MINERAL RESOURCES OF THE CHARLES M. RUSSELL WILDLIFE REFUGE, FERGUS, GARFIELD, McCONE, PETROLEUM, PHILLIPS, AND VALLEY COUNTIES, MONTANA

By

U.S. Geological Survey

and

U.S. Bureau of Mines

Chapter A. By U.S. Geological Survey and U.S. Bureau of Mines

Chapter B. Geology and evaluation of the mineral resources of the Charles M. Russell Wildlife Refuge

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Chapter C. Petroleum evaluation of the Charles M. Russell Wildlife Refuge

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Chapter D. Economic appraisal of the Charles M. Russell Wildlife Refuge

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

STUDIES RELATED TO WILDERNESS

In accordance with the Provisions of the Wildernesss Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated "wilderness," "wild," or "canoe" when the Act was passed were incorporated into the National Wilderness Preservation System, and some of them are currently being studied. The Act provided that areas under consideration for Wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of the Charles M. Russell Wildlife Refuge, Montana.

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CHAPTER A

SUMMARY

By

U.S. Geological Survey and U.S. Bureau of Mines

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SUMMARY

A mineral survey of the Charles M. Russell Wildlife Refuge, Montana, was initiated in 1975 and completed in 1978. The total refuge comprises 980,000 acres (396,000 ha) along the Missouri River and Fort Peck Lake in Fergus, Phllips, Valley, McCone, Petroleum, and Garfield Counties; fifteen subareas totaling 161,480 (65,350 ha) are under consideration for wilderness inclusion. The results of the investigation indicate that parts of the area have a moderate potential for oil and gas, and a low to moderate potential for lightweight aggregate, bentonite, and coal. Areas with potential are shown on figure 1. The potential for other mineral commodities is very low to nil.

The Upper Cretaceous Judith River Formation is the oldest bedrock in the refuge. It is overlain by 1,600 ft (488 m) of sandstone, siltstone, and shale belonging to, from oldest to youngest, the Cretaceous Bearpaw Shale, the Fox Hills Sandstone, the Hell Creek Formation, and the Tertiary Fort Union Formation. These rocks are locally overlain by unconsolidated glacial and glacial-related deposits of Pleistocene age and Holocene alluvial deposits. The dip of beds in the refuge is rarely greater than 3 degrees and the directions of dip reflect four major structural features: Bowdoin Dome north of the Refuge; the Bearpaw and Little Rocky Mountains to the northwest; the Blood Creek syncline to the south; and the Williston Basin to the east.

The refuge has a moderate potential for hydrocarbon accumulations. Liquid hydrocarbons (oil) have been generated in Mississippian and older Paleozoic rocks and may have accumulated in predominantly stratigraphic traps locally enhanced by structure. The potential is good for biogenic gas accumulations in Upper Cretaceous deposits at depths less than 2,000 ft (610 m). Potential accumulations of oil and gas are difficult to delineate because of the absence of subsurface stratigraphic and structural controls within the refuge.

Resources of bentonite are estimated at about 3.2 billion tons (3 billion t), and the potential ranges from low to moderate. The highest quality bentonite beds are in the Cretaceous Bearpaw Shale; impure montmorillonitic beds are present in the Cretaceous Fox Hills Sandstone and Hell Creek Formation and the Tertiary Fort Union Formation.

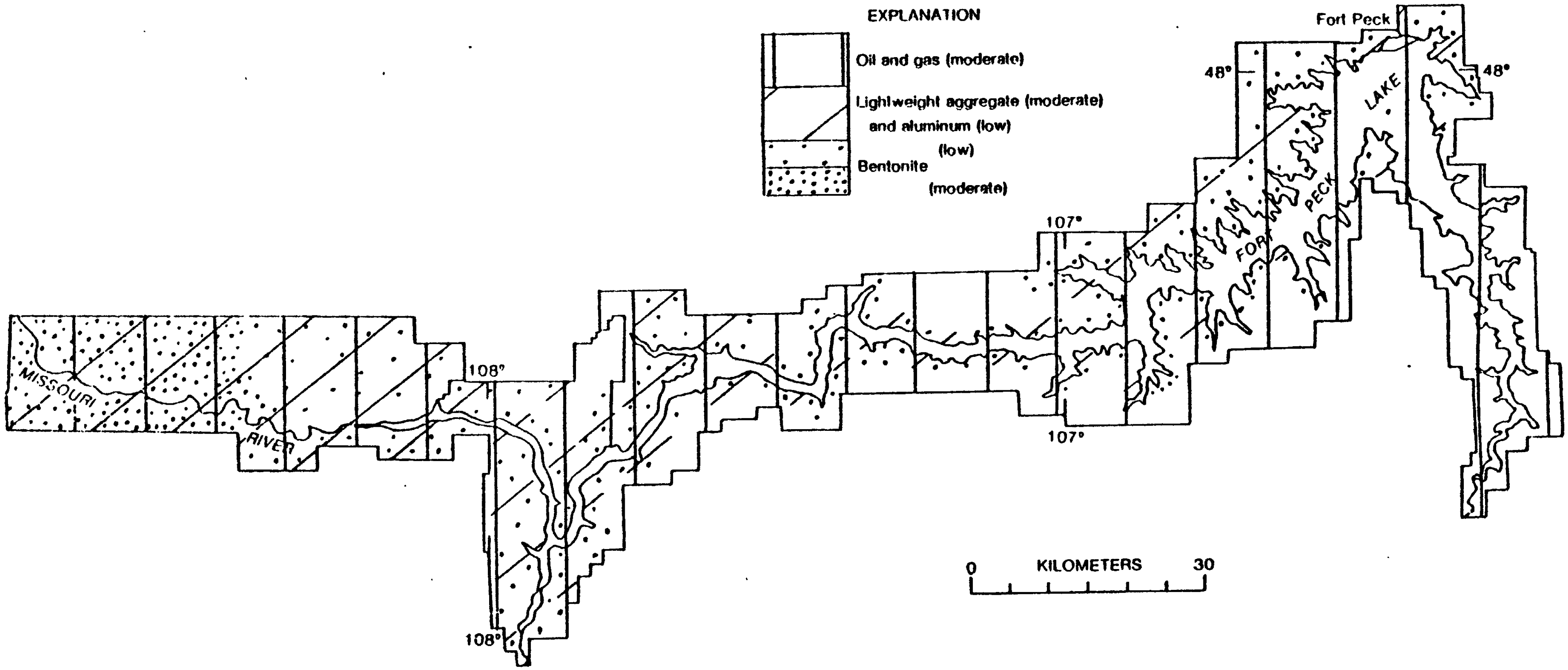


Figure 1a.--Map showing areas of oil and gas, lightweight aggregate, and bentonite resource potential in the Charles M. Russell Wildlife Refuge.

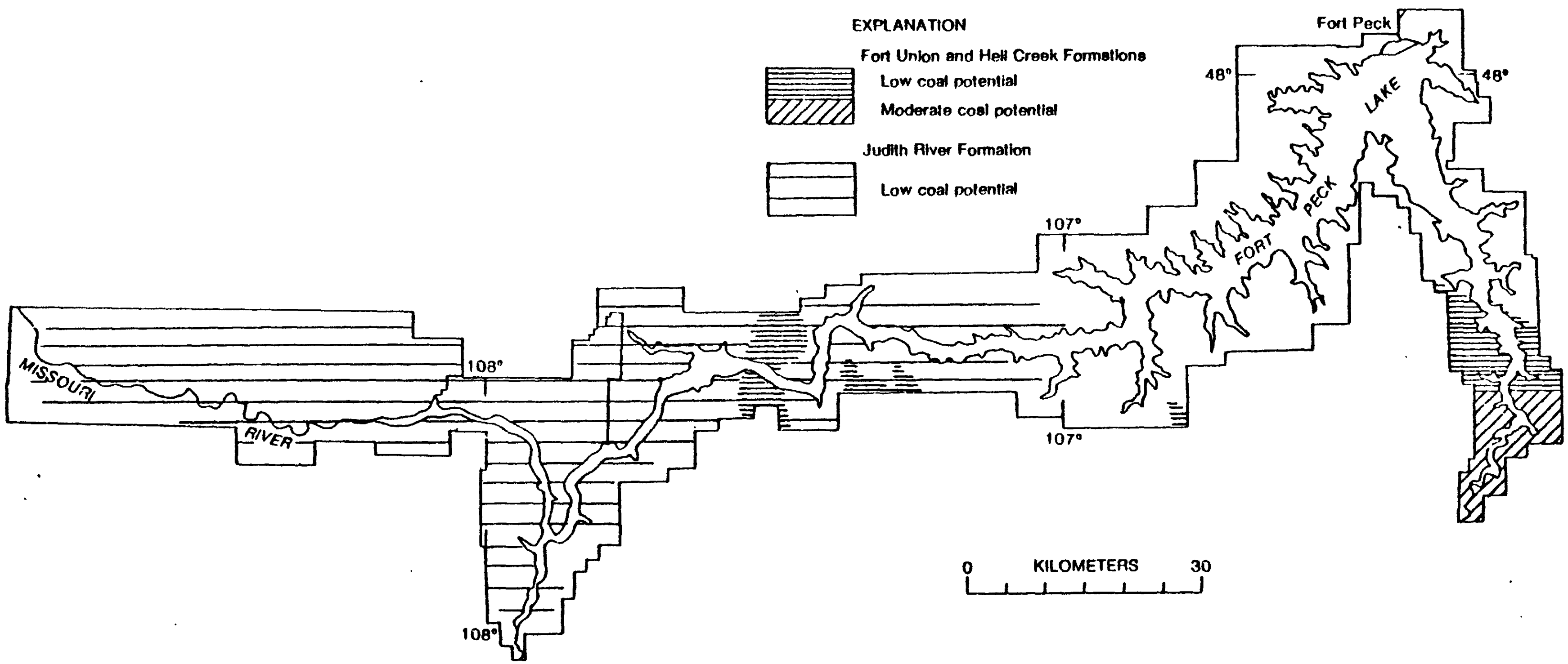


Figure 1b.--Map showing areas of coal resource potential in the Charles M. Russell Wildlife Refuge.

The refuge is estimated to contain more than 290 million short tons (260 million t) of coal. The Judith River Formation, which crops out at the west end of the refuge, may contain about 190 million short tons (170 million t) of coal. The beds average less than 2.5 ft (0.76 m) in thickness and contain about 40 percent ash. The Hell Creek and Fort Union Formations are estimated to contain 100 million short tons (90 million t) of coal in beds which range in thickness from 1 to 5 ft (0.3 to 1.5 m).

Most tested samples of the Bearpaw Shale have a moderate potential for use as lightweight aggregate. The area contains significant quantities of sand and gravel, but this commodity occurs in abundance in more accessible areas.

CHAPTER B

GEOLOGY AND EVALUATION OF THE MINERAL RESOURCES OF THE CHARLES M. RUSSELL WILDLIFE REFUGE

By

Claudia W. Frahme
U.S. Geological Survey

Introduction

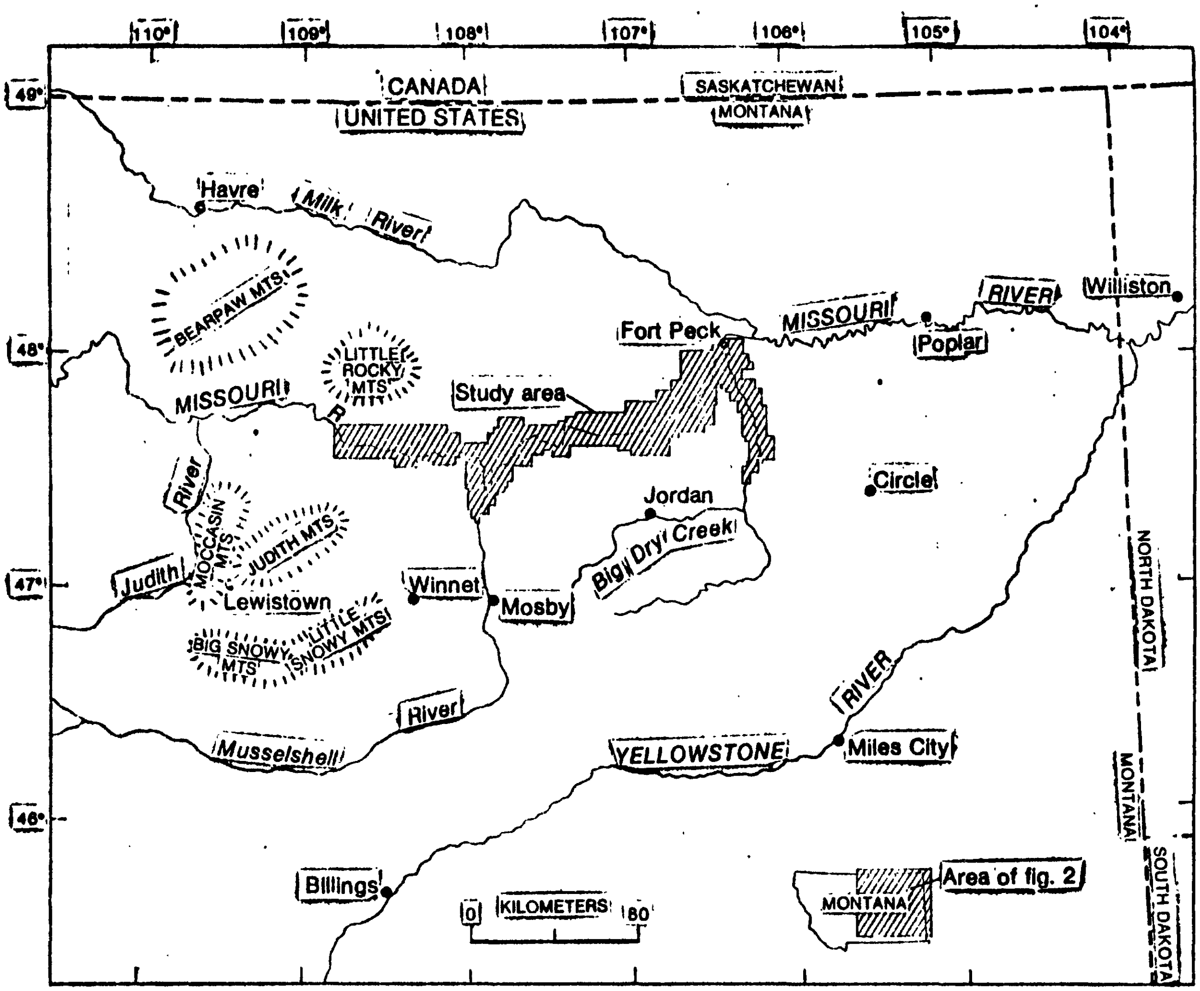
A mineral survey of the Charles M. Russell Wildlife Refuge (fig. 2) was conducted in 1975 by the U.S. Geological Survey and the U.S. Bureau of Mines as part of a study to determine the suitability of parts of the area for inclusion in the National Wilderness Preservation system. At the time of the investigations, the refuge was jointly administered by the U.S. Fish and Wildlife Service and the U.S. Bureau of Land Management.

The refuge comprises 396,600 ha along the Missouri River and Fort Peck Lake in Fergus, Phillips, Petroleum, Garfield, Valley, and McCone Counties, Montana, Fort Peck Dam, begun in 1933, impounds the waters of the Missouri River to form Fort Peck Lake. (The eastern arm of the lake, the "Big Dry Arm," occupies the former channel of Big Dry Creek.) At present, 15 subareas within the Refuge (fig. 3), totaling 65,350 ha are under consideration for wilderness inclusion. Data were gathered from the entire refuge with special emphasis on the 15 proposed areas. In the interest of completeness and continuity, geologic sampling and mapping were also done in the adjacent 18,730 ha U-L Bend National Wildlife Refuge located north of the mouth of the Musselshell River.

The topography of the refuge is varied. The western part, locally called the "Missouri Breaks," consists of deeply eroded coulees and steeply rounded hills. The central part is composed of broad flat benches which have been carved into sheer, inaccessible bluffs along the Missouri River channel. The eastern part of the refuge consists primarily of steep-sided hills and badlands topography. Hummocky terrain resulting from mudflows and slumping of soft bedrock is common throughout the refuge. Much of the U-L Bend National Wildlife Refuge has extremely low relief due to the presence of infilled channels and floodplains of Pleistocene alluvium. Away from the deeply incised Missouri River channel, the topography gradually changes to broadrolling, glaciated plains. Fort Peck Lake covers 100,810 ha or about one fourth of the refuge and has a maximum depth of 67 m. The maximum pool elevation of the lake is 695.1 m. The highest point in the Refuge is 1,006 m at our Dogtown benchmark in sec. 1, T. 21 N., R. 32 E. The field data contained in this report were gathered from June through September, 1975, during which period the reservoir was at or near maximum pool elevation.

Access via two-lane paved highways is limited to U.S. 191 which crosses the Missouri River at Robinson Bridge in the western part of the Refuge and State Highway 24 which crosses Fort Peck Dam. Unsurfaced and unimproved gravel roads from Circle, Jordan, Fort Peck, and Malta, Montana, provide good access to many parts of the refuge when dry. Jeep roads and trails are impassable during wet weather and are commonly washed out following periods of heavy rain or runoff. Areas immediately adjacent to the river and lake are best reached by boat. Recreation and

Figure 2.--Index map showing location of Charles M. Russell Wildlife Refuge, Fergus, Phillips, Valley, McCone, Petroleum, and Garfield Counties, Montana.



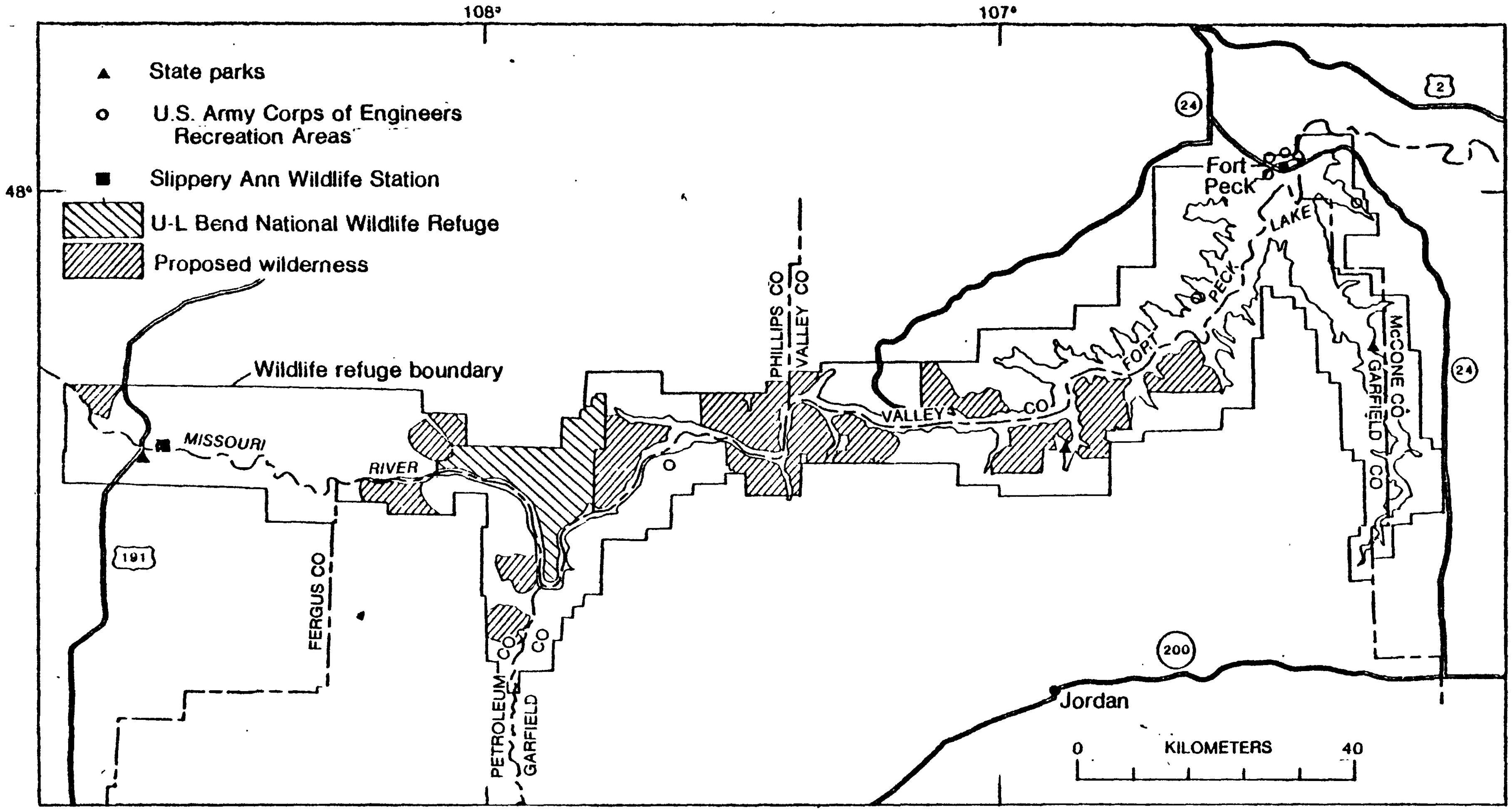


Figure 3.--Index map of 15 proposed wilderness areas in the Charles M. Russell Wildlife Refuge, Montana.

camping facilities are available at James Kipp, Hell Creek, and Rock Creek State Parks; at the Slippery Ann Wildlife Station of the U.S. Fish and Wildlife Service; and at seven areas maintained by the U.S. Army Corps of Engineers (fig. 3).

The Lewistown, Jordan, and Glasgow 2° topographic maps cover the Wildlife Refuge at a scale of 1:250,000. It is also covered by 54 U.S. Geological Survey topographic maps at the scale of 1:24,000 and two maps at 1:62,500. Map coverage at these scales is not yet available for T. 21 N., R. 23 E. In addition the area is covered by U.S. Bureau of Land Management Recreation Access Guide planimetric maps at various scales from 1:125,000 to 1:200,000. These maps are available at the District Offices in Lewistown, Malta, and Miles City. The base map for plate 1 was compiled on an enlargement of the 2° maps to a scale of 1:125,000.

The climate of the refuge is semiarid. The average annual precipitation is probably between 25 and 35 cm. Malta has an average annual precipitation of 32.5, Fort Peck 28.4, and Lewistown 45.2 cm. Most of the precipitation is in the form of thundershowers from May through August. The average annual snowfall at Malta is 71 cm accumulated primarily from December through March. The refuge has warm summers with a few days of temperature greater than 35°C. during July and August. January is the coldest month with an average temperature in the range of -12° to -9°C. Winds average 16 to 19 km per hour with gusts over 80 km per hour. Small craft warnings are common on Fort Peck Lake.

About one third of the refuge supports stands of ponderosa pine, juniper, and Douglas fir. Cottonwoods and willows grow on the Missouri River floodplain, along some of the major drainages, and adjacent to springs and seeps. Plant cover is sparse over much of the refuge and consists primarily of sagebrush and grasses. These plants are most abundant in the till of treeless glaciated plains and in the alluvium of broad stream valleys. The topography and the character of the rocks in the Range are not conducive to well-developed soil profiles.

Previous investigations

The first record of the geology along this part of the Missouri River was made by Meriwether Lewis and William Clark when they travelled through the area in 1805. Meek (1876) reported on Cretaceous and Tertiary invertebrates in the upper Missouri country. Barnum Brown (1907) described the fauna and flora of the Hell Creek Formation. Thom and Dobbin (1924) and Tschudy (1970) described the stratigraphy and palynology of the Cretaceous/Tertiary boundary in the refuge. Collier and Knechtel (1939) investigated the coal resources of McCone County. U.S. Army Corps of Engineers (1963) prepared a report on the development of land and water resources along the Missouri River, which included the westernmost part of the refuge. Jensen and Varnes (1964) described the geology of the Fort Peck area and Bell (1965) studied the stratigraphy of northwestern McCone County. Colton, Lemke, and Lindvall (1961) prepared a glacial map of eastern Montana.

Present investigations

The present investigations by the U.S. Geological Survey were conducted by Claudia W. Frahme and Dudley D. Rice. During the summer of 1975, Frahme spent about 11 weeks in the field collecting geological and geochemical data. The field work was assisted by Margaret E. Riggs, Jennifer L. Forman, and Thomas D. Bowden. Michael M. Baker provided logistical support. Rice compiled and interpreted the data on the potential for hydrocarbons; these investigations are discussed in Chapter C of this report. In addition the investigation of claims and the measurement of coal and bentonite reserves were made by the U.S. Bureau of Mines whose activities and results are presented in Chapter D.

A major part of the survey was devoted to geologic mapping since only the Fort Peck and McCone County areas were previously mapped in detail. The mapping was conducted by foot traverses. Access into the area was by four-wheel drive vehicle, boat, and helicopter. Three hundred eighty rock and fossil samples were collected during the course of mapping and a special effort was made to obtain samples representative of the entire stratigraphic section. Seventy-five samples of stream sediment were taken and panned concentrates were obtained at 21 of the sample sites. A total of 442 samples were analyzed in a mobile field laboratory and at the Denver, Colorado, laboratories of the U.S. Geological Survey under the direction of R. T. Hopkins, Jr.

Acknowledgments

We wish to express our appreciation to members of the U.S. Fish and Wildlife Service and the Bureau of Land Management for providing housing facilities, boats, radios, a helicopter, and backup support for the field crews. We particularly wish to thank Larry Calvert, John Foster, Ron Shupe, and Rollei Kreiger of the U.S. Fish and Wildlife Service; Ed Zaidlicz, Joe Gibson, and Fred Payton of the U.S. Bureau of Land Management; and Don Beckman of the U.S. Army Corps of Engineers.

We wish to express our appreciation to Dr. Richard B. Berg of the Montana Bureau of Mines and Geology who supervised the testing of shales for use as lightweight aggregate; to Maynard Duckworth of the Bureau of Land Management who supervised the physical testing of bentonite samples; and to William A. Cobban, Norman F. Sohn, John H. Hanley, and Robert H. Tschudy, of the U.S. Geological Survey who identified fossils collected during the study. Edwin R. Landis, Richard W. Lemke, and Roger B. Colton of the U.S. Geological Survey provided valuable insight into several aspects of the report.

Geology

Geologic setting

The Charles N. Russell Wildlife Refuge is part of the northern Great Plains and is bordered on the west and southwest by the Bearpaw, Little Rocky, Moccasin, Judith, and Little Snowy Mountains (fig. 2). The refuge contains a succession of nearly flat-lying marine, brackish, and fresh-water rocks ranging from Late Cretaceous to early Tertiary in age. For about 50 million years northeastern Montana was subjected to repeated transgressions and regressions of the waters of the Cretaceous seaways. These fluctuations resulted from a combination of uplift, batholith emplacement, and volcanic activity in western Montana, and basin subsidence in eastern Montana and the Dakotas. The sediments deposited in the refuge consist of thick units of dark gray marine shale alternating with relatively thin wedges of near-shore marine sandstone and nonmarine mudstone and sandstone in a coastal plain environment.

The area became a heavily vegetated plain replete with swamps and sluggish meandering streams after the final retreat of the sea. This environment with minor modifications persisted into early Tertiary time. During most of Tertiary time, the area was intermittently gently uplifted and extensively eroded. The former extent or existence of Tertiary rocks younger than the Fort Union Formation in the Refuge is not known. During the Pleistocene, almost all of the refuge was glaciated and the course of the Missouri River was shifted southward from the Milk River Valley to its present position.

About 518 m of sandstone, siltstone, and shale are exposed in the refuge. These rocks comprise five formations, which are, from oldest to youngest, the Judith River, Bearpaw, Fox Hills, Hell Creek, and Fort Union. They are shown in a generalized stratigraphic section in figure 4 and on the geologic map in plate 1. These rocks are locally overlain by unconsolidated Pleistocene glacial and glacial-related deposits and Holocene alluvium.

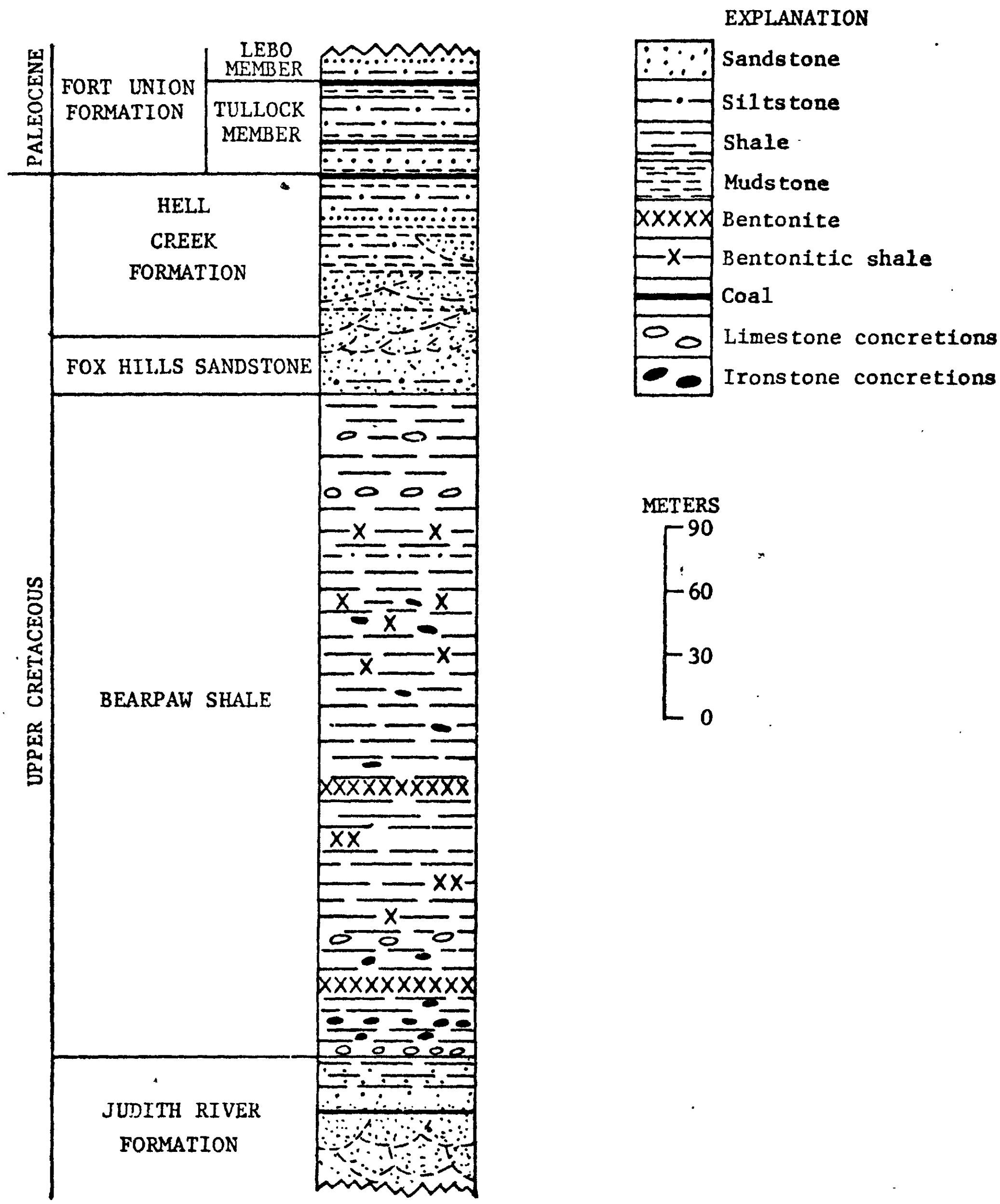
Cretaceous rocks

Upper Cretaceous rocks exposed in the area are part of the Montana group and comprise the Judith River Formation, Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation.

Judith River Formation

The Judith River Formation is light gray and tan sandstone and brown and gray shale which thins to the south and east from about 150 m near the mouth of the Judith River to about 5 m at Glendive (Bowen, 1915, 1920). Only the upper 60 m of the formation is exposed in the high bluffs along the Missouri River in the westernmost part of the

Figure 4.--Generalized stratigraphic section of Upper Cretaceous and Paleocene rocks exposed in the Charles M. Russell Wildlife Refuge.



refuge. An exposure in NE1/4 SE1/4 sec. 24, T. 21 N., R. 23 E. consists primarily of 38 m of poorly cemented light gray fine- to medium-grained quartz sandstone that weathers light yellowish brown. The sandstone is and ironstone concretions. It may belong to the middle sandstone member of the Judith River Formation as described by Johnson and Smith (1964, p. 47).

A widespread low-grade coal and carbonaceous shale (0.3-2.1 m) is near the top of the sandstone. Bowen (1914) described a similar coal bed near the top of the Judith River Formation south of the refuge between the Judith and Musselshell Rivers, that is overlain by marl or breccia containing oyster shells. Oysters were not found near the coal bed in the refuge and therefore the correlation of the two beds is uncertain. A dark brown, gray, and black sandy shale with orange limestone concretions is at the top of the Judith River Formation; it grades up into the Bearpaw Shale.

Bearpaw Shale

The Bearpaw Shale is widely exposed in the refuge except in the area bordering the southern part of the Big Dry Arm. It is mostly a dark gray argillaceous shale with calcareous and ferruginous concretions and many thin beds of bentonite. Many of the weathered surfaces have a thick popcorn-like rind and contain large selenite crystals.

The bentonite beds, common throughout the region, range in thickness from 5 mm to 2 m--the thickest beds are in the lower half of the formation. Their light green, brown, and cream colors contrast markedly with the dark- gray shales. Most bentonite beds are lenticular, even though some can be traced for many miles.

The presence of bentonite can be observed from a distance on steep-sided hills, in cutbanks, and in landslide scars, by a white alkali crust on the underlying shale. Water migrating along minute fractures in the shale is deflected along the surfaces of the impervious bentonite beds and the dissolved salts are deposited by evaporation at the outcrop. The relative impermeability of bentonite and bentonitic shales is a major cause of the slumps and mudflows so characteristic of the Bearpaw Shale.

Fossiliferous ironstone, limestone, and septarian concretions ranging from a few centimeters to several meters in diameter are common in the Bearpaw. Some ironstone concretions are distinctly oval in shape, contain bits of nacreous shell material, and formed in and around the shells of flat-coiled ammonites.

An estimate on the thickness of the Bearpaw Shale was not obtained in the Refuge because of the lack of sufficient exposure and marker beds. Jensen and Varnes (1964) estimate the thickness to be 347 m in the vicinity of Fort Peck and found it to range in thickness from 275.5

to 320.7 m in oil and gas wells and east of Fort Peck. Johnson and Smith (1964) judged the formation to be about 355 m thick 21 km east of Mosby.

Jensen and Varnes (1964, pl. 2) divided the Bearpaw Shale into six units on the basis of lithology and the nature and distribution of concretions and bentonite beds. Their units can only be roughly identified in the western part of the refuge. Unit #1 of Jensen and Varnes includes 50 m of bentonitic shale with dark ironstone concretions, overlain by a 43 cm-thick-bed of pale-green bentonite. It corresponds with a 38.1-m-thick zone of similar lithology exposed 1.5 km east of Duval Creek in NE1/4 sec. 35, T. 22 N., R. 24 E. The bentonite bed at the top is 25 to 180 cm thick and can be traced in outcrop for several miles. Unit #3 contains abundant oyster shells and is exposed in the area west of Sevenmile Creek. The ironstone concretions of Unit #5 are exposed northwest of Herman Point in secs. 12 and 13, T. 22 N., R. 31 E. The upper unit, unit #6, crops out throughout the eastern two-thirds of the Refuge. Its sandy shale beds are most evident in the U-L Bend area. Fossiliferous limestone concretions are common. Barite fills cracks and cavities in a few of the concretions.

Fox Hills Sandstone

The Fox Hills Sandstone consists of fine- to medium-grained sandstone with some shale and sandy mudstone in the lower part. It is about 36.6 m thick in the Fort Peck area (Jensen and Varnes, 1964), but is mostly between 18 and 25 m thick elsewhere in the refuge. A minimum thickness of 12.2 m is in Wagon Coulee in sec. 2, T. 22 N., R. 35 E. The formation was mapped west of the Musselshell River as part of the Lance Formation by Reeves (1927, fig. 9). The lower contact of the Fox Hills was placed at the base of light gray shale and mudstone that lie above typical dark-gray Bearpaw Shale.

The formation is divided into three parts: a lower unit of light gray-weathering shale and sandy mudstone; a middle unit of poorly cemented yellowish-brown sandstone; and an upper unit of white sandstone known as the Colgate Member. The lower unit weathers to gentle slopes whereas the upper two units form steep-sided rimrock and cliffs. The lower unit is commonly 3 to 6 m thick and comprises most of the Fox Hills section in areas where the formation is thin. East of Billy Creek the upper part of the formation consists entirely of the middle unit, and it is composed of bright-yellowish-brown, massive and thinly bedded, poorly consolidated, fine-grained sandstone. Small-scale crossbedding, round dark-brown limonite concretions 1 to 8 cm in diameter, and larger dark brown lens-shaped sandstone bodies cemented by calcium carbonate are common features.

The Colgate Member (fig. 5) caps the middle unit between Lost Creek and Billy Creek (T. 21-22 N., R. 31-34 E.) on the south side of the Missouri River and from the east end of Iron Stake Ridge (T. 22 N., R. 33 E.) almost to the mouth of Timber Creek (T. 23 N., R. 34 E.) on the

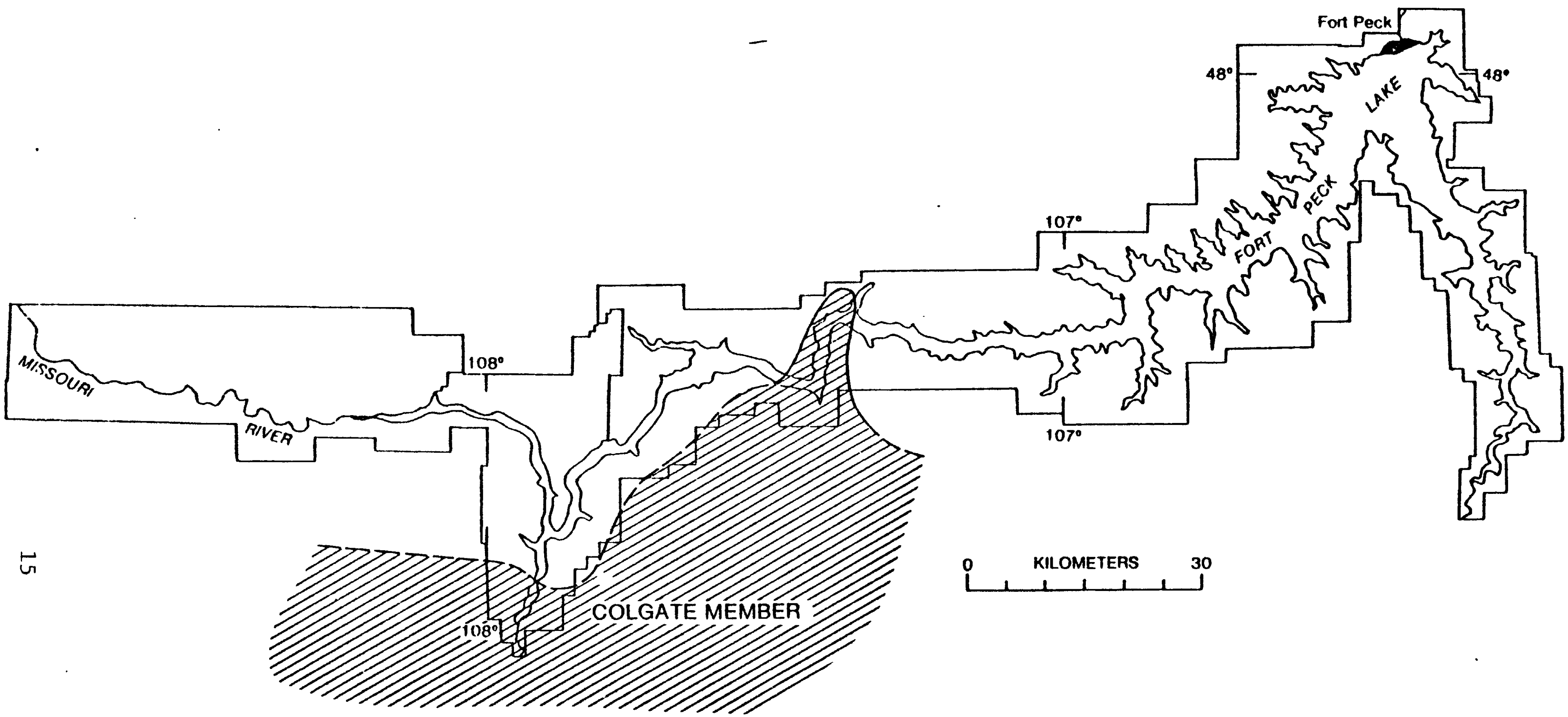


Figure 5.--Areal distribution of Colgate Member, Fox Hills Sandstone in and near Charles M. Russell Wildlife Refuge.

north side of the river. Outside the refuge, this unit crops out west of the Musselshell River in the drainages of Drag and Dovetail Creeks. Calvert (1912) originally assigned the Colgate to the Lance Formation, but this was later changed to its present usage by Thom and Dobbin (1924). The member is 60 cm thick in its northernmost exposure and up to 15.2 m thick between Devils Creek and Seven Blackfoot Creek.

The Colgate Member is composed of light-gray, fine- to medium-grained micaceous sandstone that weathers brilliant white. The sandstone is poorly sorted with subangular to angular grains of quartz and feldspar in a matrix of kaolinite. Near Seven Blackfoot Creek, the member contains large-scale crossbeds up to 3 m long and 2.4 m thick. At other localities, it appears to be massive or contains small-scale crossbeds and ripple marks. There is abundant evidence (Jensen and Varnes, 1964; Collier and Knechtel, 1939; Dobbin and Reeside, 1929; Thom and Dobbin, 1924) that the white Colgate sandstone changes facies to the north and east to a sandstone that is more appropriately assigned to the Hell Creek Formation. In the refuge, this change is best illustrated north of Seven Blackfoot Creek where the white Colgate sandstone thins rapidly to the north until a sandstone in its stratigraphic position assigned to the Hell Creek is occupied by a cliff-forming medium-grained brown sandstone with large-scale crossbeds identical in form to those seen in the Colgate Member 13 km to the south.

Brown (1907), Bowen (1915), and Dobbin and Reeside (1929) have reported finding marine invertebrates in the Fox Hills Sandstone in and near the refuge. However, during the present study only carbonized plant fragments were found.

There has been much controversy over the existence of an unconformity at the contact of the Fox Hills Sandstone and the Hell Creek Formation. Brown (1914), Bauer (1924), Badgley (1953), Dobbin and Reeside (1929) and Bell (1965) found conglomerates and eroded surfaces at the contact, but considered them to be of no importance on a regional scale. Bauer (1925) described a 7-12 cm thick conglomerate at the Fox Hills-Hell Creek boundary approximately 24 km south of Jordan which Brown (1962) later found to be traceable for hundreds of square miles along the Missouri River near Fort Peck and south to Forsyth.

Despite the fact that the bedding in both formations is essentially parallel, Jensen and Varnes (1964, p. F22) found two types of evidence to indicate an erosional unconformity between the Fox Hills Sandstone and the Hell Creek Formation: "1. The sharp and channeled contact between the two formations and the substantial local difference in thickness of the Fox Hills; 2. The abrupt and substantial differences across the contact in sedimentary and ecological characteristics. Other data that indicate an unconformity are the irregular distribution pattern of the Colgate Member and its abrupt lateral facies change with the Hell Creek Formation; and the presence of kaolinite in the matrix of the Colgate Member, which if formed nearby, or in place, indicates an extensive period of leaching in a continental environment."

Hell Creek Formation

The Hell Creek Formation is the youngest formation of the Montana Group and is latest Cretaceous in age. It was named and described by Brown (1907) for typical exposures along Hell Creek (T. 21 N., R. 37 E.) a few miles south of the refuge. Brown reported the thickness of the formation in its type area as 97.2 m. In the vicinity of Seven Blackfoot Creek, the formation is 61-73 m thick. Bell (1965) reported a thickness of 85.3 along Sando Arroyo in T. 24 N., R. 43 E.

The varicolored Hell Creek beds are commonly termed the "somber beds" due to the predominance of muted shades of gray, brown, violet, and green. The lower part of the formation is a well cemented, medium-grained sandstone that forms resistant ledges and lenses. Large-scale crossbedding in it and other sandstone beds in the formation has been ascribed in part to wind action (Collier, 1918). Locally at the top of the resistant sandstone bed, there are long sinuous channel-fill deposits; many contain layers of poorly sorted conglomerate. Near Billy Creek in NW1/4 sec. 16, T. 22 N., R. 34 E., the conglomerate is as much as 3 m thick and contains fragments of well rounded siltstone and shale and subangular cobbles of quartz sandstone. The presence of well developed channels with associated mud cracks in this unit of the Hell Creek Formation both near Billy Creek and east of Timber Creek together with the absence of the Colgate Member of the Fox Hills Sandstone in this area provide further evidence for a significant disconformity between the two formations.

The upper part of the formation contains lenticular deposits of moderately bentonitic claystone, shale and siltstone with minor sandstone and lignite and a few thin light green and dark brown bentonite beds. The formation weathers to sparsely vegetated round-topped hills and ridges and typical badland topography.

Large ellipsoidal and cylindrical lenses of sandstone cemented by calcite are one of the most prominent features of the Hell Creek. They commonly occur in thick crossbedded sandstone beds. Round gray concretions up to 12 cm in diameter are in sandstones in the middle and upper parts of the formation at several localities. They consist of medium-grained quartz cemented by pyrite and constitute less than 1 percent of the sandstone facies. Ironstone concretions are also in the formation.

East of Hell Creek, especially along the southern margins of the Big Dry Arm, thin discontinuous beds of coal and carbonaceous shale enhance the somber appearance of the upper beds of the Hell Creek. Elsewhere in the refuge they are absent or comprise only a very minor part of the stratigraphic section. The lower contact of the Hell Creek Formation was placed at the top of the Colgate Member, where present, or at the base of thick, brown, medium-grained crossbedded sandstone underlying the varicolored "somber" beds.

Tertiary rocks

Fort Union Formation

Only the lower part of the Fort Union Formation is present in the refuge, and it is represented by the Tullock Member and the lower part of the Lebo Member as defined by Brown (1952); they are not differentiated on plate 1. The contact at the base of the Fort Union as defined by Brown (1962) is drawn at the lowest persistent bed of lignite above the highest known occurrence of dinosaur bones at or within 15 m of a marked color change from the dark colored Hell Creek rocks below to the yellowish rocks of the Fort Union above.

The Tullock Member conformably overlies the Hell Creek Formation and is conformably overlain by the Lebo Member. It consists of 45 to 53 m of light-yellow, gray, and brown sandstone, siltstone, and shale interbedded with relatively thick continuous coal beds. Fossil wood, tree stumps, leaves, and plant fragments are abundant. Beds of medium- to coarse-grained sandstone accumulated as channel-fill and floodplain deposits. Mineralogically, they are almost identical to the Hell Creek sandstones, consisting of quartz, plagioclase, dolomite, and mica cemented by calcite and kaolinite. Ironstone concretions are in some of the sandstone units. The siltstones and shales are only slightly bentonitic and beds of bentonite are rare. Prominent in the section are bright-reddish-orange clinker beds which resulted from baking and fusing of beds of siltstone and shale when adjacent coal beds burned.

Collier and Knechtel (1939) described six important lignite and sub-bituminous coal beds in the Tullock Member which they labeled U through Z. Each of them varies considerably in thickness. The Z bed, 30-90 cm thick, is the lowest in the member, and can be traced throughout McCone County and as far west as Devils Creek. Collier and Knechtel (1939, p. 18) noted that it "is probably not a single continuous bed but rather a succession of lenses of coal in about the same stratigraphic position." In the vicinity of Nelson Creek (T. 21 N., R. 42 and 43 E), several coal beds occur locally in the upper part of the Hell Creek Formation below the "Z" coal bed. The "U" coal bed is the uppermost unit of the Tullock Member and it attains a maximum thickness of 6.1 m (Collier and Knechtel, 1939).

The lower 23 m of the Lebo Member is poorly exposed on the top of ridges and benches between Flat and McGuire Creeks in T. 20-21 N., R. 42-43 E. It consists primarily of brown, argillaceous, crossbedded, channel sandstone with minor lenses of coal, light-gray sandstone, and dark gray siltstone.

Quaternary deposits

Quaternary deposits in the refuge consist of unconsolidated ground moraine, glaciofluviatile and glaciolacustrine sediments related to the Wisconsin Glaciation (Colton and others, 1961), and pre-glacial and post-glacial fluviatile deposits. Only the Pleistocene Kintyre(?) Formation and Holocene and Pleistocene(?) fluviatile deposits are shown on plate 1. These units in the Fort Peck area are described by Jensen and Varnes (1964, p. 26-42). Yellow-brown glacial till and isolated erratics cap the high benches throughout the Refuge except for the upper drainage of Big Dry Creek where glaciolacustrine sediments accumulated adjacent to the ice sheet (Colton and others, 1961). In the U-L Bend National Wildlife Refuge, two thick Pleistocene(?) channel-fill deposits mark the former drainage pattern of the Musselshell River to the north along the present course of Telegraph and Beaver Creeks and of another younger stream (the Missouri River(?)) which occupied the present valley of Hawley Creek and then turned northward along the Musselshell drainage. The well-preserved meander pattern of this stream is shown in plate 1. The outcrop of these fluviatile deposits consists of silt, clay, and fine grained sand, but coarser material (pebble through boulder in size) are in the lower part of the Musselshell channel where it has been dissected by Jim Wells Creek (sec. 10, T. 20 N., R. 30 E.).

Kintyre(?) Formation

The Kintyre Formation was named by Jensen and Varnes (1964) for exposures of fluviolacustrine sediments near Kintyre siding about 8 km west of Frazer. The sediments were largely deposited on stagnant ice in the old Missouri River trench. Most Kintyre outcrops exhibit irregular hummocky topography of low, rounded knobs and closed depressions, but nearly vertical cliffs form in areas of rapid erosion. They describe the formation as consisting of varying proportions of light tan silt, very fine sand, and dark brown clay and silty clay. Bedding in the formation ranges from massive to delicately cross-laminated and from nearly horizontal to contorted. Jensen and Varnes (1964) mapped four exposures of the Kintyre Formation in the refuge in the Fort Peck area.

Eight areas between Duval Creek and Devils Creek are shown as Kintyre(?), the uncertainty being due to the distance from the type area and to the apparent absence of the formation between Devils Creek and Fort Peck. The maximum thickness of the unit is 61 m near Beauchamp Creek.

The Kintyre(?) rests on top of the Judith River Formation at its three westernmost outcrops and elsewhere on the Bearpaw Shale. West of Siparyann Creek, it consists of faintly bedded gray plastic mudstone and shale in the lower part and brown mudstone and shale in the upper part. The rocks weather yellowish brown and contain numerous small crystals of secondary gypsum. Farther east at the mouth of Beauchamp Creek, the formation is coarser and is composed of gray and light brown silty shale and fine-grained sandstone with minor sandstone pebbles up to 2 cm in diameter. Deformed bedding, possibly crossbedding, is in some of the steep inaccessible cliff faces bordering the lake, and in the outcrop opposite Squaw Creek. Due to the proximity of the former channel of the Musselshell River and to the overall similarity of the

Kintyre(?) sediments to those of the channel-fill deposits, the assignment of the outcrop opposite Squaw Creek to the Kintyre(?) Formation is somewhat more problematic.

Pleistocene(?) and Holocene alluvium

Alluvium in stream channels tributary to the Missouri River ranges in size from clay through fine gravel due both to the low relief of the drainage basins and to the relatively fine nature of the material being eroded. However, larger streams in areas of high relief are commonly fast-flowing during spring runoff and contain large glacial boulders intermixed with finer sediments.* Due to the relocation of the Missouri River during the Pleistocene from the Milk River Valley to its present position (Jensen and Varnes, 1964), the Missouri River floodplain is not as broad and well developed as it is east of the refuge.

*Jensen and Varnes (1964, p. 39) state that 1-14 m of postglacial and Holocene alluvium has accumulated in stream channels north of Fort Peck.

