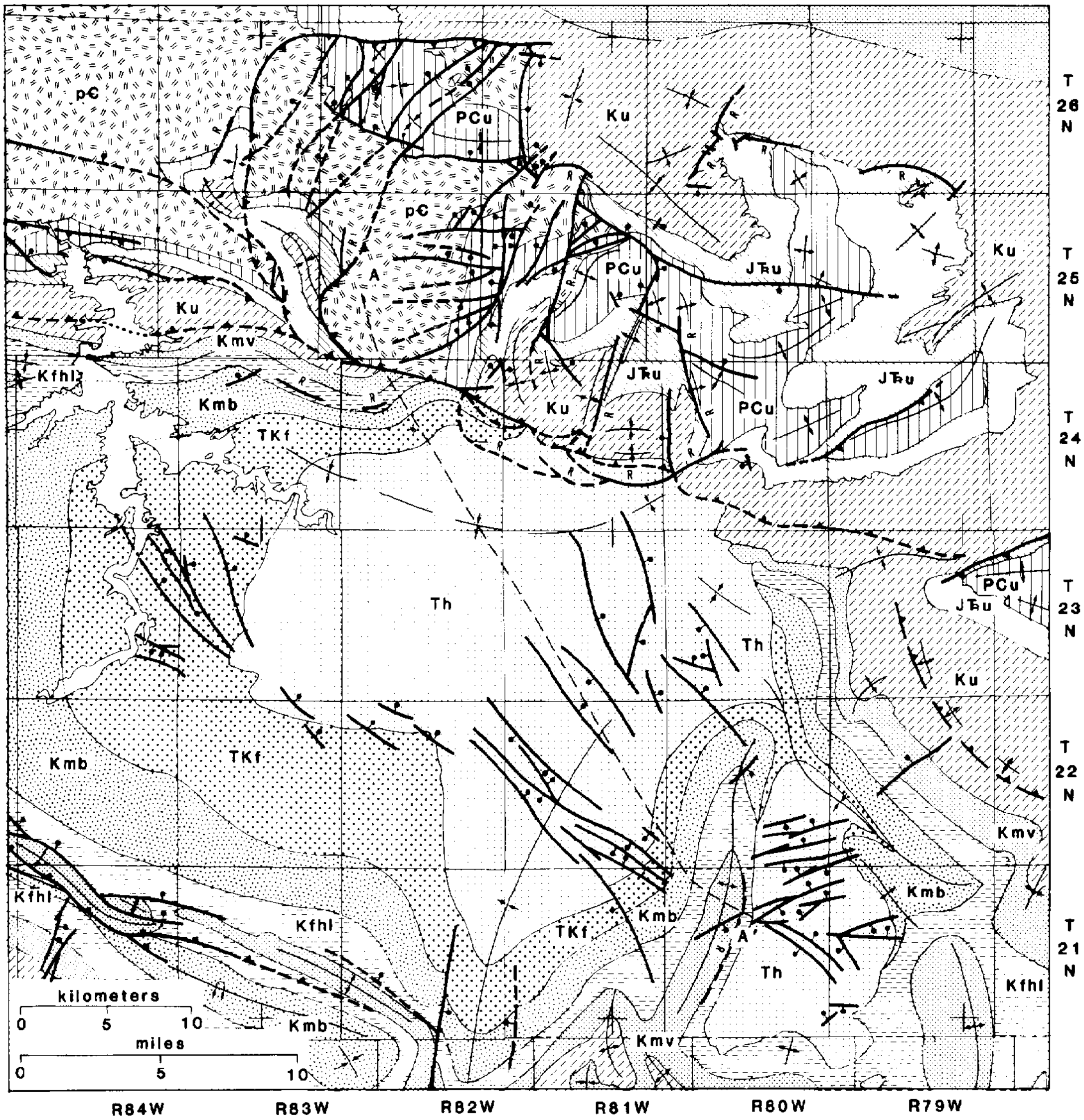
Thick Coal

The thick coal unit consists of massive sandstone with local beds of conglomerate, bedded sandstone, gray to dark-gray mudstone, dark-gray shale, carbonaceous shale, and coal beds. The lower part of the unit (upper Ferris and basal Hanna) is as much as 5000 ft (1500 m) thick. The upper part of the unit (Hanna) is as much as 7000 ft (2100 m) thick.

The massive sandstone is light gray and tan to brown, fine- to coarse-grained and granular in places, trough and planar cross-bedded, commonly slump structured, partly ferruginous, locally arkosic, and concretionary. Basal parts of the massive sandstone are scour based and contain clasts that came from the associated finer grained rocks. These sandstones are chiefly lithic arenites and locally arkosic arenites (Ryan, 1977). The massive sandstones are generally 20–100 ft (6–30 m) thick. In the middle part of the thick coal interval (lower part of the Hanna Formation) beds of massive sandstone are stacked in sequence to as much as 300 ft (90 m) in the Hanna basin and to as much as 600 ft (180 m) in the Carbon basin.

The parallel-bedded sandstone is tan and gray, generally fine- to medium-grained, and contains thin beds of conglomerate in the northern Hanna basin. These sandstones coarsen upward, are current ripple marked and current laminated, and may occur in irregular thin beds. The beds are generally 1–3 ft (0.3–1 m) thick where associated with the mudstone, siltstone, shale, and coal beds. Where associated with the massive sandstone deposits, they are generally less than 3 m thick.

The gray to dark-gray mudstone, siltstone, shale, and claystone deposits vary greatly in thickness. In places, mudstone beds are as thick as 70 ft (20 m), but they are generally less than 40 ft (12 m) thick. The shale, claystone, and siltstone beds are each generally less than 10 ft (3 m)



EXPLANATION

Th	HANNA FORMATION (LOWER EOCENE-UPPER PALEOCENE); about 2896 m thick.
TKf	FERRIS FORMATION (LOWER PALEOCENE-UPPER CRETACEOUS); 1524 to 1890 m thick.
Kmb	MEDICINE BOW FORMATION (UPPER CRETACEOUS); 1219 to 1829 m thick.
Kfhl	FOX HILLS SANDSTONE-LEWIS SHALE (UPPER CRETACEOUS); 884 to 1036 m thick.
Kmv	MESAVERDE GROUP (UPPER CRETACEOUS); Almond, Pine Ridge, Allen Ridge, and Haystack Mountain formations; 1402 m thick.
Ku	UNDIFFERENTIATED (UPPER-LOWER CRETACEOUS); Steele Shale, Niobrara, and Frontier formations (Upper); Mowry Shale, Thermopolis Shale (including Muddy Sandstone Member), and Cloverly Formation (Lower); 1485 m thick.
JTru	UNDIFFERENTIATED (JURASSIC-TRIASSIC); Morrison and Sundance formations (Jurassic); Jelm, Alcova Limestone, and Red Peak formations and uppermost part of Goose Egg Formation (Triassic); 463 m thick.
PCu	UNDIFFERENTIATED (PERMIAN-CARBONIFEROUS); Goose Egg Formation (Permian); Tensleep Sandstone (Pennsylvanian); Amsden Formation (Pennsylvanian and Mississippian ?); Madison Limestone (Mississippian); includes a thin Cambrian sandstone in northwest part of area; 494 m thick.
pC	PRECAMBRIAN; crystalline rocks, chiefly granites.
	CONTACT
	FAULT—dashed where inferred; bar and ball on downthrown side.
R	FAULT, REVERSE—dashed where inferred; R on upthrown side.
	FAULT, THRUST—dashed where inferred; barb on upthrown side.
	ANTICLINE
	SYNCLINE
	SYNCLINE, OVERTURNED

Figure 4—Geologic map of pre-Miocene rocks, Hanna basin area, showing areal relationships of the Shirley Mountains–Freezeout Hills uplift and the Hanna basin and other areas structures. Line A–A′ designates the cross section of Figure 2. Sources of map are Love et al. (1955), Lowry et al. (1973), and field mapping by the author.

