

**STATUS OF MINERAL RESOURCE INFORMATION FOR THE
NORTHERN CHEYENNE INDIAN RESERVATION, MONTANA**

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CONCLUSIONS

Coal is the most important mineral resource on the Northern Cheyenne Indian reservation. There is an estimated 23 billion tons of coal of which 5 to 6 billion tons may be mined by surface mining methods. Further study of the coals should include surface mapping at a scale of 1:24,000, and drilling 10 to 15 holes per township to depths of 200 to 500 feet.

Ten test wells for oil and gas have been drilled on the reservation since 1952; none were successful. The deepest well penetrated 9,255 feet to Precambrian rocks; none of the others tested below the Jurassic Morrison Formation. Marine rocks older than the Morrison Formation are continuous with productive formations in nearby Powder River Basin but are virtually untested on the reservation.

The recommended systematic mapping of the coal beds will provide information on deposits of clay and sand and gravel and may disclose structural features that control accumulations of gas and oil.

INTRODUCTION

The Northern Cheyenne Indian Reservation (Figure 1) occupies about 680 square miles in eastern Big Horn and southern Rosebud Counties, Montana. The principal settlements within the reservation are Lame Deer and Busby located in the northern part of the reservation along U. S. Highway 212. The largest nearby towns are Ashland, at the east edge of the reservation,

Hardin, about 30 miles west, and Forsyth, about 40 miles north. The Tongue River, a major tributary of the Yellowstone River, forms the eastern boundary of the reservation, and Rosebud Creek, a somewhat smaller tributary of the Yellowstone, crosses the northwestern corner. Both streams flow northeastward in broad, alluvial valleys. A high, northeastward-trending intricately dissected divide between the two streams makes up the major part of the reservation. The Spray Mountains rise fairly steeply northwest of Rosebud Creek and cover an area of 40 to 50 square miles in the northwestern corner of the reservation. Elevations range from about 4,500 feet in the Spray Mountains and on the highest part of the Rosebud Creek-Tongue River divide to about 2,900 feet in the Tongue River valley at the northeastern corner of the reservation.

Mineral Resources on the reservation consist primarily of coal. There are no known occurrences of metallic minerals. Nonmetallic minerals include building stone, sand and gravel, bentonite, claystone, and clinkers. Potential utilization of the nonmetallic minerals presently appear to be limited to local usage. There has been no production of oil and gas from the reservation, although ten wells have been drilled.

Coal beds underlie the entire Northern Cheyenne Reservation; much of the coal is in beds that are at too great a depth for surface mining. However, of an estimated 23 billion tons of coal underlying the reservation, it is estimated that surface mining may be applicable for about 5-6 billion tons.

Present Investigation

This report is a compilation and summary of information on the geology and mineral resources in the Northern Cheyenne Indian Reservation, and the potential for the economic development of these resources. Published and unpublished reports consulted in assembling the report are listed in the references. In addition, resource computer files of the Geological Survey and Bureau of Mines were searched for references to specific mineral deposits in the reservation.

Legal and Environmental Considerations

Within the last several years, legal and environmental considerations in the development of mineral resources have become more and more restrictive and complicated. This trend is anticipated to continue at least into the near future. These considerations have had a very definite affect on the availability of mineral resources and a much more dramatic effect on their price. This is especially true in the case of coal, the principal mineral resource on the Northern Cheyenne Reservation.

The reservation does, however, have a very definite advantage in that many restrictions on non-Indian lands do not apply to Indian lands. This could well evolve into a definite advantage within the next few years for development of the reservation's resources.

GEOLOGY

Rock Units

Rocks exposed in the Northern Cheyenne Indian Reservation belong to the Tongue River Member of the Fort Union Formation of Paleocene age. They are overlain by Holocene alluvial deposits along the larger streams, most notably along the Tongue River and Rosebud Creek (Hopkins, 1973).

The Tongue River Member of the Fort Union Formation is as much as 1,500 feet thick in the reservation. The uppermost part of the member crops out on the Tongue River-Rosebud Creek divide in the southeast corner of T. 6 S., R. 39 E., and rocks about 350 feet above the base of the Tongue River Member, as defined in the Forsyth coal field north of the reservation (Dobbin, 1930), are exposed near the level of Rosebud Creek in the northern part of T. 2 S., R. 41 E. The member thins southwestward across the reservation in the subsurface by interfingering with the underlying Lebo Shale Member of the Fort Union Formation.

The Tongue River Member consists of light-gray and light yellowish gray fine to very fine-grained sandstone, light-gray siltstone, light to dark-gray sandy shale and mudstone, brown carbonaceous shale, and coal. The sandstone beds are locally several tens of feet thick and characteristically form ledges and cliffs. The thicker coal beds commonly are burned along their out crops, and the resulting heat has baked and fused overlying shale and sandstone into resistant masses of red clinker, or scoria, for thicknesses of tens of feet,

depending on the thickness of the coal that has burned.

Alluvial deposits that form the flood plains of the larger streams are reported to be as thick as 97 feet beneath the flood plain of the Tongue River on the east side of the reservation (Hopkins, 1973). The deposits consist of mostly unconsolidated poorly stratified layers of clay, sand, and gravel. According to Hopkins (1973), most of the larger

rock fragments in the deposits are clinkers derived from the Fort Union Formation.

The Tongue River Member of the Fort Union Formation is underlain by about 8,500 feet of older sedimentary rocks that have been penetrated by wells drilled for oil and gas. Listed in Table 1, below, in order of increasing age and depth are the rock units present at surface or in the subsurface in the reservation.

TABLE 1

Rock Units at the Surface and in the Subsurface in the Northern Cheyenne Indian Reservation (Descriptions mainly from American Stratigraphic Co. sample logs; thicknesses of Cretaceous and older rocks from the Superior Oil Co. 22-19, Northern Cheyenne well, sec. 19, T. 2 S., R. 40 E.)

Quaternary System.

Holocene Series.

Alluvium. Unconsolidated poorly stratified clay, sand, and gravel deposited along the major streams. Fragments of clinker make up the largest rock fragments in the deposits. Thickness as much as 97 feet.

Tertiary System.

Paleocene series.

Fort Union Formation.

Tongue River Member. Ledge-forming light-gray and light yellowish-gray sandstone, light-gray siltstone, dark-gray shale, sandy shale, and mudstone, brown carbonaceous shale, and coal. Thickness about 1,500 feet.

Lebo Shale Member. Dark-gray mudstone and claystone; contains abundant ferruginous concretions and a few lenticular beds of light-gray sandstone; coal bed at the base. Thickness 200-300 feet.

Tulloch Member. Light-gray calcareous sandstone and gray sandy and silty shale; minor amounts of coal. Thickness about 250 feet.

Cretaceous System.

Upper Cretaceous Series.

Hell Creek Formation. Dark-gray and dark greenish-gray contains a coal bed at the base. Called the Lance Formation in some early reports. Thickness about 400 feet.

Fox Hills Sandstone. Light- to very light gray friable sandstone interbedded with medium to dark gray shale and siltstone. Thickness about 200 feet.

Bearpaw Shale. Medium to dark-gray bentonitic slightly micaceous shale; several thin beds of white to very light-gray bentonite. Thickness about 765 feet.

Parkman Sandstone. Very light gray glauconitic slightly calcareous fine to medium-grained sandstone; interbedded gray shale and sandy shale. Corre-

lates with the Judith River Formation of central Montana. Thickness about 180 feet.

Claggett Shale. Gray bentonitic shale containing a few stringers of light-gray siltstone and thin beds of bentonite. Thickness about 340 feet.

Eagle Sandstone and Telegraph Creek Formation, undivided. Gray shale and interbedded light-gray siltstone; a few beds of light-gray fine- to medium-grained micaceous glauconitic sandstone near the middle including the Shannon Sandstone Member, about 35 feet thick, about 300 feet above the base of the unit. Thickness about 700 feet.

Niobrara and Carlile Shales, undivided. Dark-gray alternately calcareous and noncalcareous shale and bentonitic shale; a few thin beds of light-gray fine-grained sandstone; scattered fish bones and scales. Thickness about 875 feet

Greenhorn Formation. Dark-gray bentonitic shale containing few beds of bentonite, and, in the upper part, thin beds of light-gray fine-grained calcareous glauconitic sandstone and gray scaly limestone. Thickness about 285 feet.

Belle Fourche Shale. Dark-gray shale containing several beds of light-gray and grayish-green bentonite; some interlaminated light-gray siltstone. Equivalent to the Frontier Formation of areas to the west. Thickness about 315 feet.

Lower Cretaceous Series.

Mowry Shale. Dark-gray shale, siliceous near the top of the formation; some interbedded light-gray very fine grained micaceous sandstone and thin beds of bentonite. Thickness about 400 feet.

Newcastle Sandstone. Light-gray very fine to medium-grained calcareous locally glauconitic sandstone; some interbedded light-gray siltstone and dark-gray shale. Called the Muddy Sandstone in some parts of the Powder River basin. Thickness about 70 feet.

Skull Creek Shale. Dark-gray bentonitic shale. Thickness about 80 feet.

Fall River Formation. Light-gray very fine to fine-grained micaceous sandstone interbedded with gray siltstone and dark-gray shale. Upper half is generally more silty and scaly than the lower half and in some wells is called the "basal Colorado silt." Thickness about 215 feet.

Lakota Formation. Light-gray, green, and maroon claystone interbedded mostly in the lower part with gray and brownish-gray medium to coarse-grained sandstone. Upper, variegated claystone interval called the Fuson Shale in some wells. Thickness about 200 feet.

Jurassic System

Morrison Formation. Purplish-red and green claystone, calcareous in the lower part; interbedded very light-gray fine to medium grained calcareous sandstone near the base. Thickness about 120 feet.

Swift Formation. Greenish-gray flaky noncalcareous shale interbedded with light-gray calcareous glauconitic very fine to fine-grained sandstone; a few thin beds of brownish-gray oolitic limestone. Thickness about 275 feet.

Rierdon Formation. Greenish-gray calcareous shale and marl. Thickness about 150 feet.

Piper Formation and underlying Jurassic rocks, undivided. Red and green calcareous claystone in upper part; light-gray limestone and dolomite in the middle part; and orange-red claystone interbedded with anhydrite in the lower part. Thickness about 165 feet.

Triassic System

Spearfish Formation. Orange-red very fine and fine-grained dolomitic sandstone and sandy claystone. Thickness about 140 feet.

Triassic and Permian Systems.

Goose Egg Formation. Interbedded orange-red calcareous siltstone, white anhydrite, and thin beds of light-gray cherty dolomite. Thickness about 95 feet.

Pennsylvanian System.

Tensleep Sandstone. Light-gray and pinkish-gray very fine to fine-grained dolomitic sandstone, light-gray and tan cherty dolomite, and light-gray sandy dolomite. Locally cemented by anhydrite in the subsurface. Thickness about 95 feet.

Amsden Formation. Light-gray and light pinkish-gray cherty dolomite; interbeds of red shale. Thickness about 85 feet.

Mississippian System.

Mission Canyon Formation. Light-gray and light grayish-tan cherty bioclastic dolomite; locally contains beds of light to dark-gray anhydrite. Equivalent to the upper part of the Madison Limestone of the Bighorn Mountains to the west. Thickness about 775 feet.

Lodgepole Limestone. Light-gray and brownish-gray oolitic bioclastic limestone and dolomite. Equivalent to the lower part of the Madison Limestone of the Bighorn Mountains to the west. Thickness about 380 feet.

Devonian System

Duperow Formation. Light-gray, grayish-brown, and pinkish-gray dolomite; a few shaly partings. Equivalent to the Jefferson Formation of nearby areas to the west. Thickness about 165 feet.

Silurian System.

Interlake Formation. Light-tan to very light gray fragmental dolomite. Thickness as much as 75 feet; pinches out westward within the reservation.

Ordovician System.

Red River Formation. Light-gray and light-tan granular dolomite. Equivalent to the Bighorn Dolomite of nearby areas to the west. Thickness about 315 feet.

Winnipeg Sandstone. Grayish white very fine to fine-grained quartzose sandstone. Thickness about 65 feet.

Cambrian System.

Cambrian rocks, undivided. Tan and gray glauconitic limestone; partings of green micaceous shale. Thickness about 30 feet.

Precambrian rocks.

Dark greenish-gray gabbro.

Structure

The Northern Cheyenne Reservation is in the north-central part of the Powder River Basin, which is a large north-trending topographic and structural feature about 275 miles long and slightly more than 100 miles wide in northeastern Wyo-

ming and southeastern Montana. The northern part of the basin in Montana is bordered by the northern end of the Bighorn Mountain uplift on the west; the Porcupine Dome and Miles City Arch, which lie generally north of the Yellowstone River, on the north; and the Black Hills Uplift on the east. The structural configuration of the northern part of the

basin has been depicted on structure contour maps by Dobbin and Erdman (1955) and Balster (1973).

The main structural feature in the reservation is a broad syncline whose axis trends generally northeastward parallel to and a short distance west of the Tongue River (Figure 2). Rocks on the flanks of the syncline are inclined very gently southeastward or northwestward towards the axis, generally less than one degree. The structural relief, as shown by Balster (1973) is slightly more than 1,200 feet, the structurally highest part being in the northwestern corner of the reservation, and the structurally lowest part near the southeastern corner. Slight subsidiary folds of very low amplitude that trend obliquely to the axis of the principal fold interrupt the otherwise uniform southeasterly dip in the northern part of the reservation between Lame Deer and Ashland (Balster, 1973). These folds consist of a southward plunging anticlinal nose and flanking synclinal trough on the east as shown on Figure 2.

The reservation is not crossed by any major faults. Geologic work in the reservation is insufficiently detailed to show the presence of minor faults. However, minor northwestward trending faults having displacements of 50-100 feet and extending for distances of several miles are common in the Fort Union Formation in bordering areas both south and west of the reservation (Matson and Blumer, 1973, pl. 5C; unpublished data, Peabody Coal Co.). Faults having similar trends and displacements to those outside the reservation probably cut the surface within the reservation along the Rosebud-Tongue River divide and elsewhere.

MINERAL RESOURCES

Mineral resources of value or potential value in the Northern Cheyenne Indian Reservation include coal, oil and gas, bentonite, building and ornamental stone, claystone and shale, clinker, and sand and gravels. Of these coal is the most important.

Coal

Coal mining in the Western states is expanding at a rapid rate and expansion is predicted to continue at least in the foreseeable future. Several factors are responsible for this growth. Many electric power plants have converted from oil and gas to coal in compliance with U. S. Government policy to become less dependent on foreign sources of energy. Also, many coal users have found it necessary to reduce sulfur dioxide emissions to comply with Environmental Protection Agency standards. This has resulted in a large demand for low sulfur Western coal. In addition, nuclear electrical generating capacity has fallen behind previous predictions. Additional coal supplies may also be needed in the near future for conversion to other energy forms such as synthetic natural gas and synthetic liquid fuels. In response to the increased need for coal, a substantial amount of attention is now being directed toward establishing new sources of coal to supply the expanding market. The coal resources on the reservation could contribute significantly toward supplying these markets.

TABLE 2
Oil and Gas Test Wells Drilled in the Northern Cheyenne Indian Reservation, to January 1975.
[Data from Petroleum Information, Denver, Colorado]

Map no. Fig. 2	Name of well	Location: Township, Range, quarter, and section			Year Compl.	Surface elev., feet	Total depth, feet	Oldest formation tested
1	Superior Oil Co., 22-19 Northern Cheyenne Tribe	2S.	40E.	SE NW 19	1965	3,546	9,255	Precambrian rocks
2	Shell Oil Co., CH-1 Government	2S.	42E.	SW NE 13	1952	3,755	3,226	Claggett
3	Shell Oil Co., 6 Northern Cheyenne Tribe	2S.	42E.	NW SE 30	1952	3,697	2,802	Bearpaw
4	Shell Oil Co., 5 Northern Cheyenne Tribe	2S.	44E.	SW SE 9	1953(?)	2,871	2,000	Hell Creek
5	King Resources, 1-32 Cheyenne Tribal	2S.	44E.	NE NE 32	1969	3,290	6,530	Lakota
6	King Resources, 1-2 Cheyenne Tribal	3S.	43E.	NE NE 2	1969	3,414	6,641	Morrison
7	Davis Oil Co., 1 Cheyenne Tribal	4S.	39E.	SE SE 36	1970	4,485	7,500	Lakota
8	Apache Corp., 1 Cheyenne Tribal	5S.	39E.	SE SE 36	1971	4,567	7,467	Skull Creek
9	King Resources, 1-1 Cheyenne	5S.	41E.	SW SE 1	1969	4,090	7,563	Morrison
10	King Resources, 1-6 Sandcrane Cheyenne	5S.	41E.	SW SE 6	1969	4,226	7,567	Morrison

Geologic Setting and Controls

Coal occurs in thick, generally persistent beds in the Tongue River Member of the Fort Union Formation in the region of the Northern Cheyenne Indian Reservation. Almost no specific information has been published on the thickness and extent of the coal beds within the reservation; however, mapping and drilling adjacent to the reservation and some limited information from oil and gas wells can be used to indicate broadly the sequence and thickness of coal beds that are present. Much systematic drilling for coal has been done on the

reservation by private individuals or companies, but information from this work is closely held and none of it was available in preparing this report.

Areas of strippable coal on the margins of the reservation are described by the Montana Bureau of Mines and Geology (Matson and Blumer, 1973).

The sequence of coal beds at the northern and southern edges of the reservation are shown by [Figure 3](#), [Figure 4](#), and [Figure 5](#). Some of the coals occupy fairly consistent stratigraphic positions and although their thicknesses vary from place to place, they can be traced for many miles in outcrops and drill holes. Others are local lenses. The interval

between the coal beds generally also varies, and locally beds merge or split into separate benches, which in poorly explored areas makes correlation uncertain. The use of different sets of bed names in different areas partly reflects the difficulty of correlating beds that have not been traced across intervening regions.

