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STRATIGRAPHY AND ECONOMIC GEOLOGY OF THE GREAT FALLS-LEWISTOWN COAL FIELD CENTRAL MONTANA

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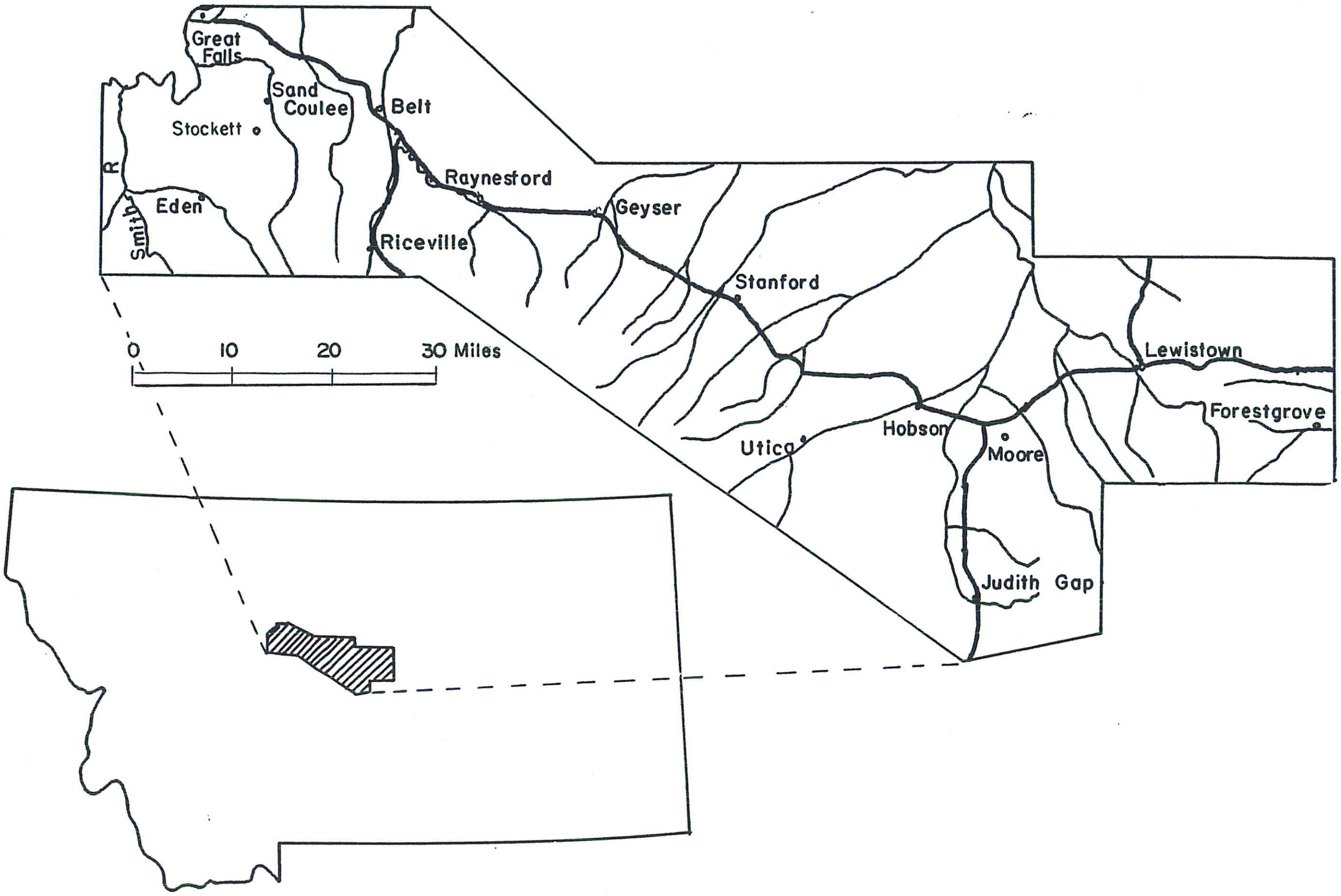

Figure 1.—Index map showing location of Great Falls-Lewistown coal field.

ABSTRACT

The lower part of the Morrison Formation, a terrestrial section consisting of 45 to 200 feet of varicolored mudstone and shale interbedded with lenses of gray sandstone and limestone, was deposited upon an emergent surface of marine Jurassic rocks. In a near-desert, interior-drainage environment, the upper Morrison and Kootenai rocks of central Montana then accumulated as lacustrine and flood-plain deposits. The upper Morrison consists of 5 to 50 feet of black shale intercalated with coal as much as 12 feet thick. The coal is depositionally discontinuous, having accumulated to greatest thickness in relatively small swamplands marginal to one or more lakes that occupied most of central Montana during late Morrison time.

The kinds of leaf compressions in black shale associated with coal indicate a xeric climate around the interior lakes, which eventually drained or filled, exposing the carbonaceous matter to subaerial erosion. After renewed uplift to the west, or increase in local aridity, or both, easterly flowing streams deposited and reworked the alluvial basal Kootenai sandstone over the entire area. In places small channel cutouts developed in the peat, but the porous organic remains produced a surface generally resistant to erosion. Regionally, basal Kootenai sandstone rests unconformably on upper Morrison beds, although the unconformity is relatively small. Compaction rather than erosional features characterize the Morrison-Kootenai contact.

The Great Falls-Lewistown field contains an estimated 750 million short tons of bituminous and subbituminous coal reserves in seams more than 14 inches thick. The nature and distribution of this coal make it amenable to future use for coal-steam-electric power generation in central Montana.

Stratigraphy and Economic Geology of the Great Falls-Lewistown Coal Field, Central Montana

by

Arnold J. Silverman and William L. Harris

INTRODUCTION

The current resurgence of the coal industry in the United States promises to produce the most important economic, social, and political effects of any activity in the raw materials industry in the next few years. Private industry and state and federal governments have consigned large sums of money and considerable manpower to a broad research and development program for coal extraction and utilization. Coal's future, defined by the needs of an expanding industrial economy throughout the world, seems to be tied to low-cost power production in steam-electric plants and to hydrogenation and gasification processes, which produce hydrocarbon products desirable for industrial and domestic use.

Within the western states, the rapid expansion of coal production in the last five years has been stimulated by the electric power industry. Availability of large tonnages of low to intermediate rank coal, which can be mined economically, coupled with an abundant supply of water, has led to increasing use of coal-steam-electric plants to supply the growing power demands of western urban areas. The federal government has estimated that national electric power requirements could increase at a rate of 6 to 8 percent a year over the next 20 years, coal production increasing concurrently at a slightly smaller rate. The western states, especially Montana, Utah, Wyoming, and North Dakota, contain huge reserves of lignite and subbituminous and bituminous coal; Montana contains by conservative estimate, 222 billion tons, or more than 13 percent of the national reserves.

As part of a long-range state program of obtaining information for the Coal Information Center, a summer field study of the Great Falls-Lewistown coal field, in Cascade, Judith Basin, and Fergus Counties, central Montana, was undertaken in 1965 (Fig. 1). The economic growth of the Great Falls area and the geographic setting of this field with respect to potential demand for electric power and hydrocarbon products in western Montana, northern Idaho, and eastern Washington were the main factors in choosing this study area. The field work involved sample collection and detailed description of the stratigraphy of the coal-bearing sequence. Well logs supplied additional data. On the basis of the geologic mapping by Fisher (1909), Calvert (1909), Vine (1956), and Gardner (1959), supplemented by the new information, an attempt was made to re-evaluate the geologic interpretation of the origin of the coal, as well as the economic potential of the coal.

HISTORY OF COAL PRODUCTION IN THE AREA

In the seven decades between 1885 and 1955, the Great Falls-Lewistown coal field produced almost 36 million tons of coal, or approximately 23 percent of the state production during the period. In the last decade the area has produced less than 1 percent of the coal mined in Montana. The causes for this decline are intimately related to the dieselization of the railroads and the coal's poor competitive position with respect to oil and natural gas.

Nearly 12 million tons of coal was extracted in the first two decades of mining history. During this early period, the number of producing mines increased from five to fifteen in Cascade County and from four to ten in Fergus County, a few large mines yielding most of the production. These larger operations included the Castner-Anaconda mine at Belt, estimated to have produced about 300,000 tons a year for 25 years, 7.5 million tons total; the Lochray-Anaconda mine at Belt, estimated to have produced about 230,000 tons a year over 10 years, or 2.3 million tons; and the Cottonwood mine near Stockett, which produced about 1,800 tons a day for 15 years, or a total of 5.4 million tons. During the three decades between 1900 and 1930, operators in the Great Falls-Lewistown field employed most of the 3,000 to 4,000 coal miners in the state. The ready markets and the large scale of the mining operations seemed to insure the economic stability of the industry.

By contrast, in the period 1950-60, production from Cascade County was small (about 43,500 tons) and had a total value of only $250,000, averaging about $5.75 per ton. Coal was mined from small underground operations employing but few men, and production costs were high relative to return.

The number of men employed in the present seasonal operation of coal mines in the Great Falls-Lewistown field is small and variable. Bituminous miners in Montana produce two to eight tons per man per day of work, and average six tons per man per day, figures well below the national average.

PREVIOUS GEOLOGIC WORK

The geology of the area adjacent to the coal field was first mapped by W. H. Weed (1899, 1900). Weed included what is now called the Morrison in the Cascade Formation and placed the basal Kootenai sandstone in the Dakota Formation, both of which he called Early Cretaceous in age.

The Great Falls-Lewistown coal field was completely mapped by Fisher (1909) and Calvert (1909), who were primarily interested in the coal and the economically productive areas. Fisher found floras associated with the coal, fresh-water mollusks, and dinosaur bones in the Morrison, and correlated the lower part of the formation with the Morrison of Colorado. He placed the upper part of the Morrison Formation in the Kootenai Formation (Lower Cretaceous) on the basis of fossil floras.

Cobban (1945) defined the contact between the Morrison and Kootenai Formations as it is known today. He described the unconformity at the base of the Kootenai in the Cut Bank area on the north end of the Sweetgrass arch, where post-Morrison erosion has removed the Morrison and Swift Formations, and correlated the base of the Kootenai with the base of the massive sandstone overlying the coal in the Great Falls coal field. Brown (1946), on the basis of the paleobotanical material, concluded that the unconformity also represents the Jurassic-Cretaceous time boundary and that considerable time elapsed between deposition of the two units. His evidence for the long hiatus was based primarily on the absence of Morrison-like species in the Kootenai Formation.

Yen (1952) has dated part of the lower Morrison as Purbeckian (Late Jurassic) or older, on the basis of fresh-water molluscan faunas from the Lewistown and Harlowton area. Yen (1951) also described a fresh-water molluscan fauna from the Kootenai near Harlowton, which he correlated with the Cloverly of Wyoming and the Peterson Limestone of Idaho, indicating that the upper Kootenai is younger than earliest Cretaceous in age. Tschudy (L. R. Wilson, personal communication, 1966) has found pollen that strongly supports the Cretaceous age of the Kootenai.