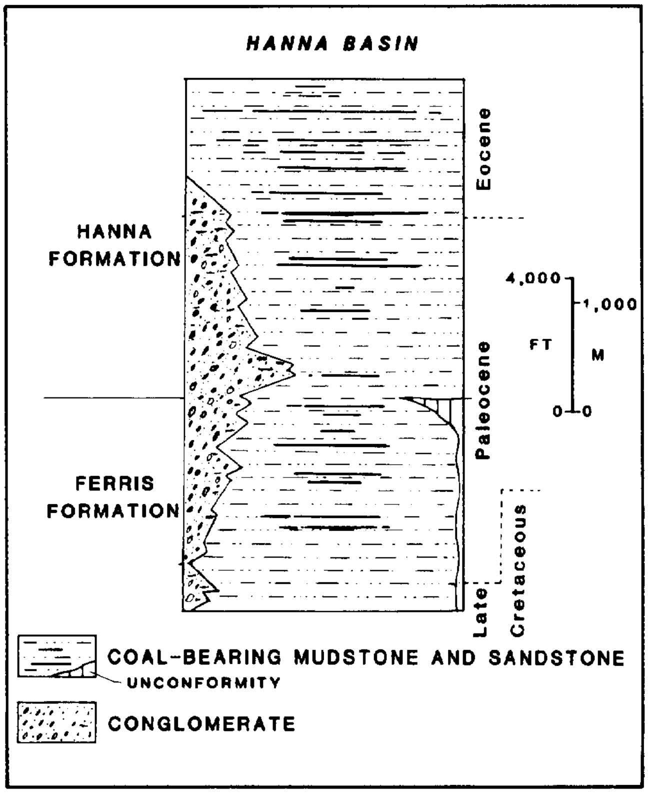


Figure 5—Generalized stratigraphic column of the coal-bearing, Ferris–Hanna interval in the Hanna basin.

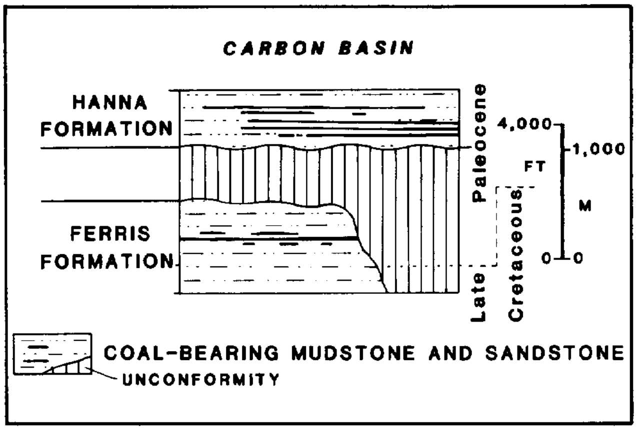


Figure 6—Generalized stratigraphic column of the coal-bearing, Ferris–Hanna interval in the Carbon basin.

thick. In the lower part of the unit (upper Ferris Formation) the carbonaceous shales are generally less than 10 ft (3 m) thick, but in the upper part of the unit (Hanna Formation) the black carbonaceous shales are generally 10–40 ft (3–12 m) thick. Coaly shale beds have been found to be as thick as 100 ft (30 m) in this upper part of the thick coal unit. The geometric relationship of typical coal, mudstone, parallel-bedded sandstone, shale, and carbonaceous shale beds to a massive sandstone complex is shown in Figure 10.

The coal beds are as much as 38 ft (12 m) thick in the Hanna basin. In the lower part of the unit (upper Ferris) about thirty coal beds are greater than 5 ft (1.5 m) thick, but only four are greater than 20 ft (6 m) thick (Glass and Roberts, 1980). Two coal beds of the lower unit occur in the Carbon basin; there the lower bed is as much as 20 ft (6 m) thick, but the upper coal bed is less than 5 ft (1.5 m) thick. In the upper part of the thick coal unit in the Hanna basin (Hanna Formation) there are twenty-four coal beds greater than 5 ft (1.5 m) thick, but no more than eight exceed 20 ft (6 m) (Glass and Roberts, 1980). In the Carbon basin, three persistent coal beds of the upper unit exceed 5 ft (1.5 m) in thickness, but only one exceeds 20 ft (6 m) in thickness. The relationship of upper unit coal zones within finer grained rock intervals and the massive sandstones of the Carbon basin is shown in Figure 11.

Microfossils from samples collected by Blanchard and Comstock (1980) and Gill et al. (1970) show that in the western Hanna basin the age of each assemblage is (1) middle Paleocene from the lower part of the unit (lower half of Ferris), (2) middle Paleocene to late Paleocene from near the lower middle part of the unit (near top of Ferris), (3) late middle Paleocene from the upper middle part of the unit (basal Hanna), (4) late Paleocene from the middle upper part of the unit (middle Hanna), and (5) Eocene from near the top of the unit (near the top of Hanna). In the Carbon basin the age of each assemblage is (1) early middle Paleocene from the lower part of the unit (upper Ferris), (2) late Paleocene from the lower upper unit (lower Hanna), and (3) late Paleocene from the base of the upper unit (base of Hanna).

Thin Coal

The thin coal unit mapped below the base of the coal-bearing rocks (base of upper Ferris) in the western Hanna basin (Figure 8) is 800–1200 ft (~250–370 m) thick. There the rocks of the thin coal unit have a brown color that is not as evident in the overlying thick coal unit or in the other parts of the thin coal units. Similar strata, about 600 ft (180 m) thick, occur in the southeastern Hanna basin where the brown rocks form the basal part of a thin coal unit. Rocks having this brown color are massive sandstone beds that are brown to orange brown, soft, and ferruginous. The finer grained rocks of this thin coal unit are the same as those of the other thin coal and thick coal units. The coals associated with these beds of brown massive sandstone are less than 1 ft (30 cm) thick and are associated with thin 1-3 ft (30-90 cm) black and brown carbonaceous shale and claystone intervals. Microfossils from samples collected by Blanchard and Comstock (1980) show that the age of the assemblage is early to middle Paleocene.

Other parts of the thin coal unit that have been mapped occur between the thick coal units (upper Ferris and lower Hanna), lateral to the lower thick coal unit (upper Ferris), and below the upper thick coal unit (Hanna) (Figure 8). The thin coal unit is about 7000 ft (2100 m) thick where the subdivision lies below the upper thick coal unit. In the eastern Hanna basin, paleosols between the mudstone beds are indicated by white to light-gray, hackly, thin sandstone and siltstone layers. Zones of root traces were seen on the uppermost part of the massive sandstone deposits in a few places.