Coal in the Fort Union Formation in the northern part of the Powder River basin is sub-bituminous in rank. The sulfur and ash contents are low. Sulfur generally is in the range of 0.2 to 1.1 percent and ash in the range of 4 to 10 percent on the as-received basis. Typical analyses of coal from

areas adjacent to the reservation are shown on [Table 3](#). Additional analyses, including forms of sulfur and constituents of the ash, are given by Matson and Blumer (1973).

Three locally thick beds, and several thinner ones extend into the northern part of the reservation from areas farther north. The three principal beds are the Knoblock, Rosebud, and Sawyer beds as shown by [Figure 4](#). The McKay and Robinson beds which lie below the Rosebud bed, and the E and Garfield beds which are above the Sawyer bed, may be locally important coals in the northern part of the reservation.

TABLE 3
 Analyses of Coal, as Received, from the Tongue River Member of the Fort Union Formation near the
 Northern Cheyenne Indian Reservation
 [In percent; analyses calculated from data given by Matson and Blumer, 1973]

Bed name	Sec.	Location		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heat value Btu*
		T.	R.						
Sawyer	6	12S	43E	26.15	29.96	38.00	5.90	0.21	8,805
Knoblock	36	1S	42E	24.97	30.70	38.54	5.79	.41	9,086
Knoblock	8	3S	45E	27.32	30.21	37.80	4.68	.12	8,666
Rosebud	24	1S	42E	26.69	26.65	37.12	9.54	1.54	8,383
Canyon	3	6S	40E	29.20	28.56	36.72	4.86	.43	7,991
Wall	16	6S	41E	25.37	27.79	38.75	6.21	.43	8,583
Brewster- Arnold	28	6S	42E	26.11	32.11	24.22	7.56	.43	8,444

*British thermal units

Knoblock Bed.--The Knoblock bed is about 300 feet above the base of the Tongue River Member of the Fort Union Formation and is a thick and important bed north and east of the reservation. It has been traced in a broad arc from sec. 8, T. 5 S., R. 43 E. where it emerges from below the level of the Tongue River northward along the sides of the Tongue River valley to the northeast corner of the reservation and from there westward to the western part of T. 1 S., R. 42 E. It is a prospectively thick and important bed in at least the eastern one-half of the reservation. The coal is 54 feet thick without partings in the vicinity of Ashland, and about 25 feet thick along the reservation boundary in sec. 11, T. 2 S., R. 43 E. about 9 miles northwest of Ashland. A bed tentatively correlated with the Knoblock bed is 33 feet thick, and at a depth of 380 feet as interpreted from the electric log of the Shell Oil Co., 6 Northern Cheyenne Tribe well in sec. 30, T. 2 S., R. 42 E., about 3 miles northeast of Lame Deer. The Knoblock thins from Ashland southwestward, and, about the middle of T. 4 S., R. 44 E., it splits into three benches. Coal in the Knoblock bed probably aggregates about 30 feet in thickness in an interval of about 75 feet along the Tongue River at the southern edge of the reservation (Matson and Blumer, 1973, pl. 34).

Rosebud Bed.--The Rosebud coal bed lies 60 to about 165 feet below the Knoblock bed along the northern edge of the reservation. A coal bed 6½ feet thick, tentatively correlated in this report with the Rosebud, crops out about 160 feet below the Knoblock bed at the north edge of the reservation in sec. 7, T. 2 S., R. 44 E. (Bass, 1932, p. 72). The

Rosebud bed is 13 feet thick about a mile north of the reservation in sec. 5, T. 2 S., R. 41 E., where it crops out a few feet above the valley bottom of Rosebud Creek (Dobbin, 1930, p. 55). The bed is present, and is as much as 16 feet thick in drill holes in T. 2 N., R. 38 E. west of the reservation. Thom and others (1935, p. 103) report a coal bed 9 feet thick, which they tentatively correlate with the Rosebud bed, along Rosebud Creek opposite the mouth of Thompson Creek in T. 4 S., R. 38 E. The distribution and thickness of the coal in areas adjacent to the reservation indicate that the bed probably underlies the northwestern part of the reservation with an average thickness of at least 10 feet.

McKay Bed.--A coal bed 10 feet thick is reported at a depth of about 50 feet in a water well in the stream valley of Rosebud Creek at the reservation in sec. 8, T. 2 S., R. 41 E. (Hopkins, 1973). This coal is at the stratigraphic level of the McKay bed, which north and west of the reservation is commonly about 11 feet thick and is about 25 feet below the Rosebud. Available information suggests that the McKay may be continuous beneath at least the northwest corner of the reservation in parts of T. 2 S., R. 38 to 41 E.

Robinson Bed.-- The Robinson bed is 100 to 120 feet below the McKay bed in areas northwest of the reservation where it is locally about 15 feet thick. The Terret bed, which is approximately at the horizon of the Robinson bed, crops out along the Tongue River north of Ashland where it is as much as 5 feet thick. The distribution of coal at the Robinson-Terret horizon suggests that the bed may

locally be 5 to 10 feet thick in the subsurface in the northwestern corner of the reservation.

Sawyer Bed.--The Sawyer bed, about 250-330 feet above the Rosebud bed, and about 180 feet above the Knoblock bed, forms a prominent clinker within the reservation on bluffs along the lower course of Rosebud Creek. The coal is 19 feet thick adjacent to the reservation in sec. 6, T. 2 S., R. 43 E. (Matson and Blumer, 1973, pl. 30). The thickness of clinker produced by burning of the coal suggests the bed may maintain a thickness of at least 19 feet within the reservation farther south in Tps. 2 and 3 S., Rs. 38 to 43 E. Bass (1932, p. 82) reports coal in the Sawyer bed is 20 or more feet thick on the east side of the Tongue River east of Ashland in T. 3 S., R. 45 E., which is compatible with an eastward-trending band of thick coal in the Sawyer bed in the northern part of the reservation.

E Bed.--A coal about 8 feet thick crops out below Garfield Peak about 350 feet above the Sawyer bed in the northern part of T. 2 S., R. 43 E. This coal is tentatively correlated by Bass (1932, p. 67) with the E bed as mapped in areas east of the reservation. The coal probably extends southward under the higher parts of the Tongue River-Rosebud Creek divide in T. 2 S., Rs. 42 and 43 E.

Garfield Bed.--Garfield Peak, on the Tongue River-Rosebud Creek divide in sec. 9, T. 2 S., R. 43 E., is capped by a clinker 60 feet thick, which forms an extensive plateau farther south in the northern part of the reservation. The Garfield coal bed, which burned to form this clinker, may be

present locally on high divides in the northern part of the reservation, with a thickness in excess of 20 feet.

Coal beds along the southern edge of the Northern Cheyenne Indian Reservation have been mapped by Baker (1929) and Matson and Blumer (1973). The stratigraphic relations of the coal beds is shown by [Figure 5](#).

The principal coals in the southern part of the reservation are the Canyon, Wall, and Brewster-Arnold beds. Stratigraphically higher beds, including the Dietz and Anderson beds, may also be thick enough to contain substantial resources locally.

Canyon Bed.--The Canyon bed, which is about 500 feet below the top of the Tongue River Member of the Fort Union Formation, has a thickness of 24 feet in the Apache Corp., 1 Cheyenne Tribal well, as interpreted from the gamma-ray log of the well. The coal is 29 feet thick about 4 miles to the east in sec. 3, T. 6 S., R. 40 E. (Matson and Blumer, 1973, pl. 6). The Canyon bed is widespread south of the reservation. It can reasonably be projected with a thickness of 20-30 feet under the Tongue River-Rosebud Creek divide in much of T. 5 S., Rs. 39 and 40 E., and perhaps into the next tier of townships to the north.

Wall Bed.--The Wall bed, which is 200-250 feet below the Canyon bed, crops out low on the valley sides of Rosebud Creek in the southern part of the reservation. It crops out, also, in the valley of Cook Creek along the reservation boundary farther east. At both places, it has burned to form a prominent bed of clinker. Coal in the Wall bed is 48 feet thick near the reservation boundary in the

Apache Corp., 1 Cheyenne Tribal well, not including a bed 5 feet thick about 15 feet below the main coal. Drill holes south of the reservation suggest the bed is about 30 feet thick at the reservation boundary in T. 5 S., R. 41 E. The electric log of the Davis Oil Co., 1 Tribal well in the southern part of the reservation in sec. 36, T. 4 S., R. 39 E. indicates a coal bed 65 feet thick at the horizon of the Wall bed. The top of the coal lies at a depth of about 460 feet in this well.

The Wall is widespread in areas south of the reservation. On this basis, and on the basis of the limited data from the oil and gas wells in the reservation, it appears likely that the coal underlies a large area in the south half of the reservation with an average thickness of perhaps 30 feet.

Brewster-Arnold Bed.--The Brewster-Arnold bed, is about 270 feet below the Wall bed on the reservation in the lower part of the valley of Cook Creek, mainly in T. 5 S., R. 42 E. The coal bed is 18 feet thick in the vicinity of Cook Creek, including a shale parting 2 feet thick (Matson and Blumer, 1973, pl. 6). The Brewster-Arnold bed is 16 feet thick in the Apache Corp., 1 Cheyenne Tribal well in sec. 36, T. 5 S., R. 39 E., a few miles to the west. The Pawnee bed, a coal bed 8-10 feet thick on the east side of the Tongue River in T. 5 S., R. 43 E. (Warren, 1959, pl. 23) is at about the stratigraphic position of the Brewster-Arnold bed, and probably is its correlative east of the reservation. The distribution of the bed and its thickness at scattered localities suggest the coal is probably 10 feet or more thick within the reservation in much of T. 5 S., Rs. 38-42 F., and in the southern parts of T. 4 S., Rs. 40-42 E.

Dietz and Anderson Beds.--The Dietz and Anderson beds are 8 and 7 feet thick, respectively, in the Apache Corp. 1 Cheyenne Tribal well at the southern edge of the reservation. These two coals probably underlie at least the southern part of the Tongue River Rosebud Creek divide in Tps. 4 and 5 S., Rs. 39-41 E. Except for this well, information is not available to determine their thicknesses elsewhere.

Potential Resources

Potential resources of 23 billion short tons of coal are estimated for nine coal beds presumed to be fairly widespread in the Northern Cheyenne Indian Reservation, as shown on [Figure 6](#) and [Table 4](#). The estimates are based on extremely limited information about the thickness and distribution of the coal, and, therefore, are subject to correction as more information from private drilling and other sources becomes available. Coal beds other than the ones listed on [Table 4](#) are known to be present on the reservation. Most of them are probably thinner than the nine beds for which resources are calculated. In the aggregate, the thinner beds constitute an appreciable additional resource.

No differentiation of resources is made according to depth, but perhaps 5 percent of the coal is at depths shallow enough for stripping. However, Rawlins (1974, p. 86) has estimated there is 10 billion tons of surface-minable coal on the Crow and Northern Cheyenne reservation. Perhaps 5-6 billion tons of this can be assigned to the Northern Cheyenne reservation.

TABLE 4
Potential Coal Resources in Nine Principal Coal Beds, Northern Cheyenne Indian Reservation
(1,700 short tons of coal per acre foot)

Bed	Area (acres)	Average thickness (feet)	Short tons (billions)
Knoblock	180,000	28	8.9
Rosebud	125,000	9	2.0
McKay	70,000	8	1.0
Robinson	5,000	7	.1
Sawyer	83,000	13	1.9
E	7,000	8	.1
Wall	140,000	30	5.5
Brewster-Arnold	98,000	11	1.9
Canyon	54,000	20	1.9
Total (rounded)			23

TABLE 7
Major Oxide Composition (In Percent) of the Ash of Coal Samples from the Vicinity of the Northern Cheyenne Indian Reservation

Bed name, location	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	P ₂ O ₅	SiO ₂	SO ₃	TiO ₂	Source of data
Roland T.8-9S., R.39E.	15.6	22.8	7.2	0.7	8.2	1.0	1.1	28.3	12.9	0.7	1
Anderson T.7S., R.39E.	11.9	17.6	5.5	.8	4.6	5.2	.4	40.9	10.6	.9	1
Wall T.6S., R.41E.	14.4	12.7	7.8	.5	3.9	3.8	.3	42.0	10.9	.9	1
D T.9S., R.38E.	18.4	8.5	6.5	1.9	5.9	1.2	-	41.8	-	.9	2
G T.9S., R.38E.	13.0	20.5	4.7	.6	8.0	4.0	-	31.9	-	.9	2
M T.9S., R.38E.	15.9	23.8	4.3	.6	7.9	2.7	-	26.4	-	1.2	2
Knoblock T.1S., R.43E.	17.0	17.0	5.2	.4	5.0	.3	.3	37.2	11.2	.8	1
Rosebud T.1S., R.43E.	16.0	11.0	17.8	1.0	3.4	.7	.5	35.6	10.1	.5	1

Sources of data:

1. Calculated average sample from Matson and Blumer, 1973, p. 27, 36, 41 and 125.
2. Average sample, Shell Oil Co.

Coal Characteristics

Trace Elements.--Coal contains a large number of elements the less volatile of which are concentrated several-fold in the ash of the coal as a result of burning. Representative analyses showing the content of 31 trace elements and 9 major oxides in coal beds in the vicinity of the Northern Cheyenne Indian Reservation are given in [Table 5](#), [Table 6](#), and [Table 7](#). The analyses illustrate the variability that can be expected in coals from different beds in the Fort Union Formation, or from the same bed at different places. The potential enrichment of trace elements for the samples listed in [Table 5](#), [Table 6](#), and [Table 7](#) ranges from 21 times (sample D161320 containing 4.74 percent ash) to 1.2 times (sample D160981 containing 84.9 percent ash). Assuming the maximum enrichment, coal ash would be a submarginal source of supply for trace elements for typical coals in the Tongue River Member.

Rank.--Coal in the Tongue River Member of the Fort Union Formation increases in rank from lignite in North Dakota to subbituminous B in southern Rosebud County, Montana, and northern Wyoming. The rank of the coal on the reservation is typically subbituminous C. Coals of this rank contain a high moisture content, have heat values ranging from 8300 to 9500 Btu's per pound on a mineral matter free basis and are nonagglomerating and noncoking.

Analyses of the coals on the reservation and surrounding areas are listed in [Table 8](#). A partial analysis of the Knoblock bed from the Cheyenne Meadows field indicates an ash content of 4.1 percent, sulfur content of 0.4 percent, and a heating value of 8,400 Btu's per pound (Rawlins, 1973, p. 121).

Subbituminous coals from Montana have a much higher moisture content and lower heat values than bituminous coals that are mined in eastern and central United States. These detrimental qualities tend to be mitigated by the low sulfur content and low ash content of Montana subbituminous coals.

Subbituminous coal tends to disintegrate or slack on exposure to the weather, particularly when alternately wetted and dried or exposed to hot sunshine. Also, reactive coals, such as subbituminous coals, tend to heat due to oxidation, and if the heat accumulates can result in spontaneous combustion. As a consequence, subbituminous coal cannot be stored in large piles for long periods of time.

Some of the coal beds on the reservation may contain a high sulfur content. Fortunately, these beds are in the minority. The McKay bed is an example of high sulfur coal. The average sulfur content of six drill cores of the McKay bed in the Colstrip area is 1.50 percent (Matson and Blumer, 1973, p. 78, 80). Some of the coal beds contain partings and inclusions with a high ash content as well as a high sulfur content; these are the Dietz No. 1, Wall, and Canyon beds in the southwestern part of the reservation (Matson and Blumer, 1973, p. 34, 35, 38-40). The sulfur contained in these partings is normally pyrite, but occasionally there is much sulfur in organic form.

TABLE 8
 Analyses of Coal from Mines on the Northern Cheyenne Indian Reservation

Sample	Form of analyses	Moist.	Volatile matter	Fixed carbon	Ash	Sulfur	Air dry loss	Heating val. (Btu)
Soldier Gulch stoker ¼" to 1½" 9/25/65	A	27.8	28.9	38.9	4.4	0.4	15.4	8,760
	B		40.1	53.8	6.1	.6		12,130
	C		42.7	57.3		.6		12,920
Soldier Gulch lump +1½" 9/25/65	A	27.7	29.6	39.2	3.5	.4	16.4	8,870
	B		40.9	46.9	4.9	.6		12,270
	C		43.0	54.2		.6		12,890
Alderson Gulch D-51574	A	28.7	27.5	39.6	4.2	.3	15.0	8,630
	B		38.6	55.5	5.9	.5		12,100
	C		41.1	58.9		.5		12,860
Busby School mine	A	16.3	33.8	44.9	5.0	.4		9,570
	B		40.4	53.6	6.0	.5		11,430
	C		42.9	57.1		.5		12,160
Typical coal on reservation	A	25	35	45	7	.5		8,600

A - Sample as received

B - Sample air-dried

C - Sample moisture and ash free

Preparation.--Modern coal preparation techniques can lower the ash content of run-of-mine coal by removing rock dilutants. These include shale partings, sandstone inclusions, pyrite lenses, sulfur balls, and other high density materials. Little information of the cleaning characteristics of Montana coal have been reported. Geer and Yancey (1955, p. 44) report that removal of impurities heavier than 1.60 specific gravity from a sample of the Rosebud bed at Colstrip reduced the ash content from 10.5 to 8.8 percent and the sulfur content from 0.75 percent to 0.56 percent. Their

results are probably typical of the performance that can be expected by mechanically cleaning similar coals on the reservation.