The terminology of the basal Kootenai sandstone is somewhat confusing in the central Montana area. In the Williston Basin, the basal Lower Cretaceous sandstone is called the Lakota Sandstone. This unit may have an eastern source and has been traced into central Montana on the basis of petrographic similarities (W. Ballard, personal communication, 1966). In the Cat Creek area of central Montana, petroleum geologists sometimes call the basal Kootenai sandstone the Third Cat Creek sandstone, which is a local name and one not widely accepted elsewhere. The basal Kootenai sandstone on the Kevin-Sunburst dome is called the Cutbank Sandstone, but the stratigraphic relations of this unit with similar units to the south are not clear. All of these names have been generally confused in the literature, and the extent and correlation of the units have not been determined. Therefore, in order not to further confuse the terminology, the name "basal Kootenai sandstone" has been used in this paper in referring to the basal sandstone of the Kootenai Formation in the Great Falls-Lewistown coal field.

ACKNOWLEDGMENTS

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GEOLOGY

GENERAL SETTING

The Great Falls-Lewistown coal field lies on the north flank of the Little Belt and Big Snowy Mountains and is bounded on the south by outcrop of the coal-bearing beds (Fig. 2). Dips on the mountain front reach 25° but rapidly diminish basinward.

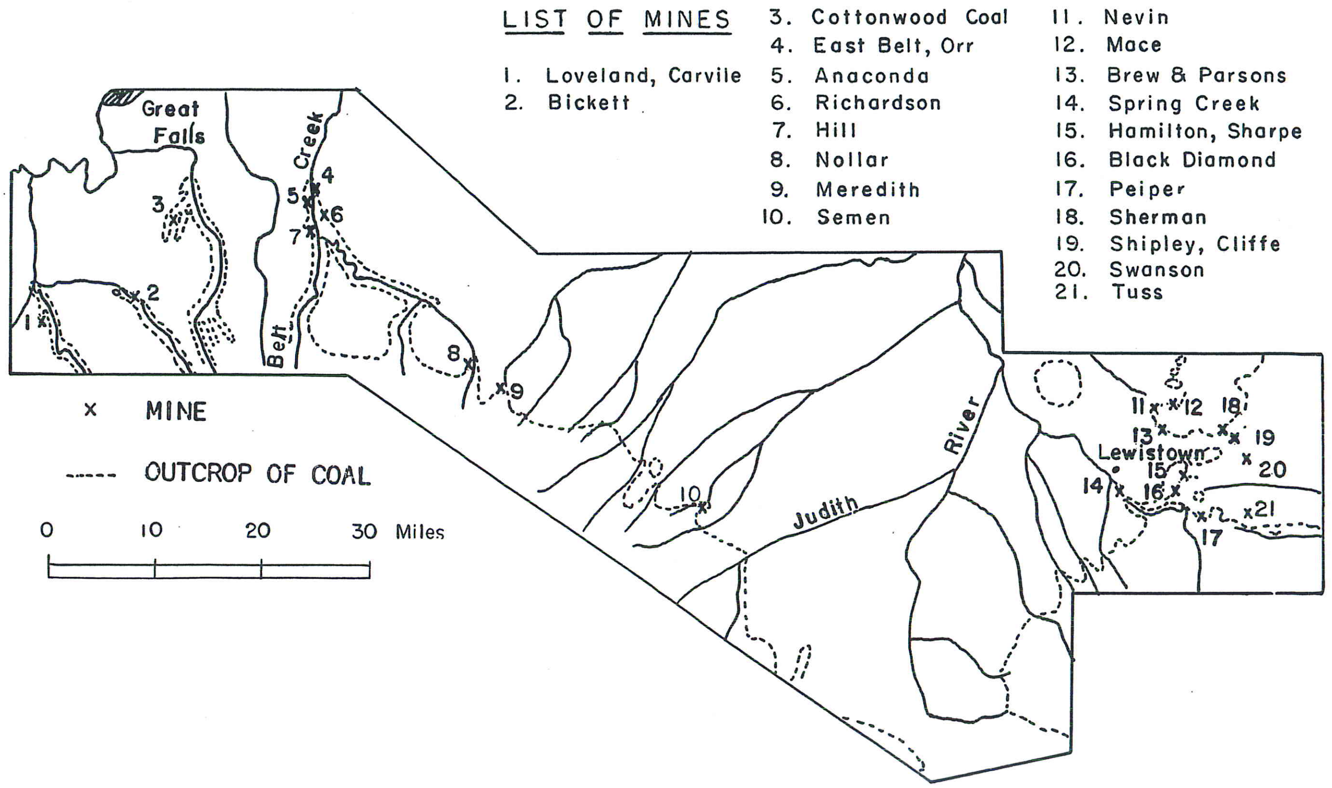

Figure 2.—Outcrop of coal in Great Falls-Lewistown coal field.

The coal field can be divided into local coal basins or districts on the basis of the thickness and lateral extent of the coal and carbonaceous shale. In the Great Falls part of the field four such basins are defined: Stockett-Sand Coulee, Belt Creek, Otter Creek, and Sage Creek. The Lewistown area includes Rock Creek, McDonald Creek, and Warm Springs Creek basins. The northward extension of each basin is not well defined in the subsurface, and there is almost no control for placing the northern boundary.

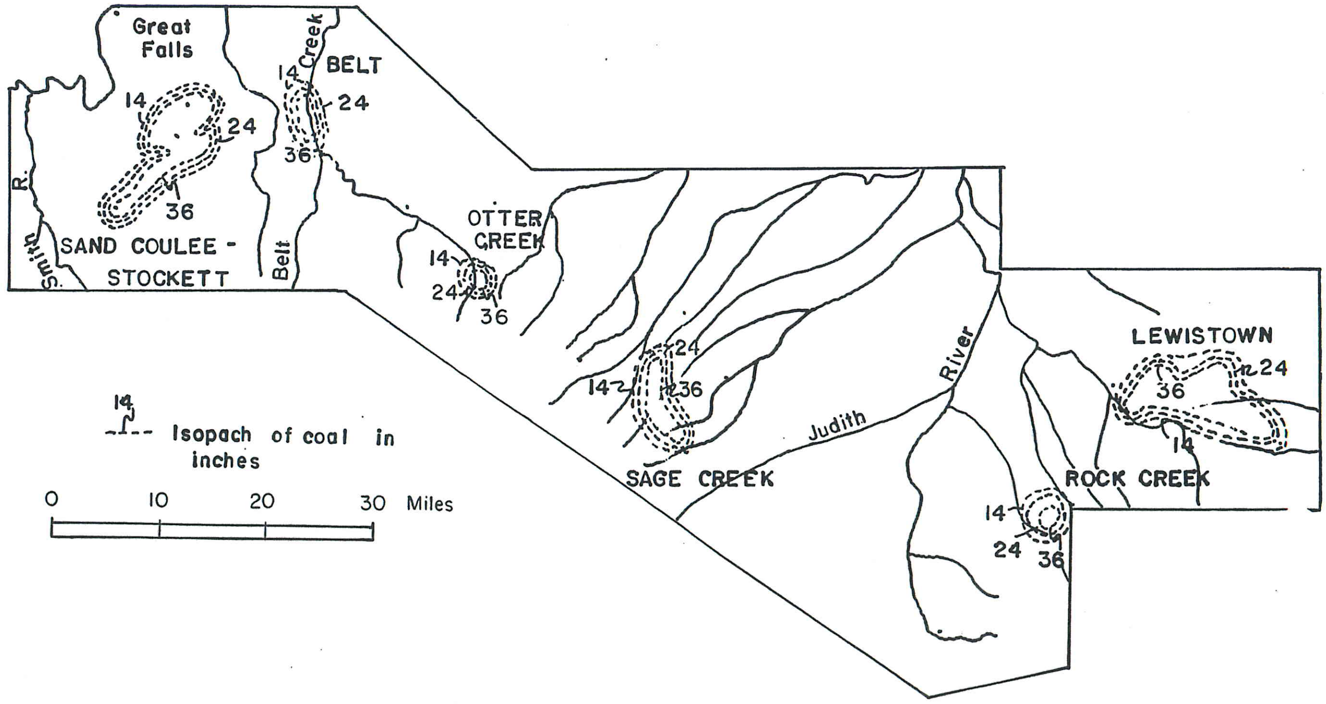

Figure 3.—Isopach of coal in basins of Great Falls-Lewistown coal field.

Along an east-west line, the coal pinches rapidly near the margins of the basins (Fig. 3). Most of the basins show one or two well-defined bone (coaly shale) or shale partings, which separate coal beds 6 inches to 12 feet thick. The coal is overlain either by a few feet of very locally restricted shale, siltstone, or sandstone of Morrison lithology, or by the widely distributed uniform basal Kootenai sandstone. The coal-bearing sequence in the area between basins is characterized by gray to black carbonaceous shale of variable thickness, in places partly missing, owing to post-Morrison erosion.

STRATIGRAPHY

Rocks in the general area of the Great Falls-Lewistown coal field range from Paleozoic through Recent. Paleozoic rocks include approximately 5,500 feet of limestone, shale, and sandstone prominently exposed in the Little Belt, Big Snowy, Judith, and South Moccasin Mountains. Mesozoic rocks, about 3,500 feet thick, are predominantly clastic, but include some evaporite and limestone; they are exposed along the flanks of the mountains and on the sides of the coulees that cross the area. Cenozoic rocks consist of a thin veneer of terrace gravel in the Judith River basin, glacial outwash east of Great Falls, and alluvium in the coulee bottoms (Pl. 1).

SWIFT SANDSTONE (JURASSIC)

The Swift Sandstone, the upper member of the Ellis Group (Upper Jurassic) is the oldest unit discussed herein (Fig. 4). The Ellis was named by Peale (1893) in the area near Fort Ellis in south-central Montana and was raised to group status by Cobban (1945), who divided it into the Sawtooth, Rierdon, and Swift Formations. The Swift is tan to gray sandstone interbedded with greenish-gray shale and ranges in thickness between 20 and 90 feet. Generally, it unconformably overlies lower units of the Ellis Group, but in places it rests on Madison Limestone (Mississippian). The Swift forms a distinctive outcrop pattern of low cliffs along the coulees. It is well exposed along Sand Coulee, Ming Coulee, Belt Creek, and Big Springs Creek.

Locally, the base of the Swift Sandstone is a conglomerate containing chert pebbles as large as 3 inches in diameter. The basal conglomerate, rarely more than 2 feet thick, grades upward into fine-grained sandstone, which is well indurated and cemented by calcite. Cross-bedding is common in the Swift; beds are predominantly about an inch thick although locally they are as much as 12 inches thick. Where it is unweathered, the unit is light-gray massive sandstone and beds seem to be 2 to 4 feet thick. It weathers to orange-brown limonite-stained flaggy sandstone in beds 2 to 6 inches thick.

The sandstone in the upper part of the Swift consists of at least 80 percent quartz, as much as 10 percent chert, and 3 to 4 percent glauconite, zircon, and tourmaline combined. The grains are subangular, and much of the quartz shows overgrowths. The cement is predominantly calcite, but some clay material also is present.

The contact of the Swift Sandstone with the overlying Morrison seems to be conformable over the area, despite the change from marine to continental deposition. The contact is placed at the top of the uppermost prominently exposed calcareous sandstone, above which mudstone dominates the section.

MORRISON FORMATION (JURASSIC)

The Morrison Formation consists of 50 to 250 feet of mudstone containing lenses of limestone, sandstone, coal, and shale. Exposures are poor except where roads cut through the Morrison or where mines have been opened in the coal. Good exposures can be seen along the road south of Stockett, on Running Wolf Creek, and north of Forestgrove. In general, the Morrison is very nonresistant to erosion, and consequently it is seen as a slope covered by brush and rock slabs and capped by basal Kootenai sandstone. The Morrison was named for outcrops near Morrison, Colorado, by Eldridge (1896) and was correlated into central Montana by Fisher (1909).