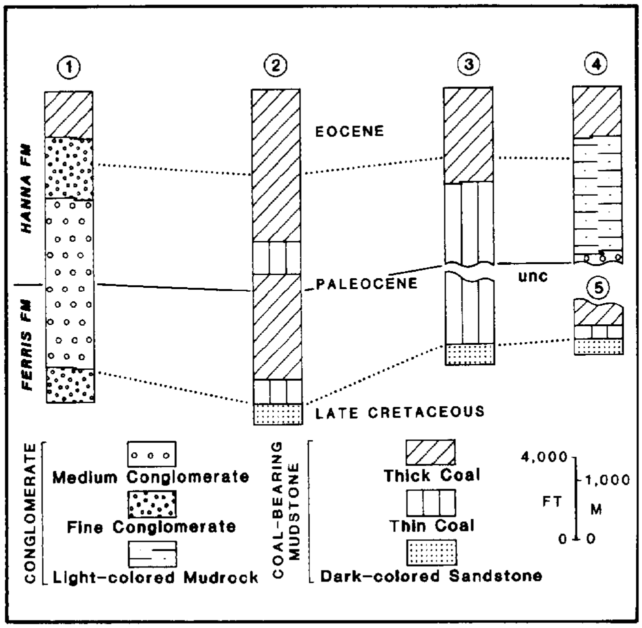


Figure 7—Stratigraphic sections of the conglomerate and coal-bearing lithologies and subdivisions of the Ferris–Hanna interval. The generalized lines of the sections that are shown on Figure 8 are in the Hanna basin, except section 5, which is on the north side of the Carbon basin.

Conglomerate

Beds of conglomerate along the northern margin of the Hanna basin are chiefly arkosic, but lithic conglomerate is also present. The components of the arkosic conglomerate are fragments of granite, black and gray chert, gray quartzite, gray sandstone, the Lower Cretaceous light-gray Mowry Shale, vein quartz, the Lower Cretaceous Cloverly Formation, and metamorphic rocks. The arkosic conglomerate beds are interbedded with conglomeratic sandstone, muddy sandstone, and thin mudstone. Diameters of clasts within this thick conglomerate succession of the northern Hanna basin (Figures 5 and 7) are seen to increase upward to a maximum and then to decrease upward. A corresponding lateral decrease in diameter is seen to occur southward from the northern periphery of the Hanna basin. Corresponding vertical and lateral changes also occur in the bedding.

The lithic conglomerate consists chiefly of clasts of gray sandstone, gray quartzite, light-gray Mowry Shale, and chert. These conglomerates are found only in small, local areas of short vertical extent relative to the arkosic conglomerates. The lithic conglomerate is interbedded with sandstone and mudstone deposits. These same mudstones are dominant lithology of the light-gray beds that overlie the lithic conglomerate in northeastern Hanna basin.

The conglomerate has been subdivided into "medium" and "fine" categories at arbitrary boundaries because of the lateral gradations and intertonguing. The original definitions were as follows: the medium conglomerates consisted of clasts having diameters roughly between 2 and 6 in. (5 and 15 cm) and the fine conglomerates had clasts with diameters less than 2 in. (~5 cm). In practice, the mapping showed that defining fine conglomerate as having clasts less than 1.5 in. (4 cm) in diameter is more useful. Bedding characteristics of the conglomerate and of the associated lithologies change as these clast diameters change.

Arkosic Medium Conglomerate

The lower 3900 ft (1200 m) (upper Ferris) of the medium conglomerate unit consists of light-gray to white, tan and brown to yellow-brown conglomerate and conglomeratic sandstone sequences that crop out between intervals of gray, pebbly sandstone. The sequences appear as layers of small to large pebbles in the lower part of the unit. The overall grain size coarsens upward, and near the top, small cobbles (4 in., or 10 cm diameter or less) are a dominant part of the sequence. Where dominant, some of the small cobble beds are clast supported with infillings of feldspar and quartz grains. The sequences are as much as 25 ft (8 m) thick; the individual beds of the sequences are generally from 0.5 to 3 ft (15 to 90 cm) thick. In a few places, the beds showed some indistinct internal bedding and imbrication. The intervals of pebbly sandstone include thin beds and lenses of light-gray and white to gray sandy mudstone and claystone. The pebbly sandstone intervals have plane bedding in a few places. These intervals of pebbly sandstone are generally 20–40 ft (6–12 m) thick.

The upper 4000 ft (1200 m) (Hanna Formation) of the medium conglomerate unit is chiefly white to light gray and tan. The interval continues to coarsen upward to about the lower 1000 ft (300 m) of this upper part. Clast-supported conglomerates become common. The feldspar content of the upper part of the conglomerate also increases relative to the lower part. This upper part merges into the overlying arkosic fine conglomerate.

Arkosic conglomerate (Hanna) crops out above light-colored mudstone beds between Troublesome and Difficulty creeks in T. 24 N., R. 81 W. The residuum of weathered granite boulders is present along the concealed Shirley thrust fault in Sec. 22, T. 24 N., R. 81 W. The conglomerate lies within a small syncline south of the thrust fault. The medium conglomerate here is much the same as that of the larger, arkosic medium conglomerate unit already described, except the intervals of pebbly sandstone are generally less than 10 ft (3 m) thick and mudstone beds are not present. The thickness of the unit may be as much as 600 ft (180 m).

Arkosic Fine Conglomerate

The unit of arkosic fine conglomerate (Hanna) is about 3000 ft (900 m) thick. The fine conglomerate consists of a sequence of gray and tan beds of arkosic conglomerate, conglomeratic sandstone, and coarse sandstone interspersed in gray, sandy mudstone deposits. The clasts in these conglomerates are generally less than 1 in. (~2 cm) in diameter. The conglomerate units occur as plane beds and small lenses, whereas the sandstone units are chiefly trough cross-bedded and have the appearance of irregular lenses. The sequences of conglomerate and sandstone form lenticular bodies that are thin (less than 15 ft, or 4.5 m) relative to their width of several tens of meters. These bodies have a scoured contact with the underlying mudstone. The fine conglomerate grades laterally into the coal-bearing unit. Where this gradation takes place, the sandstone beds