Neither finely-disseminated pyrite nor organic sulfur can be removed by mechanical cleaning. Although the sulfur content of the coal beds in the reservation area are normally low, a large proportion of this sulfur is commonly in organic form. The ratio of organic sulfur to pyritic sulfur is typically about 3 or 4 to 1. Organic sulfur can be removed from coal by a process that was recently developed by the Mineral Research and Explora-

tion Institute of Turkey (Abelson, 1975 p. 793). In this process, the coal is briefly heated to 400°C. and compressed. Considerable water and most of the organic sulfur is driven off, and the end product is a solid briquette. Although the process was developed specifically for upgrading lignite, it probably would be applicable to the subbituminous coals on the reservation.

Mining Methods

Mining methods that are applicable for coal mining are surface mining and underground mining. Although it is not intended here to discuss these mining methods in detail, some of the more important aspects, as applied to future coal mining on the reservation, will be covered.

Surface Mining.--Surface mining, specifically the area method, dominates coal mining activity in eastern Montana. This situation is likely to continue in the immediate future as surface mining has been described "as the only truly economic method of large-volume production of low rank coal" (Groff, 1968, p. 43). Consequently, the exploration activities of the Montana Bureau of Mines and Geology as well as private companies are directed entirely to locating and evaluating coal deposits under a limited amount of overburden. For example, the Montana Bureau of Mines and Geology classifies coal fields according to overburden thicknesses of 0-50, 50-100, 100-150, 150-200, and 200-250 feet. Where the coal is less than 10 feet thick, a limit of 100 feet is assigned as the maximum overburden. Other limits are 150 feet of overburden where the coal is 10 to 25 feet thick,

200 feet of overburden where the coal is 25 to 40 feet thick, and 250 feet of overburden where the coal is more than 40 feet thick. The Bureau of Mines classifies coal reserves suitable for surface mining according to the following criteria:

1. minimum coal bed thickness of 5 feet.
2. overburden ranging between a maximum of 60 to 200 feet.
3. stripping ratio between 1.5 to 1 and 10 to 1.

Initial exploration activities on the reservation should be centered around the location of coal deposits that satisfy the above criteria and therefore will be suitable for surface mining.

Surface mining may be subdivided into five separate categories. These are open pit, contour surface, area surface, auger, and surface longwall. Open pit surface mining, which is used for mining low-grade copper deposits in the western United States, is not usually applicable for coal mining. Contour surface mining is applicable to steep hillside topography. Although coal is mined extensively by the contour surface method in the eastern United States, it will have little application on the reservation. The gently rolling and relatively flat topography on the reservation is suitable for area surface mining and will be by far the most important for its mining coal.

At an area surface coal mine, the overburden is drilled and broken by explosives. The overburden is removed by draglines and/or power shovels and deposited in an adjacent cut where the coal has been removed. Next, the exposed coal is drilled and blasted. The coal is then loaded by power shovels or front end loaders into trucks and hauled

to a processing plant. Here the coal is crushed and loaded into unit trains for shipment.

About one-half of the present coal production in the United States is mined by surface methods. There are at present five large-production coal mines in eastern Montana; all are area surface mines. Four of these are in the reservation area -- one near Decker to the south of the reservation, one at Sarpy Creek to the northwest, and two near Colstrip northeast of the reservation. Surface coal mining on the reservation would probably duplicate the successful practices that are followed at these mines. The coal production for Montana in 1975 is expected to be about 19.8 million tons -- nearly all from surface mines. Production is expected to increase to 41.0 million tons per year by 1980, and the number of surface coal mines is expected to increase to nine (Glass, 1974, p. 19, 20).

Water will be required at a surface coal mine for sprinkling, fire protection, domestic and sanitary uses. About 5,000 gallons per day will be adequate to supply the domestic and sanitary requirements of a large surface mine (National

Academy of Sciences, 1974, p. 42). Water quantity necessary for road sprinkling will depend on the weather and length of road networks. Water required for all purposes may range from 90,000 to 250,000 gallons per day (Final environmental statement, Crow ceded area lease, Westmorland resources mining proposal, 1974, p. 16).

Necessary capital investment and operating costs have been estimated by the Bureau of Mines for a surface coal mine in the northern Great Plains with an annual production of 9.2 million tons (Katell and Hemingway, 1974a). This study assumed a 25-foot coal bed, an average overburden thickness of 70 feet, and an operating life of 20 years. Assuming a 90 percent recovery, annual acreage required would be 231. A summary of the required capital investment, operating costs, and selling price of the coal by annual output capacity is given in Table 9. About 213 employees would be required to operate the mine. Costs for wages and union welfare are those in effect as of May 12, 1974. Costs for material and equipment are based on 1973 and early 1974 cost indexes.

TABLE 9
 Summary of Capital Investment and Operating Costs for an Open Pit Coal Mine -- Annual Production
 9.2 Million Tons (Katell et Al, 1974a).

Estimated initial capital investment	\$29,871,000	
Estimated deferred capital investment	\$26,415,000	
Total capital investment	\$56,286,000	
Capital investment per ton of production		\$6.12
Operating cost per year	\$20,914,400	
Operating cost per ton of production		\$2.27
Selling price per ton (12% discounted cash flow)		\$2.66

The Bureau of Mines study indicates a coal selling price of \$2.66 per ton. The average selling price for Montana coal at the point of shipment was \$2.20 per ton in 1973 which compares favorably with an average of \$8.12 per ton for the United States as a whole. The price of Montana coal must be kept well below the national average to offset the high transportation costs to distant markets. Capital costs, operating costs, and consequently the price of coal have risen rapidly in the last few years. For example, a short term contract with the TVA in 1975 to furnish 450,000 tons of coal from Colstrip was at a contract price of \$5.00 per ton (Mining Congress Journal, 1975a, p. 5). The delivered price to western Kentucky of \$19.00 a ton illustrates the relatively high shipping cost compared to selling price at the mine.

Auger mining, which is a variety of surface mining, has gained wide use in the eastern coal province. In this type of mining, an auger machine bores horizontal holes in the exposed coal at the highwall of an open pit mine. The holes are 21 to 96 inches in diameter and up to 250 feet deep. This type of mining is confined almost entirely to outcrop coal and highwalls of contour surface mines on steep slopes. Capital costs are low and productivity is high, but recovery is low, i.e. a maximum of about 50 to 60 percent. This type of surface mining will have little application on the reservation because little or no steep slope surface mining is likely. However, auger mining could be used on the highwall of the last cut of an area type surface mine and might find application in some especially favorable areas. For example, Matson and Blumer (1973, p. 33) mention coal beds that are exposed in the valleys of Rosebud Creek and

its tributaries in the southwestern part of the reservation. Auger mining may be applicable in these areas, but large-scale production from auger mining on the reservation is unlikely.

Underground Mining.--Most of the coal that has been mined in the United States has been mined by underground methods--specifically the room and pillar method. In the room and pillar method, the mine is divided into rooms from which the coal is extracted and pillars which are left to support the mine roof. Coal recovery is only about 55 percent. Coal beds from about 28 inches thick to about 10 feet thick have been mined by the room and pillar method. Thus, from a strictly extraction standpoint, the coal beds on the reservation that are from about 28 inches thick to about 10 feet thick could be mined by conventional coal mining techniques that are based on the room and pillar method. Room and pillar mining of thicker beds may be possible by using techniques that have been successful in thick bedded deposits of materials other than coal. Large-scale mining by the room and pillar method, however, would require the opening of large underground areas. These areas must be ventilated in gassy mines to prevent the accumulation of explosive gas. Under these conditions, reactive subbituminous coal is susceptible to spontaneous combustion. Also, sealing off worked-out areas in non-gassy mines has not been successful in preventing spontaneous combustion. Consequently, coal beds on the reservation cannot be safely mined on a large-scale by room and pillar methods.

Coal is also mined by the longwall method. In the retreating longwall method, entries are driven

into the coal bed so as to divide the coal into panels that are about 450 feet wide. These panels are then mined by a machine that slices the coal from the 450 feet working face. The coal falls onto a conveyor that carries it to one of the entries. As the coal is removed, the mining machine, conveyor, and powered roof support move forward allowing the roof to cave behind the roof supports. An advantage of the retreating longwall method is that recovery is about 90 percent. Still, about 10 percent of the coal remains in worked-out areas and would be susceptible to spontaneous combustion.

The advancing longwall method is commonly used to mine coal in Europe. In this method, the longwall face is simply advanced through the coal bed. Haulage ways and ventilation ways are constructed from rock packwalls as the longwall face advances. Coal recovery is almost 100 percent. This method is now being tried experimentally in a deep gassy mine in Colorado. The roof supports for the haulage ways and ventilation ways are being constructed from high early strength concrete rather than rock packwalls. This mining system, though still unproven, appears at the present time to offer the most promise for underground coal mining on the reservation, although mining would be confined to beds less than 10 feet thick, since this is the maximum height of currently available roof supports.

Several methods have been developed in Europe for mining coal beds that are thicker than 10 feet. In a common mining method, slices of the coal bed are mined by the longwall method. These slices of coal are roof to floor. In the United Kingdom, the first slice is mined while advancing and

the second slice while retreating. In Poland, slices are worked two at a time advancing and the next two retreating; the horizontal offset between slices is 100 feet. In other countries, all of the slices are removed by the longwall retreating method. The horizontal offset between slices is 65 to 100 feet in Yugoslavia and Czechoslovakia, 200 feet in Romania, and 260 to 500 feet in U.S.S.R. (Symposium on the methods of working thick coal seams, 1966, p. 9, v. 1)

Unfortunately, mechanization of the slicing system for mining thick coal beds has been difficult. Also, the vertical enlargement of entries for haulage and ventilation from one lift to another is costly. As a consequence, a longwall mining with sublevel caving system is being developed for mining thick coal beds in France (Coates, D. F., Cochrane, T. S., and Ellis, G., 1972, p. 72-74). In this mining system, a horizontal slice is mined at the base of the coal bed by the conventional longwall method (Figure 7). A double drum shearing machine cuts coal from the face, and this coal is removed with a face conveyor. The immediate roof is supported by walking hydraulic roof supports. The remainder of the overlying coal is broken by pressure and movement of the overlying strata. This coal falls onto a conveyor at the rear of the roof supports. Water is infused into the coal before mining to reduce dust and prevent the accumulation of heat that could lead to spontaneous combustion. At the present time, efforts are being directed to completely mechanize the removal of the caved coal and to improving the roof support system.

Where it is necessary to prevent surface subsidence or there is danger of fire in the mine, a

common European practice is to backfill worked-out areas with noncombustible material such as crushed or ground rock. Backfilling may be necessary during underground coal mining on the reservation if the danger from spontaneous combustion in the mine is significant. Furthermore, mining without backfilling may cause overlying unmined coal beds to fracture because of nonuniform subsidence. Air could enter these fractures and result in spontaneous combustion of the overlying coal beds. If backfilling is necessary for these reasons, a substantial additional expense will be added to the cost of underground mining.

The surface longwall method is now being developed in West Virginia as an alternative to contour surface mining. A narrow cut is opened parallel to the coal outcrop. An entry is then driven about 250 feet into the coal bed. A side of the entry is the longwall face which is mined with conventional longwall equipment. The surface longwall method may be applicable to coal outcrops that are exposed on the sides of steep ravines and gullies.

Other underground mining systems will no doubt be devised to safely mine reactive coals and thick beds, as more attention is given to the unique problems associated with mining western coals. It is important to note, however, that even with a proven underground mining system, the cost of underground mining would be much higher than the cost of surface mining. For example, recent cost estimates indicate that coal from an underground mine would cost about three times as much as coal from a surface mine (Katell and Hemingway, 1974a, p. 5; 1974b, p. 4). Therefore, at the present time, coal on the reservation cannot be

mined by underground methods because of technical as well as economic limitations.

Markets

Electrical Power Generation.--The largest market for reservation coal in the immediate future will be for electrical power generation. Generally, contracts for the sale of coal to electrical power plants specify limits on the moisture, ash, and sulfur contents; penalties are assessed for exceeding specified limits. Similarly, a minimum heat content is specified. The quality of subbituminous coal can be upgraded, if necessary, by removing some of the moisture content with thermal dryers (Paulson and others, 1974, p. 53). Also, the ash and sulfur contents can usually be reduced and the heat content increased by mechanical cleaning as mentioned previously. However, most subbituminous coal is sold as crushed run-of-mine coal that has not received any further upgrading, and the price at the point of shipment is adjusted accordingly.

Additional parameters of importance to coal combustion in power plants are related to the ash composition. The composition of coal ash determines its fusion characteristics. In pulverized coal firing, the ash fusion characteristics determine whether the ash can be removed in either the liquid or dry form, and the furnace is designed accordingly. Therefore, coal from different sources cannot be indiscriminately fired in a given furnace because of possible incorrect ash fusion characteristics for some of the coals. Coal with an ash softening temperature above 2600°F., for example, cannot be used in cyclone furnaces (Spicer and

Leonard, 1968, p. 3-22). Consequently, limits on ash softening temperature are sometimes specified which, in turn, could be a limiting factor for the sale of some of the reservation coals.

Each boiler manufacturer through experience has developed empirical methods for evaluating coal ash fluidity characteristics. These methods have not been standardized between manufacturers. They commonly depend on the amount of bases and acids in the ash. The bases are Fe_2O_3 , CaO , MgO , Na_2O , K_2O ; the acids are SiO_2 , Al_2O_3 , and TiO_2 .

Most efficient modern power plants are designed to operate with steam temperatures about 1000°F. This recent development has caused a new type of fouling deposit to occasionally form on the boiler tubes. The source of these deposits are some sodium and potassium compounds in the coal, particularly the chlorides, which decompose in the flame, are vaporized, and combine with SO_3 . These alkali or alkali-iron sulfates then condense on the boiler tubes. Coal ashes containing 2-5 percent Na_2O are considered medium fouling for Western coals; higher Na_2O contents may cause severe fouling (Winegartner and Ubbens, 1974, p. 6). Some boiler manufacturers, recognizing that most of the alkali associated with fouling problems is in the form of chlorides, evaluate fouling potential by noting the total chlorine content in the coal. Matson and Blumer (1973) report high alkali contents ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) in the coal ash from some of the coal beds near the reservation. These coals could cause severe fouling problems in a modern high temperature steam power plant. Presumably, coals with a similar high alkali content will also be found on the reservation.

A physical property of coal that is important for pulverized coal firing in power plants is grindability. Grindability is a composite physical property that is dependent on other specific properties such as hardness, toughness, strength, tenacity, and fracture. Grindability is presently measured by the Hargrove Grindability Test which is a standard test of the American Society for Testing and Materials. The Hargrove grindability of Rosebud coal from Sarpy Creek is 56. A grindability of this magnitude is about average for American coals and probably also represents the grindability of most reservation coals.

Summarizing then, coal specifications for power plant use include the usual properties such as moisture, ash, sulfur, and heat content. Also of importance are the softening temperature as well as the initial deformation temperature and fluid temperature of the ash. Ash fluidity characteristics are often evaluated by analyzing the ash for acids and bases. Fouling characteristics are dependent on the alkali and chlorine contents. The grindability index is helpful in evaluating the ease of grinding the coal for pulverized fuel firing. The important point to note here is that all of these parameters should be determined in any future investigations of reservation coals.

Metallurgical Applications.--A resource investigation by the Bureau of Mines has established that substantial iron ore reserves are present in southwestern Montana (Roby and Kingston, 1966, p. 63). Although the iron ore is of low-grade, this investigation indicated that the iron ore could be upgraded to satisfy industry requirements. Due largely to recent uncertainties in foreign supplies of

mineral raw materials, it has been reported that a "billion-dollar iron rush is taking place in the United States" (Sastry, 1975, p. 60). Coal from the reservation could play an important role in supporting an industry that is related to Montana iron ore deposits.

Upgraded iron ore from the Montana deposits could be agglomerated to form pellets. It is interesting to note that the annual growth rate of the iron ore pelletizing industry in the United States is about 15 percent. Large quantities of natural gas and fuel oil are currently being used in pelletizing plants, but decreasing supplies and higher costs of these fuels have directed attention to coal as an alternate fuel. Coal firing for pelletizing plants is now being investigated by the Bureau of Mines at the Twin Cities Metallurgy Research Center. Preliminary results indicate that 75 pounds of subbituminous coal per ton of pellets are required for induration (Sastry, 1975, p. 60).

Almost all iron production in the United States is the result of iron ore reduction in blast furnaces using coke as the fuel. Normally, coal is formed into coke and then charged into blast furnaces. Unfortunately, reservation coals are non-coking, and therefore cannot be used in the usual manner. However, there are processes for making suitable fuels for blast furnaces from noncoking coal. One of these is the Formcoke process developed by FMC (Food Machinery Corp.). Three thousand tons of 1½-inch briquettes of Formcoke have been tested in a blast furnace. Results of a 6-day long run were reported to be highly satisfactory (Corriveau, 1974, p. 86).

Direct reduction of iron ore is gaining increased attention as a method for producing iron

from iron ore. Nearly 4 million tons per year of sponge iron are produced by direct reduction in North America, and demand might reach 27 million tons per year in 10 years (Sastry, 1975, p. 60). United States capacity is about 1 million tons per year. These direct reduction plants are now fueled with natural gas or fuel oil. In view of the shortages and escalation costs of these fuels, solid fuels derived from coal may soon be favored for direct reduction of iron ore. There have been in the past some failures of solid fuel direct reduction facilities, but at the present time a number of solid fuel plants are operating successfully (Greenwalt, 1974, p. 70). Two direct reduction processes which use coal are the Stelco-Lurgi-Republic Steel-National Lead (SLRN) and the Krupp. In addition, Allis Chalmers has developed a small production unit which uses a combination of coal, gas, and oil.

The eventual development of Montana's iron ore resources appears promising. This, in turn, is likely to result in additional markets for Montana coal, and coal from the reservation should contribute significantly to supplying this market.