Structure

Four major structural features surround the Charles M. Russell Wildlife Refuge: Bowdoin Dome about 72 km north of the refuge; the Bearpaw and Little Rocky Mountains to the northwest; the Blood Creek Syncline centered on an east-west-trending axis immediately south of the Refuge and the Williston Basin centered about 240 km to the east. (See Chapter B.) These features and associated northeast- and northwest-trending surface lineaments are the end result of Laramide orogenic forces which caused the lateral adjustment of basement blocks along shear zones of early Precambrian age (Thomas, 1974). Northeast-trending weakness zones served as conduits for the Tertiary intrusive and extrusive igneous activity south and west of the refuge.

Several lineaments exist in and near the refuge. The major northeast-trending lineament is the Musselshell-Weldon-Brockton lineament which crossed Big Dry Creek a few kilometers south of the Refuge boundary. Other northeast-trending lineaments include the southernmost part of the Big Dry Arm and the course of the Missouri River east of Hell Creek. The northwest-trending lineaments are more topographically prominent and they are reflected in the drainages of Bear, Nelson, and Timber Creeks and in the lower reaches of McGuire Creek, South Fork of Rock Creek, and the Big Dry Arm. There are numerous other examples of northwest-trending ridges and stream drainages, but some of them, especially in the west half of the refuge, are probably related to glacial movement.

The dip of strata in the refuge rarely exceeds 3^{o} and the overall dip directions reflect nearby major structural features. Thus, in the western part of the refuge the strata dip east and southeast; in the central part of the refuge they dip mostly to the south; and in the easternmost part they dip southeast. Strata exhibiting dips greater than 5^{o} are rotated slump blocks.

Three small normal faults are shown in plate 1. The fault at Bell Bottoms in sec. 35, T. 22 N., R. 24 E. trends northeast with a displacement of 18 m. Here the lower part of the Bearpaw Shale is in the northern downthrown block, adjacent to strata of the Judith River Formation. The fault at Tripp Divide in sec. 12, T. 20 N., R. 30 E. also trends northeast. The northern block of Fox Hills Sandstone is downthrown about 24 m and is in contact with the Bearpaw Shale in the southern block. The fault at Boxelder Creek in SE1/4 T. 23 N., R. 42 E. trends northwest and changes into a gentle monocline in that direction. The Hell Creek Formation in the downthrown southern block is in contact with the Fox Hills Sandstone in the northern block. The amount of displacement along the fault is not known, but it may be as much as 30 m.

Geochemical investigations

The Charles M. Russell Refuge has submarginal resources of aluminum with little or no potential for other metallic resources. The samples and their analytical results are discussed in the following paragraphs.

Sampling and analytical techniques

A total of 442 rock, stream sediment, and panned concentrate samples were collected during the course of geologic mapping (pl. 2). All samples were analyzed for 30 elements by a semiquantitative emission spectrographic technique (Grimes and Marranzino, 1968). In addition stream sediment and panned concentrate samples were analyzed for gold, copper, lead, and zinc by atomic absorption. Forty-eight selected samples of shale, mudstone, and siltstone were analyzed by emission spectrophotometry for Al_2O_3. Fifty-eight selected sandstone samples were analyzed for uranium and thorium by delayed neutron activation.

Evaluation of sample data

None of the samples contain minerals or elements in sufficient concentrations to indicate mineral-resource potential. The area is lacking in evidence of mineral occurrence such as areas of altered rock that are characteristic of mineralized areas elsewhere.

Manganese is concentrated in amounts up to 3,000 ppm in sandstone and up to 5,000 ppm in manganosiderite concretions. Barium is most abundant in sandstones, stream sediments, and panned concentrate samples. Some samples contain greater than 5,000 ppm barium. Although these concentrations of manganese and barium are high, the elements are not considered to be of potential economic value since minerals containing these elements are finely disseminated in the samples and their occurrence at such high concentrations is limited.

Table 1 lists the mean values, standard deviations, and threshold values for copper, nickel, lead, and the threshold values for arsenic, molybdenum, and zinc for six lithologic populations. The threshold values for copper, nickel, and lead equal the mean plus two standard deviations. Arsenic, molybdenum, and zinc were not detected in most samples, and therefore the threshold values were arbitrarily defined as three times the lower limit of analytical detection. The 42 samples that contain anomalous concentrations of one or more of these elements are plotted on figure 6. The samples contain anomalously large amounts of these elements only in comparison to other samples from the study area and not for sedimentary rocks in general.

The category "Shales, Mudstones, and Bentonites" in table 1 contains the largest number of shales with anomalous values of nickel, lead, and molybdenum. These elements were probably concentrated by adsorption onto particles of clay, organic matter, and iron from ground water. Larger amounts of nickel also occur in Cretaceous sandstones, whereas larger amounts of lead occur with small amounts of zinc in recent stream sediments, particularly in the channels of streams draining the Little Rocky Mountains (fig. 6). Sandstone concretions from the Hell Creek Formation were evaluated according to the threshold values determined for sandstones. They contain as much as 1,000 ppm arsenic and 500 ppm nickel. Nickel and arsenic apparently occur as replacements of iron in the pyrite cementing quartz and feldspar grains. Nickel, iron, and arsenic may have been removed from percolating fluids during diagenesis by localized concentrations of organic matter.

One hundred three sandstone samples average 2 ppm uranium and 7 ppm thorium. Boron, barium, beryllium, cobalt, chromium, lanthanum, niobium, scandium, and vanadium are more concentrated in shales and mudstones. None of the samples contain detectable amounts of silver, gold, bismuth, cadmium, tin, or tungsten.

Geochemistry of Cretaceous black shale

Over one half of the stratigraphic interval exposed in the Refuge consists of black shales. Minor elements may be concentrated in black shales in amounts up to 100 times greater than average crustal abundance (Krauskopf, 1955). Table 2 compares the average composition of 106 samples of black shale from the Bearpaw Shale with the average composition of two other populations of black shale samples and the average shale of Krauskopf (1967, Appendix III).

Analyses of 17 samples of black shale and claystone from the Pierre Shale and related rocks were selected from Tourtelot (1962). Four samples are from the Claggett Shale in Fergus and Carbon Counties, Montana; one from the Bearpaw Shale in Rosebud County, Montana; and twelve from the Pierre Shale in Crook County, Wyoming, and Corson, Dewey, Hughes, Lyman, and Stanley Counties, South Dakota. The Claggett Shale is equivalent to the upper part of the Gammon Ferruginous Member and to the Mitten Member of the Pierre Shale. The Bearpaw Shale is equivalent to the upper Pierre Shale. It was anticipated that the average values for the Pierre Shale would compare favorably with the Bearpaw values due to similarities of age and lithology and to the proximity of the two formations. Although most of the element concentrations are similar, manganese and strontium are more concentrated in the Pierre Shale whereas boron, barium, beryllium, and zirconium are more concentrated in the Bearpaw Shale. Tourtelot (1962) detected a strong positive correlation between manganese and strontium in the Pierre Shale and found that these elements increased markedly from west to east in his study area.

The average composition of 87 samples of black shale of Late Cretaceous age from Kansas and Texas was computed from the data of Vine and Tourtelot (1969). The composition compares favorably with that of the Pierre Shale and with the average composition of all types of shale

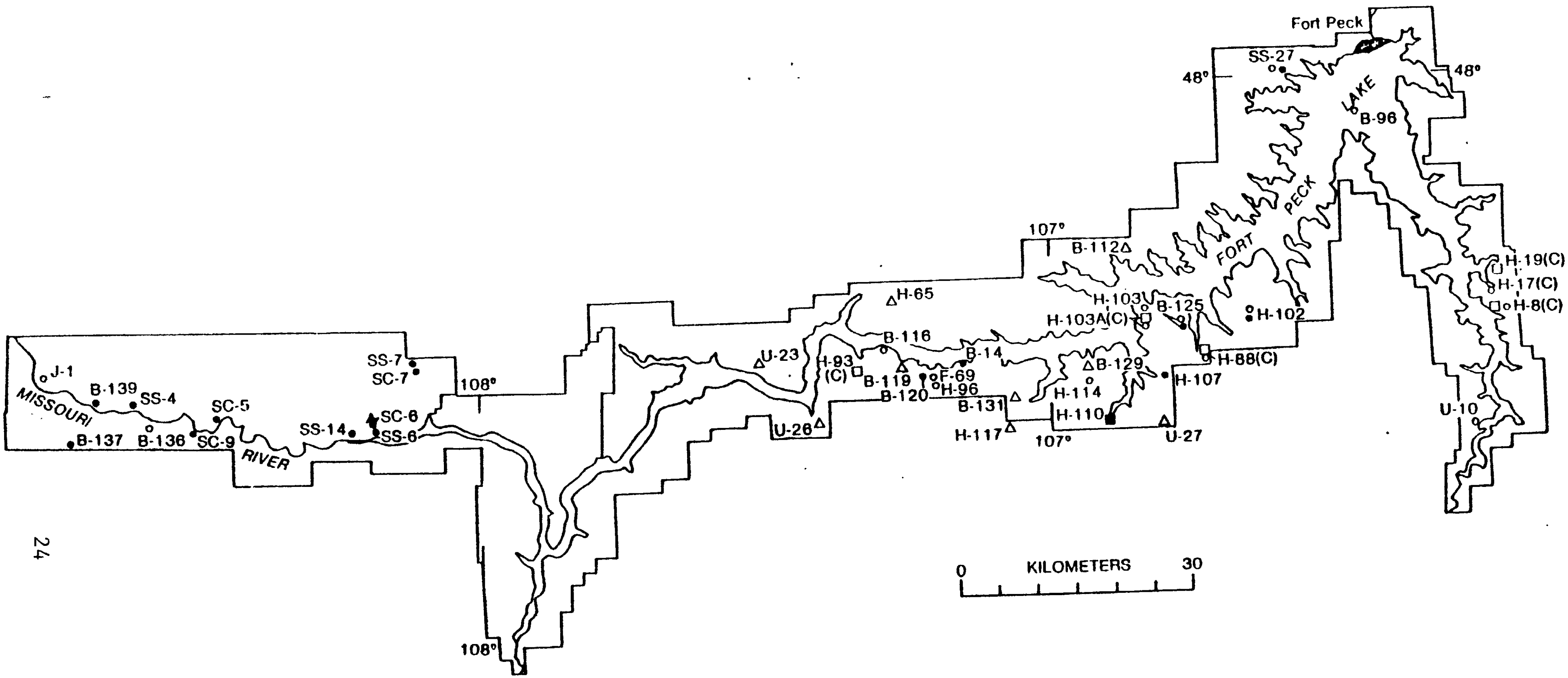


Figure 6.--Localities of samples containing anomalous amounts of nickel (open circle), lead (solid circle), molybdenum (open triangle), zinc (solid triangle), arsenic (open square), and copper (solid square), Charles M. Russell Wildlife Refuge, Montana. Maximum values (in ppm) = Ni, 500; Pb, 70; Mo, 50; Zn, 700; As, 1000; Cu, 30.

Table 1.--Means, standard deviations, and threshold values for defining anomalously high concentrations of Cu, Ni, Pb, As, Mo, and Zn in sandstones, siltstones, shales, mudstones, and bentonites, stream sediments, and panned concentrate samples from the Charles M. Russell Wildlife Range, Montana

[Numbers in parentheses are lower limits of analytical detection. Threshold values for copper, nickel, and lead are defined as the mean plus two standard deviations. Threshold values for arsenic, molybdenum, and zinc are arbitrarily defined as three times the lower limit of analytical detection. In parts per million.]

		Cu(5)				Ni(5)				Pb(10)				As(200)		Mo(5)		Zn (200)	
	No. of samples	Mean	Standard deviation	Threshold value	No. of anom. samples	Mean	Standard deviation	Threshold value	No. of anom. samples	Mean	Standard deviation	Threshold value	No. of anom. samples	Threshold value	No. of anom. samples	Threshold value	No. of anom. samples	Threshold value	No. of anom. samples
Sandstones	143	8	6	20	1	20	15	50	4	16	5	26	0	600	0	15	3	600	0
Sandstone concretions	7	---	---	20	0	---	---	50	4	---	---	26	0	600	5	15	0	600	0
Siltstones	11	10	5	20	0	17	14	45	1	13	4	21	0	600	0	15	0	600	0
Shales, mudstone, bentonites	172	28	21	70	0	37	22	81	6	25	17	59	8	600	0	15	6	600	0
Stream sediment	76	14	8	30	0	28	11	50	1	20	6	32	5	600	0	15	0	600	0
Panned concentrates	21	20	15	50	0	37	20	77	0	23	15	53	4	600	0	15	0	600	1
TOTAL	--				1				16				17		5		9		1

Table 2.—Comparison of the average composition of black shales from the Bearpaw Shale, Charles M. Russell Wildlife Refuge, Montana, with black shales from the Pierre Shale, Upper Cretaceous black shales from Kansas and Texas, and the average shale of Krauskopf (1967) and the number of samples of Bearpaw Shale containing elements in excess of minimum enrichment values for metal-rich shales. [Semiquantitative spectrographic analyses by R. T. Hopkins, M. L. Santopietro, and Henry Lopez. N, not detected at the limit of sensitivity shown; ND, not determined; leaders (--); Al_2O_3, Fe, Mg, Ca, Ti in percent; other elements in ppm.]

	Bearpaw Shale (106 samples)		Pierre Shale[1/] (17 samples)	Upper Cretaceous[2/] black shales Kansas and Texas (87 samples)	Average[3/] shale	Average of Columns 3, 4, 5	Minimum Enrichment Values	Number of Bearpaw Samples exceeding minimum enrichment value
	Average	Range	Average	Average				
Column---	1	2	3	4	5	6	7	8
Al_2O_3	15.63	6.6-17.0	15.40	12.30	15.10	14.3	ND	--
Fe	4.10	0.7-10.0	3.93	2.85	4.70	3.8	ND	--
Mg	1.10	0.3-3.0	1.27	.92	1.34	1.2	ND	--
Ca	.73	0.07-3.0	1.08	6.75	2.50	3.4	ND	--
Ti	.55+	0.1-0.06	.36	.16	.45	.3	0.7	25
Ag	.5N	--	.5N	ND	.1	.1	7.0	0
As	200N	--	14.0	ND	6.6	10.0	ND	--
Au	10N	--	30N	ND	<0.05	<0.05	ND	--
B	202	50-500	117	84	100	100	200	35
Ba	724	300-2,000	559	430	580	523	1,000	18
Be	2.9	1.5-10.0	1. 5	ND	3	2	3	21
Bi	10N	--	10N	ND	.01	.01	ND	--
Cd	20N	--	50N	ND	.3	.3	ND	--
Co	16	5.0N-30	15	10	20	15	30	0
Cr	107	20-300	70	118	100	96	700	0
Cu	29	5.0L-70	65	54	57	59	200	0
La	44	20-100	30	24	40	31	70	15
Mn	240	20-1000	512	250	850	537	1,000	0
Mo	5N	5.0N-50	10N	18	2	10	200	0
Nb	20N	20.0N-20.0	8	10	20	13	ND	--
Ni	38	5.0L-100	52	56	95	68	300	0
Pb	26	10.0N-70	16	23	20	20	100	0
Sb	100N	--	100N	ND	1.5	1.5	ND	--
Sc	15	5-30	15	9	10	11	30	0
Sn	10N	--	10N	ND	6	6	ND	
Sr	171	100N-700	735	136	450	440	1,500	0
V	341	70-1,000	320	150	130	200	1,000	0
W	50N	--	100N	ND	2	2	ND	--
Y	23	10.0L-50	22	19	30	24	70	0
Zn	200N	--	270	156	80	169	1,500	0
Zr	152	30-500	66	117	200	128	200	3

1 Tourtelot (1962), Samples C870-873, C875-878, C880-882, C884-888, and C890.

2 Vine and Tourtelot (1969), Sample sets 18 and 19.

3 Krauskopf (1967), Appendix 111.

4 Vine and Tourtelot (1970).

5 Average of 48 samples.

as compiled by Krauskopf (1967). The major differences are the higher calcium content and the lower concentrations of aluminum, iron, manganese, and strontium in the shales from Kansas and Texas.

Comparison of the average elemental values for the Bearpaw Shale with the average values for the three other populations as shown in column 6 of table 2 indicate that the Bearpaw Shale contains less calcium, copper, manganese, nickel, and strontium and more boron, barium, beryllium, and vanadium. Taking into account that some minor elements in black shale have a much wider range of values than others, Vine and Tourtelot (1970) determined the minimum elemental enrichment values for defining metal-rich shales. They defined the minimum enrichment value as the midpoint of the 90th-100th percentile interval as determined from the sum of the percent frequency distribution for 779 samples of black shale. Forty-four samples of Bearpaw Shale have elemental values in exces of the minimum enrichment values for titanium, boron, barium, beryllium, lanthanum, and zircon (figs. 7, 8, 9, 10, and 11, table 3).

Detailed examinations of the mineralogy of these samples were not made, but X-ray diffraction traces of seven samples indicate that quartz, plagioclase, montmorillonite, and illite are the major rock-forming minerals with gypsum, mica, and kaolinite-chlorite as accessory minerals. Organic carbon was not determined, but the abundance of shell material in concretions in the shale indicates that organic matter was abundant at the time of shale deposition. Samples enriched in titanium and zirconium may have larger amounts of fine detrital minerals containing these elements. The abundance of clays and colloidal material, however, suggests that these elements along with boron, barium, and beryllium were concentrated by adsorption onto the weakly charged surfaces of clay particles. These elements can also be concentrated from seawater in living organisms and subsequently released before or during burial and diagenesis. Inasmuch as the upper part of the Bearpaw Shale in the refuge crops out continuously from the Musselshell River to the Big Dry Arm, the concentration of samples containing anomalous amounts of these elements in the area between Herman Point and Bell Point appears to be independent of stratigraphic horizons. Samples in the western part of the refuge containing anomalous amounts of boron, barium, and titanium may or may not be related to stratigraphic intervals.

Forty-eight samples of black shales average 15.63 percent Al_2O_3. Forty-three of these samples have Al_2O_3 contents in excess of the average value of 14.3 percent shown in table 2 column 6. The locations of the four samples that contain 17.0 percent Al_2O_3 are shown in figure 11 and chemical analyses are given in table 3. All four samples were collected at approximately the same elevation and considering the small southward dip of the beds, they may represent an aluminum-rich horizon, the extent of which is not known. Patterson and Dyni (1973, p. 40) defined an aluminous shale as one containing 20-24 percent Al_2O_3 and

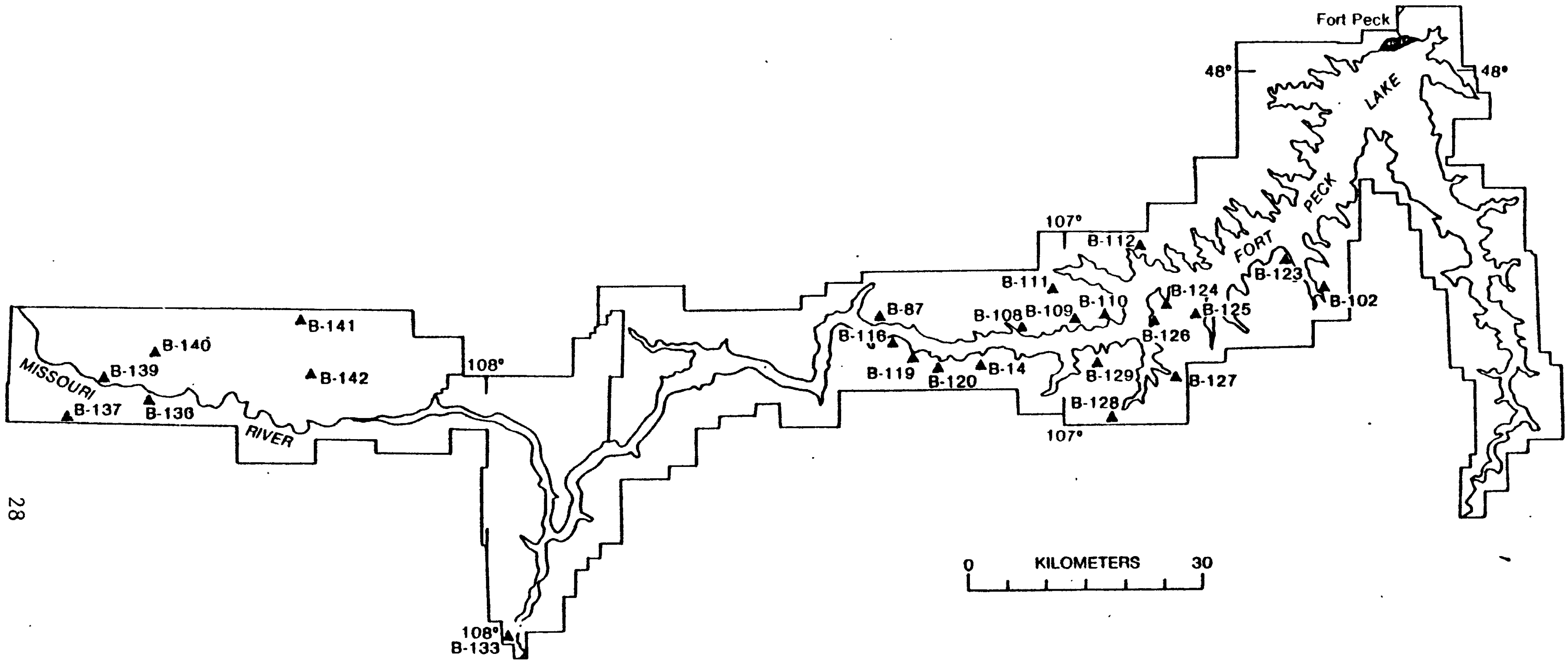


Figure 7.--Localities (solid triangles) of numbered samples of Cretaceous black shale enriched in titanium, Charles M. Russell Wildlife Refuge, Montana. Values in table 3; range of values for all black shale samples from 0.1 to >1.0 percent.

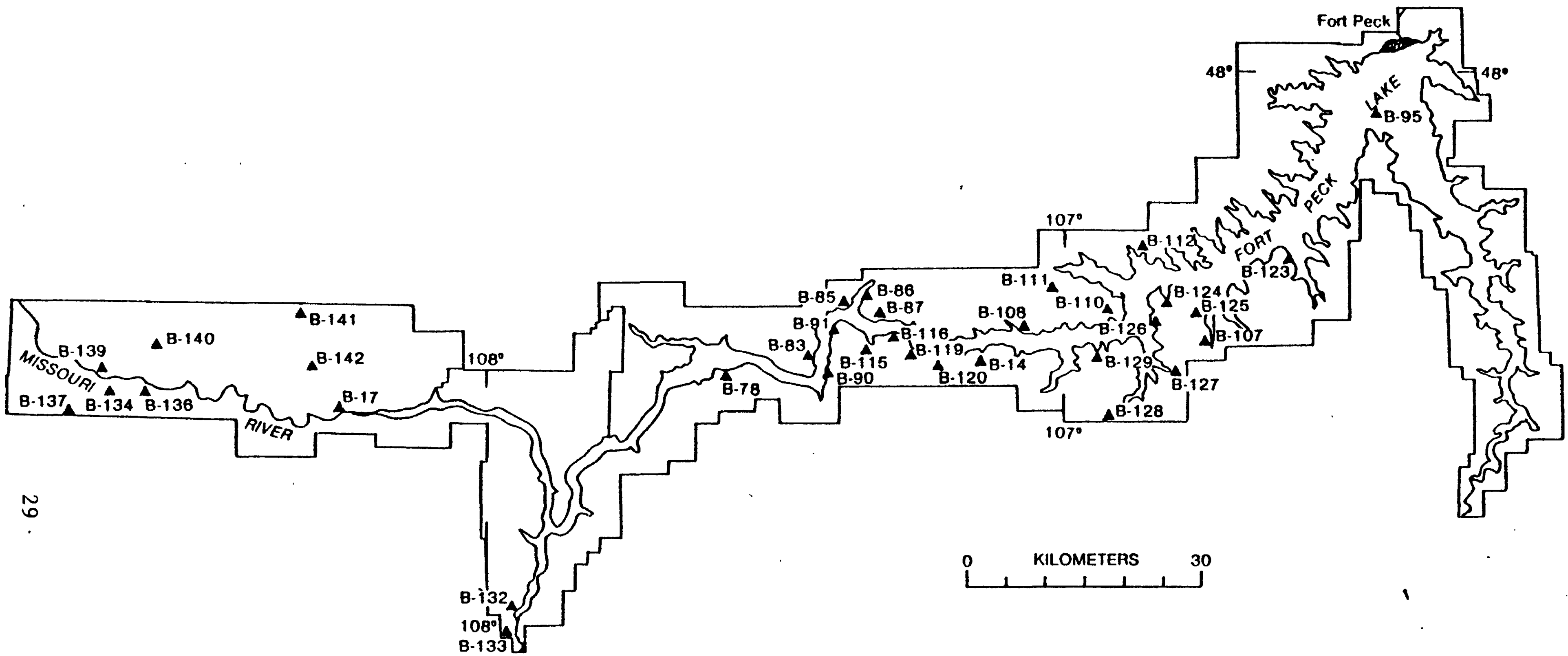


Figure 8.--Localities (solid triangles) of numbered samples of Cretaceous black shales enriched in boron, Charles M. Russell Wildlife Refuge, Montana. Values shown in table 3; range values for all black shale samples 50-500 ppm.

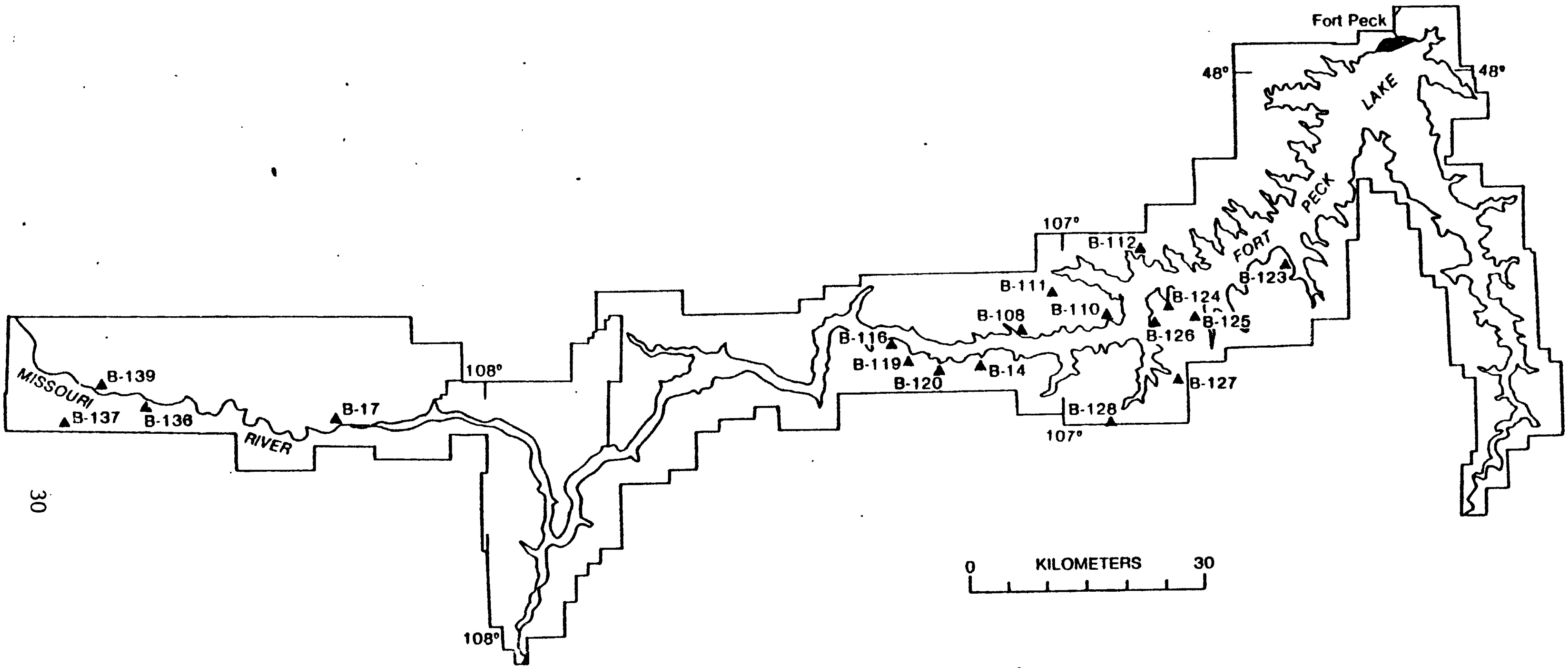


Figure 9.--Localities (solid triangles) of numbered samples of Cretaceous black shales enriched in barium, Charles M. Russell Wildlife Refuge, Montana. Values shown in table 3; range of values for all black shale samples 300-2000 ppm.

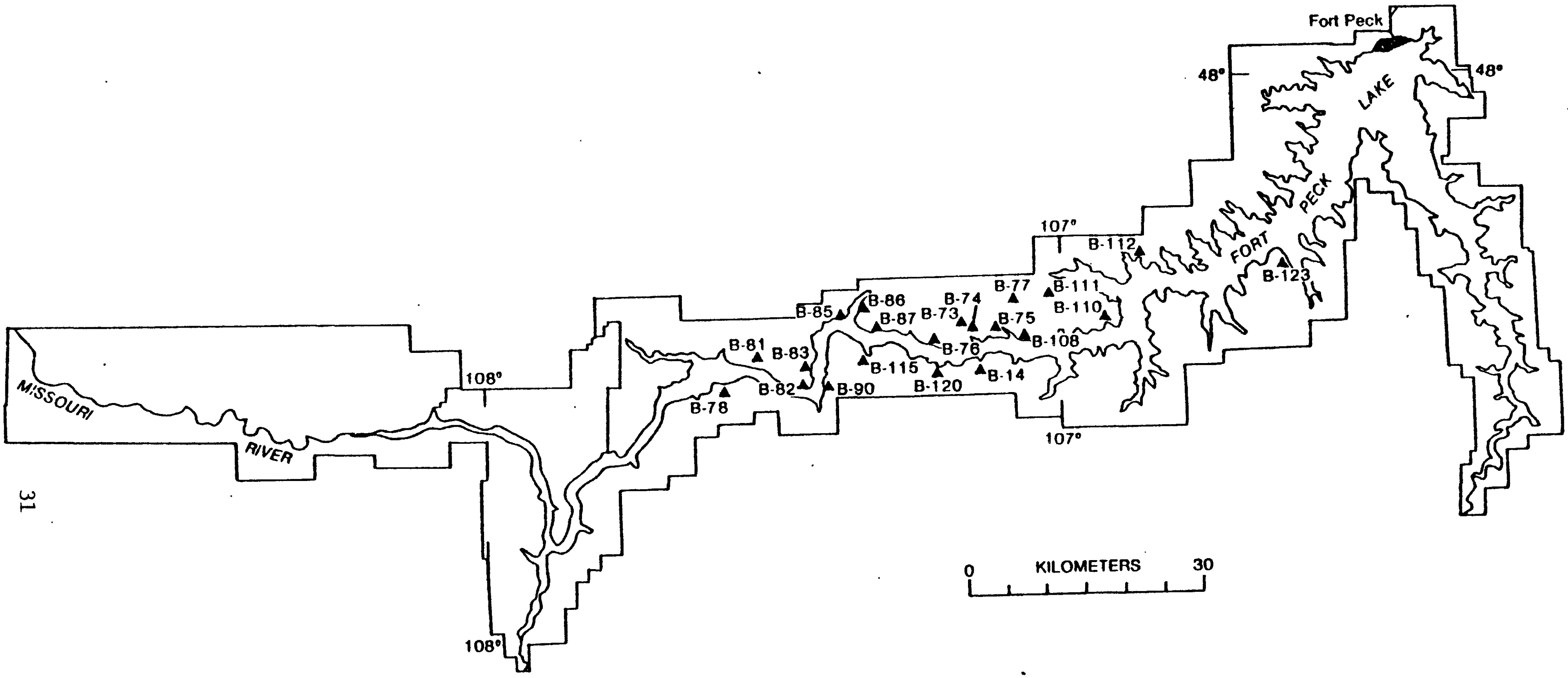


Figure 10.--Localities (solid triangles) of numbered samples of Cretaceous black shale enriched in beryllium, Charles M. Russell Wildlife Refuge, Montana. Values shown in table 3; range of values for all black shale samples 1.5-10.0 ppm.

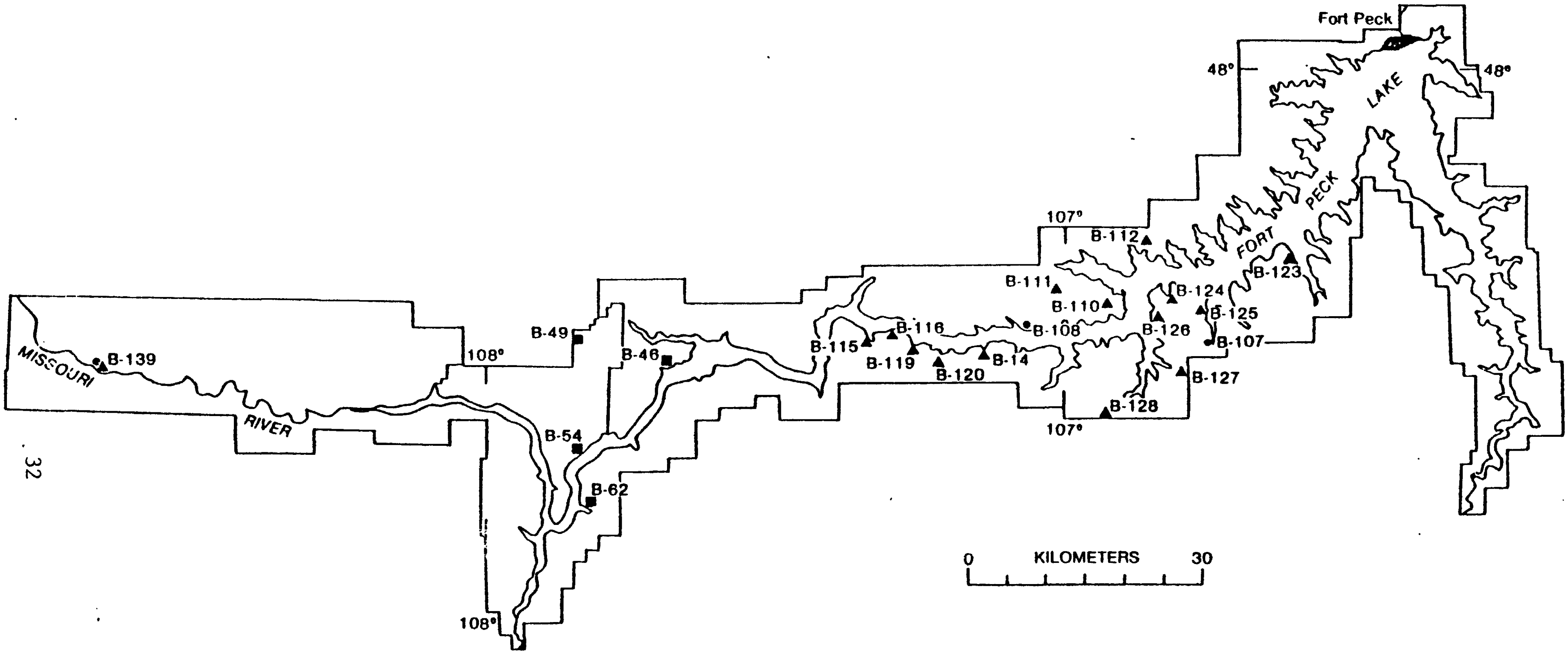


Figure 11.--Index map showing locations of samples of Cretaceous black shale enriched in lanthanum (triangle), zircon (dot), and Al_2O_3 (square), Charles M. Russell Wildlife Refuge, Montana. Values shown in table 3; range of values for all black shale samples: lanthanum, 20-100 ppm; zirconium, 30-300 ppm; Al_2O_3, 6.6-17.0 percent.

Table 3.--Partial chemical analyses of black shales from the Bearpaw Shale, Charles M. Russell Wildlife Refuge, Montana, enriched in Ti, B, Ba, Be, La, and Al_2O_3. Ag, As, Au, Bi, Cd, Nb, Sb, Sn, W, and Zn below limits of detection for all samples. [Semiquantitative spectrographic analyses by R. T. Hopkins, M. L. Santopietro, and Henry Lopez. Nd, not determined; N, not detected at the sensitivity level shown; G, detected in amounts greater than the sensitivity level shown; L, detected in an undetermined amount below the sensitivity level shown.]

Sample Number	X-Coordinate	Y-Coordinate	Fe	Mg	Ca	Ti	B	Ba	Be	Co	Cr	Cu	La	Mo	Mn	Ni	Pb	Sc	Sn	V	Y	Zn	Al_2O_3
			percent				ppm																percent
B-14	25,000	3,550	10.0	2.0	1.5	1.0G	500	2,000	5.0	30	200	70	100	5.0N	1,000	70	70	30	200	1,000	50	200	ND
B-17	-57,550	-3,100	7.0	2.0	0.3	0.7	300	1,500	2.0	20	200	30	30	5.0N	300	70	50	20	100	500	50	150	16.4
B-46	-15,900	1,800	1.5	0.5	0.1	0.2	150	500	2.0	5	30	15	20	5.0N	70	15	15	10	100	150	15	70	17.0
B-49	-27,400	4,700	1.5	0.5	0.2	0.2	150	500	2.0	15	50	15	20	5.0N	150	20	15	10	100	200	15	70	17.0
B-54	-27,100	-9,350	1.0	0.3	0.15	0.15	70	300	1.5	5N	30	5	20	5.0N	50	5	10N	7	100	150	10	50	17.0
B-62	-24,750	-16,900	1.5	0.5	0.3	0.2	50	300	2.0	7	30	5	20	5.0N	70	15	10L	7	100	150	15	70	17.0
B-73	21,100	8,350	5.0	2.0	0.7	0.7	200	700	7.0	20	200	50	50	5.0N	200	50	30	20	300	300	30	200	ND
B-74	23,100	7,650	3.0	1.5	0.5	0.7	200	300	10.0	20	150	50	50	5.0N	150	50	20	20	300	300	20	150	ND
B-75	26,100	7,900	5.0	1.5	1.0	0.7	150	300	5.0	20	150	50	50	5.0N	100	50	20	20	300	300	20	150	ND
B-76	18,400	5,900	3.0	1.0	0.5	0.7	200	500	5.0	15	100	30	50	5.0N	200	70	20	20	200	500	30	150	ND
B-77	26,650	10,900	3.0	1.0	1.0	0.7	150	300	5.0	20	100	30	50	5.0N	200	50	20	20	300	300	20	200	ND
B-78	-8,300	1,150	5.0	1.5	0.5	0.7	300	300	5.0	30	150	70	50	5.0N	500	70	30	20	150	500	30	150	ND
B-81	-2,180	3,550	3.0	0.7	0.7	0.5	150	300	5.0	15	50	30	50	5.0N	300	50	15	15	150	200	30	150	ND
B-82	2,000	500	3.0	1.0	0.15	0.7	200	500	5.0	20	100	30	70	5.0N	150	70	20	15	100	500	30	150	ND
B-83	3,300	3,700	7.0	1.5	0.7	0.7	300	700	5.0	20	200	70	70	5.0N	300	50	50	20	150	700	30	200	ND
B-85	7,750	9,000	3.0	1.5	0.7	0.7	300	500	5.0	15	150	70	70	5.0N	100	50	50	20	150	700	30	150	ND
B-86	10,500	10,900	3.0	0.5	0.15	0.7	300	300	5.0	15	70	30	50	5.0N	200	50	20	15	150	500	20	150	ND
B-87	12,300	7,900	7.0	2.0	0.7	1.0	300	500	5.0	30	150	50	50	5.0N	500	70	50	20	150	700	30	200	ND
B-90	5,450	1,100	5.0	1.0	0.5	0.7	300	300	5.0	10	100	50	50	5.0N	200	50	20	15	100	500	20	150	ND
B-91	5,950	6,250	3.0	1.5	0.5	0.7	300	500	3.0	30	100	50	50	5.0N	500	50	50	15	100	500	20	100	ND
B-95	76,800	34,000	5.0	1.0	0.2	0.7	300	700	2.0	15	100	50	30	5.0N	150	50	15	15	150	300	20	100	ND
B-102	70,000	10,800	7.0	2.0	0.7	1.0	200	700	2.0	30	150	50	50	5.0N	700	70	30	20	200	300	30	200	ND
B-107	54,950	5,450	5.0	1.0	2.0	0.7	300	1,000	3.0	15	100	50	50	15.0	500	50	30	20	200	300	50	300	ND
B-108	31,000	7,400	7.0	3.0	2.0	1.0G	500	1,500	5.0	30	200	70	50	10.0	500	70	50	30	300	700	50	300	ND
B-109	37,300	7,700	7.0	2.0	1.5	1.0	200	1,000	3.0	20	100	50	70	7.0	500	50	50	20	200	500	50	150	ND
B-110	40,950	8,450	10.0	3.0	3.0	1.0G	300	1,500	5.0	30	200	50	100	10.0	700	70	50	30	700	500	50	200	ND
B-111	35,000	12,100	5.0	0.7	2.0	1.0	300	1,500	5.0	20	150	15	100	5.0N	200	50	30	20	300	500	50	200	ND
B-112	46,800	16,750	7.0	1.5	3.0	1.0	300	1,500	5.0	20	150	15	100	30.0	300	50	50	20	300	500	30	200	ND
B-115	9,950	4,550	5.0	1.0	1.5	0.7	300	1,000	5.0	30	100	50	100	5.0N	700	70	30	20	300	300	50	200	ND
B-116	14,300	5,700	10.0	3.0	0.7	1.0G	500	2,000	3.0	30	300	70	100	10.0	300	100	50	30	200	1,000	50	200	ND
B-119	17,000	3,600	10.0	1.5	1.5	1.0G	500	1,500	3.0	15	150	50	100	30.0	200	70	50	30	300	1,000	50	200	ND
B-120	20,000	2,100	10.0	2.0	0.5	1.0G	500	2,000	5.0	30	300	70	100	5.0N	300	70	70	30	200	1,000	50	200	ND
B-123	65,400	14,900	7.0	1.5	1.5	1.0G	300	1,500	5.0	20	150	50	100	5.0N	300	50	50	30	200	700	30	200	ND
B-124	49,650	9,700	7.0	2.0	1.5	1.0G	300	1,500	3.0	20	150	50	100	5.0N	300	50	50	30	300	700	50	200	ND
B-125	53,050	8,250	10.0	3.0	2.0	1.0G	500	2,000	3.0	30	200	70	100	5.0N	500	100	70	30	300	700	50	200	ND
B-126	47,500	6,900	7.0	3.0	2.0	1.0G	500	2,000	3.0	20	200	50	100	5.0N	500	70	50	20	300	700	50	200	ND
B-127	51,250	600	7.0	2.0	3.0	1.0	500	1,500	3.0	30	150	70	100	5.0N	700	50	50	20	300	500	30	150	ND
B-128	42,100	-4,850	7.0	1.5	1.0	1.0	300	1,500	3.0	20	150	50	100	5.0N	300	50	30	20	200	500	30	200	ND
B-129	40,900	2,700	7.0	1.5	1.5	1.0	300	700	3.0	20	150	50	50	50.0	200	50	50	20	500	500	20	200	ND
B-132	-34,950	-28,850	5.0	1.0	1.5	0.7	300	1,000	3.0	15	150	50	50	5.0N	200	50	50	20	300	700	30	200	ND
B-133	-36,150	-32,300	7.0	1.0	0.5	1.0	300	1,000	3.0	20	150	50	50	5.0N	300	70	50	20	200	700	20	200	ND
B-134	-87,850	-1,000	7.0	1.5	1.5	0.7	300	1,000	3.0	30	150	50	50	10.0	700	70	70	20	300	700	30	200	ND
B-136	-82,350	-1,300	10.0	1.5	1.0	1.0	500	1,500	3.0	30	300	50	70	5.0N	300	100	50	30	300	1,000	50	200	ND
B-137	-92,630	-3,900	7.0	1.5	1.0	1.0	300	1,500	3.0	20	300	50	70	5.0N	300	70	70	20	300	700	30	200	ND
B-139	-88,400	1,600	7.0	2.0	0.2	1.0	300	1,500	3.0	30	300	50	100	15.0	300	70	70	30	300	1,000	50	500	ND
B-140	-81,700	4,100	7.0	1.5	1.5	1.0	300	1,000	3.0	15	150	50	50	5.0N	300	70	50	20	200	700	30	150	ND
B-141	-64,000	8,700	7.0	1.5	1.0	1.0	300	700	3.0	15	150	30	50	5.0N	300	30	30	20	200	300	30	150	ND
B-142	-61,650	2,400	7.0	1.5	1.0	1.0	300	700	3.0	20	150	50	70	5.0N	500	50	50	20	200	700	30	150	ND

noted that shales of this quality are widely distributed throughout the United States. The extraction of aluminum from shales is not yet economically feasible, and the black shales in the refuge are therefore classed as a submarginal aluminum resource.

Resources of industrial materials

The Charles M. Russell Wildlife Refuge contains large potential deposits of bloating shale for lightweight aggregate and small deposits of bentonite. However, large similar deposits of both rocks exist elsewhere in northern and eastern Montana, that are more favorable for mining, transportation, and processing. Deposits of sand and gravel, clinker, riprap, and ceramic clay and shale exist locally. Coal resources are discussed in Chapter D by the U.S. Bureau of Mines.

Lightweight aggregate

Nineteen shale samples and one sample of reworked glacial till were tested by the Montana Bureau of Mines and Geology to determine their usefulness as lightweight aggregate. The results are shown in table 4. Rock fragments 12-19 cm in diameter were preheated to 500°C and the temperature was repeatedly increased 50°C per 15-minute interval up to 700°C. The samples were then transferred to another furnace and heated to 1038°C, 1093C, 1149°C, and 1204°C for 20 minutes each and the condition of the heated product was described for each of these temperatures.

Eleven samples from the Bearpaw Shale produced good to excellent products. Most outcrops from which these samples were taken are noticeably bentonitic and display thick, popcorn-like rinds of weathered material on outcrop. However, sample B-134 was fissile and weathered to paper-thin chips, apparently due to a higher organic content. Four Bearpaw Shale samples were not suitable for lightweight aggregate. Three of these (B-123, B-124, and B-130) are from the Hell Creek area and were taken from a stratigraphic interval approximately 36 to 60 m below the base of the Fox Hills Sandstone. This less bentonitic interval is within unit #6 of the Bearpaw Shale as described by Jensen and Varnes (1964). The presence of admixed bentonite in the Bearpaw Shale and also in the shales of the Cretaceous Colordo Group (Sahinen, 1957) appears to be a key indicator of their suitability for use as lightweight aggregates.

Bentonite

Bentonite is devitrified and chemically altered volcanic material consisting mainly of smectite clay minerals. Three major industrial uses of bentonite are the manufacture of iron ore pellets, foundry sands, and oil-well drilling mud. These uses rely heavily on the

Table 4. **Physical properties of heated shale samples from the Charles M. Russell Wildlife Range, Montana, and suitability for use as lightweight aggregate.** (Testing by Montana Bureau of Mines and Economic Geology).

Sample No.	Test results				Suitability for lightweight aggregate
	1038°C. (1900°F.)	1093°C. (2000°F.)	1149°C. (2100°F.)	1204°C. (2200°F.)	
75-B-6	Slight bloat —	Fair bloat, crackling	Good bloat, incipient glaze	ood bloat, incipient fusion and adhesion	Good product--good expansion at high end of range
75-B-11	---do---	Spalling, good round bloat	Excellent round bloat	Good bloat, adhesion	Very good product, in particular at high end of range
75-B-15	No bloat	Incipient bloat	---do---	---do---	---do---
75-B-16	Slight bloat	---do---	Fair round bloat	Fair bloat, adhesion	Fair--not much expansion
75-B-17	---do---	Spalling, good round bloat	Good bloat, slight adhesion	Fair bloat, adhesion	Good--somewhat brittle
75-B-18	No bloat	No bloat	Slight bloat, glazed	Fused	Not suitable--very little expansion
75-B-19	Good bloat	Good round bloat	Excellent bloat, glazed	Excellent bloat, adhesion	Excellent--bloats well over a wide range
75-B-24	Slight bloat	Minor bloat	Fair bloat, adhesion	Good bloat, incipient fusion	Good product
75-B-66	---do---	Fair bloat, incipient glaze	Excellent bloat, glaze	Excellent bloat	Excellent--good expansion over a moderate range
75-B-90	---do---	Good bloat, minor glaze	Excellent round bloat, minor glaze	Excellent bloat, adhesion	Excellent--good expansion over a wide range
75-B-122	Moderate bloat	Good round bloat	Excellent round bloat, incipient glaze	Excellent bloat, adhesion	Excellent--good bloat over a wide range
75-B-123	Slight bloat	Slight bloat	Slight bloat	Slight bloat adhesion	Unsuitable--only minor expansion
75-B-124	Minor bloat	Minor bloat	Fair bloat, glaze	Fair bloat, adhesion	Poor-narrow bloating range
75-B-130	No bloat	No bloat	Incipient bloat	Fair bloat, adhesion	Unsuitable--only minor expansion
75-B-134	Moderate bloat	Fair bloat	Excellent round bloat slight glaze	Food bloat, adhesion	Excellent--good expansion over a wide range
75-B-139	Slight bloat	Slight bloat	Excellent bloat, spalling	Good bloat, adhesion	Very good--good expansion over a wide range
75-J-3	---do---	Fair bloat	Good bloat, glaze, adhesion	Bloat and incipient fusion	Poor--narrow expansion range
75-H-49	No bloat	Slight bloat	Slight bloat	Some bloat and incipient fusion	Unsuitable--poor expansion
75-K-3	---do---	No bloat	No bloat, slight glaze	Bloat and fusion	---do---
75-U-21	---do---	---do-	Incipient bloat, glaze	Good bloat adhesion	Poor-very narrow range

Table 5.--Physical and chemical properties of selected bentonites from the Charles M. Russell Wildlife Refuge, Montana, and the specifications of the American Petroleum Institute (1974) for bentonite used in oil-well drilling fluids. Testing by U.S. Bureau of Land Management, Worland, Wyoming. [Leaders (--), not measured.]

Sample Number	X-Coordinate	Y-Coordinate	Thickness (cm)	Grit1/	pH2/	Yield (barrels)	Apparent iscosity (cps)	Water oss (cm^3)	Green trength (psi)	Dry trength (psi)	Color
					Bearpaw Shale						
B-3	-95,400	8,400	45	3.3	7.3	30	3/2	57.5	9.1	127.0	Green
B-7	-46,750	1,850	30	0.1	8.1	30	3/2	28.5	8.9	173.5	Gray-green
B-9	-47,750	-300	20	3.3	7.5	40	4/2	54.0	8.0	151.0	Green
B-20	-34,850	-4,450	25	2.0	8.8	46	5/2	72.0	10.5	93.0	Gray
B-69	-16,050	-3,600	20	0.2	8.5	46	5/2	118.5	8.9	146.5	Do.
B-117	14,300	5,700	20	0.6	5.2	51	6/2	61.0	8.2	167.0	Do.
B-135	-87,650	-1,100	30	0.3	4.6	30	3/2	ALL	10.7	105.5	Cream
B-138	-92,950	1,700	60	3.9	8.5	61	9/2	23.0	8.8	163.0	Green
					Hell Creek Formation						
H-5	93,500	8,000	91	2.0	8.5	30	3/2	53.0	5.3	130.5	Brown-green
H-20	94,700	3,500	15	---	8.0	30	3/2	74.0	38.3	137.0	Green
H-22	94,500	3,700	10	0.2	8.4	30	3/2	72.0	4.1	139.0	Do.
H-28	93,300	-8,700	122	0.5	8.5	30	3/2	37.5	5.8	117.5	Green-gray
H-29	91,900	-12,100	92	0.1	7.6	30	3/2	25.0	5.9	146.5	Green
H-53	91,050	-3,000	61	0.7	8.5	40	4/2	21.0	6.4	170.0	Gray
H-54	91,050	-3,000	25	1.2	8.4	30	3/2	32.3	5.5	129.5	Do.
H-55	91,050	-3,000	122	---	7.8	30	3/2	42.0	5.6	148.4	Do.
H-61	88,500	6,100	92	0.4	7.3	30	3/2	19.0	4.4	173.5	Green
H-120	85,800	12,100	60	3.0	8.1	51	6/2	27.5	8.3	157.0	Brown
API Specifications (1974) for oil-well drilling fluids			---	<4.0	>8.2	>91.8	>30/2	<13.5	---	---	---

1/ Weight percent >200 mesh

2/ 6 weight percent slurry

viscous and thixotropic properties of bentonite-water mixtures and the ability of the clay to perform satisfacotrily over a broad temperature range.