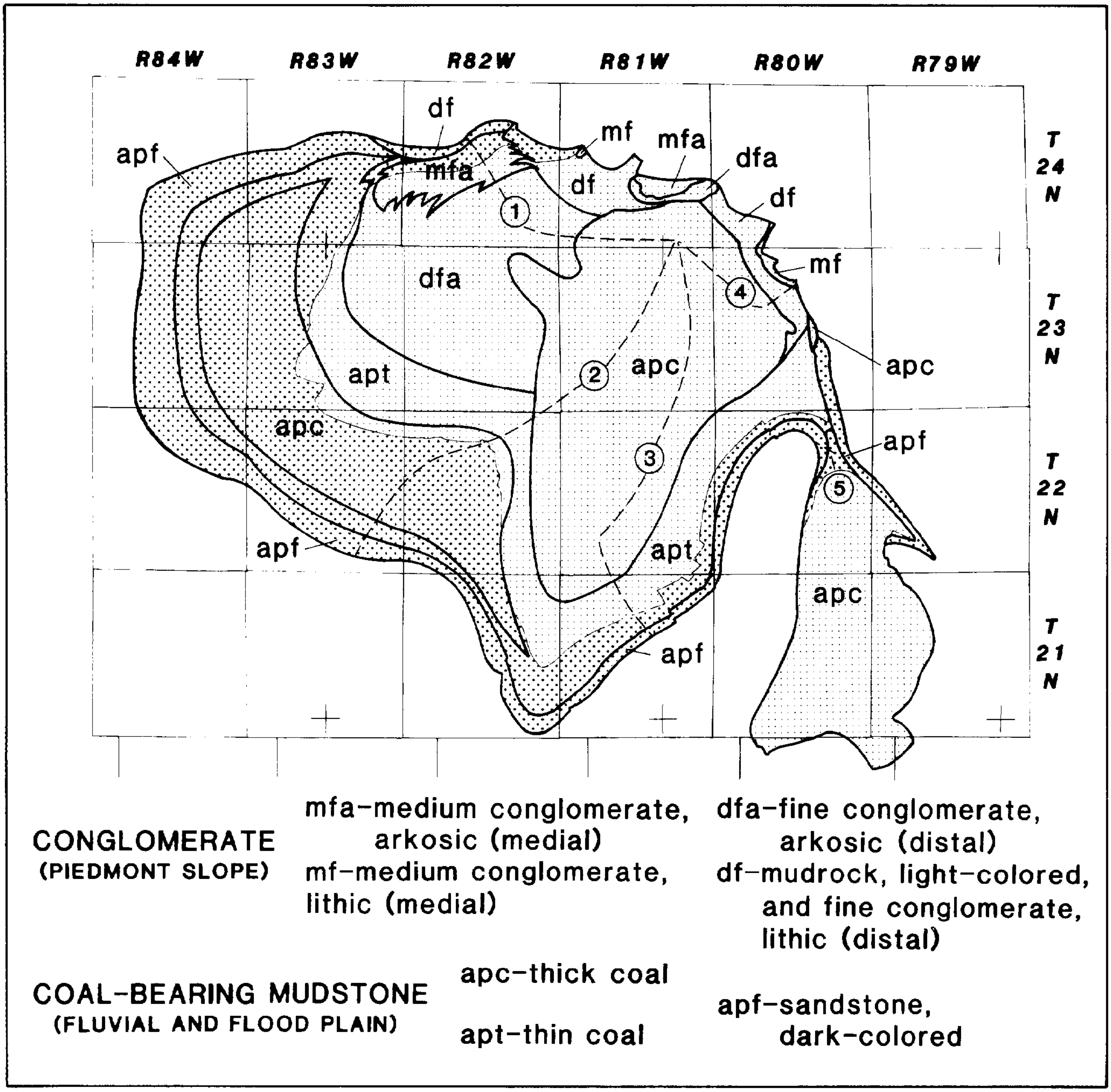


Figure 8—A composite map of the conglomerate and coal-bearing lithologies and subdivisions of the Ferris–Hanna interval, showing the environments of deposition. Note how the synorogenetic piedmont slope deposits grade into fluvial and floodplain deposits. Proximal and upper medial piedmont slope deposits are missing because of later uplift and erosion. Numbered lines indicate sections shown in Figure 7. Dot patterns outline the Ferris and Hanna formations as shown in Figure 4.

become trough and planar cross-bedded and the conglomerates occur only locally. The gray, sandy mudstone beds are indistinct units that generally occur correspondingly in regular beds about 5–10 ft (1.5–3 m) thick and locally contain thin sandstone and carbonaceous claystone and shale beds.

The medium conglomerate unit that crops out between Troublesome and Difficulty creeks in T. 24 N., R. 81 W. grades laterally into fine conglomerate that has the same bedding style as that seen in the larger unit of arkosic fine conglomerate already described. The fine conglomerate unit may grade southward into a unit of sandstone and pebbly sandstone, but the relationship is obscured by faulting and rock dips that are in opposite directions.

Lithic Medium Conglomerate

These conglomerates occur in small areas that have been intensely deformed. Beds of gray and brown conglomerate (Hanna?) occur in the middle of a thick, light-colored mudstone unit in T. 24 N., R. 81 W. This conglomerate consists chiefly of gray sandstone and Mowry Shale pebbles

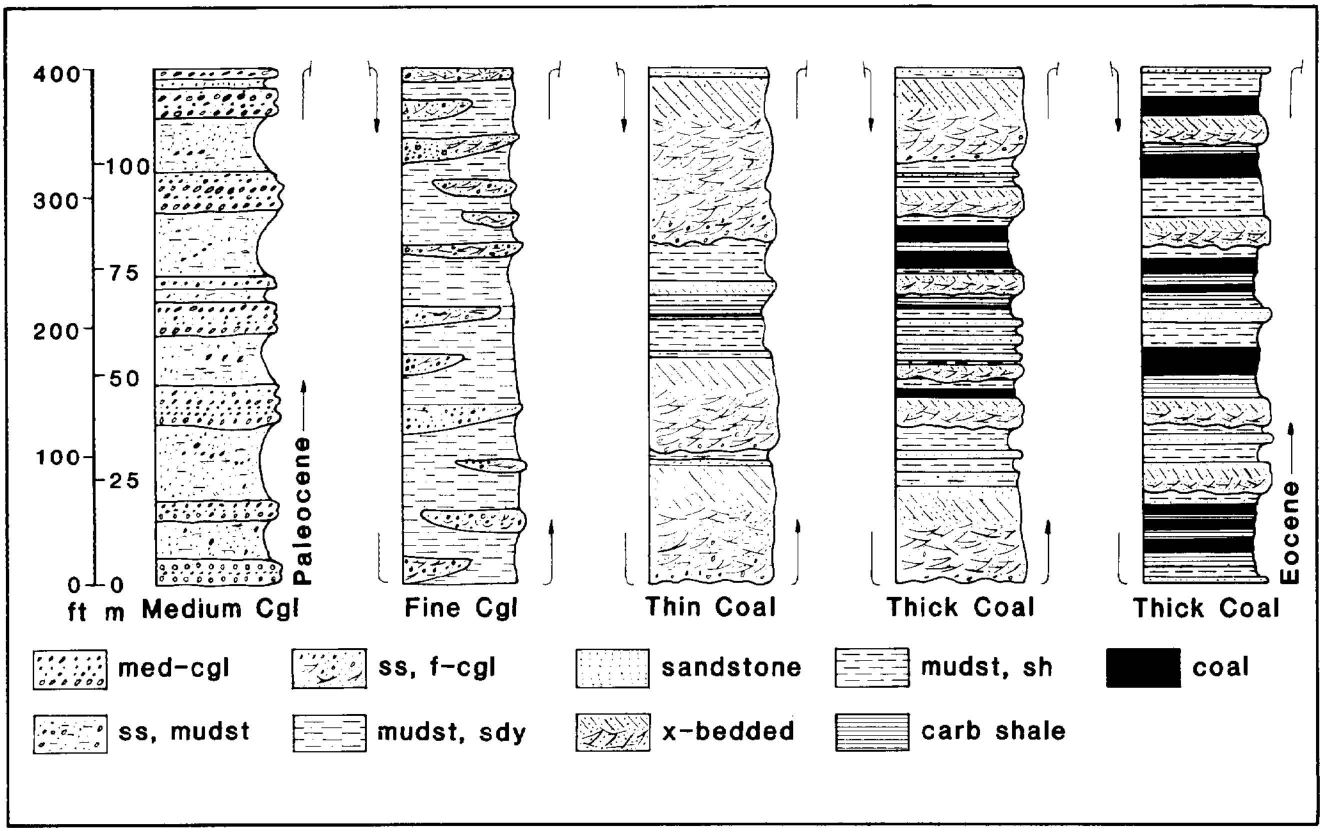


Figure 9—Selected examples of vertical sections showing subdivisions of the general lithologies. The subdivisions contain intervals of the principal rock types. All examples are from the upper part (Hanna Formation) of the Ferris-Hanna interval in the Hanna basin. The rocks in the sections are middle Paleocene and Eocene in age.

