STATUS OF MINERAL RESOURCE INFORMATION FOR THE CROW INDIAN RESERVATION, MONTANA

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SUMMARY AND RECOMMENDATIONS

The minerals of economic interest on the Crow Indian Reservation include coal, petroleum, natural gas, bentonite, claystone and shale, pumice, limestone, gypsum, silica sand, building stone and uranium. Of these, coal has the greatest potential.

The northeastern and southeastern parts of the reservation have been explored for coal by private companies; additional work by the U.S. Geological Survey or the U.S. Bureau of Mines is not warranted.

The Crow Reserve Area is unexplored but contains potentially valuable coal deposits. Recommended future work includes geologic mapping augmented by drilling 10 to 15 holes per township to depths of 200 to 500 feet.

The Powder River Basin including the Crow Reservation is a major oil producing region. However, most of the production has come from the Wyoming portion of the basin. Large areas in the reservation are poorly explored for petroleum and it seems likely that additional resources will be found. Bentonite has the best potential for development of the non-fuel minerals on the reservation. Commercial bentonite beds are widespread, but there has been no production. Systematic sampling and drilling should be undertaken to further define quality and quantity of the bentonite.

INTRODUCTION

The Crow Indian Reservation (Figure 1) includes about 3,600 square miles in the Big Horn and the southeastern part of Yellowstone Counties, Montana. Billings and Hardin, Montana, are near the northern edge of the reservation, and the Montana-Wyoming border forms much of the southern edge.

The northern ends of the Bighorn and Pryor Mountains extend from areas farther south into the southwestern part of the reservation where they form a large area of steep-walled canyons and high mountain slopes. Rolling grass-covered hills and broad valleys flank the mountains on the north and northeast and make up the greatest part of the reservation. The Wolf and Rosebud Mountains form an elevated, highly dissected area along the east side of the reservation. The Bighorn River, which flows generally north-eastward, and its large tributary, the north-flowing Little Bighorn River, cross the reservation, joining at Hardin, and are the major drainage ways. Elevations range from about 9,000 feet in the Bighorn Mountains to about 2,900 feet at the confluence of the Bighorn and Little Bighorn Rivers at Hardin.

The Burlington Northern Railroad follows the Little Bighorn Valley along its route from Billings to Sheridan and points south.

In addition to mineral rights on land within the present reservation boundary the Crow Tribe of Indians own mineral rights in the ceded land north of the present boundary extending to the Yellowstone River.

In 1904, the Crow Indians ceded this area to the Federal Government. Proceeds from the sale of the ceded land to settlers were to be credited to the tribe. In 1958, Congress restored to tribal ownership all vacant and undisposed tracts of this ceded land. In addition to the mineral rights on the restored land, mineral rights retained by the Government were also returned to the tribe. In the ceded area, mineral rights now held by the Indians total about 150,000 acres.

PRESENT STUDY

This report is a compilation and summary of information on the geology and mineral resources in the Crow 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.

Most of the information on mineral occurrences on the Crow Reservation was obtained from publications of the U.S. Bureau of Mines, U.S. Geological Survey, and the Montana Bureau of Mines and Geology.

GEOLOGY

Setting

Parts of four major geologic features are included in the Crow Indian Reservation. These are the west flank of the Powder River basin, a northwest-trending synclinal feature at least 250 miles long and as much as 100 miles wide in eastern Wyoming and southeastern Montana; the south flank of the Bull Creek syncline, a large east-trending fold in central Montana; and the northern parts of the Bighorn and Pryor uplifts which extend from south-central Montana southeast into Wyoming. These features, and many subsidiary folds and faults associated with them, were formed in early Tertiary (Eocene) time (Richards, 1955, p. 77-78). They account for the distribution of rock units in the reservation, the oldest rocks being exposed in the core of the Bighorn uplift where it has been breached by deep canyons tributary to the Bighorn River, and the youngest rocks, exclusive of surficial stream terrace deposits and alluvium, being exposed east of the Little Bighorn River on the flank of the Powder River basin.

Rock Units

About 11,000 feet of sedimentary rocks, including all geologic systems from Precambrian to Tertiary, except for the Silurian, are exposed in the Crow Indian Reservation. These rest unconformable on a basement of Precambrian metamorphic and igneous rocks exposed in the Bighorn Mountains. The Spearfish Formation of Triassic age and older rocks form the Bighorn and Pryor Mountains in the southwestern part of the reservation. Belts of successively younger Jurassic and Cretaceous rocks are exposed in the foothills and plains north and northeast of the mountains. Lower Tertiary rocks of the Fort Union and Wasatch Formations crop out east of the Little Bighorn River in the Wolf and Rosebud Mountains. Locally extensive deposits of terrace gravel border the major streams of the reservation on broad benches at several levels, including most notably terraces along the Bighorn and Little Bighorn Rivers.

Rock units exposed in the reservation and their thicknesses in outcrops and drill holes are listed in Table 1. A simplified geologic map, Figure 2, shows the distribution of major groups of rock units. Detailed geologic maps of large parts of the reservation are by Thom and others (1935), Blackstone (1940), Richards (1955), Knechtel and Patterson (1956), and Stewart (1958)

TABLE 1

Rock units in the Crow Indian Reservation

[After Thom and others (1935) and Richards (1955)]

- Quaternary System.
  - Holocene Series.
    - Alluvium. Unconsolidated silt, sand, and gravel on the flood plains of the largest streams, principally along the Bighorn and Little Bighorn Rivers. Thickness 0-130 feet.

- Quaternary and Tertiary Systems.
  - Pleistocene, Pliocene, and Miocene Series.
    - Stream terrace deposits. Stream deposited silt, sand, and gravel on benches 100 to 650 feet above the present streams principally along the Bighorn River. Pebbles and cobbles of limestone, basalt, andesite, and subordinate amounts of sandstone, quartzite, granite, gneiss, and chert make up the gravels. Thickness 5 to 40 feet.

    - Volcanic ash. Light-gray shards and pumiceous particles of acidic volcanic glass and crystals of feldspar, quartz, and other mineral grains; reported in sec. 12, T. 4 S., R. 31 E. and sec. 20, T. 2 S. , R. 34 E. (Magill and others, 1966). The deposits are included with stream terrace deposits by Thom and others (1935) and by Richards (1955). Thickness 5 to 7 feet.

- Tertiary System.
  - Eocene Series.
    - Wasatch Formation. Generally nonresistant yellowish-gray fine grained sandstone, gray mudstone, brown carbonaceous shale, and thin coal beds. Exposed in the higher parts of the Wolf Mountains. Thickness about 350 feet.

  - Paleocene Series.
    - Fort Union Formation.
      - Tongue River Member. Mostly ledge-forming light yellowish gray and light-gray fine-grained sandstone, gray mudstone, brown carbonaceous shale, and locally thick beds of coal. Forms rugged buttes, mesas, and broad upland surfaces on inter stream divides in the Wolf and Rosebud Mountains and adjacent areas. Thickness 850 to 1,800 feet.

      - Lebo Shale Member. Nonresistant dark-gray to grayish-black claystone and shale, subordinate lenses as much as 10 feet thick of yellowish-gray sandstone; numerous zones of ferruginous concretions; minor thin coal beds. Forms gentle treeless slopes and local badlands. Thickness 800 to 1,200 feet

Tullock Member. Locally ledge-forming yellowish-gray and light-gray fine-grained sandstone and gray shale; some thin beds of brown carbonaceous shale, and thin, discontinuous beds of coal. Forms low hills or low west-facing scarp. Thickness about 300 feet.

Cretaceous System.

Upper Cretaceous Series.

Hell Creek Formation. Generally nonresistant light-gray fine grained fluviatile sandstone and greenish-gray siltstone and sandy shale; sandstone commonly contains large brown concretions and concretionary masses. Called the Lance Formation by Thom and others (1935). Thickness 600 to 650 feet.

Bearpaw Shale. Dark-gray shale containing gray limestone concretions and numerous thin beds of bentonite. Forms saddles and valleys. Thickness 850 to 1,100 feet.

Parkman Sandstone. In northern part of the reservation consists of light-gray sandy shale and yellowish-gray fine-grained sandstone. In southern part consists of massive yellowish-gray sandstone overlain by dark-gray sandy shale, thin beds of sandstone, and a thin coal bed locally near the top. Forms ridges. Thickness 280 to 350 feet.

Cody Shale.

Claggett Shale Member. Dark-gray shale containing gray limestone concretions that in the upper part of the member weather orange and brown; many thin bentonite beds in the lower part. Forms grassy slopes. Thickness 350 to 650 feet.

Eagle Sandstone Member. Thick-bedded yellowish-gray fine-grained sandstone and minor interbedded gray sandy shale. Forms massive cliffs and mesas. Present along the north border of the reservation near Pryor Creek and in a small area a few miles to the east. Thickness 100 to 225 feet.

Shale Member equivalent to Eagle Sandstone. Dark- to medium-gray sandy shale containing many thin hard beds of rusty-weathering ferruginous sandy concretions; a thin ledge-forming bed of sandstone about 170 feet above the base, and a zone about 20 feet thick of bentonite and bentonitic shale about 280 feet above the base. Present in the eastern part of the reservation. Thickness 375 to 425 feet.

Telegraph Creek Member. Gray and yellowish-gray sandy shale; forms yellowish sandy soil. Thickness 750 to 850 feet.

Niobrara Shale Member. Dark-gray shale containing numerous gray septarian limestone concretions and thin bentonite beds; a thin zone of calcareous shale about 80 feet above the base forms a conspicuous band of light-colored soil. Thickness 400 feet.