Eighteen bentonite samples were tested by the Bureau of Land Management for these physical properties at their Worland, Wyo. laboratory. The results are shown in table 5. According to standards established by the American Petroleum Institute (1974) the yield and water-loss values shown indicate that the bentonites tested are unsuitable for use as drilling mud. There is disagreement among bentonite consumers and producers as to the range of test values acceptable for taconite pellets and foundry sands as well as for the range of substandard values for all three uses which can be improved by beneficiation with organic or inorganic substances or by blending together two or more bentonites with different properties.

In general terms, the taconite industry requires bentonites with moderately high apparent viscosities (25/2 to 30/2) and high dry bond strengths (greater than 140-150 psi)[1]. Eight of the samples have

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[1] Green bond strength refers to the compressive strength of a core 5 cm in diameter and 5 cm long composed of 5 percent bentonite, 3 percent water, and 92 percent quartz sand at room temperature. Dry bond strength refers to the compressive strength of an identical core after it has been heated at 122°C for at least 2 hours.

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inferior dry bond strengths and all have low apparent viscosities. The foundry industry relies primarily on green strength values for bentonite evaluation. All samples of the Bearpaw bentonites and two samples of the Hell Creek bentonites have green strength values greater than 6.5 psi and could be used as binders in foundry sands.

All samples listed in table 5 were collected at outcrops. An effort was made to collect less weathered material from cutbanks wherever possible. Nevertheless the physical and chemical properties of these samples may be markedly different from unexposed samples taken from the same beds under 6 or more meters of overburden. These differences are due both to the chemical weathering of the bentonites at or near the surface and to original local variations in the composition and depositional environment of the volcanic ash at the time of deposition. Thus table 5 gives at best only an approximation of the physical properties of bentonite beds within the refuge. However, additional insight can be gained by comparing the data on the Bearpaw bentonites with that gathered by the Bureau of Land Management (Bigsby and Sollid, 1975) for two Bearpaw bentonite beds currently under claim by American Colloid Company. The samples were collected in the Regina area north of the refuge by auger drilling at depths ranging from 1.5 to 15.0 meters of overburden. The grit content, green bond, and dry bond properties of the Bearpaw samples from Regina compare favorably with the

Bearpaw samples from the refuge. However, the viscosities and the pH values of the Regina samples are higher and the water-loss properties are markedly lower, although not low enough to qualify the samples for use as drilling mud. If the Regina samples are representative of subsurface bentonite quality in the refuge, some bentonites might be suitable for use in taconite pellets as well as foundry sands.

The most serious obstacle to future bentonite strip mining in the refuge, other than the thinness of most of the beds, is the amount of overburden. In Wyoming the currently economic overburden:bentonite stripping ratio is about 10:1. In the Regina claims the maximum ratio is 10:1. Within the refuge the topography in the bentonite-bearing areas consists of relatively flat uplands dissected by broad tree-covered valleys. In addition, the thickest bentonite occurs about 60-90 m below the upland surface. Thus the stripping ratio may range from 0:1 to 50:1 in a little more than 1 kilometer. In addition, the shale slopes along the sides of steeper valleys would be unstable if mined. However, mining could be conducted in long narrow strips paralleling the larger drainages (e.g., Rock, Siparyann, and Duval Creeks) wherever warranted by the thickness and quality of the bentonite and the depth of overburden.

The thicker Bearpaw bentonites are continuous over large distances, but the bentonites in the Hell Creek Formation and the bentonitic mudstones in the Fort Union Formation are more lenticular. Bentonites from the Hell Creek Formation were collected in T. 20, 21, 22, and 23 N., along the Big Dry Arm. Elsewhere in the refuge the Hell Creek bentonites were considered too silty or too thin to be of value. Along the Big Dry Arm, vegetation is not a problem to mining, and the overburden is considerably less than in the western part of the refuge. Accessibility, however, is extremely limited and some of the more desirable beds crop out close to the lake in terms of both elevation and geography. The Hell Creek beds are not suitable for drilling mud or taconite pellets. Only two samples have green strengths high enough to warrant consideration for use in foundry sands.

In summary, a few bentonite beds in the Bearpaw Shale are thick enough and of good enough quality to be produced as a binder for foundry sands and possibly taconite pellets. Mining would be limited to relatively small areas on gently sloping valley sides and benches where the overburden:bentonite ratio is favorable. Predicted reserves for the Regina claims are 7,990 metric tons per hectare (4,750 short tons per acre) of processed bentonite (Bigsby and Sollid, 1975).

The Hell Creek bentonites are of low quality and of very limited extent. Deposits of this type have been used as sealants for stock ponds and irrigation ditches by ranchers, but many other deposits of material of comparable quality (including glacial till) exist in more accessible areas outside the refuge.

Sand and gravel

Principal sources of sand and gravel are small lenticular deposits of Pleistocene Wiota Gravel west of Fort Peck (Jensen and Varnes, 1964, pl. 1), and alluvium in some stream channels. Large alluvial deposits occur in the channels of the Musselshell River and Big Dry, Hell, Seven Blackfoot, Sand, and Armells Creeks. Most other stream channels contain pockets of sand, but those between Timber Creek and the western boundary of the refuge contain large amounts of admixed clay and shale chips. Gravel and boulders are locally exposed in deeply eroded gullies in the Pleistocene channels of the Musselshell River and its tributary in the U-L Bend National Wildlife Refuge. However, the upper part of the channel-fill is silt and the extent of any sand and gravel deposits deeper in the channels is not known. The Kintyre(?) Formation near U-L Bend might also provide satisfactory sand and fine gravel. Good quality sand could be obtained from the middle unit of the Fox Hills Sandstone and parts of the Hell Creek Formation by mechanical crushing.

Clinker

Discontinuous deposits of clinker occur in the Fort Union Formation in T. 21 and 22 N. along the Big Dry Arm. At some localities the clinker comprises 10-20 percent of the outcrop, but elsewhere it is totally absent. The extent of the burned area away from the outcrop is not known. Clinker is used extensively for road metal in McCone and Garfield Counties.

Riprap

Glacial boulders could be used for riprap, but no localized deposits are known to exist in the refuge. Although the Fox Hills, Hell Creek, and Fort Union Formations contain thick units of sandstone, the material is commonly poorly cemented with calcite and bentonitic mudstone and weathers too easily to be used as riprap.

Ceramic clay and shale

Because bentonitic clays and shales have a great affinity for water, they undergo extensive shrinking and cracking during desiccation and heating and are not suitable for the manufacture of ceramic products. Since most of the rocks exposed in the refuge contain intermixed bentonitic material, none of the samples were tested for ceramic properties. The Montana Bureau of Mines and Geology tested 15 samples from the Fort Union Formation in Daniels, Sheridan, and Roosevelt Counties and found them suitable for use in common brick (Sahinen and others, 1960). Ninety-five other samples from eastern Montana were poorly suited for brick and other fired products (Berg and others, 1970, 1973). Two samples of kaolinite from the Colgate Member of the Fox Hills Sandstone in sec. 28, T. 18 N., R. 27 E. exhibited good ceramic properties and could be blended with a more plastic clay to make white ceramic ware (Berg and others, 1970).

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CHAPTER C

HYDROCARBON EVALUATION OF THE CHARLES M. RUSSELL WILDLIFE REFUGE

By

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Introduction

The Charles M. Russell Wildlife Refuge is located along the banks of the Fort Peck Reservoir and the Missouri River in the Northern Great Plains of north-central Montana. In order to properly evaluate the oil and gas potential of proposed wilderness areas within the wildlife refuge an expanded area, as shown on figure 12, was investigated. This additional area was necessary to provide subsurface control to project into the Wildlife Refuge and to examine the characteristics of nearby hydrocarbon production.

The study area is situated on the northern flank of the Blood Creek syncline, the westernmost extension of the Williston Basin. The Williston Basin, which was a sedimentary basin during much of Paleozoic and Mesozoic time, is one of the largest structural basins in the United States with sedimentary rocks attaining a maximum thickness of greater than 4,877 m in the central part of the basin in western North Dakota. The Blood Creek syncline is bounded to the north by the Bowdoin dome and Little Rocky Mountains, to the west by the gravity faulting along the southern flank of the Bearpaw Mountains, and to the south by the Cat Creek anticline and Central Montana uplift.

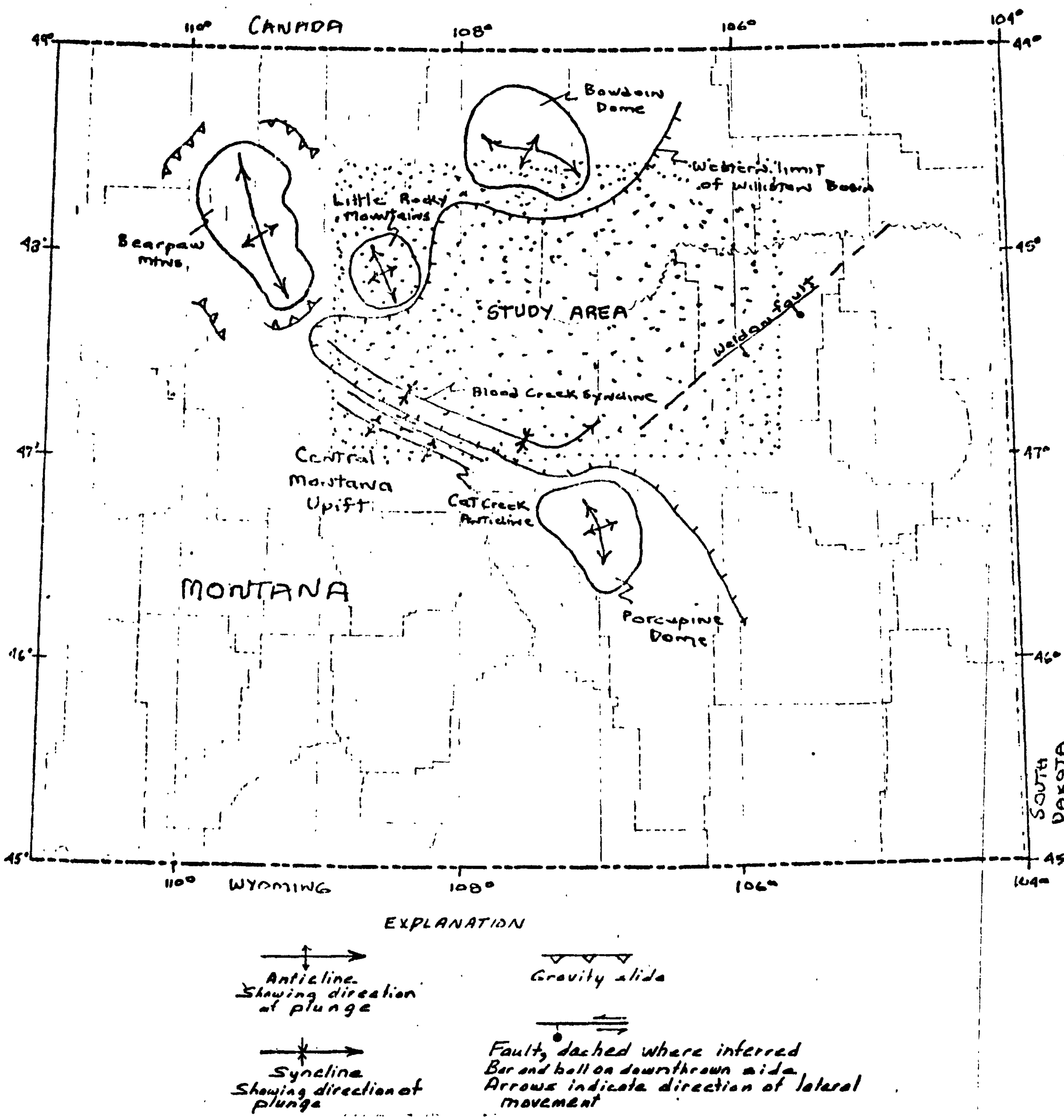
Although no production has been established in the wildlife refuge or areas in close proximity, the Williston Basin proper contains more than 150 oil fields that have produced approximately 800 million barrels of oil. In addition, major reserves of oil have been established in the Central Montana uplift to the south, and significant undetermined resources of shallow dry natural gas are being actively exploited in the Boudoin dome area to the north and Bearpaw Mountains area to the northwest.

To date, the hydrocarbon potential of the wildlife refuge has not been adequately assessed. There are no oil and gas exploratory wells within wildlife refuge and wells in adjacent areas are widely scattered and generally old, with poor drilling records. Because of the lack of significant structures, either detailed seismic work or closely spaced drilling must be done to locate small scale structures or stratigraphic traps.

Present study

Geophysical logs from all available oil and gas exploratory wells in the study area were examined in detail. When available, lithologic logs with other information such as porosity and hydrocarbon shows compiled by the American Stratigraphic Company were used to aid correlation and identification of potential reservoir and source rocks. Representative cross sections utilizing all available deep tests were made showing stratigraphic relations of major producing and non-

Figure 12.--Study area and major structural elements, central and eastern Montana.



producing units. Core samples were taken at selected intervals from nearby wells for source rock evaluation.

Acknowledgments

J. H. Clement of Shell Oil Co. and C. W. Spencer of the U.S. Geological Survey provided invaluable information on the general geologic setting of the study area. J. H. Hughes of the Montana Board of Oil and Gas Conservation granted permission to sample cores from nearby wells for source rock studies. C. W. Spencer examined kerogen slides to determine thermal maturation of organic matter. G. E. Claypool of U.S. Geological Survey helped in interpretation of source rock analyses.

Subsurface stratigraphy

Upper Cretaceous and Tertiary rocks with Pleistocene glacial drift constitute the exposed bedrock of the Charles M. Russell Wildlife Refuge (Chapter A). Strata ranging in age from Precambrian to Tertiary have been penetrated in nearby wells, and only rocks from the Permian and Triassic Systems are absent in this area (see figs. 13 and 14).

The following discussion covers only the stratigraphic units older than the Cretaceous Judith River Formation of the Montana Group, the oldest unit exposed in the wildlife refuge. Although many of these units have been described by Knechtel (1959) from exposures in the Little Rocky Mountains, most of the nomenclature, thicknesses, and descriptions are from subsurface control. Units from all systems penetrated will be briefly discussed because all but the Cambrian System are productive of hydrocarbons. Most systems have potential reservoir rock and many contain organic-rich shales, which may have been a hydrocarbon source for adjacent reservoir beds. Figures 15 and 16 are stratigraphic sections showing major lithologies, ages, and thickness of subsurface units. Many of the units, recognized or present only in the subsurface, have widespread usage by petroleum geologists, but have not been formally accepted by the U.S. Geological Survey.

Precambrian

Precambrian rocks have been penetrated in only one nearby well, the Seaboard-Honolulu Loberg No. 1 well, located in SE1/4 NE1/4 sec. 26, T. 30 N., R. 36 E., where drilling samples are interpreted to be granite or gneiss of pre-Belt age. Because of lack of well data, distribution of rock types over the rest of the area is poorly known. As discussed in detail in later sections, the thickness and distribution of many Paleozoic and Mesozoic rocks and associated hydrocarbon accumulations were controlled by intermittent movement on ancestral features, many of which originated in Precambrian rocks.

Figure 13.--Correlation chart of Paleozoic rocks for Charles M. Russell Wildlife Refuge and adjacent areas, showing producing intervals.

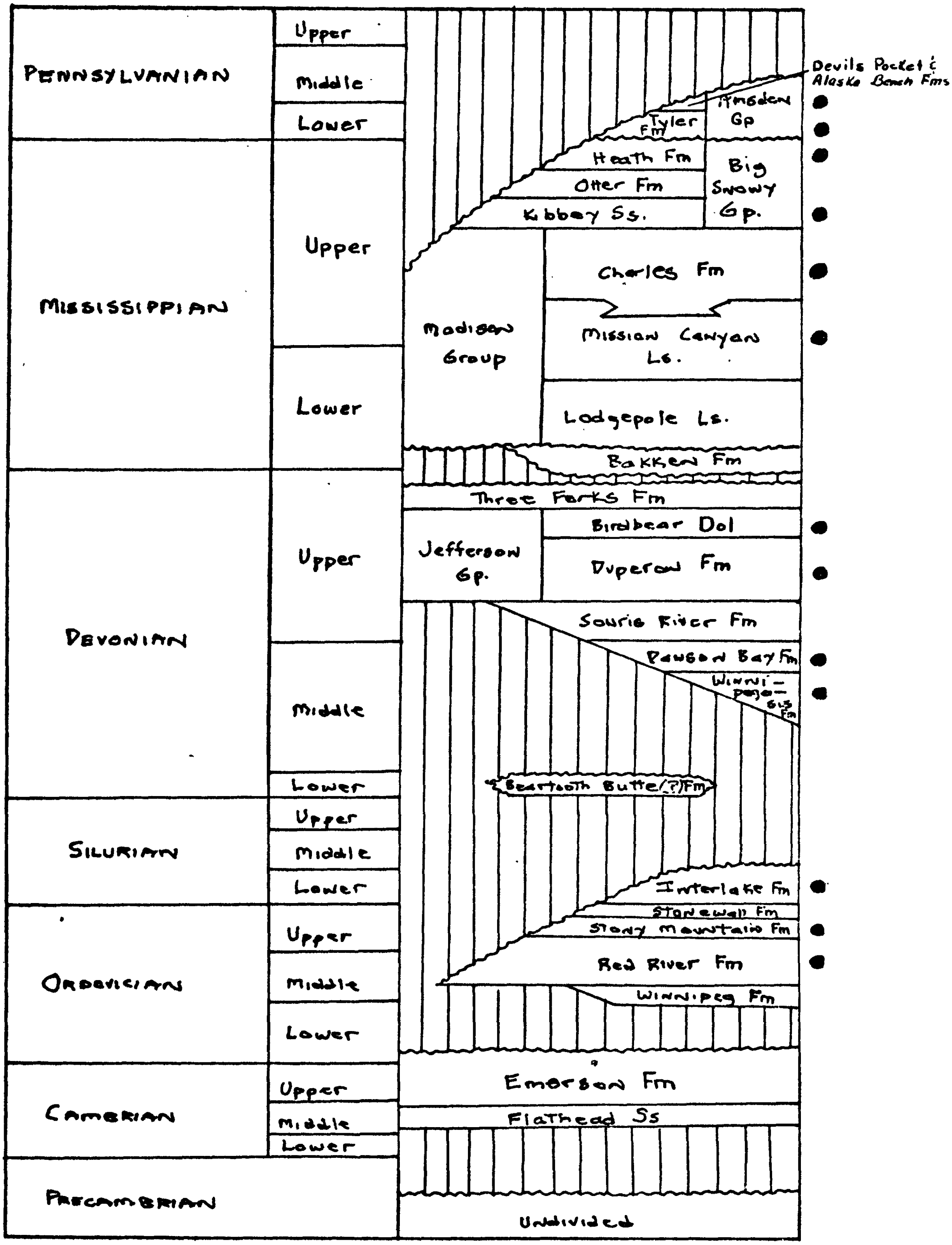
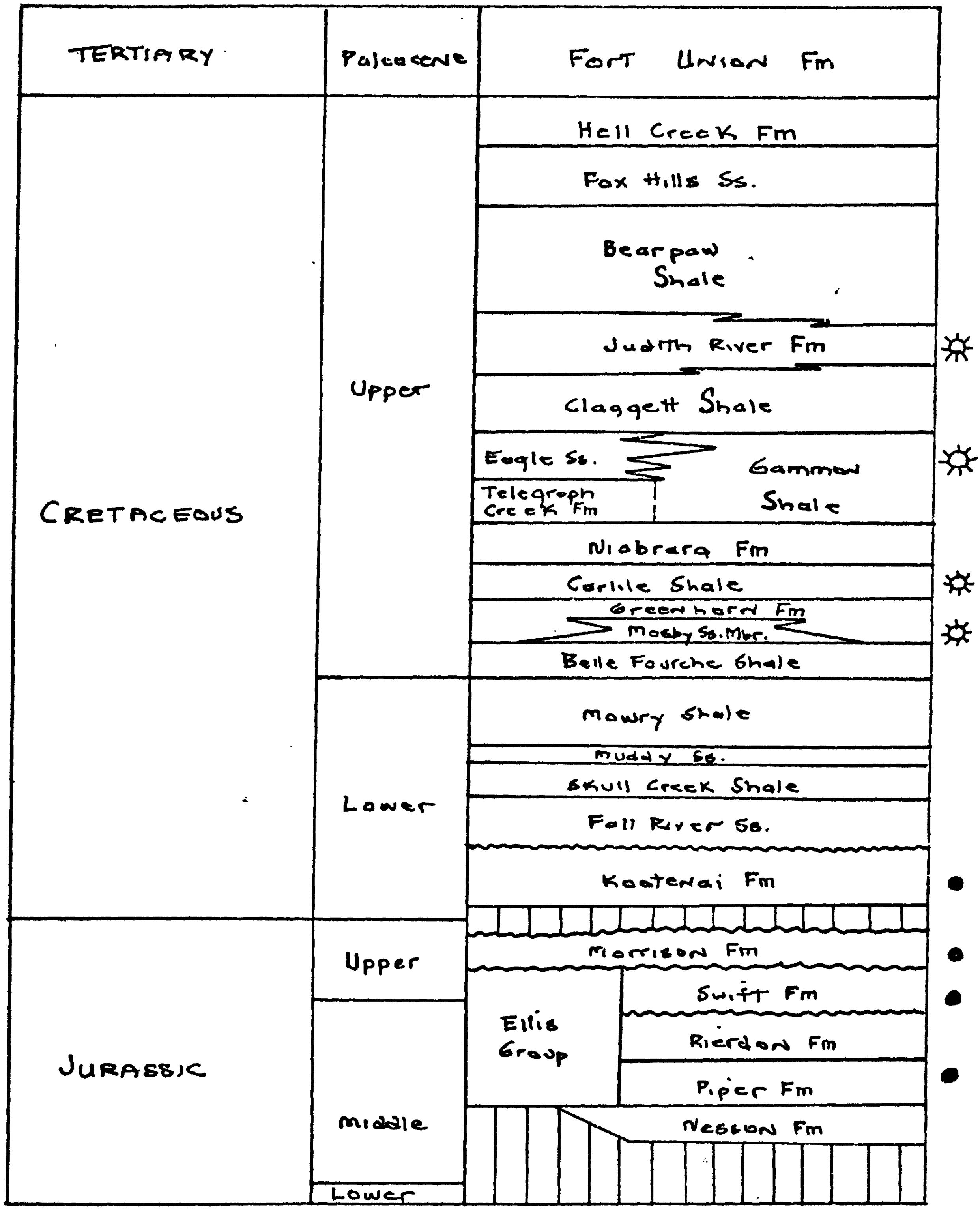


Figure 14.--Correlation chart of Mesozoic rocks for Charles M. Russell Wildlife Refuge and adjacent areas, showing producing intervals.



Cambrian

Cambrian rocks, penetrated in only one well in the study area, are assigned to the Flathead Sandstone and Emerson Formation (part). The basal Flathead Sandstone, which is 6 m thick in the Seaboard-Honolulu Loberg No. 1 well and less than 15 m thick in the vicinity of the Little Rocky Mountains (Knechtel, 1959, p. 727) rests unconformably on an irregular Precambrian surface with considerable local relief. The unit consists of fine to coarse-grained quartzose sandstone with dolomitic cement.

The overlying Emerson Formation, which is 315 m thick in the Seaboard-Honolulu Loberg No. 1 well and between 290 and 335 m at its type locality in Emerson Gulch in the Little Rocky Mountains (Knechtel, 1959, p. 72), is predominantly dark gray to green shale with upward increasing interbeds of lilght-gray to white, glauconitic sandstone, sandy and glauconitic marlstone, and fossiliferous limestone. As shown by Lochman (1950, p. 328) in the Little Rocky Mountains area, deposition of the Emerson Formation continued into Early Ordovician time.

To date, hydrocarbon production from the Cambrian in the northern Rocky Mountain area has been extremely limited with no established production.

Ordovician

Ordovician rocks in the study area are assigned to the Winnipeg, Red River, Stony Mountain, and Stonewall Formations. Unconformably overlying the Emerson Formation, which is partially of Early Ordovician age, is the Winnipeg Formation. The Winnipeg Formation is thickest in the central part of the Williston basin (Foster, 1972, fig. 5), but pinches out by deposition in the study area between wells 3 and 4, section A-A', plate 3. Carlson (1958, 1960) described in detail and named three members of the Winnipeg in western North Dakota: a basal sandstone, a medial shale, and an upper dolomitic sandstone. However, only calcareous sandstone with minor dolomite interbeds is present in the eastern part of the study area.

The Red River Formation conformably overlies the Winnipeg Formation and unconformably overlies older Cambrian strata where the Winnipeg Formation is absent. As illustrated in figure 17, the Red River Formation is present over the entire area except the extreme southwestern corner. The Red River ranges in thickness from 0 to 104 m in the study area, but attains a thickness greater than 244 m in the central part of the Williston basin (Foster, 1972, p. 77). In the thick central part of the basin, the Red River Formation consists of limestone, but grades into light-gray to tan dolomite on the basin

Figure 15.--Generalized stratigraphic section for Paleozoic rocks for Charles M. Russell Wildlife Refuge and adjacent areas.

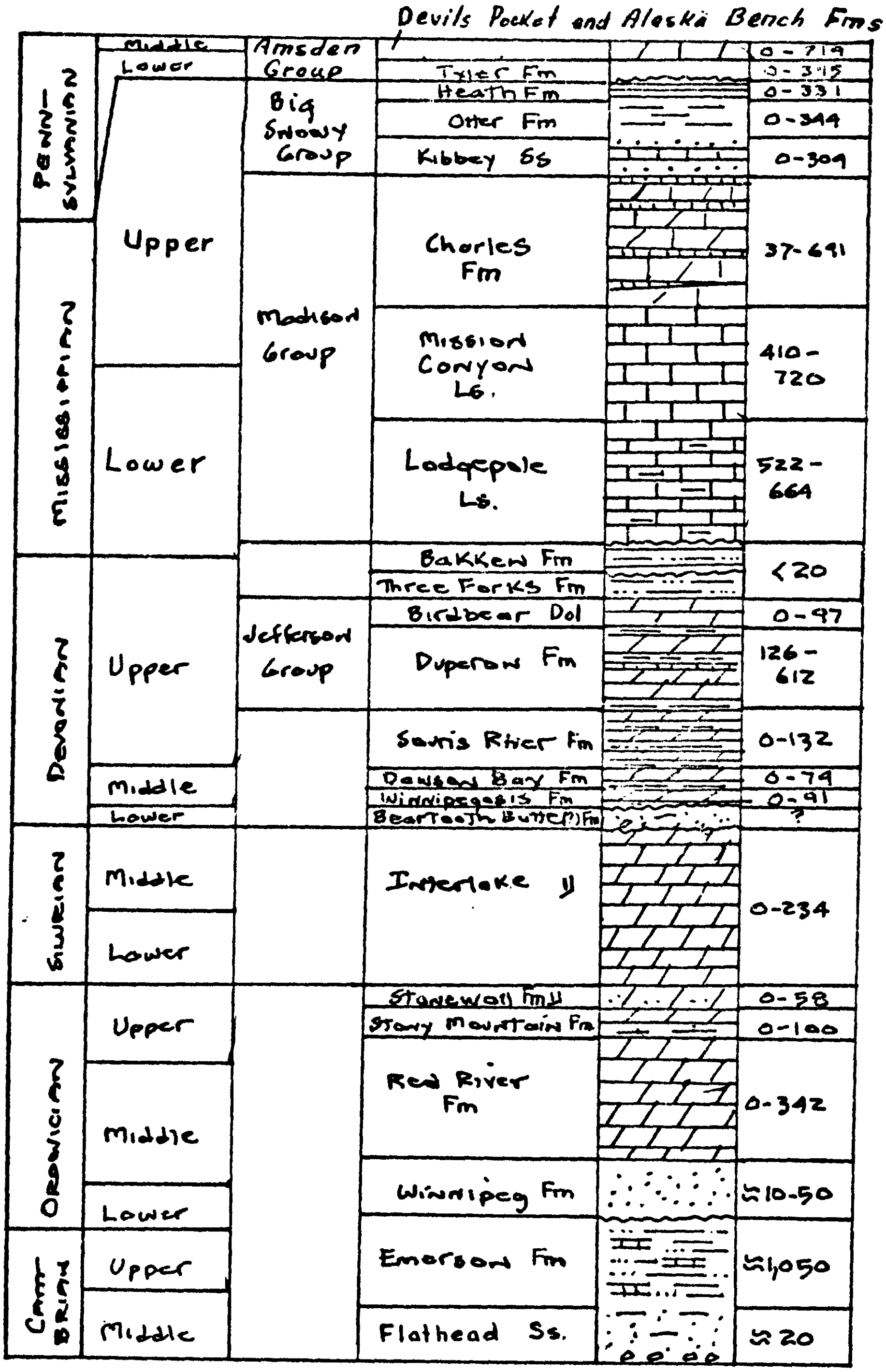
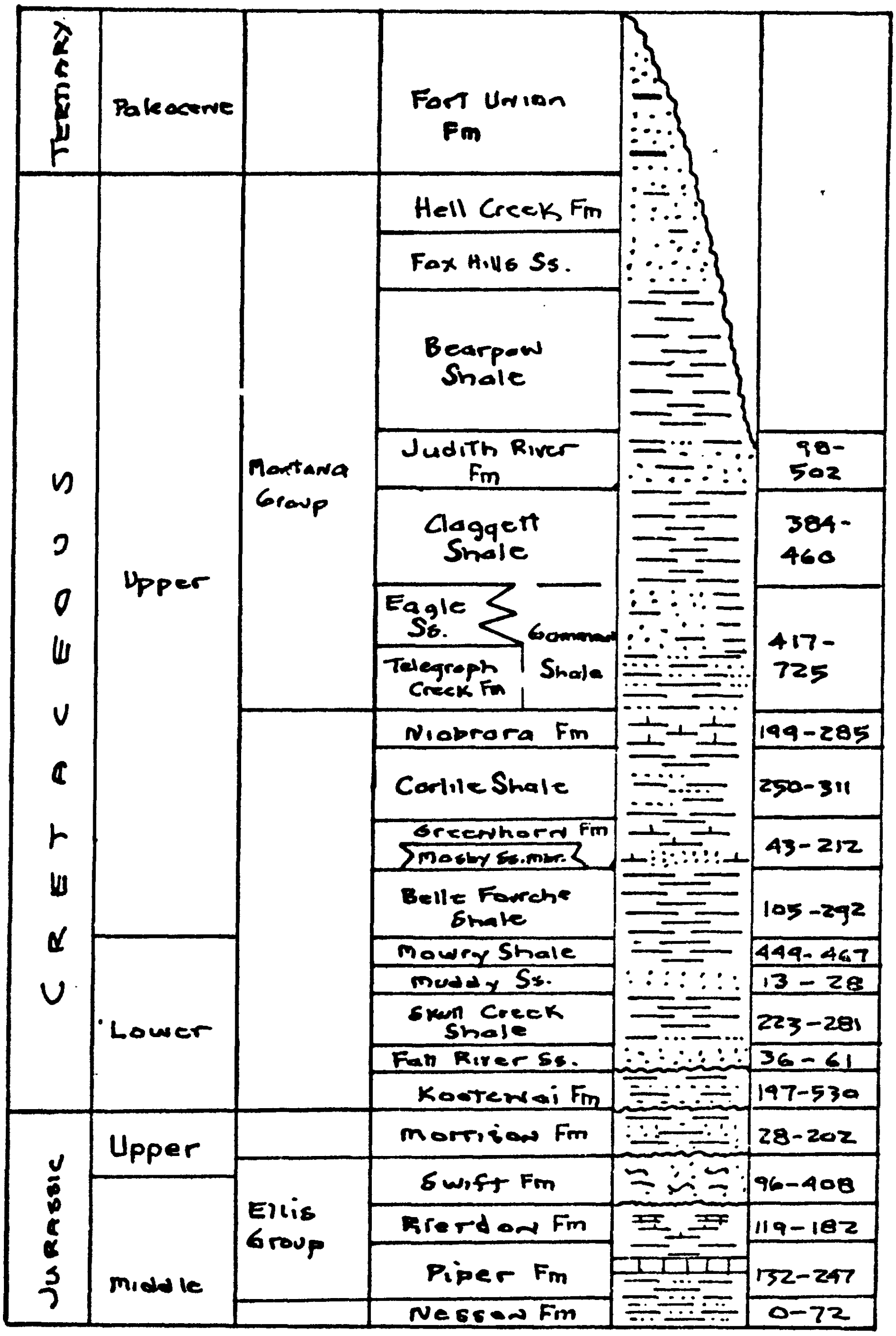


Figure 16.--Generalized stratigraphic section of Mesozoic rocks for Charles M. Russell Wildlife Refuge and adjacent areas.



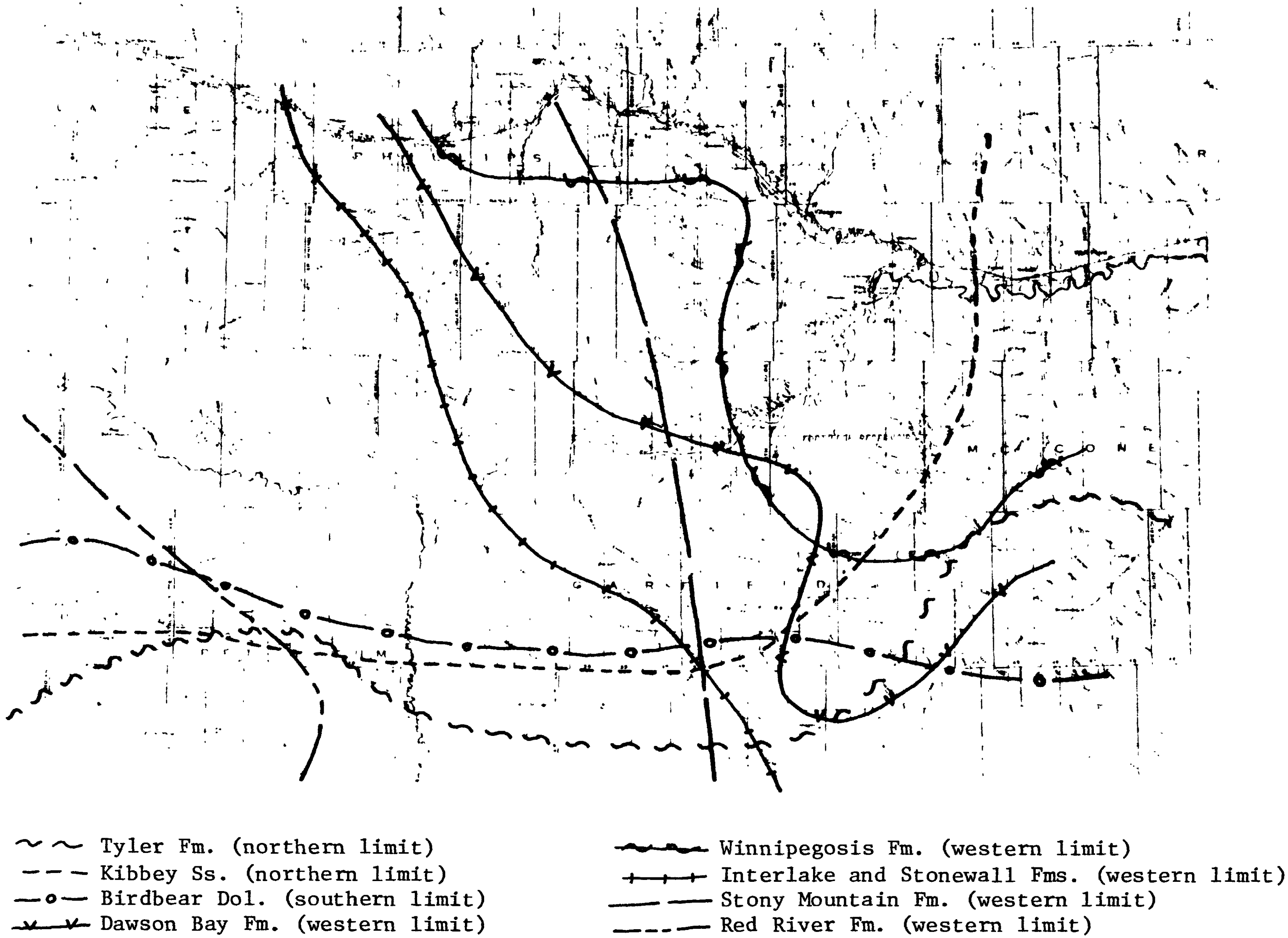


Figure 17.--Approximate limits of producing formations of western Williston Basin and central Montana.

margins as exemplified in the study area. The rhythmic evaporite-carbonate cycles typical of the uppermost part of the formation in the central part of the basin are absent in the study area.

Conformably overlying the Red River Formation is the Stony Mountain Formation, which ranges from 0 to 30 m in thickness. Figure 17 shows the western erosional extent of the unit. The Formation consists of the Gunton Member at the top, sometimes called the "Stony Mountain Shale Member", and the Stoughton member at the base. The Stoughton Member is comprised of gray argillaceous limestone and calcareous shale. The contact between this member and the underlying Red River carbonates provides a key marker horizon for subsurface correlations. The Gunton Member contains light-colored dolomite which becomes difficult to distinguish from the Red River in the study area where the Stoughton Member thins or is absent.

The Upper Ordovician Stonewall Formation, which conformably overlies the Stony Mountain Formation, ranges in thickness from 0 to 18 m and has the same approximate limits as the Silurian Interlake Formation (fig. 17). The lithology of the Stonewall is light gray to white dolomite which is commonly sandy at the base.

The Williston basin is the major producing area of Ordovician hydrocarbons in the Rocky Mountains. Main production to date has come from the Red River Formation with minor production from the Gunton Member of the Stony Mountain Formation along the Cedar Creek anticline. Production has been established from structural-stratigraphic traps along a belt that marks a change from limestone to dolomite. This belt coincides with porosity-permeability zones developed in algal-stromatolite sequences which probably formed in a tidal-flat environment bordering the basin (Foster, 1972, p. 85). In northeast Montana, Red River production is associated with thinning on paleostructures (Ballard, 1969, p. 16-17).

Dow (1974, p. 1255) identified the medial shale of the Winnipeg Formation as the source rock for most lower Paleozoic oil in the Williston Basin, particularly that in the Red River. However, the shale unit is absent in the study area and can be considered a source bed only if long range migration took place. The Stoughton Member at the base of the Stony Mountain Formation is a potential source bed in the eastern part of the study area.

Silurian

The Interlake Formation conformably overlies the Stonewall Formation and is Early to Middle Silurian in age (Ross, 1957). The formation is more than 305 m thick in the central part of the basin, but thins markedly by a combination of depositional thinning and post-Silurian erosion toward the basin margins. The western extent of the Interlake, which attains a maximum thickness of 71 m in the study area, is shown on figure 17. The formation is characterized by predominantly light gray to white dolomite with minor green shale partings.

Significant oil accumulations were generated from tidal zone organic debris along the then-positive Cedar Creek and Nesson anticlines (Hansen, 1972, p. 265).

Devonian

Middle and Upper Devonian and possibly Lower Devonian rocks are in the study area (fig. 13). Red beds included in the basal part of the Winnipegosis Formation of Middle Devonian age may include strata of the Beartooth Butte Formation of Early Devonian age (Sandberg and Mapel, 1967). Overlying the Winnipegosis is the Middle Devonian Dawson Bay Formation and the following Upper Devonian units in ascending order: Souris River Formation, Jefferson Group including Duperow and Birdbear Formations, and the Three Forks Formation. The Bakken Formation spans the Devonian-Mississippian boundary in north-central Montana.

The Winnipegosis Formation, restricted to the northeast part of the study area as shown in figure 17, unconformably overlies the Silurian Interlake Formation. Here, the Winnipegosis Formation is as much as 28 m thick and consists of two units. The lower unit is red dolomitic shale and siltstone and argillaceous dolomite. It is equivalent to the Ashern Formation (Baillie, 1951), a term used extensively in Canada by surface geologists, but included in the Winnipegosis Formation by Sandberg and Hammond (1958). The upper unit, which is less extensive, is light gray to light brownish gray crystalline dolomite.

The Dawson Bay Formation conformably overlies the Winnipegosis Formation and unconformably overlies the Interlake Formation beyond the limits of the Winnipegosis. The formation, whose limits are shown on figure 6, is as much as 24 m thick. Similar to the Winnipegosis, the Dawson Bay Formation is divided into a lower argillaceous unit and an upper carbonate unit. The argillaceous unit contains grayish-red dolomitic shale or siltstone and argillaceous dolomite. The upper carbonate unit is brownish-gray crystalline dolomite.

The Upper Devonian Souris River Formation and the more extensive Duperow Formation conformably overlie Middle Devonian units in the eastern part of the study area, but unconformably overlie the Interlake, Stonewall, Stony Mountain, Red River, Winnipeg, or Emerson Formation on the margins of the Williston Basin in the western part of the study area.

The Souris River Formation, ranging in thickness from 0 to 40 m, is absent in the southwestern part of the study area as shown in wells 1 through 4, section A-A', plate 3. It contains gray, brownish-gray, greenish-gray, argillaceous olomite and limestone, shale, siltstone, and anhydrite.

The Duperow Formation is the lower formation of the subsurface Jefferson Group and is the most extensive Devonian unit in the Williston Basin. In the study area, the Duperow ranges in thickness from 38 to 187 m and is composed of light- to-dark gray, brownish-gray and brown limestone, argillaceous limestone, dolomitic limestone, dolomite, and anhydrite interbedded with thin beds of dolomitic shale and siltstone, and argillaceous dolomite. The upper 3 to 6 m is generally greenish gray dolomitic shale or shaly dolomite. The Duperow conformably overlies the Souris River Formation over most of the study area and is differentiated from the thinner bedded and more argillaceous beds of the Souris River.

The overlying Birdbear Dolomite, the upper unit of the Jefferson Group, is commonly known as the Nisku Formation by petroleum geologists. The formation attains a maximum thickness of 30 m in the study area, but is absent in the southern part (fig. 17). Over most of the Williston Basin, the Birdbear forms a marker bed because of its uniform thickness and lithology. The Birdbear is light gray to brownish gray, finely crystalline, saccharoidal dolomite. The anhydritic facies which is present in the upper part in the central part of the basin is not developed in study area.

The Upper Devonian Three Forks Formation attains a thickness of 19 m in the study area and has the same approximate thickness as Birdbear Formation (Sandberg, 1961, plate 11). The Three Forks contains greenish gray, grayish orange, and grayish red dolomitic shale and siltstone, and marl.

In the central part of the Williston Basin, deposition was essentially continuous between the Three Forks and overlying Bakken Formations, but along the western margin there is an erosional disconformity between the units. The Bakken Formation is less than 3 m thick in the study area and its equivalent is included with the Three Forks Formation on cross sections. The unit, which consists of dark gray shale, is absent by erosion south of the Missouri River (Sandberg and Mapel, 1967, fig. 10).

Significant Devonian production in the Williston Basin is from the Duperow Formation on the Nesson anticline of North Dakota, where there are several pay zones in the cyclic deposits. Recently, important production has been established from the Birdbear Formation with minor amounts from the Winnipegosis and Dawson Bay Formations in northeast Montana. Swenson (1967) showed the relationship between oil accumulations and solution of salt and collapse for Birdbear production. Kinard and Cronoble (1969) believed that most production of the Winnipegosis was structurally trapped with fracturing playing an important role in development of permeability.

Shale in the Upper Devonian-Lower Mississippian Bakken Formation has been identified as the principal source rock for the Madison reservoirs in the Williston basin (Dow, 1974, p. 1257). Dow (1974) did not, however, type the Devonian reservoired oils to any of his three major source beds: Winnipeg, Bakken, or Heath. This Devonian oil was probably then generated locally in restricted source rocks. Probable Souris River, Duperow, and Three Forks Formations.

Mississippian

The Mississippian System in the study area is represented by the Madison and Big Snowy Groups. The Madison Group, which is present over the entire area, is divided, in ascending order, into the Lodgepole Lower Mississippian) and Mission Canyon Lower and Upper (Mississippian) Limestones and the Charles Formation (Upper Mississippian age). The Big Snowy Group of Chester age, with its type section in the Big Snowy Mountains of the Central Montana Uplift, consists of, in ascending order, the Kibbey Sandstone, and Otter and Heath Formations.

The Lodgepole Limestone, which disconformably overlies the Bakken Formation, varies in thickness from 162 to 202 m with a general thickening trend to the south. The formation consists of light- to dark-gray fragmental limstone with minor argillaceous partings which is typical of the shelf facies (Nordquist, 1953). In the subsurface, the unit locally contains mounds of algal and crinoid debris.

The conformably overlying Mission Canyon Limestone ranges in thickness from 125 to 219 m. The shelf facies of this unit in the study area is characterized by coarser and more fragmental texture and more massive bedding than the shelf facies of the Lodgepole (Sandberg, 1962). Ooolitic limestones and concentrations of nodular chert are common. Because the contact between the Mission Canyon and Lodgepole is gradational, the contact is placed at the change from the more argillaceous and thinner bedded limestone below to the less argillaceous and thicker bedded limestone above.

The Charles Formation is as much as 211 m thick in the southern part of the study area but thins to 11 m in the north. It is less widely distributed regionally than the underlying units of the Madison Group and is absent in north central Montana by pre-Pennsylvanian and pre-Jurassic erosion (Craig, 1972, fig. 6). The cyclically interbedded lithologies of the Charles are limestone, dolomite, anhydrite, and shale. Salt is the dominant evaporite in the central part of the basin. The contact between the Mission Canyon and Charles is generally placed at the base of the lowest anhydrite or salt bed. Because these evaporite beds are not widespread, the position of the contact varies vertically and the lower Charles is a facies of the upper part of Mission Canyon Limestone.

The Big Snowy Group is confined by erosion to the southern part of the study area, a narrow belt which coincides with the Central Montana uplift. This belt extends eastward into a large bulbous area that covers most of North Dakota and northwestern South Dakota (Craig, 1972, fig. 7).

The basal Kibbey Sandstone conformably overlies the Madison Group and is the most widespread formation of the group (fig. 17). The formation, which attains a maximum thickness of 94 m has three informal units. The basal unit is mostly red shales and siltstones. The middle unit is a marker bed of limestone and the upper unit is interbedded sandstone, shale, and siltstone with minor amounts of anhydrite.

The overlying Otter Formation has a maximum thickness of 102 m and is less extensive than the underlying Kibbey, but more extensive than the overlying Heath Formaton. The Otter is mostly greenish gray shale with interbedded argillaceous shale and dolomite. The less extensive Heath Formation is as much as 101 m thick and contains interbedded dark gray to black, organic rich shales and limestones.

The Ratcliffe zone, an informal term, of the Charles Formation is the main Mississippian oil-producing horizon of the Williston Basin. The production, which is centralized in northeast Montana and northwest North Dakota, is established in algal pelletoid mounds which formed in the shallower parts of the Charles sea (Hansen, 1966, p. 2262-2263). This mound development was partly controlled by movement along ancient fault trends. Minor amounts of oil have also been produced from the Mission Canyon Limestone along Cedar Creek anticline.

The only other Mississippian production is from the Kibbey Sandstone along the northwest side of the Weldon fault in the Weldon field which marks the most westerly production in the Williston Basin. Here the oil was entrapped by a combination of regional westward truncation of the pay section, the development of a tight updip barrier, and the formation of a structural nose (Edmisten and Foster, 1969).

As stated earlier, Bakken shales have been identified as the source rock for Mississippian oil. Dow (1974, p. 1258) stated that the expelled Bakken oil migrated vertically through fracture systems into the overlying reservoirs. This upward migration was generally cut off by the Charles evaporites. One exception, however, is the Weldon field, where Bakken oil migrated upward along the Weldon fault into the Kibbey Sandstone. Mississippian oil also may have been generated from shale partings in the Madison carbonates.

The Heath Formation of the Big Snowy Group contains dark colored, organic-rich shales that appear to be potentially excellent source beds. Kranzler (1966) noted the relationship between the position of the Heath shales and the oil-bearing Tyler sandstones further suggesting the Heath as a source rock.

Pennsylvanian

Pennsylvanian rocks unconformably overlie the Big Snowy Group and are represented by the Tyler, Alaska Bench and Devils Pocket Formations of the Amsden Group. Because these rocks are restricted areally to the extreme southern part of the study area and are not present in the

Wildlife Refuge, the unit does not have any hydrocarbon potential, but a brief discussion adds to general understanding of geologic history of the area.

The basal Tyler Formation attains a maximum thickness of 120 m in the study area, but is confined by erosion to the southern part (fig. 17). The Tyler is divided into two members separated by a limestone marker. Both members are characterized by siltstones and shales and locally thick beds of sandstone.

The overlying Alaska Bench and Devils Pocket Formations are as thick as 68 m, but are present only in wells 3 and 11, section A-A', and well 4, section B-B', plate 3. The unit contains light colored limestone and dolomite with minor shale.

The Tyler Formation has provided substantial oil production in the Central Montana Uplift with minor production in the Williston basin of southwestern North Dakota. Production in the Central Montana uplift which was a narrow trough during Early Pennsylvanian time, is predominantly stratigraphically controlled in channel sandstones which are situated in a variety of structural positions. Minor production controlled primarily by structure has been established from carbonates of the Amsden along Cat Creek anticline.

As postulated earlier, the dark, organic-rich shales of the Heath Formation are probably the source rock for the Tyler oil in the Central Montana Uplift. In southwestern North Dakota, Tyler oil has been correlated to organic extracts of adjacent Tyler shales (Williams, 1974).

Jurassic

Jurassic rocks in the study area are assigned to the Nesson, Piper, and Rierdon Formations of Middle Jurassic age, the Swift Formation of Middle and Late Jurassic age, and the Morrison Formation of Late Jurassic age. The Piper, Rierdon, and Swift Formations constitute the Ellis Group. Except for the Nesson Formation, these Jurassic rocks are present over the entire area and thin gradually toward the margins of the Williston basin due to marine onlap.

The Nesson Formation is present in only one section, well 1 on section B-B', plate 3. There it consists of 22 m of red marlstone, and shale, anhydrite, limestone, and dolomite. The marlstone and shale are red in color.

The Piper Formation conformably overlies the Nesson Formation in the above one well, but elsewhere it unconformably overlies units ranging progressively in age from the Mississippian Charles Formation in the north to the Pennsylvanian Amsden Group in the south. The formation ranges in thickness from 40 to 75 m, and consists of three widespread members, named, in ascending order, the Tampico Shale Member, Firemoon

Limestone Member, and Bowes Member by Nordquist (1955). The Tampico is mostly gray to greenish-gray shale with interbedded sandstone and limestone. The overlying Firemoon forms a distinctive marker bed consisting of light colored limestone. The Bowes is brownish-red shale with interbedded limestone.

The Rierdon Formation conformably overlies the Piper and varies in thickness from 36 to 55 m. This unit is greenish-gray calcareous shale that grades upward into marlstone.

The Swift Formation consists of greenish-gray interbedded siltstone and shale overlain by glauconitic quartzose sandstone with interbedded siltstone and shale. The formation unconformably overlies the Rierdon Formation and ranges in thickness from 29 to 124 m.

The Swift is overlain unconformably by the Morrison Formation which contains mudstones, shales, siltstones, sandstones, and thin beds of coal. The thickness of the Morrison varies considerably from 9 to 62 m.

The closest and most significant Jurassic production is from the Bowes dome on the north flank of the Bearpaw Mountains. The upper part of the Firemoon Limestone Member and sandy oolitic limestone in the lower part of the Bowes Member of the Piper Formation produce oil on a closed, relatively flat structure (Hunt, 1956). There is also minor Firemoon production in the Central Montana Uplift to the south.