Gasification.--Natural gas is one of the cheapest and most convenient fossil fuels. In addition, the heat value is high, and natural gas is virtually non-polluting. These attributes have caused the consumption of natural gas to grow at a rate of 5.4 percent per year between 1947 and 1971 compared with a rate of 3.1 percent per year for total energy consumption. The rising consumption of natural gas has taxed present sources to supply the demand. For example, many distributors will not accept new customers, and cold weather restrictions for industrial users are becoming more

common. Furthermore, discoveries of additional reserves of natural gas have not matched consumption in any year since 1966, and the reserve position continues to deteriorate (Weir, 1973, p. 24). The widening gap in the supply demand situation for natural gas, which is expected to reach 6 trillion cubic feet annually by 1985 (Osborn, 1974a, p. 33), has caused an increased interest in the gasification of coal to produce synthetic natural gas.

At the present time, gasification by the Lurgi method is favored for commercial application. In a Lurgi gasifier, coal sized 1½-inch by ¾-inch enters the pressurized reactor through a lock hopper at the top. Oxygen and steam are injected at the bottom. The steam serves as a source of hydrogen for the gas. The gas from the reactor next undergoes a catalytic shift conversion in which steam reacts with carbon monoxide to give the desired hydrogen/carbon monoxide ratio. The gas is then purified. This gas has a low heating value but can be upgraded by a methanation process to yield a pipeline gas with about 1000 Btu's per cubic foot.

The El Paso Natural Gas Co. has announced plans to build a coal gasification plant in New Mexico using the Lurgi process to produce 250 million cubic feet of gas per day. Originally, the plant was estimated to cost \$250 million (Maugh, 1972, p. 44). In the fall of 1973, the cost of the plant was estimated to have increased to over \$400 million (Perry, 1974, p. 25). To offset the high capital costs of coal gasification plants, it is essential that low cost coal is available. Coal mined on the reservation by surface method. can meet this requirement. Also, subbituminous coals are particularly suitable for gasification because they are

non-agglomerating, and they are more reactive than bituminous coals. In addition, the coals on the reservation can easily meet the ash requirements for the Lurgi process, (under 30 percent), although some blending may be necessary to insure a uniform feed.

A capacity of 250 million cubic feet of gas per day is about the minimum economic size of a coal gasification plant. Considering a subbituminous coal of 8500 Btu's per pound, the coal requirement will be about 9.4 million tons per year (Weir, 1973, p. 24). Assuming a 30-year plant life, the quantity of coal required would be 282 million tons. The coal reserves on the reservation are sufficient to supply coal quantities of this magnitude.

Several so-called second generation coal gasification processes are currently under development. Among these are the Synthane process, developed by the Bureau of Mines, and Hygas process, developed by the Institute of Gas Technology, the Bi-gas process, developed by Bituminous Coal Research, and the CO₂ acceptor process developed by the Consolidation Coal Co. The latter process is of special interest as it is being developed to gasify subbituminous coal and lignite. Which of these processes will be the most economical for commercial use will not be known for 2 or 3 years. Capital costs, maintenance costs, and operating costs will be lower for the second generation gasification plants than for the Lurgi plants. The main reason for this is that the Lurgi gasifier is a low pressure unit with a very small capacity. Therefore, a 250-million cubic foot per day coal gasification plant requires 31 gasifiers; whereas, a second generation plant would require only two or three (Maugh, 1972, p. 45).

Selling price of gas from second generation coal gasification plants can only be estimated because it is based on costs, as well as other factors, which can only be estimated at this time. These would include additional development costs, design costs, coal costs, labor costs, environmental and pollution costs, equipment costs, and changing government policies. Also, markets and the selling prices for byproducts such as tars, oils, and sulfur that are produced in the gasification processes are unknown. Nevertheless, an estimate of the cost of a coal gasification plant producing synthetic natural gas in 1974 dollars with an output of 250 million cubic feet daily is about \$300 million, and the gas cost is estimated at \$1.50 per thousand cubic feet or per million Btu's (Osborn, September 1974b, p. 479). Other estimates are as low as \$.94 per million Btu's (Coal Age, 1974, p. 86, 87). By 1985, five Lurgi coal gasification plants and 11 second generation coal gasification plants are projected to be in operation, but these will supply only about 7 percent of the demand for gas at that time (Osborn, 1974a, p. 33). If this projection proves to be accurate, coal gasification plants could provide an important market for reservation coal.

Underground or in situ gasification of coal may be applicable to some of the coal beds on the reservation. The Bureau of Mines conducted underground gasification experiments in Alabama during the 1940's and 1950's, but these experiments were discontinued because of the low quality of the gas as well as other problems. New advances in technology may offer solutions to the previously encountered difficulties. For example, oxygen can now be produced at a much lower cost.

Use of oxygen in the gasification process, rather than air, would greatly increase the quality of the gas, as nitrogen dilution would be eliminated. Also, improvements have been made in hydraulic or fracturing with explosives, and directional drilling. Because of these recent developments, the Bureau of Mines has activated its underground gasification project which is now active near Hanna, Wyoming.

In a commercial underground coal gasification project, boreholes would be drilled from the surface into the coal bed. The boreholes would be linked by directional drilling, but lasers have recently been proposed for this purpose (Perry, 1974, p. 25). The coal would then be fractured hydraulically or by explosives. Next, the coal would be ignited. Oxygen and possibly steam would be injected down one borehole and gas removed from another. When the coal between the boreholes was depleted, the process would be transferred to another borehole couple.

An advantage of underground gasification is that a clean fuel can be produced. The heat content of the gas is low, but the gas can be used near the gasification site for electrical power generation and industrial uses or upgraded to the quality of natural gas. Underground mining is eliminated, along with its low productivity and health and safety problems; surface mining is eliminated along with its environmental concerns. Hence, underground gasification in its final developed form will be a cheap method for extracting energy from coal beds. The most attractive sites will be in deep, thick beds in which techniques for underground mining have not yet been developed (Abelson, 1973). Several coal beds on the reservation are in this category.

Underground gasification sites will be restricted to areas where the roof of the coal bed is impermeable to gas (Hucka and Das, 1973, p. 50). There may be problems with subsidence. Techniques for insuring a uniform flow and quality of the gas have not been established. Contamination of groundwater may be a problem. The solutions to these problems are dependent on additional research and development. Nevertheless, underground gasification may offer a solution to the recovery of a large part of the coal resources on the reservation, especially since a large part of the coal cannot be mined by using present day technology.

Synthetic Natural Gas and Liquid Fuels.-- Large-scale conversion of coal to synthetic liquid fuels has been an attractive possibility for many years. The high point in coal conversion to synthetic liquid fuels with regard to both rapid technology advances as well as production was reached in Germany during World War II. Two processes were developed--the Bergius process, which is a hydrogenation process, and the Fischer-Tropsch gas synthesis process. A commercial size synthetic liquid fuels plant is presently operating in South Africa using 13 Lurgi coal gasifiers to provide synthesis gas for the production of 5,000 barrels of gasoline per day. A recent report by the Federal Energy Administration concluded that the Fischer-Tropsch liquefaction process in its existing form is uneconomical and should not be widely deployed (Gillette, 1974, p. 718).

Most of the coal conversion research in the United States is being directed toward improving hydrogenation processes. The Synthoil process, under development by the Bureau of Mines, is a

hydrogenation process that shows considerable promise for economically producing synthetic liquid fuels from coal. In the Synthoil process, coal in a carrier oil is brought into contact with a catalyst under high temperature and pressure. Hydrogen is introduced into the reactor, and the resulting reaction produces more oil. Although the process was originally designed to produce a clean boiler fuel, it is readily adaptable to the production of diesel oil and gasoline. A pilot plant is now being built which will produce about 1,000 gallons of oil from 8 tons of coal per day (Mining Congress Journal, 1975b, p. 7). Commercial plants are envisioned which will produce 3-4 million gallons of Synthoil daily from 20,000 - 30,000 tons of coal per day.

Coals with a high hydrogen content are best for use in the Synthoil process as well as other hydrogenation processes because the cost of reacting additional hydrogen with the coal is reduced. Thus, high volatile bituminous coals are preferred. As a consequence, future synthetic liquid fuel plants using hydrogenation processes will not use low rank coals such as those found on the reservation. Mainly because of low cost subbituminous coal can be used, research is continuing on gas synthesis processes. Significant progress in gas synthesis technology could drastically change the synthetic liquid fuel picture and result in a substantial market for reservation coal.

Transportation

The amount of coal needed for the present number of local markets on the reservation is small. Markets include domestic heating, use by

farmers and ranches, and other light industry. If large-scale mines are developed on the reservation, the energy contained in the coal will be utilized in distant markets. There are two ways these distant markets can be supplied. First, the coal would be simply shipped to distant markets; the most likely transportation method would be by unit trains, but slurry pipelines are a possibility. Second, the coal could be converted near the mine site to a different form of energy such as electrical power, gas, or liquid fuels and these, in turn, transported to distant markets.

Unit Trains.--Unit trains consist of special purpose rail haulage equipment that is specially designed to transport coal over large distances.

Unit trains are loaded at the mine site, travel over existing rail lines to specific destinations, are unloaded, and return directly back to the mine site--all on a predetermined schedule. Storage and loading facilities at the mine are required that are capable of loading 10,000-ton unit trains in only a few hours. The large economies achieved by unit trains transportation over conventional rail transportation are largely the result of three principal factors: design efficiency, equipment balance, and intensive use (Glover and others, 1970, p. 1). Except for the cost of spur lines to the mine site, unit trains have an enormous advantage over other transportation systems because they use existing rail lines. Thus, capital costs are relatively low, and lead time between the planning stages and full-scale operation is minimized. The cost of transporting coal with unit trains has been reported to be 0.5 cents per ton mile (Wasp, 1969, p. 76).

Unit trains are currently used to transport all of the coal from the five large-scale mines in eastern Montana. All of this coal is used for electrical power generation. Surface mining along with unit trains transportation to distant markets, particularly for electrical power generation, appears at this time to be the most viable combination for developing the coal resources on the reservation.

Slurry Pipelines.--The other alternative to unit trains transportation of coal to distant markets is transportation by slurry pipeline. In this method, the coal is crushed and ground to an extremely fine size, water is added, and the resultant slurry is pumped through pipelines. Advantages are those of a continuous transportation system, and low labor costs. A slurry pipeline was constructed to transport coal from a mine in southern Ohio to a power plant near Cleveland, Ohio, but operation of this pipeline was discontinued because of competition from rail transportation. A 273-mile 18-inch pipeline is now in operation in Arizona transporting coal from a surface mine to a power plant. The coal is ground to 325 mesh and mixed with water at an equal ratio of coal to water by weight. About 3,200 acre-feet of water are required per year (Coal Age, 1971a, p. 82). This slurry pipeline represents an application of current pipeline technology and indicates that slurry pipelines are feasible for transporting coal in certain specific applications such as over rugged terrain (Coal Age, 1971b, p. 151).

The transportation of (coal by slurry pipelines, however, does present some problems. Although some studies have reported slurry pipelines in a favorable light (Wasp, 1969, p. 73-75), others have

indicated that the cheapest way to move large volumes of coal over large distances on land is by unit trains and not by slurry pipelines (Zachar and Gilbert, 1968, p. 5-8).

An additional problem is supplying the water that serves as the transporting medium. The problem has been emphasized by the recent opposition that has developed over the proposed Wyoming-Arkansas slurry pipeline. This pipeline would require 15,000 acre feet of water per year which is a large quantity of water (sufficient for a city of nearly 100,000 people) to be supplied by a semi-arid region.

The slurry, after partial dewatering, can be conveniently fired under boilers (Duzy, 1967, p. 60-63) but with a necessarily reduced boiler efficiency that is due largely to the heat required to evaporate the water in the coal slurry. Slurry pipelines may find applications for transporting coal over rough terrain where adequate water is available, but unit trains appear at this time to be the best method for transporting reservation coal over large distances.

Electrical Power.--Mine site electrical power generation coupled with extra high voltage transmission is a possible system for utilizing reservation coal. Included are electrical power plants that are located at convenient water sources such as lakes or dams but are nevertheless close to the mines that supply coal. Mine site electrical power generation has gained wide acceptance as a means of utilizing western coal in Wyoming and Arizona. The economic and technical considerations for building mine site power plants in Montana are similar but not identical.

Considerations related to coal for electrical power generation have been discussed previously, but mine site power generation creates additional problems that must be considered. Foremost among these is the provision for an adequate water supply. A 1,000 megawatt coal fired electrical generating plant will require about 2.5 million tons of coal and about 20,000 acre feet of water annually. This water requirement assumes the plant operates at full load and uses an evaporative cooling tower. If a cooling pond such as a lake or dam is used, the water requirement is reduced to 12,000 acre feet per year. Water requirements can be further reduced to 2,000 acre feet per year with a dry cooling tower. Dry cooling towers, which are similar in principal to an automobile radiator, are attractive for use in arid and semiarid regions because of their low water requirements. Most dry cooling towers are outside the United States and at electrical generating plants of relatively small size, i.e., 250,000 kilowatts or less. Dry cooling towers are very costly. For example, a natural draft dry cooling tower for an 800 megawatt coal fired plant costs about \$31.2 million, but a natural draft wet tower costs only \$9 million (Woodson, 1971, p. 77). Thus, there is considerable economic incentive to locate electrical power plants at sites where relatively large supplies of cooling water are available.

Bottom ash and especially fly ash from electrical generating plants have many industrial markets. The increased interest in recent years toward recycling waste materials has caused much more attention to be directed toward expanding these markets. The best known uses for fly ash are cement manufacture, concrete construction, con-

crete products, filler material in tile, rubber, paint, putty, soil amendments, plant-growth stimulants, soil stabilization, abrasives, mineral filler in asphalt, lightweight aggregate, water purification, oil well cementing and grouting, and a filtering medium for water and other fluids (Quilici, 1973, p. 5). The Coal Research Bureau of West Virginia University has developed a process for making bricks from both fly ash and bottom ash. The Bureau of Mines is conducting research using fly ash to prevent drainage pollution from surface mines. Probably the most promising use for large quantities of fly ash is an admixture to concrete. The fly ash admixture gives concrete a lower weight and superior strength. Fly ash admixtures are used extensively in many foreign countries.

In 1972, total ash production in the United States was 46.2 million tons, but overall utilization was only 7.5 million tons. At the present time, then, ash production greatly exceeds demand. Consequently, in view of the lack of probable markets near the reservation, fly ash from mine site electrical power plants will present a disposal problem instead of a salable byproduct. Fortunately, both fly ash and bottom ash can be conveniently buried along with spoil at surface mines.

Synthetic Natural Gas and Synthetic Liquid Fuels.--One of the most important factors in developing a synthetic natural gas and a synthetic liquid fuel industry on or near the reservation is that an adequate water supply must be available. A plant converting coal to 100,000 barrels of synthetic fuels per day will require approximately 65,000 acre feet of water per year. A plant converting coal to 250 million standard cubic feet of gas per day

will require from 20,000 to 30,000 acre feet per year.

Energy Parks.--The energy park concept involves the production of energy in its various forms, e.g., electrical power, gas, and liquid fuels, in an integrated industrial complex. Advantages are primarily due to economies resulting from optimized design and operation that are associated with large-scale production. Location of energy parks is dependent on trade-offs between the cost of transporting the energy products to market and the cost of transporting coal to points of use where it in turn is converted to the energy products. Other factors, in addition to large supplies of coal, are adequate water supplies, manpower availability and attendant factors such as adequate housing, roads, etc., as well as methods for dealing with the environmental impacts.

An energy park has been proposed for construction at Glasgow, Montana, to use the large reserves of nearby lignite. Others will no doubt be proposed to utilize additional coal reserves in eastern Montana. The large coal reserves on the reservation could play a large part in supporting energy parks. Projected water requirements for the large-scale development of the coal reserves in eastern Montana are about 2.6 million acre feet per year (Rawlins, 1973, p. 121). Water resource studies by the U. S. Bureau of Reclamation indicate that this water requirement can be supplied from existing and planned storage dams and by construction of aqueducts to transfer water to points of use (Rawlins, 1973, p. 121; Aldrich, 1969, p. 89-93).

Environmental Aspects

Rehabilitation.--The environmental aspects of surface mining of western coals, especially the rehabilitation of mined land, has recently received a large amount of attention from scientists and engineers as well as the general public. Although inputs from the general public are highly desirable as they tend to be composed of varied viewpoints, the discussion here will be confined to the technical aspects of coal mining and its influence on the environment. New concepts and methods ranging from better mine designs to more effective vegetation techniques are reported monthly in the technical literature. Therefore, no aspect of this great wealth of information can be fully developed here, but those of the greatest importance will be discussed.

Much of the concern about the environmental effects of surface mining developed from past practices in the eastern United States. This concern has largely centered around contour surface mining in which the spoil was cast over the hillside. This practice caused stream silting and acid drainage from the exposed pyrite-bearing rocks. Little attempt was made to rehabilitate the worked-out areas in the past. At the present time, a haul back system is used at contour surface mines so that the surface is returned to approximately its original form. But, as mentioned previously, contour surface mining is not generally applicable to the coal beds on the reservation; the topography is much more favorable to area surface mining.

A study by the National Academy of Sciences (1974) concluded that there "presently exists technology for rehabilitating certain western sites

with a high probability of success". These include sites with over 10 inches of annual rainfall. The annual precipitation at Lame Deer is 12 to 16 inches, and therefore rainfall may not be a limiting factor in rehabilitating mined areas on the reservation.

Coal mining on the reservation will be best accomplished with a systems approach. In this way, top soil removal, overburden removal, coal removal, spoil grading, top soil placement, surface manipulation, revegetation, and possibly irrigation are integrated into an overall mining and rehabilitation plan. These individual operations are performed according to a schedule and in a way that is dictated by the mining and rehabilitation plan. Methods for performing these operations and their timing will be dependent on inputs from mining engineers, hydrologists, soil scientists, range managers, wildlife managers, and possibly foresters. A substantial body of knowledge has been accumulated in these fields, and its application to rehabilitating surface mined areas is an excellent example of technology transfer.