Carlile Shale Member. Dark-gray shale, sandy in the middle part; ironstone concretions about 100 feet above the base and large brown limestone concretions about 180 feet above the base. Thickness 275 feet.

Greenhorn Calcareous Member. Dark-gray calcareous shale, weathers light gray; limonitic bentonite bed at the base. Thickness 60 to 100 feet.

Lower Member. Dark-gray shale containing brown or gray septarian limestone concretions; bed as much as 8 feet thick of bentonite 30 to 60 feet above the base. Thickness 200 feet.

Frontier Formation. Dark-gray sandy shale and interbedded lenses of sandstone mostly in the lower part; red ferruginous concretions in the basal 70 feet and brown calcareous concretions near the top. Several beds of bentonite including the Soap Creek bed, locally more than 10 feet thick, at the top. The Frontier Formation and overlying Lower Member of the Cody Shale are assigned to the Belle Fourche Member of the Cody Shale by Knechtel and Patterson (1956). Thickness 275 feet.

Mowry Shale. Dark-gray silicious shale, siltstone, and very fine-grained sandstone; weathers light gray; contains many fish scales; several beds of bentonite including the Clay Spur bentonite bed at the top. Forms a broad ridge or cuesta. Thickness 345 to 400 feet.

Thermopolis Shale. Dark-gray shale; contains a zone of sandstone dikes about 350 feet below the top of the formation, and several beds of bentonite. A unit as much as 75 feet thick of light-gray sandstone and interbedded shale, assigned to the Newcastle Sandstone, is present at about the horizon of the sandstone dikes in the subsurface in the eastern part of the reservation. Thickness 425 feet.

Cloverly Formation.

Upper part. Dark-gray shale and interbedded thin-bedded brown slabby sandstone, underlain by red and gray shale and interbedded siltstone. A sandstone bed 8 to 15 feet thick at the top of the member in the valley of Pryor Creek has been called the Birdhead Sandstone. The brown sandstone and dark-gray shale sequence in the upper part of the unit is called the Fall River Formation or the Dakota Sandstone in drill holes in the eastern part of the reservation. Thickness 250 to 300 feet.

Pryor Conglomerate Member. Discontinuous ridge- and cliff-forming conglomeratic sandstone containing thin lenses of chert pebbles in a fine- to coarse-grained sandstone matrix. Conglomeratic sandstone and red and gray shale equivalent to the Pryor Conglomerate Member and its associated red shales are called the Lakota Formation in drill holes in the eastern part of the reservation. Thickness 0 to 150 feet.

Jurassic System.

Upper Jurassic Series

Morrison Formation. Nonresistant greenish-gray siltstone and sandstone and variegated shale. Thickness 140 to 280 feet.

Swift Formation. Light-gray glauconitic sandstone and siltstone and greenish-gray calcareous shale; ledge-forming very fine grained calcareous sandstone at the base. Thickness 90 to 170 feet.

Rierdon Formation. Olive-gray calcareous shale and oolitic lightgray limestone. Thickness 175-390 feet.

Middle Jurassic Series.

Piper Formation. Gypsum at the base overlain by light-gray thin-bedded ledge- and cliff-forming fine-grained limestone in the middle part, and red siltstone and shale at the top. Thickness 150 to 180 feet.

Triassic and Permian Systems.

Chugwater Formation. Upper part is moderate- to dark-red fine- to very fine grained sandstone and subordinate red siltstone and shale; contains a bed generally 5 to 10 feet thick of light-gray limestone from 90 to 200 feet below the top. Red shale and siltstone interbedded with gypsum and dolomite in the basal 30 to 40 feet. Basal part is equivalent to the Goose Egg Formation of northern Wyoming. Forms ridges and bluffs facing towards the mountains. Thickness 375 to 675 feet.

Pennsylvanian System.

Tensleep Sandstone. Light-gray to light yellowish-gray fine- to medium-grained crossbedded sandstone and a few thin beds of limestone and dolomite. Forms ledges and dip slopes on the mountain flanks. Thickness 0 to 115 feet.

Amsden Formation. Red shale and siltstone and gray sandstone, limestone, and dolomite; cherty in middle part. Thickness 230 to 280 feet.

Mississippian System.

Madison Limestone. Light-gray and light purplish-gray limestone and dolomite; chert beds 40 to 80 feet above the base. Breccia zones and solution caverns filled with fragments of red shale and siltstone and gray limestone in the upper 150 feet. Forms cliffs and broad dip slopes on the flanks and crests of the Bighorn and Pryor Mountains. Thickness 705 to 750 feet.

Devonian System.

Three Forks Shale and Jefferson Limestone, undivided. Upper part is light brownish- and greenish-gray shaly and sandy limestone; lower 100 feet is very light gray dolomite and dolomitic limestone; forms ledges. Equivalent Devonian rocks in the subsurface in the eastern part of the reservation are assigned to the Duperow Formation. Thickness about 240 feet.

Beartooth Butte Formation. Gray limestone and limestone breccia; interbedded red sandstone and shale. Fills channels cut at a few places on the underlying Bighorn Dolomite. Thickness 0 to 150 feet.

Ordovician System.

Bighorn Dolomite. Upper part is light-gray to white thin- to medium bedded dolomite and dolomitic limestone; lower 180 feet is lightgray to light-brown dolomite that commonly forms a single massive cliff. Ordovician rocks in the subsurface in the eastern part of the reservation are assigned to the Red River Formation and the underlying Winnipeg Sandstone. Thickness 285 to 480 feet

Cambrian System.

Gallatin Limestone and Gros Ventre Formation, undivided. Upper part is gray glauconitic limestone and flat-pebble limestone conglomerate interbedded with thin greenish-gray shale and siltstone partings; lower part is greenish-gray shale and siltstone containing a few beds of gray limestone. Thickness 700 feet.

Flathead Sandstone. Greenish-gray sandy shale and interbedded brown sandstone; a basal bed of coarse-grained reddish-brown sandstone contains small quartz pebbles. Thickness about 250 feet.

Precambrian rocks.

Gray and red granite cut by dikes of diabase, olivine gabbro, hornblende diorite, and peridotite.

Explanation for Figure 2

Quaternary and Tertiary	QT	Terrace deposits
Tertiary	Twf	Wasatch and Fort Union Formations
Late Cretaceous	Kh	Hell Creek Formation
	Ku	Upper Cretaceous rocks underlying the Hell Creek Formation
Early Cretaceous	Kl	Lower Cretaceous rocks
Jurassic and Triassic	JT	Jurassic and Triassic rocks
Permian, Pennsylvanian, and Mississippian	PPM	Permian, Pennsylvanian, and Mississippian rocks
Ordovician, Devonian, and Cambrian	ODC	Ordovician, Devonian, and Cambrian rocks
Precambrian	p∈	Precambrian rocks

Contact

Fault

Structure

The structural configuration of rocks in the Crow Indian Reservation is shown by Figure 3.

Folds

Bighorn and Pryor Uplifts

The Bighorn and Pryor uplifts coincide generally with the Bighorn and Pryor Mountains, parts of which extend into the southwestern part of the reservation. As described by Richards (1955, p. 69), the north end of the Bighorn Mountains is a northward-plunging anticline with a broad top and steep limbs. The surface rocks on much of the crest of the anticline are the Madison Limestone and overlying lower part of the Amsden Formation. Upturned edges of steeply dipping beds of the Tensleep Sandstone and overlying younger rocks up to the Frontier Formation comprise the steeply dipping northeast limb of the fold and wrap around the gently plunging north end. Between the Bighorn and Pryor Mountains to the west is a structural and topographic basin known as the Dryhead-Garvin basin in which Triassic and lowermost Jurassic rocks are mostly exposed.

The Pryor Mountains (Figure 2) define a broad-topped uplift having steeply dipping or faulted flanks (Blackstone, 1940). The Tensleep Sandstone, Amsden Formation, and Madison Limestone are widely exposed on the crest of the uplift. Steeply dipping Triassic and Jurassic rocks form the east flank. A fault abruptly terminates the uplift at its north end.

A very broad, low, poorly defined arch trends from the north end of the Bighorn Mountains northeastward through Hardin. Rocks east of this arch dip generally eastward at about 1°-2° into the Powder River basin in eastern Montana. Rocks west of the arch dip generally north-eastward or northward at about 1° into the Bull Creek syncline in central Montana.

Subsidiary Folds

Many folds subsidiary to the major mountain uplifts interrupt the otherwise uniform eastward or northeastward-dipping rocks on the flanks of the Bighorn and Pryor Mountains and in the plains to the north and east. Most of these folds have low amplitudes. As places near the mountains they are outlined by ridges or cuestas of resistant limestone or sandstone in lower Cretaceous or older rocks. Farther from the mountains where nonresistant Cretaceous or Tertiary rocks form the ground surface, the folds are topographically inconspicuous. Figure 3 shows the positions of some of the fold axes, and Table 2 lists their location, oldest formation exposed on crest, and amount of structural closure.

Explanation for Figure 3

Structure contours

Drawn on top of the Cloverly Formation or its subsurface equivalents; interval 500 feet; datum mean sea level. Contours projected above ground where the Cloverly Formation is eroded away; contours not shown on the crests of the Pryor and Bighorn uplifts

Fault

Axis of anticline

Axis of syncline

Named anticline, dome or uplift listed on Table 1

Data adapted from: Thom and others (1935), Richards (1955), Knechtel and Patterson (1956), Stewart (1958), and Petroleum Ownership Map Co.,Casper, Wyo., Structure contour map Powder River basin, 1974.