In the Sweetgrass arch area in northwestern Montana, the Swift Formation is the main productive unit of both oil and gas in the Jurassic. Lateral facies changes in glauconitic Swift sandstones combined with structure are the main trapping mechanisms in the area.

Calcareous shale and marlstone of the Rierdon Formation deposited under normal marine conditions are probably the source rocks for Jurassic oil in the areas discussed.

Cretaceous

Upper Cretaceous and Tertiary rocks crop out in the Charles M. Russell Wildlife Refuge. Older Cretaceous rocks are present beneath the entire study area and are as thick as 1,067 m. In the study area, Lower Cretaceous rocks are assigned, in ascending order, to the Kootenai Formation, Fall River Sandstone, Skull Creek Shale, Muddy Sandstone, and Mowry Shale. Upper Cretaceous rocks are assigned to the Belle Fourche Shale, Greenhorn Formation with Mosby Sandstone Member, Carlile Shale, Niobrara Formation, Telegraph Creek Formation, and Eagle Sandstone which grade eastward into the Gammon Shale, Claggett Shale, and Judith River Formation. The upper part of the Judith River Formation, Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation are the Cretaceous units exposed within the Wildlife Refuge.

The basal Kootenai Formation lies unconformably on the Upper Jurassic Morrison Formation over the entire study area. The unit ranges in thickness from 60 to 162 m. A basal sandstone that is commonly conglomeratic forms a sharp contact with the underlying Morrison. The rest of the formation contains light to dark gray siltstones and shales with siderite pellets and interbedded sandstone.

The Fall River Sandstone, 11 to 12 m thick, consists of light gray, quartzose sandstone with interbedded shale and siltstone. The Fall River unconformably overlies the Kootenai Formation, while younger Cretaceous units are in conformable relationship.

The Skull Creek Shale is a gray, bentonitic shale that ranges in thickness from 68 to 86 m. The basal 30 m are gradational with the underlying Fall River Sandstone and contain interbedded sandstone, siltstone, and shale.

The Muddy Sandstone ranges in thickness from 4 to 9 m and has a gradational contact with underlying Skull Creek shale. It varies from shaly siltstone to glauconitic sandstone.

The overlying Mowry Shale is characterized by gray bentonitic shale. The upper part of the formation consists of light gray, siliceous shale with interbeds of shaly sandstone and siltstone. The Clay Spur Bentonite Bed at the top of the formation is a widespread marker bed the top of which is designated as the Lower-Upper Cretaceous boundary. The Mowry is uniform in thickness ranging from 137 to 142 m.

The overlying Belle Fourche, Greenhorn, Carlile, and Niobrara Formations form a thick sequence of predominantly marine shale in the lower part of the Upper Cretaceous. The Belle Fourche Shale at the base consists of medium- to dark-gray bentonitic shale with interbeds of bentonite. The formation is more than 61 m thick with a maximum of 89 m over most of the area where it is overlain by the Mosby Sandstone Member of the Greenhorn Formation. However, in the extreme eastern part of the study area where the Mosby is absent by nondeposition, the Belle Fourche thins markedly to 32 m.

The Greenhorn Formation consists of dark gray calcareous shale with local interbeds of limestone. The Mosby Sandstone Member, locally known as the Phillips sandstone, an informal economic unit, forms the basal unit of the formation over most of the study area. This 8 to 15 m unit contains calcareous sandstone with minor shale interbeds. The Greenhorn Formation ranges in thickness from 13 to 17 m over most of the area where Mosby is present to greater than 65 m in the eastern part of the study area where it thickens at the expense of the underlying Belle Fourche.

The Carlile Shale, termed the Bowdoin sandstone, an informal economic unit, by petroleum geologists, is a dark gray shale with interbeds of sandy shale or shaly sandstone in the middle. The formation ranges in thickness from 76 to 95 m.

The overlying Niobrara Formation gradually thins from 87 m in the west to 61 m in thickness in the eastern part of the study area. The formation contains- medium to dark-gray shale which is calcareous and speckled at the top.

West of the Musselshell River, the Telegraph Creek Formation and Eagle Sandstone overlie the Niobrara Formation. The Telegraph Creek Formation, which is about 51 m thick, consists of interbedded sandy shale, siltstone, and thin-bedded sandstone. The upper and lower contacts are gradational with the shale of Niobrara below and sandstone of Eagle above.

The Eagle Sandstone forms an eastward thinning unit of wedge clastics which is about 91 thick in the west and pinches out by deposition near the Musselshell River to the east. The Eagle is mostly light gray, in part glauconitic sandstone with thin sequences of marine and nonmarine shale and mudstone.

East of the Musselshell River, the Telegraph Creek-Eagle interval is assigned to the Gammon Shale which thickens eastward to as much as 221 m. The Gammon is comprised of dark gray shale with interbeds of bentonite and siltstone.

The Claggett Shale is lithologically similar to the underlying Gammon Shale but thins eastward from 140 to 117 m. The Ardmore Bentonite Bed, a 9- to 12-m zone of bentonite beds at the base of the Claggett, forms an excellent time marker in the northern Rocky Mountains.

Finally, the Judith River Formation forms another eastward projecting wedge of clastics similar to the Eagle Sandstone. The Judith River thins to 15 m in the east from a maximum of 153 m in the west. In the western part of the study area, the formation contains a basal marine sandstone overlain by nonmarine mudstone, sandstone, and lignite. This succession grades eastward into predominantly marine sandstone with thin shale and siltstone interbeds.

Nearby Cretaceous production is predominantly natural gas from relatively shallow depths. Large reserves of natural gas have been discovered in the Eagle Sandstone on the flanks of the Bearpaw Mountains. This production is controlled primarily by gravity faulting set off by Laramide volcanism in the Bearpaw Mountains (Reeves, 1924). Minor production is also established from the Carlile Shale and Judith River Formation in this area.

Other more recent discoveries have been made in the vicinity of the Bowdoin dome. This natural gas production is from shallow, poorly developed sandstones of shelf origin in the Mosby Sandstone Member of Greenhorn Formation and the Carlile Shale, known locally by informal names--the Phillips and Bowdoin sandstones, respectively--by subsurface petroleum geologists. Early drilling in the 1930's showed this production to be structurally controlled. Recent discoveries have proven this production to be stratigraphically controlled over a much larger area.

Minor Eagle gas was also found on Guinn dome in 1931. However, this gas has a low BTU value and has never been commercially produced.

The Cat Creek oil field, which actually is a group of three fields occupying separate closures along the Cat Creek anticline, was one of the first oil fields in Montana. Significant production was established from the Fall River Sandstone and a stray sandstone in Kootenai Formation with minor production from the Morrison and Swift Formations and from the Amsden Group.

Nixon (1973) showed the Mowry shale to be a major source rock for the Muddy Sandstone and early Late Cretaceous reservoirs in the northern Rocky Mountains. However, he further stated that the Mowry was not buried deep enough over most of Montana to have generated oil. Source rocks for nearby shallow gas production do not, however, require deep burial for generation. Details of hydrocarbon generation will be briefly discussed in another section. Cretaceous oil in the Cat Creek field probably migrated up from Paleozoic source beds along major fault and fracture systems into Cretaceous reservoirs.

Structural geology

The Charles M. Russell Wildlife Refuge and adjacent study area are situated on the northern flank of the Blood Creek syncline in north-central Montana (fig. 12). This east-west trending syncline, a product of the Late Cretaceous-early Tertiary Laramide orogeny, is a westerly extension of the Williston Basin, one of the largest structural basins in North America. The area is bounded on the north by the Bowdoin dome, a major fold, and by the Little Rocky and Bearpaw Mountains which are of volcanic origin. These features are all Laramide structures that had no effect on earlier geologic history of the area, except that they may have been submarine platforms during Late Cretaceous time. To the south, the Blood Creek syncline is bordered by the Central Montana Uplift, an area which has had a complex structural and stratigraphic history since early Paleozoic time.

During most of the Paleozoic Era, the study area was located along the western shelf area of the huge intracratonic Williston Basin, which had a depositional center in northwesern North Dakota. During Cambrian through Early Ordovician, Upper Devonian, and Mississippian times, the study area was part of a broad shelf area adjacent to the Cordilleran geosyncline in western Montana and Idaho. The Central Montana uplift, which was the site of a trough during Cambrian time, was slowly uplifted from Ordovician through Late Devonian time. Development of another depositional trough, which began in Mississippian Madison time, culminated in the formation of the Big Snowy trough, which was the site of thick Late Mississippian and Pennsylvanian sedimentation.

During Jurassic time, the study area again was part of an expansive shelf area of the Williston Basin with a westerly connection to the geosyncline. By Cretaceous time, north-central Montana was part of a large north-south trending interior seaway. Central Montana remained a depositional trough in Jurassic and Cretaceous Kootenai time but was deformed into a complex anticlinorium during the Laramide orogeny. It is important to note, however, that the study area was structurally high to source beds in the Williston Basin and Central Montana uplift prior to the Laramide orogeny in Late Cretaceous time and thus was along the migration routes of any expelled hydrocarbons.

In the western part of the study area, the Blood Creek syncline is terminated by faulting along the south flank of the Bearpaw Mountains. This gravity faulting and landsliding was caused by volcanic activity and uplift of the Bearpaw Mountains during Laramide time. Large blocks of Upper Cretaceous strata slid on weak bedding planes in the Colorado shale down the flanks of the uplift. The head of the landslides was broken by many normal faults which formed the traps for large gas accumulations in the Eagle Sandstone and the Judith River Formation (Maher, 1969; Schorning, 1972). The extent of this faulting has not been clearly defined.

Although the wildlife refuge is located in the broad, seemingly structureless Blood Creek syncline, the presence of a major northeasterly and northwesterly trending lineament block system as detailed by Thomas (1974) in the greater Williston Basin-Blood Creek syncline area undoubtedly had an effect on the geologic and petroleum history of the study area. Although the exact cause of these lineaments, which are well expressed in aerial photographs, is not known, they suggest a general weakness of the basement. In nearby areas, these lineaments have proven to have had an effect on local stratigraphy and oil and gas accumulations. Ballard (1969) noted that all Red River production in northeastern Montana is associated with depositional thinning along lineaments. Hansen (1969) discussed how productive algal pelletoid reef development in the "Radcliff" zone of the Charles Formation is controlled by paleomovement along trends of weakness. Entrapment of oil in the Kibbey Sandstone at Welton field was enhanced by regional westward truncation of the reservoir beds by pre-Jurassic to post-Pennsylvanian movement along the Welton fault (Edmisten and Foster, 1969). Sandberg and Mapel (1967) showed offset of Devonian isopachs along the Weldon fault. Thomas (1974, fig. 13) mapped lineaments, particularly northwest trending, which cross the study area. These undoubtedly had an effect on stratigraphy and possible oil and gas entrapment in the study area. However, not enough detailed drilling has been done to evaluate their effect.

Oil and gas production in adjacent areas

There is no oil and gas production from inside the Charles M. Russell Wildlife Refuge. Table 6 reviews nearby production from stratigraphic horizons present in the study area. Figure 18 locates these fields in reference to the study area.

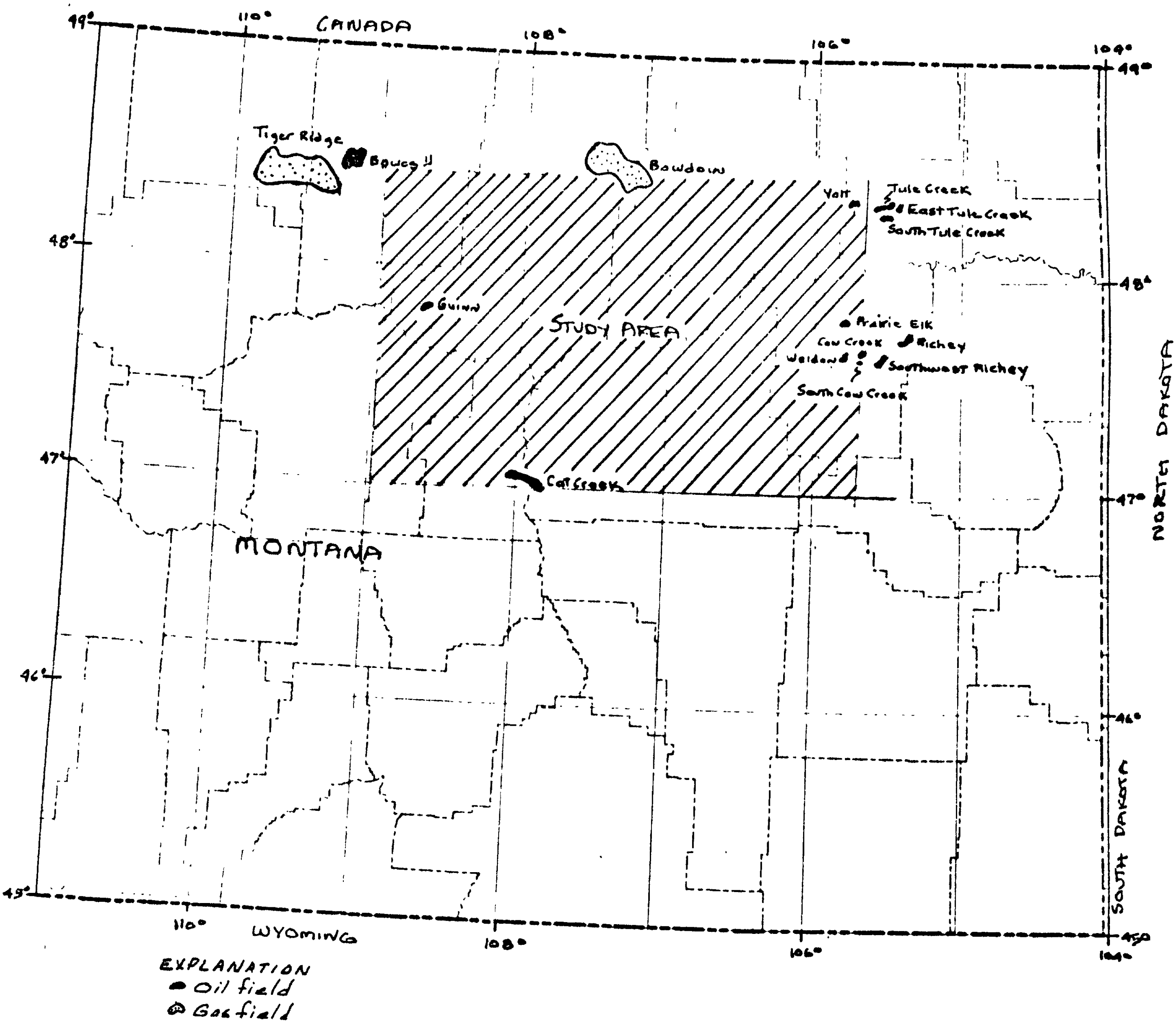
Although most of the fields are indicated as structural traps, recent discoveries in the Williston Basin, especially northeastern Montana, are predominantly stratigraphically controlled. Therefore the study area may be an overlooked area for potential oil and gas accumulations.

Table 6.--Nearby oil and gas fields

Field	Formation Age	Oil or gas	Type of trap	Cum Prod. MMBLS	Cum Prod. MMCF	*Ult Recovery MBBLS	*Ult Recovery MMCF
Bowdoin	Carlile Shale Mosby Sandstone Member of Greenhorn (Late Cret.)	Gas	Structural-stratigraphic	128,618	(1/1/74)		210,000
Bowes	Piper (Middle Jur.) Eagle Sandstone (Late Cret.)	Oil Gas	Structural Structural	7,851 32,029	(1/1/75) (2/1/75)	8,900	 --
Cat Creek	Amsden Group (Penn) Swift (Late and Middle Jur.) Morrison (Late Jur.) Kootenai (Early Cret.) Fall River Sandstone (Early Cret.)	Oil	Structural	22,312	(1/1/75)	31,310	
Cow Creek	Charles (Late Miss.)	Oil	Structural	91	(1/1/75)	150	
Cow Creek, East	Kibbey Sandstone (Late Miss.)	Oil	Structural	773	(1/1/75)	1,700	
Guinn	Eagle Sandstone (Late Cret.)	Gas	Structural	shut-in			--
Prairie Elk	Charles (Late Miss.)	Oil	Structural-stratigraphic	30	(9/1/74)		--
Richey	Charles (Late Miss.)	Oil	Structural	1,847	(9/1/74)		--
Richey, southwest	Interlake (Sil.) Dawson Bay (Middle (Dev.)	Oil	Structural	1,811	(1/1/75)	1,900	
Tiger Ridge	Carlile Shale (Late Cret.) Eagle Sandstone (Late Cret.) Judith River (Late Cret.)	Gas	Structural-stratigraphic	55,644	(12/1/74)		735,000
Tule Creek	Birdbear (Late Dev.)	Oil	Structural	6,544	(1/1/75)	9,000	
Tule Creek, East	-do-	Oil	Structural	1,878	(1/1/75)	2,100	
Tule Creek, South	-do-	Oil	Structural	595	(1/1/75)	650	
Volt	-do- Charles (Late Miss.)	Oil	Structural	1,751	(1/1/75)	2,700	
Weldon	Kibbey (Late Miss.)	Oil	Structural-stratigraphic	6,836	(1/1/75)	7,000	

*Ultimate recovery equals cumulative production plus proved reserves.
Source of data: Petroleum Information's Oil and Gas production Report
Montana Board of Oil and Gas Conservation Annual Review

Figure 18.--Map showing nearby oil and gas production.



Oil and Gas Potential

A few basic concepts of hydrocarbon generation will be discussed and must be understood before the oil and gas potential of any area can properly be assessed. Oil and gas accumulations are often associated, but commonly they are found completely independent of each other. These occurrences of oil and gas accumulations are related to their different origins within the three generally recognized stages of thermal maturation of organic matter in sedimentary rocks: (1) Immature--biological processes at shallow depths in accumulating sediments generate gas consisting chiefly of methane. (2) Mature--thermal cracking processes generate liquid hydrocarbons (oil) and high molecular-weight gas. (3) Postmature--gas, consisting chiefly of methane, is generated by destruction of liquid hydrocarbons and higher molecular-weight gases and by conversion of organic matter to carbon-rich residues and volatile compounds in response to increasingly severe thermal cracking.

Natural gas produced during the immature stage is referred to as biogenic gas to emphasize the fact that biological processes are responsible for its formation. This methane-rich gas is formed by the breakdown of organic matter, primarily carbohydrates and protein, by anaerobic bacteria. The limiting factors for its generation after sediment burial when traps are available are temperature, abundance of organic matter, and continuation of anaerobic conditions (Rice, 1975).

The products of the mature and postmature stages are dependent upon thermal cracking processes which are controlled by temperature and duration of heating (geologic time) factors. The relative importance of time versus temperature has been discussed by Hunt (1975). For example, peak oil generation occurs at temperatures ranging from 125°F for old Paleozoic rocks to 350°F in young Tertiary rocks. Temperature is controlled primarily by depth of burial.

Another major element in the formation of hydrocarbons is the deposition of organic-rich, fine grained sediments and (or) carbonates. These sediments, if preserved in a nonoxidizing environment, represent potential source rocks. During burial with increasing temperature and geologic time, some of this organic matter will be converted to hydrocarbons. The amount of oil generated depends on the volume of the source rock and the concentration and type of organic matter it contains. Abundant marine material, which is usually sapropelic, will generate oil, whereas nonmarine material, which is generally humic, will generate mostly gas during the mature stage.

Finally, at some point during the thermal maturation of organic matter, sufficient hydrocarbons are generated to allow oil and (or) gas expulsion from the source rock. These hydrocarbons migrate along vertical or horizontal pathways until they are trapped in porous, permeable reservoir rock. Traps are formed by a variety of structural and stratigraphic features capped by an impervious cover.

Various methods were employed in the study area in an effort to learn at what specific subsurface depths or stratigraphic intervals liquid hydrocarbons were generated if organic-rich source beds were present. The following techniques which were helpful in this determination are discussed briefly below: burial and temperature history, hydrocarbon shows, visual kerogen examination, carbon preference index (CPI), hydrocarbon/organic carbon ratio, hydrocarbon percentage, and saturated/aromatic hydrocarbon ratio versus hydrocarbon/organic carbon ratio.

(a) Burial history

Because temperature and time are the two most important elements controlling the generation of hydrocarbons, maturation levels may be estimated by reconstructing the burial history of an area. The average temperature gradient in the study area is $1^{o}C$ per 30 m using an average surface temperature of $16^{o}C$. On the basis of present day gradient and surface temperature, 1,524 m of burial is required to generate oil in Paleozoic rocks using a peak generation temperature of $66^{o}C$. As stated earlier, the temperature may be as low as $52^{o}C$, especially for Ordovician and Silurian rocks. Mesozoic rocks, on the other hand, require a minimum of 2,134 m of burial at $85^{o}C$ because less time is involved.

Based on inferred depths of burial at the end of Cretaceous time, as shown in table 7, Mississippian and older Paleozoic rocks have been buried at sufficient depths to have generated oil. Burial depths may be underestimated for Paleozoic rocks because a thick cover of Upper Mississippian Big Snowy Group and Pennsylvanian rocks were probably deposited over the entire area, but were removed by pre-Jurassic erosion. In addition, Upper Ordovician and Silurian carbonates have been removed from the western part of the study area by erosion. Mesozoic rocks, however, were probably never buried deep enough to have generated oil.

(b) Hydrocarbon shows

American Stratigraphic Company lithologic logs were examined for hydrocarbon shows in the study area as an indicator of maturation. Good, even oil staining was reported from wells in Ordovician, Devonian, and Mississippian rocks. Only questionable shows were reported from Mesozoic rocks. Allthough these shows in Mississippian and older rocks may be from migrated oil, their consistency over the area suggests that these intervals are mature.

Table 7.--Inferred depths of burial at end of Cretaceous for study area

	West	Central	East
Jurassic	1,402 m	1,402 m	1,341 m
Mississippian	1,554 m	1,554 m	1,676 m
Devonian	2,073 m	1,920 m	2,103 m
Silurian	Absent	2,103 m	2,438 m
Ordovician	2,134 m	2,164 m	2,499 m

(c) Visual kerogen examination

Correia (1971), Staplin (1969), Wilson (1971), and others have discussed the effects of temperature and time on organic matter. Pollen, spores, and sapropelic (amorphous) material undergo changes in color and transparency with increasing maturation. Fresh material is transparent and yellow. With increasing temperature and time, colors change from yellow to orange and brown and finally to black. This material changes concurrently from transparent to translucent and finally to opaque. As shown in table 8, organic matter from Paleozoic rocks in the study area is generally mature according to Staplin's TAI standards (1969). Mesozoic organic matter, on the other hand, is generally immature in appearance.

The following methods are chemical maturity indicators. These are based on the premise that the composition of hydrocarbons in potential source beds changes with increasing temperature and time.

(d) Carbon preference index (CPI)

Bray and Evans (1961, 1965) defined a maturity index (carbon preference index) using the distribution of ratios of odd- to even-numbered carbon heavy n-paraffins for fine grained sediments. They showed from a large number of samples that oil and potential oil source rocks are characterized by a carbon preference index ranging from 0.90 to 1.15. Values greater than this range indicate immaturity. As shown in table 9, Paleozoic rocks in the study area fall within the oil and oil source rock range. Sample 2 has an even preference (CPI 0.88), but the implications of values less than 0.90 are not totally understood (G. E. Claypool, pers. commun., 1977). Mesozoic source beds are inconclusive because the younger Cretaceous sample indicates maturity and an older Jurassic sample indicates immaturity. This might be explained by the fact that these ratios can be controlled by the type of organic matter as well as stage of maturation (Rodgers and Koons, 1971, p. 72).

Table 8.--Sample identification, percent organic carbon, and thermal alteration index

No.	Age and formation	Depth (m)	Location (sec.,T.,R.)	Organic carbon (weight percent)	Thermal (lt. index (stage)
1	Cretaceous Fall River	1,486	20/21N/46E	0.83	Immature
2	Mississippian Mission Canyon	2,167	20/21N/46E	.37-.40	Mature
3	Silurian Interlake	2,792-2,795	20/21N/46E	0.14	Do.
4	Ordovician Stony Mountain	2,891-2,892	20/21N/46E	0.32	Do.
5	Mississippian Charles	1,605	12/30N/41E	0.55	Do.
6	Devonian Birdbear	1,976	12/30N/41E	0.14	Mature
7	Devonian Duperow	1,995	12/30N/41E	0.24	Do.
8	Devonian Duperow	2,131	12/30N/41E	0.20	Do.
9	Devonian Souris River	2,189-2,190	12/30N/41E	0.25	Do.
10	Mississippian Charles	1,130-1,131	16/30N/37E	0.48	Do.
11	Devonian Winnipegosis	2,772-2,774	20/21N/46E	0.33	Do.
12	Miss.-Dev. Bakken	2,201-2,204	2/29N/47E	13.76-13.90	Do.
13	Cretaceous Mowry	1,114-1,117	10/19N/37E	1.37	Immature
14	Cretaceous Carlile	936-944	10/19N/37E	2.24	Do.
15	Jurassic Rierdon	1,295-1,298	2/23N/31E	0.30	Do.
16	Jurassic Rierdon	1,170-1,189	15/30N/25E	0.70	Immature-Mature
17	Mississippian Heath	1,828-1,832	2/18N/43E	0.99-1.01	Mature

(e) Hydrocarbon/organic carbon ratio

The hydrocarbon to organic carbon ratios for potential source rocks can be used as an indicator of both maturation and possible migration. With increasing depth of burial and time, the ratio slowly increases with mature source rocks generally having a ratio greater than 1.0 (G. E. Claypool, pers. commun., 1976; Hitchon, 1974, p. 518). In the study area, all samples analyzed have ratios greater than 1.0, suggesting maturity (table 9). In addition, a ratio greater than 10.0 suggests possible migration of hydrocarbons (G. E. Claypool, pers. commun., 19). In the study area, the hydrocarbon to organic ratio of 10.50 for the Devonian Birdbear Dolomite implies that hydrocarbons migrated into this carbonate from adjacent shales.

(f) Hydrocarbon percentage

With increasing maturation, the percentage of hydrocarbons of the total extract should increase along with the hydrocarbon/organic carbon ratio. This percentage could, however, be affected by the nature of the organic matter. If nonmarine material is present, mostly gas will be generated, but probably at a later stage than oil generation. In the study area, the Jurassic is the only interval analyzed with less than 30 percent hydrocarbons which suggests immaturity (table 9).

(g) Saturated/aromatic hydrocarbon ratio versus hydrocarbon/organic carbon ratio.

Baker and Claypool (1970) found that plotting the saturated to aromatic hydrocarbon ratio against the hydrocarbon to organic carbon ratio is significant in differentiating between the metamorphosed (post-mature) and unmetamorphosed (mature and immature) sediments. Unmetamorphosed samples fall into a linear trend with saturated to aromatic hydrocarbon ratios less than 2 and a range of hydrocarbon to organic carbon ratios. Metamorphosed rocks generally fall in an area of low hydrocarbon to organic carbon ratios and saturated to aromatic hydrocarbon ratio values greater than 2. A plot for the study area (fig. 19) shows that all analyzed samples fall within unmetamorphosed zone (mature or immature).

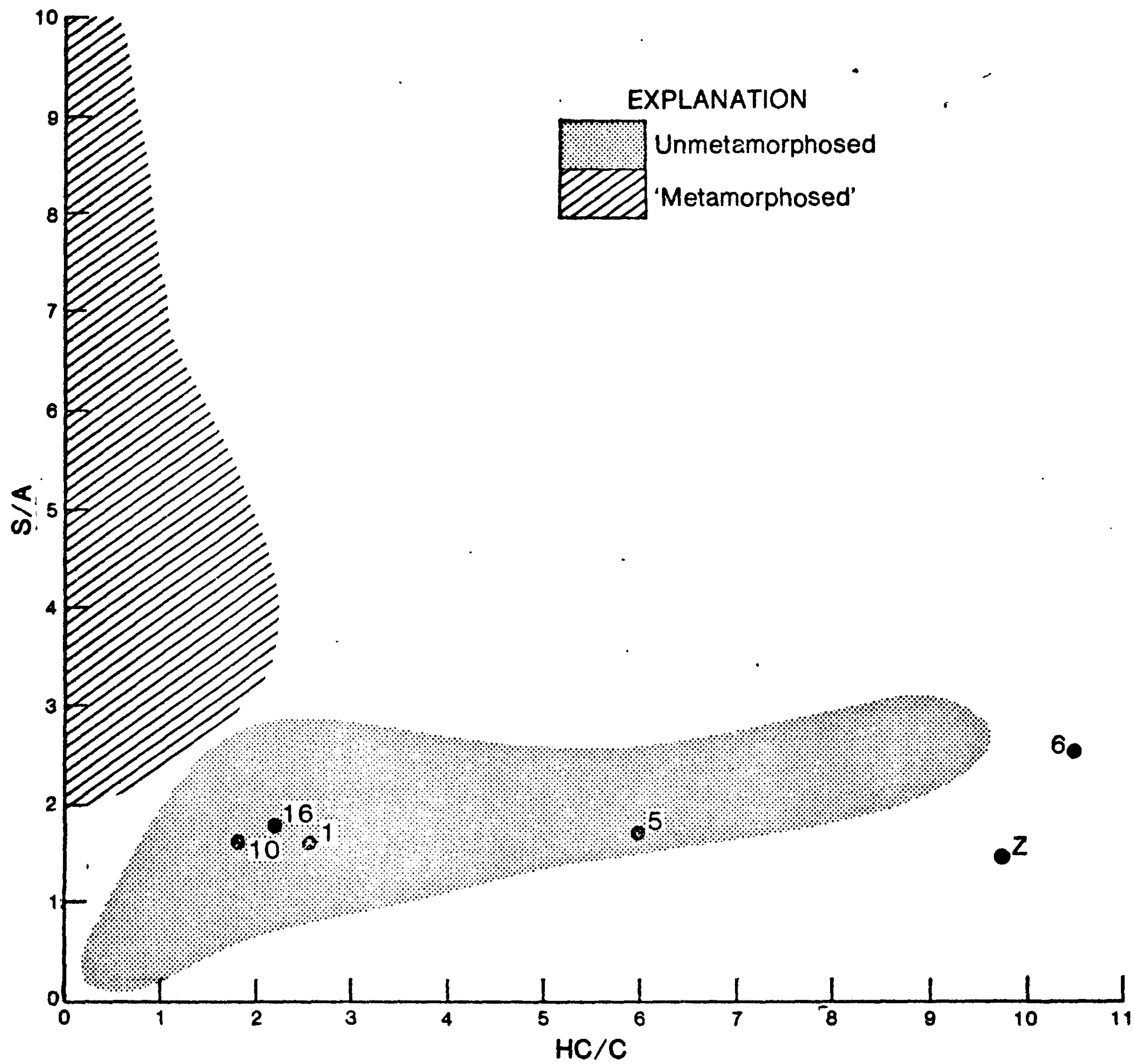
After evaluating these various methods of determining maturation level, I have concluded that Mississippian and older Paleozoic rocks in the study area have probably generated liquid hydrocarbons. Inferred depths of burial (table 7) suggest that minimal conditions were met during Cretaceous time. In addition to this necessary thermal history, adequate source beds plus adjoining reservoirs and traps must be present in this mature part of the section before significant amounts of oil can be expected to have accumulated.

Williams (1974) recognized three oil types in the main part of the Williston Basin: one type primarily in Ordovician and Silurian rocks, a second type confined mainly to Mississippian Madison rocks, and a third

Table 9.--Analytical Data of Selected Samples

Sample No.	Age and Formation	Carbon preference Index	Hydrocarbons (ppm)	Hydrocarbons / Organic carbon	Saturated / Aromatics	Hydrocarbons (percent)	Hydrocarbons / Nonhydrocarbons
1	Cretaceous Fall River	1.08	211.0	2.54	1.57	31.1	0.45
2	Mississippian Mission Canyon	.88	380.0	9.74	1.51	43.0	.75
5	Mississippian Charles	1.04	331.0	6.01	1.71	35.0	.53
6	Devonian Birdbear	1.13	147.0	10.50	2.66	30.4	.43
10	Mississippian Charles	1.03	88.0	1.83	1.59	28.0	.38
16	Jurassic Rierdon	1.27	156.0	2.22	1.78	18.1	.22

Figure 19.--Plot of hydrocarbon/organic carbon ratio versus saturated aromatic hydrocarbon ratio for six selected samples in study area.



type in Pennsylvania Tyler reservoirs in North Dakota. He determined source beds by identifying strata in the petroleum-bearing part of the section which possess the geochemical requirements essential for effective source beds. Williams' (1974) main criterion was that source beds contain a minimum of 0.4 percent organic carbon (Momper, 1972). A list of possible source beds with the range of organic carbon as presented by Williams is shown in table 10. Organic-carbon contents for selected units in the study area are recorded in table 8. On the basis of this requirement, units of Ordovician, uppermost Devonian, and Mississippian age are potential source beds.

Another indicator of richness of source beds is the concentration (ppm) of hydrocarbons of the total extract. Baker (1972) used 100 ppm as the breakoff for adequate source beds. As shown in table 9, both Devonian and Mississippian rocks contain intervals which meet Baker's minimal requirement in the study area.

On the basis of both of these stipulations, the Ordovician Stony Mountain Formation is considered as a source bed for Ordovician and Silurian oil in the study area. It is also in close contact with reservoir rocks which produce in adjacent areas. Shale in the Winnipeg Formation, which Williams (1974) mentioned as the source for lower Paleozoic oil, is not present in the study area. Devonian shales and carbonates are probable sources for Devonian reservoired oil. Shale in the Bakken Formation is an excellent source bed for Upper Devonian and Mississippian oil where it is developed north of the Missouri River. Shaly interbeds and carbonates in the Madison Group are potential source beds for Mississippian oil. In the Central Montana Uplift to the south, shale in the Heath Formation is the probable source of Tyler-reservoired oil.

Because the study area is situated on the northwest flank of the broad Blood Creek syncline, traps for Paleozoic oil will be predominantly stratigraphic in nature with local structural enhancement. The western edges of Ordovician and Silurian units terminated by a combination of deposition and erosion are prime targets for lower Paleozoic oil. Subcrop and local structure combined with porosity and permeability variations of Devonian carbonate units such as the Winnipegosis, Dawson Bay, and Birdbear Formations are likely areas for entrapment of Devonian oil. In addition, cyclical deposits of carbonates interbedded with shales and evaporites in the Souris River and Duperow Formations are other possible Upper Devonian traps. Mississippian oil is probably reservoired in the Charles Formation, the upper unit of the Madison Group. In northeastern Montana, Mississippian Charles oil is produced from algal pelletoid mounds localized along basement lineaments. Similar mounds may be developed along basement lineaments in the study area. Also, the Charles Formation is progressively truncated and overlain by impervious Jurassic shales containing some evaporites to the north creating possible stratigraphic traps.

Table 10.--List of potential source beds of Williston Basin with organic carbon contents (from Williams, 1974)

Age and Formation	Organic Carbon Weight Percent
Pennsylvanian Tyler	0.20-3.60
Pennsylvanian Heath	0.67-9.07
Mississippian Lodgepole	0.03-0.89
Miss.-Dev. Bakken	0.65-10.33
Ordovician Stony Mountain	0.10-0.48
Ordovician Red River	0.14-0.54
*Ordovician Winnipeg	0.05-0.74

*Shale interval considered principal source bed for Lower Paleozoic oil in Williston Basin by Williams is absent in study area.

In addition to the liquid hydrocarbon potential which has been discussed previously, the entire study area, including the Charles M. Russell Wildlife Refuge has the possibility of shallow, biogenic gas accumulations. To date, significant resources in adjacent areas have been discovered in the following Upper Cretaceous units: Mosby Sandstone Member of Greenhorn Formation, sandy intervals in the Carlile Shale, Eagle Sandstone, and Judith River Formation. On the flanks of the Bearpaw Mountains to west and north of the study area, biogenic gas accumulations are structurally controlled by gravity faulting resulting from Laramide volcanic activity. Shallow gas production in the Bowdoin field to the north was originally thought to be structurally controlled. Recent exploration has proven these accumulations to be stratigraphically controlled. Biogenic gas accumulations are probably present in the study area and are stratigraphically controlled in the units listed above. The only controlling restraint is depth because these methane-rich gases are probably in solution at depths greater than about 610 m.

Economic Appraisal

Mississippian and older Paleozoic rocks in the study area have probably generated liquid hydrocarbons. These hydrocarbons may have accumulated in the Charles M. Russell Wildlife Refuge in predominantly stratigraphic traps locally enhanced by structure. Potential accumulations are difficult to pinpoint because no exploratory wells have been drilled in the wildlife refuge and no geophysical data are available. These accumulations, which are probably greater than 1,219 m below ground elevation, could be explored for by directional drilling along the fringes of the wildlife refuge.

There is also a good potential for shallow, biogenic gas accumulations similar to the Bowdoin field to the north. These accumulations may be present in Upper Cretaceous shelf sequences, less than 610 m in depth. The potential for gas can only be determined by exploration, including drilling.

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CHAPTER D

ECONOMIC APPRAISAL OF THE CHARLES M. RUSSELL WILDLIFE REFUGE

By

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MINERAL COMMODITIES

Coal and bentonite, along with possible oil and gas, constitute nearly all the mineral potential of the Charles M. Russell Wildlife Refuge. At least 290 million short tons (260 million t) of coal and 3.2 billion short tons (2.9 billion t) of bentonite are estimated to be present. Several other commodities have been mined from formations which crop out on, or underlie, the Refuge. They are ceramic clays, placer gold, expandable shale, and uranium. Although there has been no production, both petroleum and natural gas have been found within 6 miles (10 km) of the Refuge. No exploration drilling for either commodity has yet taken place within the area, but a potential for both, based upon indicated and inferred structures, exists.

Since the early 1900's, more than 20 federal actions have affected mineral acquisition in the Wildlife Refuge area. Detailed outlines of these actions are available in the Federal Register. An unpublished summary of these actions has been prepared by the U.S. Bureau of Land Management staff at Lewistown, Montana. The U.S. Army Corps of Engineers and U.S. Fish and Wildlife Service can restrict mineral activities on much of the refuge. In principle, oil and gas leasing is allowed, but areas open to leasing have not been designated. A moratorium on claim location, but not oil and gas leasing, has been imposed during the time of the present mineral inventory, and for at least 1 year after its completion. In addition to Federal jurisdiction, the State of Montana supervises exploration and mining on all lands within the State.

In 1976, two parcels of land in the UL Bend area, totaling about 21,000 acres (8,500 h), were added to the wilderness preservation system. Specific constraints governing use of minerals in wilderness areas have been developed.

Petroleum and natural gas

The United States produced about 3 billion barrels of petroleum (406 million t) in 1978, about half of the petroleum it consumed. United States reserves were about 27,800 million bbls (3,700 million t) in 1978, about 5 percent of known world petroleum reserves (American Petroleum Institute news release, April 30, 1979, 3 p.).

The United States produced about 19,000 billion cubic feet (538 billion m^3) of natural gas in 1978. Domestic reserves in 1978 were about 200,000 billion cubic feet (5,000 billion m^3), about 10 percent of world reserves (American Gas Association news release, April 30, 1979, 3 p.). Most of these gas reserves were discovered during petroleum exploration.

History, production, and access

Although some wildcat wells have been drilled nearby (fig. 20),

Figure 20.--NEAR HERE. Petroleum and natural gas exploration near the Charles M. Russell Wildlife Refuge.

no petroleum or natural gas wells have been drilled on the Wildlife Refuge. Exploration has been discouraged by refuge and reservoir management policies.

With adequate planning, subsurface exploration of the refuge could be carried out with negligible surface disturbance. Vertical and directional drilling, from outside the Refuge, from Fort Peck Lake, and from existing roads could explore, develop, and possibly produce from much of the Refuge. The network of existing roads allows access to much of the area. Where necessary, air cushion vehicles and boats could also be used.

From 1965 to 1975, about 180 leases were recorded on State and private lands within 6 miles (10 km) of the Wildlife Refuge. In 1975 about 1,150 parcels of land in this same area were being held under Federal oil and gas leases. Between 1954 and 1975, at least 120 firms and individuals leased land near the Refuge for petroleum and natural gas exploration.

Although no hydrocarbons have been produced, petroleum and natural gas have been found within 6 miles (10 km) of the Refuge. Drill holes with hydrocarbons near the Refuge are noted in fig. 20 (Nos. 1-8).

Possible hydrocarbon traps

Potential petroleum and natural gas traps exist within 10 miles (16 km) of the Charles M. Russell Wildlife Refuge and may continue into it. Arcuate outcrop patterns and lineaments in aerial photographs indicate leads to possible structures on and near the Refuge.

At the Beauchamp Creek area, an anomalous stream pattern, at least 6 miles (10 km) long and 4 miles (6 km) wide, is shown by the curved ridges and stream courses indicating a possible underlying structure. Much of the area is inside the wildlife refuge (fig. 21).

Figure 21.--NEAR HERE. Pattern of ridge crests and drainages along Beauchamp Creek.

In general, magnetic anomalies are associated with the Beauchamp Creek area, although even larger anomalies have been mapped elsewhere nearby (Zietz and others, 1968, fig. 2).

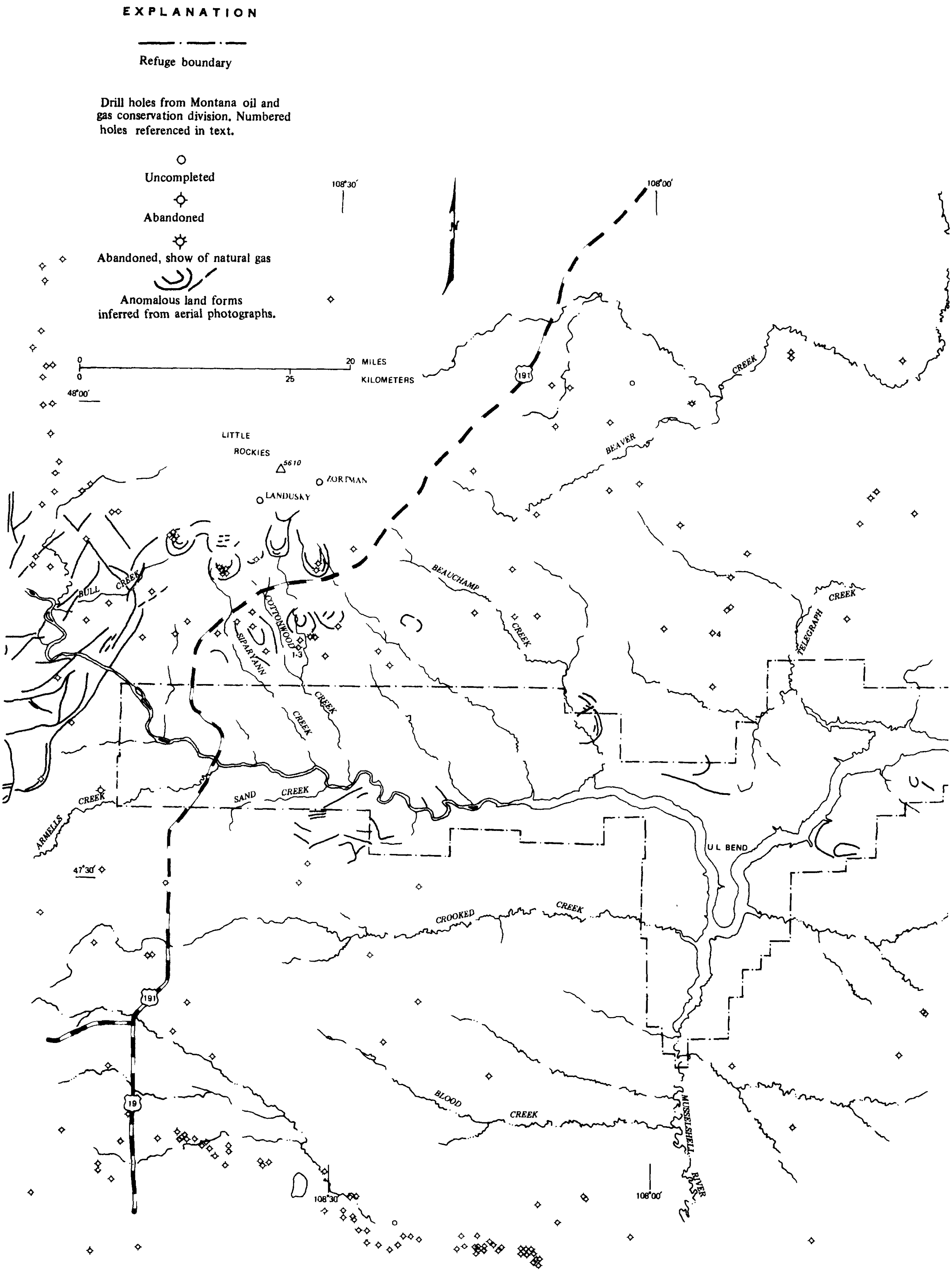
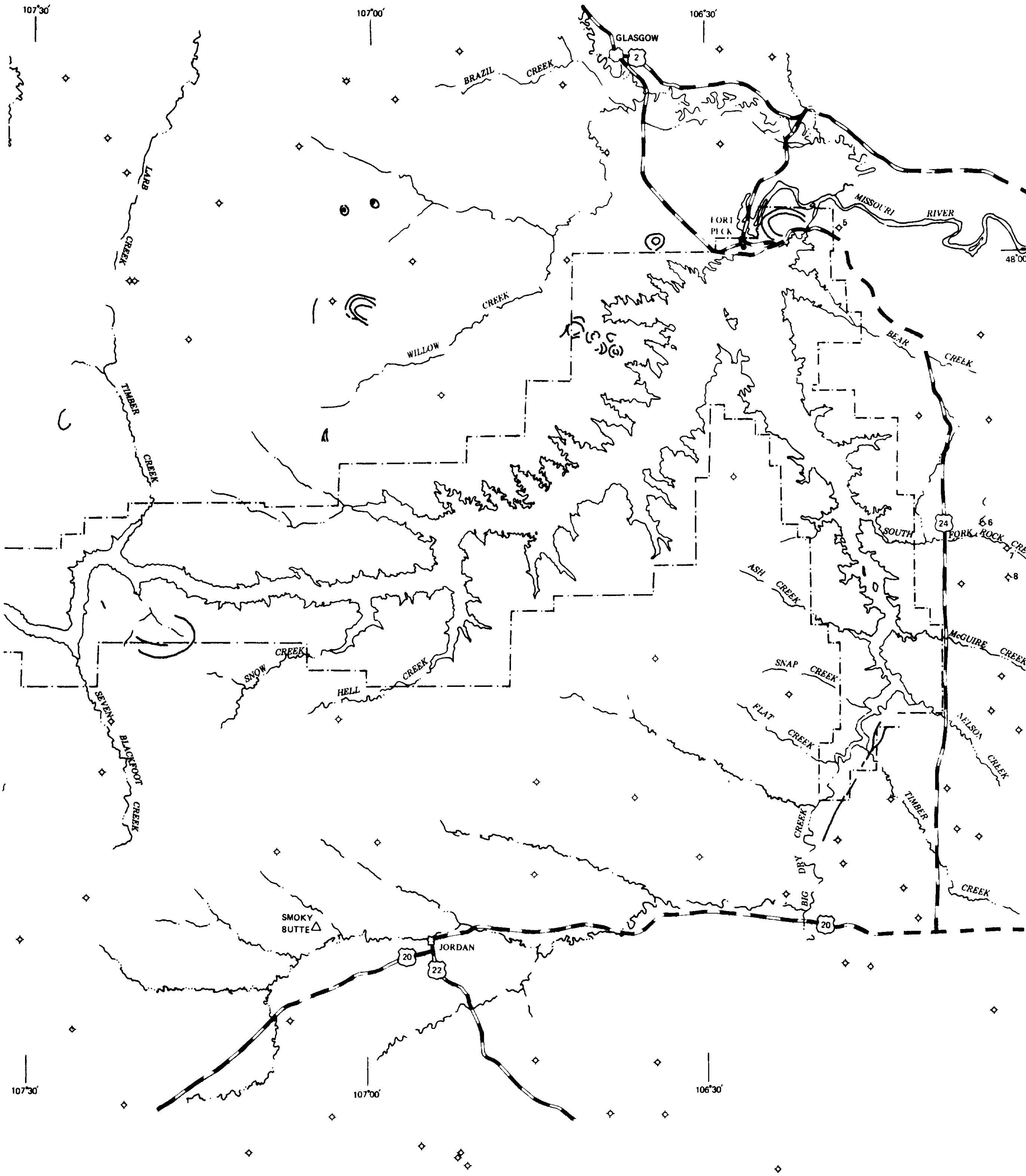


Figure 20.--Petroleum and natural gas exploration near the Charles M. Russell Wildlife Refuge. Base from 1:250,000 scale Army Map Service maps.


107°30'
107°00'
106°30'
GLASGOW
2
BRAZIL CREEK
LARB CREEK
MISSOURI RIVER
FORT PECK
48°00'
WILLOW CREEK
TIMBER CREEK
BEAR CREEK
24
SOUTH FORK ROCK CREEK
ASH CREEK
McGUIRE CREEK
SNOW CREEK
HELL CREEK
SEVEN BLACKFOOT CREEK
SNAP CREEK
FLAT CREEK
NELSON CREEK
TIMBER
BIG DRY CREEK
CREEK
SMOKY BUTTE
JORDAN
20
22

A northeast-trending lineament, visible in the Dry Creek area of the Wildlife Refuge, may be controlled by a fault (fig. 20). This lineament, nearly at right angles to numerous northwest-trending lineaments at the east end of the Refuge, is parallel to the Weldon fault zone. Northeast-trending faults, downthrown to the southeast and subparallel to the Weldon fault, have been interpreted from seismic data secured near the Refuge (Amoco Production Co., unpublished seismic maps, written communication, April 1, 1976).

Other possible structural traps have been found during geological and geophysical work within about 20 miles (32 km) of the Refuge. Because the anomalous areas are extensive and border or surround the Refuge, they may also extend into it to some degree. Anomalies have been reported: north of UL Bend, about 10 miles (16 km) from the Refuge; northeast of Fort Peck, adjacent to the Refuge; southeast of the Big Dry Creek arm of Fort Peck Lake, within 7 miles (11 km) of the Refuge; north of McGuire Creek, approximately 3 miles (5 km) east of the Refuge; and northeast of Rock Creek, about 15 miles (24 km) from the Refuge. (Amoco Production Company and Rainbow Resources, Incorporated, unpublished written communications, 1976).

Bentonite

In this report, bentonite is used as a general term for clay containing substantial amounts of montmorillonite derived from volcanic ash which has been devitrified and chemically altered. Because of its swelling, bonding, thixotropic, and viscous properties, bentonite has a wide variety of industrial uses. The casting industry uses it to bind molding sand; the taconite industry to bind finely ground iron ore into pellets; and the drilling industry to add to drilling fluid. These accounted for 23 percent, 17 percent, and 28 percent, respectively, of total domestic consumption in 1978 (Ampian, 1979). United States bentonite production in 1978 was estimated to be 4,202,000 short tons (3,800,000 t) (Ibid). Major importers of United States bentonite are: Canada, the United Kingdom, West Germany, Australia, Saudi Arabia, Japan, and the Netherlands.

History and production

The Wildlife Refuge is adjacent to the Chinook-Malta-Glasgow bentonite district, which is one of five districts in Wyoming, Montana, and South Dakota supplying most of the world's swelling bentonite (Patterson and Murray, 1975, p. 534). Montana bentonite is becoming more important as the need increases for clay for the taconite industry. Two major producers, American Colloid Co. and Federal Bentonite Co., have announced plans to construct processing plants, and to begin large-scale mining in the Chinook-Malta-Glasgow district. In 1977, Federal Bentonite applied for mining permits to produce 300,000 tons (270,000 t) per year. One proposed plant site is 45 miles (72 km) north of the Refuge, near Malta, Montana, and the other within 10 miles (16 km) of the Refuge, near Glasgow, Montana. A railroad spur has been constructed to the Glasgow location. Both plants will be near enough to process Wildlife Refuge bentonite, if available.