The lower part of the Morrison is predominantly light-greenish-gray to medium-gray mudstone composed of mixed-layer illite-montmorillonite and kaolinite. Interbedded with the mudstone are light-gray fresh-water limestone beds, which reach a maximum thickness of 10 feet and in places grade laterally into fine-grained sandstone. Petrographically, the limestone is a micrite (Folk, 1959) or microcrystalline lime mud containing sand and silt grains and a few mollusk shell fragments.

Sandstone lenses, as much as 35 feet thick, are interbedded near the middle of the Morrison and weather tan to orange and flaggy. The sandstone is moderately well sorted, subangular, and partly cemented with calcite, and contains some brown interstitial clay. The mineralogy is 90 to 95 percent quartz, 5 to 10 percent chert, and feldspar, tourmaline, and zircon totalling less than 1 percent.

The upper part of the Morrison, as much as 60 feet thick, is medium to dark-gray carbonaceous shale containing coal and lenses of fine-grained sandstone. The coal ranges from a few inches to 12 feet in thickness and may be in one bed or in two or

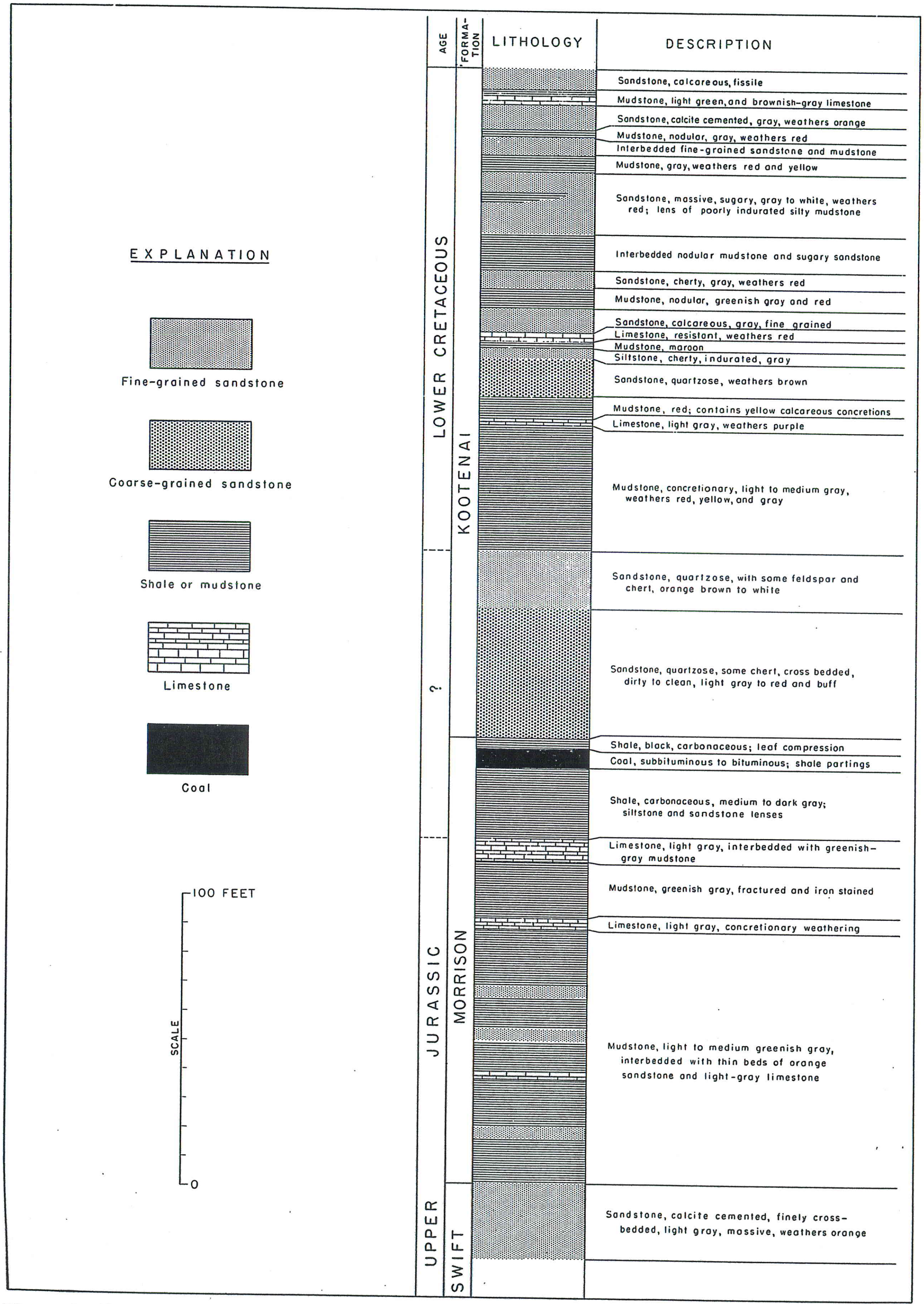

Figure 4.—Composite stratigraphic column of Kootenai and Morrison in Great Falls-Lewistown coal field.

three benches separated by shale, sandstone, or siltstone partings. The siltstone and sandstone beds in the upper part of the Morrison range to 2 feet in thickness, although in the eastern part of the area lenses 25 feet thick are present. The sand grains are 90 to 95 percent quartz, a few percent chert, and about 2 percent zircon and tourmaline combined.

Unidentifiable fragments of dinosaur bones were found in greenish-gray mudstone in the lower part of the Morrison at Armington Junction, Riceville, and Forestgrove. Partly petrified wood was found south of Stockett in close association with the coal seam and carbonaceous shale in the upper part of the Morrison. Abundant leaf compressions were found in black shale and carbonaceous siltstone at Belt and Lewistown. In both localities the leaf fossils were in the upper part of the Morrison, within 15 feet of the basal Kootenai sandstone. The flora tentatively identified are as follows:

- Pteridophites (Ferna)
    - *Coniopteris* c.f. *bella*
    - *Cladophlebis* c.f. *virginiensis*
- Cycads
    - *Nilssonia* sp.
    - *Zamites* sp.
    - *Podozamites* c.f. *lanceolatus*
- Conifers
    - *Pagiophyllum* sp.
    - *Athrotaxites* c.f. *berryi*

KOOTENAI FORMATION (CRETACEOUS)

The Kootenai Formation overlies the Morrison on an erosional unconformity and is 400 to 500 feet thick. It consists of a basal sandstone unit overlain by red, green, and gray mudstone containing numerous limestone and sandstone lenses. The Kootenai was named by Dawson (1886) for outcrops in the southern Canadian Rockies and was correlated with strata in the Great Falls area by Fisher (1909).

Thickness of the basal Kootenai sandstone ranges from 1½ to 85 feet, but in most places it is 30 to 45 feet. The unit is buff to light red and very friable. A prominent sedimentary feature is the 1-foot cross-bedding in most parts of the area.

At the base, the sandstone is dirty, poorly sorted, and medium to coarse grained. Chert pebbles as large as ½ inch in diameter are common in the western part of the area. The interstitial material contains mica and kaolinite. In thin sections of the lower part of the unit, it is seen to be poorly cemented, has a relatively low porosity, and is medium to coarse grained and moderately well sorted. Quartz is the most common constituent, making up 80 percent of the rock, but locally it may be as little as 20 percent. The quartz grains are subrounded to rounded, and overgrowths are common. Sedimentary rock fragments composed of quartz grains are sparse. Chert, characterized by its color (dark brown or black), locally makes up 80 percent of the sandstone near the base and averages about 30 or 40 percent. Grains are more angular and of larger average size than the associated quartz grains. Some fragments of chalcedony are present, and chalcedony veinlets were noted in some of the chert grains. Zircon and tourmaline amount to less than ½ percent, and plagioclase feldspar is very rare. Higher in the unit the sand is well sorted, medium to fine grained, and relatively porous. In some areas, the sandstone at the top of the unit is almost 100 percent quartz, containing only a few feldspar and chert grains.

Above the basal sandstone, the Kootenai Formation is a heterogeneous mixture of sediments*, including red or maroon mudstone that provides the red soil of the area and tends to color the underlying beds the same rich red. Greenish-gray mudstone is also common but not as well exposed; it is locally cemented by calcite, and concretions weather out of it. Clay analysis of the maroon mudstone indicates the great preponderance of mixed-layered illite-montmorillonite, kaolinite being minor. This composition is like that of the greenish-gray mudstone of both the Morrison and Kootenai Formations. Lenticular and discontinuous sandstone interbedded with the green and maroon mudstone is medium to fine grained and poorly indurated. Sandstone containing 25 percent chert grades upward into clean quartz sandstone. Fresh-water-limestone lenses are abundant in the Kootenai, and dark-gray shale and thin coal seams have also been reported.

Excepting the basal sandstone, the beds in the Kootenai Formation are very discontinuous. Individual beds cannot be followed farther than a few hundred yards, and in large outcrops they may be seen to lense out over a short distance.

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*One of several clay mines east of Great Falls in the vicinity of Belt is an underground mine in the NW¼SW¼ sec. 31, T. 19 N., R. 7 E., in Armington Coulee. A 4-foot bed of gray shale just above a bed of massive sandstone has been mined here. Both the shale and the sandstone are in the Kootenai Formation. A sample of the shale is reported to have the following composition in percent: SiO_2 59.3, Al_2O_3 27.0, Fe 1.7, CaO 0.3, MgO 0.2, Na_2O 1.1, K_2O 0.8, TiO_2 0.6 (Sahinen and others, 1958, p. 38, sample 71). "The plasticity and green strength are fair; the drying and firing shrinkage are low. The P. C. E. is cone 30 (3002°F), and the firing range is 2300°F to 2650°F. The fired color is gray. The firing must be conducted carefully so that the carbonaceous matter will be expelled without damaging the brick. It is a good ceramic raw material, particularly when blended with other clays. It has long been used in this manner in making a good grade of high-heat duty fire brick." (Sahinen and others, 1958.)

MORRISON-KOOTENAI UNCONFORMITY

Large rounded cobbles, which locally form a conglomeratic base, the abrupt change in lithology, and channeling are field evidence for an unconformity at the bottom of the basal Kootenai sandstone. Neither the time interval nor the amount of erosion represented by this unconformity seems very great.

Chert pebbles and cobbles, which range from ½ inch to 6 inches in diameter, are present at the basal Kootenai contact in the western part of the area. These pebbles and cobbles may be found in areas where the overlying sandstone is not at all conglomeratic. The operator of the East Belt mine (Sam Williamson, personal communication, 1965) noted that where the coarse sandstone directly overlies the coal seam, rounded or flat cobbles are found at the contact. Cobbles at the Morrison-Kootenai contact were also found at Armington, along the Smith River, and in a small coulee 6 miles south of Great Falls.

The base of the Kootenai Formation is defined as the base of a medium- to coarse-grained generally continuous sandstone, which overlies a typical Morrison sequence of dark-gray shale and coal resting upon greenish-gray mudstone. In one locality just west of Stockett the basal Kootenai sandstone is absent; at Stockett the sandstone is interbedded with red and greenish-gray mudstone. Over most of the area, however, the basal Kootenai sandstone is continuous, and the virtual uniformity in appearance and mineralogy is the outstanding characteristic of the unit. Underlying the sandstone, in most of the area, is an appreciable thickness of black shale interbedded with coal. This unit generally ranges from 25 to 60 feet in thickness but along Otter Creek it thins to 3 feet. Typical lower Morrison beds lie directly below.