Of these individual operations, consider first top soil removal--an operation that has received minimal attention in the past. Scraper-loaders are advocated for this purpose especially where the top soil is thin and where it is desirable to minimize dilution and contamination from other material (Persse, 1973, p. 34, 35). The top soil can be stockpiled for later use but is best hauled directly to cover previously graded spoil (National Academy of Sciences, 1974, p. 54).

Grading of spoil is costly, and consequently much attention has been given to improving the grading operation. The grading of spoil banks is

usually done with very large crawler tractors. Since the spoil material is unconsolidated, these tractors are equipped with oversize blades. For example, a specially designed tractor for overburden grading is equipped with a blade 24 feet wide and 86 inches high. Grading to about 16 percent slope appears to be satisfactory at Colstrip.

A 4- to 6-inch-deep layer of top soil is next placed over the grade spoil. The underlying moisture holding subsoil should not be toxic to plants. Experiments at Colstrip established that "surface manipulation" of the top soil improves water retention. These treatments are called gouging, deep chiseling, dimpling, and basin dozing. They are designed to hold rain and trap snow.

Time for planting is critical. In the reservation area, early spring or late fall seeding is the most reliable. Native species of plants are best, but some introduced species have specific qualities that are essential for rapid establishment and development of vegetation. Winter wheat and Sudan grass are being grown successfully at Colstrip (Cornforth, 1973, p. 42). Fertilizer is always used at Colstrip, and a sprinkling system can be used if needed during hot, dry weather. Soil amendments such as straw mulch are helpful in storing moisture and promoting vegetation growth.

In Montana, the cost of applying top soil ranges from \$250 to \$500 per acre. The costs of spoils shaping, placing top soil, seedbed preparation, seeding, and planting at one project in eastern Montana totaled \$711 per acre (National Academy of Sciences, 1974, p. 87). Another estimate, which included the removal and replacement of topsoil, grading of spoil, restoration of drainage, and prevention of water pollution, and planting and

seeding of reclaimed land, was approximately \$2,000 to \$2,500 per acre (Weir, 1973, p. 27).

Operations pertinent to rehabilitating surface mined lands have been only briefly covered here. Persse (1973) has evaluated surface mining techniques that have been specifically developed to minimize environmental damage. Hodder (1970) has described reclamation research at Colstrip. The results of this research are reported by Cornforth (1973, p. 40-42). An overall summary of the rehabilitation of western coal lands and a comprehensive list of references are given in a recent report of the National Academy of Sciences (1974). The point to be noted here is that surface mined land on the reservation can be reclaimed by established techniques with no particular difficulty, and the development of unforeseen unsolvable problems is highly improbable.

Aquifers.--Coal beds in the northern Great Plains are commonly aquifers and are often used by farmers and ranchers as a source of water. Surface mining may disrupt flow patterns through these aquifers. Fortunately, the amount of disturbed land at any time will be small so that only local dislocations will occur. A study of the hydrologic effects of surface coal mining in southwestern Montana showed that water levels in wells near the mining operation declined (Van Voast, 1974, p. 12).

Emissions from Combustion.--Sulfur dioxide (SO₂) emissions from coal burning plants, if of sufficient concentration, are harmful to both plant and animal life. The Environmental Protection Agency has set the limit on SO₂ emissions from

new power plants as 1.2 pounds of SO₂ per million Btu's. Higher emissions are allowed for older plants, but these plants will eventually be required to conform to this standard, either through the addition of emissions controls or through burning low sulfur coal. The Btu vs. coal sulfur content relationship for conformance to the EPA standard is shown on [Figure 8](#). Ten percent of the sulfur is presumed to remain in the ash (Zachar and Gilbert, 1968, p. 5-24). For coal containing 8500 Btu per pound, the maximum allowable sulfur content in the coal is 0.6 percent. Using analyses of coal beds near the reservation reported by Matson and Blumer (1973) as a rough guide, most of the coal beds will meet the EPA SO₂ emission requirement. However, mechanical cleaning may be necessary for some of the coal to reduce its pyrite content. Coal cleaning may be necessary for some of the stratigraphically higher beds in the southwestern part of the reservation and those in the north part of the reservation. The coal beds on the eastern part of the reservation appear to be generally low in sulfur contents especially the Knoblock bed which contains only about 0.4 percent sulfur.

Radioactive elements in coal remain in the ash after combustion. Uranium has been recovered from the ash of some "dirty" North Dakota lignites, but uranium in economically recoverable quantities has not been reported in reservation coals. Smaller quantities of radioactive elements in the ash may require attention to prevent possible human health hazards from some forms of ash disposal, e. g. concrete admixtures, construction fill material. etc. Any future investigations of reservation coals should include checks for radioactive elements.

Some trace elements in coal may also cause a health hazard due to liberation of these elements during combustion. Arsenic and mercury, for example, are highly toxic to humans and animals. They are exceptionally dangerous pollutants. The volatility of both mercury and arsenic is relatively high in both the elemental and combined forms. Mercury and arsenic in coal would therefore be mobilized into the atmosphere by combustion (Bertine and Goldberg, 1971, p. 234). New arsenic standards have been proposed by the Occupational Safety and Health Administration. These new standards will reduce the minimum permissible arsenic concentration from the present level of 0.5 mg to 0.004 mg per cubic meter of air averaged over an 8-hour period. It has been reported that samples of coal from Montana and Wyoming contained 33 ppm and 18.6 ppm of mercury respectively (Joensuu, 1971, p. 1027). These were among the highest of 36 coal samples that were analyzed. Clearly, future investigations of reservation coals should include mercury and arsenic analyses as well as analyses of other elements, e.g. lead, that could possibly cause a health hazard.

Recommendations for Coal Development

1. Surface mining is the best method for obtaining large-scale production from the coal resources on the reservation at the present time. Areas suitable for surface mining are defined by established criteria which depend on bed thickness and depth of overburden. A comprehensive and systematic investigation should be undertaken to determine the location and extent of the areas that are suitable for surface mining. This investigation

would include ground surveys by geologists and engineers, aerial surveys, and diamond drilling. Also, the quality of the coal should be evaluated by appropriate laboratory analysis.

2. At the present time, conventional underground coal mining is limited to coal beds less than about 10 feet thick. In addition, a safe method for large-scale underground mining of reactive coals such as subbituminous coal has not been developed. Consequently, most of the coal on the reservation cannot now be mined on a large scale by underground mining. However, mining research has greatly expanded in the last two years. Undoubtedly, underground mining systems will be developed to successfully mine the thicker coal beds. Therefore information will be needed on the quality and extent of the deeper coal beds, although the timetable for pertinent underground mining research developments and thus the need for the information is not clear at this time. Assuming that better, safer, and more economical underground mining systems are developed in the near future through rapid advances in mining technology, it may be desirable to survey the entire reservation at the present time to establish the reserves and quality of the coal beds, with regard to not only surface mining, but underground mining as well.

3. Present or potential use will dictate the minimum requirements for rehabilitating surface mined land. Therefore, baseline studies should be undertaken now to establish these minimum rehabilitation requirements. The study would include present or potential use of shallow aquifers, farm and range potential, and investigation of the entire plant-animal ecosystem as it presently

exists or has existed in the past if altered by external factors such as overgrazing.

4. Development of the coal resources on the reservation will depend to some extent on available water. Actual mining operations will require a minimal amount of water that should be readily available on the reservation. However, on-site conversion to other energy forms, e.g., electricity, gas, liquid fuels, will require water resource developments such as dams and aqueducts. Water resource investigations should be undertaken to establish water sources and methods for making these water supplies available while minimizing disruptions to present users. Water resource investigations should include the entire spectrum of possible coal resource development from mining to complete on-site conversion.

5. Mining enterprises tend to be planned and developed from a relatively narrow viewpoint that includes primarily technical and economic factors. Sound planning and development, however, require that all of the positive and negative effects be quantified and evaluated to the fullest possible extent. The environmental aspects of mining, which include accenting the positive effects, e.g., altering the topography to prevent soil erosion, as well as the avoidance of negative effects, e.g., stream pollution, can be readily established. Thus, all costs related to mining, which includes rehabilitating mined land, can be evaluated in ways that are no different from any other enterprise. But definitive boundaries are necessary in order to select the best rehabilitation techniques and to evaluate their cost.

The social impact to residents of the reservation, resulting from the development of the coal

resources, needs to be considered also during early planning stages.

It is recommended that quantification of all aspects of coal resource development on the reservation be pushed as far as possible so that trade-offs among objectives can be evaluated in a meaningful way. Only then can intelligent choices be made that range from no development of the coal resources to full development and industrialization of the area.

Oil and Gas

Geologic Setting and Controls

The geologic controls for the accumulation of oil and gas are fairly well understood in their broad outline. Oil and gas are generated from organic materials in marine rocks by microbial activity, and by the heat and pressure of burial. The gaseous and liquid hydrocarbons are squeezed out from the sites where generated into porous and permeable reservoir rocks interlayered with the source beds. The hydrocarbons move within the reservoir rocks towards regions of lower pressure, generally laterally and upward. Eventually most of the hydrocarbons escape to the surface. Underground accumulations can occur, however, where migration is locally impeded. Structural traps for oil and gas occur if the oil and gas migrate to the crests of structurally closed domes or anticlines where hydrocarbon-carrying reservoir rocks are capped by impermeable strata. Stratigraphic traps can occur within uniformly dipping reservoir rocks that are sealed off at their upward edge by a discontinuity of the reservoir stratum or a decrease in its poros-

ity. In both structural and stratigraphic traps, the hydrocarbons accumulate in the interstices of the reservoir rock in the structurally high part of the trap. Formation water, if present, is displaced and escapes at structurally lower levels.

The Northern Cheyenne Indian Reservation has been prospected for oil and gas intermittently since 1952, but none has been found. Test wells were drilled at 10 places in the reservation between 1952 and 1971, as shown on the structure contour map (Figure 2) and described in Table 2. The deepest well penetrated 9,255 feet to Precambrian rocks; none of the others tested rocks below the Jurassic Morrison Formation.

Rocks equivalent to those that underlie the reservation produce oil and gas at several nearby places in the northern part of the Powder River basin, notably from the Liscomb Creek field, about 18 miles northeast of the reservation; the Pumpkin Creek field, 30 miles northeast of the reservation; the Ash Creek field, about 24 miles south of the reservation; and the Lodge Grass, Hardin, and Snyder fields, which are respectively 14, 25, and 20 miles west or northwest of the reservation (Figure 9). Table 10 lists the locations, producing formations, and other information about these and other nearby fields.

Potential Resources

On the basis of presently available information, the Northern Cheyenne Indian Reservation does not contain structural traps favorable for oil and gas accumulations. However, all the rocks older than the Hell Creek Formation, except the Lakota and Morrison Formation, are marine rocks depos-

ited in shallow to moderately deep epicontinental seas that supported abundant marine life. They are continuous with formations that produce oil and gas in nearby parts of the Powder River basin. Several of the formations have possibilities for oil and gas in stratigraphic traps in the reservation.

The geologic occurrence of oil and gas, and the possibilities for future discoveries in the northern part of the Powder River basin, have been discussed by many writers, and have been summarized by Perry (1960) and Kinnison (1971). The following discussion is based largely on their observations and conclusions.

Upper Cretaceous rocks that have potential for oil and gas in the reservation include the Parkman Sandstone, and the Shannon Sandstone Member and other sandstone beds in the Eagle Sandstone and Telegraph Creek Formations, undivided. Sandstone beds comprising these rocks tend to be fairly widespread, tabular bodies; traps for petroleum depend primarily on variations in porosity and permeability within the potential sandstone reservoirs. Both the Parkman and Shannon Sandstones are at relatively shallow depths of 4,000 feet or less, and are fairly accessible for testing. Seven wells have been drilled in the reservation through these rocks (Table 2). This density of drilling is too low to more than barely test their potential.

Thin sandstone lenses in rocks equivalent to the Belle Fourche Shale contain gas in the Hardin field, a few miles northeast of the reservation, and thin sandy beds and lenses are present in the Belle Fourche Shale and basal part of the overlying Greenhorn Formation in the reservation. Information from the present drill holes suggests that reservoir conditions are probably inadequate for

more than minor occurrences of oil or gas in these rocks.

Lower Cretaceous rocks contain more than 90 percent of the oil and gas so far discovered in the Cretaceous System in the Powder River basin. Nearly all of the production comes from the Newcastle and Fall River Formations. The Newcastle Sandstone is thought by many geologists to represent a delta complex that was built out into a shallow Cretaceous sea from land areas to the east across a very broad area in eastern Montana and Wyoming. The formation is characterized by complexly interfingering sandstone and shale beds that have provided excellent trapping conditions for hydrocarbons on the east side of the basin where many oil fields have been discovered in the formation and where exploration has been intensive. There is no information at hand to indicate that sandstone beds in the formation do not also provide favorable sites for the accumulation of oil and gas in the northern part of the basin, including the area of the Northern Cheyenne Indian Reservation.

The Fall River Formation, like the Newcastle, consists largely of shoreline and offshore sandstone deposits locally having good reservoir characteristics for oil and gas, and the Fall River Formation is also a potential producing formation in the reservation.

Six wells drilled in the reservation have tested the Newcastle Sandstone, and five of these wells were drilled through the Fall River Formation (Table 2). Neither formation has been adequately explored for oil and gas within the reservation by the present sparse pattern of drill holes.

Jurassic rocks produce small amounts of oil and gas in the Powder River basin (Kinnison, 1971, p. 604). Within the reservation the Swift Formation and overlying lower part of the Morrison Formation contain sandstone beds that locally may provide reservoirs for petroleum. Perry (1960, p. 16) states that the porosity of the Jurassic sandstones tends to be low, and the potential for oil and gas, therefore, is probably also low. Only four drill holes in the reservation reached rocks older than the Morrison Formation (Table 2); Jurassic rocks are, therefore, virtually untested within the reservation boundaries, and they are a possible target for oil and gas exploration.

The Tensleep and Amsden Formation of Pennsylvanian age and laterally equivalent rocks contain oil and gas at several places in the Powder River basin, including the Lodge Grass and Snyder fields a few miles west of the reservation. The Tensleep, in particular, contains thick sandstone beds having good reservoir characteristics. Pennsylvanian rocks have been reached by only one well in the reservation; and the potential, therefore, is virtually untested.

The upper part of the Madison Limestone of Mississippian age produces oil from the Soap Creek field a few miles west of the reservation. The equivalent Mission Canyon Formation which underlies the reservation is considered a potential reservoir for oil and gas in Montana (Perry, 1960, p. 19-20, Kinnison, 1971, p. 596). Porous zones providing good reservoir characteristics consist of fractures and vugs in the limestone. Kinnison (1971, p. 598) points out, however, that the Madison commonly contains fresh water, which indicates flushing of the original formation fluids,

including perhaps much of the petroleum that might have originally been present. Only one well has penetrated the Mission Canyon Formation and underlying Lodgepole Limestone in the reservation; and the oil and gas possibilities of the Mississippian rocks within the reservation, therefore, are almost untested.

Devonian, Silurian, and Ordovician rocks make up a sequence of carbonate rocks that produce oil and gas targets for exploration in other parts of eastern Montana (Perry, 1960, p. 20-22). According to Kinnison (1971, p. 595), Ordovician rocks of the Red River Formation commonly contain shows of oil in the northern part of the Powder River basin, and the formation characteristically contains intercrystalline to vuggy porosity in discontinuous zones and thus has good potential for stratigraphic traps. The Silurian Interlake Formation thins westward and pinches out in the subsurface near the west edge of the reservation (Kinnison, 1971, fig. 7), which provides stratigraphic trapping possibilities in the western half of the reservation. Devonian, Silurian, and Ordovician rocks are practically untested within the reservation.

Kinnison (1971, fig. 27) has speculated that the oil in place in Cretaceous and older rocks in the Powder River basin in Wyoming and Montana totals 17.8 billion barrels, including known reserves and cumulative production to 1971 of about 3.5 billion barrels. His estimate is based on a comparison of the volumes of rock in the basin that are well explored and that contain petroleum deposits with volumes of rock in the same formations that have petroleum possibilities but are poorly explored or are unexplored. If a part of this

potential resource is assigned to the Northern Cheyenne Indian Reservation in proportion to the volume of prospective rock present, a potential resource of 270 million barrels of oil in undiscovered deposits can be calculated for the reservation. This simple calculation assumes that the petroleum deposits are distributed in the poorly explored parts of the basin evenly enough to give the Northern Cheyenne Reservation its proportional share, which is only approximately true at best. No one knows how much less acreage will be drilled because of the elimination of the depletion allowance. The shallow and intermediate prospects will continue to be drilled but the deeper prospects will suffer and they have been historically the large "long shot" discoveries.

Transportation and Markets

There are no oil pipelines in or near the reservation. The gas pipeline serving the Liscom Creek field is about 18 miles northeast of the reservation (Magill and others, 1967, p. 24). Due to the energy shortage there will be no problem marketing the oil.

Environmental and Social Effects

The oil and gas industry doesn't cause any greater impact on the environment than any other industry that requires roads. It is easier on the environment than some of the other mineral extracting industries.

The social effect will tend to be positive, as the oil and gas royalties could be used to raise the

standard of living on the reservation. However, the oil industry will require little or no local labor.

NONMETALLIC MINERALS

Nonmetallic minerals are those that do not fall into the metal or fuel class. They are commonly called industrial minerals because of their wide usage for industrial purposes, and include such materials on the reservation as sand and gravel, building stone, bentonite and clinkers.

Bentonite

Bentonite is a type of clay consisting essentially of the mineral montmorillonite. Certain unusual physical properties lead to its utilization in industry. Principal uses are in drilling mud, foundry sand and pelletizing (iron ore). Minor usage is in animal feed, oil refining catalysts, waterproofing and sealing.