Faults

Faults have been mapped at many places in the Crow Indian Reservation by Blackstone (1940), Thom and others (1935), Richards (1955), Knechtel and Patterson (1956), and Stewart (1958), among others.

The North Pryor fault (Blackstone, 1940), or the Castle Butte fault as it was called by Thom and others (1935), terminates the Pryor Mountains on tile north, and is one of the largest faults in the reservation. Its maximum displacement is about 2,000 feet, up thrown on the south, and its linear extent is about 14 miles (Thom and others, 1935; Blackstone, 1940). It brings the Cloverly Formation on the north against the Madison Limestone on the south. A fault or fault zone branches northward from the North Pryor fault in T. 5 S., R. 25 E.; the Chugwater Formation on the west is brought into contact with the Cloverly Formation on the east along this zone of faults. According to Blackstone (1940), the North Pryor fault is reverse fault that dips southward under the north end of the Pryor uplift.

The Big Bull Elk fault is a northwest-trending vertical fault on the crest of the Bighorn uplift that extends for about 9 miles in Tps. 8 and 9 S., Rs. 30 and 31 E. According to Stewart (1958), the fault has a displacement of 2,400 feet, upthrown on the east, about 5 miles north of the Montana State line. Cambrian and Precambrian rocks on the east are brought against the Mississippian Madison Limestone on the west (Stewart, 1958).

The Garvin fault (Stewart, 1958) extends along the base of the steeply dipping west flank of the Bighorn uplift in Mississippian and Pennsylvanian rocks parallel to and about 3 miles west of the Big Bull Elk fault. Displacement along this fault is probably a few tens of feet, upthrown on the east. The Camp Creek fault, or fault zone (Stewart, 1958), extends at right angles from the Garvin fault westward into the Dryhead-Garvin basin in T. 8S., Rs., 28 and 29 E. The fault or fault zone has a cement of about 225 feet, upthrown on the south, where it crosses Bighorn River (Richards, 1955, p. 75).

An easterly trending fault in T. 5 S., Rs. 29 and 30 E., cuts the and northeast sides of Grapevine dome (Richards, 1955, p. 75). The cement of this fault is about 100 feet, upthrown on the south, and surface trace is about 3 miles long in Pennsylvanian and younger rocks. It dies out eastward in the Morrison Formation.

The Black Gulch fault zone (Thom and others, 1935) in T. 9 S., to 36 E., is a series of faults that trends discontinuously eastward in Jurassic and Cretaceous rocks across the Black Gulch dome and Aberdeen uplift for about 11 miles. The westernmost and largest faults in this zone has a maximum displacement of about 700 feet near crest of the Black Gulch dome (Knechtel and Patterson, 1956, pl 1).

Cretaceous and Tertiary rocks are cut by minor faults at several in the central part of the reservation north of the Bighorn Mountains. echelon zone of northeast-trending faults cuts the east flank of the reek anticline between the Woody Creek dome and the Two Leggin uplift. Southernmost and largest of these faults extends for about 4½ miles the Woody Creek dome, and has a displacement of about 200 feet, on the northwest (Richards, 1955, pl. 1). series of northeast- trending faults cuts the Fort Union Formation southeastern corner of the reservation near the Ash Creek anticline. the largest of these, along Youngs Creek in T. 9 S., R. 38 E., has a displacement of about 75 feet (Shell Oil Co., 1974). Other faults in the Fort Union Formation farther to the north have displacements generally than 50 feet.

MINERAL RESOURCES

General

The Crow Reservation contains potentially valuable resources of coal, petroleum, natural gas, bentonite, clay-shale for expanded, light- weight aggregate, limestone, dolomite, gypsum, zeolites, pumicite, building stone, and uranium.

The geologic occurrences and potential for development of selected rock or mineral resources in the Crow Indian Reservation are summarized in Table 3.

Energy

Coal

General

Coal mining in the western states is expanding at a rapid rate and is predicted to continue at least in the foreseeable future.

The coal resources on the reservation could contribute significantly toward supplying the expanding markets.

Coal occurs in the eastern part of the Crow Indian Reservation in the Cloverly, Parkman, a local nonmarine equivalent of the Bearpaw, Hell Creek, and Wasatch Formations, and in the Tullock, Lebo Shale, and Tongue River Members of the Fort Union Formation. The coals in all but the Tongue River Member of the Fort Union Formation are generally thin or limited in extent, and the resources are small. Coal constitutes a major resource in the Tongue River Member of the Fort Union Formation.

Coal in the Cloverly Formation

A bed of impure coal has been reported in the Cloverly Formation just south of the Little Bighorn River in sec. 22, T. 9 S., R. 34 E. (Thom and others, 1935, p. 46, 86). The coal bed is about 40 feet above the base of the formation and is interbedded with gray shale and yellowish-gray sandstone probably equivalent to the so-called rusty beds of the Cloverly. The coal is described as follows:

	Ft.	in.
Gray shale.		
Coal	4	2
Bone		3½
Coal	1	
Bone		3½
Coal	1	3½
	7	½

According to Thom and others (1935, p. 86) the coal could not be traced to nearby areas, and apparently is a local lens.

Coal in the Parkman Sandstone

A coal bed as much as 8 feet thick is reported by Thom and others (1935, p. 86) to have been penetrated by domestic water wells in the town of Lodge Grass. The bed was mined within a mile of town in sec. 13, T. 6 S., R. 35 E. The coal is under shallow cover in this vicinity, and may have possibilities for stripping (Thom and others, 1935, p. 86).

Coal in Nonmarine Equivalents of the Bearpaw Shale

Near the Montana-Wyoming border, the lower part of the unit mapped as the Bearpaw Shale by Thom and others (1935, pl. 1) contains a coal bed reported to be about 3 feet thick. Small amounts of coal were once mined from this bed in secs. 25 and 36, T. 9 S., R. 35 E. (Thom and others, 1935. p. 86; Knechtel and Patterson, 1956, p. 36, pl. 1). The coal-bearing unit is assigned by Knechtel and Patterson (1956) to the upper part of their Judith River Formation. They state that the coaly rocks grade northward within a few miles into marine rocks of the Bearpaw Shale that do not contain coal.

Coal in the Hell Creek Formation

Thom and others (1935, p. 87) state that the Hell Creek Formation called the Lance Formation in their report) contains a few thin, local streaks and lenses of coal of little commercial value. Measurements of he coal are not given.

Coal in the Fort Union Formation

Tullock and Lebo Shale Members

The Tullock Member of the Fort Union Formation is characterized by my thin beds of brown carbonaceous shale and, at many places in the northern part of the Powder River basin, thin beds and lenses of coal. None has been specifically reported in the Crow Indian Reservation, although coal beds as thick as 5 feet are present in the Tullock Member in the Tullock Creek coal field, which adjoins the reservation of the north (Rogers and Lee, 1923, pl. 15). Rogers and Lee (1923, pl. 14) reported a single bed less than 1 foot thick in the Tullock at the north boundary the reservation in T. 1 S., R. 36 E.

The Lebo Shale Member of the Fort Union Formation, which overlies the Tullock Member, has not been systematically examined for coal in the W Indian Reservation, but, like the Tullock, a few local lenses of coal characterize the member in adjoining areas. Barnum (1974) describes two 1 beds near the middle of the member, one about 3 feet thick and the other 6.5 feet thick within about 200 feet south of sec. 31, T. 9 S., 37 E. Beds at approximately the same elevation are 9 and 10 feet thick near the northwest corner of sec. 32, T. 9 S., R. 37 E., according to Thom and others (1935, p. 101), who regard them as questionably equivalent to the Sawyer and Lee coal beds, two coals in the Tongue River Member of Fort Union Formation farther north.

Tongue River Member

The Tongue River Member of the Fort Union Formation contains very large amounts of coal of commercial value in the Crow Indian Reservation. Coal-bearing rocks of the member underlie an irregular north-trending band, narrowing gradually to the north, that includes parts of Tps. 1 to 10 S., R. 37 E., and all of the adjacent Tps. 1 to 10 S., R. 38 E. The entire thickness of the member and part of the overlying Wasatch Formation are present in the Wolf and Rosebud Mountains in the southern part of this band; only the lower part of the member occurs in the northern part, north of T. 7 S.

Information on the coal in the Tongue River Member comes mainly from Thom and others (1935, p. 87-103). A map from this shows the position of coals near the base of the member (Thom and others, 1935, pl. 14). Recently, Shell Oil Company (1974) submitted to the U.S. Geological Survey, for environmental analysis, maps of coal in a proposed strip-mining area along Youngs Creek in the central part of T. 9 S., R. 38 E., and the Peabody Coal Company has made available to the Crow Indian Tribe information from drilling on coal leases in the northern part of the reservation in Tps. 1 to 3 S., Rs. 37 and 38 E. (Driggs and Hobbs, 1974). The Tongue River Member has been studied for its coal in adjacent areas to the south, east, and north (Rogers and Lee, 1923; Baker, 1929; Dobbin, 1929; Matson and Blumer, 1973; Barnum, 1974).

Coal in the Tongue River Member of the Fort Union Formation occurs in beds ranging from a few inches to at least 100 feet thick. Some beds have been traced widely in the northern part of the

Powder River basin; others are local lenses. The intervals between the beds are fairly constant in some areas. Locally, however, the coal beds abruptly merge or split with the result that coal-bed correlations at places are uncertain. Coal-bed thicknesses, likewise, vary appreciably from place to place.