Channeling is the most compelling evidence for an unconformity at the base of the Kootenai. These channels range in amplitude from 2 inches to at least 5 feet. The larger channel fillings are commonly partly covered by talus so that only part of the channel is seen.

At Armington, on the east side of Belt Creek, a cast of a channel crosses the north-trending mine entry at right angles. The channel is about 7 inches wide and 3 inches deep and is exposed along 10 feet of length. The underlying shale beds are actually cut out and not simply deformed.

Along the Smith River on the west side of the coulee south of the Orr School, the Morrison-Kootenai contact is exposed in a long road cut. In several places small channels having 1 to 2 feet of relief can be seen in the Morrison, although in other parts of the cut an undulatory contact with the black shale shows only compaction of the underlying beds.

In the road cut just south of Stockett the upper part of the Morrison contains 25 feet of black shale overlain by 4 inches of coal (Fig. 5). The basal Kootenai sandstone averages 30 inches thick and where it is exposed it seems to overlie the coal conformably on an undulatory surface. The sandstone thickens and thins, and compaction is greatest where the sand is thickest. Directly overlying the sand is the typical red and greenish-gray mudstone of the Kootenai Formation. A mile to the northeast of this outcrop, 68 inches of coal is separated from the basal Kootenai sandstone by 1 foot of shale; 2½ miles to the southwest, in Giffen Coulee, 78 inches of coal is separated from the sandstone by 8 to 10 feet of shale. The thin coal at the Stockett section may be explained by erosion that removed most of the coal, or by nondeposition in this particular locality.

In the first east-trending canyon off Sand Coulee and north of Centerville, the basal Kootenai is in angular discordance with the underlying Morrison beds exposed in one wall of the canyon. This is probably part of a large channel, as the same relationship is not expressed on the other wall of the canyon. The angularity can be seen in places along 60 feet of intermittent exposure. A section of siltstone and black shale 3 feet thick has been beveled off by erosion within a horizontal distance of 15 feet.

At the Loveland mine a channel fill that overlies the coal is exposed above the mine adit. The Morrison coal and black shale are nearly horizontal; the overlying beds of alternating mudstone and fine-grained sandstone dip steeply to the south. The feature described is interpreted as accretion beds filling an old stream channel carved on the Morrison surface. Higher beds of the basal Kootenai sandstone were then deposited nearly horizontally over the channel fill. This explanation could be applied to the situation as seen at Centerville.

Where post-Morrison channeling can be seen, it is small in magnitude of relief, as typified in the Armington and Smith River sections. Williamson (personal communication, 1966) reported that cutouts interrupt the coal at the East Belt mine, but these also are minor in relief and small in area.

In most places the undulatory configuration of the base of the sandstone is due to compaction of the underlying shale and coal. Examples are found at Stockett, Armington, Skull Butte, the Boston and Montana mine (Belt Creek), and along the Smith River. At Stockett a 4-inch coal seam underlies the basal Kootenai sandstone here 30 inches thick. The base shows undulations having a relief of 6 to 8 inches. The coal differs but little in thickness over 20 to 30 feet of lateral exposure. In some areas the flat-lying basal Kootenai sandstone exhibits no appreciable irregularity at the bottom surface.

At the second road cut east of Armington, near Otter Creek, the section of black shale underlying the basal Kootenai sandstone is about 4 feet thick and coal is absent (Fig. 6). Light-greenish-gray mudstone and gray limestone and siltstone, typical of the lower part of the Morrison, underlie the dark shale. In most places the shale and coal sequence is at least 25 feet thick, generally as much as 50 feet thick. The reduced Otter Creek section can be explained in either of two ways: (1) most of the upper Morrison could have been removed by post-Morrison erosion; or (2) the Otter Creek area could have been topographically high on the edge of the basin during most of the time of deposition of the upper part of the Morrison, so that very little black shale and no peat was deposited. The latter explanation is more likely in this place, as coal has not been noted in adjacent areas south and west of this outcrop. Furthermore, coal is not present in an outcrop of the upper part of the Morrison between Armington and Armington Junction, indicating that the Otter Creek locality may have been the edge of the area in which coal-forming material was deposited (Fig. 6).

The Morrison and Kootenai Formations seem to be conformable in the Sage Creek (Lehigh) area. Within an east-west distance of 1½ miles, however, the thickness of the mudstone and siltstone between the coal and the base of the Kootenai Formation ranges from 6 to 25 feet (Fig. 7). About 2½ miles west the mudstone and siltstone pinch out, and the basal Kootenai sandstone directly overlies the coal bed, and 3 to 4 miles west, in Hazlett Creek, the coal pinches out (Fisher, 1909). On the west side of Skull Butte, 4 inches of coal is cut out by erosion, as viewed along an 8-foot width of adit.

Six miles south of Lewistown the upper part of the Morrison consists mainly of 25 feet of interbedded black shale, coal, and siltstone (Fig. 8, Castle Creek section). Directly below the basal Kootenai sandstone is a medium-grained quartz sandstone 3½ feet thick, perhaps formed as a bar or beach. The coal is a 24-inch seam divided into two benches. On Casino Creek, 3 miles northwest, the coal is 23 inches thick, and Calvert (1909) reported that on Big Springs Creek, 4 miles northeast, the coal is 68 inches thick. Nondeposition rather than erosion is believed to account for the relationship in this area.

JURASSIC-CRETACEOUS BOUNDARY PROBLEM

The exact position of the Jurassic-Cretaceous boundary in the study area has not been definitely established (Fig. 4). Compression remains of several plant genera were found by the authors in black shale in the upper part of the Morrison. These plants are essentially the same as the flora described from the Kootenay Formation of Canada. Neither flora is diagnostic of the exact age of the beds from which it came. C. N. Miller (personal communication, 1965) believes that the Jurassic-Cretaceous boundary cannot be placed on the basis of floral evidence without the presence of angiosperms, which are diagnostic of post earliest Cretaceous age.

On the basis of mollusks, Yen (1952) dated the light-gray mudstone and limestone in the lower part of the Morrison as uppermost Jurassic (Purbeckian) or older in age. The early Cretaceous age of the Kootenai is based on fresh-water mollusks (Yen, 1951), substantiated by Tschudy's work on pollen (L. R. Wilson, personal communication, 1966). Therefore, the Jurassic-Cretaceous boundary falls within a section of 150 to 200 feet of strata that include the upper part of the Morrison and the basal Kootenai sandstone, but it cannot be placed more precisely on fossil evidence. The sharp lithologic break, however, is a convenient and reasonable horizon at which to place the Jurassic-Cretaceous contact.

GEOLOGIC HISTORY

The history of the units most involved in this discussion is one of continental deposition after regression of the widespread Upper Jurassic sea. The Swift is a regressive sandstone, probably a beach sand, left by the northward-retreating seaway. Cobbles at the base of the Swift indicate a high-energy environment, and the genera *Ostrea* and *Gryphaea* indicate marine conditions. This general regression left a terrestrial area, which probably was not much above sea level and had very low relief. The regression was sporadic, as shown by the thin glauconitic sandstone beds in the lower part of the Morrison, which indicate renewed marine incursions (Hanson, 1959).

The continental sequence of Jurassic and Cretaceous rocks in central Montana is characterized by shale or mudstone, siltstone, and sandstone, but contains subordinate amounts of limestone, bentonite, black shale, and coal. Jurassic uplift of the Rocky Mountains farther west, coupled with a semi-arid to arid climate, provided the environment for the development of a great pediment surface, which passed east and north into a low flat surface that emerged from the sea. Along the entire Rocky Mountain front, sediment was shed eastward over this newly developed surface by east-flowing rivers carrying the erosional products from the western mountains. Inland lakes and swamps, perhaps at times merging to form one large lake slightly above sea level and covering most of central Montana, characterized the depositional surface. In this environment of near-desert interior drainage, the Morrison accumulated as lacustrine, flood plain, and occasional channel and volcanic ash deposits, to be followed by a similar accumulation of continental clastic deposits of Cretaceous age, the Kootenai Formation. Essentially the same conditions were postulated by Stokes (1944) for the terrestrial Morrison deposits of the Colorado Plateau.

The environment during deposition of the lower part of the Morrison in central Montana is one of lacustrine and flood-plain deposition. The mudstone contains large pieces of dinosaur bone, which, judged from their fragmental appearance, probably were transported some distance, possibly from points outside the area. Lack of remains of other animals and plants in the lower part of the Morrison may indicate a dry climate, in which widely separated and perhaps seasonal streams winding across the emergent plain supplied water for several lakes.

The upper part of the Morrison was deposited during a time in which sufficient water was available, particularly in the basins, to promote abundant plant growth. In the lakes, where the influx of clastic sediment was very slow and where water was stagnant for a long period of time, marginal coal swamps developed. At numerous localities the coal thins abruptly, indicating that the edge of a basin of coal accumulation was nearby.

The kinds of leaves found as compressions indicate a mild climate, and only rare freezing temperatures. Cycads are presently found in tropical environments, and the ferns are also somewhat indicative of mild climate. The presence of the conifers *Pagiophyllum* and *Athrotaxites* indicates a dry or xeric climate, either chemically or in actuality. The thick, heavily cutinized leaves of *Zamites*, *Podozamites*, and *Nilssonia* support this interpretation. The close association of coal with the above plant genera indicates that although water was present, it was not always chemically available to the plants.

The mild climate may have been partly due to the moderating effect of the Upper Jurassic seaway lying to the north. It has been noted that during the Late Jurassic the warmer climatic zones, as indicated by floras and faunas, extended much farther north than they do today (Arkell, 1956), if living forms occupy the same climatic environment that like forms did in the Jurassic. This theory also assumes that the continents were in approximately the same position during the Mesozoic as they are today.

The nearly structureless appearance of the coal, the lack of underclay, and the small size and delicacy of fossil leaf and stem compressions of cycads, ferns, and conifers in associated black shale all indicate that small trees, shrubs, and perhaps moss and algae or bacterial matter composed the organic accumulation in a fresh-water lake or swamp. Rapid decomposition of the organic matter by aerobic and anaerobic bacteria, helped by alternate wetting and drying on the margins of the lake or swamp, allowed peat to accumulate to a thickness of 100 feet or more in places. Although most of the organic matter could have accumulated in place, some woody debris was probably carried into the coal basins by streams, which also carried the clastic material that formed the bone and shale partings. The rapid pinching of coal outward from the accumulation center reflects the moisture boundary of plant growth, the dry climate restricting plant accumulation to the lake margins or swamps where water was readily available.

Either plant filling or water drainage exposed the peat bogs, at least in part, to a minor amount of subaerial erosion. Clastic deposits accumulated in local depressions or channels. After renewed uplift of the mountains to the west, the area was covered by a thick wedge of alluvial sand, the massive, cross-bedded, and graded basal Kootenai sandstone. In places small channel cutouts developed in the peat, but the porous organic remains were very resistant to erosion. The contact of the basal Kootenai on the coal throughout the entire area is therefore characterized by compactional rather than erosional features. The period of erosion as indicated by the lack of significant channeling, was probably short, but lack of fossil control precludes determining the absolute time. Brown (1946) believed that the hiatus was considerable because some Morrison plant species are not found in the Kootenai. Stokes (1950) indicated that a considerable amount of time may be represented in an unconformity on a broad alluvial plain of this type, during which little erosion but considerable reworking of the fluvial material takes place. The result would be an appreciable time gap between two formations that show very little physical discordance.