Volcanic materials, mostly volcanic ash, were deposited in ponds and lakes that were present during deposition of the Tongue River Member of the Fort Union Formation, and subsequently have been altered to bentonite, a clay consisting largely of the mineral montmorillonite. The ash was mixed with and diluted by other sediment during deposition, and bentonitic claystones in the Fort Union Formation are generally lenticular and impure.

In 1972, the average value of bentonite was \$10.60 per short ton nationwide, while Wyoming bentonites averaged \$10.13 at the same time the average value of Montana bentonites was only \$6.38 per short ton (U. S. Bureau of Mines, 1974, p. 308).

Bentonite of rather poor quality occurs on the Northern Cheyenne Reservation at several places. It can be easily recognized by its "popcorn" like texture. During rainy periods, bentonite of moderate to high dilatancy soaks up many times its own volume of water, swells, and becomes a slippery thixotropic gel. On drying, the swollen clay contracts to nearly its original volume, and in so doing, cracks and forms the peculiar, popcorn like, clay bloom. Bentonite beds in general resist weathering to a slightly greater degree than the enclosing shales; this, along with their lighter color and flowage caused by swelling during the rainy season, tends to make the beds conspicuous and easily traceable along their outcrops. Often the flowage makes a bed appear on the surface to be much thicker than it actually is.

Known Productive Occurrences

Outcrops of bentonite or bentonitic clay were noted by Magill, Hubbard, and Stinson (1967, p. 27) on the Northern Cheyenne Reservation in three locations: sample 1, sec. 2, T. 3 S., R. 43 E.; sample 2, sec. 17, T. 2 S., R. 41 E.; and sample 3, sec. 6, T. 5 S., R. 43 E. [Table 11](#) lists the test results on samples taken from these locations. D.T.A. (differential thermal analyses) indicated that the clay mineral in all three samples was montmorillonite.

Sample No. 1 was taken across a 6-foot bed of bentonite in the SWSE $\frac{1}{4}$ sec. 2, T. 3 S., R. 43 E., about 1 mile south of Interstate Highway 212 and 5 miles west of Ashland. The bed appears to have a southwest-northeast strike and dips a few degrees to the northwest. It is from 6 to 8 feet thick, is

underlain by sandstone and overlain by a bentonitic siltstone. Test results given in [Table 11](#) indicate that the material should be good for use in lining canals, reservoirs, etc., to prevent seepage of water. It was by far the best material sampled from the Northern Cheyenne Reservation for this purpose.

The deposit represented by sample 1 contains a minimum of 5,000 tons of bentonite covered by less than 20 feet of overburden.

Sample 2 was taken across the 12-foot bed of bentonitic clay in the center of sec. 17, T. 2 S., R. 41 E., on a small knoll about 400 feet west of the Lame Deer-Colstrip road $2\frac{1}{2}$ miles north of Lame Deer. Weathering out of this bed are numerous colorless and translucent selenite (gypsum) crystals.

There is virtually no overburden on the bed, but the potential tonnage is limited by the fact that it is located on a small knoll and its extension to the south is covered by sandstone, siltstone, and clinkers, having a thickness of about 150 feet.

As can be noted from data in [Table 11](#), sample 2 was the poorest of the three samples tested, as far as bentonitic qualities were concerned. However, it has been used with apparently satisfactory results to line a pond to prevent water seepage at a saw-mill about 1 mile north of Lame Deer.

Sample 3 was taken from the top 10 feet of a 20-foot bed in the SE $\frac{1}{4}$ sec. 6, T. 5 S., R. 43 E., about 1 mile north of the small village, at the site of the Birney Day School. It crops out on the north side of Birney Creek about one-quarter mile north of the road. Because of the steepness of the slope above the outcrop, it would be difficult to mine more than a few thousand tons without excessive removal of overburden.

TABLE 11
 Test Data on Bentonite Samples

Sample No.	Swelling capacity in millilitres of 2.0 gram sample	Percent grit (+325 mesh)	Yield (bbl per ton)
1	6.5	4.0	26.8
2	1.5	7.4	13.0
3	4.5	14.8	13.4

Viscosity for Slurries Containing Various Clay Percentages

Sample No.	Percent clay	Viscosity (centipoises)	Percent clay	Viscosity (centipoises)	Percent clay	Viscosity (centipoises)
1	6.0	1.7	15.0	6.2	21.0	19.6
2	6.0	1.2	15.0	1.7	35.0	6.4
3	6.0	1.4	15.0	2.1	35.0	16.6

Wall Building Properties - for Slurries Containing 6 Percent Clay by Weight

Sample-Filtrate No.	in ml for indicates time in minutes			Thickness of cake in 1/32 in.
	2	15	30	
1	8.0	26.0	37.5	1.5
2	91.5	240.0	328.0	.4
3	40.0	106.0	137.0	.5

As indicated by the test data in [Table 11](#), the material is only fair to poor quality. However, it was the best bentonitic material observed on the southeast part of the reservation during a limited reconnaissance. It should be of some value for local use for lining to retard seepage in reservoirs and canals.

Bentonite exposed on the Northern Cheyenne Reservation is not of sufficient quality or quantity to be of significant potential economic importance. Undoubtedly, further search would reveal additional material similar in quality to that already

sampled. Bentonite deposits in areas adjacent to the reservation (Knechtel and Patterson, 1956) are much larger and of better quality.

Production and Reserves

Production of bentonite from the reservation has been limited to not over a few hundred tons all for local use. Reserves of similar material are adequate for local needs in the foreseeable future.

Bentonite on the reservation does not appear to be a material that could be developed into a large economic resource.

Building and Ornamental Stone

Sandstone has been used for many years for construction purposes on the reservation. Houses, barns, and store buildings have been built from locally mined sandstone. Clinkers have been used to a limited extent as a building and ornamental stone.

Known Production Occurrences

A typical example of the use of sandstone in construction is in the front of the general store at Birney. Sandstone outcrops are extensive on the reservation, much of it, however, is not suitable for building stone. It is either too massive, not sufficiently indurated, or not suitably located for surface mining. Thin beds of sandstone showing ripple marks are exposed in cliffs along the west side of the Tongue River in the southeastern part of the reservation.

Clinkers are exposed at numerous places on the reservation where the sandstone and shales have been melted and fused into material of sufficient size to be of use in construction or for decorative purposes.

Production and Reserves

Production of building stone from the reservation has only been for local use. Distance from markets, plus the fact that similar stone can be

found over large areas outside the reservation, would make the development of a building or ornamental stone industry on the reservation unlikely. Some will continue to be used locally, but none is sufficiently unique in character to warrant shipment any distance to markets. Reserves of desirable stone in any one location are limited, although on the reservation as a whole, they are extensive.

Claystone and Shale

The Tongue River Member of the Fort Union Formation contains claystone and shale that is suitable at places for making common brick, and which could also be used as raw material for expanded-shale lightweight aggregate for concrete. Tests have been made by the Montana Bureau of Mines and Geology (Berg and others, 1973) of samples of cuttings from nine drill holes located south of the reservation in Big Horn and Rosebud Counties. The rocks tested are typical of the Tongue River basin, including the part of the member exposed in the Northern Cheyenne Indian Reservation. Forty-eight samples from the nine drill holes were tested for their water of plasticity, drying shrinkage, P.C.E. (pyrometric cone equivalent), firing shrinkage, fired color, hardness, and bloating characteristics. Chemical and mineralogic composition were also determined for each sample. [Table 12](#) indicates suitability of these rocks for brick and lightweight aggregate.

TABLE 12

Test Results of Samples of Claystone and Shale from the Tongue River Member of the Fort Union Formation for suitability as brick and lightweight aggregate (Data from Berg and others, 1973)

Use	Unsuitable	Rating, percent of samples tested			
		Poor	Possible	Fair to good	Excellent
Common brick	31	8	55	6	----
Lightweight aggregate	44	2	----	46	8

Potential Resources

Sampling of claystone and shale in the Tongue River Member of the Fort Union Formation is too sparse and unsystematic to show the amount of the member that could be used for making bricks or lightweight aggregate, or to identify stratigraphic intervals that might be particularly favorable for these uses. Test results in the area south of the reservation suggest, however, that the reservation contains substantial resources of clay suitable for both uses, and that the resource is probably widely distributed.

Clinker

Clinker, otherwise known as natural slag, scoria, or porcelanite is partly melted, partly vitrified rock or shale. The term "clinker" includes all of the several types that have been produced from the fusing and melting of an overlying formation by the intense heat that rises from an underlying burning coal bed. Heat from the burning coal oxidizes the iron in the overlying formations sufficiently to turn them a reddish color. In the

fused zone near the fire, the rocks are often gray, black, yellow, or greenish. Immediately overlying the coal and around fissures formed by cracking and slumping of the beds, the rocks are often completely melted and have a slaggy vitreous appearance, show flow lines, and some contain frothy vesicular masses caused by the expansion and escape of gases and water vapor from the rocks.

Coal beds in the Tongue River Member of the Fort Union Formation more than about five feet thick commonly have burned along their outcrops, and the resulting heat has baked and altered the overlying sandstone and shale into masses of clinker. The thickness of rock affected by the heat of burning depends partly on the thickness of coal consumed, and the proportion of easily altered shale in the sequence of rocks above the coal. Locally, clinker having a thickness of 60 to 100 feet marks the positions of the thicker beds in the reservation. The clinker generally is conspicuous shades of red. It resists erosion, and typically has been left as a capping on buttes and divides in many parts of the reservation.

The largest and most extensive clinker zone on the reservation is the one formed by the burning of the Garfield coal bed. This bed is extensively exposed along Interstate Highway 212 east of Lame Deer. This clinker bed has a thickness of more than 200 feet in the highway cuts in the SW $\frac{1}{4}$ sec. 30, T. 2 S., R. 43 E. The bed is resistant to erosion and has formed mesas and plateaus that are extensive in the central portion of the reservation.

Outside the reservation, clinkers have been crushed and screened for roofing granules, walkways, etc. Large pieces are used as decorative stone in building construction. Such uses are restricted to local markets by transportation costs. The fact that clinker beds are extensive both on and off the reservation plus the lack of local markets restricts their economic development for other than local usage.

Production and Reserves

No production records have been kept on clinker production as it has been all used locally. Clinker reserves on the reservation are essentially unlimited and amount to hundreds of millions of tons which are available for surface mining.

Sand and Gravels

Several small patches of stream-terrace gravel have been mapped by Bass (1932, pl. 3) on the west side of the Tongue River northwest of Ashland in T. 2 N., R. 44 E. The gravel caps benches about 100 feet above the present river level. Six small deposits, all about 80 acres in extent, are shown bordering the river by Bass, who

describes them as consisting of a basal gravel layer about 12 feet thick overlain by several feet of silt. Much of the gravel material consists of pebbles about half an inch to 1½ inches across, mostly of hard fossiliferous limestone, chert, and igneous rocks.

Productive deposits of sand and gravel occur along the Tongue River and Rosebud Creek. Intermittently a commercial gravel pit is operated in the NE $\frac{1}{4}$ sec. 21, T. 3 S., R. 44 E., about 4 miles by road southwest of Ashland. Material from this area is used locally and by the county road department. Deposits are neither plentiful nor of particularly good quality.

Production and Reserves

There are no data available on the production of gravel from the reservation. In any event, it has been small and has only been used locally.

Reserves are sufficient for local use, but the material is not of sufficient quality to warrant its transportation any distance.

RECOMMENDATIONS FOR FURTHER WORK

Coal is the major resource in the reservation. Information on the coal is scattered and unorganized, and is not sufficient to assess mining and reclamation possibilities for large areas in the reservation. A program of geologic mapping and drilling is recommended as a means of establishing the continuity and correlation of coal beds in the reservation, of determining coal quality, and of refining resource evaluations according to depth,

bed thickness, location, and coal constituents including ash and sulfur. Surface mapping is recommended at a scale of 1:24,000, beginning in areas that are not leased for mining, and where information on the coal from any source is lacking. Drilling with a density of 10-15 drill holes per township to depths of 200-500 feet should accompany mapping to give the required information on coal thickness and quality, and to help identify potential sites for mining. As a byproduct, systematic mapping can be expected to provide information on deposits of sand, gravel, and clay, and will disclose structural features such as faults that might have a bearing on the accumulation of oil and gas.

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Table 6.—Semiquantitative spectrographic analyses (in ppm) for 19 trace elements in 31 samples of coal from the Powder River basin. [In the sample column, (T) and (B) indicate top and bottom of the bed, respectively. All values have been calculated from analyses on ash of coal.]

Sample No.	Sample interval (ft)	B	Ba	Be	Co	Cr	Ca	La	Mn	Mo	Nb	Ni	Sc	Sn	Sr	Ti	V	Y	Yb	Zr
WYODAK-ANDERSON COAL BED, WYODAK MINE, GILLETTE, WYO.																				
D160987	(Tipple)	30	200	<0.15	1.	5	2	<5	10	0.5	1.	2.	1.	<0.5	50	200	10	2	0.2	10
D160986	(Shot-pile)	50	200	.3	3.	7	3	<5	200	1.	2.	7.	3.	<.5	50	500	30	5	.7	20
D160985	3.(T)	30	150	<.15	1.5	2	1	<5	50	.3	<1.	3.	.7	<.5	20	100	7	2	.2	5
D160984	10.	50	150	.2	2.	5	2	7	50	.5	1.5	5.	1.	<.5	20	200	15	1	.1	10
D160983	10.	30	200	.3	2.	7	3	10	30	.7	2.	7.	2.	<.5	30	500	20	5	.5	15
D160982	10.	30	200	<.15	1.	5	2	<5	20	.5	<1.	5.	1.	<.5	30	200	10	2	.2	10
D160981	.5	50	500	<.15	<.5	50	20	<5	50	<.5	20.	15.	15.	<.5	150	5,000	150	<1	2.	150
D160980	3.5	20	300	<.15	2.	7	3	<5	15	.7	<1.	3.	1.5	<.5	50	300	15	2	.3	15
D160979	5.	20	200	<.15	1.5	10	3	<5	15	.7	<1.	3.	1.5	<.5	30	300	20	3	.3	15
D160978	5.	20	300	<.15	.7	2	1.5	<5	10	.5	<1.	2.	1.	<.5	50	200	7	2	.2	10
D160977	5.	20	300	<.15	.7	2	2	<5	20	.5	2.	2.	.7	<.5	50	200	5	1.5	.2	10
D160976	5.	30	300	<.15	1.	2	2	<5	10	.7	3.	2.	1.	<.5	70	200	5	2	.2	10
MONARCH COAL BED, BIG HORN MINE, SHERIDAN, WYO.																				
D161320	(Tipple)	30	500	0.15	1.5	3	1.5	3	30	0.5	<1.	5.	1.5	<0.5	100	200	10	3	0.15	10
ANDERSON-DIETZ COAL BED, DECKER MINE, DECKER, MONT.																				
D161317	(Tipple)	30	500	0.15	0.7	3	1.5	3	7	1.5	1.	3.	1.5	<0.5	300	300	10	3	0.15	10
D161318	do.	30	500	.15	1.	3	1.5	3	15	1.5	<1.	3.	1.5	<.5	300	300	15	3	.15	10
D161319	do.	30	500	.15	1.	3	1.5	3	10	1.5	<1.	3.	1.5	<.5	300	300	10	3	.15	10
ROSEBUD COAL BED, BIG SKY MINE, COLSTRIP, MONT.																				
D163179	6.8(T)	70	700	0.7	<0.5	5	3	7	50	10.	<1.	1.5	1.5	<0.5	300	300	7	3	0.3	30
D163180	5.7	70	150	<.15	<.5	5	3	7	70	2.	2.	1.5	1.5	<.5	200	300	7	3	.3	20
D163181	5.0	50	150	<.15	<.5	5	2	5	20	1.5	<1.	1.	1.	<.5	70	200	5	2	.2	15
D163182	5.0	50	150	<.15	<.5	3	3	<5	30	3.	<1.	1.	1.5	<.5	100	300	7	3	.3	30
D163183	2.1	70	100	.15	.5	1.5	3	5	50	5.	<1.	1.5	1.	<.5	70	150	5	3	.15	10
D163182	.5	30	70	<.15	<.5	15	15	<5	70	5.	<1.	<3.	<3.	<.5	70	3,000	30	10	1.	150
D163184	2.5(B)	70	100	.7	<.5	2	5	7	70	3.	5.	1.5	2.	<.5	100	300	7	5	.3	20
D163187	(Tipple)	50	500	.5	1.	3	3	<5	30	7.	1.5	3.	1.5	<.5	150	300	7	2	.3	20
MCKAY COAL BED, BIG SKY MINE, COLSTRIP, MONT.																				
D163186	5.4(T)	70	200	1.	<0.5	2	2	5	15	0.7	1.	2.	1.	<0.5	200	150	5	3	0.3	10
ROSEBUD COAL BED, ROSEBUD MINE, COLSTRIP, MONT.																				
D161321	(Shot-pile)	100	200	0.3	<1.	3	7	<5	100	3.	3.	0.7	1.5	<0.5	200	300	10	3	0.3	30
D161322	do.	100	200	.5	<1.	5	5	<5	100	2.	5.	1.	2.	<.5	300	1,000	10	5	.5	50
MCKAY COAL BED (CORES), ROSEBUD MINE, COLSTRIP, MONT.																				
D161796	?	150	30	1.5	2.	2	3	<5	30	5.	2.	5.	1.5	<0.5	200	200	7	5	<0.1	15
D161797	?	150	200	1.5	1.5	3	3	<5	50	1.5	3.	5.	1.5	<.5	200	300	7	5	.5	20
D161798	?	100	700	.7	<1.	3	3	<5	20	1.5	2.	1.	<1.	<.5	300	150	5	3	.3	10
D161799	?	70	50	1.5	<1.	3	3	<5	20	2.	<1.5	1.5	<1.	<.5	200	300	10	3	.3	20