The coal is subbituminous in rank. The sulfur content is in the range of 0.2 to 1.0 percent, and ash in the range of 4 to 11 percent for most beds at most places. Selected partial analyses of coal from the reservation and from closely adjacent areas are given by Table 4. Other analyses of Fort Union coals have been published by Matson (1969, p. 224 and by Matson and Blumer (1973) who give information also on the composition and feasibility of the coal ash.

The principal coal beds that underlie the reservation in the Tongue River Member are shown by eight stratigraphic sections, Figure 4 and Figure 5, and are briefly discussed below:

Roland Bed: The Roland bed, which lies at the top of the Tongue River Member of the Fort Union Formation, is commonly 8 to 13 feet thick adjacent to the reservation in Tps. 8 to 10 S., Rs. 38 and 39 E. (Baker, 1929, p. 61). The bed underlies high parts of the main stream divides farther west within the reservation in the same townships and probably in the eastern parts of the tier of townships to the west. The bed commonly is burned along its outcrop and under shallow cover, which reduces the amount of coal remaining. Substantial amounts are probably available, however, at shallow depths.

Smith Bed: The Smith bed lies about 190 to 200 feet below the Roland bed along the east side of the reservation. It is tentatively correlated with the D bed in the proposed Shell Oil Co. mine at Youngs Creek in the southern part of T. 9 S., R. 38 E. The Smith bed is as much as 16 feet thick in T. 8 S., R. 38 E. The coal is probably fairly widely distributed beneath interstream divides in Tps. 7 to 10 S., Rs. 38 and 39 E. Erosion as probably removed the Smith bed in most or all of T. 6 S. and townships farther to the north.

Anderson Bed: The Anderson bed is a thick and economically important coal in Tps. 7 to 10 S., Rs. 37 and 38 E. It is tentatively correlated with the G bed in the proposed Shell Oil Co. Youngs Creek mine. The Anderson lies about 120 feet below the Smith bed in areas adjacent to the Reservation on the east; within the reservation the Anderson bed, as tentatively correlated on Figure 4, is, at places, less than 20 feet below e Smith. Coal in the Anderson bed averages about 25 feet thick adjacent to the reservation in T. 7 S., Rs. 38 and 39 E. (Matson and Blumer, 1973, pl. 5A), and is 15 to 30 feet thick within the reservation to the west. Information was unavailable about the distribution and extent of the bed within the reservation, but its distribution in adjacent areas suggests the bed may underlie 80 or more square miles in Tps. 6 to 10 S., Rs. 37 and 38 E. with an average thickness exceeding 20 feet.

Dietz Bed: The Dietz bed and its presumed equivalents, the Monarch and M beds, lies from 40 to as much as 180 feet below the Anderson bed. Coal in the Dietz bed is more than 50 feet thick locally in the Squirrel Creek area, T. 8 S., R. 38 E., and is probably more than 30 feet thick at most places elsewhere in the Wolf and Rosebud Mountains in Tps. 6 to 10 S., Rs. 37 and 38 E. In areas near the reservation, coal at the Dietz horizon commonly occurs in two or more benches, separated by intervals of shale (Matson and Blumer, 1973). Correlation of the individual coal beds within the coal zone over distances of several miles is difficult and uncertain. Locally the Dietz and Anderson beds converge and form a nearly continuous coal sequence 80 to 100 feet thick.

Canyon Bed: The Canyon bed and its presumed equivalents the Slater Creek and 0 beds are thick and widespread in the southeastern part of the reservation, and together with the Anderson and Dietz beds, contain a large part of the total coal resource. The Canyon bed ranges in thickness rom about 10 to 25 feet. The Canyon and Dietz beds commonly are separated by 50 to 100 feet of sandstone and shale, but the two locally converge, such as near locality 1, Figure 4.

Wall Bed: The Wall bed of Baker (1929) is correlated with the Carney bed of areas south of the reservation (Barnum, 1974), and with the bed of the Shell Oil Co. in T. 9 S., R. 38 E. The Carney bed is the base of the Tongue River Member of the Fort Union Formation at the south edge of the reservation, as mapped by Barnum (1974). Coal in the Wall nearly 50 feet thick adjacent to the reservation in T. 6 S., R. 38 E., t the coal apparently thins southwestward to about 10 feet at the south edge of the reservation in T. 10 S., R. 38 E. Available information is sufficient to show the thickness and extent of the bed within the reservation north of T. 6 S., R. 38 E.; however, the part of the Tongue River Member that contains the Wall and overlying beds probably does not extend northward beyond the north end of the Rosebud Mountains in the southeastern part of T. 4 S., R. 37 E.

Rosebud bed.--The Rosebud bed is an estimated 500 to 600 feet below the Wall bed, and is an important coal bed in the northern part of the reservation in Tps. 1 to 4 S., Rs. 37 and 38 E. The coal averages about 16 feet thick in Tps. 1 and 2 S., Rs. 37 and 38 E., according to Driggs and Hobbs (1974, p. 3). Thom and others (1935, pls. 14 and 15) have mapped a coal bed 8 to 12 feet thick in T. 3 S., Rs. 37 and 38 E. that appears to be at about the horizon of the Rosebud bed. They tentatively identify a coal bed 9 feet thick as the Rosebud bed just east of the reservation in the southeastern part of T. 4 S., R. 38 E. The bed has not been recognized on logs of oil and gas wells southeast of this locality, and apparently the coal becomes thin or is absent within a short distance to the south.

The lower part of the Tongue River Member of the Fort Union Formation, including the part containing the Rosebud and older coal beds, grades southward in the east-central part of the reservation into shaly rocks containing little or no coal. Rocks equivalent to the lower part of the Tongue River Member are assigned to the Lebo Shale Member of the Fort Union Formation in the southeastern part of the reservation.

McKay bed.--The McKay bed has an average thickness of about 11 feet in Tps. 1 and 2 S., Rs. 37 and 38 E., and lies 2 to about 25 feet below the Rosebud bed (Driggs and Hobbs, 1974). It has not been positively identified south of T. 3 S., R. 38 E.

Robinson bed.--The Robinson bed averages about 15 feet thick and is 100 to 120 feet below the McKay bed in Tps. 1 and 2 S., Rs. 37 and 38 E. Its distribution farther south has not been determined.

Burley bed.--The Burley bed, with an average thickness of about 7 feet in Tps. 1 and 2 S., Rs. 37 and 38 E., is 55 to 60 feet below the Robinson bed, and is the lowest coal in the Tongue River Member of the Fort Union Formation in the northern part of the reservation. Like the Robinson bed, it has not been identified south of T. 3 S., R. 38 E.

Potential Resources

Potential resources of coal in the Crow Indian Reservation are estimated to be about 17 billion short tons in nine principal beds, as tabulated on Table 5. This figure will be modified by additional formation as it is made available from work in progress by the Shell and Gulf Oil Companies and by others. Coal beds are present in the reservation other than the ones for which estimates are made Oil Table 5, and these coals provide an appreciable additional resource.

Reserves

General

Coal underlies 33,000 acres in the eastern part of the reservation shown in Figure 6. In the northern part of the reservation in the Sarpy Creek area about 350 feet of the lower part of the Tongue River Member is present (Bureau of Indian Affairs, 1974, p. 71). In the Rosebud Mountains the entire section from the Badger Clinker to the e of the Tongue River Member is present (Thom and others, 1935, pl. 6).

The coal beds in the Tongue River Member commonly vary substantially thickness. In addition, some of the coal beds are split into or three benches, separated by as much as 50 feet (Warren, 1959, 570). The coal beds generally tend to thicken in a southwesterly section (Groff, 1968, p. 570). The coal beds dip about 50 feet per mile to the southeast in the southeastern part of the reservation and about 15 feet per mile in the northeastern part (Balster, 1973).

There has not been a systematic investigation of the minable coal resources on the reservation. However, areas north and southeast of reservation have been thoroughly examined. The information obtained these investigations can be projected onto the reservation to identify minable coal beds and to estimate the coal reserves in these beds.

TABLE 5

Potential Coal Resources in Selected Beds in the Tongue River Member of the Fort Union Formation, Crow Indian Reservation. [1,770 Short Tons of Coal per Acre Foot Assumed in All Calculations]

Bed name	Assumed average thickness (feet)	Assumed area (acres)	Resources (billions of short tons)
Roland	9	21,000	0.3
Smith	7	25,000	.3
Anderson	20	54,000	1.9
Dietz	35	90,000	5.6
Canyon	20	105,000	3.7
Wall	20	140,000	4.9
Rosebud	10	8,000	.1
McKay	10	8,000	.1
Robinson	10	3,000	.05
Total (rounded)			17

North of the Reservation

The most important minable coal beds in the northern part of the reservation and in the ceded area to the north of the reservation are the Rosebud, McKay, and Robinson beds. In the Sarpy Creek area, the Rosebud and McKay beds are combined to form a 32-foot-thick bed. An unnamed 3- to foot-thick bed (probably the Stocker Creek bed) is 5-10 feet below the Rosebud-McKay bed. The Robinson bed, about 20 feet thick, lies about 50-100 feet below the Rosebud-McKay bed.