The basal Kootenai sandstone was deposited and reworked by streams to produce a unit that ranges between 1½ and 85 feet in thickness. Its lithology is almost uniform, the only marked lateral variation being the gradation of the basal pebbly sandstone or conglomerate eastward into medium-grained sandstone. Toward the top, the unit becomes cleaner, well sorted, and in places pure quartz sandstone, indicating that the sand has been reworked and the finer material winnowed away either by stream action, or more likely, by the wind.

Lack of continuous beds in the upper part of the Kootenai indicates a return to deposition under fluvial or lacustrine conditions, similar to those under which the Morrison was deposited. Local unconformities are numerous in the section. Restricted black shale and coal in the Kootenai indicate temporary standing water in the environment, but the general lack of fossils in the associated varicolored shale suggests a fairly arid climate at the time of deposition.

COAL DEPOSITS

COAL BASINS

The coal seam in the Stockett-Sand Coulee basin consists of three benches and two bone partings (Fig. 5). The lower coal bench is 1 to 2 feet thick and the middle bench is 4 to 7 feet thick. They are separated by 1 foot of coaly shale. The upper coal bench was not mined. The roof rock in this area is composed of Morrison shale and siltstone as much as 3 feet thick, which in turn is overlain by the basal Kootenai sandstone. In Ming Coulee, between Stockett and Smith River, coal crops out along the drainage southwest of the town of Eden. Mines in this area were not extensively developed, although the coal seam ranges from 2½ to 7 feet in thickness. It is overlain in most places by the basal Kootenai sandstone, but in a few localities Fisher (1909) reported as much as 10 feet of shale and sandstone resting on the coal and overlain by coarse massive sandstone.

In the Belt basin, total thickness of the three benches of coal averages 5 feet, excluding shale partings 1 to 2 feet thick (Fig. 6). This coal is overlain by dark-gray shale except in a few localities where the shale was removed by erosion and the basal Kootenai rests upon the coal. In the Otter Creek basin the coal is divided into two benches, total thickness of which averages 3 to 4 feet. The benches are separated by a shale parting 1 to 15 inches thick. The upper bench is overlain by shale and clay 2 to 3 feet thick, which in turn is overlain by the basal Kootenai sandstone.

South and west of Windham is the Sage Creek basin, which contains coal benches ranging in total thickness from 2½ to 7 feet and averaging 5½ feet (Fig. 7). The bottom bench, which contains the best coal, averages 2½ feet in thickness. It is separated from the middle bench, which is 1 foot thick, by 2 to 6 inches of shale parting. The top bench is 2 feet thick and is underlain by 1½ feet of shale parting and overlain by as much as 15 feet of coaly shale, shale, and siltstone. The basal Kootenai sandstone overlies the roof rock. Near Utica a small amount of coal was mined from a seam that is 4 feet thick but lacks horizontal continuity. A small amount of coal was removed from a 30-inch seam along Saegar Creek, but excessive ash content contributed to overall poor quality.

In the Lewistown field, coal in the Rock Creek basin underlies an area of 14 square miles and averages 3½ feet in thickness. Two benches, of nearly equal thickness, are separated by 1 foot of bone parting. In most places 1 foot of coaly shale overlies the seam, and the basal Kootenai overlies the shale. Where the shale roof is missing, the basal Kootenai rests directly on the coal.

The Warm Springs Creek basin, on the west side of Judith Mountains south of Warm Springs Creek, has an area of 3 square miles. The seam averages 3½ feet in total thickness and consists of two benches, the lower ranging from 2 to 2½ feet in thickness. In places the top bench has a thin clay or bone roof, which is overlain by the basal Kootenai sandstone.

The McDonald Creek basin extends from Big Springs Creek on the west to Forestgrove and Giltedge on the east. The coal seam ranges from 2½ to 5 feet in thickness and averages 3½ feet in the vicinity of the Lewistown Dome (Fig. 8). Generally, two well-defined benches, each ranging in thickness from 6 inches to 3 feet, are separated by less than 1 foot of bone parting and black shale. Basal Kootenai rests upon the coal except in a few places where a thin shale or sandstone roof is present.

CHEMISTRY AND PETROGRAPHY OF THE COAL

The coal in the Great Falls-Lewistown field has been analyzed chemically by the U. S. Bureau of Mines (1932). The analyses are presented in Tables 1 and 2 as the average of 15 samples from the Great Falls field and 14 samples from the Lewistown field.

Table 1.—Analyses of coal from Great Falls coal field*.
(Moisture- and sulfur-free basis.)

	Average	Range
Volatile matter	28.79%	34.8 -22.7%
Fixed carbon	52.07%	57.8 -47.1%
Ash content	19.13%	30.2 -12.7%
Btu/lb.	11,118**	12,900- 8,690
Sampled thickness, in.	60.5	106.5 -38.0
Bed thickness, in.	74.5	137.0 -48.0

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*Includes 5 analyses, Belt basin; 4 analyses, Smith River; 2 analyses, Stockett-Sand Coulee basin; 2 analyses, Otter Creek basin; and 2 analyses, Sage Creek basin.

**13 analyses.

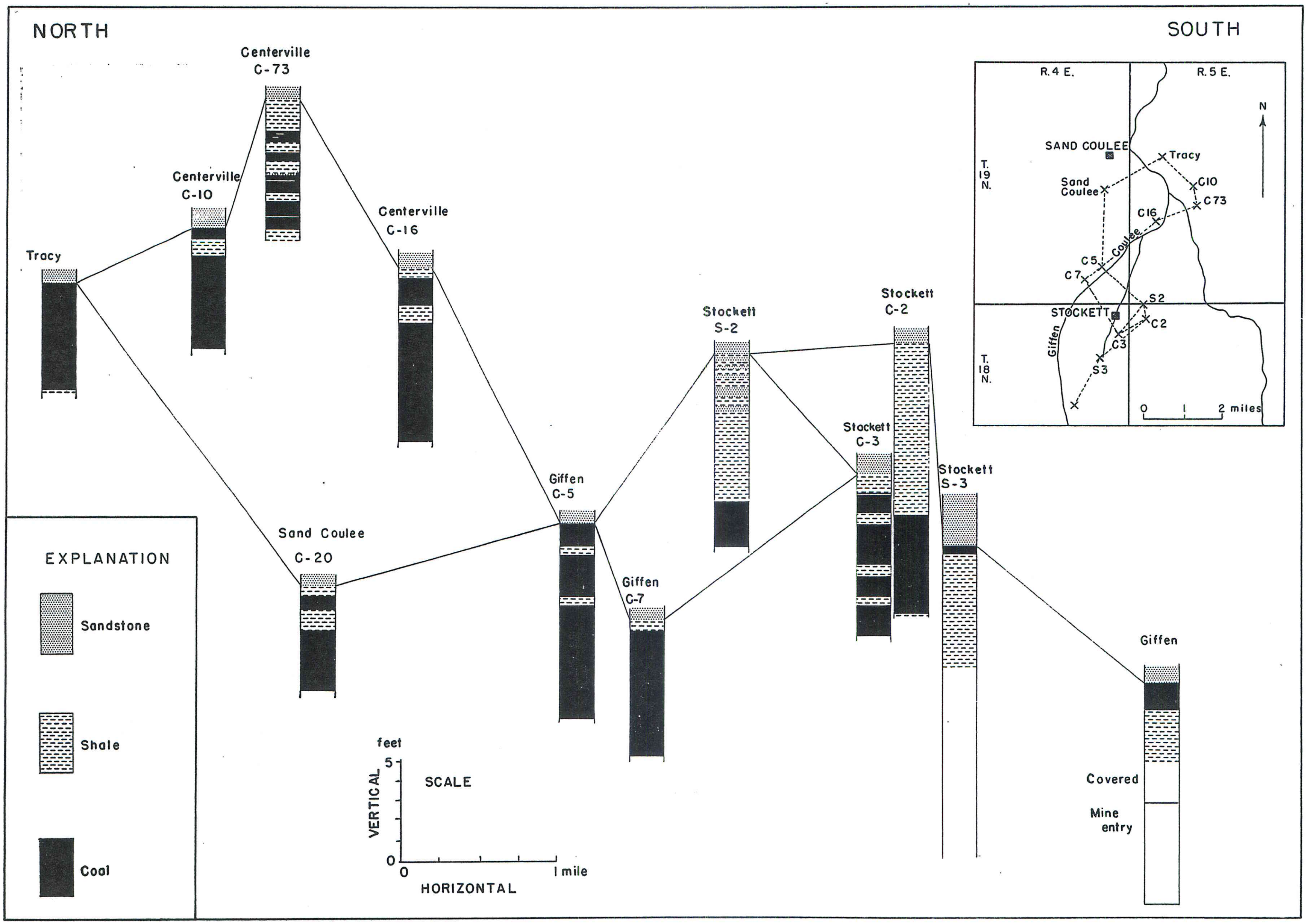

Figure 5.—Kootenai-Morrison unconformity in Stockett-Sand Coulee coal basin.

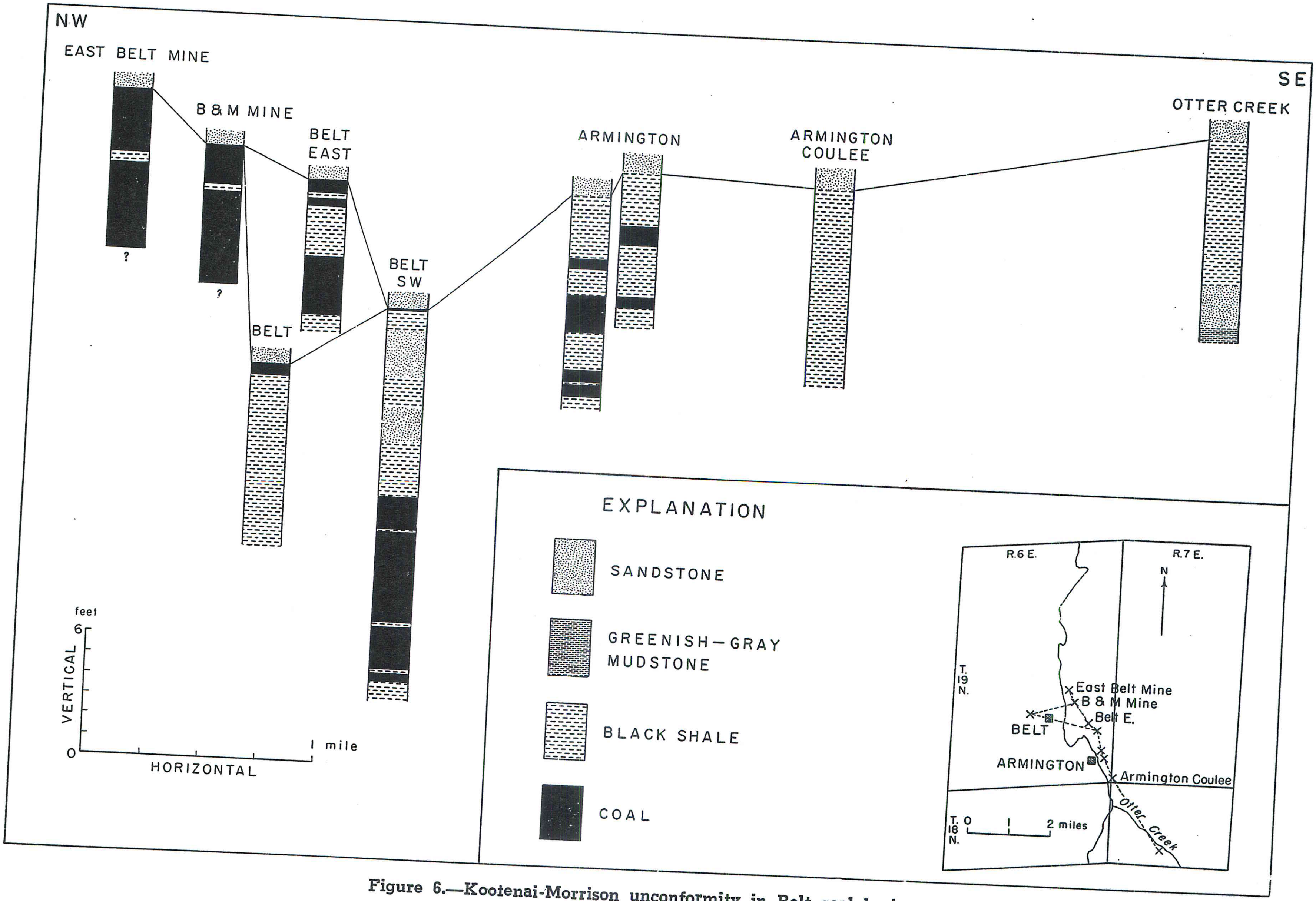

Figure 6.—Kootenai-Morrison unconformity in Belt coal basin.