Table 10.—Oil and gas fields in the northern part of the Powder River basin, Montana, and nearby areas to the west

[Data as of September, 1974; from Petroleum Information, Denver, Colorado]

Name	Location		Producing formation	Year discovered	Cumulative production		Number of producing wells
	Township	Range			Oil, bbls ¹	Gas, MFC ²	
Big Horn County							
Snyder	1 S.	35 E.	Tensleep	1954	391,338	—	3
Hardin	1 S.	33, 34 E.	Frontier (Belle Fourche)	1913	—	1,232,529	34
Lodge Grass	6 S.	35, 36 E.	Tensleep	1964	205,558	—	1
Soap Creek	6 S.	32 E.	Tensleep, Asmden, and Madison	1921	1,789,150	458	18
Ash Creek	10 S.	38 E.	Shannon Sandstone Member, Cody Shale	1952	723,996	4,679	5
Custer County							
Liscom Creek	1, 2 N.	45 E.	Shannon Sandstone Member, Cody Shale	1959	—	844,324	7
Powder River County							
Pumpkin Creek	1 S.	49, 50 E.	Telegraph Creek	1954	—	no record	8
Leary	8, 9 S.	51 E.	Newcastle Sandstone	1969	160,059	122,477	3
Wright Creek	8 S.	53 E.	Newcastle Sandstone	1969	159,658	167,839	5
Powder River and Carter Counties							
Bell Creek	8, 9 S.	53, 54, 55 E.	Newcastle Sandstone	1967	66,431,569	34,405,673	228

¹ Barrels ² Thousand cubic feet

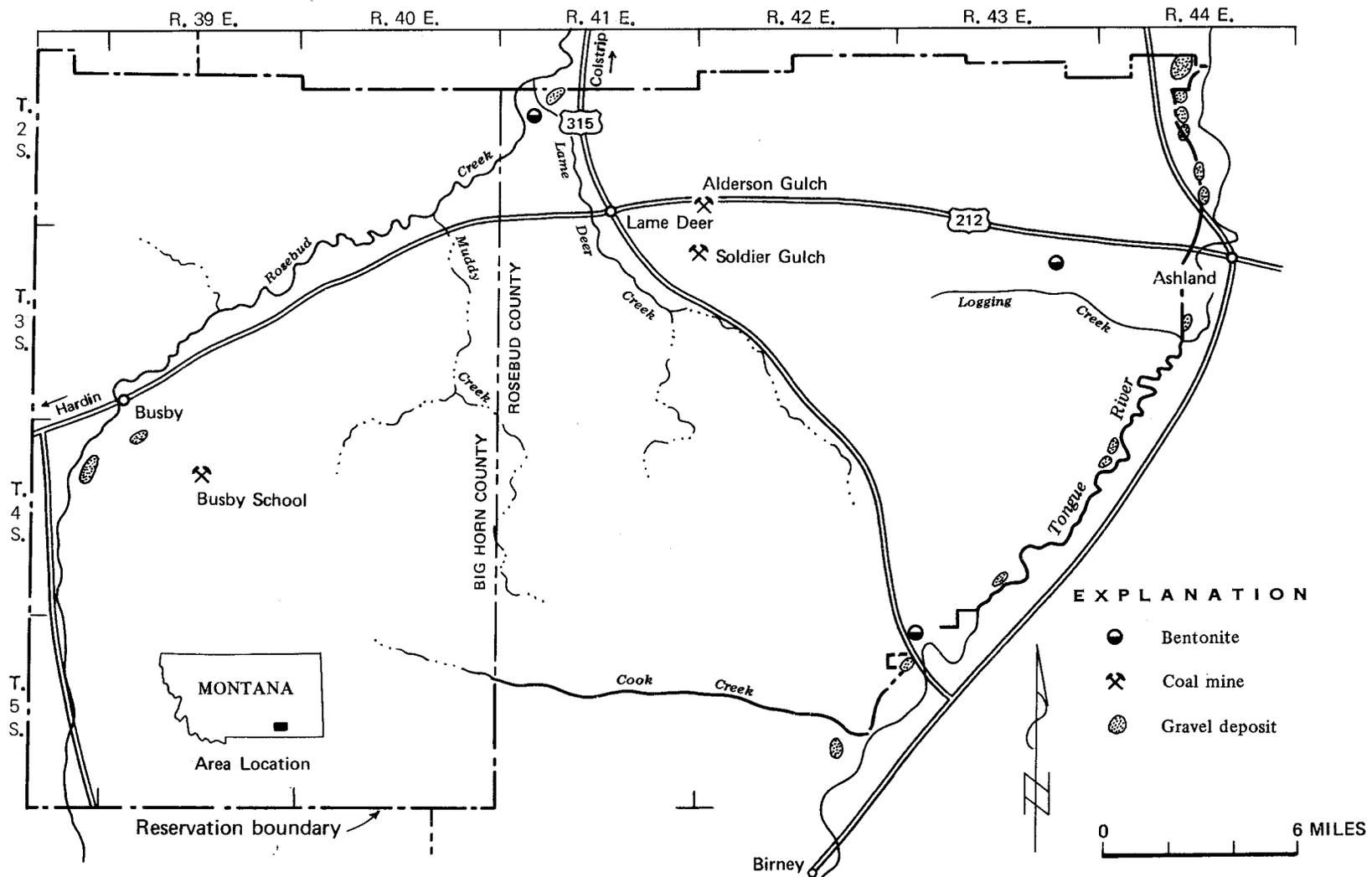


Figure 1. Index map, Northern Cheyenne Reservation, Big Horn and Rosebud Counties, Montana.

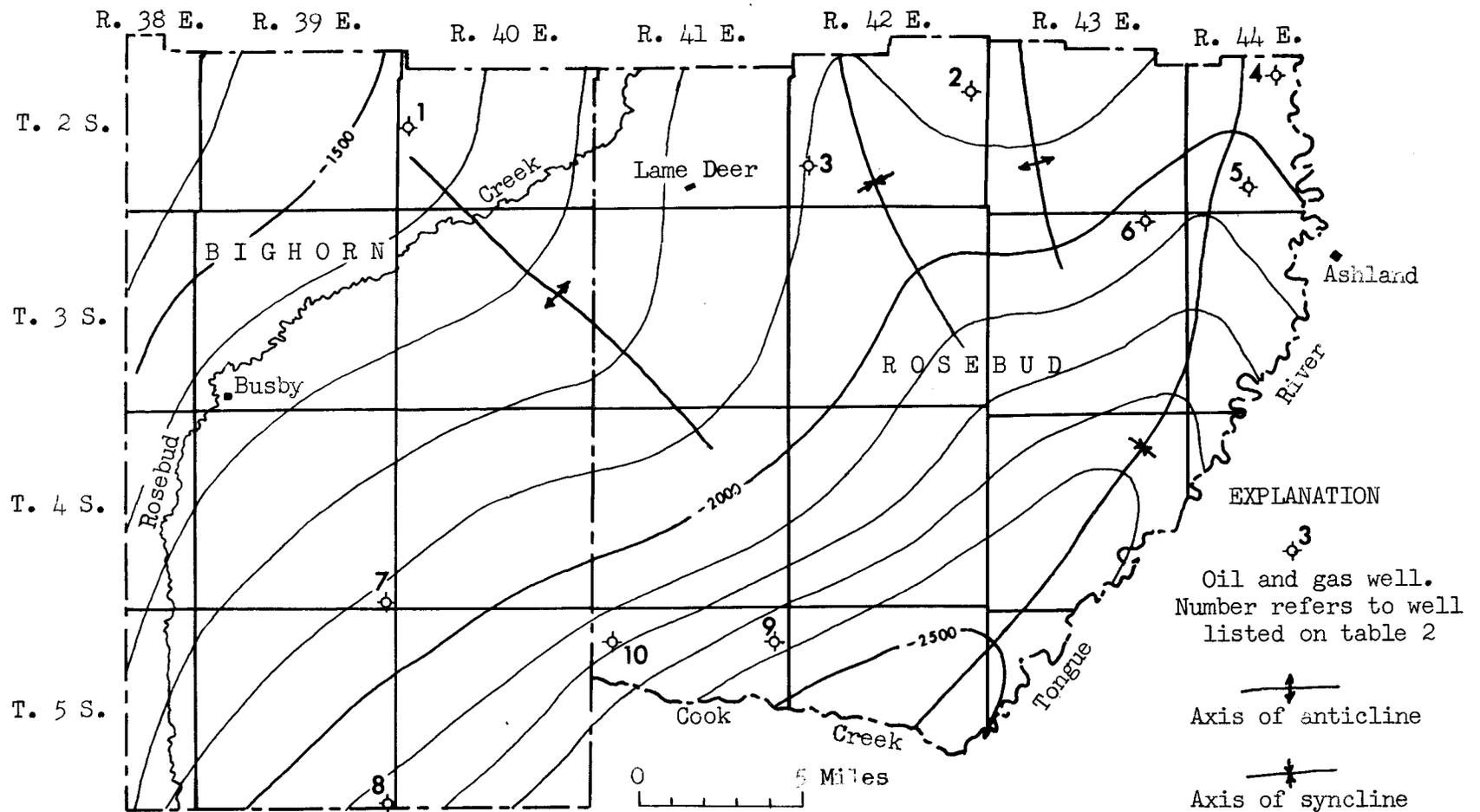


Figure 2. Structure contour map, base of the Greenhorn Formation (Cretaceous), showing locations of oil and gas test wells; contour interval 100 feet. From Balster, 1973.

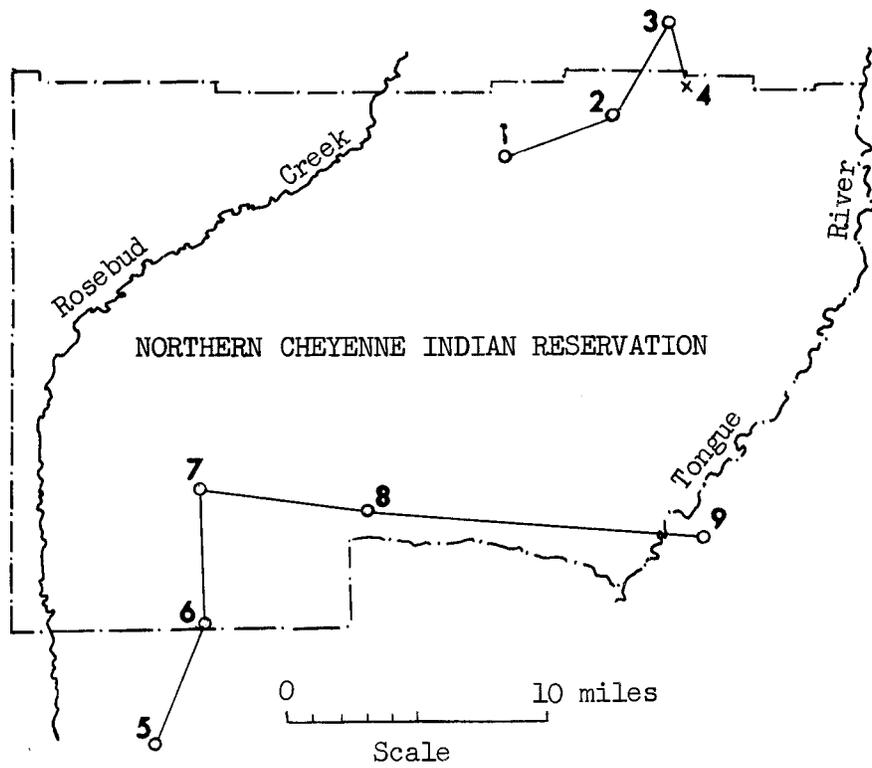


Figure 3. Lines of sections. See Figures 4 and 5.

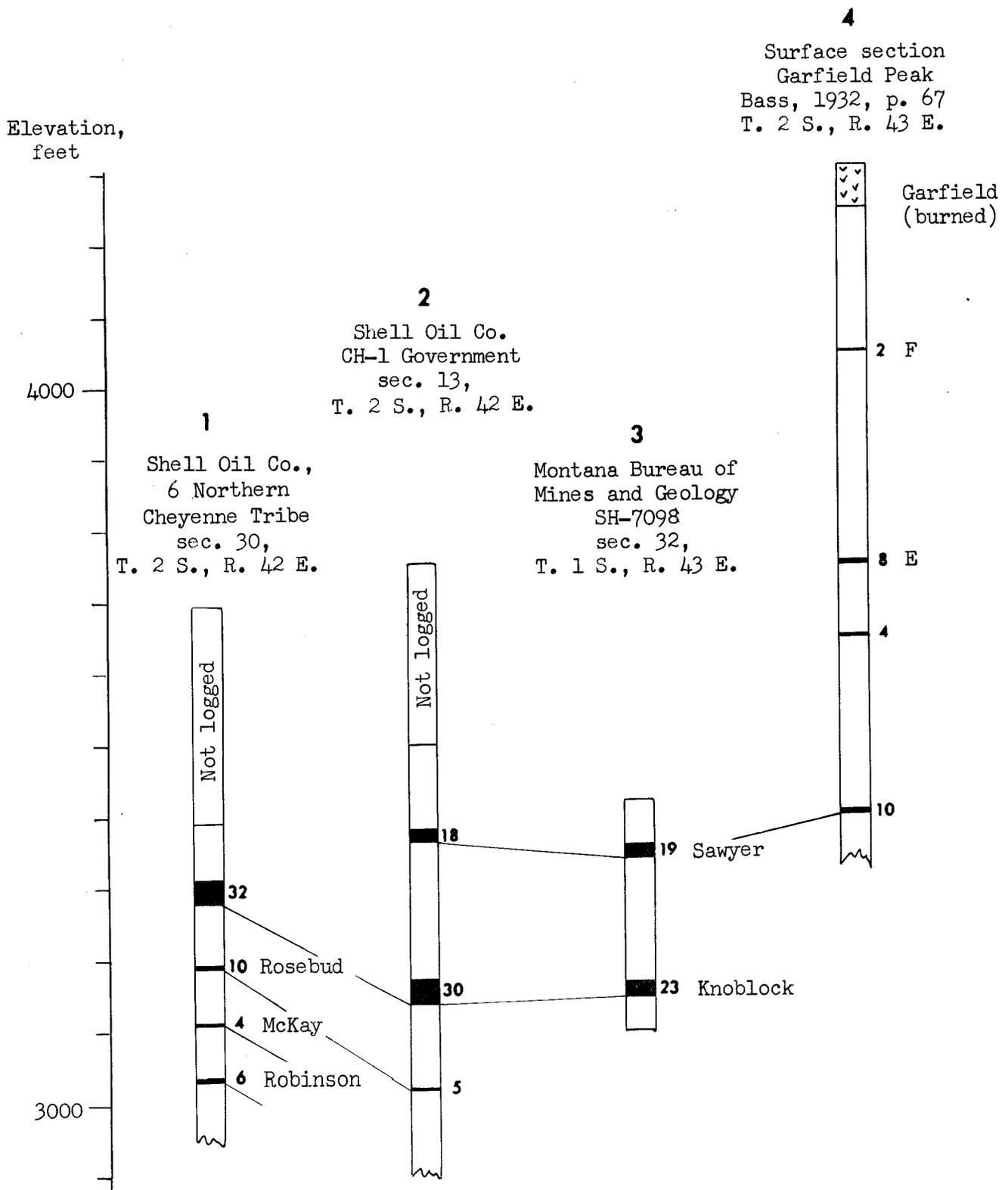


Figure 4. Correlation of coal beds, northern part of the Northern Cheyenne Indian Reservation. Numbers show thickness of coal. Line of section shown on Figure 3.

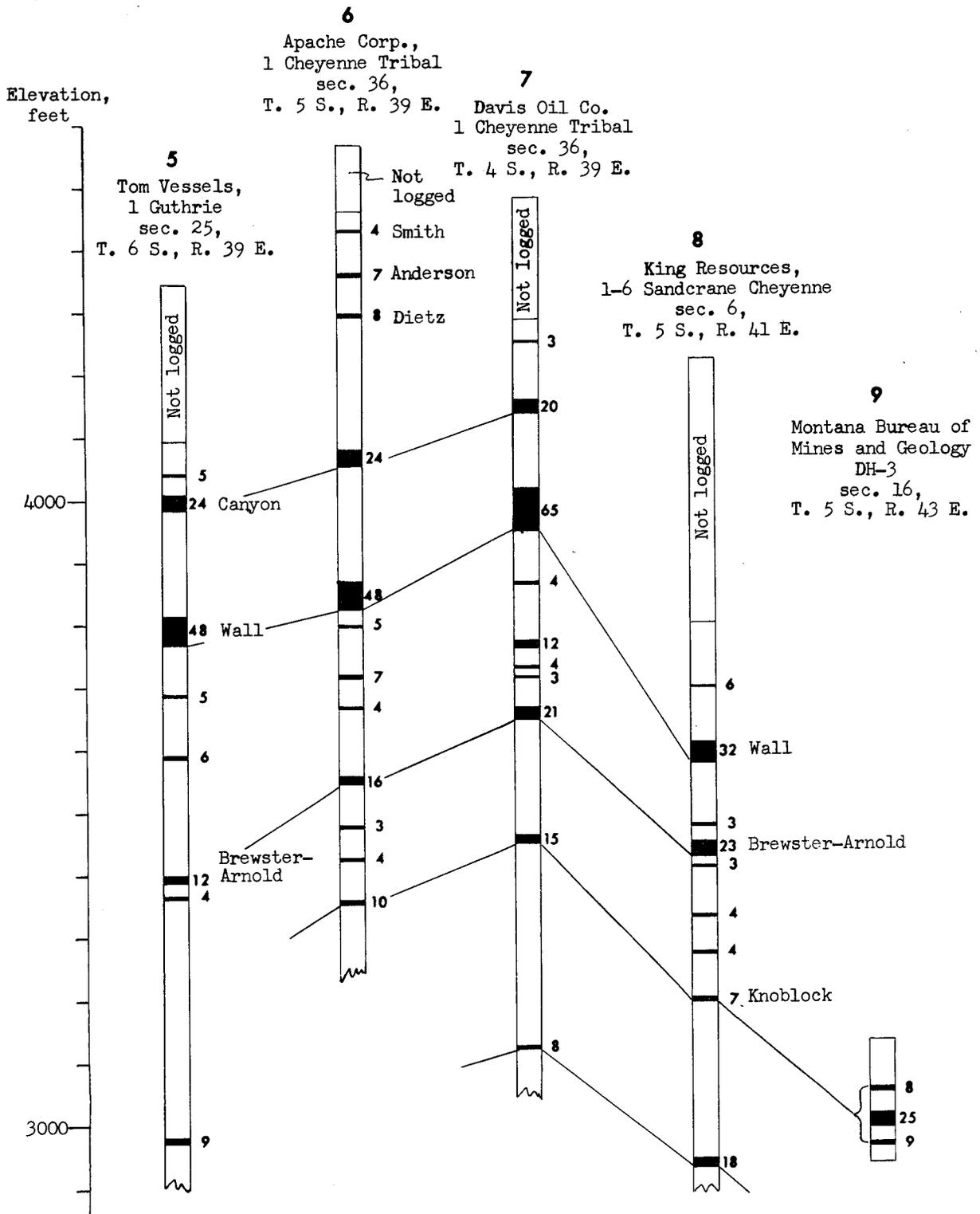


Figure 5. Correlation of coal beds, southern part of the Northern Cheyenne Indian Reservation. Numbers show thickness of coal. Line of section shown on Figure 3.