Southeast of the Reservation

The Montana Bureau of Mines and Geology has thoroughly investigated the coal beds in the area southeast of the reservation that could be mined by surface methods (Matson and Blumer, 1973, p. 18-37). This area contained reserves in the Roland, Smith, Anderson, Dietz No. 1 and No. 2, Canyon, and Wall beds. Lateral projections of these beds onto the reservation indicate they could be mined by surface methods. Faults with displacements of as much as 200 feet may extend onto the reservation (Matson and Blumer, 1973, p. 21). Displacements of this magnitude could affect mining and detailed structure maps of these faulted beds would be a prerequisite to mining.

In the extreme southeastern part of the reservation, the Anderson (20 feet thick) is at or below the water level of Youngs Creek (Matson and Blumer, 1973, pl. 33). The combined Dietz No. 1 and No. 2 (52 feet thick) and the Canyon bed (13 feet thick) lie below the Anderson bed. Coal beds 27 feet thick and 7 feet thick underlie the Canyon bed. The combined thickness of these beds is 128 feet.

On the Reservation

A major source of information on the coal beds within the reservation is Magill, Hubbard, and Kock (1966, p. 16-19). The locations of the mines are shown in Figure 6, and bed descriptions and coal analyses are given in Table 6. Several mines are in coal beds in formations below the Tongue River Member. These beds tend to be thin and contain a high ash content, but their relatively easy access may favor early development.

The Keisling mine is inactive and located in NW ¼ Sec. 35, T- 4 S., R. 37 E. A section of the bed is as follows:

Top	Clay
Coal	4 feet 6 inches
Shale	0 feet 3 inches
Coal	0 feet 8 inches
Shale	0 feet 3 inches
Coal	9 feet 6 inches
Bottom	Shale

A 6-foot-thick coal bed lies about 15 feet below the mined bed. The Shaw mine is inactive and located about 8 miles east of Lodge Grass. The coal bed that was mined ranges from 9 to 11½ feet thick, but only the lower 6 feet was mined. The upper 4 feet (reportedly poor coal) was left to help support the soft sandstone and shale roof. Below the coal bed is shale. A 16-foot-thick coal bed is about 60 feet above the mined bed, and a 4- to 5-foot coal bed is 9 feet above the 16-foot coal bed.

The Glen Leming mine is inactive and located in the N ½ Sec. 16, T. 7 S., R. 36 E. A section of the coal bed is as follows:

Top	Clay
Coal (soft)	0 feet 10 inches
Clay	0 feet 2 inches
Coal	3 feet 2 inches
Bottom	Coal and shale

Other mines on the reservation produced coal for local use.

Magill and others (1966, p. 20) estimated that the reservation contains a minimum of 5 billion tons of coal and a maximum of possibly two or three times this amount.

The aggregate thickness of the coal beds north of the reservation is 60 feet. These coal beds tend to thin in a southerly direction toward the reservation (Rogers and Lee, 1923, pl. XIV, pl. XV). For example, a coal bed tentatively identified as the Rosebud bed is only 9 feet thick on the east side of Rosebud Creek at the mouth of Thompson Creek (Thom and others, 1935, p. 103, 104); whereas the Rosebud bed averages about 25 feet thick northeast of the reservation. Several coal beds lie above the Rosebud bed and should be present in the Spray Mountains and Little Wolf Mountains, but there is little information on the aggregate thickness of the coal beds in the northeastern part of the reservation.

Little information is available on the aggregate thickness of the coal beds in the eastern part of the reservation but, as indicated in Table 6, there is at least one coal bed as thick as 25 feet. In the southeastern part of the reservation, the aggregate thickness of the coal beds is 128 feet (Matson and Blumer, 1973, pl. 33). These coal beds can be assumed to be present in the Wolf Mountains and the Rosebud Mountains.

Surface mining is applicable for an estimated 10 billion tons on the Crow and Northern Cheyenne Indian Reservations (Rawlins, 1974a, p. 86). The estimated amount of this coal on the Crow Indian Reservation is 4-5 billion tons. In the ceded area north of the reservation, an estimated 1½ to 2 billion tons of coal can be mined by surface methods in the Sarpy Creek area (Rawlins, 1974b, p. 58). Several coal beds have been mapped in the ceded area by Rogers and Lee (1923, pls. XIV, XV, and XVI), but are uniformly too thin to be mined at this time.

Coal Characteristics

The coal in the Tongue River Member of the Fort Union Formation on the reservation is typically subbituminous Crank. Coals of this rank contain a high moisture content with heat values ranging from 8300 to 9500 BTU's per pound on a mineral matter free basis and are noncoking.

Analyses of the coal on the reservation and surrounding areas are given in Table 6. 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 8400 BTU's per pound (Rawlins, 1973, p. 121).

Subbituminous coals from Montana are inferior to bituminous coals that are mined in eastern and central United States because of the much higher moisture content and lower heat values. These detrimental qualities, however, tend to be offset by low sulfur contents and low ash contents.

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 during oxidation and can result in spontaneous combustion. As a consequence, subbituminous coal cannot be stored in large piles for long periods of time.

A few of the coal beds, such as the McKay bed, on the reservation may contain a high sulfur content. The average sulfur content of six drill cores of the McKay bed in the Colstrip area was 1.50 percent (Matson and Blumer, 1973, p. 78, 80). The Dietz No. 1, Wall, and Canyon beds in the southwestern part of the reservation (Matson and Blumer, 1973, p. 34, 35, 38-40) contain partings and inclusions which have high ash content as well as a high sulfur content. The sulfur in these partings is normally pyrite, but occasionally there is high organic sulfur.

Coal Preparation

Modern coal preparation techniques can lower the ash content of run-of-mine coal by removing shale partings, sandstone inclusions, pyrite lenses, sulfur balls, and other high-density materials.

Little information is available concerning cleaning characteristics of the subbituminous coals that are on the reservation. However, 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 to 0.56 percent.

Cleaning the Rosebud coal at 1.50 specific gravity or higher would present no particular difficulty. These results are probably typical of what can be expected from mechanically cleaning similar coals on the reservation.

Neither finely-disseminated pyrite nor organic sulfur can be removed by mechanical cleaning. Organic sulfur can be removed form coal by a process that was recently developed by the Mineral Research and Exploration Institute of Turkey (Abelson, 1973, p. 793). In this process, the coal is briefly heated 400ºC 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

Applicable coal mining methods are surface mining and underground mining. The gently rolling and relatively flat topography on the reservation is suitable for area strip mining. This mining method will be by far the most important for mining coal on the reservation.

At an area strip 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 out 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.

Surface Mining

Surface mining, specifically the area strip method, dominates coal mining activity in eastern Montana. This is likely to continue in the immediate future because surface mining has been described "as the only truly economic method of large-volume production of low rank coal" (Groff, 1968, p. 43).

There are, at present, five large-production coal mines in eastern Montana; all are area strip mines. Four of these are in the reservation area--one near Decker to the southeast of the reservation, one at Sarpy Creek to the north, and two near Colstrip northeast of the reservation. Surface coal mining in other localities on the reservation would probably follow successful practices at these mines.

Water will be required at surface coal mines for road 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). The water quantity necessary for road sprinkling will depend on the weather and length of road networks. The water required for all purposes may range from 90,000 to 250,000 gallons per day (U. S. Bur. Indian Affairs, 1974, p. 16).

The 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. The annual acreage required, assuming a 90 percent recovery, 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 7. 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.

The Bureau of Mines study assumes 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 $8.12 per ton for the United States. However, 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, 1975, 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.

TABLE 7

Summary of Capital Investment, Operating Costs of Coal for an Open Pit Mine--annual Production 9.2 Million Tons (Katell and Others, 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 percent discount cash flow)	2.66

Auger mining, which is a variety of surface mining, has gained wide use in the eastern coal province. This type of surface mining will have little application on the reservation because of unfavorable topography. 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, such as in the valleys of Rosebud Creek and its tributaries in the southwestern part of the reservation (Matson and Blumer, 1973, pl- 33).

Underground Mining

Most of the coal mined in the United States has been mined by underground methods, specifically by the room and pillar method. However, because of technical as well as economic limitations, coal on the reservation cannot be mined by underground methods.

Markets and Uses

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 specific limits. Similarly, a minimum heat content is specified. Also of importance are the softening temperature, the initial deformation temperature, and the 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. These parameters should be determined in future investigations of reservation coals.

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), and the ash and sulfur content can usually be reduced and the heat content increased by mechanical cleaning. However, most subbituminous coal is sold as crushed run-of-mine coal that has not been upgraded, and the price at the point of shipment is adjusted accordingly.

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). Coal from the reservation could play an important role in supporting an industry that is related to Montana iron ore deposits. Coal firing for iron-ore 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). 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

The widening gap between supply and demand of 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, oxygen, and steam are combined in a pressurized reactor. 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.

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 methods 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 may be sufficient to supply quantities of this magnitude. An estimate of the cost of 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, 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 will 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. In a commercial underground coal gasification project, boreholes would be drilled from the surface into the coal bed, and would be linked by directional drilling, or by lasers (Perry, 1974, p. 25). The coal would then be fractured hydraulically or by explosives and the coal ignited. Oxygen and possibly steam would be injected down one borehole and gas removed from another. When the coal between the boreholes is depleted, the process will be transferred to another borehole couple.

Underground gasification in its final developed form may be a relatively inexpensive 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, p. 1297). Several coal beds on the reservation are in this category.

Before effective gasification can take place, several potential problems must be solved. These are: subsidence, insuring a uniform flow and quality of the gas, and contamination of groundwater. Nevertheless, underground gasification may offer a solution to the recovery of a large part of the coal resources on the reservation, most of which cannot be mined economically.