More than 2,800 clay claims, encompassing more than 164,000 acres (66,000 h), have been staked within 35 miles (56 km) of the Wildlife Refuge. These are widely distributed in groups, primarily north of the Refuge. On the Refuge, the White Rock group of nine claims, staked for kaolinite, encompasses 1,440 acres (583 h).

Resource estimates

In the western half of the refuge, bentonite suitable for pelletizing taconite concentrates and for binding foundry sand, crops out in significant amounts. The deposits are within reasonable haul distances of two proposed processing plants north of the Wildlife Refuge and could be profitably mined according to a study using 1977 costs and prices. Projected increases in worldwide demand, and depletion of known high-grade deposits have improved the potential of Montana bentonite deposits.

For this report the largest bentonite deposit extending onto the Refuge has been given the name "Siparyann bed." Estimated bentonite resources in this bed within the Wildlife Refuge are 30,000,000 tons (28,000,000 t) under less than 35 feet (10 m) of overburden, and 1,100,000,000 tons (1,000,000,000 t) under more than 35 feet (11 m) of overburden. Other estimated bentonite resources on the Refuge are listed in table 11. The total estimated bentonite resource in beds 2 inches thick

Table 11.--NEAR HERE. Estimated bentonite resources on the Charles M. Russell Wildlife Refuge, except for the Siparyann bed.

or greater is 3.2 billion tons (2.9 billion t). Although an attempt was made to correlate thinner beds by using a computerized technique to compare sequences of bed thickness data (Davis, 1973), few beds could be correlated over wide areas.

The resource and reserve estimates are based on a density of 100 pounds per cubic foot (1,600 kg/m^3). Volumes were calculated by using bed thicknesses measured at outcrops, and areas measured from maps. At many outcrops, the bentonite bed probably has swollen to exaggerated thicknesses; consequently, the reported resource figures may be greater than actual resource quantities. Bentonite under more than 35 feet (11 m) of overburden may be unsuitable for most commercial applications; usually, such material is not weathered enough to be of desirable quality.

Description of deposits

Potentially usable bentonite on the Wildlife Refuge is primarily in the Cretaceous Bearpaw Shale. Impure montmorillonitic beds crop out in the Cretaceous Fox Hills and Hell Creek Formations as well as in the Paleocene Fort Union Formation.

Table 11.--Estimated bentonite resources on the Charles M. Russell Wildlife Refuge, except for the Siparyann bed

[Data gathered and recorded in inch-pound system; 1 ft = 0.3048 m; 1 in. = 2.54 cm; 1 short ton = 0.9072 t]

[Thousands of short tons]

Outcrop bed thickness	2 to 6 inches		6 inches to 2 feet		2 to 4 feet		
Overburden thickness	Less Than 35 feet 1/	Greater Than 35 feet 2/	Less Than 35 feet 3/	Greater Than 35 feet 2/	Less Than 35 feet 4/	Greater Than 35 feet 3/	Total
Siparyann area	17,000	352,000	68,000	1,300,000	8,700	170,000	1,900,000
UL Bend area	4,000	38,000	14,000	115,000	--	--	172,000

1/ Indicated submarginal resources.
2/ Inferred submarginal resources.
3/ Indicated paramarginal resources.
4/ Indicated paramarginal resources which could be classed as indicated reserves if the land were opened to mining.

In the Bearpaw Shale, distinct beds of bentonite are mostly from a fraction of an inch to 3 feet (1 m) thick. Montmorillonitic beds in the Hell Creek and Fort Union Formations may be thicker, but their montmorillonite content is much lower. One Bearpaw Shale bentonite bed is 6 feet (2 m) thick at the outcrop. Weathering, water content variations, and overburden weight have affected the thickness of the beds at the outcrop. The bentonite is pale yellow, greenish-yellow, olive green, blue, gray, and yellowish-orange. Yellowish-orange colors are especially prominent near the tops of intensely weathered beds. Most bentonite is cohesive, waxy, sectile, and, when moist, soft; however, some of the more weathered clay, nearly always pale yellow, is consolidated, earthy, and resembles corn meal. Lower contacts of most clay beds are sharp, and the upper gradational. The surfaces of most montmorillonitic outcrops on the Refuge have weathered to a texture resembling popcorn or alligator hide. Crystals of selenite, calcite, and barite weather out from many of these outcrops. Sheets of montmorillonitic soil may cover entire slopes.

Numerous surficial movements, large slump blocks, and mud slides have obscured, duplicated, or mixed clay outcrops. Most individual bentonite beds can be neither traced at the surface for more than 0.5 mile (0.8 km) nor from one outcrop to another. However, the Siparyann bed crops out within the Wildlife Refuge for at least 30 miles (48 km).

According to X-ray analysis, common nonclay constituents are gypsum, quartz, plagioclase, biotite, and glass shards. Less abundant nonclay minerals are potassium feldspar, calcite, barite, jarosite, natrojarosite, dolomite, goethite, pyrite, and zircon. Illite and kaolinite are less abundant than montmorillonite, but may be the locally predominant clays, especially in the Hell Creek, Fort Union, and Fox Hills Formations.

Siparyann

The Siparyann bed, the Wildlife Refuge's thickest and most continuous bentonite bed in the Bearpaw Shale, can be traced on both sides of the Missouri River from the west end of the Refuge to Nichols Coulee; further east it lies below water level (fig. 22). The bed is approximately

Figure 22.--NEAR HERE. Localities of clay samples from the Siparyann area.

80 to 200 feet (25 to 65 m) stratigraphically above the base of the Bearpaw Shale. It is from 1 feet (0.3 m) thick at the outcrop near the west boundary of the Wildlife Refuge to as much as 6 feet (2 m) near Siparyann Creek. These thicknesses may be exaggerated by swelling at the outcrop. Most samples from this bed appear to be suitable for either foundry sand or taconite pellet bonding.

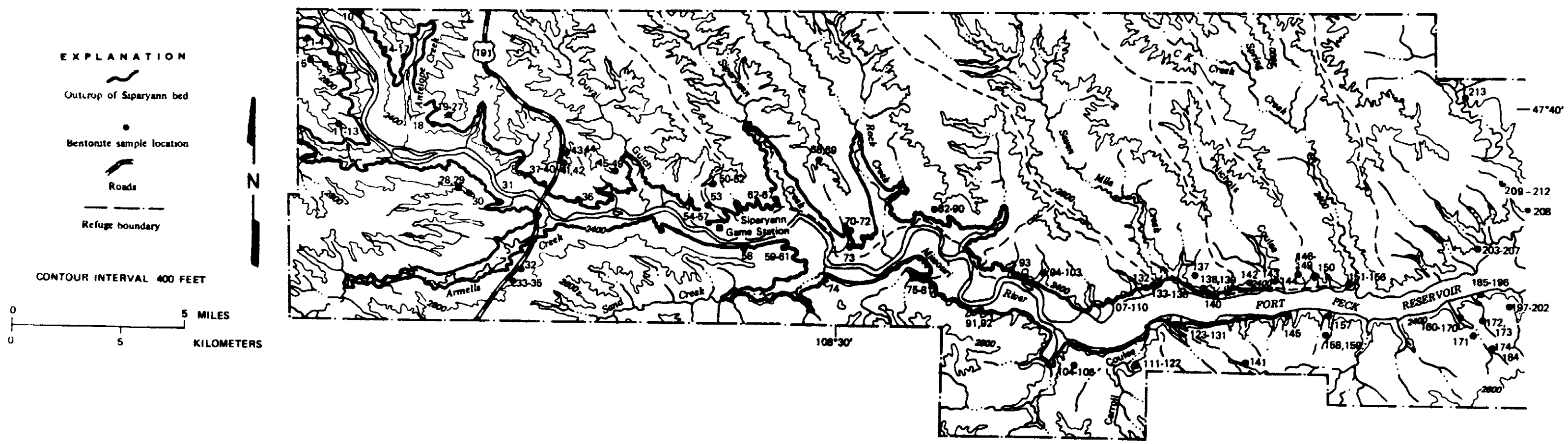


Figure 22.--Localities of clay samples from the Siparyann area. Base from 1:250,000 scale Army Map Service map.

An unnumbered table to accompany fig. 22, clay samples from the Siparyann area

Data for samples shown on figure 22.

[--, not tested]

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 meter;

1 inch = 2.54 centimeters; 1 psi = 6895 pascals; 1 pound = 0.4536 kilogram]

Sample				Percent		Viscosity		Foundry		Pelletizing	
No.	Type	Length (feet)	Description	Grit (+200 mesh)	pH	Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
1	Channel	3.5	Bearpaw bentonite	4.2	7.6	--	--	8.0	47	--	--
2	do	1.0	do	6.5	7.8	--	18.0	7.2	62	--	--
3	do	1.5	do	5.2	7.1	--	--	7.7	50	--	--
4	do	1.5	do	20.7	6.9	--	18.0	6.6	61	--	--
5	do	1.8	do	7.7	8.6	--	--	6.9	67	--	--
6	do	1.1	do	22.7	8.4	--	--	6.4	54	--	--
7	do	1.1	do	[illegible]	6.0	--	18.0	5.6	63	--	--
8	do	1.8	do	5.0	8.7	--	--	8.6	32	--	--
9	do	1.2	do	4.5	9.1	--	--	8.0	64	--	--
10	do	1.4	Bearpaw bentonite, Siparyann bed	12.2	7.3	--	18.0	5.9	56	--	--
11	do	3.0	do	3.5	8.1	--	18.0	--	--	--	--
12	do	1.5	do	11.0	5.3	--	18.0	5.8	74	--	--
13	do	1.6	Bearpaw bentonite	34.2	4.7	--	--	4.3	75	--	--
14	do	1.8	Bearpaw bentonite, Siparyann bed	13.0	8.1	--	18.5	5.3	50	--	--
15	do	.6	Bearpaw bentonite	11.2	7.5	--	--	6.8	71	--	--
16	do	1.8	Bearpaw bentonite, upper layer (same bed)	20.2	4.7	--	18.0	--	--	--	--
17	do	1.8	Bearpaw bentonite, lower layer (same bed)	5.2	8.4	--	--	9.1	58	--	--
18	do	2.7	Bearpaw bentonite, Siparyann bed	--	--	--	--	--	--	--	--
19	do	.6	Bearpaw bentonite	1.7	6.4	--	--	8.0	81	8	12.2
20	do	.6	do	2.7	4.3	--	--	7.8	44	--	--
21	do	2.8	do	6.0	5.8	--	18.0	7.7	62	--	--
22	do	1.8	do	6.7	6.5	--	--	8.8	41	--	--
23	do	1.4	do	6.7	6.1	--	--	8.4	39	--	--
24	do	1.0	do	18.5	6.8	--	--	5.9	62	--	--
25	do	2.2	do	6.0	4.9	--	--	9.7	32	--	--
26	do	.8	do	11.5	5.0	--	--	8.9	30	--	--
27	do	.7	do	4.0	4.7	--	--	11.1	22	--	--
28	do	2.0	do	6.5	8.1	--	--	6.8	45	--	--
29	do	1.2	do	11.7	7.8	--	18.0	8.0	46	--	--
30	do	2.5	do	6.5	7.8	--	--	7.4	50	--	--
31	do	5.2	do	5.7	8.5	--	18.0	7.5	53	--	--
32	do	.8	do	1.7	[illegible]	--	--	5.9	44	--	--
33	do	1.0	do	5.5	5.8	--	--	[illegible]	43	--	--
34	do	7.5	do	1.0	7.2	--	--	5.2	73	9	12.[illegible]
35	do	.6	do	3.7	7.2	--	--	8.8	57	--	--
36	do	2.5	do	11.5	8.4	--	18.5	7.3	50	--	--
37	do	.6	do	5.5	8.3	--	--	9.0	41	--	--
38	do	1.2	do	5.7	9.2	--	19.5	8.7	29	--	--
39	do	1.3	do	3.3	4.3	--	--	10.1	44	--	--
40	do	2.0	do	3.7	7.0	--	18.5	7.4	47	--	--
41	do	1.0	Bearpaw bentonite, upper layer (Siparyann bed)	12.0	6.6	--	--	--	--	--	--
42	do	3.8	Bearpaw bentonite, lower layer (Siparyann bed)	5.7	8.0	--	19.5	[illegible]	[illegible]	9	[illegible]
43	do	.7	Bearpaw bentonite	13.0	9.7	--	--	5.8	23	--	--
44	do	.7	do	1.3	9.3	--	18.0	10.5	20	--	--
45	do	1.0	do (layers from top to bottom, Siparyann bed)	[illegible]	5.8	--	[illegible]	7.2	[illegible]	--	--
46	do	3.6	do (layers from top to bottom, Siparyann bed)	2.5	8.3	--	[illegible]	6.6	63	--	--
47	do	.8	do (layers from top to bottom, Siparyann bed)	11.7	7.4	--	18.0	--	--	--	--
48	do	.6	do (layers from top to bottom, Siparyann bed)	3.[illegible]	7.3	--	18.5	5.9	74	--	--
49	do	3.0	do	11.7	7.6	--	--	5.1	42	--	--
50	do	.9	do	3.3	4.1	--	--	7.5	50	--	--

Sample				Percent grit (+200 mesh)	pH	Viscosity		Foundry		Pelletizing	
No.	Type	Length (feet)	Description			Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
51	Channel	2.3	Bearpaw bentonite-------------------------	5.7	7.9	--	18.5	5.4	69	--	--
52	do-----	1.2	do---------------------------------------	7.0	9.4	--	--	5.6	39	--	--
53	do-----	1.3	do---------------------------------------	5.7	7.2	--	21.0	5.4	37	--	--
54	do-----	.5	do---------------------------------------	3.5	7.4	--	19.5	8.0	58	--	--
55	do-----	1.1	do---------------------------------------	23.5	5.8	--	--	5.8	59	--	--
56	do-----	5.7	Bearpaw bentonite, Siparyann bed----------	5.0	9.6	--	19.0	7.0	61	9	23.0
57	do-----	4.5	Bearpaw bentonite-------------------------	12.5	6.5	--	--	4.7	41	--	--
58	do-----	6.0	Bearpaw bentonite, Siparyann bed----------	7.0	7.5	--	19.5	6.2	58	9	23.0
59	do-----	.7	Bearpaw bentonite	5.5	8.7	--	19.5	6.5	55	9	25.0
60	do-----	1.1	do (layers from top to bottom, Siparyann bed)	11.2	9.1	--	20.0	6.8	50	7	21.0
61	do-----	.6	do	--	--	--	--	--	--	--	--
62	do-----	6.0	Bearpaw bentonite, Siparyann bed----------	3.3	7.4	--	18.5	6.4	66	--	--
63	do-----	.6	Bearpaw bentonite-------------------------	29.3	4.1	--	18.5	5.2	28	--	--
64	do-----	.8	do---------------------------------------	9.7	8.3	--	--	7.3	74	--	--
65	do-----	1.4	do---------------------------------------	6.3	4.7	--	18.0	7.4	68	--	--
66	do-----	2.4	do---------------------------------------	8.0	7.1	--	--	9.4	52	--	--
67	do-----	1.1	do---------------------------------------	9.3	8.2	--	--	7.5	67	--	--
68	do-----	1.0	do---------------------------------------	10.2	7.9	--	18.5	7.3	46	--	--
69	do-----	1.0	do---------------------------------------	5.2	7.0	--	--	7.9	44	--	--
70	do-----	1.4	do---------------------------------------	3.7	6.0	--	18.5	8.6	56	--	--
71	do-----	.7	do---------------------------------------	12.7	7.7	--	--	8.0	61	--	--
72	do-----	.6	do---------------------------------------	2.5	4.6	--	--	7.8	68	--	--
73	do-----	2.8	Bearpaw bentonite, Siparyann bed----------	29.5	9.6	--	19.0	--	--	10	15.0
74	do-----	2.5	do---------------------------------------	10.2	8.5	--	19.5	7.0	55	8	17.0
75	do-----	1.7	Bearpaw bentonite-------------------------	9.2	8.4	--	--	7.8	65	--	--
76	do-----	.6	do---------------------------------------	3.2	6.7	--	18.0	7.6	48	--	--
77	do-----	.8	do---------------------------------------	2.2	6.1	--	--	8.2	49	--	--
78	do-----	.9	do---------------------------------------	36.0	8.2	--	--	6.3	48	--	--
79	do-----	1.0	do---------------------------------------	2.7	7.2	--	--	9.2	45	--	--
80	do-----	.9	Bearpaw bentonite, upper layer (same bed)	2.5	9.0	--	--	8.9	51	--	--
81	do-----	.5	Bearpaw bentonite, lower layer (same bed)	3.5	9.8	--	18.5	6.6	55	--	--
82	do-----	1.8	Bearpaw bentonite-------------------------	16.5	6.4	--	--	5.3	67	--	--
83	do-----	1.2	do---------------------------------------	27.2	5.3	--	--	4.8	58	--	--
84	do-----	1.0	do---------------------------------------	1.5	7.7	--	--	7.9	67	--	--
85	do-----	.6	do---------------------------------------	1.2	7.7	--	--	8.6	54	--	--
86	do-----	.8	do---------------------------------------	20.2	6.6	--	--	6.1	58	--	--
87	do-----	.9	do---------------------------------------	5.0	6.3	--	18.5	7.3	37	--	--
88	do-----	.9	do---------------------------------------	3.2	6.5	--	--	6.4	51	--	--
89	do-----	1.0	do---------------------------------------	4.2	5.0	--	18.5	10.0	29	--	--
90	do-----	1.0	do---------------------------------------	9.7	9.2	--	--	7.5	58	--	--
91	do-----	1.0	Bearpaw bentonite, upper layer (Siparyann bed)------	15.7	7.4	--	19.0	7.6	92	7	29.0
92	do-----	1.0	Bearpaw bentonite, lower layer (Siparyann bed)------	13.2	8.0	--	18.0	--	--	--	--
93	do-----	2.0	Bearpaw bentonite, Siparyann bed----------	4.7	9.1	--	20.0	7.8	71	9	17.0
94	do-----	.6	Bearpaw bentonite-------------------------	3.2	4.6	--	--	7.8	57	--	--
95	do-----	.5	do---------------------------------------	2.2	6.1	--	--	7.4	51	--	--
96	do-----	.9	do---------------------------------------	8.0	6.0	--	--	7.1	60	--	--
97	do-----	.5	do---------------------------------------	5.2	5.5	--	18.5	7.6	44	--	--
98	do-----	1.8	do---------------------------------------	6.2	5.4	--	--	7.1	45	--	--
99	do-----	2.1	do---------------------------------------	5.2	4.3	--	18.5	7.3	47	--	--
100	do-----	.8	do---------------------------------------	8.7	5.1	--	--	7.2	62	--	--
101	do-----	1.0	Bearpaw bentonite, upper layer (Siparyann bed)------	.7	8.9	--	19.0	9.1	59	9	26.0
102	do-----	.4	Bearpaw bentonite, middle layer (Siparyann bed)------	.2	9.4	--	19.0	6.8	54	9	21.0
103	do-----	.5	Bearpaw bentonite, lower layer (Siparyann bed)------	.0	9.8	--	20.5	9.2	42	7	26.0
104	do-----	.3	Bearpaw bentonite-------------------------	8.2	4.1	--	--	9.2	38	--	--
105	do-----	.5	do---------------------------------------	1.7	7.4	--	7.7	7.7	55	--	--

Sample				Percent		Viscosity		Foundry		Pelletizing	
No.	Type	Length (feet)	Description	Grit (+200 mesh)	pH	Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
106	Channel	0.4	Bearpaw bentonite	1.2	8.0	5.0	--	8.1	34	--	--
107	do	1.0	do	4.5	4.7	--	19.0	7.3	66	--	--
108	do	.8	do	[illegible]	[illegible]	--	--	7.5	.8	--	-
109	do	.3	do	19.0	8.0	--	18.0	7.3	45	--	--
110	do	1.0	do	8.7	9.7	--	--	10.3	36	--	--
111	do	.7	do	8.0	4.2	--	--	7.6	57	--	--
112	do	.4	do	7.2	5.9	--	--	7.2	50	--	--
113	do	.8	do	7.2	7.3	--	--	7.6	77	--	--
114	do	.4	do	19.7	4.9	--	--	6.5	53	--	--
115	do	1.3	do	4.0	4.0	--	--	8.4	30	--	--
116	do	.2	do	5.0	4.2	--	--	6.3	49	--	--
117	do	.5	do	7.0	3.9	--	--	7.0	51	--	--
118	do	.6	do	5.5	7.1	--	--	7.1	68	--	--
119	do	.5	do	7.2	4.3	--	--	7.5	37	--	--
120	do	.4	do	20.2	4.1	--	--	6.8	43	--	--
121	do	.4	do	10.2	4.2	--	--	6.9	54	--	--
122	do	.5	do	13.2	5.0	--	--	6.5	66	--	--
123	do	2.5	do	5.0	8.3	--	--	6.9	61	--	--
124	do	.6	do	9.2	4.4	--	--	6.7	40	--	--
125	do	1.3	do	5.5	6.6	--	--	--	--	--	--
126	do	1.1	do	38.0	4.4	--	--	5.0	34	--	--
127	do	.8	Bearpaw bentonite, upper layer (Siparyann bed)	5.7	6.4	--	18.5	7.5	43	--	--
128	do	.8	Bearpaw bentonite, lower layer (Siparyann bed)	2.7	7.9	--	19.0	2.8	60	8	9.0
129	do	1.0	Bearpaw bentonite	3.5	4.1	--	--	7.5	44	--	--
130	do	2.3	do	8.2	5.2	--	--	6.7	56	--	--
131	do	1.2	do	7.2	5.7	--	19.0	6.1	63	--	--
132	do	2.2	Bearpaw bentonite, Siparyann bed	1.0	9.4	--	--	10.5	30	--	--
133	do	.5	Bearpaw bentonite	11.2	--	--	--	8.9	110	--	--
134	do	1.0	do	8.8	--	--	--	8.0	58	--	--
135	do	1.8	do	4.2	--	--	18.5	8.9	75	--	--
136	do	1.5	do	3.5	--	--	18.5	8.7	93	--	--
137	do	.8	do	4.0	--	--	--	9.0	79	--	--
138	do	1.2	do	2.5	--	--	--	9.4	111	--	--
139	do	.8	do	10.0	--	--	18.0	8.1	112	--	--
140	do	2.0	Bearpaw bentonite, Siparyann bed	2.3	8.5	--	18.0	5.2	70	--	--
141	do	6.0	Bentonitic Bearpaw shale	8.0	6.5	--	--	--	--	--	--
142	do	1.0	Bearpaw bentonite	7.5	--	--	--	8.5	102	--	--
143	do	.9	Bearpaw bentonite, upper layer (Siparyann bed)	1.2	--	--	19.0	6.7	102	9	21.0
144	do	.6	Bearpaw bentonite, lower layer (Siparyann bed)	.1	--	--	19.0	7.9	94	8	21.0
145	do	2.0	Bearpaw bentonite, Siparyann bed	14.0	7.8	--	19.0	8.6	41	8	21.0
146	do	1.5	Montmorillonitic Bearpaw	8.5	--	--	20.0	6.2	57	--	--
147	do	.5	do	3.0	--	--	--	9.1	71	--	--
148	do	.5	do	1.8	--	--	--	7.3	46	--	--
149	do	.7	do	2.8	--	--	--	5.6	65	--	--
150	do	.7	do	16.0	--	--	18.5	7.5	57	--	--
151	do	.7	do	3.2	--	--	--	8.4	69	--	--
152	do	1.0	do	5.0	--	--	18.5	7.2	73	--	--
153	do	.6	do	5.2	--	--	--	8.1	62	--	--
154	do	.7	do	6.1	--	--	--	8.6	43	--	--
155	do	.5	do	6.2	--	--	--	9.4	80	--	--
156	do	.4	Montmorillonitic silt	9.2	--	--	--	7.9	50	--	--
157	do	1.3	Bearpaw bentonite	6.0	--	--	18.0	9.0	95	--	--
158	do	1.3	do	5.8	--	--	18.0	8.1	81	--	--
159	do	.6	do	9.0	--	--	--	10.1	101	--	--
160	do	.2	do	5.2	4.2	--	--	7.1	64	--	--

Sample				Percent grit		Viscosity		Foundry		Pelletizing	
No.	Type	Length (feet)	Description	(+200 mesh)	pH	Baroid	Marsh funnel	Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry strength (pounds)
161	Channel	0.3	Bearpaw bentonite	5.1	4.3	5.0	--	7.7	43	--	--
162	do	1.4	do	10.1	5.5	--	--	7.0	40	--	--
163	do	.7	do	3.5	9.1	--	--	7.7	53	--	--
164	do	.6	do	4.0	4.8	--	--	7.2	39	--	--
165	do	.6	do	7.0	4.3	--	--	6.4	58	--	--
166	do	.2	do	2.0	7.0	--	--	7.1	65	--	--
167	do	.6	do	--	--	--	--	--	--	--	--
168	do	.2	do	11.7	4.1	--	--	7.8	52	--	--
169	do	.2	do	3.0	7.1	--	--	7.1	74	--	--
170	do	.3	do	6.2	4.5	--	--	7.1	63	--	--
171	do	.7	do	38.0	5.0	--	--	--	--	--	--
172	do	1.0	do	2.2	4.8	--	--	7.1	63	--	--
173	do	1.0	do	4.7	7.2	--	--	7.4	55	--	--
174	do	.7	do	8.0	4.2	--	--	7.6	57	--	--
175	do	.4	do	7.2	5.9	--	--	7.2	50	--	--
176	do	.8	do	7.2	7.3	--	--	7.5	77	--	--
177	do	.4	do	19.7	4.9	--	--	6.5	53	--	--
178	do	1.3	do	4.0	4.0	--	--	9.[illegible]	30	--	--
179	do	.2	do	5.0	4.2	--	--	6.3	49	--	--
180	do	.5	do	7.0	3.9	--	--	7.0	51	--	--
181	do	.6	do	6.5	7.1	--	--	7.1	68	--	--
182	do	.5	do	7.2	4.3	--	--	7.5	37	--	--
183	do	.4	do	20.2	4.1	--	--	6.8	43	--	--
184	do	.4	do	10.2	4.2	--	--	6.9	54	--	--
185	do	.4	do	3.0	7.1	--	--	8.2	36	--	--
186	do	.8	do	16.0	5.[illegible]	--	18.5	8.0	80	--	--
187	do	.5	do	11.0	4.[illegible]	--	--	7.0	47	--	--
188	do	.1	do	14.7	4.0	--	--	7.0	42	--	--
189	do	.3	do	4.2	4.1	--	--	5.7	57	--	--
190	do	2.5	Montmorillonitic Bearpaw shale	4.7	4.9	--	--	4.4	73	--	--
191	do	.2	Bearpaw bentonite	11.2	3.4	--	--	4.0	64	--	--
192	do	.3	do	2.7	4.7	--	--	7.4	50	--	--
193	do	.4	do	1.1	6.8	5.5	--	10.3	57	--	--
194	do	1.1	do	7.8	5.0	5.0	--	7.6	55	--	--
195	do	.2	do	3.0	--	--	--	9.3	62	--	--
196	do	.5	do	8.0	6.5	7.5	--	7.1	39	--	--
197	do	.5	do	13.2	5.0	--	--	6.5	66	--	--
198	do	.1	do	15.5	4.5	--	19.0	7.5	72	7	--
199	do	.8	do	4.2	3.8	--	--	8.2	53	--	--
200	do	1.1	do	9.5	5.5	--	13.0	8.2	46	--	--
201	do	.9	do	19.7	7.2	--	--	7.5	32	--	--
202	do	.8	do	2.2	7.4	--	--	--	--	--	--
203	do	.6	do	5.0	--	--	18.5	9.7	65	--	--
204	do	.7	do	15.0	--	--	--	8.4	84	--	--
205	do	1.0	do	6.0	--	--	19.0	8.9	77	--	--
206	do	1.0	do	22.5	--	--	--	7.2	84	--	--
207	do	1.0	do	7.0	--	--	19.0	9.3	68	--	--
208	do	.6	do	7.5	--	--	18.5	6.4	70	--	--
209	do	.4	do	2.9	--	--	--	9.8	110	--	--
210	do	.5	do	3.0	--	--	18.5	9.4	76	--	--
211	do	1.0	do	5.0	--	--	--	9.8	68	--	--
212	do	.5	do	4.0	--	--	18.5	8.8	69	--	--
213	do	.7	do	14.2	--	--	--	--	--	--	--

Representatives of American Colloid and Federal Bentonite report that the bentonite north of the Refuge which they propose to mine is possibly correlative with the Siparyann bed. At these proposed mine sites, however, the bentonite is in two distinct beds, 10 feet (3 m) apart. Other possibly correlative beds, in a 20-foot (6-m)-thick interval in the Little Rocky Mountains, were reported by Knechtel (1959, p. 745).

UL Bend area

Bentonite beds in the Bearpaw Shale in the UL Bend area are exposed primarily along the lower slopes of the shoreline of Fort Peck Lake, although a few exposures are in coulee walls (fig. 23). Slumping, with

Figure 23.--NEAR HERE. Localities of clay samples from the UL Bend area.

rotation and duplication of beds at the outcrop, is widespread along Fort Peck Lake. The beds are from 1 inch to 2.5 feet (2.5 cm to 0.76 m) thick, averaging approximately 9 inches (23 cm), and are stratigraphically above the Siparyann bed.

Eastern Refuge and South UL Bend areas

Bentonite beds in the Bearpaw Shale on the Wildlife Refuge east of the Musselshell River average about 3 inches (8 cm) thick. The thickest, about 16 inches (40 cm), is exposed near the north end of the Fort Peck Dam spillway. Average stratigraphic distance between bentonite beds on the east end of the Wildlife Refuge is about 9 feet (3 m), although there are intervals of more than 50 feet (15 m) without significant bentonite beds. In the Bearpaw Shale south of the UL Bend area, the average bed is about 2 inches (5 cm) thick, and the stratigraphic distance between beds is 50 to 120 feet (15 to 36 m). In the eastern part of the Refuge and south of UL Bend, bentonite beds are stratigraphically above the Siparyann bed.

Montmorillonitic clays from south of UL Bend and the eastern part of the Wildlife Refuge are likely to find little use; beds are thin, exposures poor, distance between them significant, and quality poor. However, bentonite and montmorillonitic clays suitable for local use are available from several areas, such as near the Fort Peck Dam spillway and west and north of the South Fork of Duck Creek (fig. 24). Some

Figure 24.--NEAR HERE. Localities of clay samples from the eastern part of the Charles M. Russell Wildlife Refuge and south of UL Bend.

Bearpaw, Hell Creek, and Fort Union bentonite or montmorillonitic beds probably could be used for sealing local water impoundments.

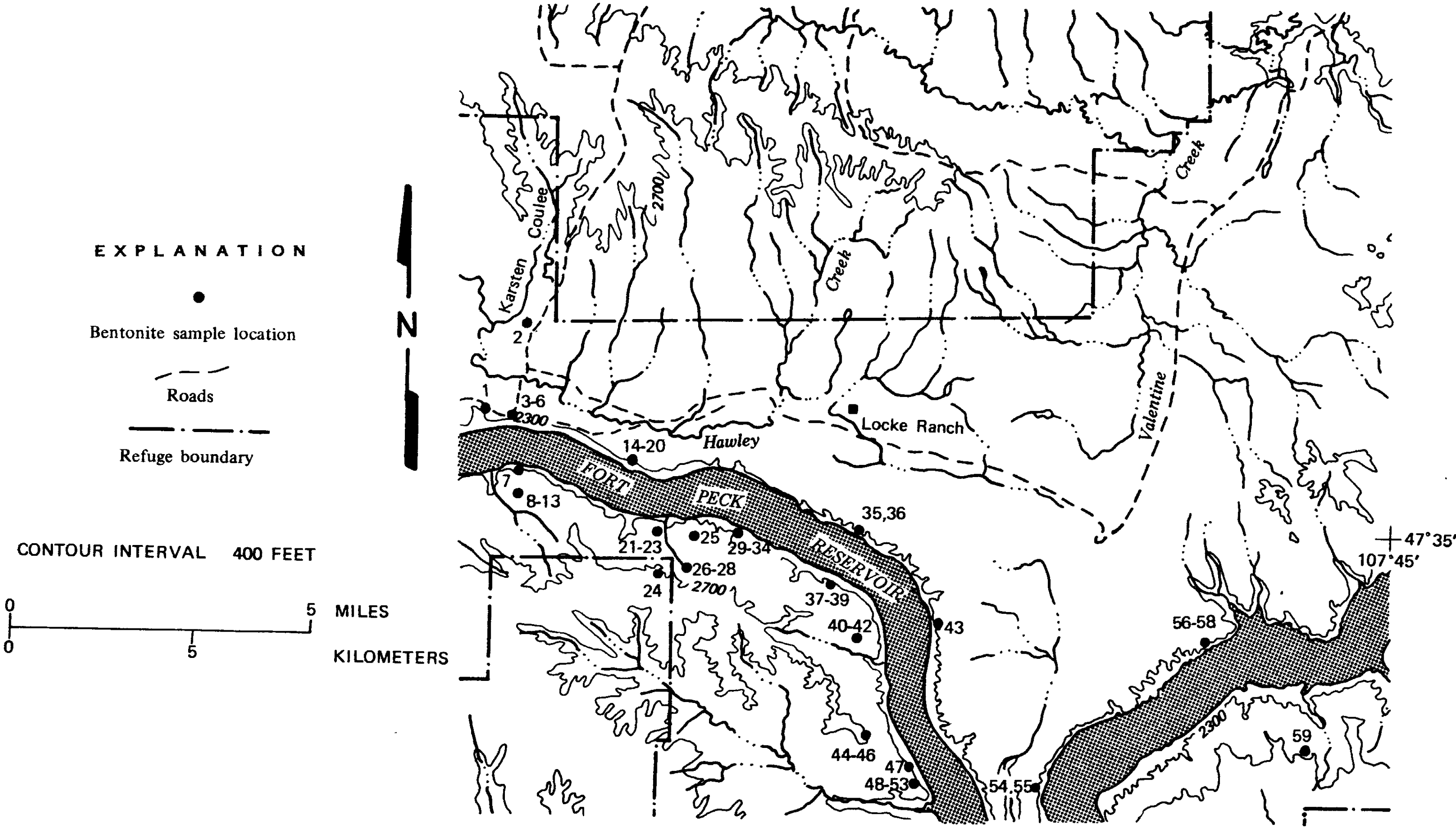


Figure 23.--Localities of clay samples from the UL Bend area. Base from 1:250,000 scale Army Map Service map.

An unnumbered table to accompany fig. 23, Localities of clay samples from the UL Bend area

Data for samples shown on figure 23.

[Data gathered and recorded in inch-pound system; 1 ft = 0.3048 m; 1 psi = 6895 pascals]

[--, not determined]

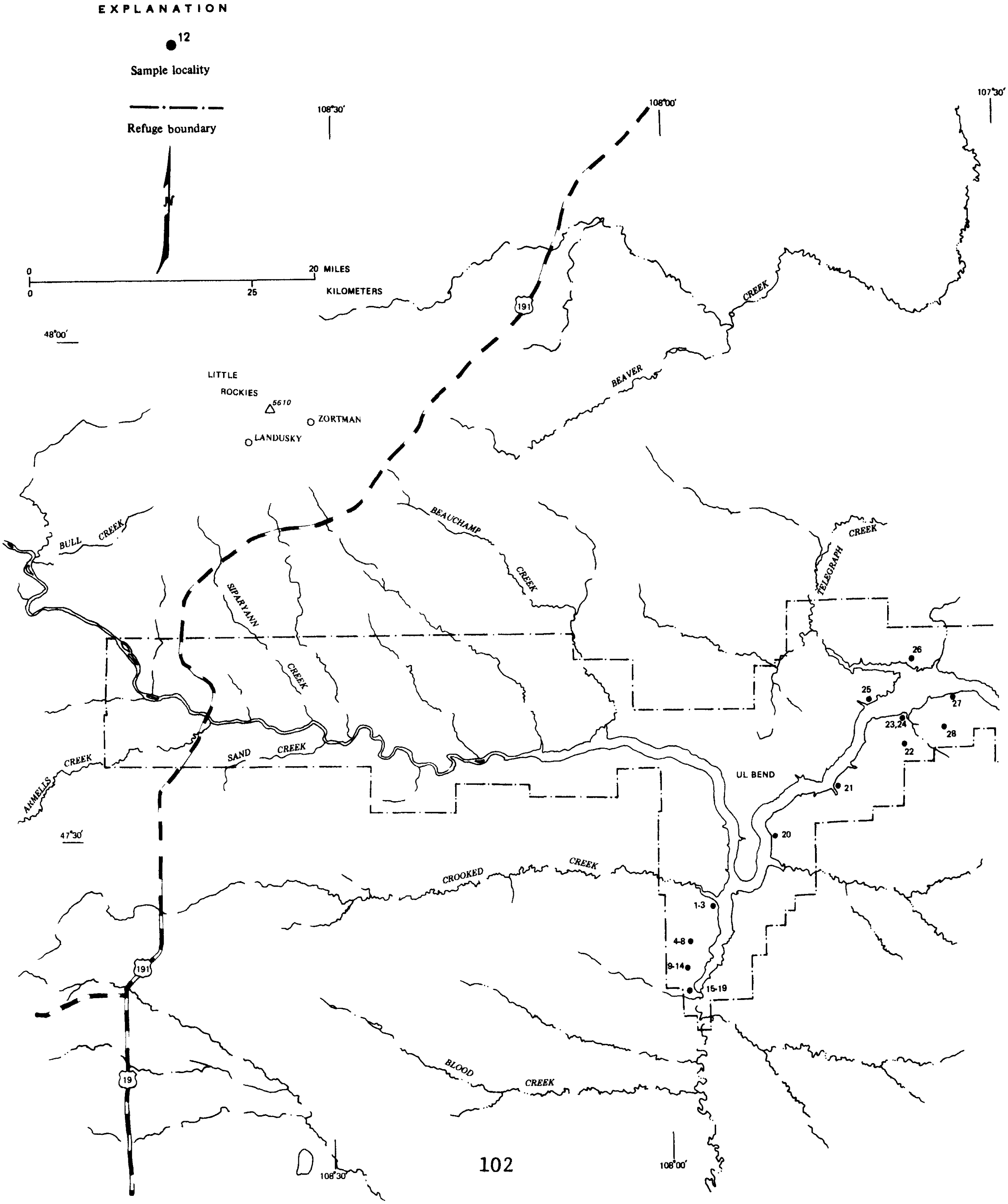
Sample				Percent Grit		Viscosity		Foundry	
No.	Type	Length (feet)	Description	(+200 mesh)	pH	Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)
1	Channel	0.6	Bearpaw bentonite----------------	3.7	7.6	--	--	6.7	92
2	do-----	1.6	do-----------------------------	5.3	8.3	--	19.0	7.6	46
3	do-----	.8	do-----------------------------	5.7	5.6	--	19.0	6.7	84
4	do-----	1.7	do-----------------------------	4.0	7.6	--	--	6.8	87
5	do-----	.8	do-----------------------------	2.3	5.1	--	19.0	7.5	92
6	do-----	.7	do-----------------------------	5.7	4.1	--	--	7.0	71
7	do-----	.9	do-----------------------------	3.2	8.5	7.5	18.0	8.6	73
8	do-----	.2	do-----------------------------	19.5	4.2	5.0	--	6.5	48
9	do-----	.5	do-----------------------------	26.9	4.7	4.5	--	7.0	50
10	do-----	.6	do-----------------------------	3.0	5.3	10.0	19.5	7.1	86
11	do-----	.3	do-----------------------------	14.4	--	--	--	7.1	44
12	do-----	.3	do-----------------------------	5.3	7.3	6.5	--	7.3	74
13	do-----	.4	do-----------------------------	1.3	--	--	--	9.1	64

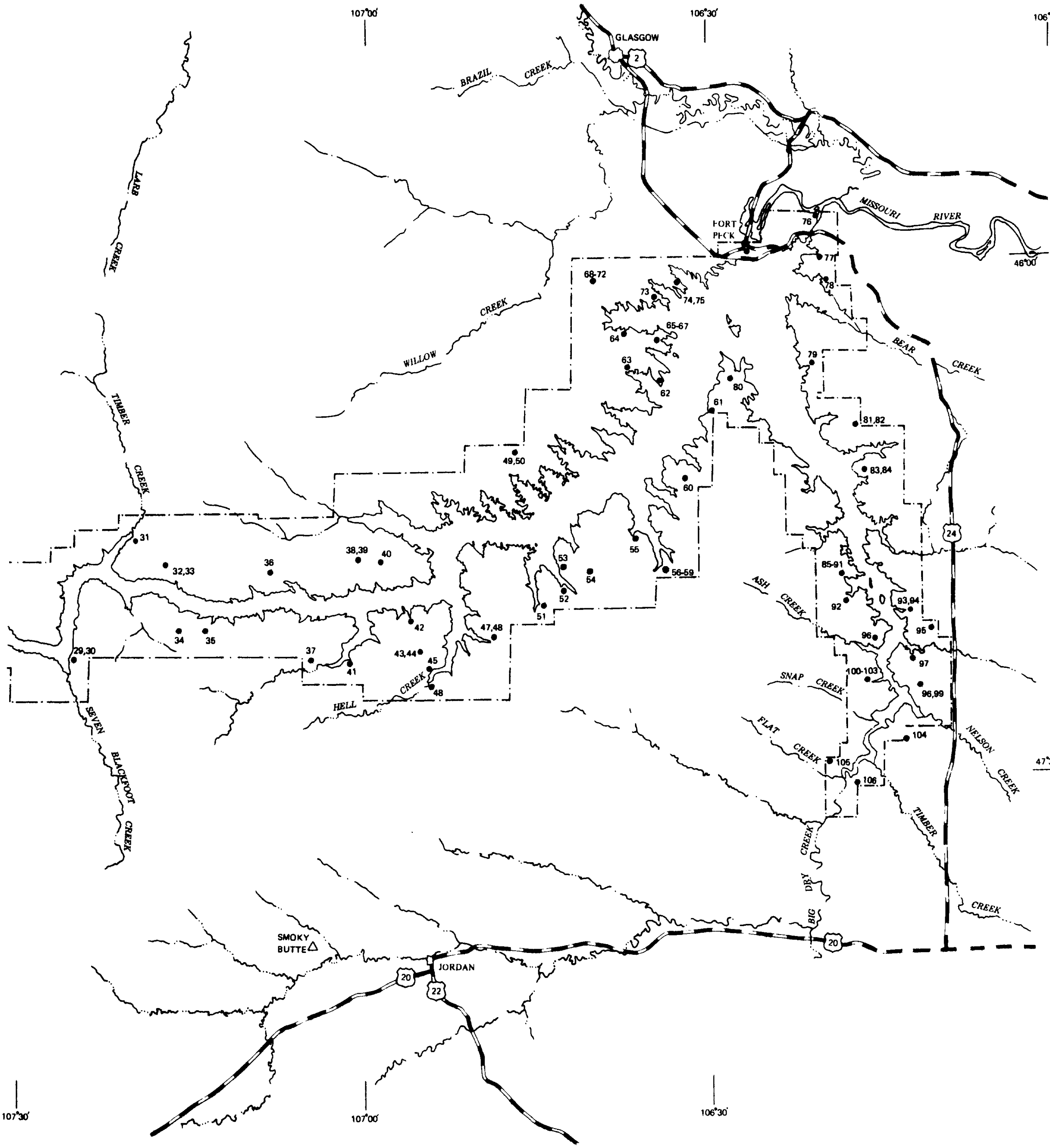
Sample				Percent Grit (+200 mesh)	pH	Viscosity		Foundry	
No.	Type	Length (feet)	Description			Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)
14	Channel	1.2	Bearpaw bentonite-------------	1.2	--	--	--	9.9	84
15	do-----	.8	do----------------------------	3.0	--	--	18.5	9.5	84
16	do-----	.6	do----------------------------	4.0	--	--	--	9.5	88
17	do-----	.8	do----------------------------	2.5	--	--	--	9.9	72
18	do-----	.7	do----------------------------	6.2	--	--	--	9.0	79
19	do-----	1.0	do----------------------------	2.0	--	--	19.0	9.6	92
20	do-----	.5	do----------------------------	4.0	--	--	--	11.1	90
21	do-----	.2	do----------------------------	38.5	6.8	--	--	3.8	27
22	do-----	1.2	do----------------------------	6.5	7.0	--	--	6.5	45
23	do-----	.8	do----------------------------	6.7	7.5	--	18.0	7.4	41
24	do-----	.7	do----------------------------	25.7	6.7	--	--	6.6	46
25	Grab	--	Montmorillonitic Bearpaw shale	.7	8.4	--	--	--	--
26	Channel	.3	Bearpaw bentonite-------------	46.9	3.8	--	--	4.2	23
27	do-----	.5	do----------------------------	5.5	4.5	--	--	7.0	46
28	do-----	1.0	do----------------------------	1.0	6.6	--	--	--	--
29	do-----	.3	do----------------------------	5.0	8.0	5.5	--	7.7	67

Sample				Percent		Viscosity		Foundry	
No.	Type	Length (feet)	Description	Grit (+200 mesh)	pH	Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)
30	Channel	0.5	Bearpaw bentonite	5.2	5.0	6.0	--	7.5	71
31	do	.3	do	11.2	4.5	5.0	--	8.1	52
32	do	.8	do	6.2	--	--	18.0	6.5	51
33	do	.3	do	7.0	6.1	5.5	--	6.4	62
34	do	.5	do	1.0	4.5	5.5	18.5	7.7	62
35	do	1.5	do	5.0	7.3	--	--	10.4	33
36	do	1.3	do	31.7	9.2	--	--	8.9	26
37	do	1.3	do	2.1	7.9	7.0	--	7.8	78
38	do	.3	do	7.0	6.8	6.0	--	6.2	120
39	do	.4	do	2.1	7.8	5.0	--	8.3	57
40	do	.3	do	8.5	7.8	6.0	--	10.2	58
41	do	.3	do	.8	4.4	6.0	--	9.9	60
42	do	.6	do	16.1	4.7	5.5	--	8.0	62
43	do	.5	do	1.0	5.0	--	--	8.6	45
44	do	.2	do	30.0	6.8	--	--	4.8	48

Sample				Percent		Viscosity		Foundry	
No.	Type	Length (feet)	Description	Grit (+200 mesh)	pH	Baroid	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)
45	Channel	0.5	Bearpaw bentonite	16.5	6.8	18.0	--	6.2	55
46	do	.4	do	25.2	6.7	--	--	5.0	54
47	do	.7	do	12.5	7.8	5.0	--	6.5	75
48	do	.8	Montmorillonitic Bearpaw shale	2.7	7.4	--	--	--	--
49	do	.3	Bearpaw bentonite	35.5	7.4	--	17.5	1.0	26
50	do	.6	do	21.7	6.8	--	--	6.1	38
51	Grab	--	Montmorillonitic Bearpaw clay	1.5	7.3	--	18.5	--	--
52	Channel	.4	Bearpaw bentonite	26.2	7.4	--	--	5.0	31
53	do	.2	do	23.0	7.0	--	--	4.8	36
54	do	.6	do	10.0	4.3	--	--	9.6	37
55	do	.5	do	3.3	4.2	--	--	8.5	41
56	do	.5	do	1.7	4.4	--	--	7.9	42
57	do	.6	do	2.7	5.1	--	--	--	--
58	do	.6	do	2.3	8.3	--	--	--	--
59	do	.5	do	6.3	7.7	--	--	7.3	51

Figure 24.--Localities of clay samples from the eastern part of the Charles M. Russell Wildlife Refuge and south of UL Bend. Base from 1:250,000 scale Army Map Service maps.




107°00'
106°30'
106°
GLASGOW
2
BRAZIL CREEK
LARB CREEK
WILLOW CREEK
TIMBER CREEK
MISSOURI RIVER
FORT PECK
46°00'
BEAR CREEK
ASH CREEK
SNAP CREEK
FLAT CREEK
NELSON CREEK
TIMBER
DRY CREEK
BIG
HELL CREEK
SEVEN BLACKFOOT CREEK
24
20
22
JORDAN
SMOKY BUTTE
47°
107°30'
68-72
73
74,75
76
77
78
79
80
81,82
83,84
65-67
64
63
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49,50
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32,33
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38,39
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56-59
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85-91
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93,94
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98,99
100-103
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29,30
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43,44
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47,48
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An unnumbered table to accompany fig. 24, clay samples from the eastern part of the Charles M. Russell

Wildlife Refuge and south of UL Bend

Data for samples shown on fig. 24.