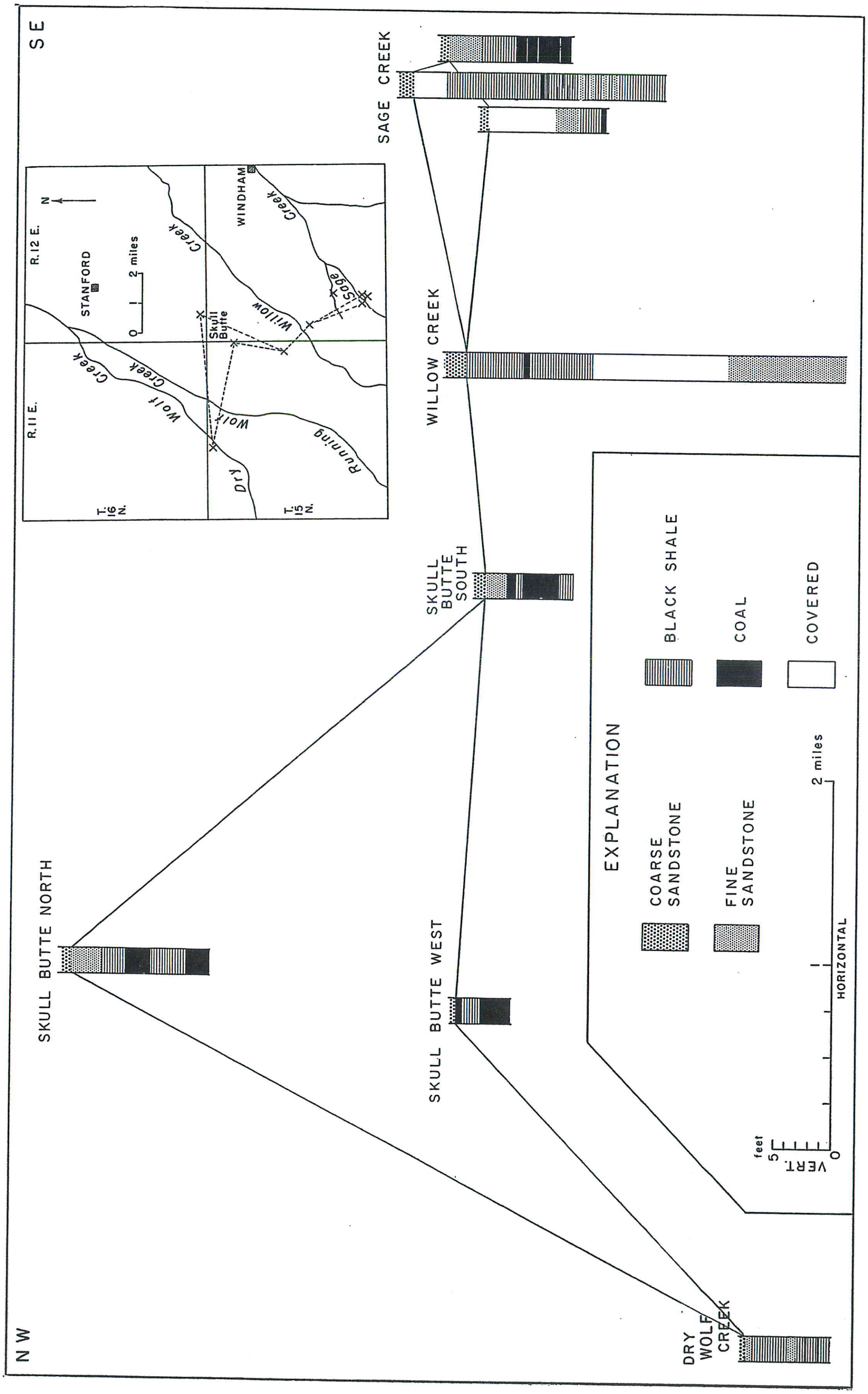

Figure 7.—Kootenai-Morrison unconformity in Sage Creek coal basin.

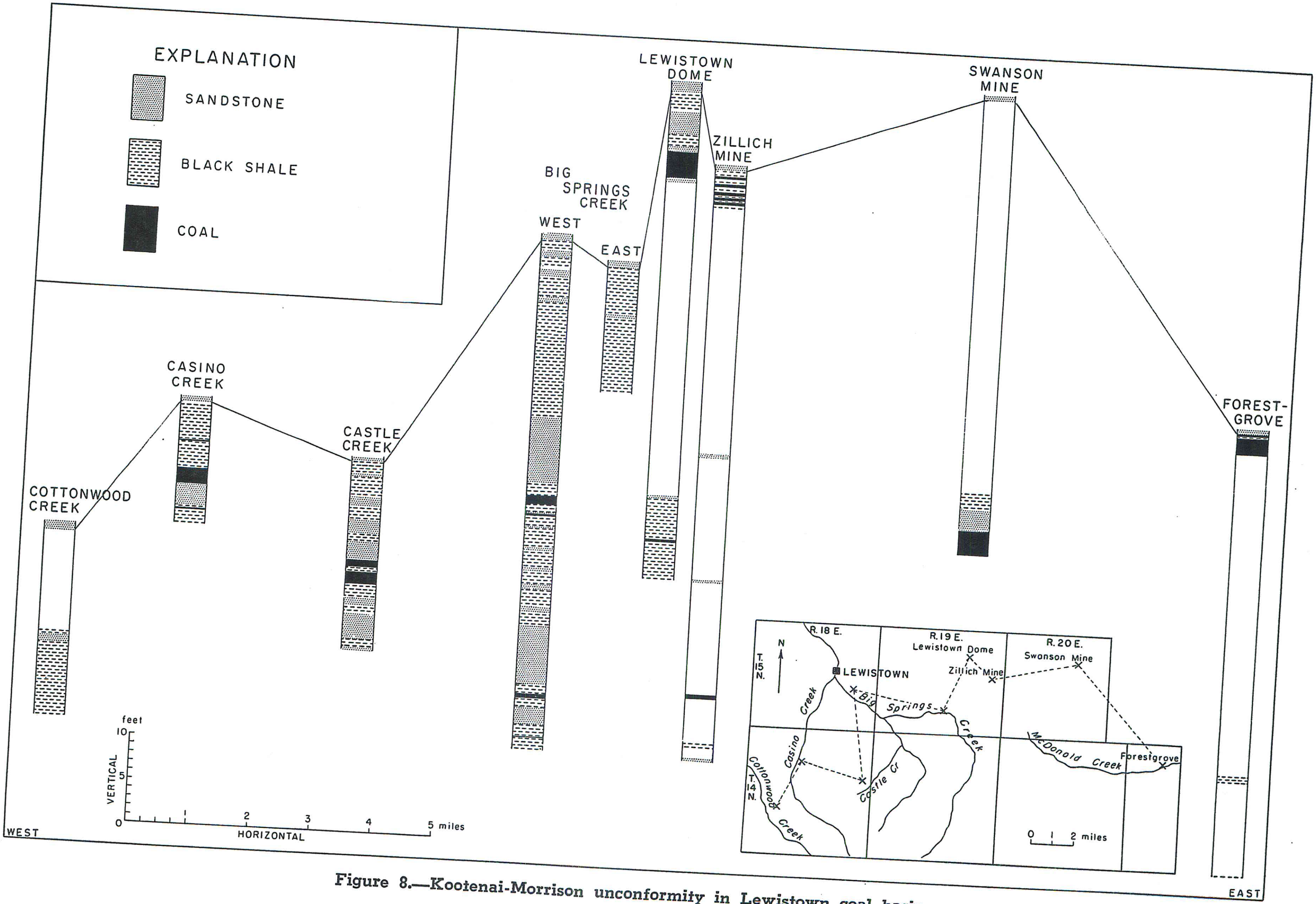

Figure 8.—Kootenai-Morrison unconformity in Lewistown coal basin.

Table 2.—Analyses of coal from Lewistown coal field[a]. (Moisture- and sulfur-free basis.)

	Average	Range
Volatile matter	31.74%	37.5 -28.2%
Fixed carbon	55.54%	60.9 -45.8%
Ash content	12.79%	23.5 - 8.4%
Btu/lb.	11,909	12,940-10,110
Sampled thickness, in.	40.1	68.0 -19.0
Bed thickness, in.	47.4[b]	74.0 -24.0

[a] Includes 7 analyses, McDonald Creek basin; 3 analyses, Warm Springs Creek basin; and 4 analyses, Big Spring Creek area.
[b] 13 measurements.

On the basis of the average Btu value, the Great Falls-Lewistown coal can be ranked as subbituminous B to high-volatile C bituminous, according to the American Society of Testing Materials classification. The sulfur in the coal averages 2.7 percent in the Great Falls field and 3.7 percent in the Lewistown field, but ranges from 0.5 to 5.5 percent in individual samples. The amount of sulfur differs considerably within a given bench and between benches. The moisture content of the air-dried coal in the Great Falls field ranges from 1.0 to 4.0 percent, and in the Lewistown field from 7.0 to 23.0 percent. On the basis of the analyses, the coal in the Stockett-Sand Coulee basin is the best in the field, as it is thicker, contains less ash, and has greater heating value than those in the other basins. Coal in the McDonald Creek basin is also better than the average in these same factors.

The coal throughout the Great Falls-Lewistown area is composed mainly of durain and fusain, but contains minor layers of vitrain. The durain and fusain are black, have a dull luster, and are strongly checked, breaking parallel and perpendicular to the bedding. This mixture composes about 90 percent of the coal. The vitrain is jet black and has vitreous luster and conchoidal fracture. It occurs in layers or stringers 2 to 3 inches long and 1/16 to 1/4 inch thick and makes up about 5 percent of the coal. The other 5 percent of the coal consists of clay stringers and pyrite nodules.