Synthetic Liquid Fuels

The large-scale conversion of coal to synthetic liquid fuels has been an attractive possibility for many years. High-volatile, bituminous coals with a high hydrogen content are best for use in hydrogenation processes because the cost of reacting additional hydrogen with the coal is reduced. Therefore, future synthetic liquid fuel plants using hydrogenation processes will probably not use low rank coals such as those found on the reservation.

Research is continuing on gas synthesis processes, however, mainly because low-cost subbituminous coal can be used. Significant progress in gas synthesis technology could result in a substantial market for reservation coal.

Transportation

General

Assuming that large-scale mines are developed on the reservation, most of the coal will be utilized in distant markets. There are two ways these markets can be supplied. First, the coal would by simply shipped to the distant markets; the most likely transportation method would be unit trains, but slurry pipelines are possibilities. 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 train 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 to electrical power generation plants. Surface mining along with unit train 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 Pipeline

The alternative to unit train 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. The advantages are those of a continuous transportation system, and low labor costs. 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. Five wells tap deep sandstone aquifers (3,500-3,800 feet deep) to supply water for the pipeline (Coal Age, 1971a, p. 82).

An important problem for some areas is supplying the volume of water required. 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 from a semiarid region.

Electrical Power System

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 annually require about 2.5 million tons of coal and about 20,000 acre feet of water. 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. The water requirement can be further reduced to 2,000 acre feet per year with a dry cooling tower. Dry cooling towers, which are similar in principle 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 of 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 coal to 25 where a relatively large supply of cooling water is available.

Byproducts: Coal-fired electrical generating plants produce large volumes of ash. Bottom ash and especially fly ash however 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, concrete 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 U.S. 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.

In 1972, total ash production in the United States was 46 2 million tons, but overall utilization was only 7.5 million tons. The lack of probable markets near the reservation indicates that fly ash from mine site electrical power plants will- present a disposal problem. Fortunately, both fly ash and bottom ash can be conveniently buried along with spoil at surface mines. This disposal method has been successful in Arizona.

Synthetic 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. The advantages are primarily due to economies resulting from optimized design and operation that are associated with large-scale production. The 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. Requirements for location are: large supplies of coal, adequate water supplies, manpower availability, and attendant factors such as adequate housing, roads, etc., and 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, and possibly the large coal reserves on the reservation. 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

Surface Rehabilitation

The environmental aspects of surface mining of western coals, especially the rehabilitation of mined land, has recently received a large amount of attention. Much concern has developed from past practices in the eastern United States. The practice of casting spoil over the hillside at contour surface mines caused stream silting and acid drainage from the exposed pyrite-bearing rocks. However, contour surface mining is not generally applicable to the coal beds on the reservation; the topography is much more favorable to area strip mining.

A study by the National Academy of Sciences concluded that there "presently exists technology for rehabilitating certain western sites with a high probability of success" (National Academy of Sciences, 1974). These include sites with over 10 inches of annual rainfall. The annual precipitation at Lame Deer is 12 to 16 inches, and therefore rainfall will 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, topsoil removal, overburden removal, coal removal, spoil grading, topsoil 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 input from mining engineers, hydrologists, soil scientists, range managers, wildlife managers, and foresters.

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

Grading of spoil is costly, and consequently much attention has 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 equipped with a blade 24 feet wide and 86 inches high. Grading to about a 16 percent slope appears to be satisfactory at Colstrip.

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

The 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, 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 inkling 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 topsoil ranges from $250 to $500 acre. The cost of spoils shaping, placing topsoil, seedbed preparation, ding, 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, prevention of water pollution, and planting and seeding of reclaimed land, was approximately $2,000 to $2,500 per acre (Weir, 1973, p. 27).

Rehabilitation methods for surface mined lands have only been briefly covered here. Persse (1973) has evaluated surface mining techniques minimize environmental damage and his work should be consulted if further tail is needed. 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 flow disruption may 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). It is expected that after mining, water in all affected wells other than those removed by mining will adjust upward and may become higher than pre-mining levels.

Emissions

Sulfur dioxide ($S0_2$) emissions from coal burning plants are harmful to both plant and animal life, if in sufficient concentration. The Environmental Protection Agency has set the limit on $S0_2$ emissions from new power plants as 1.2 pounds of $S0_2$ 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 emission controls or by burning coal containing lesser amounts of sulfur. The Btu vs. coal sulfur content relationship for conformance to the EPA standard is shown in Figure 7. Ten percent of the sulfur is presumed to remain in the ash (Zachar and Gilbert, 1968, p. 5-24). For coal containing 8500 Btu's 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 $S0_2$ 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 southeastern part of the reservation.

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, such as concrete admixtures, construction and fill material. Any future investigations of reservation coals should include checks for radioactive elements.

Some trace elements in coal such as arsenic and mercury may also be health hazards due to their liberation during combustion. New standards have been proposed by the Occupational Safety and Health Administration (O.S.H.A.) which 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. Future investigations of reservation coals should include mercury and arsenic analyses as well as analyses of other elements that could possibly cause a health hazard.

Recommendations

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 should include ground surveys by geologists and engineers, aerial surveys, diamond drilling, and appropriate laboratory analyses to determine the quality of the coal.

2. Because conventional underground coal mining is limited to coal beds less than about 10 feet thick, 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 2 years and underground mining systems may be developed to successfully mine the deeper coal beds such as those on the reservation. Therefore, it is important to determine, the quality and extent of the deeper coal beds, although the timetable for pertinent underground mining research developments is not known.

3. Studies should be undertaken to establish minimum rehabilitation requirements of surface mined lands. The study should consider present or potential use of shallow aquifers, farm and range potential, and the entire ecosystem.

4. Development of the coal resources on the reservation will depend to some extent on available water. Also, on-site conversion of coal to other forms of energy, such as electricity, gas, and liquid fuels, will require water resource developments such as dams and aqueducts. Investigations should be made to establish water sources and methods for making these water supplies available while minimizing disruptions to present users.

Petroleum and Natural Gas

General

Four oil fields and one gas field have been discovered on and near the reservation (Magill and others, 1966, p. 20). Two oil fields on the reservation are the Soap Creek and Lodge Grass fields (Figure 1 and Figure 8). Ash Creek oil field, on the Montana-Wyoming border, and the Hardin gas field, on the north boundary of the reservation, are both partly within the reservation (Figure 1 and Figure 8). The Snyder oil field, northeast of the Mardin gas field, is just outside the reservation (Magill and others, 1966, p. 20). As of January 1, 1975, no new oil or gas fields had been discovered on the reservation. Table 8 summarizes pertinent data.

Oil and gas were first discovered on the reservation at the Soap Creek oil field in 1921 (Thom and Moulton, 1921). Exploration has proceeded intermittently on and near the reservation since then. A total of about l90 wells had been drilled for oil and gas on the reservation to the end of 1974. Of these, about 85 are field wells drilled to define and develop the Soap Creek, Hardin, Ash Creek, and Lodge Grass fields, and the others are unsuccessful tests drilled to depths of a few hundred to more than 10,000 feet, and are widely scattered in the eastern and northern parts of the reservation.

Geologic Setting and Controls

Two formations of Late Cretaceous age (Cody Shale and Frontier Formation) and three of Pennsylvanian or Mississippian age (Tensleep Sandstone, Amsden Formation, and Madison Limestone) are productive in one or more of the fields.

Oil and gas are thought to be generated from organic matter in marine rocks by microbial activity and by heat and pressure during burial and lithification. The oil and gas hydrocarbons, along with interstitial formation waters, are expelled by compaction of the sediments into any available porous and permeable stratum in which the hydrocarbons migrate to regions of lower pressure. Movement generally is updip. Most of the fluids and gases escape to the surface and are dissipated. Under certain favorable conditions, however, oil and gas will separate from the moving Formation water and accumulate in sealed-off reservoirs or traps underground. Hydrocarbon traps can form structurally by folding or faulting, or they an form stratigraphically as a result of intraformational changes in the porosity and permeability of the reservoir rocks. In both structural and stratigraphic traps, the hydrocarbons accumulate under pressure in the structurally highest part of the trap. Formation water is displaced from e trap and escapes at structurally lower levels.

Structural traps favorable for accumulation of oil and gas can be discovered by careful mapping of the surface rocks, or by conventional geophysical techniques. Traps formed mainly by intraformational variations of permeable and impermeable strata are not directly detectable from the surface. Recognition of areas that might contain stratigraphic traps depends on an accurate analysis and reconstruction of the depositional and structural history of the rocks to be explored, and an understanding of the fluid dynamics of the depositional basin. Information helpful in such analyses become available partly as a result of the exploration itself.

Almost all the sedimentary rocks in the Crow Indian Reservation older than the Late Cretaceous Hell Creek Formation are marine in origin, except for the Morrison and lower part of the Cloverly Formations. Fossils and sedimentary features indicate that most of the rocks were deposited in warm epicontinental seas that were shallow or intermediate in depth and that supported abundant marine life. Much of the very thick sedimentary column, therefore, consists of rock units that are either potential source rocks, potential reservoir rocks, or both.

Potential Resources

The Powder River basin in Wyoming and Montana, including the Crow Indian Reservation, which is partly in the basin and partly adjacent to it on the west, is a major oil producing region in the Rocky Mountain area. Most of the oil production, to date, has come from the Wyoming part of the basin, and most of the production in Wyoming is from the east side of the basin--the side opposite from the reservation. The productive formations are continuous from Wyoming into Montana, and many of the sedimentary features that favor the accumulation of oil and gas in Wyoming are found also in Montana.