[--, not tested]

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 meter;

1 inch = 2.54 centimeters; 1 psi = 6895 pascals; 1 pound = 0.4536 kilogram]

Sample				Percent		Viscosity	Foundry		Pelletizing	
No.	Type	Length (feet)	Description	Grit (+200 mesh)	pH	Marsh Funnel	Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
1	Channel	0.3	Bearpaw bentonite	7.7	5.8	--	7.1	62	--	--
2	do	.5	do	12.7	6.8	--	7.1	67	8	11.0
3	do	.3	do	26.7	5.1	--	6.7	33	7	14.2
4	do	.7	do	8.2	6.8	--	6.6	41	--	--
5	do	.2	do	31.0	5.5	--	4.8	71	--	--
6	do	.2	do	8.7	4.8	--	7.7	49	--	--
7	do	.7	do	16.0	3.8	--	7.0	35	--	--
8	do	.3	do	4.0	7.9	--	7.8	49	--	--
9	do	.5	do	7.7	6.8	--	6.8	37	--	--
10	do	.4	do	13.0	7.8	--	6.2	40	--	--
11	do	.5	do	1.0	4.4	--	7.6	43	--	--
12	do	.2	do	26.0	7.4	--	5.1	53	--	--
13	do	.1	do	28.5	4.2	--	7.3	39	--	--
14	do	.2	do	4.7	6.4	--	--	--	--	--
15	do	.5	do	31.2	9.2	--	11.0	24	--	--
16	do	.2	do	13.0	4.5	--	6.2	41	--	--
17	do	.6	do	3.7	7.2	--	6.1	77	--	--
18	do	.3	do	22.2	6.3	--	5.1	36	--	--
19	do	.1	do	22.0	5.3	--	5.8	38	--	--
20	do	.8	do	4.2	7.0	--	7.8	44	--	--
21	do	.5	do	.3	5.0	18.0	8.8	39	--	--
22	do	.5	do	5.0	7.8	--	7.8	44	--	--
23	do	.5	do	15.9	5.2	--	6.9	75	--	--
24	do	.7	do	15.0	4.8	--	6.6	66	--	--
25	do	.5	do	4.5	7.8	18.5	--	--	--	--
26	do	.5	do	1.0	--	--	--	--	--	--
27	do	.5	do	18.1	7.1	--	6.4	37	--	--
28	do	1.0	do	25.0	7.0	--	1.2	32	--	--
29	do	.7	do	37.7	8.0	--	4.8	51	--	--
30	do	.7	do	17.7	7.4	--	7.0	31	--	--
31	do	.5	do	53.2	8.1	--	3.5	54	--	--
32	do	3.1	Hell Creek silty montmorillonitic clay	.5	7.7	--	--	--	--	--
33	do	2.4	do	1.5	7.6	--	--	--	--	--
34	do	.7	Bearpaw bentonite	19.3	8.6	--	6.8	44	--	--
35	do	.8	do	6.0	6.8	--	--	--	--	--
36	do	.5	do	49.2	3.9	--	6.8	25	--	--
37	do	.6	do	9.0	4.3	--	6.5	36	--	--
38	do	.5	do	18.0	4.4	--	7.9	38	--	--
39	do	.5	do	22.2	3.5	--	9.3	25	--	--
40	do	.6	do	10.7	7.0	--	9.2	46	--	--
41	do	.9	do	15.2	8.8	--	8.1	35	--	--
42	do	3.1	Hell Creek montmorillonitic silty shale	.7	7.7	--	--	35	--	--
43	do	1.5	Underclay beneath carbonaceous shale, Hell Creek Formation	2.0	6.5	--	--	--	--	--
44	do	2.0	Hell Creek montmorillonitic silty shale	7.0	7.1	--	--	--	--	--
45	do	2.5	do	1.5	8.2	--	--	--	--	--
46	do	5.0	do	4.0	7.8	--	10.2	56	--	--
47	do	.5	Bearpaw bentonite	7.2	--	--	--	--	--	--
48	do	1.0	Hell Creek montmorillonitic silty shale	.5	7.8	--	8.5	43	--	--
49	do	.5	Bearpaw bentonite	34.7	8.3	--	--	--	--	--
50	do	.5	do	.5	7.6	--	--	--	--	--
51	do	8.0	Hell Creek montmorillonitic silty shale	17.0	--	--	--	--	--	--
52	do	.8	do	5.[illegible]	6.8	--	--	--	--	--

Sample				Percent Grit (+200 mesh)	pH	Viscosity (Marsh Funnel)	Foundry		Pelletizing	
No.	Type	Length (feet)	Description				Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
53	Channel	0.5	Bearpaw bentonite	13.5	3.9	--	6.6	53	--	--
54	do	.5	Hell Creek montmorillonitic silty shale	28.0	--	--	--	--	--	--
55	do	.8	Fox Hill bentonite	4.3	8.1	--	7.8	57	--	--
56	do	1.9	Hell Creek montmorillonitic silty shale	2.0	8.6	--	--	--	--	--
57	do	1.3	do	6.3	6.0	--	--	--	--	--
58	do	.7	Bearpaw bentonite	22.0	7.6	--	3.2	29	--	--
59	do	.5	do	7.2	--	--	10.2	56	--	--
60	do	5.0	Hell Creek montmorillonitic silty shale	1.0	8.0	--	--	--	--	--
61	do	.5	Bearpaw bentonite	13.5	3.9	--	6.1	39	--	--
62	do	.2	do	16.7	4.7	--	7.5	31	--	--
63	do	.5	do	11.2	4.1	18.5	6.5	38	--	--
64	do	.6	do	23.2	7.1	--	5.5	74	--	--
65	do	.2	do	10.5	7.2	--	8.2	50	--	--
66	do	.1	do	34.2	8.3	--	4.9	84	--	--
67	do	.4	do	12.2	7.0	--	--	--	--	--
68	do	.2	do	.2	7.7	--	--	--	--	--
69	do	.2	do	.2	8.0	--	--	--	--	--
70	do	.3	do	34.5	7.7	--	5.2	73	--	--
71	do	.1	do	1.0	7.0	--	10.3	41	--	--
72	do	1.0	do	.5	8.2	--	--	--	--	--
73	do	.4	do	.7	8.8	--	8.3	53	--	--
74	do	.2	do	37.2	7.7	--	--	--	--	--
75	do	.5	do	.2	8.0	--	--	--	--	--
76	do	1.3	do	6.0	9.9	--	8.7	23	--	--
77	do	.6	do	10.0	4.4	--	10.0	38	--	--
78	do	1.0	do	22.0	4.1	--	7.4	34	--	--
79	do	.6	do	20.2	4.3	--	7.7	39	--	--
80	do	.6	do	31.7	7.7	--	3.9	56	--	--
81	do	.7	Hell Creek montmorillonitic silty shale	2.0	8.0	--	--	--	--	--
82	do	1.0	do	27.7	7.0	--	--	--	--	--
83	do	.7	do	.2	6.9	--	--	--	--	--
84	do	.8	do	1.7	7.0	--	--	--	--	--
85	do	8.0	Underclay beneath carbonaceous shale in Hell Creek Formation	3.2	--	--	--	--	--	--
86	Chip	30.0	Hell Creek montmorillonitic silty shale	2.0	--	--	--	--	--	--
87	Channel	1.2	do	1.7	7.6	--	--	--	--	--
88	do	1.5	do	9.0	--	--	--	--	--	--
89	do	2.3	do	.1	7.7	--	--	--	--	--
90	do	1.8	do	.2	--	--	--	--	--	--
91	do	3.7	do	11.0	--	--	--	--	--	--
92	do	2.0	do	2.0	--	--	--	--	--	--
93	do	1.5	do	2.0	8.4	--	--	--	--	--
94	do	1.0	do	3.2	7.3	--	--	--	--	--
95	do	3.0	Underclay beneath coal, lower Fort Union Formation	3.7	7.8	--	--	--	--	--
96	do	2.0	Underclay beneath carbonaceous shale Hell Creek Formation	1.9	--	--	--	--	--	--
97	do	.5	Underclay beneath coal, lower Fort Union Formation	5.0	7.0	--	--	--	--	--
98	do	1.0	do	[illegible]	7.6	--	--	--	--	--
99	do	3.8	Overclay above coal, lower Fort Union Formation	45.0	5.1	--	--	--	--	--
100	do	4.0	Underclay below carbonaceous shale, Hell Creek Formation	3.0	--	--	--	--	--	--

Sample				Percent Grit (+200 mesh)	pH	Viscosity Marsh Funnel	Foundry		Pelletizing	
No.	Type	Length (feet)	Description				Green Strength (psi)	Dry Strength (psi)	Drop (18")	Dry Strength (pounds)
101	do-----	2.5	Hell Creek montmorillonitic silty shale	2.5	--	--	--	--	--	--
102	do-----	4.1	Underclay below coaly layer, lower Fort Union Formation--------------------	1.8	--	--	--	--	--	--
103	do-----	7.01	do-----------------------------------	5.5	--	--	--	--	--	--
104	do-----	4.0	Hell Creek montmorillonitic silty shale	2.2	7.0	--	--	--	--	--
105	do-----	6.2	do-----------------------------------	4.0	5.8	--	--	--	--	--
106	do-----	1.3	do-----------------------------------	4.1	6.4	--	--	--	--	--

Results of clay testing

Eighteen bentonite samples were collected by the U.S. Geological Survey and tested by the Bureau of Land Management in a reconnaissance survey of the Refuge. The results are shown in table 12. More detailed sampling,

Table 12.--NEAR HERE. Physical and chemical properties of selected bentonites from the Charles M. Russell Wildlife Refuge, Montana

and resource estimation, were performed by the U.S. Bureau of Mines.

Test results of the Bureau of Mines clay samples are listed in tables accompanying figures 22, 23, and 24. Select samples were analyzed for taconite pelletizing. Of the sampled clays in their natural state, none are suitable as a drilling fluid additive. Many are satisfactory for taconite and foundry sand bonding. Many of marginal quality may be improved by blending with other clays or by treatment with chemical additives. Because clay samples were collected at outcrop, the test results give only an approximation of the physical properties of bentonite beds at greater depth.

Mining, reclamation, and processing

Bentonite mining in the Bearpaw Shale on the Wildlife Refuge could utilize standard earth-moving equipment to remove the overburden and topsoil, loosen and remove the clay, replace the overburden, regrade the surface, and replace the topsoil. Bentonite in Montana and Wyoming is generally mined to depths of 35 to 75 feet (11 to 23 m). Clay at greater depths is not weathered sufficiently to be suitable for present major uses. Mining on the Wildlife Refuge would involve long, winding strips of land from 100 to 300 feet (30 to 90 m) wide following the bentonite outcrop. The land could be reclaimed during, or shortly after, mining.

The shale and clay are soft and easily mined without blasting. A layer of clay might have to be left to prevent contamination with soft, underlying shale. Proper drainage would help the mine floor and access roads to dry quickly after a rain and allow heavy equipment to operate.

Table 12.--Physical and chemical properties of selected bentonites from the Charles M. Russell Wildlife Refuge, Montana, and the specifications of the American Petroleum Institute for bentonite used in oil-well drilling fluids. Samples collected under the direction of Claudia Wolfbauer Frahme, U.S. Geological Survey. Testing by U.S. Bureau of Land Management, Worland, Wyoming. 1/

[<, less than; >, greater than; leaders (---), no value given]

Sample Number	X- Coordinate 2/	Y- Coordinate 2/	Thickness (cm)	Grit 3/	pH 4/	Yield (barrels)	Apparent Viscosity (cps)	Water Loss (cm^3)	Green Strength 5/ (psi)	Dry Strength 6/ (psi)	Color
					Bearpaw Shale						
B-3	-95,400	8,400	45	3.3	7.3	30	3/2	57.5	9.1	127.0	Green.
B-7	-46,750	1,850	30	0.1	8.1	30	3/2	28.5	8.9	173.5	Gray-green.
B-9	-47,750	-300	20	3.3	7.5	40	4/2	54.0	8.0	151.0	Green.
B-20	-34,850	-4,450	25	2.0	8.8	46	5/2	72.0	10.5	93.0	Gray.
B-69	-15,050	-3,600	20	0.2	8.5	46	5/2	118.5	8.9	146.5	Do.
B-117	14,300	5,700	20	0.6	5.2	51	6/2	61.0	8.2	167.0	Do.
B-135	-87,650	-1,100	30	0.3	4.6	30	3/2	ALL	10.7	105.5	Cream.
B-138	-92,950	1,700	60	3.9	8.5	61	9/2	23.0	8.8	163.0	Green.
					Hell Creek Formation						
H-5	93,500	8,000	91	2.0	8.5	30	3/2	53.0	5.3	130.5	Brown-green.
H-20	94,700	3,500	15	---	8.0	30	3/2	74.0	38.3	137.0	Green.
H-22	94,500	3,700	10	0.2	8.4	30	3/2	72.0	4.1	139.0	Do.
H-28	93,300	-8,700	122	0.5	8.5	30	3/2	37.5	5.8	117.5	Green-gray.
H-29	91,900	-12,100	92	0.1	7.6	30	3/2	25.0	5.9	146.5	Green.
H-53	91,050	-3,000	61	0.7	8.5	40	4/2	21.0	6.4	170.0	Gray.
H-54	91,050	-3,000	25	1.2	8.4	30	3/2	32.3	5.5	129.5	Do.
H-55	91,050	-3,000	122	---	7.8	30	3/2	42.0	5.6	148.4	Do.
H-61	88,500	6,100	92	0.4	7.3	30	3/2	19.0	4.4	173.5	Green.
H-120	85,800	12,100	60	3.0	8.1	51	6/2	27.5	8.3	157.0	Brown.
PI Specifications (1974) for oil well drilling fluids			---	<4.0	>8.2	>91.8	>30/2	<13.5	---	---	---

1/ Sample locations on plate 1. See sampling analytical methods section for test procedures.
2/ Plate 1.
3/ Weight percent >200 mesh.
4/ 6 weight percent slurry.
5/ Green bond strength for this table refers to the compressive strength of a core 5 cm in diameter and 5 cm long composed of 5 percent bentonite, 3 percent water, and 92 percent quartz sand at room temperature.
6/ Dry bond strength for this table refers to the compressive strength of a core identical to that prepared for green bond strength tests after it has been heated at 122°C for a least 2 hours.

Economic feasibility

At 1977 costs, bentonite could be produced from the Siparyann bed for about $11.00 per ton ($12.00 per t) bulk or $18.00 per ton ($20.00 per t) sacked, f.o.b. plant. These total costs compare favorably with 1977 selling prices of about $16 per ton ($18.00 per t) bulk taconite-grade and $24 per ton ($26.00 per t) sacked foundry-grade Wyoming bentonite. The expense of a 60 mile (100 km) truck haul to the Malta railhead would be involved. However, because distance to the major Great Lakes taconite plants is less than from Wyoming mines, total transportation costs compare favorably with similar costs for Wyoming bentonite mines selling to the same markets.

Any new producer in Montana may need a substitute for natural gas, which is normally used for bentonite drying; none was available for new, large-scale industrial users in 1976. Coal could be used and is available from nearby sources both on and off the Wildlife Refuge.

Ownership and administration

Bentonite that meets certain criteria is legally termed an "uncommon variety" mineral commodity, and on public lands can be located and patented under the general mining laws. Bentonite that fails to meet these criteria is considered a "common variety" clay, subject to sale under the Materials Sales Act of 1947. In this study no attempt was made to classify bentonite as "common" or "uncommon." Permits would have to be obtained from the State of Montana, the U.S. Sport Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the U.S. Bureau of Land Management before bentonite mining could be undertaken on the Wildlife Refuge. Some land near, and on, UL Bend has been designated as wilderness. Special restrictions apply to use of mineral lands in wilderness areas.

Coal

Domestic use of coal, mainly for generating power, is increasing; this trend will probably continue as coal is substituted for other fuel or converted into synthetic liquid or gaseous fuel.

Montana coal, largely untapped, represents about 11.2 percent of domestic resources; however, in 1976 only about 4 percent of total domestic production came from the State (Westerstrom, 1978, p. 40, 41; Mining Informational Service, 1977). Almost all 1976 Montana coal production was consumed in Montana, mainly for producing power (Mining Informational Service, 1977), mostly because of high transportation costs. The Montana product contains less sulfur than much eastern and midwestern coal, although its heat content is often lower.

History and production

Coal leasing has been reported near, but not on, the Wildlife Refuge. Small mines in the vicinity of Seven Blackfoot Creek and Haxby Point reportedly produced 2,450 tons (2,000 t) of coal, probably between the 1920's and the 1940's (U.S. Geol. Survey unpub. data, Billings). The coal was from the upper Hell Creek or the lower Fort Union Formations. Between 1921 and 1955, about 213,000 tons (193,000 t) of subbituminous coal were produced intermittently from the Judith River Formation at the Phillips power plant's Russell mine, 4 miles (6 km) up the Missouri River from the western boundary of the Wildlife Refuge (Six Interior Bureaus and the Interior Missouri Basin Field Committee staff, 1962, p. 39). Production was used for generating power and home heating.

Burlington Northern, Inc., proposes to mine 35,500 tons per day (32,200 t/d) of Fort Union Formation coal from an area about 6 miles (10 km) southeast of the Wildlife Refuge. From it they plan to manufacture anhydrous ammonia, methanol-methyl fuel, and synthetic diesel fuel.

Resource estimates

The Wildlife Refuge's coal resources are about 290 million short tons (260 million t), consisting of about 100 million short tons (90 million t) in the Fort Union Formation and 190 million short tons (170 million t) in the Judith River Formation (table 13).

Table 13.--NEAR HERE. Estimated coal resources, Charles M. Russell Wildlife Refuge.

Coal areas as described during this study are shown in figure 25.

Figure 25.--NEAR HERE. Coal areas, Charles M. Russell Wildlife Refuge.

Except for Judith River coal, beds of lignite or subbituminous coal thinner than 2.5 feet (0.76 m) are reported only in tables for individual coal study areas. This exception was made because Judith River beds have been mined nearby. Coal beds consisting of more than one-half shale, or containing more than one-third ash, were omitted from the resource estimates, except for the Judith River beds. A specific gravity of 1.3 was used for the coal resource calculations. Polygonal area weighting was used.

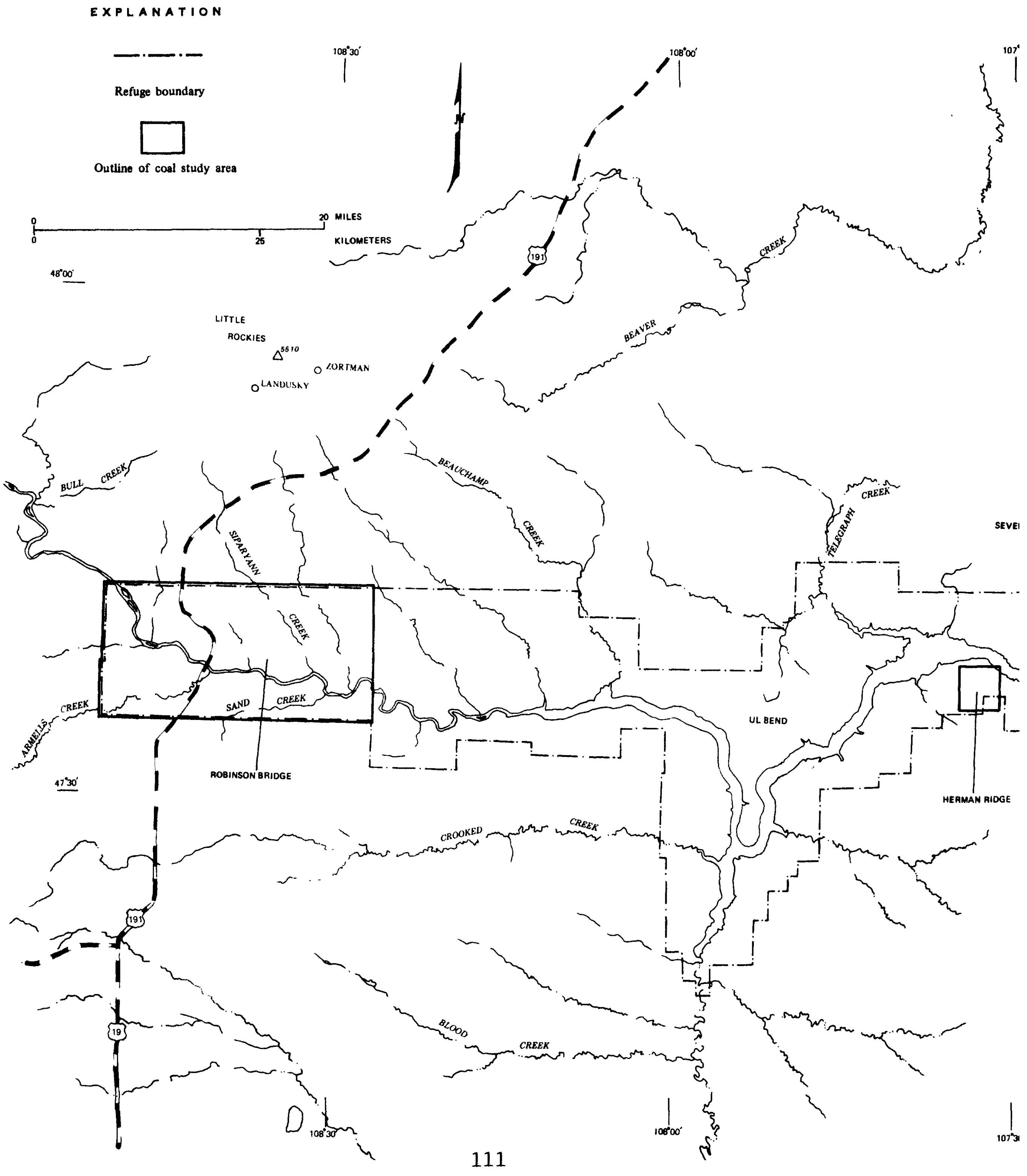
Table 13.--Estimated coal resources, Charles M. Russell Wildlife Refuge

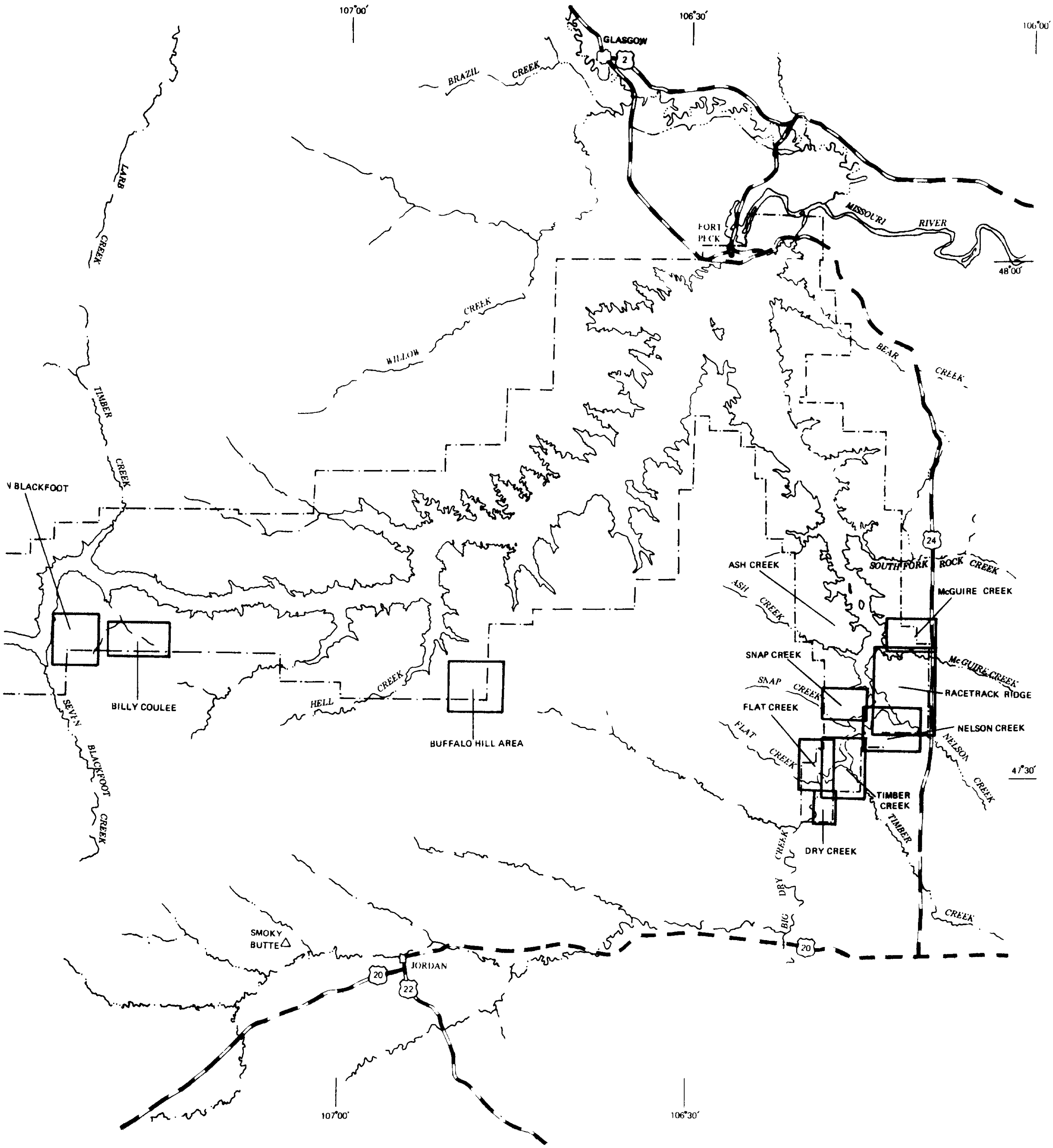
[Data gathered and recorded in inch-pound system. 1 short ton = 0.9072 t]

Area	Estimated quantity (million short tons)
Billy Coulee	1.6
Buffalo Hill	2.0
Dry Creek	6.8
Flat Creek	5.0
Herman Ridge	3.8
McGuire Creek	1.1
Racetrack Ridge	60.9
Nelson Creek	6.2
Robinson Bridge	1/ 190.0
Snap Creek	8.2
Timber Creek	3.2
TOTAL (Rounded)	290.0

1/ Averages less than 2.5 feet (0.76 m) in thickness and more than 30 percent ash.

Figure 25.--Coal areas, Charles M. Russell Wildlife Refuge. Base from 1:250,000 scale Army Map Service maps.





107°00'
106°30'
106°00'
GLASGOW
2
BRAZIL
CREEK
LARB
CREEK
FORT
PECK
MISSOURI
RIVER
48°00'
WILLOW
CREEK
BEAR
CREEK
TIMBER
CREEK
BLACKFOOT
24
SOUTH FORK
ROCK CREEK
ASH CREEK
ASH
CREEK
McGUIRE CREEK
McGUIRE CREEK
SNAP CREEK
SNAP
CREEK
RACETRACK RIDGE
FLAT CREEK
FLAT
CREEK
NELSON CREEK
NELSON
CREEK
47°30'
BILLY COULEE
HELL
CREEK
BUFFALO HILL AREA
SEVEN
BLACKFOOT
CREEK
TIMBER
CREEK
TIMBER
DRY CREEK
DRY
CREEK
BIG
CREEK
SMOKY
BUTTE
20
JORDAN
20
22
107°00'
106°30'

Geology

Coal cropping out in the Charles M. Russell Wildlife Refuge is in the Paleocene Fort Union Formation and the Upper Cretaceous Judith River and Hell Creek Formations.

The Tullock Member of the Fort Union Formation caps many ridges in the southeastern and central parts of the Wildlife Refuge. The next higher Fort Union Member, the Lebo, crops out on a few crests of the highest ridges in the eastern part of the Wildlife Refuge. Regional dip of the Tullock Member is approximately 15 to 25 feet per mile (2.8 to 4.7 m/km) to the southeast. Westernmost occurrence of Tullock coal is about 5 miles (8 km) east of Devils Creek Recreation site. Most coal beds in the Lower Fort Union Formation are lenticular and less than 10 feet (3 m) thick.

Beds consist mainly of bands of lustrous coal interbedded with dull coal, carbonaceous shale, clay, silt, and sand. Correlation of beds is aided by more persistent interbedded sediments, but correlation of most coal beds between outcrops more than a mile (1.6 km) apart is difficult.

Montmorillonite is less abundant higher in the Tullock Member than lower. Hard, carbonate-cemented concretionary sandstone lenses as much as 30 feet (9 m) thick cap many of the plateaus in the eastern part of the Wildlife Refuge. Layers of sideritic concretions as much as an inch (2.5 cm) thick are numerous between coal beds. Nodules of pyrite or marcasite in some silty, sandy interbeds are as much as 4 inches (10 cm) across.

Coal in the Judith River Formation has been reported to be subbituminous (Combo and others, 1949, p. 12; Bowen, 1912, p. 337). It is mostly black with some brown. Dull coal, which decomposes to a powder on surface exposures, and bright coal, which is jointed and breaks up into blocky, angular, 2- to 6-inch (5- to 15-cm) fragments, are present. Some joint surfaces are stained yellow by limonite.

On the Wildlife Refuge two layers containing Judith River coal crop out. One, with coal as much as 2.6 feet (0.8 m) thick, is near the top of the Formation; the other is approximately 100 feet (30 m) lower. Coal thickness in the upper layer averages 1.4 feet (0.4 m), and in the lower 1.7 feet (0.5 m). The beds are widespread. The lower beds were traced approximately 6 miles (10 km) easterly from the western boundary of the Refuge to Fort Peck Lake where they are submerged. The upper coal beds were traced easterly about 17 miles (27 km) from the western Refuge boundary to where they also dip below lake level.

Drill hole data indicate that the Judith River Formation continues beneath the Wildlife Refuge but thins to the east. The Formation's top is about 1,600 feet (490 m) below ground level near the Wildlife Refuge's eastern edge. Judith River Formation coal beds are generally less numerous and thinner to the east. Available drill hole logs from near the Refuge, while not used for tonnage calculations, indicate that most significant upper Judith River coal is probably west of Hell Creek.

Clinker beds, or fused sediments, are found where thick coal beds have burned at outcrops. In a clinker area immediately north of Nelson Creek, significant amounts of at least three coal beds have burned. Likewise, to the west, around Herman Ridge, significant quantities of coal have burned. Irregular collapse depressions and slumping overlie some areas of burned coal. The subsurface extent of the clinker zones is unknown and was not considered in coal tonnage calculations.

Ash Creek

The Ash Creek area is in the east part of the Refuge (fig. 25) where only on steep slopes are the nearly horizontal beds well exposed. Most beds are near the contact of the Hell Creek and Fort Union Formations. Because the coal is mainly shaly, silty, or sandy, and occurs principally in lenses and erosional remnants capping ridges, resource estimates were not made. The coal stratigraphy in the Ash Creek area is described in table 14.

Table 14.--NEAR HERE. Coal stratigraphy, Ash Creek area.

Billy Coulee

The Billy Coulee area (fig. 25) is in the south-central part of the Refuge. Several subbituminous coal seams lie in the lower part of the Tullock Member of the Fort Union Formation. Exposures are discontinuous; erosion has isolated them into small, irregular bodies. One bed, at the base of the Formation, composed of two coal layers separated by a 1-foot (0.3-m)-thick shale layer, averaged about 4.5 feet (1.5 m) in thickness. It is overlain by a 2-foot (0.6-m)-thick silty sandstone and a coaly, carbonaceous layer, about 30 feet (9 m) higher. Several thinner coal seams in the area contain no resources.

Table 14.--Coal stratigraphy, Ash Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone----------------------------------	20 - 40	6.0 - 12.0
Coal bed 3, carbonaceous shale and coaly shale	3 - 5	0.9 - 1.5
Shale, siltstone, and sandstone, partly montmorillonitic------------------------------	7 - 15	2.1 - 5.0
Coal bed 2, carbonaceous shale and coaly carbonaceous shale----------------------------	2 - 4	0.6 - 1.2
Shale, siltstone, and sandstone, partly montmorillonitic carbonaceous shale layers and thin, coaly layers------------------------	20	6
Coal bed 1, carbonaceous shale? with about 25 percent coal; overlies 3.5-foot (1.1-m) white clay layer------------------------------------	2.2	0.7
Silty sandstone and shale, montmorillonitic with carbonaceous shale-----------------------	Base not seen	

About 1.6 million short tons (1.5 million t) of subbituminous coal resources are estimated for the approximately 212 acres (86 h) of Billy Coulee coal bed 1. Coal outcrops and sample localities in the Billy Coulee area are shown in figure 26 and resource estimates are summarized

Figure 26.--NEAR HERE. Coal outcrops and sample sites, Billy Coulee area.

in table 15.

Table 15.--NEAR HERE. Estimated coal resources, Billy Coulee area.

Buffalo Hill

Coal in the Tullock Member of the Paleocene Fort Union Formation is intermittently exposed along the hillsides in the Buffalo Hill area (fig. 25). The two beds for which resources were estimated were 4 and 5 feet (1.2 and 1.5 m) thick. A poorly exposed clinker zone may indicate a 3- to 6-foot (0.9- to 1.8-m) coal bed. The coal stratigraphy is described in table 16.

Table 16.--NEAR HERE. Coal stratigraphy, Buffalo Hill area.

One sample was taken from each of the two thickest exposed coal beds (fig. 27). The Buffalo Hill area, composed of approximately 130 acres

Figure 27.--NEAR HERE. Coal outcrops and sample sites, Buffalo Hill area.

(53 h), is estimated to have measured coal resources of about 2 million short tons (1.8 million t). Most of it has less than 60 feet (18 m) of overburden. If the clinker zone overlies a coal bed, about 1 million tons (0.9 million t) of additional resources may be present.

Dry Creek

The Dry Creek area is at the extreme southeast corner of the study area (fig. 25).

Most of the coal is in the lower part of the Paleocene Fort Union or upper part of the Cretaceous Hell Creek Formations. Bedding is nearly horizontal. Interbeds tend to be silty sand, claystone, and carbonaceous shale. Poor exposure on the west side of Big Dry Creek precluded correlation of these beds with those on the east side. Those cropping out on the west side are less than 1.5 feet (0.5 m) thick and intensely weathered. A thick coal bed lies east of Big Dry Creek. Ranging from 4 to 9 feet (1 to 3 m) thick, the bed crops out along deeply incised streams, between elevations of 2300 and 2400 feet (700 and 730 m). Higher beds are thin, shaly, and discontinuous.

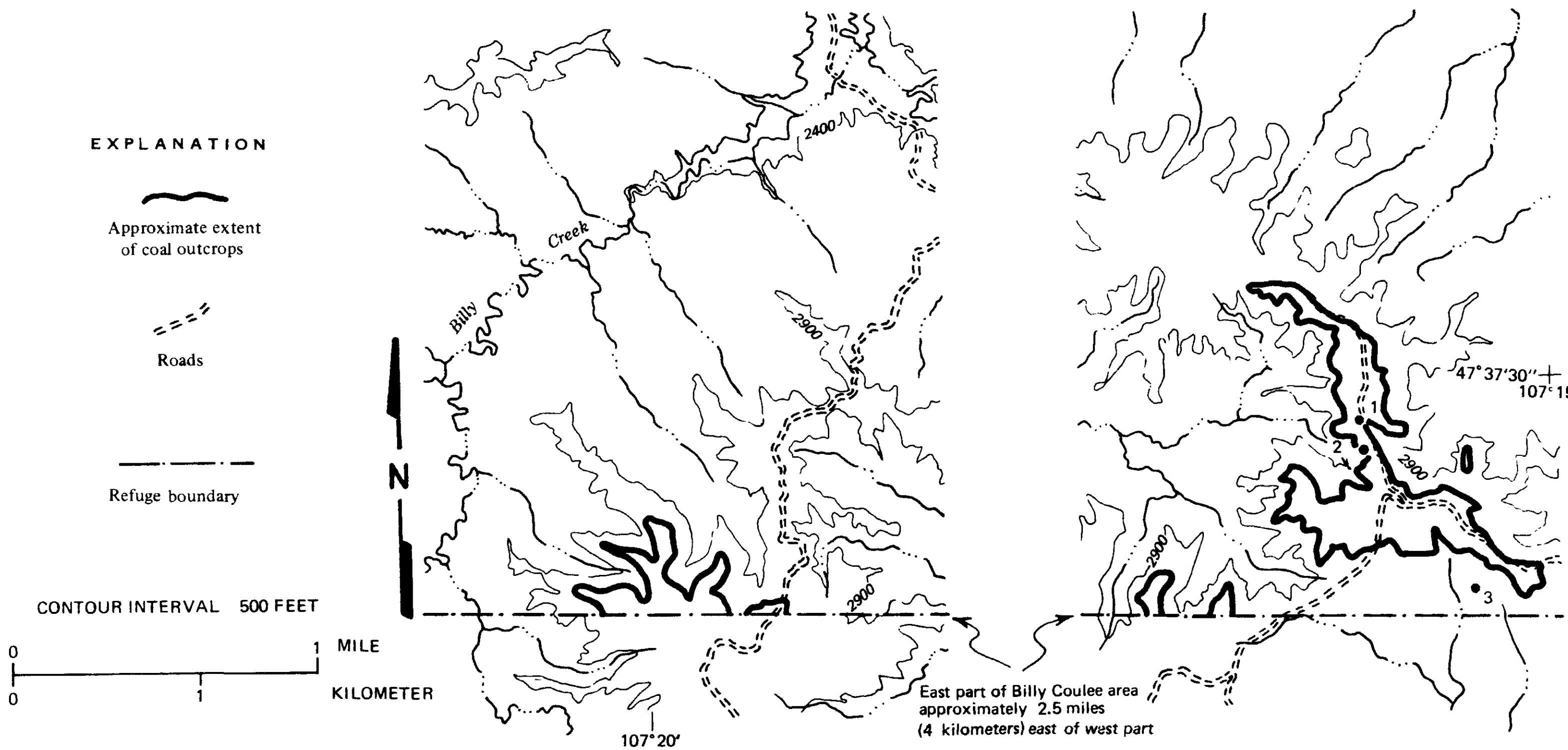


Figure 26.--Coal outcrops and sample sites, Billy Coulee area. Base from 1:24,000 scale U.S. Geological Survey maps.

An unnumbered table to accompany fig. 26, Billy Coulee area

Data for samples shown on figure 26.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent				Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur forms, percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	1	4.5	18.1	38.1	29.0	32.9	1.1	2.8	44.4	0.9	17.9	5590	6830	2120	0.21	0.01	0.09
2	2	2.0	32.2	27.4	13.5	59.1	1.3	1.6	24.2	.6	13.2	2320	3420	2520	.14	.01	.75
3	1	4.0	25.7	33.2	15.0	51.8	1.4	2.0	30.0	.7	14.1	3250	4370	2200	.46	.01	.60

Table 15.--Estimated coal resources, Billy Coulee area.

[Data gathered and recorded in inch-pound system;
1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	2.5 - 5.0	73	47	8
60 - 90	2.5 - 5.0	9	18	0
90 - 120	2.5 - 5.0	2	4	0

Table 16.--Coal stratigraphy, Buffalo Hill area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone, carbonaceous shale, and at least two coal beds to 0.3 foot (0.09 m) thick	70 - 80	20 - 24
Coal bed 3, lustrous black with conchoidal fracture in part	4.9	1.5
Silty sandstone	4.0	1.2
Carbonaceous shale	2.0	.6
Silty sandstone	9.5	2.9
Coal bed 2, carbonaceous shale, 3.75 feet (1.19 m) overlying 4 feet (1.22 m) of coal; black and lustrous in part	7.8	2.4
Brown siltstone	5.5	1.7
Carbonaceous shale	1.5	.5
Silty sandstone, partly montmorillonitic, with thin carbonaceous shale layers to about 1.0 foot (0.3 m). Poorly exposed	35.0	11.0
Coal bed 1(?), clinker outcrops, probably overlies a 3- to 6-foot (0.9- to 1.8-m) coal bed	5.0	1.5
Silty sandstone and shale, partly montmorillonitic, with carbonaceous shale layers	Base not seen	

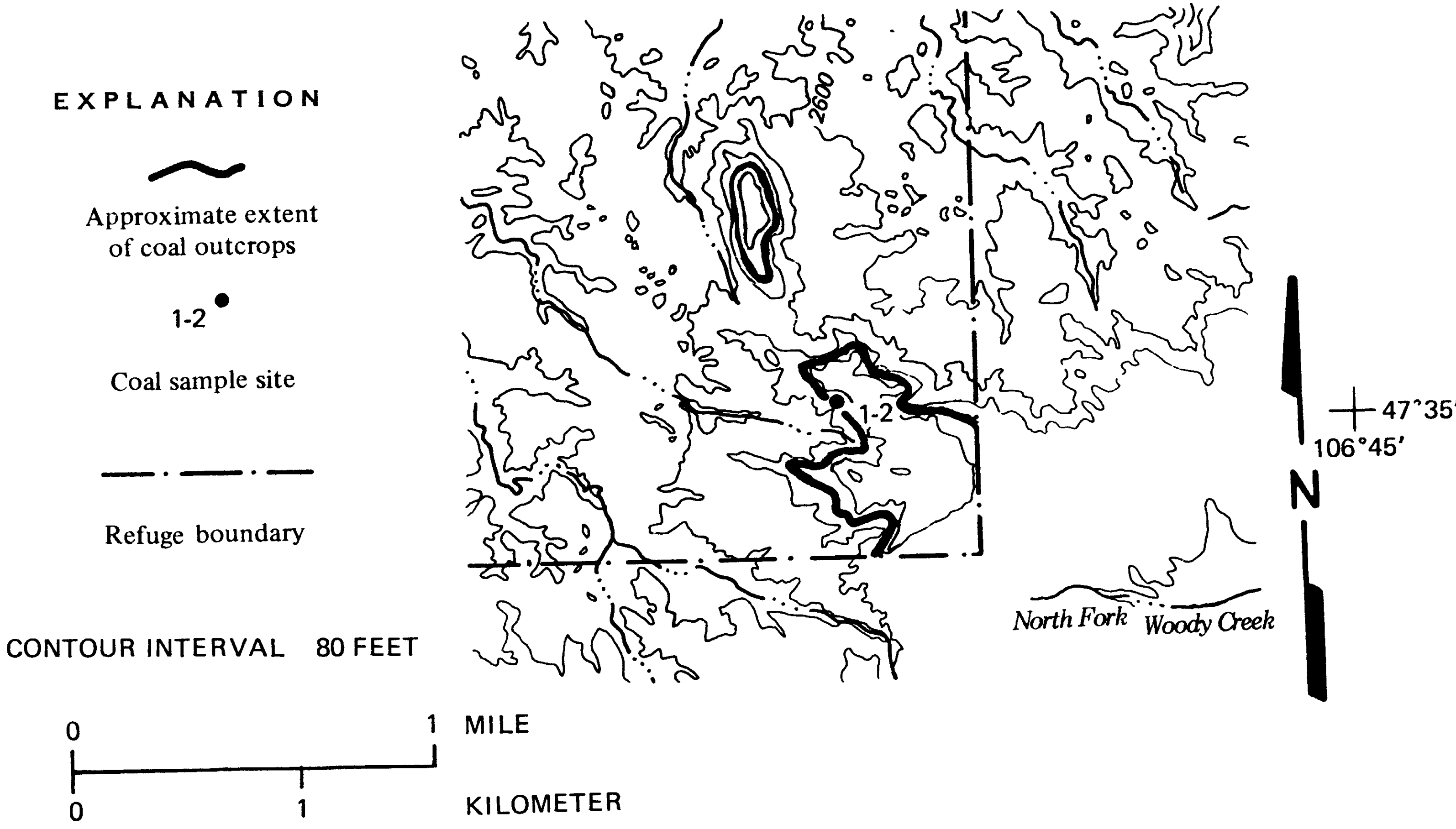


Figure 27.--Coal outcrops and sample sites, Buffalo Hill area. Base from 1:62,500 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 27, Buffalo Hill area.

Data for samples shown on figure 27.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent			Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal										Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	3	4.9	25.8	37.4	33.3	29.3	0.8	2.4	46.2	0.8	20.5	5010	6750	2370	0.33	0.01	0.26
2	2	4.0	30.4	37.9	33.9	28.2	.8	2.6	47.1	.8	20.2	4910	7050	2380	.52	.01	.26

East of the Dry Creek area, higher in the Fort Union Formation, thick coal beds, associated with clinker in many places, crop out extensively. One bed, in secs. 30 and 31, T. 20 N., R. 43 E., contains a total of at least 111 inches (2.8 m) of coal.

Dry Creek area sample sites are shown in figure 28, and a summary of the

Figure 28.--NEAR HERE. Coal outcrops and samples sites, Dry Creek area.

coal resources in table 17. All the resources were calculated for

Table 17.--NEAR HERE. Estimated coal resources, Dry Creek area.

coal bed 1, which averaged about 6 feet (2 m) thick throughout the calculation area of approximately one square mile (258 h).

Flat Creek

The Flat Creek area is in the southeast corner of the Wildlife Refuge (fig. 25). Area coal tends to split, thin, and grade into carbonaceous shale. The bedding of the lower Fort Union and upper Hell Creek Formations is nearly horizontal. Resource estimates were made for beds 1 through 5, which total about 1,400 acres (570 h); the beds range from about 1.5 to 5.0 feet (0.5 to 1.5 m) thick. A composite description of the coal stratigraphy in the Flat Creek area is in table 18.

Table 18.--NEAR HERE. Coal stratigraphy, Flat Creek area.

A resource summary is in table 19 and coal outcrops and sample sites are

Table 19.--NEAR HERE. Estimated coal resources, Flat Creek area.

shown in figure 29.

Figure 29.--NEAR HERE. Coal outcrops and sample sites, Flat Creek area.

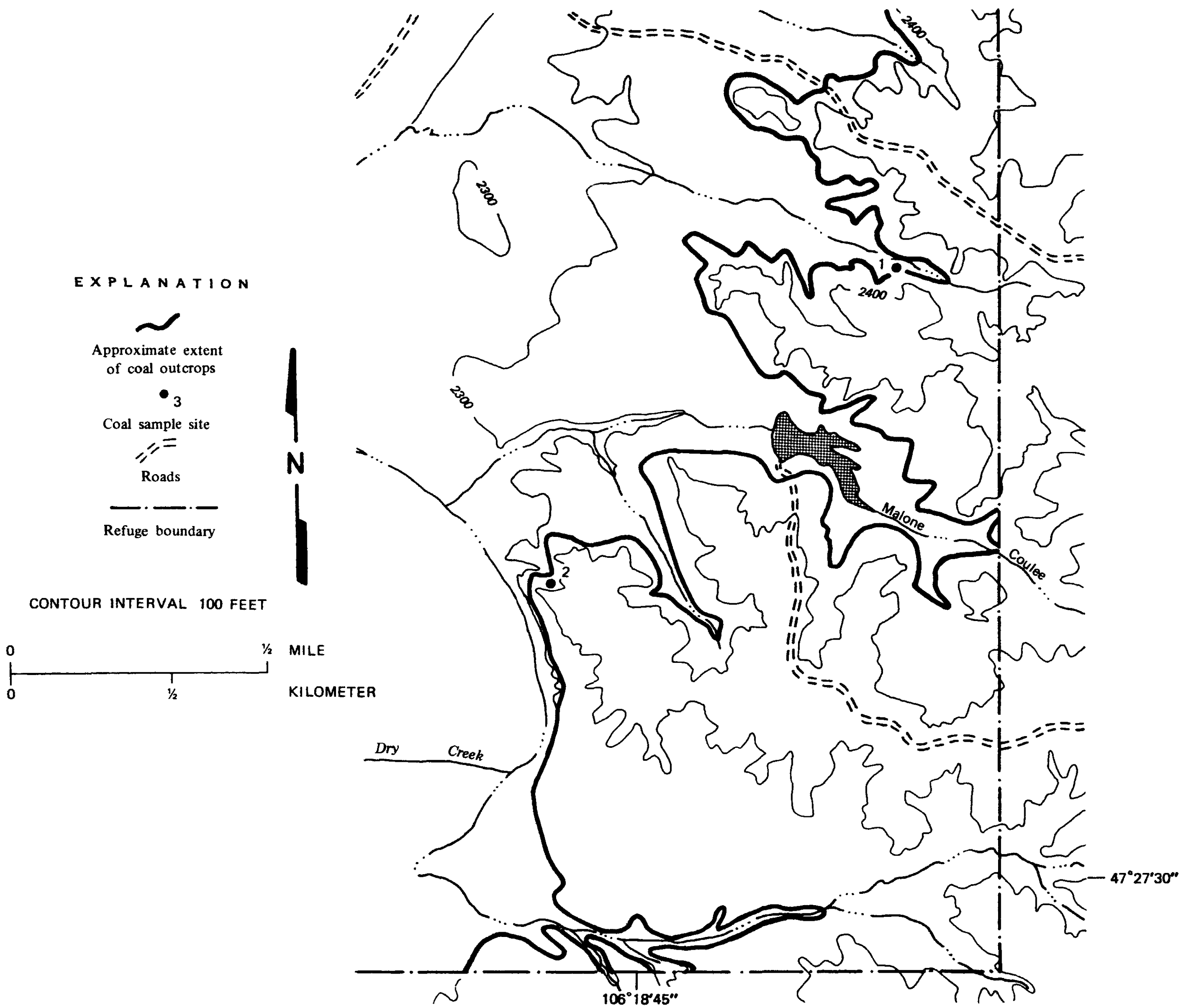


Figure 28.--Coal outcrops and sample sites, Dry Creek area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 28, Dry Creek area

Data for samples shown on figure 28.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent			Ultimate Analysis, Percent						Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	1	8.5-9.0	30.8	36.0	33.5	30.5	0.7	3.0	46.7	0.9	18.2	5100	7370	2190	0.14	0.03	0.30
2	1	5.5	29.2	39.1	22.6	38.3	1.0	2.4	40.0	.9	17.4	4270	6040	2190	.40	.02	.31

Table 17.--Estimated coal resources, Dry Creek area.

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	2.5 - 5.0	36	62	
	5.0 - 10.0	130	270	21
60 - 90	2.5 - 5.0	8	50	0
	5.0 - 10.0	29	26	0
90 - 120	2.5 - 5.0	5	12	0
	5.0 - 10.0	18	11	0

Table 18.--Coal stratigraphy, Flat Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty, partly montmorillonitic, sandstone shale, carbonaceous shale, and at least five intermittently exposed beds of coal and carbonaceous shale as much as 10 feet (3.0 m) thick	200	60.0
Coal bed No. 1, partly replaced or accompanied by up to 60 inches (1.5 m) of carbonaceous shale	3.2	1.0
Silty sandstone and shale, some montmorillonitic, with thin coal beds and carbonaceous shale	30 - 60	9 - 18
Coal bed No. 2, part associated with up to 18 inches (0.46 m) of carbonaceous shale and part almost entirely carbonaceous shale	1.3 - 4.3	0.4 - 1.3
Silty sandstone and shale, montmorillonitic, with carbonaceous shale layers	Base not seen	

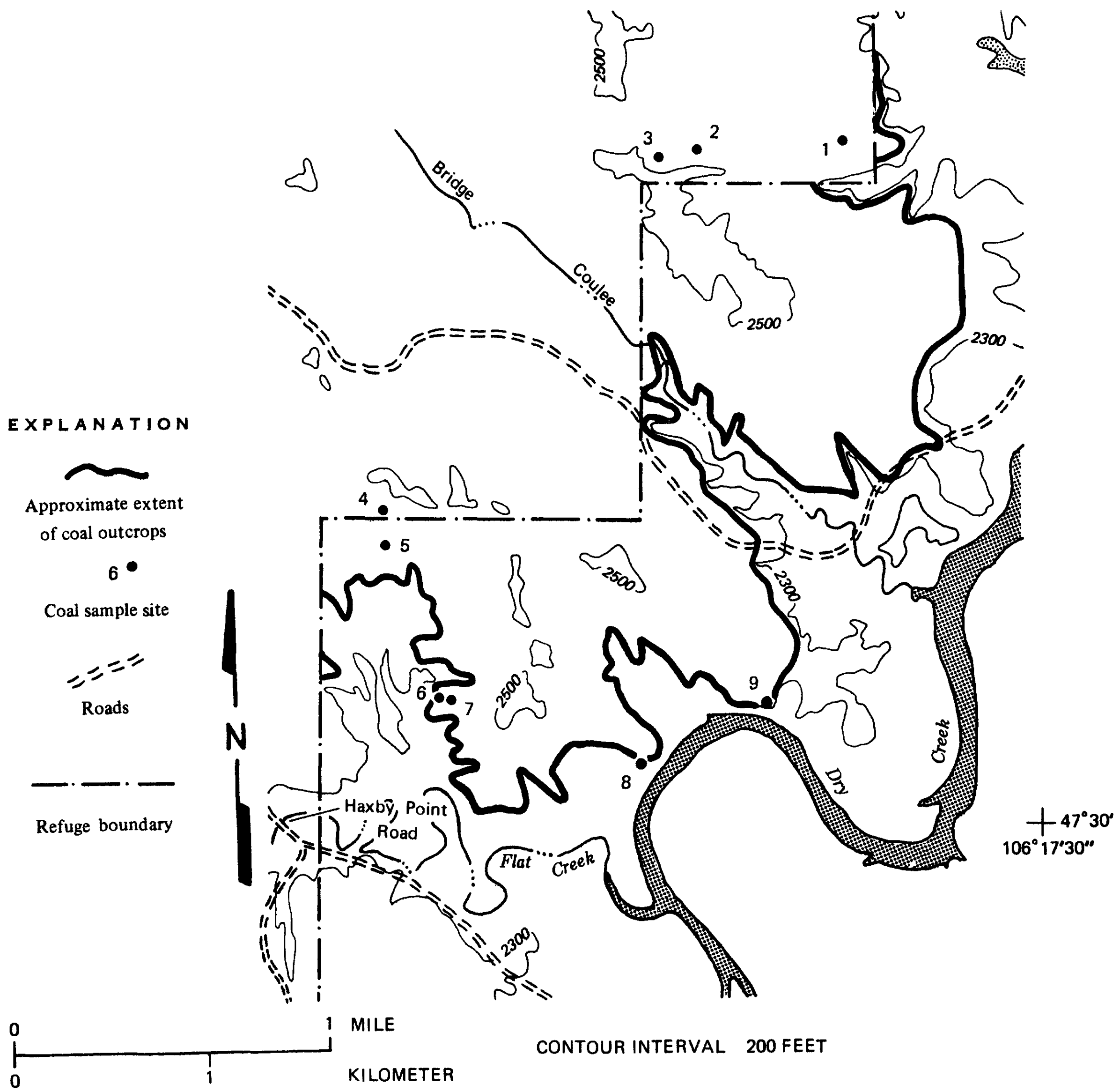
Table 19.--Estimated coal resources, Flat Creek area.

[Data gathered and recorded in inch-pound system;
1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	1.5 - 2.5	17	48	1.0
	2.5 - 5.0	34	80	2.0
	5.0 - 10.0	22	36	0
60 - 90	1.5 - 2.5	7	53	0
	2.5 - 5.0	33	46	0
	5.0 - 10.0	4.0	15	0
90 - 120	1.5 - 2.5	13	31	0
	2.5 - 5.0	17	34	0
	5.0 - 10.0	4.0	16	0
More than 120	1.5 - 2.5	3	20	0
	2.5 - 5.0	15	76	0
	5.0 - 10.0	10	56	0

Figure 29.--Coal outcrops and sample sites, Flat Creek Area. Base from 1:24,000 scale U.S. Geological Survey map.