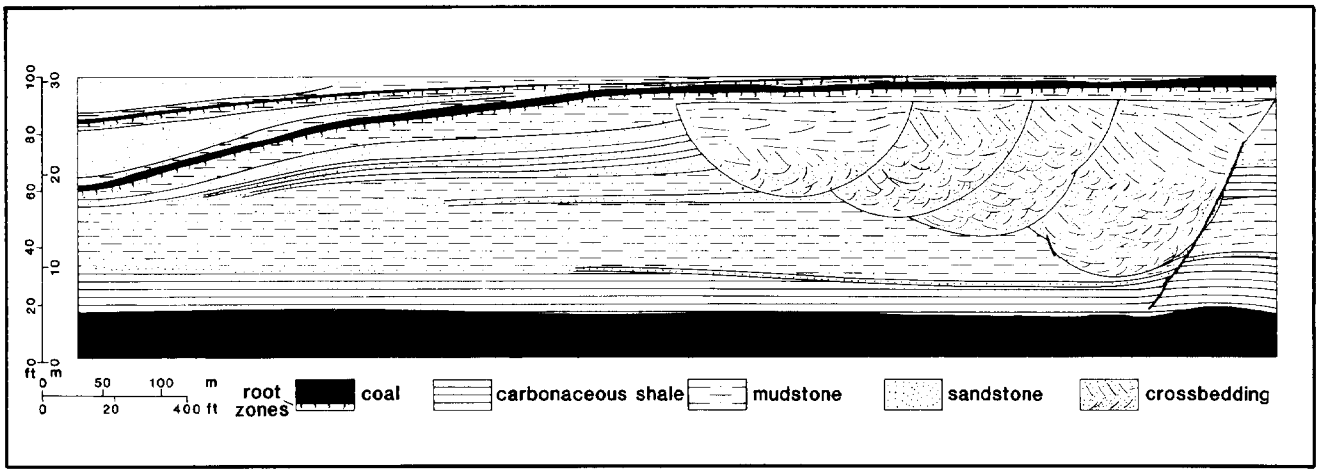


Figure 10—Schematic sketch of units of fluvial and floodplain deposits (Hanna Formation) as exposed in the highwall of cast mine in Hanna basin. Datum is at the base of the large, lower coal bed. The cross section shows the lateral and vertical relationship of a leftward migrating channel system to levee and overbank splay sandstone deposits, flood basin mudstone beds, and splay sandstone with coal beds. The Sandstone layers at upper left are later deposits. The fault to the right of the channel-fill complex developed during differential compaction as the interval was deposited, but the attitude of the bed also suggests that some structural warping of strata occurred prior to and during deposition of the interval.

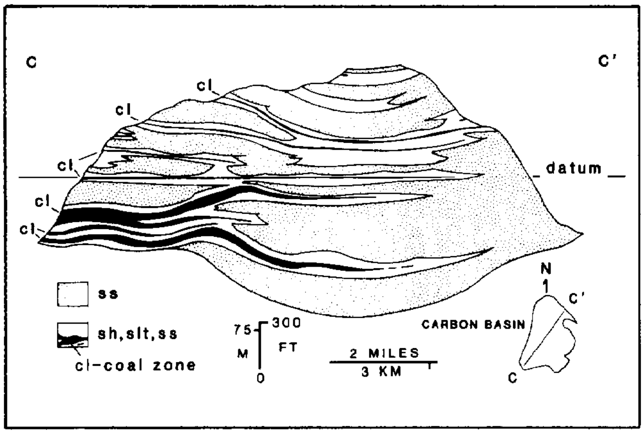


Figure 11—Schematic cross section of the Hanna Formation in Carbon basin. The interval of strata shows the predominance of massive, channel-fill sandstone sequences. The interval from the basal coal zone to the top of the formation is late Paleocene in age, but the channel sandstone below the basal coal zone probably was deposited during the middle Paleocene, a time of uplift and erosion southeast of the Hanna basin.

and small cobbles interbedded with sandstone and sandy mudstone. Particles from Niobrara marlstone were also found within the conglomerate. Clasts are as much as 6 in. (15 cm) in diameter. Beds of conglomerate are as thick as 4 ft (1.2 m) within this sequential unit. This sequential unit may be as much as 600 ft (180 m) thick.

The unit of lithic conglomerate on the northeast margin of the Hanna basin occurs in a structurally complex area. The conglomerates lie at the base of a thick, light-colored mudstone unit, where they chiefly consist of pebbles and small cobbles of gray sandstone and quartzite interbedded with layers of sandstone. The beds of conglomerate are generally less than 4 ft (1.2 m) thick, but a few beds are as thick as 10 ft (3 m). This sequential unit of conglomerate and sandstone is at least 400 ft (120 m) thick.

Lithic Fine Conglomerate

Occupying an area chiefly in T. 24 N., R. 82 W., this unit of conglomerate contains clasts that are as much as 2 in. (5 cm) in diameter at the base. This conglomerate, the lateral equivalent of the dark-colored conglomeratic sandstone, consists of about 1600 ft (500 m) of light-gray, tan, brown, and dark-gray conglomerate and sandstone sequences cropping out between intervals of gray mudstone. In a few places, sequences of conglomerate and sandstone are as much as 20 ft (6 m) thick, but for the most part, the sequences are less than 15 ft (4.5 m) thick. The individual conglomerate beds are generally planar, irregular, and 0.5 to 4 ft (15 cm to 1.2 m) thick. The internal structure is generally indistinct. The sandstone beds are plane bedded and trough cross-bedded; planar bedding was seen in one exposure. The intervals of mudstone occur in units as thick as 20 ft (6 m), but this thickness is difficult to determine because the conglomerate and sandstone sequences are interspersed within the mudstone. Carbonaceous claystone beds generally less than 1 ft (30 cm) thick occur within the mudstone. The lithic conglomerate is overlain by the thick arkosic conglomerate interval.

Light-Colored Mudrock

Lateral to and overlying the lithic medium conglomerate, the light-colored mudrock unit consists of a thick sequence of mudstone, cross-bedded sandstone (which is thick in places), parallel-bedded sandstone, and concretion beds. The unit may be as much as 6000–7000 ft (1800–2100 m) thick. The mudstone deposits are generally gray but are locally greenish gray to medium dark gray and bentonitic. The mudstone beds have been found to be as much as 200 ft (60 m) thick, but their general thickness is from 5 to 40 ft (1.5 to 12 m). The cross-bedded sandstone is light gray and tan, fine- to medium-grained and locally conglomeratic, and generally less than 15 ft (4.5 m) thick, although they are locally as thick as 30 ft (9 m). These trough cross-bedded sandstones appear as narrow channel fillings with scour bases. Parallel-bedded sandstone is tan to brown and light gray, generally fine grained, and locally concretionary and calcareous. These beds of sandstone occur as thin, widespread units generally 1–2 ft (30–60 cm) thick, but can also occur as thick as 11 ft (3.5 m). The purple and brown ironstone concretions are the most common horizontal beds within the mudstone; beds of tan, calcareous claystone concretions as much as 2 ft (60 cm) thick are locally common. Zones of root traces and thin paleosols can be found in places.

The thick sequence of mudstones includes equivalents of both the Ferris and Hanna formations in the northern Hanna basin. The Ferris part disappears under the Shirley thrust plate within a few miles east of the contact with the arkosic conglomerate. In the eastern Hanna basin, the light-colored mudstones thin to about 3000 ft (900 m), where they grade laterally southward into the coal-bearing lithologies.