Acetate-peel investigation of the coal samples shows considerable fragmentation of the coaly matter. Cutin, trilete spores, and plant cell walls were observed, but nothing identifiable as to plant type was noted. The material now forming the coal has apparently undergone a considerable amount of organic decay before burial. The physical character of the coal seems compatible with the postulated explanation of origin.

RESERVES

A discussion of economic utilization of the coal involves mainly a consideration of the rank and grade of available reserves, possible mining methods applicable to coal extraction in this particular field, and the requirements of the prospective consumer.

Total production to date in the Great Falls-Lewistown field is estimated to be about 36 million short tons. As a rule of thumb, production plus loss in mining can be estimated as twice this figure. The size of each coal basin has been estimated (Fig. 3) on the basis of all known information from the literature, drill logs, and our own field study. Reserve estimates are believed to be conservative, and include all classes of coal in beds more than 14 inches thick and having an average specific gravity of 1.4. In Table 3 the reserves are compared with the estimates given by Combo and others (1949). The discrepancy in the calculations is due mainly to differences in the size of coal basins as estimated for the two studies.

Table 3.—Estimate of coal reserves of the Great Falls-Lewistown field.

	Combo and others (1949)		Silverman and Harris
Location	Measured and indicated (short tons)	Inferred (short tons)	All classes (short tons)
Cascade County	390×10^{6}	45×10^{6}	314×10^{6}
Judith Basin County	156×10^{6}	88×10^{6}	115×10^{6}
Fergus County	269×10^{6}	72×10^{6}	393×10^{6}
Total	815×10^{6}	205×10^{6}	822×10^{6}

A further comparison with the work of Combo and others (1949), on the basis of bed thickness versus tonnage, is given in Table 4. A breakdown of the total reserves in each of the coal basins of the field, as calculated by this study, is given in Table 5.

On the basis of our calculations we find that the reserves of coal in beds more than 36 inches thick, as a percentage of the total reserves, is 65 percent in Cascade County, 38 percent in Judith Basin County, and 50 percent in Fergus County. Calculations by Combo and others show approximately 60 percent of measured and indicated reserves in beds more than 36 inches thick in the Great Falls field, and about 47 percent for the Lewistown field. In the reserve data given below, no attempt has been made to subtract tonnage removed or lost in mining. The Stockett-Sand Coulee and Belt Creek basins would account for 90 to 95 percent of the 70 million short tons not available for extraction. The total reserve of these two areas, for all classes and thicknesses of coal, would be about 245 million short tons.

Table 4.—Reserve distribution, short tons, Great Falls-Lewistown field.

	Bed thickness, inches		
	More than 36	24-36	14-24
Combo and others (1949)[a]	405×10^{6}	204×10^{6}	206×10^{6}
Silverman and Harris[b]	447×10^{6}	252×10^{6}	123×10^{6}

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[a] Measured and indicated coal only.
[b] All classes of coal.

Table 5.—Reserves of individual coal basins, Great Falls-Lewistown field (short tons).

Basin	Area (sq. mi.)	Bed thickness, inches More than 36	24-36	14-24
Stockett-Sand Coulee	74.2	163.0×10^6	47.8×10^6	28.0×10^6
Belt Creek	24.8	45.0×10^6	17.0×10^6	12.0×10^6
Otter Creek	9.0	…………	11.6×10^6	7.7×10^6
Sage Creek	34.0	42.5×10^6	36.8×10^6	16.5×10^6
Rock Creek	14.5	7.5×10^6	16.0×10^6	11.0×10^6
Lewistown	120.0	189.0×10^6	122.0×10^6	48.0×10^6
Total	276.5	447.0×10^6	252.2×10^6	123.2×10^6

MINING SYSTEM

Underground mining systems have been, and will be, the only economic means of extracting coal in the Great Falls-Lewistown field. Roof conditions, especially where the coal is directly overlain by the basal Kootenai sandstone, are stable and should sustain longwall or large room-and-pillar operations with a minimum of support. The cost of removing the basal Kootenai sandstone precludes the possibility of open-pit operations in the area. As the coal bed is flatly dipping a short distance from the mountain front, mine development could proceed from the surface by inclined adit. Against the southern mountain front, the relatively steep dip of the beds (15° to 25°), and seasonal increase in surface and ground water, could restrict mining and increase costs prohibitively. Depending on the coal market, selective mining in certain localities might be dictated by the ash and sulfur content, along with local thickness variations caused by channeling and by compaction under the basal Kootenai sandstone.

Whatever the mining system selected for coal extraction, the competition in the power industry demands that the operation be mechanized. Tyler (1964) estimated that the price of labor amounts to about 50 percent of the total cost in underground coal mines in the United States. Continuous cutting and mechanical loading machines, or the use of underground hydraulic or auger mining, would have to be employed if coal in this area is to be competitive in the power market.

ECONOMIC POTENTIAL

In past years, the major consumers of coal from the Great Falls-Lewistown field were the railroads, beehive coke ovens at Belt, and local space-heating markets. These outlets are generally no longer available, and a revitalization of coal production depends upon the development of new markets. One such market possibly available to cheap coal in central Montana is coal-fired steam-electric plants for the development of supplemental power for the rapidly growing population and expanding economy of the Great Falls area. The construction of such plants to provide power to populous areas in the western states has caused a 200-fold increase in coal production in the Rocky Mountains within the last ten years.

Low-cost coal of low to medium Btu content, together with an ample water supply, are the raw materials necessary for such a thermal generating plant. In the Great Falls area, the Missouri River could supply the needed water, and utilization of the coal reserves of the Stockett-Sand Coulee and Belt Creek basins would require only a short haul. Estimated tonnages in those two basins could easily sustain a medium-size (150,000 to 200,000 kilowatt) plant for the 25-year life normally anticipated for such investments.

The use of the coal in the Great Falls-Lewistown field for other industrial markets seems, at this time, to be restricted by competition from oil and gas in the nearby Sweetgrass arch, as well as oil, gas, and coal from southern Alberta and British Columbia. Markets outside of Montana for area coals would also be strongly competitive. North Dakota and Wyoming coal can move more readily in an easterly direction, and Utah and Wyoming coal has already reached far western markets.

In terms of a long-range outlook, to 1985 and beyond, the Great Falls-Lewistown coal could participate in the expanding energy market of the Pacific Northwest. At the present time freight charges account for 25 percent of the cost of retail coal in the area. The total cost includes wholesaler's f. o. b. mine cost and margin and retailer's margin. The cost for industrial and other large consumers in the Pacific Northwest varies greatly with kind and grade of coal, transportation charges, tonnages purchased, length of contract, and available outlets for coal slack sizes, which may be difficult to market. Low cost of production and better quality coal can offset high transportation charges, as shown by the current strong competitive position of Utah and Wyoming coal in the Pacific Northwest area. To some extent, however, market conditions rather than production costs have influenced the price of coal. Because of the very competitive energy market of recent years, some coal has been sold below cost in order to maintain production levels, profits on other sales offsetting the loss on a particular contract. Thus, the current price of coal on large contracts is not indicative of the price that would prevail should a large-scale demand for coal arise.

In Montana, the small demand for bituminous coal in recent years has inhibited the development of modernized mines yielding large tonnages. On the basis of data provided by Perry, Geer, and Gentile (1965) in the Bonneville Power Administration report on Pacific Northwest Power Markets, coal from Montana delivered at a price of 35 to 40 cents per million Btu would compete with Utah and Wyoming coal in the Pacific Northwest. (Inasmuch as the low rank [subbituminous] Washington coal cannot be shipped even a short distance without losing its price advantage over outside coal, it therefore can be used only for mine-mouth electric generating plants.) Such figures might be obtained in the Great Falls-Lewistown field if mine costs could be held below $4.00 per ton of coal and if the railroads continue to reduce freight rates with innovations in coal haulage systems. Such low mine costs, slightly below the present national average for underground bituminous coal mines, would require the development of relatively shallow, large mines that are highly mechanized and at least partly automated. Geologically, the Great Falls-Lewistown coal field seems amenable to such mine development. The Great Falls-Lewistown coal could be competitive in Pacific Northwest energy markets other than electric generation in the next decade or two.

The growth of future coal requirements for the Pacific Northwest, as calculated by Perry, Geer, and Gentile (1965) for the Bonneville Power Administration for other than electric generation, depends upon reduced coal cost, improved convenience and efficiency in combustion, and development of new coal-derived products. By the year 1985, coal fields peripheral to the Pacific Northwest could supply as much as 7 million tons of the regional requirement of 25 million tons per year for all uses. Long range forecasts to the year 2000, based upon a decreasing growth rate for electric generation and a regional population of about nine million people, show that peripheral coal fields might contribute as much as 15 million tons of a regional requirement of about 40 million tons per year. Provided that the Great Falls-Lewistown coal field can develop a dependable local market in electric generation, production could expand to supply a significant part of the coal demand of the Pacific Northwest area over the next few decades.

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APPENDIX—STRATIGRAPHIC SECTIONS

Stockett section 1. NW¼SE¼ sec. 36, T. 19 N., R. 4 E., directly east of and across road from Stockett.

UPPER PART OF SWIFT SANDSTONE (JURASSIC)

	Thickness feet	Thickness inches
Sandstone, medium to fine grained, indurated; calcareous cement; weathers brown.	5	7+
Covered.	5	0
Sandstone, massive, slightly glauconitic.	6	3
Shale, light gray, discontinuous.	0	2
Sandstone, fine to medium grained, massive, glauconitic.	3	0
Shale, light gray, grading into fine-grained sandstone; weathers yellow and brown.	3	1

Stockett section 2. Sec. 1, T. 18 N., R. 4 E., in road cuts ½ mile south of Stockett.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Shale, fissile, light to medium gray.	2	7
Mudstone, moderately indurated, gray, weathers light reddish brown to brown.	3	0
Limestone concretions, iron stained.	0	6
Shale, medium to dark gray, containing carbonaceous chips and ½-inch ironstone concretions.	3	6
Sandstone, light gray, indurated, containing ¼-inch pebbles of quartz and chert.	2	6

MORRISON FORMATION (JURASSIC)

	feet	inches
Coal seam.	0	4
Shale, carbonaceous, dark gray.	25	0
Covered.	30	0
Mudstone, light gray, containing disseminated red and brown concretions.	30	0
Mudstone, very light greenish gray, containing deeply weathered red and brown sandstone beds.	26	7
Sandstone, calcareous, fine grained, light gray.	0	1+

Stockett section 3. NW¼NE¼ sec. 1, T. 18 N., R. 4 E., at first mine east of road, ⅛ mile south of Stockett.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Sandstone, medium grained.	0	10+

MORRISON FORMATION (JURASSIC)

	feet	inches
Shale, light gray.	1	0
Coal.	0	2
Shale, light gray.	0	1
Coal.	0	10
Shale, dark gray.	0	7
Coal.	2	0
Shale, dark gray.	0	6
Coal.	1	0
Shale, dark gray.	0	6
Coal.	1	6

Belt Creek section 1. NW¼SE¼ sec. 26, T. 19 N., R. 6 E., in road cut ½ mile east of Belt.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Sandstone, medium grained, cross-bedded, massive, red to buff, base dirty medium- to coarse-grained sandstone containing many carbonaceous chips.	50	0