An unnumbered table to accompany fig. 29, Flat Creek area

Data for samples shown on figure 29.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent				Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	2	3.2	24.1	37.9	20.3	41.8	0.9	2.5	36.3	0.9	17.6	4170	5490	2150	0.46	0.03	0.22
2	4	2.0	21.4	30.4	25.6	44.0	.7	2.1	36.5	.8	15.9	4230	5380	2420	.26	.01	.25
3	4	3.4	31.7	41.1	34.2	24.7	1.8	2.5	49.8	1.1	20.1	5000	7320	2080	.21	.01	1.01
4	5	2.7	27.4	35.2	28.9	35.9	1.1	2.6	42.2	.9	17.3	4740	6530	2400	.35	.01	.47
5	3	2.0	19.8	37.6	34.0	28.4	.7	2.6	46.9	1.0	20.4	5610	7000	2140	.29	.03	.26
6	1	4.25	22.4	32.0	29.1	38.9	.5	2.4	40.5	.6	17.1	4780	6160	2410	.11	.01	.29
7	2	2.0	27.0	35.5	31.8	32.7	.8	2.4	43.8	1.0	19.3	4850	6640	2250	.15	.02	.42
8	1	3.0	29.0	37.3	33.4	29.3	.6	2.8	46.3	1.1	19.9	5050	7100	2150	.09	.03	.28
9	1	2.8	27.9	39.2	20.4	40.4	1.0	2.4	37.8	.9	17.5	4100	5680	2190	.57	.03	.11

Herman Ridge

The Herman Ridge area is in the south-central part of the Wildlife Refuge (fig. 25).

Two subbituminous coal beds, thick enough to contain resources, are near the base of the Tullock Member of the Paleocene Fort Union Formation. The beds, which average 5 and 3 feet (1.5 and 0.9 m), are estimated to contain about 4 million short tons (3.5 million t) of resources. Several others were too thin and discontinuous to contain significant resources. Several small clinker deposits are associated with the thicker coal bed. The coal stratigraphy is described in table 20; resource estimates are summarized in table 21, and sample sites are shown in figure 30.

Table 20.--NEAR HERE. Coal stratigraphy, Herman Ridge area.

Table 21.--NEAR HERE. Estimated coal resources, Herman Ridge area.

Figure 30.--NEAR HERE. Coal outcrops and sample sites, Herman Ridge area.

McGuire Creek

The McGuire Creek area is east of the Big Dry Creek arm of Fort Peck Lake and west of Highway 24 (fig. 25).

Most of the coal, nearly horizontal, is in the Tullock Member of the Paleocene Fort Union Formation. Small remnants of the Lebo Member may cap the ridge. Weathering has probably oxidized much of the coal within 10 to 30 feet (3 to 9 m) of the ridge crest. Clinker is associated with parts of bed 3, and, to a lesser extent, bed 1. Coal in the McGuire Creek area tends to be shaly and discontinuous.

Stratigraphy of the McGuire Creek coal area is described in table 22.

Table 22.--NEAR HERE. Coal stratigraphy in the McGuire Creek area.

Sample sites in the area are shown in figure 31, and a summary of

Figure 31.--NEAR HERE. Coal outcrops and sample sites, McGuire Creek area.

estimated coal resources in table 23. Resource estimates, based on coal

Table 23.--NEAR HERE. Estimated coal resources in the McGuire Creek area.

beds 1 through 3, covered about 300, 70, and 85 acres (120, 30, and 35 h), respectively. Thicknesses of coal beds 1 through 3, as used for resource estimates, were 1.5 to 4.0 feet (0.5 to 1.2 m), 2.2 to 3.0 feet (0.7 to 0.9 m), and 4.5 feet (1.4 m), respectively.

Table 20.--Coal stratigraphy, Herman Ridge area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone------------------------------	0 - 30	0 - 9.0
Coal bed No. 3, partly carbonaceous shale-	1.8	0.5
Silty sandstone with thin, coaly layers and lenses of carbonaceous shale--------	30 - 90	9.0 - 27.0
Coal bed No. 2, partly shaly; contains a thin shale parting near top of bed-----------	2.9	0.9
Silty sandstone and shale------------------	7 - 40	2.1 - 12.0
Coal bed No. 1, part shaly; part contains shale as much as 3.0 feet (0.9 m) thick near the middle of the bed, and part of the bed contains thin shale near the top	4.9	1.5
Silty sandstone and shale with several thin coal and carbonaceous shale lenses as much as 3 feet (0.9 m) thick, partly montmorillonitic-------------------------	Base not seen	

Table 21.--Estimated coal resources, Herman Ridge area.

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources	
		Measured	Indicated
0 - 60	1.5 - 2.5	6	0
	2.5 - 5.0	59	18
	5.0 - 10.0	118	65
60 - 90	1.5 - 2.5	8	3
	2.5 - 5.0	13	5
	5.0 - 10.0	48	18
90 - 120	1.5 - 2.5	2	0
	5.0 - 10.0	23	13

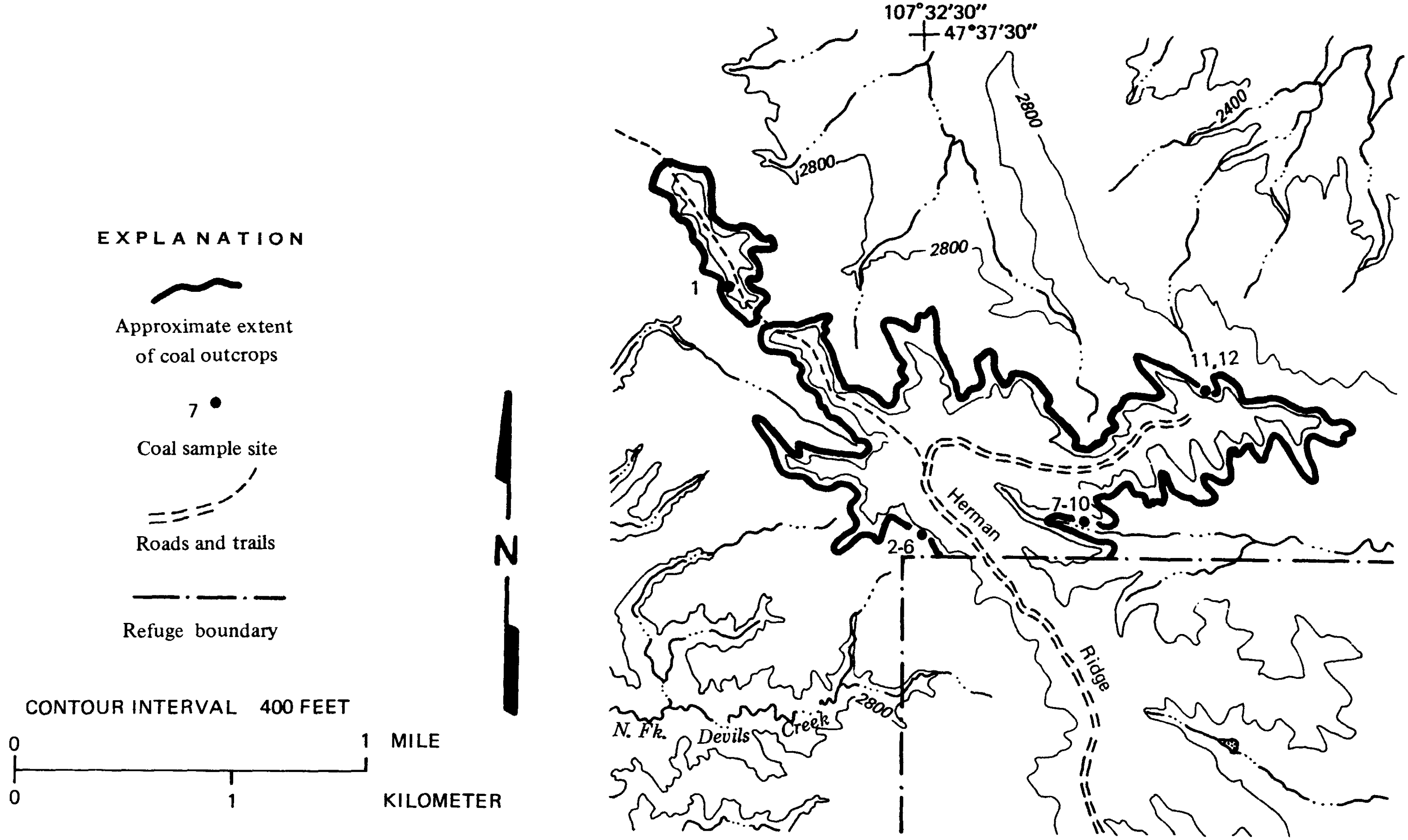


Figure 30.--Coal outcrops and sample sites, Herman Ridge area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 30, Herman Ridge area

Data for samples shown on figure 30.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

[--, not determined]

			Proximate Analysis, Percent				Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	--	1.9	35.7	42.8	40.1	17.1	0.9	2.9	54.0	1.1	24.0	5310	8260	1980	0.01	0.01	0.53
2	2 (upper part)	1.0	18.5	25.1	18.4	56.5	.9	1.7	26.7	.5	13.7	3040	3730	2880	.24	.01	.51
3	2 (lower part)	2.0	28.9	37.7	35.3	27.0	.9	2.8	48.8	.8	19.7	5240	7370	2350	.06	.05	.54
4	1	6.0	25.2	29.4	17.4	53.2	1.0	1.6	29.9	.6	13.7	3210	4290	2530	.14	.01	.57
5	--	1.9	32.3	40.9	37.5	21.6	1.4	3.1	51.3	1.1	21.5	5440	8040	1970	.32	.01	.62
6	--	2.7	17.7	34.3	32.6	33.1	1.1	2.4	45.1	1.0	17.3	5740	6980	2080	.89	.02	.0
7	2	2.8	25.0	30.4	23.2	46.4	.7	1.8	33.4	.6	17.1	3540	4720	2420	.42	.01	.13
8	1 (upper part)	1.2	21.6	8.6	14.5	76.9	.3	.1	20.4	.4	1.9	2270	2900	--	.05	.01	.15
9	1 (lower part)	5.3	24.3	33.0	26.0	41.0	.6	2.2	37.3	.8	18.1	4130	5450	2420	.25	.01	.18
10	--	1.5	25.7	37.0	34.6	28.4	1.0	2.5	46.8	1.1	20.2	5240	7050	2090	.20	.02	.55
11	2	2.5	22.8	30.6	22.6	46.8	.8	1.8	34.1	.7	15.8	3840	4970	2350	.19	.01	.46
12	1	5.3	30.0	31.9	30.3	37.8	.4	2.3	40.9	.7	17.9	4300	6150	2480	.08	.01	.20

Table 22.--Coal stratigraphy, McGuire Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone, partly montmorillonitic, with thin coal beds and two or three carbonaceous shale beds----------------------	40 - 60	12.0 - 18.0
Coal bed 4, carbonaceous shale [4 to 8 feet (1.2 to 2.44 m) thick] with 6 to 12 inches (15.2 to 30.5 cm) of coal-------------------	4 - 8	1.2 - 2.4
Silty sandstone, partly montmorillonitic------	20 - 50	6.0 - 15.0
Coal bed 3, mostly associated with approximately an equal thickness of carbonaceous shale--------------------------	3.1 - 8.0	0.9 - 2.4
Silty, partly montmorillonitic sandstone with lenses of carbonaceous shale and coal stringers--------------------	20 - 60	6.0 - 18.0
Coal bed 2------------------------------------	1.3 - 3.0	0.4 - 0.9
Silty, montmorillonitic sandstone with coal stringers and carbonaceous shale layers-----	30	9.0
Coal bed 1------------------------------------	1.5 - 4.0	0.5 - 1.2
Silty sandstone and shale, partly montmorillonitic, with carbonaceous shale lenses--------------------------------	Base not seen	

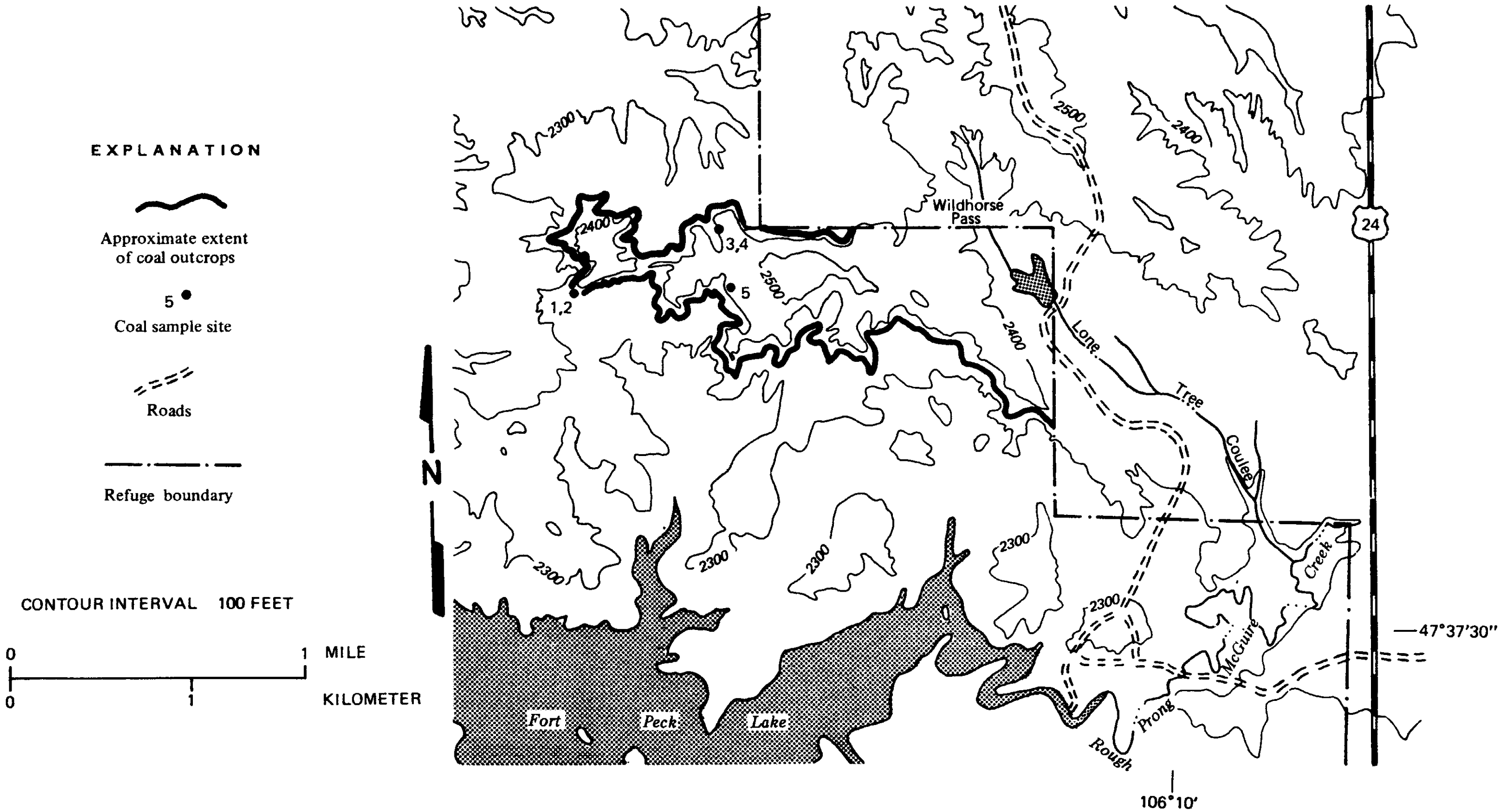


Figure 31.--Coal outcrops and sample sites, McGuire Creek area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 31, McGuire Creek area

Data for samples shown on figure 31.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent			Ultimate Analysis, Percent						Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	2	2.2	16.6	36.5	29.9	33.6	1.1	2.5	43.1	1.0	18.7	5370	6440	2140	0.54	0.02	0.34
2	3	2.2	12.9	24.4	16.0	59.6	.6	1.5	23.9	.6	13.8	2920	3350	2430	.40	.02	.11
3	2	3.0	25.4	41.8	39.0	19.2	.6	3.6	53.1	1.0	22.5	6350	8520	2180	.01	.01	.42
4	3	5.7	28.7	42.6	35.6	21.8	1.0	3.3	49.4	.9	23.6	5510	7720	2360	.31	.01	.36
5	3	5.0	20.7	45.4	24.6	30.0	1.0	2.8	42.9	1.0	22.3	5090	6420	2350	.49	.02	.30

Table 23.--Estimated coal resources, McGuire Creek area.

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	1.5 - 2.5	12	25	7
	2.5 - 5.0	32	35	0
60 - 90	1.5 - 2.5	4	10	1
	2.5 - 5.0	20	2	0
90 - 120	1.5 - 2.5	4	16	0
	2.5 - 5.0	12	1	0
More than 120	1.5 - 2.5	12	3	0
	2.5 - 5.0	5.4	2.4	0

Nelson Creek

The Nelson Creek coal area is south of Nelson Creek (fig. 25). The lower Paleocene Fort Union and upper Cretaceous Hell Creek Formations contain most of the coal. While outcrops in the Refuge are generally poor, some of the best coal exposures are near Nelson Creek. The beds are nearly horizontal, except where slumped as they are near Nelson Creek Bay.

The thicker coal beds in the Nelson Creek area are continuous; however, northern beds could not be definitely correlated with the southern, as represented by samples 5 through 10 (fig. 32). Coal beds 2

Figure 32.--NEAR HERE. Coal outcrops and sample sites, Nelson creek area.

through 6, which total about 2,600 acres (1,000 h), were used for the resource estimates. The beds range from about 1.5 to 6 feet (0.5 to 2 m) in thickness. The stratigraphy of the coal in the north part of the Nelson Creek area is described in table 24. Stratigraphy in the south part of the Nelson Creek area is described in table 25 and resource

Table 24.--NEAR HERE. Coal stratigraphy, north part of The Nelson Creek area.

estimates for the entire area are summarized in table 26.

Table 25.--NEAR HERE. Coal stratigraphy, south part of The Nelson Creek area.

Table 26.--NEAR HERE. Estimated coal resources, Nelson Creek area.

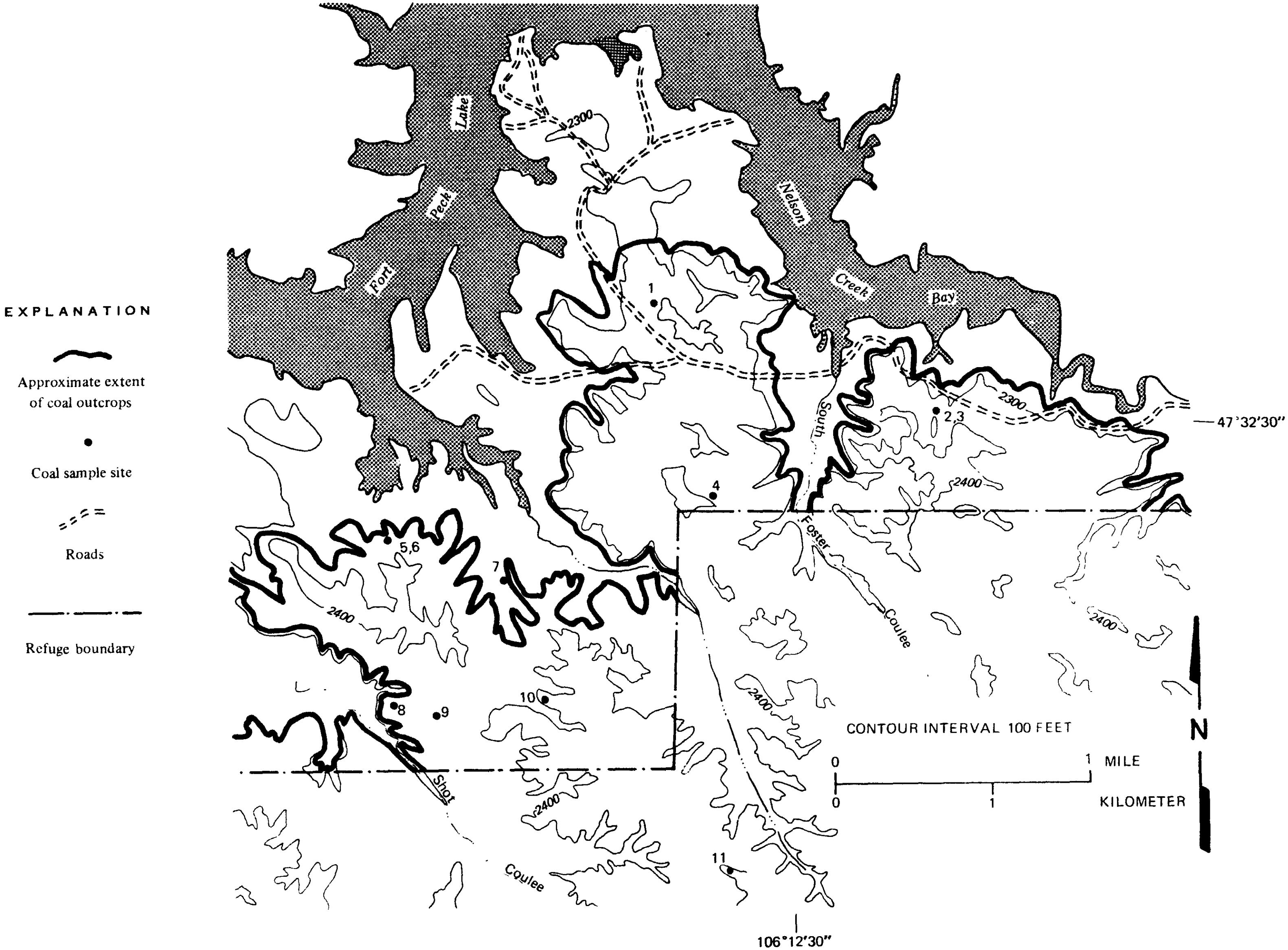


Figure 32.—Coal outcrops and sample sites, Nelson Creek area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 32, Nelson Creek area

Data for samples shown on figure 32.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

[--, not determined]

Index Map No.	Coal bed	Bed thickness (feet)	Proximate Analysis, Percent				Ultimate Analysis, Percent					Heat Content (Btu per pound)		Ash softening temperature (°F)	Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
			Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry		As received	As received	As received
1	4	3.0	28.9	45.0	34.0	21.0	0.6	3.0	49.8	0.9	24.7	5370	7550	--	0.20	0.01	0.18
2	3	2.5	24.9	43.1	28.1	28.8	1.3	2.8	43.8	1.0	22.3	4850	6450	2170	.65	.02	.31
3	4	2.5	13.6	27.6	19.4	53.0	.8	1.8	28.4	.6	15.4	3510	4060	2240	.46	.02	.19
4	3	2.5	28.9	37.1	29.8	33.1	1.9	2.2	44.8	1.1	16.9	4580	6440	2180	.51	.03	.83
5	2	3.0	21.0	38.2	32.8	29.0	.7	2.6	47.2	1.1	19.4	5650	7160	2130	.24	.02	.31
6	4	2.25	28.0	40.5	32.4	27.1	1.1	2.6	47.6	1.0	20.6	5130	7130	2130	.27	.01	.52
7	2	2.9	18.9	39.1	37.1	23.8	.9	3.0	50.4	1.1	20.8	6250	7710	2040	.26	.01	.47
8	3	2.2	27.2	39.3	25.5	35.2	.9	2.3	41.9	1.0	18.7	4610	6340	2140	--	--	--
9	5	2.75	24.4	37.9	18.3	43.8	1.4	2.2	34.3	.8	17.5	3840	5080	2190	--	--	--
10	3	1.9	20.7	36.5	35.3	28.2	1.0	2.8	48.2	.9	18.9	5890	7430	2150	.26	.01	.49
11	9	6.5	29.5	33.3	27.8	38.9	.6	2.3	37.9	.6	19.7	3930	5580	2620	.15	.01	.25

Table 24.--Coal stratigraphy, north part of the Nelson Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Poorly exposed, silty sandstone with weathered, thin coaly layers and carbonaceous shale--------------------------	50.0	15.0
Coal bed 5, has 1-inch (2.5-cm) clay parting near top of bed----------------------------	3.0	0.9
Silty sandstone-------------------------------	25.0	8.0
Coal bed 4, one to three layers of coal interbedded with silty sandstone and clay up to 44 inches (1.1 m) thick--------------	1.4 - 3.6	0.4 - 1.1
Silty sandstone and shale with thin carbonaceous shale lenses-------------------	20.0 - 30.0	6.0 - 9.0
Coal bed 3, with carbonacous shale 4 to 8 inches (10 to 20 cm) thick, about two-thirds of the way up from the base of the bed in part of the area---------------------------	2.5 - 5.8	0.8 - 1.8
Silty sandstone and shale, partly montmorillonitic and partly crossbedded; contains carbonaceous shale lenses----------	50.0	15.0
Coal bed 2, associated with carbonaceous and black shale from 14 to 60 inches (0.4 to 1.5 m) thick, mainly near the top of the bed----------------------------------	1.1 - 1.3	0.3 - 0.4
Silty sandstone, partly montmorillonitic------	10 - 15	3.0 - 5.0
Coal bed 1, associated with minor carbonaceous shale--------------------------------------	1.8 - 3.0	0.5 - 0.9
Silty sandstone and shale, montmorillonitic, with lenses of carbonaceous shale-----------	Base not seen	

Table 25.--Coal stratigraphy, south part of the Nelson Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone overburden--------------------	10.0	3.0
Coal bed 9, on ridgecrests, volume is small----	6.5	2.0
Sandstone--	5.5	1.7
Coal beds 7 and 8, minor coaly stringers in silty sandstone and shale, partly montmorillonitic, some shaly parting, some carbonaceous shale lenses-------------------	130.0	40.0
Coal bed 6, as much as 5.5 feet (1.68 m) thick, partly associated with carbonaceous shale----	1.0 - 1.9	0.3 - 0.6
Silty sandstone, partly montmorillonitic-------	20.0	6.0
Coal bed 5, partly coaly shale-----------------	1.0 - 2.8	0.3 - 0.8
Silty sandstone, partly montmorillonitic-------	5.0 - 15.0	1.5 - 5.0
Coal bed 4, associated with as much as 5.25 feet (1.6 m) of carbonaceous shale-----------	0.7 - 1.8	0.4 - 0.6
Silty sandstone, partly montmorillonitic-------	25.0	8.0
Coal bed 3, partly overlain by up to a foot of lignitic clay and coaly sandstone-----------	1.2 - 1.9	0.4 - 0.6
Silty sandstone, partly montmorillonitic-------	25.0	8.0
Coal bed 2, mostly underlain by 2 to 3.5 feet (0.6 to 1.1 m) of carbonaceous shale in claystone---------------------------------	3.0	0.9
Silty sandstone, partly montmorillonitic, with numerous thin carbonaceous shale layers	10.0 - 25.0	3.0 - 8.0
Coal bed 1, accompanied by as much as 51 inches (1.3 m) of carbonaceous shale, part is all carbonaceous shale----------------------	0.8	0.2
Silty sandstone and shale, montmorillonitic, with carbonaceous shale lenses--------------	Base not seen	

Table 26.--Estimated coal resources, Nelson Creek area.

[Data gathered and recorded in inch-pound system;
1 foot = 0.0348 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	1.5 - 2.5	100	180	44
	2.5 - 5.0	140	130	45
	5.0 - 10.0	41	24	0
60 - 90	1.5 - 2.5	29	50	3
	2.5 - 5.0	43	56	0
	5.0 - 10.0	13	0	0
90 - 120	1.5 - 2.5	15	29	2
	2.5 - 5.0	28	38	0
More than 120	1.5 - 2.5	13	29	1
	2.5 - 5.0	4	62	0

Racetrack Ridge

The Racetrack Ridge area is at the east end of the Refuge (fig. 25). Most of the coal, which is subhorizontal (fig. 33), is in the Tullock

Figure 33.--NEAR HERE. Photograph, coal bed, Racetrack Ridge area.

Member of the Paleocene Fort Union Formation. Some area coal may be in the upper Cretaceous Hell Creek Formation. Clinker is associated with several thick beds. Few beds are continuous across the entire area, but most of the thicker ones continue for at least 2 miles (3 km). Coal stratigraphy is summarized in table 27; estimated coal resources are

Table 27.--NEAR HERE. Coal stratigraphy, Racetrack Ridge area.

summarized in table 28, and sample sites are shown in figure 34.

Table 28.--NEAR HERE. Estimated coal resources, Racetrack Ridge area.

Figure 34.--NEAR HERE. Coal outcrops and sample sites, Racktrack Ridge area.

Coal beds 1 through 5, 8, and 9 were used to calculate resources. These beds underlie about 21,000 acres (8,500 h); beds average between about 2 and 6 feet (0.5 and 2 m) in thickness.

Robinson Bridge

The Robinson Bridge area is at the west end of the Refuge (fig. 25).

Two coal-bearing strata of the Cretaceous Judith River Formation crop out along the Missouri River's steeper slopes. In the western part of the area, these strata are at elevations of about 2300 and 2400 feet (700 and 732 m); in the eastern part, they are about 120 feet (40 m) lower.

The uppermost coal bed is underlain by a loose, fine-grained, sandstone, and overlain by the bentonitic shales of the Bearpaw Shale. At several sample localities, a 2- to 3-foot (0.5- to 1-m) sandy layer containing pyrite or marcasite nodules from 0.5 to 1.5 inches (1.3 to 4 cm) across lies immediately below the upper bed. The lower bed lies between fine-grained sandstone beds.

Upper coal beds crop out in the roadcut along U.S. 191 south of Robinson Bridge. Sample analyses, for 15 upper, and 2 lower beds, are in the table accompanying figure 35.

Figure 35.--NEAR HERE. Coal outcrops and sample sites, Robinson Bridge area.

Figure 33.--Photograph, coal bed, Racetrack Ridge area.

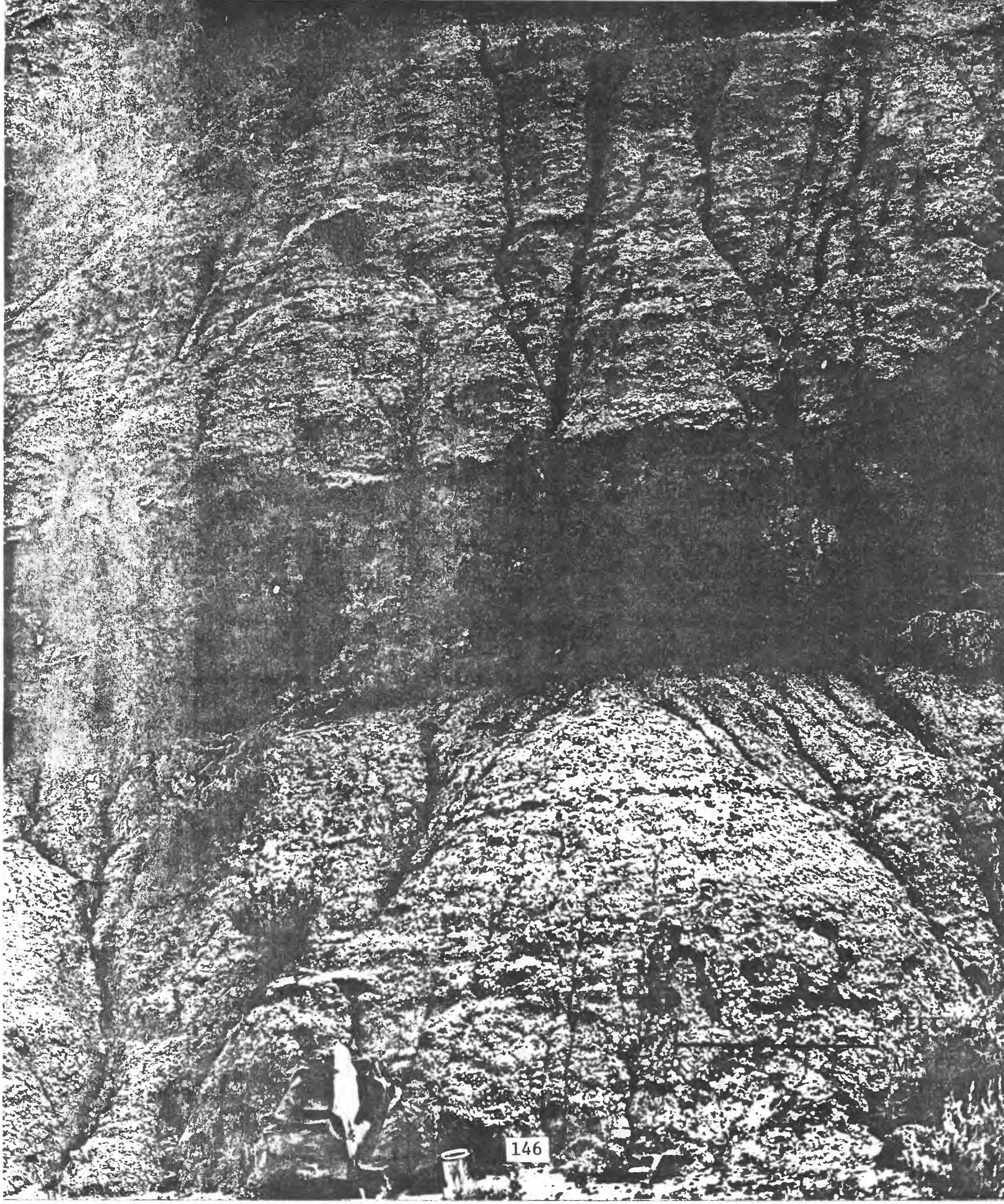


Table 27.--Coal stratigraphy, Racetrack Ridge area.

Description, from top to bottom	Thickness feet	Thickness meters
Poorly exposed silty sandstone with at least two carbonaceous shale or coal layers-------	60.0 - 100.0	18.0 - 31.0
Coal bed 9, mostly carbonaceous shale---------	3	0.9
Silty sandstone-------------------------------	20	6
Coal bed 8, partly interbedded with silty sandstone and carbonaceous shale------------	2.5 - 3.3	0.8 - 1.0
Silty sandstone and shale, partly montmorillonitic----------------------------	25	8.0
Coal bed 7, probably intermittent and partly pinched out, almost completely coal--	4.5	1.4
Silty sandstone, partly montmorillonitic------	40.0 - 60.0	12.0 - 18.0
Coal bed 6, discontinuous and partly carbonaceous shale--------------------------	1.0	0.3
Silty sandstone, partly montmorillonitic------	10.0 - 20.0	3 - 6.0
Coal bed 5, partly double layered, partly carbonaceous shale, and may pinch out-------	5.2	1.6
Montmorillonitic silty sandstone--------------	10.0 - 50.0	3.0 - 15.0
Coal bed 4, associated with as much as 60 inches (1.5 m) of carbonaceous shale. Thins to about a foot (0.3 m) in part of area-----	6.5	2.0
Montmorillonitic, silty sandstone and shale, with thin, discontinuous coal and carbonaceous shale partings-----------------	15.0 - 50.0	5.0 - 15.0
Coal bed 3, intermittent and partly carbonaceous shale--------------------------	1.8 - 2.4	0.5 - 0.7
Silty sandstone, partly montmorillonitic------	10.0 - 20.0	3.0 - 6.0
Coal bed 2, partly intermittent and partly coaly sandstone----------------------------	3.5	1.1
Silty sandstone, partly montmorillonitic------	10.0 - 40.0	3.0 - 12.0
Coal bed 1, mostly two layers, mostly carbonaceous shale and coaly sandstone-----		
Silty sand 2 to 6 feet (0.6 to 1.8 m) thick between layers----------------------------	2.0 - 6.0	0.6 - 1.8
Silty sandstone and shale, montmorillonitic with carbonaceous shale lenses-------------	Base not seen	

Table 28.--Estimated coal resources, Racetrack Ridge area

[Data gathered and recorded in inch-pound system;
1 foot = 0.0348 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	1.5 - 2.5	100	620	810
	2.5 - 5.0	270	790	800
	5.0 - 10.0	100	310	210
60 - 90	1.5 - 2.5	160	270	470
	2.5 - 5.0	67	350	280
	5.0 - 10.0	51	210	90
90 - 120	1.5 - 2.5	140	180	400
	2.5 - 5.0	23	240	300
	5.0 - 10.0	35	220	20
More than 120	1.5 - 2.5	18	340	1300
	2.5 - 5.0	8	320	1100
	5.0 - 10.0	31	160	90

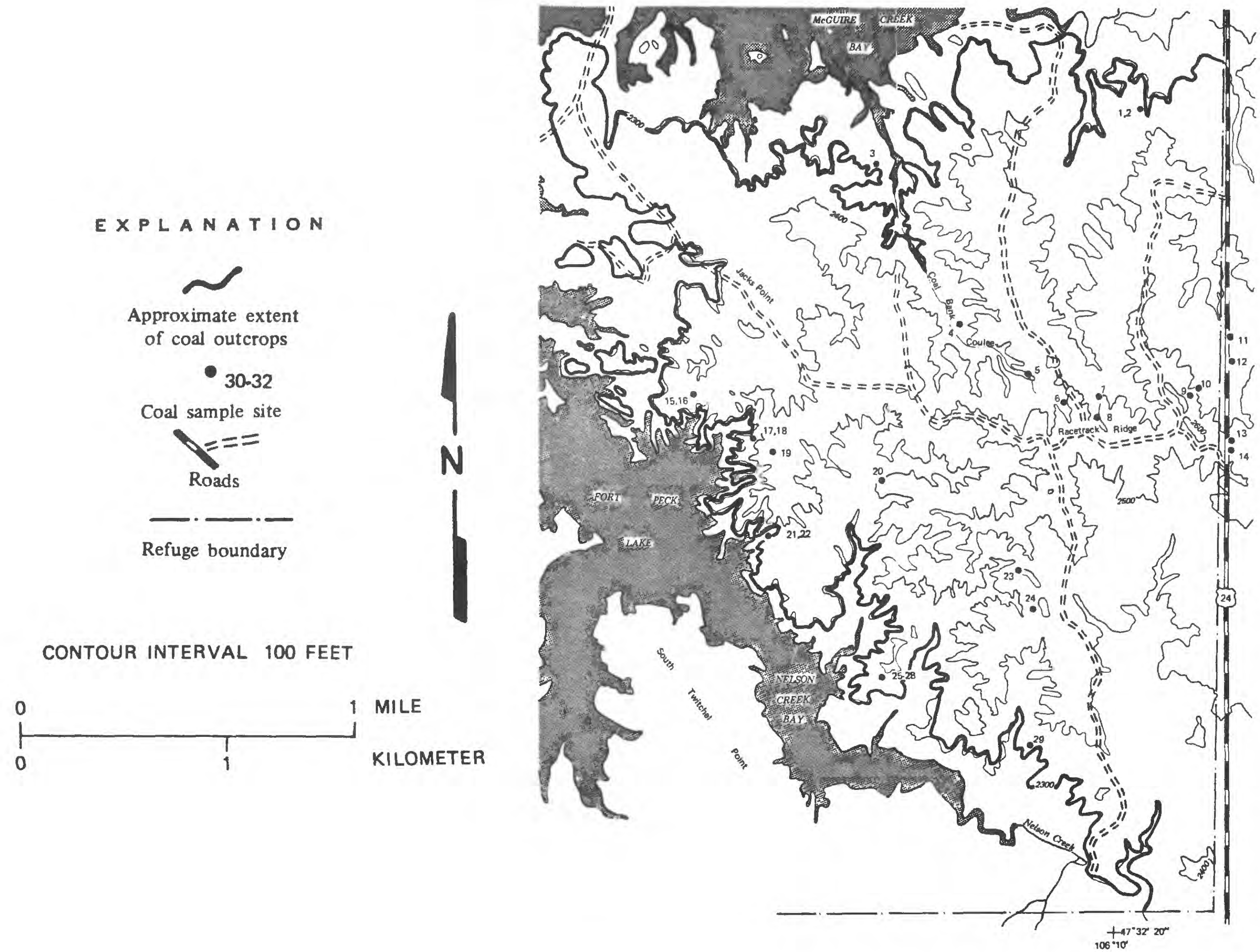


Figure 34.--Coal outcrops and sample sites, Racetrack Ridge area. Base from 1:24.000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 34, Racetrack Ridge area

Data for samples shown on fig. 34.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F − 32) = °C.]

[--, not determined]

			Proximate Analysis, Percent				Ultimate Analysis, Percent, Dry Coal					Heat content (Btu per pound)			Sulfur Forms, Percent, Sulfate	Sulfur Forms, Percent, Pyrite	Sulfur Forms, Percent, Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	2	2.4	16.9	45.1	25.5	29.4	1.4	3.1	43.2	0.9	22.0	5470	6580	2040	0.78	0.03	0.32
2	1	3.5	16.4	39.1	31.3	29.6	.7	3.3	43.8	.9	21.7	5840	6980	2220	.17	.01	.38
3	1	3.0	14.0	40.7	31.6	27.7	.5	3.2	45.3	1.0	22.3	6070	7070	2200	.10	.02	.34
4	4	6.5	21.9	39.6	33.9	26.5	.6	3.2	48.0	.9	20.8	5600	7170	2300	.10	.01	.34
5	8	3.5	21.0	32.1	28.1	39.8	.4	2.5	37.6	.7	19.0	4440	5620	2380	.09	.02	.24
6	7	4.5	20.4	30.9	22.0	47.1	.5	2.4	34.0	.6	15.4	4280	5380	--	.05	.01	.30
7	7	4.5	21.8	33.7	22.9	43.4	.5	2.7	36.1	.6	16.7	4330	5540	2460	.03	.01	.34
8	8	3.6	28.9	39.8	34.8	25.4	2.3	3.4	49.1	.6	19.0	5710	8020	2070	.66	.09	.88
9	8	3.1	37.1	40.8	33.0	26.2	2.0	2.7	47.1	1.1	20.9	4430	7050	1980	.05	.03	1.19
10	7	3.8	20.0	23.7	14.9	61.4	.7	1.5	23.0	.4	13.0	2500	3130	2570	.37	.01	.15
11	5	2.5	19.8	31.5	18.0	50.5	.9	2.2	28.2	.6	17.6	3320	4140	--	.51	.02	.21
12	5	2.5	13.3	39.4	24.6	35.9	.7	3.2	33.0	.5	26.7	4190	4830	2400	.22	.01	.34
13	9	3.0	15.9	41.7	25.6	32.7	.5	3.7	37.0	.6	25.5	4840	5760	2480	.01	.01	.37
14	9	3.0	24.0	39.7	38.5	21.8	1.9	3.7	50.9	.8	20.9	6380	8400	2060	.43	.07	.91
15	5	5.0	29.6	34.7	29.8	35.5	.6	2.3	41.9	.8	18.9	4420	6280	2300	.24	.01	.20
16	4	1.75	26.4	37.2	31.6	31.2	.7	3.0	45.7	.7	18.7	5270	7160	2160	.05	.01	.46
17	4	2.4	20.5	33.3	27.1	39.6	1.0	2.5	39.0	.9	17.0	4760	5990	2250	.36	.01	.42
18	4	3.75	16.3	38.7	39.3	22.0	1.2	2.8	51.6	1.1	21.3	6550	7830	2140	.20	.01	.80
19	5	5.2	25.1	35.1	30.3	34.6	1.1	2.3	42.1	.9	19.0	4650	6210	2140	.50	.02	.30
20	4	4-5	20.2	39.9	31.5	28.6	.7	3.0	47.9	.9	18.9	5810	7270	--	.16	.02	.34
21	1	1.8	16.8	35.3	30.6	34.1	1.4	2.3	43.8	1.1	17.3	5440	6540	2100	.05	.01	.47
22	4	4-5	17.6	38.5	28.7	32.8	.7	2.9	44.9	.8	17.9	5580	6770	2210	.20	.01	.33
23	8	3.1-3.3	19.4	28.7	18.4	52.9	.6	2.1	27.7	.5	16.2	3250	4030	2630	.28	.01	.17
24	5	3.1	23.3	34.6	21.9	43.5	1.3	2.2	33.0	.7	19.3	3730	4860	2250	.73	.01	.26
25	1	3.2	32.0	40.5	34.3	25.2	.8	2.6	48.9	1.2	21.3	4930	7240	2080	.21	.02	.33
26	2	1.1	21.7	39.2	32.5	28.3	1.0	2.5	47.1	1.1	20.0	5440	6950	2180	.32	.01	.43
27	3	2.4	16.1	33.4	31.1	35.5	.5	2.3	41.1	.9	19.7	5040	6010	2310	.12	.01	.27
28	4	2.0	22.1	37.7	36.3	26.0	.8	2.3	49.3	1.0	20.6	5590	7170	2030	.35	.02	.27
29	5	4.0	26.5	40.3	21.7	38.0	1.3	2.5	37.9	.7	19.6	4110	5600	2300	.66	.01	.30
30	1	0.2-1.2	20.1	34.1	19.2	46.7	1.2	2.3	32.3	.8	16.7	3780	4730	2190	.65	.02	.32
31	1	2.7	22.1	40.8	23.5	35.7	1.1	2.4	40.1	.8	19.9	4610	5920	2140	.61	.02	.20
32	2	2.5	23.3	37.7	23.6	38.7	.7	2.5	38.8	.7	18.6	4430	5770	--	.18	.02	.34

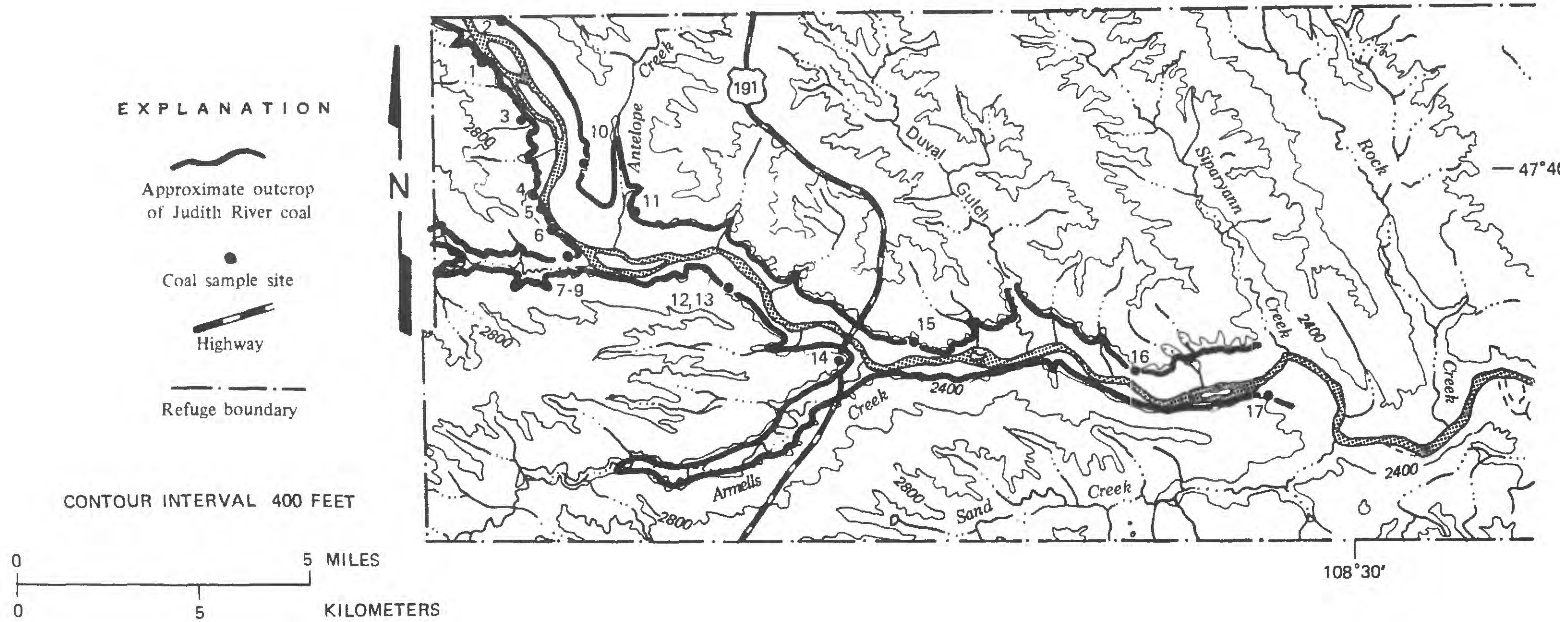


Figure 35.--Coal outcrops and sample sites, Robinson Bridge area. Base from 1:250,000 scale Army Map Service map.

An unnumbered table to accompany fig. 35, Robinson Bridge area.

Data for samples shown on figure 35.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

[--, not determined]

Index Map No.	Coal bed	Bed thickness (feet)	Proximate Analysis, Percent: Moisture as received, coal	Dry Coal: Volatile matter	Fixed carbon	Ash	Ultimate Analysis, Percent (Dry Coal): Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Heat Content (Btu per pound): As received	Dry	Ash softening temperature (°F)	Sulfur Forms, Percent: Sulfate, As received	Pyrite, As received	Organic, As received
1	Judith River, lower seams	2.5	24.2	23.2	19.2	57.6	1.3	1.8	24.7	0.9	[illegible]	3190	[illegible]	[illegible]	0.65	0.02	0.33
2	Judith River, upper seams	2.5	19.7	36.5	30.1	33.4	[illegible]	2.5	43.2	1.4	[illegible]	5210	[illegible]	[illegible]	.76	.03	.55
3	do----	1.0	30.0	43.4	37.7	21.9	1.4	2.7	53.4	1.2	21.9	[illegible]	[illegible]	[illegible]	.67	.02	.32
4	do----	1.0	33.5	43.0	30.2	26.8	2.6	2.5	48.0	2.3	18.4	[illegible]	[illegible]	[illegible]	1.27	.03	.01
5	Judith River, lower seams	1.0	23.5	33.6	36.1	30.3	1.7	3.1	47.2	1.2	16.5	5840	[illegible]	[illegible]	.64	.05	.65
6	Judith River, upper seams	2.5	21.3	22.3	19.5	58.2	.7	1.6	26.3	2.0	11.2	3150	4000	2460	.30	.02	.21
7	do----	.6	9.6	17.8	13.6	68.6	.4	1.3	20.2	.6	8.8	2800	3100	2350	.23	.01	.17
8	do----		14.7	30.5	28.2	41.3	.5	2.5	39.6	1.1	15.0	5250	6160	2190	.14	.01	.29
9	do----	1.0	11.6	29.6	24.4	46.0	.8	2.7	34.0	1.1	15.9	4600	5200	2190	.38	.01	.33
10	do----	2.0	25.8	38.5	44.6	16.9	2.1	3.1	57.4	1.5	19.0	6730	9010	1980	.91	.03	.60
11	do----	1.5	24.0	39.9	28.5	31.6	1.5	2.5	43.6	1.6	19.2	4960	6520	2030	.78	.03	.36
12	do----	1.9	18.8	17.4	13.4	69.2	1.6	1.3	18.8	1.9	7.2	2390	2940	2180	.93	.03	.32
13	do----		23.5	39.4	39.7	20.9	2.9	3.5	53.0	1.7	18.0	6600	8630	1980	1.46	.13	.60
14	do----	1.0	21.6	26.0	24.6	49.4	1.8	2.3	33.6	.9	12.0	4230	5390	2140	.04	.05	1.32
15	do----	.7	15.6	9.3	.9	89.8	.6	.6	4.6	.7	3.7	--	--	2240	.50	.03	.0
16	do----	1.0	26.7	20.6	14.2	65.2	1.2	1.4	20.9	.6	10.7	2260	3090	2130	.79	.02	.09
17	do----	1.0	13.2	5.7	1.1	93.2	.4	.3	3.5	.1	2.5	330	360	2340	--	--	--

Judith River coal in the Robinson Bridge area is under less than 1,000 feet (300 m) of overburden. Approximately 13 percent is beneath less than 200 feet (60 m). Of the 190 million short tons (170 million t) in the Robinson Bridge portion of the upper Judith River Formation, 1.6 million (1.5 million t) are measured, 14 million (13 million t) indicated, 130 million (120 million t) inferred, and 45 million (40 million t) hypothetical. Additional upper Judith River coal may underlie the Refuge as far east as Hell Creek. Robinson Bridge estimated resources involve approximately 87,000 acres (35,000 h).

Seven Blackfoot area

The Seven Blackfoot area is in the south-central part of the Wildlife Refuge (fig. 25).

Outcrops are high on the sides of ridges. Erosion has isolated some coal beds into small, irregular bodies. One is at the base of the Tullock Member of the Paleocene Fort Union Formation. It is about 2.5 feet (0.7 m) thick and contains a 1.5-foot (0.5-m)-thick shale parting. Clinker crops out nearby.

One sample was taken above, and another below, the 1.5-foot (0.5-cm)-shale parting (fig. 36). A resource estimate was not made because ash

Figure 36.--NEAR HERE. Coal outcrops and sample sites, Seven Blackfoot area.

content was excessive.

Snap Creek area

The Snap Creek area, west of the Dry Creek arm of Fort Peck Lake, is north of Highway 20 (fig. 25).