SEDIMENTATION AND TECTONISM

An increase in Laramide uplift in the Wyoming foreland resulted in the areal restriction of continental sedimentation. Erosion of the uplifts resulted in drainage systems that deposited large loads of sediments in adjacent sedimentary basins where these sediments were differentiated by grain size and degree of sorting into a variety of deposits.

Deposition Environments

Various depositional environments existed in the Hanna and Carbon basins during the Laramide orogeny. The conglomerate containing sandstone and mudstone beds is interpreted as alluvial piedmont slope deposits. The coal-bearing mudstone and sandstone beds are thought to be fluvial and floodplain deposits.

Figure 12 shows a model of the restored piedmont slope deposits. Here a portion of an alluvial fan is shown with its proximal, medial, and distal parts, which are differentiated by their grain size, sorting, and bedding type. The stream systems generally have straight channels in the proximal and upper medial fan and a lateral moving system of channels in the medial fan; the distal fan has a highly braided system of channels. From the distal fan a series of tributaries leads to a large channel system that crosses the alluvial plain.

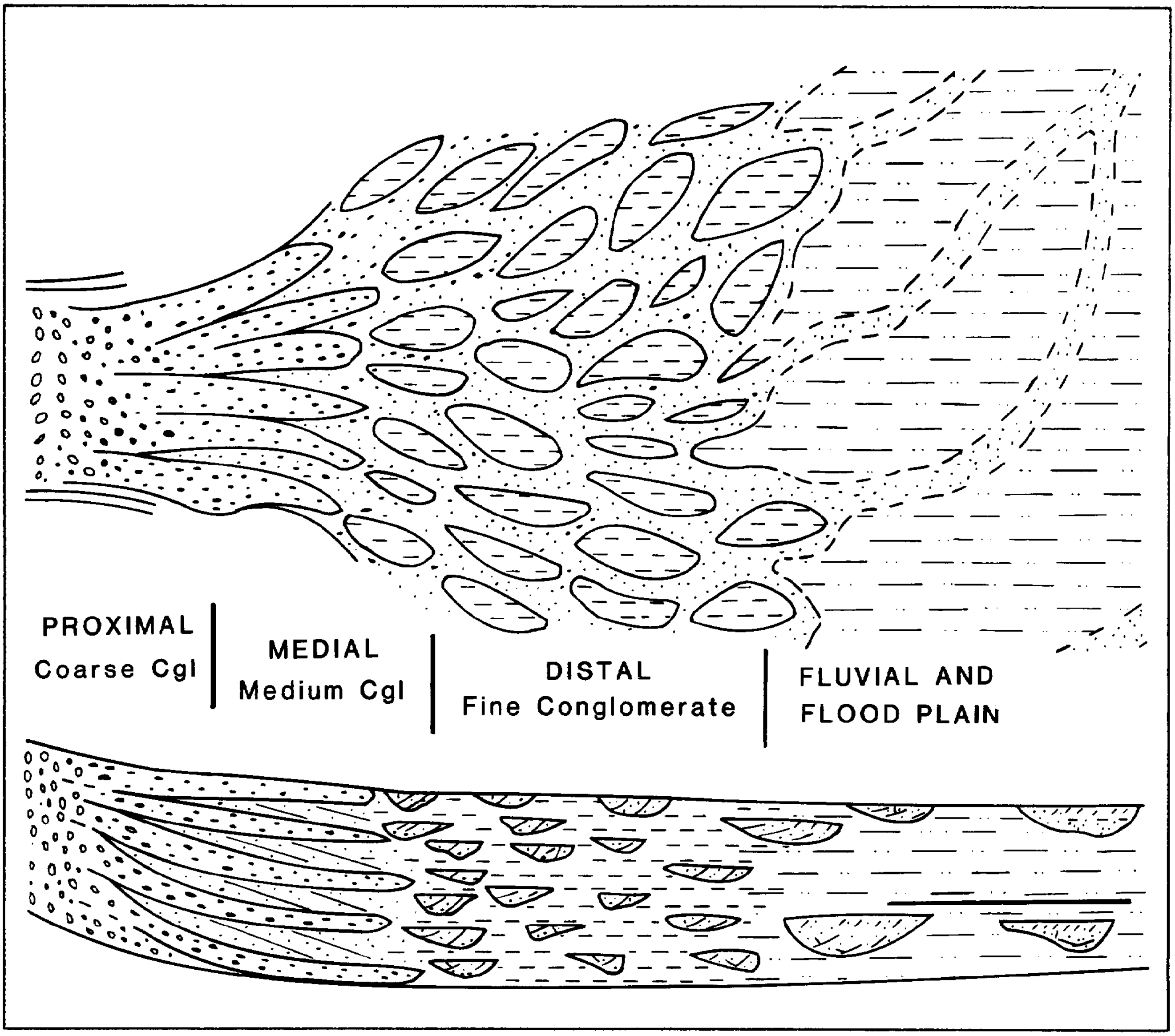


Figure 12—Idealized model of alluvial fan system and associated fluvial and floodplain system of northern and central Hanna basin. Proximal and upper medial parts of the fan are restored.

The piedmont slope deposits seen in the Hanna basin appear to be of the medial and distal parts of an alluvial fan. In the medial part, the sequences of thin-bedded, arkosic and lithic medium conglomerates and sands were deposited as bars. Within the arkosic medium conglomerates, the intervals of pebbly sand may have been wedges of sand sheets that were deposited during a different flow regime. Within the lithic medium conglomerates, the intervals of mudstone and sandstone were apparently sheet deposits. The distal deposits were short sequences of arkosic and lithic fine conglomerate and sandstone deposited in shallow channels eroded into the sandy mudstone. The sandy mudstones could have been the finer, downslope equivalents of the pebbly sandstone deposits.

The light-colored mudrock unit is included in the piedmont slope model as distal deposits lateral to the sequences of lithic medium conglomerate and the intervals of sandstone and mudstone. They were probably deposited as fine-grained, mudrich fans rather than the laterally equivalent, more normal, conglomeratic and sandy alluvial fans. Sources of the clasts in this northeastern part of the piedmont slope were from lesser uplifts that were eroded from a terrain that was mainly thick shale deposits.

The various lithologies in the coal-bearing mudstone and sandstone units are fluvial channel deposits that pass laterally into floodplain deposits, which form as intervals of coal-bearing strata. The massive sandstone beds were apparently deposited in large channels and tributaries.