MORRISON FORMATION (JURASSIC)

	feet	inches
Coal.	0	1
Shale, carbonaceous, finely fractured, weathers light gray.	0	4
Shale, carbonaceous, fractured.	0	8
Shale, fissile, dark; contains leaf compressions.	2	0
Sandstone, medium grained, massive, stained red, contains carbonaceous veins.	2	0
Coal.	0	6
Shale, carbonaceous, conchoidally fractured.	2	0
Interbedded coal and dark-gray shale.	9	0
Shale, carbonaceous, conchoidally fractured.	0	8
Shale, fractured, light to dark gray; contains carbonaceous chips.	35	0
Sandstone to siltstone, poorly indurated, cross-bedded, stained red.	22	5
Mudstone, gray, weathers yellow orange.	2	6
Mudstone, dark greenish gray.	0	10
Mudstone, poorly bedded, blue to purplish gray, weathers brown.	1	8

Belt Creek section 2. NE¼ sec. 27, NW¼ sec. 26, T. 19 N., R. 6 E., along road that enters Belt from the west (from plateau to near bottom of coulee), just north of U. S. Highways 87 and 89.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Sandstone, fine grained, to siltstone interbedded with mudstone, calcareous, weathers purplish brown and fissile.	4	0
Mudstone, conchoidally fractured, light gray, weathers light green.	0	3
Mudstone.	0	1
Shale; contains carbonaceous chips.	0	8
Shale, light gray, weathers to light-green clay.	0	6
Shale, gray, weathers light brown.	2	0
Limestone, light brownish gray, weathers red and orange brown; contains calcareous clasts and carbonceous chips.	2	2
Mudstone, arenaceous, poorly indurated, light gray, weathers red.	3	0
Sandstone, medium to fine grained, massive, well indurated, partly cemented by calcite, gray, weathers dark red spotted; contains chert and muscovite; fluting and load casts on bottom.	5	5
Shale, fissile, gray.	0	3

	Thickness	
	feet	inches
Sandstone, medium to fine grained.	1	11
Mudstone, nodular and fissile, gray, weathers red.	4	3
Sandstone, weathers red.	3	7
Mudstone, gray, weathers red.	0	8
Sandstone, fine grained, weathers red; contains shale intraclasts and carbonaceous chips.	0	8
Shale and mudstone, gray, weathers red and yellow.	3	6
Sandstone, fine grained, massive, gray and white, weathers red; grades upward into siltstone.	7	11
Mudstone, arenaceous; contains fragments of rock and mafic minerals.	2	0
Sandstone, quartzose, fine grained to sugary, weathers red.	10	5
Interbedded sugary sandstone and mudstone.	13	4
Sandstone, medium to fine grained, massive, light gray to white, weathers red; 90 percent quartz, 10 percent chert.	4	8
Mudstone, shaly, gray, showing deformation structure around calcareous nodules of mudstone.	2	0
Mudstone indurated with calcite cement.	5	8
Siltstone, greenish gray; contains fragments of red mudstone.	2	6
Mudstone, red; contains large clasts of greenish-gray siltstone.	0	5
Siltstone, greenish gray, weathers orange brown, grades into fine-grained massive sandstone at base.	5	6
Limestone; contains limestone intraclasts.	1	0
Mudstone, shaly, red, weakly resistant.	2	2
Siltstone, indurated; contains chert grains and calcite cement.	3	7
Mudstone, red, nonresistant; contains yellow calcareous concretions.	3	4
Siltstone, massive, calcareous, brownish gray, stained red; grades downward into medium-grained sandstone.	10	6
Mudstone, calcareous, concretionary, tan.	0	10
Mudstone, dark red.	8	0
Limestone, light gray, weathers purple; contains calcareous intraclasts; interbedded with light-gray mudstone containing calcareous concretions.	30	4
Mudstone, conchoidally fractured, gray, weathers yellow orange and red.	10	0
Mudstone, arenaceous, light gray, weathers white.	3	0
Sandstone, clean, white, grading downward into gray, chert-bearing, coarse-grained sandstone; basal surface gently undulating.	16	0

Morrison Formation (Jurassic)

Coal.	0	6
Shale, dark brown, stained yellow.	3	6
Bentonite, white, nonresistant, interbedded with siliceous, light-gray porcelaneous shale.	3	2
Shale, dark gray.	1	2

Otter Creek section. East side sec. 29, T. 17 N., R. 9 E., along road that ascends side of coulee from Otter Creek onto plateau between Otter and Geyser Creeks, 7 miles south of U. S. Highway 89.

Kootenai Formation (Cretaceous)

Sandstone, coarse grained, salt and pepper; contains abundant chert.	20	0

Morrison Formation (Jurassic)

Coal.	0	6
Shale, dark gray.	0	6
Coal.	1	6
Shale, dark to light gray.	6	0
Coal.	0	6
Shale, medium gray, weathers light gray; contains brown concretions.	8	6
Mudstone, medium gray.	2	0
Shale, carbonaceous, fractured, dark gray, weathers red brown and gray.	5	8
Mudstone, weathers greenish gray; contains concretions.	28	4
Mudstone, weathers yellow; contains brown calcareous concretions in layers.	2	10
Covered.	45	4
Limestone, light gray.	1	6
Mudstone, bluish and greenish gray; contains calcareous concretions as much as 6 inches in diameter.	10	10
Limestone, concretionary.	1	0
Covered.	5	10
Mudstone, medium greenish gray; contains ferruginous and limestone concretions.	5	8

Swift Sandstone (Jurassic)

Sandstone, fine grained, calcareous cemented.

Running Wolf Creek section. NE¼ sec. 10, T. 15 N., R. 11 E., on east side of Running Wolf Creek, 1½ miles south of Dry Wolf Creek road and ½ mile north of missile site.

Kootenai Formation (Cretaceous)

Sandstone, poorly sorted, medium to coarse grained, salt and pepper, light gray, weathers brown and orange.

Morrison Formation (Jurassic)

Covered.	16	0
Sandstone, poorly sorted, generally fine grained.	4	8
Sandstone, fine grained, slightly fissile, light and dark gray.	2	0
Sandstone, fine grained; mafic minerals abundant.	0	1
Mudstone, carbonaceous, resistant, medium gray; contains worm borings.	1	9
Covered.	13	10
Sandstone, medium grained, brownish gray; contains fragments of rock and mafic minerals.	0	10
Covered.	9	8
Sandstone, calcareous, fissile and concretionary, red to orange brown; secondary iron minerals fill fractures.	0	6
Mudstone, medium gray, weathers light gray; secondary iron minerals fill fractures.	9	2
Sandstone, fine grained, to siltstone, massive to fissile.	7	2
Sandstone, calcareous, fine grained, light gray, weathers red brown to orange.	1	6
Shale, carbonaceous, dark gray.	10	2

	Thickness feet	Thickness inches
Limestone, concretionary, dark gray, weathers orange and red brown.	1	3
Mudstone, conchoidally fractured, weathers brownish.	5	5
Limestone, weathers dark red brown and orange.	0	6
Shale, soft, brownish gray; contains lenses of carbonaceous shale.	2	0
Shale, fractured, slightly fissile, weathers light gray.	0	6
Shale, carbonaceous, conchoidally fractured, dark gray.	2	0
Mudstone, calcareous, light gray, weathers yellow orange and red brown; contains ferruginous nodules.	0	6
Shale, soft, medium gray.	1	8
Limestone, concretionary; secondary iron minerals fill fractures.	0	3
Shale, carbonaceous, dark gray.	4	0
Limestone, fractured, medium to light gray.	2	0
Mudstone, fractured, light greenish gray; contains red and orange concretions.	4	10
Siltstone to fine-grained sandstone, flaggy, calcareous, concretionary, light gray, weathers red brown.	0	5
Mudstone, medium greenish gray, weathers light gray.	5	8
Sandstone, fine to medium grained, finely cross-bedded, massive, flaggy at top, light tan, weathers red brown.	15	8
Covered.	39	8
Limestone, brownish gray.	5	8
Covered.	17	0
Limestone, light gray.	1	0
Covered.	21	2
Mudstone, interbedded maroon and greenish gray.	0	6
Mudstone, soft, fractured, olive colored; contains nodules.	3	7

Skull Butte section. NW¼ sec. 12, T. 15 N., R. 11 E., on west side of Skull Butte, 1 mile east of Running Wolf Creek section.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Sandstone, cross-bedded, poorly sorted, flaggy, salt and pepper; small-amplitude channeling in underlying Morrison rocks.	12	0

MORRISON FORMATION (JURASSIC)

	feet	inches
Coal.	0	10
Shale, carbonaceous, poorly indurated, dark brown.	0	8
Shale, carbonaceous, dark gray.	1	3
Coal.	2	6

Forestgrove section. SE¼ sec. 5, T. 14 N., R. 21 E., ¼ mile north of Forestgrove along dirt road that ascends to top of plateau from South Fork of MacDonald Creek.

KOOTENAI FORMATION (CRETACEOUS)

	feet	inches
Sandstone, light gray, medium grained, 70 percent quartz, 30 percent chert.	20	0

MORRISON FORMATION (JURASSIC)

	feet	inches
Coal.	0	2
Shale, compact, light gray.	0	1
Coal.	3	1
Covered, probably black shale.	36	8
Shale, carbonaceous, hard, conchoidally fractured, dark gray.	12	4
Sandstone, calcareous, fine grained, weathers brown.	10	4
Shale, hard, conchoidally fractured, dark gray.	2	0
Shale, soft, dark gray; contains gypsum crystals.	2	6
Mudstone, soft, greenish and orange gray.	3	6
Limestone, silty, indurated, medium gray.	1	2
Shale, soft, dark gray; contains orange and greenish-gray lenses and gypsum crystals.	5	2
Covered.	18	10
Mudstone, weakly indurated, slightly greenish gray.	8	6
Mudstone, soft, varicolored; contains dinosaur bones.	5	8
Mudstone, weakly indurated, medium gray, weathers light gray.	5	0
Sandstone, fine grained, calcareous, yellow orange to red brown.	4	6
Mudstone, medium gray.	6	6
Mudstone, brownish gray.	4	0
Mudstone, soft, maroon and yellow orange; contains calcareous nodules as large as 1½ inches in diameter.	4	0
Mudstone, weakly indurated, red orange and gray.	3	0
Siltstone to fine-grained sandstone, soft, yellow brown.	6	8
Sandstone, fine grained, indurated with calcareous cement, weathers red.	5	7
Mudstone, soft, greenish gray.	8	8
Limestone, silty, stained maroon and greenish; contains calcareous nodules.	1	0
Mudstone, light greenish gray.	0	6
Limestone, silty, indurated, greenish gray.	0	8
Mudstone, conchoidally fractured, green, stained maroon; contains soft ferruginous nodules.	0	10
Covered.	9	10
Mudstone, weakly indurated, medium gray.	20	0
Limestone, hard, conchoidally fractured, medium gray, weathers light gray.	5	5
Mudstone, soft, maroon.	1	0
Limestone, weathers light gray.	0	10
Mudstone, fissile, greenish gray.	2	10
Mudstone, weakly indurated, olive green, weathers brown.	2	10
Mudstone, fractured, brownish gray, weathers light gray.	1	0
Shale, fractured, weathers violet.	0	1
Mudstone, soft, greenish gray; contains limestone lenses.	4	1
Limestone, silty, greenish gray.	0	6
Mudstone, light brown, weathers maroon.	4	2

SWIFT SANDSTONE (JURASSIC)

Sandstone, glauconitic, medium to fine grained, flaggy near top, weathers orange.