The coal is in the lower part of the Tullock Member of the Fort Union Formation or in the upper Hell Creek Formation. Clinker is associated with the thicker coal beds, especially Nos. 2 and 3. All resources were calculated for coal beds 2 through 5. The four beds underlie about 1,100 acres (460 h); average thickness is from about 2.0 to 6.0 feet (0.5 to 2.0 m). The coal dips less than 3°, except in slumped areas.

Snap Creek area stratigraphy is described in table 29; a summary of

Table 29.--NEAR HERE. Coal stratigraphy, Snap Creek area.

resources is in table 30, and coal outcrops and sample sites are in

Table 30.--NEAR HERE. Estimated coal resources, Snap Creek area.

figure 37.

Figure 37.--NEAR HERE. Coal outcrops and sample sites, Snap Creek area.

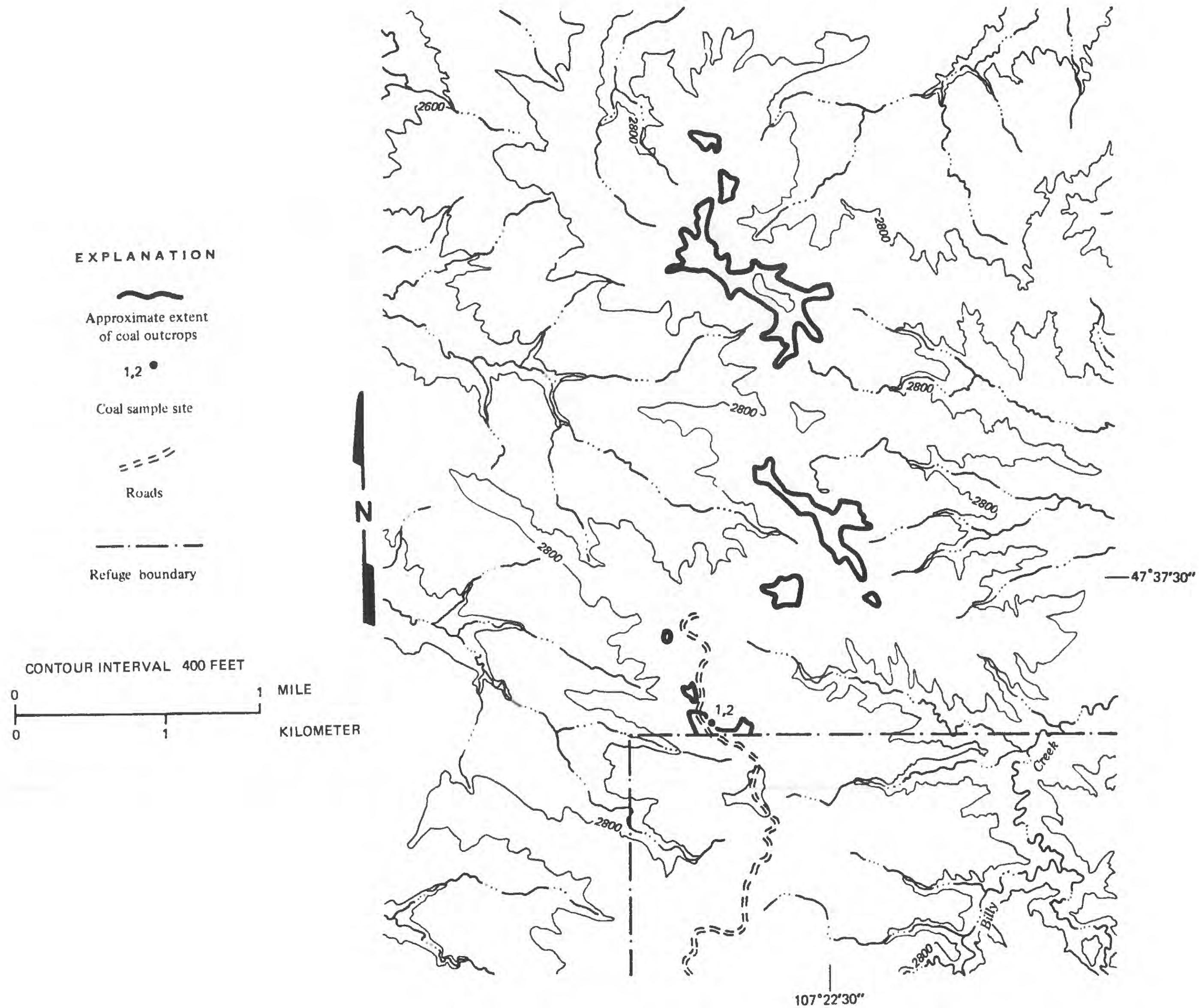


Figure 36.--Coal outcrops and sample sites, Seven Blackfoot area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 36, Seven Blackfoot area.

Data for samples shown on figure 36.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

[--, not determined]

			Proximate Analysis, Percent				Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	1 (upper)	2.5	21.0	26.2	10.4	63.4	2.4	1.4	18.5	0.5	13.8	1980	2500	2280	0.10	0.01	1.79
2	1 (lower)	2.3	24.9	26.1	13.8	60.1	.5	1.6	24.1	.5	13.2	2630	3510	--	.21	.01	.13

Table 29.--Coal stratigraphy, Snap Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone, partly montmorillonitic, with thin carbonaceous shale beds and thin coal stringers------------------------------	60.0	18.0
Coal bed 5, associated with as much as 5 feet (1.5 m) of carbonaceous shale, partly carbonaceous shale--------------------------	3.3	1.0
Silty sandstone, partly montmorillonitic, with thin, discontinuous carbonaceous shale layers--------------------------------	20.0	6.0
Coal bed 4, lenticular and partly carbonaceous shale. Associated with carbonaceous shale, which may be 6 feet (1.8 m) thick-----------	0 - 5.0	0 - 1.5
Silty sandstone with thin carbonaceous shale bands--	30.0	9.0
Coal bed 3, partly carbonaceous shale; clinker above parts of bed------------------------	4.0 - 5.0	1.2 - 1.5
Silty sandstone and shale, partly montmorillonitic, with several lenticular carbonaceous shale and coal layers----------	60.0	18.0
Coal bed 2; mostly contains silt, clay, or carbonaceous shale 0.5 to 2.5 feet (0.15 to 0.76 m) thick near the top of the bed; widely associated with clinker-----	3.8 - 6.5	1.2 - 2.0
Silty sandstone, partly montmorillonitic, with several carbonaceous shale and coal layers--	25.0	8.0
Coal bed 1, mostly carbonaceous shale and clay, may split, some carbonaceous shale 1.0 to 4.0 feet (0.3 to 1.2 m) thick--------	0 - 1.2	0 - 0.4
Silty sandstone and shale, partly montmorillonitic, with carbonaceous shale layers--	Base not seen	

Table 30.--Estimated coal resources, Snap Creek area.

[Data gathered and recorded in inch-pound system;
1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	1.5 - 2.5	29	20	8
	2.5 - 5.0	91	180	1
	5.0 - 10.0	73	64	0
60 - 90	1.5 - 2.5	4	10	3
	2.5 - 5.0	41	64	0
	5.0 - 10.0	27	18	0
90 - 120	2.5 - 5.0	21	53	0
	5.0 - 10.0	14	14	0
More than 120	2.5 - 5.0	46	57	0
	5.0 - 10.0	23	31	0

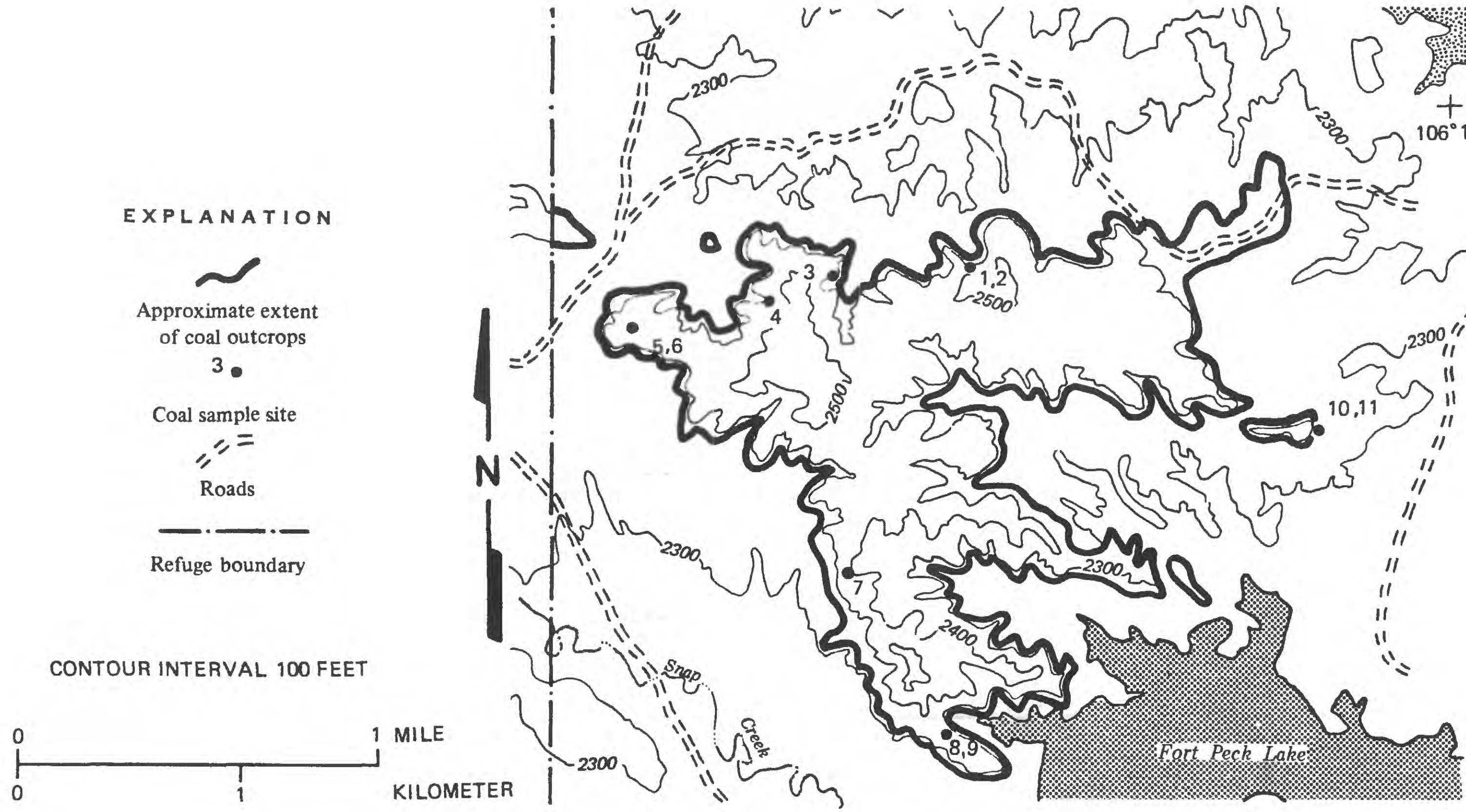


Figure 37.--Coal outcrops and sample sites, Snap Creek area. Base from 1:24,000 scale U.S. Geological Survey map.

An unnumbered table to accompany fig. 37, Snap Creek area.

Data for samples shown on figure 37.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent			Ultimate Analysis, Percent					Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal										Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	2	4.4 1.9 & 2.5	26.6	37.6	35.8	26.6	0.5	2.9	49.0	1.0	20.0	5580	7600	2050	0.09	0.01	0.24
2	3	4.3	29.1	40.3	26.4	33.3	.6	2.5	44.2	.9	18.5	4760	6720	2300	.24	.01	.21
3	4(?)	4.5	16.7	42.2	26.1	31.7	.5	3.1	43.1	.9	20.7	5520	6630	2250	.18	.01	.23
4	2	4.5	23.6	39.6	36.2	24.2	.6	3.0	50.3	.9	21.0	5840	7650	2060	.16	.03	.27
5	2	5.7	29.7	38.9	35.0	26.1	.9	2.6	46.9	1.0	19.5	5410	7690	2080	.19	.01	.44
6	3	6.0	26.7	35.4	32.7	31.9	.7	2.7	45.1	.9	18.7	5060	6900	2250	.20	.01	.31
7	3	5.5	26.2	38.5	37.2	24.3	.5	2.5	50.1	1.4	21.2	5520	7480	2190	.10	.01	.27
8	4	2.8	31.3	39.3	32.0	28.7	1.0	2.5	45.0	.9	21.9	4550	6610	2130	.54	.03	.14
9	3	4.0	23.4	39.8	23.6	36.6	.6	2.6	41.0	.9	18.3	4820	6290	2270	.38	.02	.08
10	2	3.8	20.5	38.9	30.5	30.6	1.0	2.7	43.3	.9	21.5	5110	6420	2200	.68	.02	.09
11	3	5.0	33.6	35.3	26.6	38.1	.5	2.3	38.4	.8	19.9	3770	5670	2210	.28	.02	.06

In thin exposures of upper Hell Creek, and lower Tullock, weathered coal, too thin and shaly to be a resource, crops out on a few ridge crests north of the Snap Creek area (Table 31).

Table 31.--NEAR HERE. Coal stratigraphy north of the Snap Creek area.

Timber Creek area

The Timber Creek area is at the southeast end of the Wildlife Refuge (fig. 25).

Most coal beds are in the lower part of the Paleocene Fort Union, and the upper part of the Cretaceous Hell Creek Formations; they are nearly horizontal. The thickest beds usually include at least two clay or carbonaceous shale partings. Generally they split and thin laterally within 0.5 mile (0.8 km). At least three are probably correlatable throughout the Timber Creek area. Beds 1 and 2, which total about 450 acres (180 h), and average about 3 feet (1 m) thick, were used for resource estimates in the Timber Creek area. The coal stratigraphy is described in table 32, resource estimates in table 33, and sample sites

Table 32.--NEAR HERE. Coal stratigraphy, Timber Creek area.

Table 33.--NEAR HERE. Estimated coal resources, Timber Creek area.

in figure 38.

Figure 38.--NEAR HERE. Coal outcrops and sample sites, Timber Creek area.

Mining, processing, and shipping

Most Fort Union Formation coal beds within the Refuge are beneath less than 250 feet (76 m) of overburden. Underground mining beneath these poorly consolidated sediments would be expensive; but, the beds lend themselves to surface mining. Judith River coal is, on the average, deeper, with overburden commonly as thick as 450 feet (135 m). Approximately 87 percent of the Refuge's Judith River coal is more than 200 feet (60 m) deep, and would have to be mined underground or gasified in place.

Some mining methods conflict with Montana Law. The Montana Strip Mining and Reclamation Act, Chapter 325, Montana Session Laws, 1973, Sec. 11, states "Area strip mining, a method of operation which does not produce a bench or fill bench is required". Another act, The Strip Mined Coal Conservation Act, Chapter 202, Montana Session Laws, 1973, could be used to prohibit methods, such as augering, which might leave a significant percentage of unrecovered coal. More recently, compliance with regulations issued under authority of the Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) is required of all mining operations coming within scope of that Act.

Table 31.--Coal stratigraphy north of the Snap Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone, partly montmorillonitic, partly concretionary-----------------------	30.0	9.0
Coal bed 2, poorly exposed and intensely weathered, surrounded by at least 0.6 foot (0.18 m) of carbonaceous shale; partly carbonaceous shale-------------------------	2.3 - 5.8	0.7 - 1.8
Silty sandstone and shale, partly montmorillonitic, with carbonaceous shale and coaly layers as much as 1.0 foot (0.3 m) thick------------------------------	20.0 - 35.0	6.1 - 11.0
Coal bed 1, coaly carbonaceous shale and carbonaceous shale-------------------------	1.2 - 3.3	0.4 - 1.4
Interlayered silty sandstone and shale, mostly montmorillonitic, with a few carbonaceous shale beds, partly coaly-----	Base not seen	

Table 32.--Coal stratigraphy, Timber Creek area.

Description, from top to bottom	Thickness feet	Thickness meters
Silty sandstone, some clinker----------------	5.0 - 20.0	1.5 - 6.0
Coal bed 4, interlayered coal, shale, carbonaceous shale, partly associated with clinker------------------------------------	2.3	0.7
Coal bed 3, a coaly sandstone layer about 3 feet (0.9 m) thick, in silty sandstone, partly montmorillonitic, which includes several carbonaceous shale partings and at least one coal stringer-------------------	30.0 - 100.0	9.0 - 31.0
Coal bed 2, splits and thins irregularly----	1.9	0.6
Silty sandstone, partly montmorillonitic, with thin carbonaceous shale and coaly layers---------------------------------------	30.0 - 60.0	9.0 - 18.0
Coal bed 1, splits and thins irregularly, at one site, 16-, 22-, and 13-inch (41-, 56-, and 33-cm)-thick coal layers are separated by 2 to 5 feet (0.61 to 1.5 m) of silty sand, partly carbonaceous shale, and partly underlain by as much as 2 feet (0.6 m) of carbonaceous shale-------------	0 - 4.3	0 - 1.3
Silty sandstone and shale, partly montmorillonitic, with layers of carbonaceous shale------------------------	Base not seen	

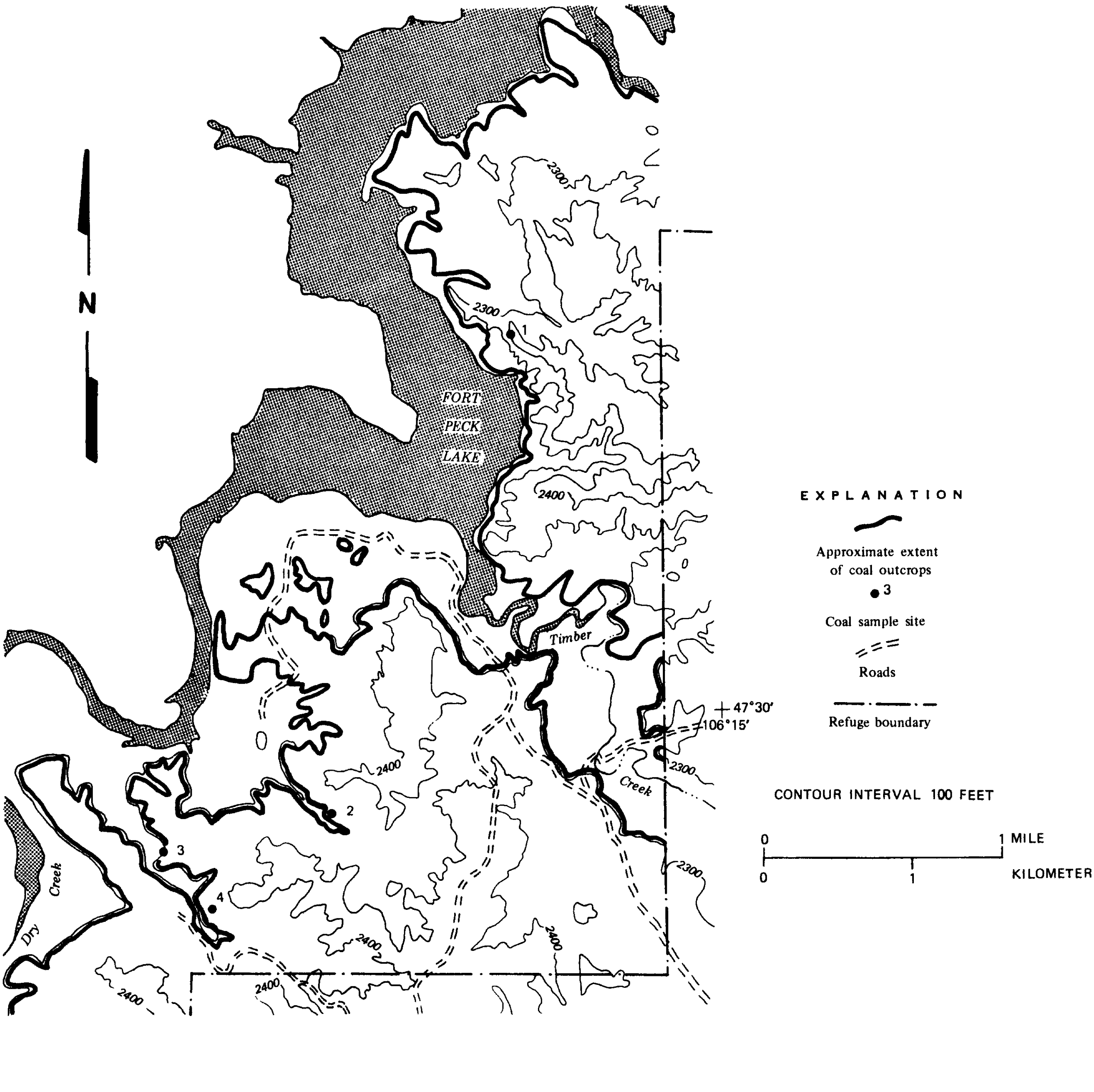
Table 33.--Estimated coal resources, Timber Creek area.

[Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 short ton = 0.9072 t]

[Short tons x 10,000]

Depth to top of coal bed (feet)	Coal bed thickness (feet)	Resources		
		Measured	Indicated	Inferred
0 - 60	2.5 - 5.0	68	190	4
60 - 90	2.5 - 5.0	3	24	1
90 - 120	2.5 - 5.0	1.0	12	0
More than 120	2.5 - 5.0	0	16	0

Figure 38.--Coal outcrops and sample sites, Timber Creek area. Base from 1:24,000 scale U.S. Geological Survey map.



An unnumbered table to accompany fig. 38, Timber Creek area

Data for samples shown on figure 38.

[These coal samples were from outcrops; most of the values are probably not representative of the unweathered coal. Data gathered and recorded in inch-pound system; 1 foot = 0.3048 m; 1 BTU per pound = 2.326 joules per kilogram; 5/9 (°F - 32) = °C.]

			Proximate Analysis, Percent			Ultimate Analysis, Percent						Heat Content (Btu per pound)			Sulfur Forms, Percent		
				Dry Coal											Sulfate	Pyrite	Organic
Index Map No.	Coal bed	Bed thickness (feet)	Moisture as received, coal	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	As received	Dry	Ash softening temperature (°F)	As received	As received	As received
1	4	2.3	26.5	28.3	18.6	53.1	1.3	1.6	28.8	0.6	14.6	2870	3910	2350	0.85	0.02	0.09
2	1	2.2	14.9	35.5	14.5	50.0	.8	2.3	27.8	.6	18.5	3390	3980	2620	.66	.03	.0
3	1	3.75	31.1	34.5	26.0	39.5	.9	2.5	39.3	.9	16.9	4120	5980	2200	.44	.03	.17
4	2	1.9	32.2	41.3	37.3	21.4	1.0	2.9	51.8	1.1	21.8	5340	7870	2140	.39	.04	.24

Many Wildlife Refuge areas, underlain by coal and other mineral commodities, may be considered exceptional in scenic and recreation values. The Montana Strip Mining and Reclamation Act, Chapter 325, 1973, Section 9, states "The department shall not approve the application for prospecting or strip mining permit where the area of land described in the applications includes land having special, exceptional, critical, or unique characteristics".

The potential for re-establishing vegetation on land typical of the central and eastern Refuge is considered poor (Packer, 1974, p. 7).

Precipitation on the Refuge is sporadic, averaging only 13 inches (33 cm) annually; the western part receives slightly more precipitation than the eastern. Irrigation water could be available from Fort Peck Lake or wells. Summer rainstorms might be used for irrigation, but would also necessitate special attention to prevent erosion during mining and reclamation.

The Wildlife Refuge coal might be effectively used for underground gasification. This method, still under development, is especially useful where beds are as thin as 3 feet (0.9 m), contain as much as 50 percent ash, and have as little as 5,000 Btu per pound (11,630 J/kg) (Hucka and Das, 1973, p. 50).

Large-scale production of synthetic natural gas from coal would be one way of utilizing Montana coal. Gasification plants might meet 7 percent of the nation's demand for synthetic natural gas by 1985 (Osborn, 1974, p. 33). Methods of synthetic liquid fuel production are also in the developmental stage. Some are the solvent extraction, synthetic alcohol, and synthetic ammonia processes of the U.S. Department of Energy.

Mine-mouth power plants, gasification, liquefaction, or slurry transport would lessen haulage problems. Transmission lines and pipelines could be used. Barges could also provide bulk transportation on Fort Peck Lake. Railroad spurs could be run into the Refuge from Circle or Brockway, about 23 miles (40 km) to the southeast, and from Winifred or Roy, approximately 35 miles (55 km) to the west.

Sand and gravel

The United States produced about 937 million short tons (850 million t) of sand and gravel, worth about $2.1 billion, in 1978. Domestic sand and gravel resources are extremely large, but not always near markets. Also, quality may not always meet specifications needed for many uses (Evans, 1979).

History and production

Probably more than 200,000 cubic yards (150,000 m^3) of sand and gravel had been produced from the Refuge by 1975. Most came from near Robinson Bridge, along the highway east of the Dry Creek area of Fort Peck Lake, and from near the town of Fort Peck.

Resource estimates

More than 2,000,000 cubic yards (1,500,000 m^3) of sand and gravel are estimated as being on the Refuge (fig. 39) in study areas named during this

Figure 39.--NEAR HERE. Sand and gravel areas on the Charles M. Russell Wildlife Refuge.

work. Most of the gravel could be used, with little or no preparation, for local roads or for fill. After sorting and cleaning, some of it could be used as aggregate. Carefully selected aggregate could be used for structural concrete.

Other commodities

Stone

Clinker, the baked or fused sediments above burned coal beds, has been crushed and used for road surfacing in the area. Usable amounts are distributed sporadically in areas of thicker coal beds. Rock from the unaltered Hell Creek, Fox Hills, Judith River, and Fort Union Formations is usually too poorly indurated to be suitable for crushed stone, although sources of rip rap are sufficient to meet local demands.

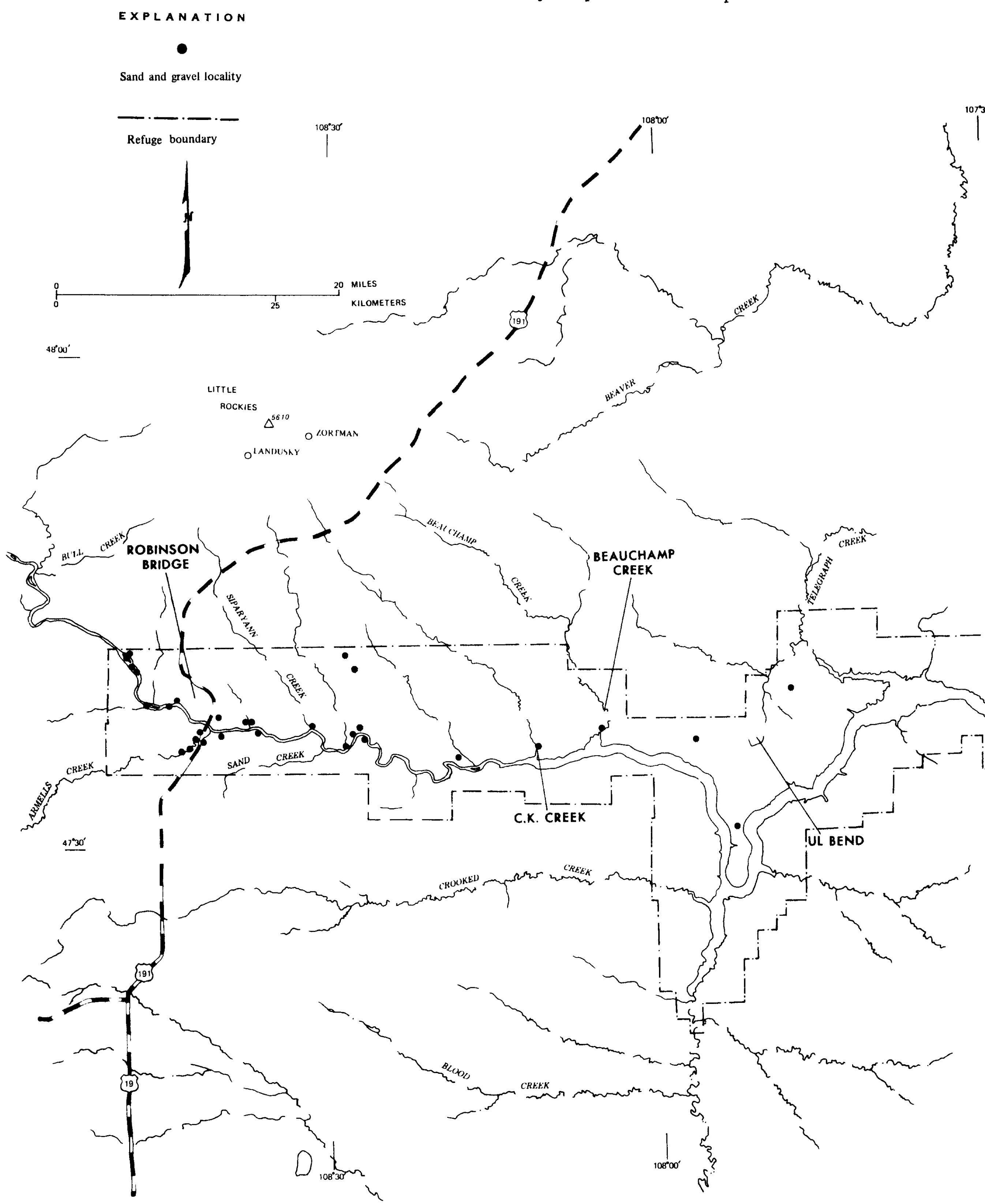
Stone resources were not estimated because this high-bulk, low-unit price commodity cannot be transported to distant markets profitably, and because local demand for stone is probably insufficient to support mining of significant quantities.

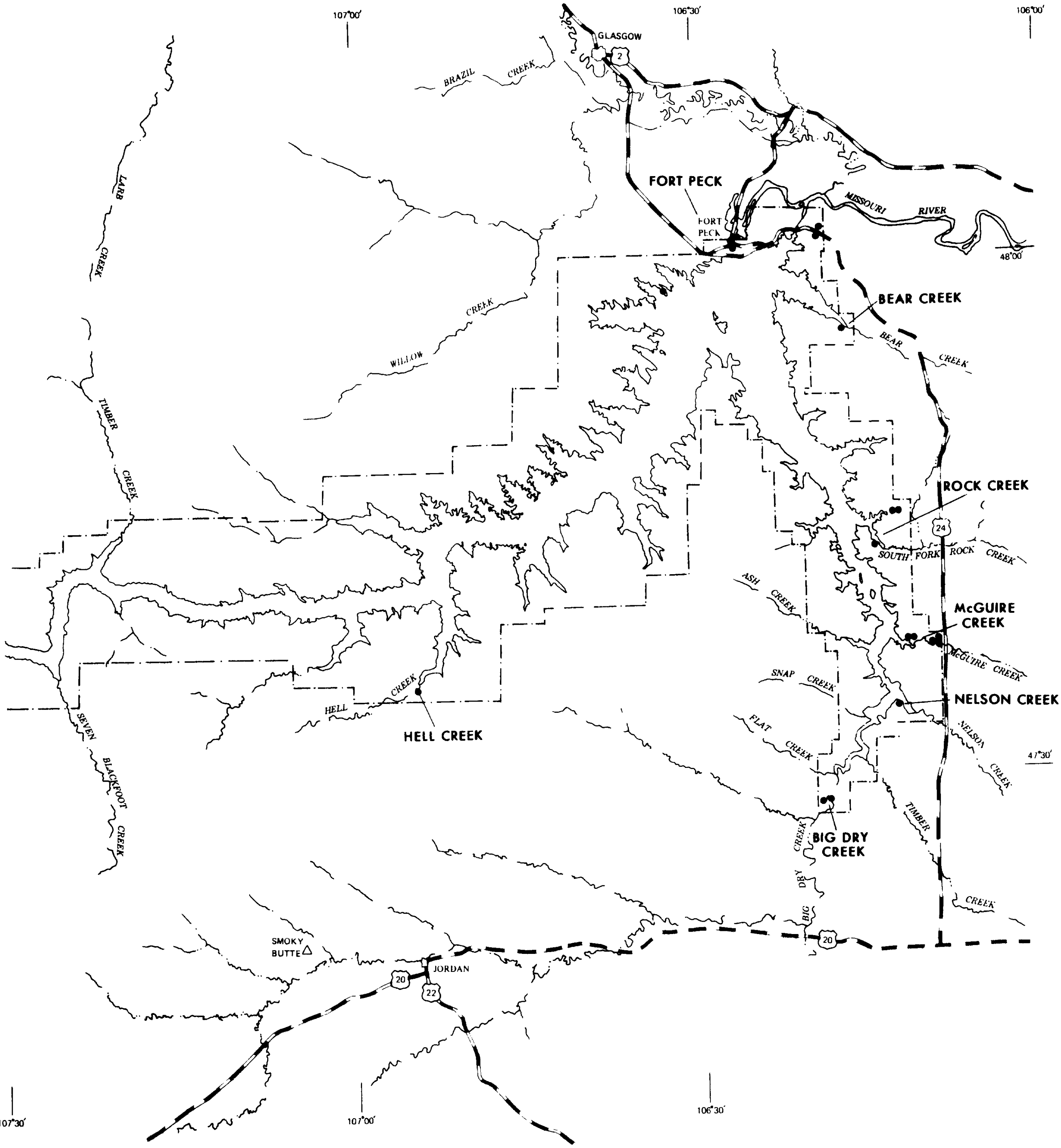
Lightweight aggregate

Domestic United States production of expandable shale and clay, used in lightweight aggregate, amounted to about 6,256,000 short tons (5,630,000 t), worth about $20,500,000 in 1977. Montana production in 1977 was about 7,000 short tons (6,400 t), worth about $11,200 (Ampian, 1978, p. 21). Lightweight aggregate, produced from shale and clay, is expanded or bloated by heating to about 2000° F (1100°C) in a rotary or traveling grate kiln.

Most domestic expanded shale is produced in rotary kilns, the preferred method for providing material for incorporation into stuctural concrete. The sintered aggregate from traveling grate kilns is used in the manufacture of masonry items.

Figure 39.--Sand and gravel areas on the Charles M. Russell Wildlife Refuge. Base from 1:250,000 scale Army Map Service maps.




107°00'
106°30'
106°00'
GLASGOW
2
BRAZIL CREEK
FORT PECK
FORT PECK
MISSOURI RIVER
48°00'
LARB CREEK
WILLOW CREEK
BEAR CREEK
BEAR CREEK
TIMBER CREEK
ROCK CREEK
24
SOUTH FORK ROCK CREEK
ASH CREEK
McGUIRE CREEK
McGUIRE CREEK
SNAP CREEK
NELSON CREEK
HELL CREEK
HELL CREEK
FLAT CREEK
NELSON CREEK
47°30'
SEVEN BLACKFOOT CREEK
TIMBER
BIG DRY CREEK
BIG DRY CREEK
CREEK
SMOKY BUTTE
20
JORDAN
20
22
107°30'
107°00'
106°30'

An unnumbered table to accompany fig. 39, Sand and gravel areas on the Charles M. Russell Wildlife Refuge.

[Data gathered and recorded in inch-pound system; 1 cubic yard = 0.7646 cubic meter; 1 inch = 2.54 centimeters; 1 foot = 0.3048 meter.]

[Data prior to 1975 from Montana State Department of Highways files]

Area	Estimated production	Estimated resources	Geology
Bear Creek	Small (1975)	More than 1,000 cubic yards (1975).	Silty, sandy gravel in 1- to 2-foot-thick lenses. 10 percent 1 to 6 inches, 85 percent sand to 1 inch, 5 percent silt to sand in beds more than 15 feet thick.
Beauchamp Creek	Unknown	53,000 cubic yards (1975)	Sand and gravel with a few boulders. Pebbles mainly 0.2 to 2 inches across, 25 percent is silt and sand.
Big Dry Creek	Less than 1,000 cubic yards (1975).	Much more than 10,000 cubic yards (1975).	Silty, sandy gravel in lenses up to 10 feet thick; pebbles mainly less than 2 inches across.
C. K. Creek	Unknown	More than 100 cubic yards (1975).	Scattered, small gravel lenses (less than 50 cubic yards) in silty sand. About 70 percent of the constituents are less than 1 inch and 30 percent are between 1 and 6 inches across.
Fort Peck	Unknown. Large amounts of local materials were used to construct Fort Peck Dam.	Much more than 150,000 cubic yards (1934, 1952, 1954, 1975)	Glaciofluvial gravel between Fort Peck and Duck Creek; relatively clean lenses of gravel up to 40 feet thick with pebbles up to 2 inches across. Silty sand beds also are up to 40 feet thick.
			Local, recent stream sediments; silty, sandy gravel with angular to subrounded pebbles up to 4 inches across.
			Residual surface deposits; 1 to 15 feet of silty, sandy gravel with few pebbles larger than 2 inches. Modified by glaciation and weathered.
Hell Creek	Minor (1975)	More than 1,000 cubic yards (1975)	Gravel lenses 1 to 5 feet thick and 10 to 500 feet long. The silty, sandy gravel contains an estimated 20 percent subangular to rounded cobbles and pebbles, mostly less than 6 inches across.
McGuire Creek	More than 100,000 cubic yards (1961-1963)	More than 6,000 cubic yards (1961, 1963, 1975)	Gravel lenses 1 to 5 feet thick, in silty sand. Probably less than 25 percent gravel. Cobbles mostly smaller than 6 inches, well-rounded to subangular.
Nelson Creek	Small (1975)	More than 20,000 cubic yards (1961, 1975)	Gravel lenses up to 15 feet thick in silty sand. Most of the constituents are smaller than 2 inches and well-rounded to subangular.
Robinson Bridge	More than 124,000 cubic yards (1940 - 1975)	1,407,000 cubic yards(?) (1940-1975)	Mainly silty sand with minor gravel pods. Nearly all cobbles and pebbles are smaller than 10 inches across.
Rock Creek	40,000 cubic yards(?) (1961, 1975)	60,000 cubic yards (1962, 1975)	Some ridgecrest gravel deposits with constituents mainly less than 4 inches across, which some contain some igneous and metamorphic constituents, many of which are coated by limy material.
UL Bend	Minor	130,000 cubic yards	Silty sand with less than 20 percent gravel in lenses 1 to 5 feet thick. Most constituents are smaller than 4 inches in diameter.
			Alluvial benches and bars 100 to 500 feet across with up to 40 percent gravel. Most of the pebbles are smaller than 2.5 inches.

Shales and clays suitable for the rotary kiln method contain impurities which are thought to be responsible for their expansion. The partially fused material retains gases; these, during heating, swell the material to several times its original size.

Geology

The Cretaceous Bearpaw Shale Formation on the Wildlife Refuge is nearly horizontal. The Bearpaw Shale on the Refuge is about 1,100 feet (335 m) thick, mostly dark gray, weakly cohesive, and contains montmorillonite, either disseminated, in lenses, or in more continuous bentonite beds.

Results of sampling

Nineteen shale samples and one sample of reworked glacial till taken by the U.S. Geological Survey were tested by the Montana Bureau of Mines and Geology to determine their usefulness as lightweight aggregate. The results are shown in table 34.

Table 34.--NEAR HERE.

Nine of 34 samples taken by the U.S. Bureau of Mines expanded favorably, as reported by the Bureau of Mines Tuscaloosa Metallurgy Research Center. The favorable samples, mainly from the Bearpaw Shale, were from lat. 47° 47.5' N., long. 106° 33.5' W.; lat. 47° 20' N., long. 107° 58' W.; lat. 47° 47.5' N., long. 106° 46.5° W.; lat. 47° 59' N., long. 106° 19.5' W.; lat. 47° 43' N., long. 106° 35' W; and lat. 47° 42' N., long. 106° 19.5' W. (Hell Creek Formation). Except for the sample from the Hell Creek Formation, density of the nine samples fired at 2000° F (1100° C) averaged 82 pounds per cubic foot (1300 kg/M^3), and at 2100° F (1150° C), 67 pounds per cubic foot (1070 Kg/M^3). Density of the Hell Creek sample, the only one of seven Bureau of Mines samples from the Hell Creek, Fox Hills, and Fort Union Formations that expanded favorably, was 102 pounds per cubic foot (1600 Kg/m^3) at 2000° F (1100° C) and 92.0 pounds per cubic foot (1440 Kg/m^3) at 2100° F (1150° C). Expansion of the samples at 2200' F (1200' C) was not favorable.

Placer gold

Fine and flour gold has been reported in bars of the Missouri River, downstream from Fort Benton (Dingman, 1932). The only known sources are distant; that rivers and streams transported much gold into the Refuge is doubtful.

Table 34.--Physical properties of heated shale samples from the Charles M. Russell Wildlife Refuge, Montana, and their suitability for use as lightweight aggregate. (Testing by Montana Bureau of Mines and Economic Geology.) 1/

Sample No. 2/	Test results 3/ 1035°C. (1900°F.)	1093°C. (2000°F.)	1149°C. (2100°F.)	1204°C. (2200°F.)	Suitability for lightweight aggregate
75-B-6	Slight bloat	Fair bloat, cracking	Good bloat, incipient glaze	Good bloat, incipient fusion and adhesion	Good product--good expansion at high end of range.
75-B-11	Slight bloat	Spalling, good round bloat	Excellent round bloat	Good bloat, adhesion	Very good product, in particular at high end of range.
75-B-15	No bloat	Incipient bloat	Excellent round bloat	Good bloat, adhesion	Very good product, particularly at high end of range.
75-B-16	Slight bloat	Incipient bloat	Fair round bloat	Fair bloat, adhesion	Fair--not much expansion.
75-B-17	Slight bloat	Spalling, good round bloat	Good bloat, slight adhesion	Fair bloat, adhesion	Good--somewhat brittle.
75-B-18	No bloat	No bloat	Slight bloat, adhesion	Fused	Not suitable--very little expansion.
75-B-19	Good bloat	Good round bloat	Excellent bloat, glazed	Excellent bloat, adhesion	Excellent--bloats well over a wide range.
75-B-24	Slight bloat	Minor bloat	Fair bloat, adhesion	Good bloat, incipient fusion	Good product.
75-B-66	Slight bloat	Fair bloat, incipient glaze	Excellent bloat, glaze	Excellent bloat	Excellent--good expansion over a moderate range.
75-B-90	Slight bloat	Good bloat, minor glaze	Excellent round bloat, minor glaze	Excellent bloat, adhesion	Excellent--good expansion over a wide range.
75-B-122	Moderate bloat	Good round bloat	Excellent round bloat, incipient glaze	Excellent bloat, adhesion	Excellent--good bloat over a wide range.
75-B-123	Slight bloat	Slight bloat	Slight bloat	Slight bloat adhesion	Unsuitable--only minor expansion.
75-B-124	Minor bloat	Minor bloat	Fair bloat, glaze	Fair bloat, adhesion	Poor-narrow bloating range.
75-B-130	No bloat	No bloat	Incipient bloat	Fair bloat, adhesion	Unsuitable--only minor expansion.
75-B-134	Moderate bloat	Fair bloat	Excellent round bloat, slight glaze	Good bloat, adhesion	Excellent--good expansion over a wide range.
75-B-139	Slight bloat	Slight bloat	Excellent bloat, spalling	Good bloat, adhesion	Very good--good expansion over a wide range.
75-J-3	Slight bloat	Fair bloat	Good bloat, glaze, adhesion	Bloat and incipient fusion	Poor--narrow expansion range.
75-H-49	No bloat	Slight bloat	Slight bloat	Some bloat and incipient fusion	Unsuitable--poor expansion.
75-K-3	No bloat	No bloat	No bloat slight glaze	Bloat and fusion	Unsuitable--poor expansion.
75-U-21	No bloat	No bloat	Incipient bloat, glaze	Good bloat adhesion	Poor-very narrow range.

1/ Sampling by U.S. Geological Survey under the direction of Claudia Wolfbauer Frahme.
2/ Plate -
3/ Rock fragments 12-1k9 cm in diameter were preheated to 500° C. and the temperature was repeatedly increased 50° C. per 15-minute interval up to 700° C. The samples were then transferred to another furnace and heated to 1038° C., 1093° C., 1149° C., and 1204° C. for 20 minutes each and the condition of the heated product was described for each of these temperatures.

Prospective sand and gravel deposits, near and on the Refuge, contained negligible gold. Nearly all samples, of about one-third cubic foot (0.0094 m^3) of gravel, were from high in the Recent sedimentary section. Detected gold was very fine-grained. One sample had 18 flakes which totaled 0.006 milligram gold. Samples with the greatest gold content were from the area between the northwest corner of the Refuge and Jones Island; they indicated a maximum value of about 7.3 cents per cubic yard (9.6 cents/m^3), at $223.575 per troy ounce gold.

Kaolinite

The Colgate Member of the Fox Hills Formation of Cretaceous age is a white, silty, friable kaolinitic quartzose sandstone that crops out in the central and southern parts of the Wildlife Refuge. It is as much as 50 feet (14 m) thick, although it is lenticular and grades laterally into brown sandstone.

Seven samples were evaluated; the sand and silt fraction (plus 325 mesh) is fine-grained quartz, feldspar, and mica. The samples contained from 84.12 to 90.84 percent SiO_2 (averaged 87.3 percent), and from 0.39 to 1.67 percent iron (averaged 0.74 percent). The clay fraction (minus 325 mesh) contained kaolinite, but, because of impurities, is off-white. Clay in all but two samples would be suitable for light-duty refractories according to pyrometric testing; however, the clay represents only 10 to 15 percent of the material. Pyrometric cone equivalents, from 14 to 28, averaged 21.4.

Uranium

No significant radioactivity was found on the Wildlife Refuge. Scintillometer readings at some of the Judith River coal outcrops were a maximum of 1.5 times average area background. However, seventeen Judith River Formation coal samples and eight Hell Creek Formation carbonaceous shale samples contained no detectable U_3O_8.

Background

Previous studies and acknowledgments

Several Federal government agencies have compiled information about minerals on the Charles M. Russell Wildlife Refuge. The U.S. Geological Survey supplied unpublished information about water well logs, leases, and coal for selected townships. Geologic data, used to evaluate sand and gravel deposits along the Missouri, were obtained from the U.S. Bureau of Reclamation study of a dam site at Rocky Point. The U.S. Army Corps of Engineers supplied geologic data from their foundation studies of the Fort Peck Dam and spillway area, and the experimental Project Gondola canal excavation site. They also supplied side-looking airborne radar imagery of the east part of the Refuge. The U.S. Bureau of Land Management provided data about oil and gas leases, bentonite, and other minerals. The U.S. Soil Conservation Service contributed information from their comprehensive soil surveys of much of the Refuge.

Reports from the Montana State Department of Highways were used to evaluate Refuge gravel deposits. They provided information about the foundation geology of Robinson Bridge. Oil and gas well stratigraphic and geophysical logs, filed with the Montana State Board of Oil and Gas Conservation, were used to evaluate Refuge oil and gas, coal, and clay potentials. Six county recorder offices made available information about mining claims and oil and gas lease locations. County road crews described various sand and gravel sources around the Refuge.

Although no commercial exploration has been conducted on the Refuge, there has been activity nearby. Several firms and individuals were very informative. American Colloid Co., notably Mr. Art Clem, supplied statistical and background data on bentonite mining. Wesco, particularly Mr. Steve Elliott, and Burlington Northern Railroad described their coal development activities. Webb Resources, Inc., Rainbow Resources, Fuelco, Ashland Oil Co., Barnes Oil Co., Tenneco, McCulloch, Chandler and Associates, Phillips Petroleum Co., Amoco Production Co., Sun Oil Co., and Union Oil Co., provided data from their oil and gas explorations.

An unpublished masters thesis by Robert E. Bell (1965) was very useful in evaluating coal in the east end of the Refuge.

Present studies

In 1975 a Bureau of Mines investigation was conducted to evaluate mineral deposits, mainly petroleum, natural gas, coal, clays, expandable shale, and sand and gravel. Claims and mining operations on and near the Wildlife Refuge were examined; formations known to contain particular commodities were evaluated throughout the area. The location and size of mineral deposits were noted, and surface samples taken. Some bentonite and montmorillonitic clay layers, coal beds, and alluvial deposits were mapped. A computer was used in an attempt to correlate groups of bentonite beds mapped in more than 70 traverses. Radioactivity of outcrops was checked by a scintillometer.

Before field work was undertaken, from July through October, courthouse record searches and literature reviews had been completed. Three two-man crews worked in the field approximately 350 man-days. Most travel was by foot and four-wheel-drive vehicles. Boats were used for about 20 percent of the work, and a helicopter for less than 5 percent. Some coal, clay, gravel, and placer gold deposits were mapped from false-color infrared aerial photographs taken during the summer of 1975 for the Bureau of Land Management. These aerial photographs also were used to locate structures possibly significant to oil and gas accumulation. Participants in the Bureau of Mines work were Michael S. Miller, project leader, Michael M. Hamilton, Otto L. Schumacher, James Rigby, and their assistants, Dave C. Clark, Carl Huie, James Kaupilla, Jerry Olson, Douglas Prihor, and Richard Rains.

Resource terminology in this report conforms to guidelines adopted by the U.S. Bureau of Mines and U.S. Geological Survey and published in U.S. Geological Survey Bulletins 1450-A (1976) and 1450-B (1978).

Sampling and analytical methods

A total of 385 clay, 116 coal, 46 placer, and 34 expandable shale samples were evaluated.

Clay samples were usually from shallow trenches dug through the zone of soil creep and intense weathering. Most were from clay-rich layers more than 6 inches (15 cm) thick; they weighed 1 to 10 pounds (0.45 to 4.5 kg) each. Except for those shipped wet for comparison purposes, the samples were air-dried between 190° F and 210° F (88° and 99° C), crushed, and shipped to the Bureau of Mines Tuscaloosa Metallurgy Research Center clay laboratory. They were examined by X-ray diffraction to select those with desirable mineralogy. Selected samples were tested for viscosity, wet and dry bond strength, grit, water loss, pH, and refractory properties. About 2 percent clay finer than 200 mesh was mixed with Al_2O_3 powder (1 to 7 micron size) for pelletizing tests. Water was added to this mixture and 1/2 ± 1/64 inch (1.3 ± 0.04 cm) balls were formed. The number of times that the moist balls could be dropped 18 inches (46 cm) before breaking was recorded. After drying overnight at 250° F (121° C), the balls were tested for compressive strength at a loading rate of 100 pounds per minute (448 newtons/minute).

The clays were tested as a foundry sand binder by mixing about 6 percent clay finer than 200 mesh with 1000 grams of AFS-57 sand. While wet, a 165-gram (5.8-ounce) sample was rammed into a 2-inch (5.08-cm) tall column and tested for compressive strength. After drying at 220° F (105° C) to 230° F (110° C) for two hours, the 2-inch (5.08-cm) column of sand bound by the clay mixture was compressed at 140 ± 20 psi per minute (965 ± 138 kilopascals/minute) until the sample failed.

The clay's suitability as a drilling fluid additive was tested by adding water and measuring the viscosity of the mixture. For one method, 22.5 grams (0.79 ounce) of clay, as received, was mixed with 350 cubic centimeters (21.35 $inches^3$) of water, and the viscosity measured at 600 rpm in a Baroid model 35 viscometer.[1/] Some samples were tested by timing the flow of a standardized clay-water mixture through a funnel (Marsh funnel test). Also, a determination was made of sample grit larger than 200 mesh.

Samples of shale and clay tested for expansion were heated to 1800°, 1900°, 2000°, 2100°, and 2200° F (982°, 1038°, 1093°, 1149°, and 1204° C). The amount of expansion caused by heating to each temperature was measured.

1/ Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey or the U.S. Bureau of Mines.

Most coal samples were from surface cuts which were deep enough to exclude the more weathered or contaminated material. Generally, only beds thicker than 24 inches (61 cm) were sampled. Most samples were sealed in new, one-half- or one-gallon (1.9- or 3.8-liter) metal paint cans, and sent to the Pittsburgh Bureau of Mines Mining and Safety Research Center laboratory. Ash, moisture, volatile matter, sulfur, and heat contents were determined. The majority of the carbonaceous shale samples and coal sample splits were sent to the Bureau of Mines Metallurgy Research Center at Reno for spectrographic determination of trace elements. Fourteen coal samples were analyzed in detail for 39 elements by the U.S. Geological Survey in Denver.

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