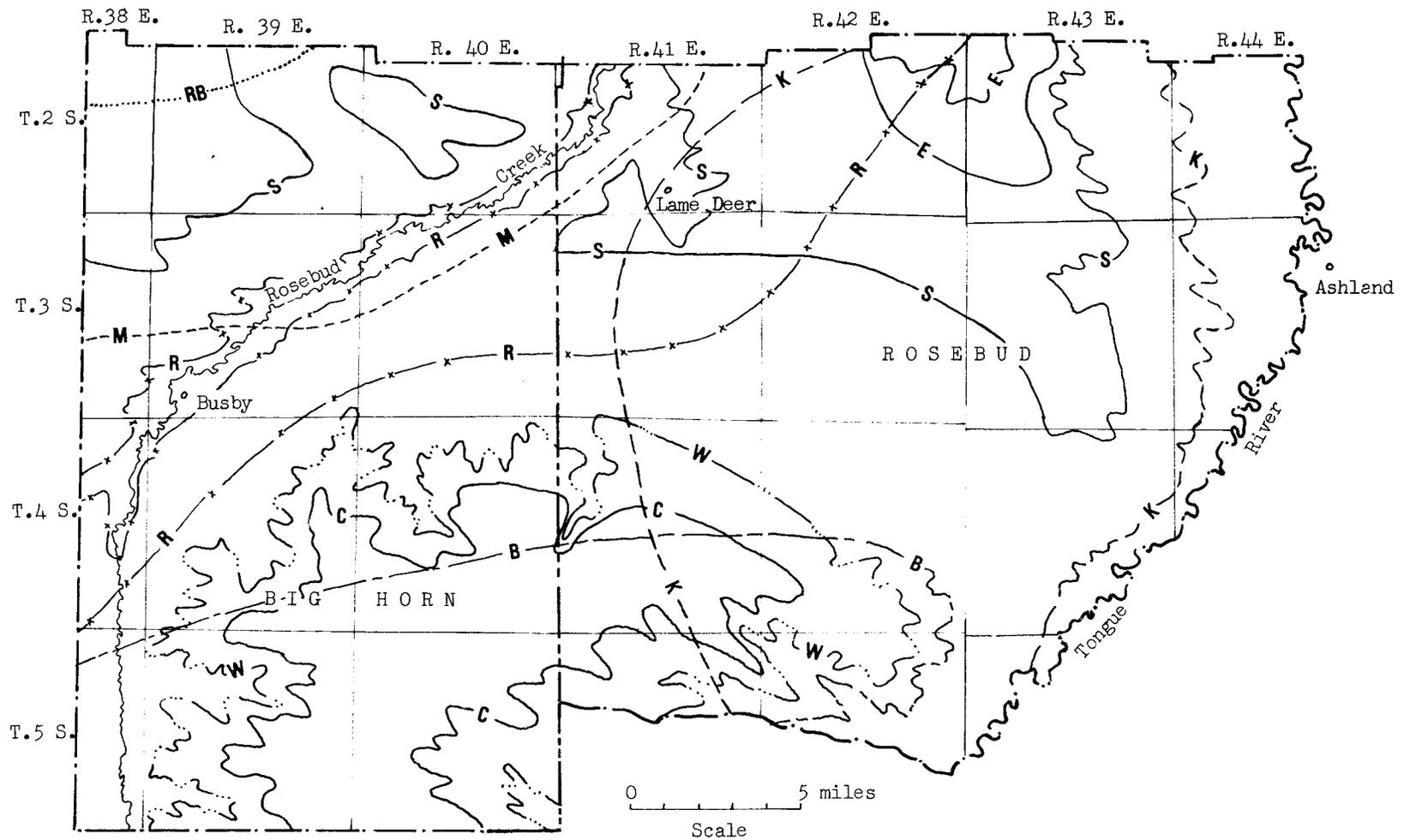


Figure 6. Areas for which coal resources are calculated in Table 4. Letter designates coal bed as follows: K, Knoblock; S, Sawyer; R, Rosebud; M, McKay; RB, Robinson; E, E; W, Wall; C, Canyon; B, Brewster-Arnold. Boundaries of coal beds approximately shown.

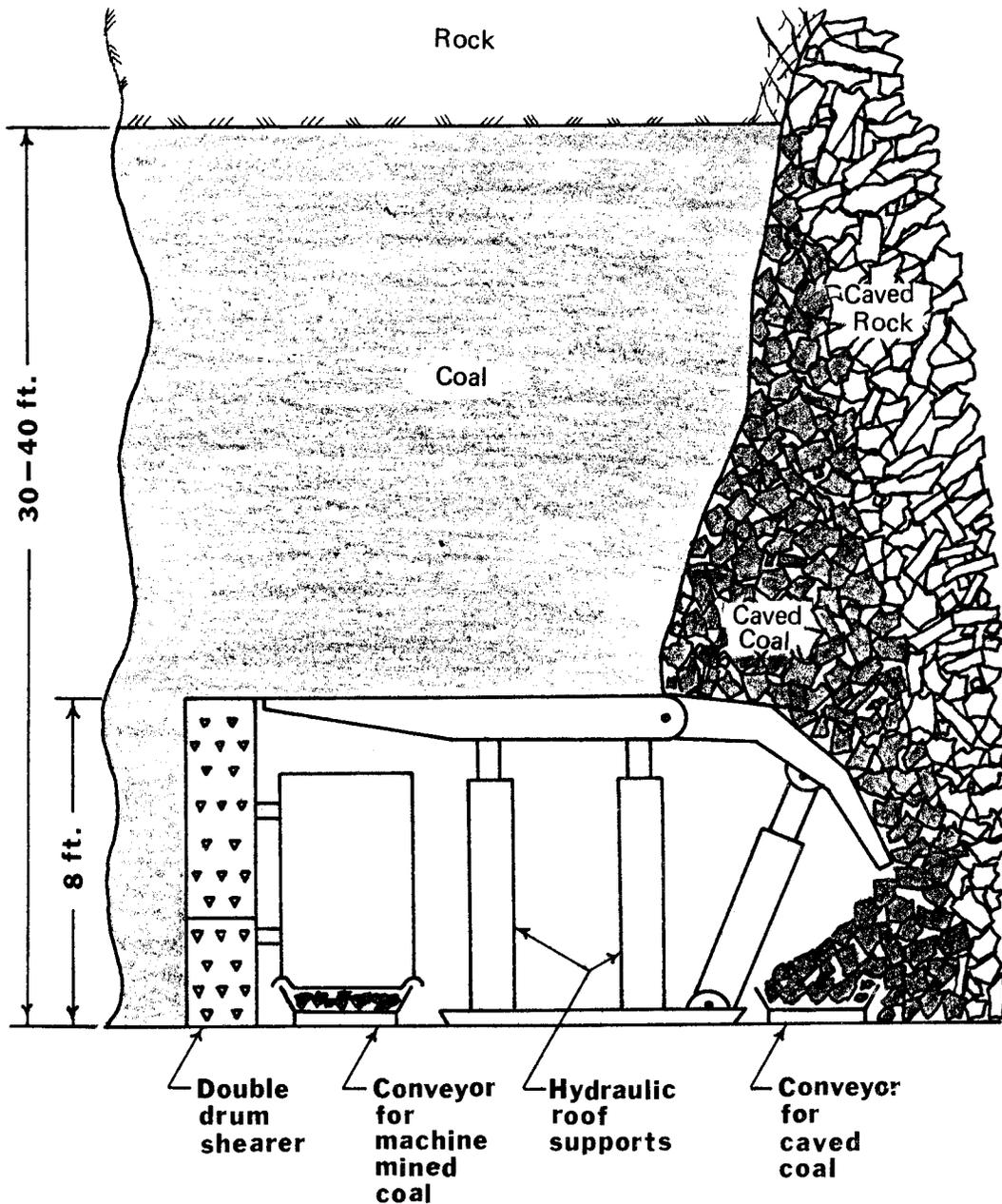


Figure 7. Longwall mining with sublevel caving. This system is used in France for mining thick coal beds.

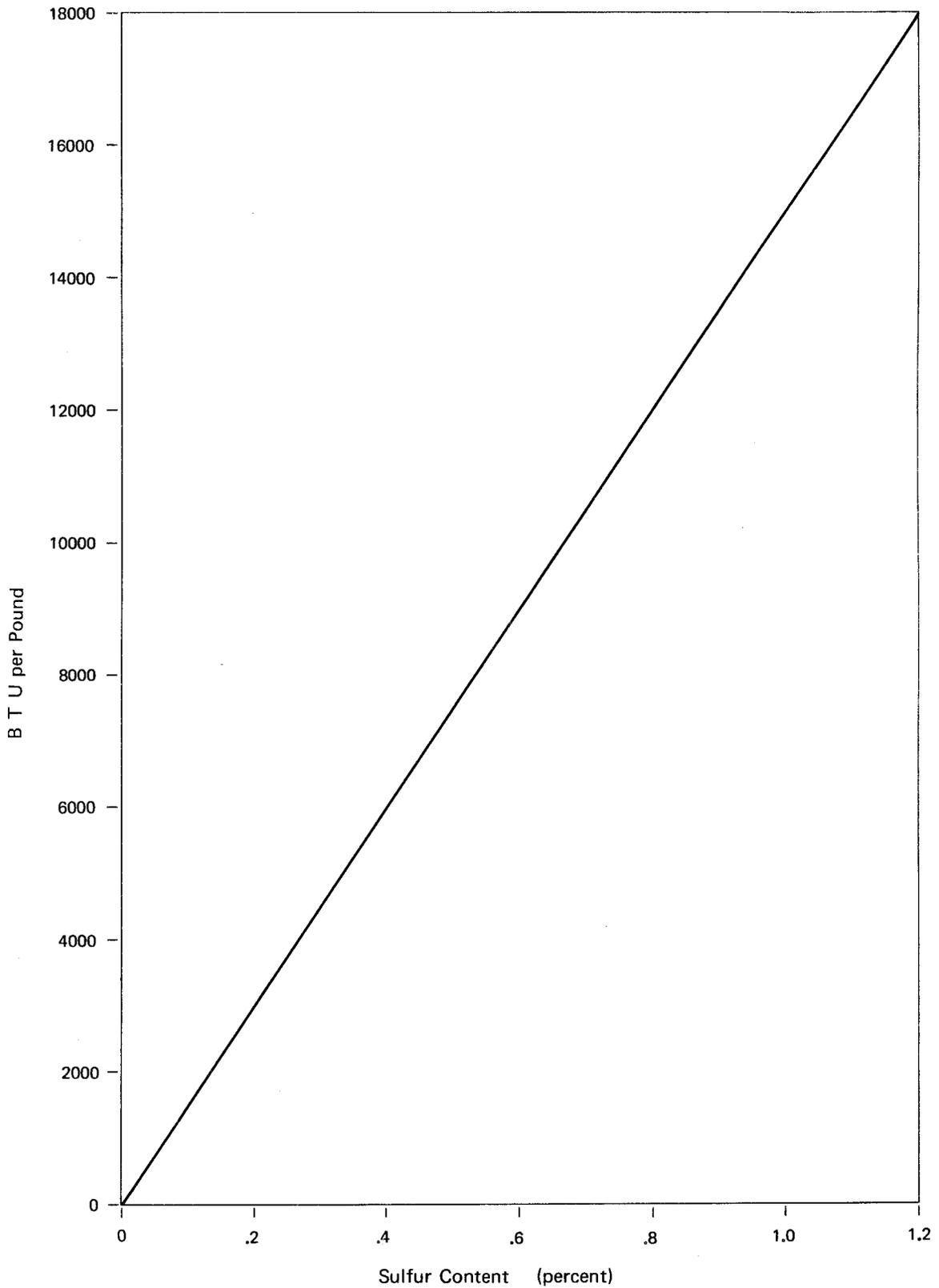


Figure 8. Maximum sulfur content that will meet EPA standard of 1.2 pounds SO₂ per million Btu (assume 10 percent of sulfur remains in ash).

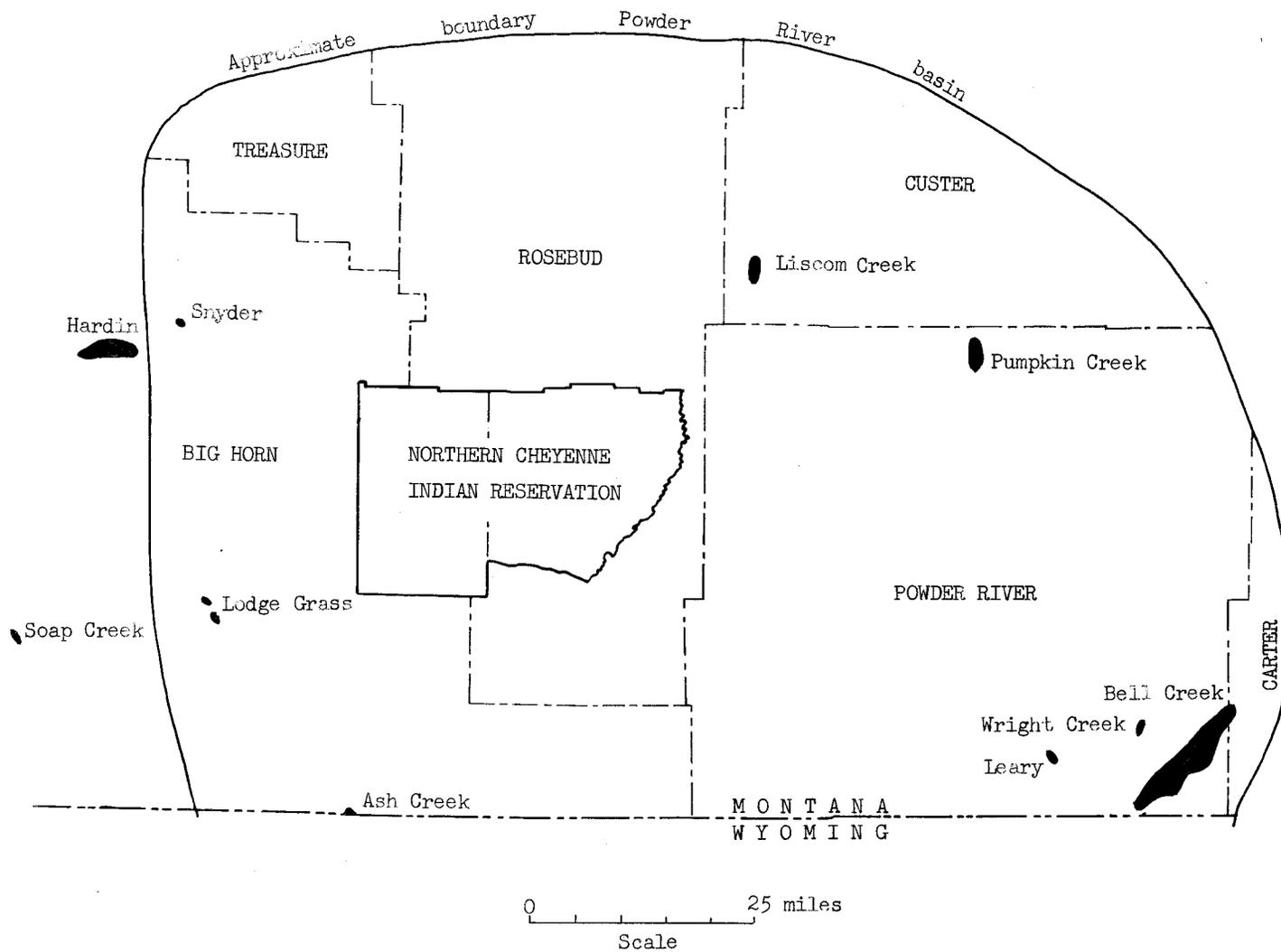


Figure 9. Oil and gas fields in the northern part of the Powder River basin, Montana, in relation to the Northern Cheyenne Indian Reservation. (See Table 10).