The main anticlines and domes in the reservation that show structural closure at the surface and thus have possibilities as structural traps for oil and gas have been tested. Except for the Soap Creek anticline, one has been productive. Three minor domes described by Thom and others (1935, pl. 1) have not been drilled, and these offer potential for small amounts of oil and gas. These three are the Plum Creek anticline, Birdhead some, and Boundary dome, all in the western part of the reservation (Table 2). The Shively Hill dome in T. 5 S., R. 27 E. has about 500 feet of closure, according to Thom and others (1935, pl. 1), and has not been drilled, but it is breached by erosion to the Madison Limestone, and therefore has only the very limited interval of Devonian and Ordovician rocks that might contain oil and gas.

About 100 townships or parts of townships with a total area of about 3,100 square miles, or about 85 percent of the reservation, are underlain by sedimentary rocks that have potential for oil and gas accumulation in stratigraphic traps. Oil- and gas-bearing sedimentary rocks are locally eroded to the Precambrian basement in the Pryor and Bighorn uplifts, and the mountainous areas are, therefore, considered unfavorable for petroleum.

Prospective areas are shown on Figure 9, Figure 10, and Figure 11 for each of six rock sequences that underlie parts of the reservation. The density of drilling is also indicated on the maps for each of the sequences.

Upper Cretaceous rocks older than the nonmarine Hell Creek Formation consist mostly of marine shale with some intercalations of sandstone, and are about 4,000 feet thick where present in their originally deposited thickness in the eastern part of the reservation, generally east of the Little Bighorn River. These rocks are a maximum of about 1,000 feet thick in the western part of the reservation where the Niobrara Member of the Cody Shale and older rocks are at the surface. Reservoir rocks of Late Cretaceous age that have good possibilities for accumulations of oil and has in the eastern part of the reservation are the Shannon Sandstone in the upper part of the Cody Shale and the Parkman Sandstone. Sandstone beds and lenses in the upper part of the Frontier Formation, which are very poorly developed in the southeastern part of the reservation become somewhat thicker and more numerous to the north and northwest (Thom and others, 1935, p. 49) and are potential reservoirs in the northern part of the reservation. About 15 percent of the prospective area of Upper Cretaceous rocks can be rated as moderately well explored for stratigraphic traps (5 wells or more per township); the remaining 85 percent of the area is rated as poorly explored or unexplored.

Lower Cretaceous rocks consist of marine shale and sandstone, except for the Pryor Conglomerate Member of the Cloverly Formation and a few feet of overlying red and gray shale and claystone, which are nonmarine.

The Lower Cretaceous rocks are 800 to about 1,000 feet thick in the Crow Indian Reservation, thinning from northwest to southeast. Oil and gas have not been found in the Lower Cretaceous sequence on the reservation, but the Newcastle Sandstone, which is present in the subsurface in the eastern part of the reservation, is a prolific producer of oil and gas at many places on the east side of the Powder River basin in Wyoming and Montana. Small amounts of oil and gas are produced from the so-called Mosser Sandstone, a coarse-grained sandstone about 60 feet thick in the Cloverly Formation at Mosser dome, about 6 miles west of the reservation in the southeast part of T. 3 S., R. 24 E. (Hadley, 1958; Perry, 1960, p. 68-69). Rocks equivalent to the rusty beds in the upper part of the Cloverly Formation produce oil and gas in the east-central part of the Powder River basin in Wyoming (Kinnison, 1971, p. 605-607). Both the Newcastle Sandstone and Cloverly Formation have possibilities for oil and gas in stratigraphic traps in the reservation. Less than 5 percent of the prospective area of Lower Cretaceous rocks can be rated as moderately well explored; more than 95 percent is poorly explored or unexplored.

Jurassic, Triassic, and Permian rocks are about 1,300 feet thick on the reservation, and are marine in origin except for the nonmarine Morrison Formation at the top of the sequence. This group of rocks comprises a varied sequence of sandstone, shale, limestone, dolomite, and gypsum. Sandstone beds in the Morrison and Swift Formations of Jurassic age contain oil in central Montana (Perry, 1960, p. 16), and these formations probably have the best potential in the sequence for oil and gas in the Crow Indian Reservation. Perry (1960, p. 16) points out, however, that the sandstone beds in the Jurassic rock units tend to be shaly and limey, porosity is low, and the sandstones generally make poor reservoirs. Jurassic, Triassic, and Permian rocks have not been thoroughly tested except at the Soap Creek and Woody Creek domes, in a small area in the vicinity of the Lodge Grass field, and in a small area southwest of Pryor. More than 95 percent of the prospective area is poorly tested or is untested.

Pennsylvanian rocks in the reservation included in Tensleep Sandstone and most of the Amsden Formation, which together are about 300 to 400 feet thick. Both formations are marine, and both contain oil and gas within the reservation at the Soap Creek field. The Tensleep Sandstone also contains oil nearby to the east in the Lodge Grass field and within a mile north of the reservation in the small Snyder field, east of Hardin. Equivalents of the Tensleep and Amsden Formations are called Minnelusa formation inmost of the Powder River basin; the Minnelusa produces oil and gas from several places in the Wyoming part of the basin (Kinnison, 1971, p.601-602). The Tensleep, in particular, contains porous sandstone beds having good reservoir characteristics. Its potential for stratigraphic traps within the reservation has barely been tested except for small areas in the Soap Creek and Lodge Grass fields, and small areas on the Woody Creek dome and southwest of Pryor.

The Mississippian Madison Limestone, which ranges from 700 to about 1,200 feet thick, contains oil and gas in its upper part at the Soap Creek field, and is a potential producer elsewhere in the reservation. Kinnison (1971, p. 596) notes that the Madison has good reservoir characteristics at many places in Montana, and shows of oil have been ported from the formation in several areas. As a negative factor, the Madison commonly contains fresh formation water, indicating that the formation has been at least partly flushed out by underground water that may have carried away much of the petroleum originally present (Kinnison, 1971, p. 598). Exploration of the Madison appears to have the reservation has conducted mainly within about 10 miles of the mountain front where formation is near the surface. The Madison appears to have fairly potential in other parts of the reservation, including particularly along the axis of the broad fold that includes the Woody Creek dome and two Leggin uplift as local culminations (Figure 3).

Devonian and older sedimentary rocks are about 1,200 feet thick in reservation, and include dolomite, limestone, shale, and sandstone, all of marine origin. The Bighorn Dolomite of Ordovician age and it surface equivalent to the east, the Red River Formation, contain shows of petroleum in many parts of the Powder River basin in Montana, and the formation is reported to have local zones of vuggy porosity that give it good reservoir characteristics (Perry, 1960, p. 21; Kinnison, 1971, p. 595).

Ordovician and older rocks have been penetrated by only nine widely scattered wells (Table 9), and their potential is very poorly tested in the reservation.

Estimating the oil and gas resource potential in the reservation is highly speculative; however, large areas in the reservation are poorly explored for petroleum in stratigraphic traps, especially in rocks older than Cretaceous and it seems likely, therefore, that additional deposits will be found. Kinnison (1971, figure 27) has estimated that the total amount of oil in place in the Powder River basin in Cretaceous and older 28 rocks is 17.8 billion barrels, or about five times the cumulative production plus known reserves to the end of 1971. On the same basis, potential resources of oil left to be discovered in the Crow Indian Reservation would be about 40 million barrels.

History and Production

Soap Creek Oil Field

The Soap Creek field is in secs. 27, 28, and 34, T. 6 S., R. 32 E., in the center of the Crow Indian Reservation (Figure 8 and Figure 12). The field is on the crest of the Soap Creek dome, which has more than 500 feet of closure, and dips ranging from gentle on the west to 30º on the east. The Morrison Formation is exposed on the crest, and the overlying Cretaceous formations are exposed on the flanks. Surface elevations of the field range from 3,412 to 3,639 feet (Magill and others, 1966, p. 27).

The discovery well, Western States Oil and Gas Co. No. 1 Tribal, is in sec. 34, T. 6 S., R. 32 E., and was completed February 11, 1921. It initially produced 200 barrels of 19º API gravity oil from an interval between 1,642 and 1,647 feet in the Amsden Formation. Development drilling led to the discovery of oil in the Madison and Tensleep Formations. Oil from these two formations is heavy and has an API gravity of 20º (Magill and others, 1966, p. 27).

Forty-three wells have been drilled in the field (Figure 12). Twenty eight were on Indian land and 15 were on deeded land. Although the field as discovered in 1921, the major portion of the development drilling was done between 1950 and 1960 (Magill and others, 1966, p. 28). On March 1, 1975, there were 21 producing wells, five shut-in wells, nine dry holes, and eight abandoned wells. Sixteen producing wells, three shut-in wells, four dry holes, and five abandoned wells were on Indian land.

The field produced intermittently from 1921 through 1946 and yearly since 1947. The maximum annual production was 216,603 barrels in 1956. The maximum annual production from tribal land was 154,286 barrels in 1956. (Magill and others, 1966, p. 28). Cumulative production from tribal lands 1,403,306 barrels through 1974 (Table 10). Cumulative production from the Soap Creek oil field was 1,796,399 barrels through 1974 (Table 11). A log of Petroleum Producers No. 8 Crow Tribal well shows the following depths, in feet, to formation tops: Morrison, 1958; Swift, 397; Rierdon, 96; Piper, 767; Chugwater, 996; Phosphoria, 1,368; Tensleep, 1,493; Amsden, ,530; and Madison, 1,835 (Magill and others, 1966, p. 28).