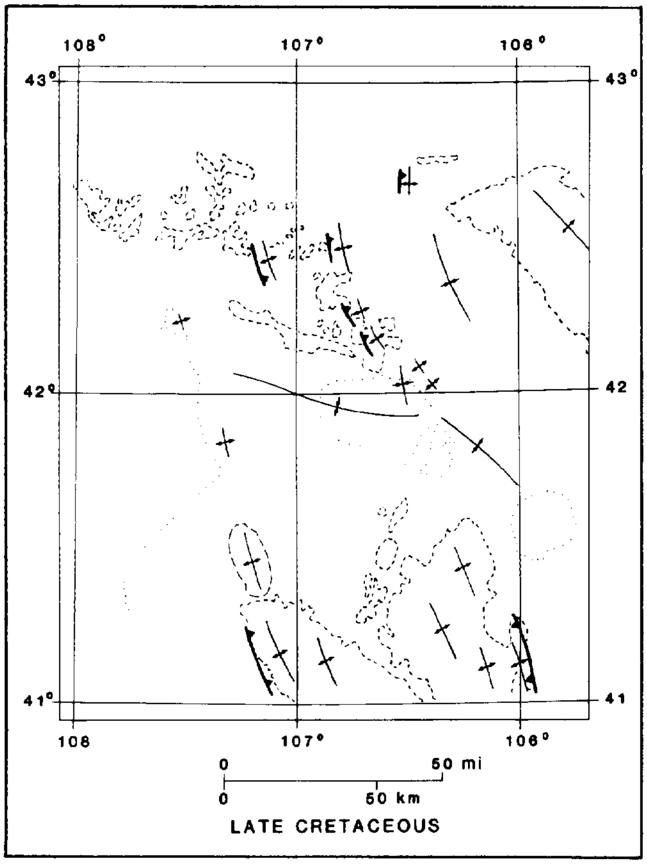


Figure 13—Regional structure pattern that formed at the end of Late Cretaceous time. Regional disconformable or unconformable relationships have not been recognized between the Upper Cretaceous and lower Paleocene strata in the Hanna basin area. Dotted lines show Tertiary and Upper Cretaceous rocks that crop out and outline the uplifts and basins. The general trends of synclinal and anticlinal forms are indicated by lines and arrows; barbs indicate the upthrown side of thrust faults.

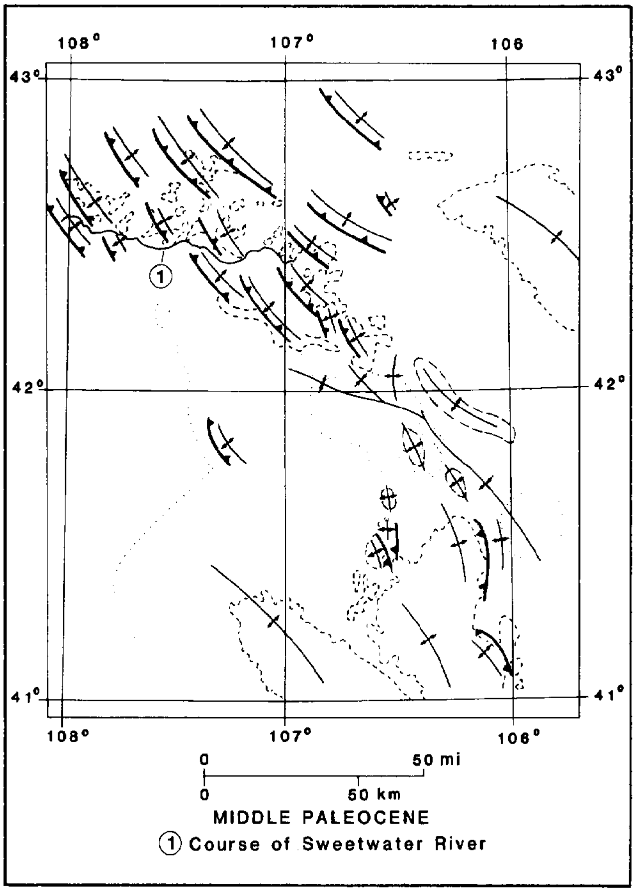


Figure 14—Regional structure pattern that had formed by the end of middle Paleocene time when the maximum Paleocene Laramide deformation had occurred. Sweetwater River drainage pattern indicates control by relict middle Paleocene fractures in Precambrian rocks of the Granite Mountains. See Figure 13 legend for explanation of symbols.

Associated with the channel deposits are flood levee and overbank sandstone beds and mudstone partings, and in one or two places, channel splay sandstones. The adjoining floodplain deposits include mudstone, thin lacustrine mudstone and shale, thin sandstone and siltstone channel splay deposits, and coal and carbonaceous shale beds deposited in the backswamps. Coal and carbonaceous shale deposits occur above and lateral to the other floodplain deposits.

Sedimentation and Uplifts

A regional syncline between large uplifts in south-central Wyoming formed during deposition of the dark-colored conglomeratic sandstone (lower Ferris) during Late Cretaceous time. For the greater part of the Hanna basin area, the syncline was filled with sediments that came from the southwest. This direction was determined mainly from paleocurrent data first reported by Ryan (1977). The source areas in this direction were most likely the early uplifts of the Medicine Bow and the Sierra Madre mountains. For the smaller area of the large syncline, the source of sediments was from the early uplifts of the Granite and Shirley mountains that were in general north–south trends (Figure 13). These and later trends are based on those regional trends of Laramide uplift described by Gries (1983b). The Late Cretaceous uplifts were probably part of a northwest-trending system of regional uplift in central Wyoming (Love, 1970). The trend of uplifts north of the Hanna basin was the source of the first fan deposits of the basin. The fan systems apparently existed in that area well into Eocene time, although the trends of the structures and the magnitude of the uplifts changed through Paleocene and early Eocene time.

Granite fragments became a common constituent of the lower thick conglomerate interval (Ferris) during early Paleocene. These early uplifts of the Granite Mountain and Freezeout Hills began to increase in extent, number, and height as the uplifts formed in northwest–southeast trends characteristic of the Paleocene structures of the Wyoming foreland (Figure 14). The confluence of fans off the northern structures was developed to their maximum areal extent by late middle Paleocene time (Figure 5). These

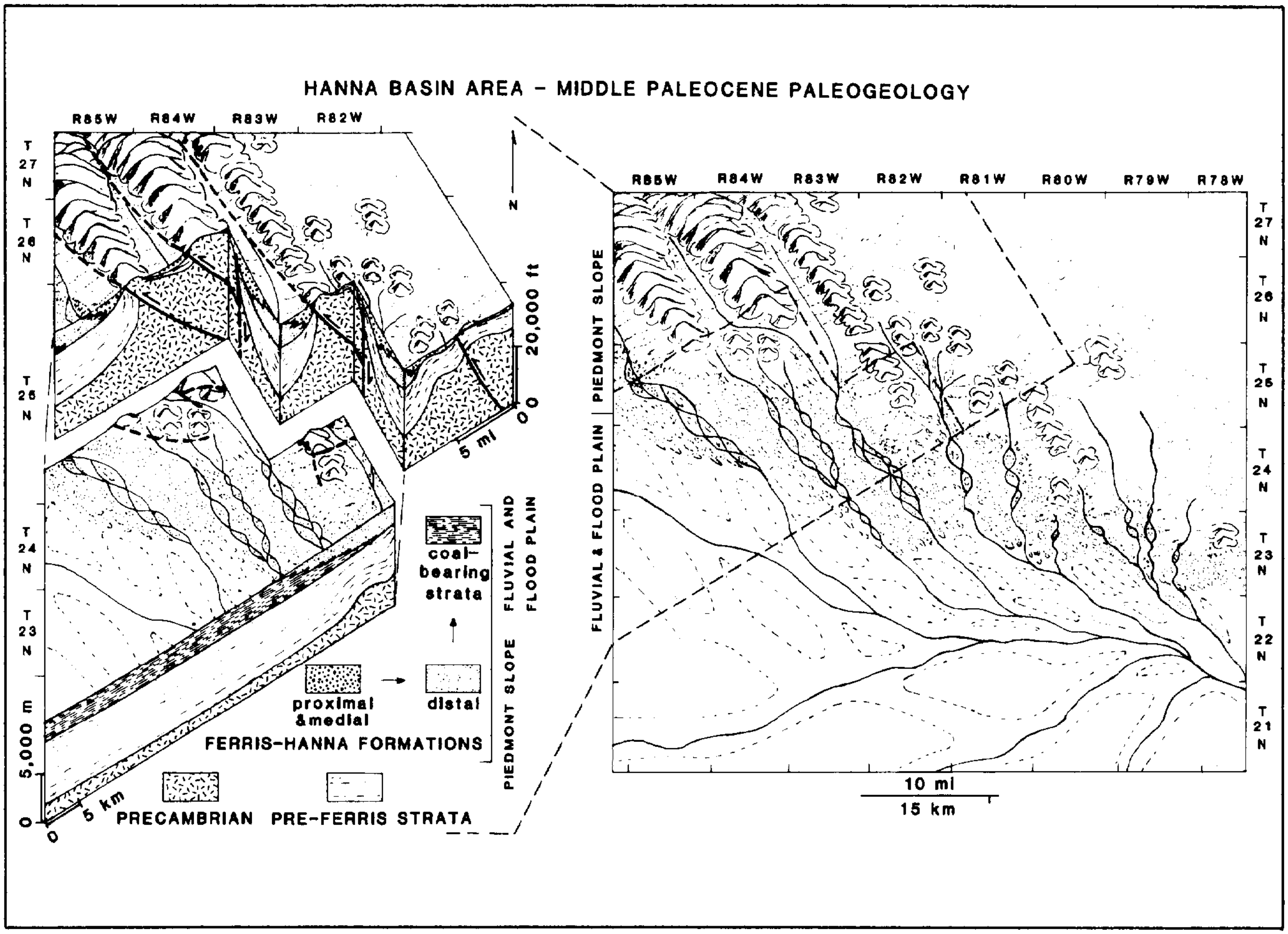


Figure 15—A schematic diagram of the Hanna basin area in late middle Paleocene time showing an example of the peripheral piedmont slope and central basin, fluvial and floodplain deposition during Laramide sedimentation in this area. Thrust-faulted, northwest-trending uplifts shed sediments into frontal synclines, which segregated the proximal part of the coalesced fans.

asymmetric uplifts north of the Hanna basin had become the predominant source area of sediments for the basin (Figure 15).

During middle Paleocene time, regional uplifts southeast of the Hanna basin resulted in complete erosion of the dark-colored sandstone and lower coal-bearing mudstone and sandstone deposits (lower and upper Ferris) in that area. The eastern margins of the Hanna and Carbon basins were affected (Figures 5 and 6). This erosion was followed by deposition during late Paleocene time of upper coal-bearing sediments (Hanna) on top of older rocks southeast of the Hanna basin. Sedimentation in the greater part of the Hanna basin, however, was continuous from early Paleocene through early Eocene time.

The last of the arkosic conglomerates was deposited between Troublesome and Difficulty creeks during late early Eocene. Deformation of this conglomerate followed when the Shirley Mountains–Freezeout Hills uplift moved south along the east–west Shirley thrust fault. This movement deformed the Ferris–Hanna rock interval and older formations (the footwall), probably during middle Eocene time (Figure 2). The time for this deformation is primarily based on late early and middle Eocene uplift of the northern Granite Mountains, as described by Love (1970). The net slip on part of this fault was estimated by Van Ingen (1978) to be 14,600 ft (4450 m), but this is probably a minimal slip. Crustal shortening by southward movement of the Granite Mountains and Shirley Mountains–Freezeout Hills uplifts, eastward movement of the Elk Mountain (Beckwith, 1941) and Medicine Bow uplifts, and northward movement of the north Laramie Range uplift caused crowding that resulted in complex structures. For example, during these movements the Shirley Mountains–Freezeout Hills uplift overrode the east-plunging end of the Granite Mountains uplift in a short lateral movement. The middle Eocene structures were the last of the large compressional deformations in the area of the Hanna basin (Figure 16). Sets of normal faults developed in the Hanna and Carbon basins during the extensional deformation and regional uplift that followed.

CONCLUSIONS

Increased structural complexity from Late Cretaceous through middle Paleocene to middle Eocene time resulted

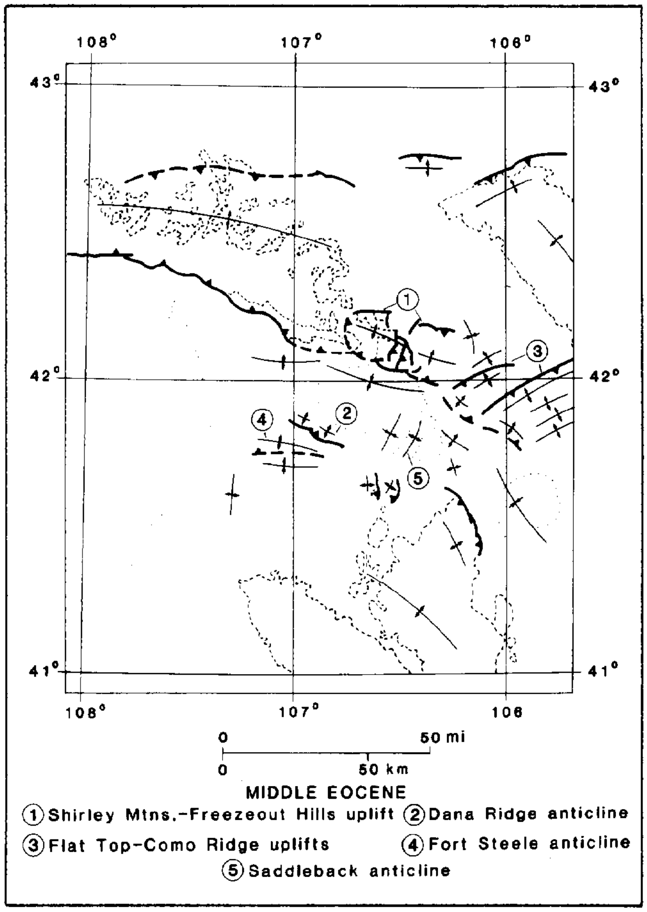


Figure 16—Regional structure pattern that formed during middle Eocene time. East-west Granite Mountains uplift and slightly overlapping Shirley Mountains-Freezeout Hills uplift moved south over thrusts. Asymmetry of present structures was established during this time. Crowding by large compressional uplifts north, south, and east of Hanna basin resulted in complicated structure when couple stresses caused counterclockwise movement around the basins. See Figure 13 legend for explanation of symbols.

from increasing uplifts and associated counterclockwise rotation from east-west- to north-south-directed couple stresses. This rotation parallels the movement of the North America plate as it overrode the Farallon plate (the movement as treated by Gries, 1983b). During this convergence of the plates, the couple stresses produced assymetric uplifts in a counterclockwise manner around the Hanna and Carbon basins (see Figure 13, 14, and 16). The earlier patterns are obscured by the last compressional deformation. This is partly because the middle Eocene structures north of the Hanna basin were the nearest and largest uplifts of the Laramide. It is also, because the north-south couple stresses produced thrusting of the middle Eocene uplifts surrounding the basin, separation of the Hanna and Carbon basins, and thrusting that was largely at right angles to Late Cretaceous thrust patterns.

During these deformations, the thick interval of the Ferris and Hanna formations was deposited as piedmont slope, and fluvial and floodplain deposits in a deeply subsiding depocenter that developed within a regional syncline. Conformable deposition over thick Upper Cretaceous rocks within the depocenter resulted in the deep but small Hanna basin during the last episode of compressional deformation. The Ferris and Hanna formations are the regional correlative coal-bearing units earlier workers strove to identify. The coal-bearing Ferris–Hanna interval is the dominant rock unit.

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