Lodge Grass Oil Field

The Lodge Grass field (Figure 8 and Figure 13) is in secs. 6, 7, 16, and 17, 6 S., R. 36 E., Big Horn County. Surface elevations of the field average 3,580 feet (Magill and others, 1966, p. 26). The discovery well, Amerada Petroleum Co. No. 1 Yellow Mule is in ¼, NW ¼, sec. 6, T. 6 S., R. 36 E., and was completed April 22, 1964. Initial production was 165 barrels of oil and 18 barrels of water daily. Amerada Petroleum and Continental Oil Co. No. 1-A Crow Tribal well in SW ¼, SW ¼, sec. 16, T. 6 S., R. 36 E., was completed May 16, 1964. Initial production was 140 barrels of oil daily (Magill and others, 6, p. 27). Ten wells have been drilled in the Lodge Grass field area (Figure 13). January 1, 1975, there was one producing well, three abandoned oil wells, and six dry holes. The one producing well is on Indian land.

TABLE 10

Oil Production from Indian Leases, Soap Creek Field. [-, no production for that year]

Year	Barrels	Year	Barrels
1932	6,812	1954	44,880
1933	4,985	1955	65,468
1934	58,878	1956	154,286
1935	28,496	1957	100,761
1936	3,778	1958	53,206
1937	694	1959	54,208
1938	3,778	1960	42,206
1939	--	1961	54,286
1940	--	1962	42,777
1941	--	1963	32,236
1942	150	1964	43,747
1943	--	1965	46 054
1944	1,108	1966	38,380
1945	338	1967	57,281
1946	60	1968	53,460
1947	11,218	1969	51,393
1948	10,389	1970	45,404
1949	--	1971	47,417
1950	26,917	1972	40,840
1951	44,902	1973	41,827
1952	14,940	1974*	38,608
1953	37,138		

*Cumulative production to January 1, 1975 is 1,403,306 barrels.

Sources: 1932-1964, inclusive, (Magill and others, 1966, p. 28) and 1965-1974, inclusive, U.S. Geol. Survey, Conservation Division. Billings, Montana.

TABLE 11

Oil Production from Soap Creek Field (1964-1974).

Year	No. producing wells	Barrels
1964	20	57,397
1965	15	58,256
1966	15	50,557
1967	17	55,931
1968	18	63,555
1969	17	61,882
1970	17	54,733
1971	18	56,640
1972	18	48,344
1973	12	49,250
1974*	18	47,381

*Cumulative production to January 1, 1975 is 1,796,399 barrels. Reserves as of January 1, 1974 are 351,000 barrels.

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division.

The field produced from two separate pools in the Tensleep Formation. Maximum annual production was 39,535 barrels of oil in 1967 (Table 12). Cumulative production from the Lodge Grass oil field was 211,839 barrels through 1974 (Table 12). Oil production from Indian leases is shown in Table 13. Cumulative production through 1974 was 123,691 barrels.

The log of the Amerada Petroleum Co. No. 1 Crow well shows the following depths, in feet, to formation tops: Mowry, 4,107 (-386); Muddy, 4,656 (-935); Skull Creek, 4,666 (-945); Dakota Silt, 4,749 (-1,028); Rierdon, 5,554 (-1,833); Gypsum Spring, 5,758 (-2,037); Chugwater, 5,883 (-2,162); Tensleep, 6,384 (-2,663); and Amsden, 6,509 (-2,788) (International Oil Scouts Association, 1965).

Hardin Gas Field

The Hardin gas field (Figure 8 and Figure 14) is on the extreme northern edge of the Crow Indian Reservation in T. 1 S., R. 33 and 34 E., Big Horn County; only part of it is on the reservation. The field is located on a structural fold that extends northeast from the Bighorn Mountains. Surface formations consist of terrace gravels and shales of the upper part of the Colorado Shale Formation. Surface elevations range from 2,900 to 3,125 feet (Magill and others, 1966, p. 25). Gas was discovered in a well drilled on the Charles Bear Ranch in 1913. The well was drilled to 2,210 feet in the Kootenai Formation and plugged back to a depth of 725 feet in the Frontier Formation. The sand thickness ranges from 8 to 22 feet; permeability and porosity are poor and gas pressure is low resulting in slow recovery (Magill and others, 1966, p. 25). All the well locations are not shown on the map because of a lack of early drilling records. On January 1, 1975, there were 48 gas wells, 34 were producing gas and 14 were shut-in (Table 14). On January 1, 1975, there were four producing gas wells on Indian lands.

TABLE 12

Oil Production from Lodge Grass Field.

Year	No. producing wells	Barrels
1964	2	30,955
1965	2	24,053
1966	3	23,230
1967	3	39,535
1968	3	25,143
1969	2	18,739
1970	2	14,789
1971	2	11,428
1972	2	9,181
1973	1	7,490
1974*	1	7,296

*Cumulative production to January 1, 1975 is 211,839 barrels.

Source: 1964-1970 inc. and 1973-1974 inc. Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, 1971-1972, Phillips Petroleum Co., Bartlesville, Oklahoma

TABLE 13

Oil production from Indian leases, Lodge Grass field

Year	Barrels
1964	18,011
1965	15,235
1966	10,335
1967	9,277
1968	12,085
1969	14,949
1970	12,028
1971	9,399
1972	7,586
1973	7,490
1974*	7,296

*Cumulative production to January 1, 1975 is 123,691 barrels.

Source: U.S. Geol. Survey, Conservation Division, Billings, Montana

TABLE 14

Production from Hardin Gas Field

Year	No. Wells Producing	Wells S.I.	Thousand cubic feet
1960	41		42,289
1961	41		53,776
1962	41		53,978
1963	41		48,630
1964	41		47, 394
1965	41		40,102
1966	38		41,005
1967	38		43,377
1968	48		36,068
1969	17	31	30,514
1970	17	31	29,151
1971	35	13	29,742
1972	35	13	21,120
1973	30	18	26,686
1974*	34	14	31,327

*Cumulative production to January 1, 1975 is 1,242,541,000 cubic feet.

Source: 1960-1974, Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division Cumulative production, Phillips Petroleum Co., Bartlesville, Oklahoma.

The first production from the Hardin gas field was in 1929, but the first recorded production from tribal land was in 1950. The maximum annual production from the field was 121,194,000 cubic feet in 1948 Magill and others, 1966, p. 26). Cumulative production to January 1, 1975, is 1,242,541,000 cubic feet (Table 14) of which 175,716,000 cubic feet was produced from tribal land (Table 15). In 1951, the field was connected to the Montana-Dakota Utilities gas pipeline (Magill and others, 1966, p. 26). The field also supplies part of the gas used in Hardin.

The log of No. 1 Crow Tribal well in the center NE ¼, SE ¼, Sec.27, T. 1 S. , R. 34 E. , shows the following depths, in feet, to formation tops: Frontier, 442; Muddy, 1,873; Dakota, 1,988; Lakota, 2,372; Morrison, 2,433; Ellis Group, 2,563; Chugwater, 3,169; Tensleep, 3,376; Charles, 3,750; and Amsden, 3,783 (Magill and others, 1966, p. 26).

Ash Creek Oil Field

The Montana portion of the Ash Creek oil field is in Sec. 3, T. 10 S., R. 38 E., Big Horn County (Figure 8 and Figure 15). The field lies on a structural nose plunging southeast into the Powder River basin. The northwest end of the nose is cut off by a northeast-trending fault. The field is east of the Bighorn Mountains in hilly terrain, and the surface exposures are of Fort Union Shale. Surface elevations range from 4,300 to 5,000 feet.

The discovery well was drilled in Wyoming in 1952. The first producer in the Montana portion of the field was J. Ray McDermotts No. 1-C Tribal well, completed July 22, 1953, in SW ¼, SW ¼, SW ¼, Sec. 3, T. 10 S., R. 38 E. The well initially produced 84 barrels daily of 34º API gravity oil from the Shannon Formation at an interval between 4,762 and 4,778 feet.

Thirteen wells were drilled in the Montana portion of the Ash Creek area resulting in seven producers and six dry holes, all on tribal land. On March 1, 1975, there was one producing well on the reservation.

TABLE 15

Gas Produced from Indian Leases, Hardin Gas Field.

Year	Cubic feet (thousand)	Year	Cubic feet (thousand)
1954	13,334	1965	6,334
1955	6,700	1966	6,875
1956	5,194	1967	6,745
1957	7,291	1968	5,532
1958	6,589	1969	5,000
1959	7,328	1970	5,997
1960	8,769	1971	3,742
1961	9,061	1972	3,568
1962	8,800	1973	3,954
1963	7,466	1974*	1,980
1964	8,098		

*Cumulative production to January 1, 1975 is 175,716 thousand cubic feet.

Source: 1954-1964 inc., 1966-1969 inc., and 1971-1974 inc., U. S. Geol. Survey, Conservation Division, Billings, Montana; 1965 and 1970, Phillips Petroleum Co, Bartlesville, Oklahoma; Cumulative production, U S. Geol. Survey, Conservation Division, Billings, Montana and Phillips Petroleum Co., Bartlesville, Oklahoma.

The maximum annual production from the Crow Reservation portion of the field was 72,609 barrels in 1966 (Table 16). Annual production in 1974 dropped to 9,161 barrels, and the cumulative production to the end of 1974 was 729,726 barrels (Table 16). During January 1975, the only active well on the reservation produced 134 barrels of oil and 1,775 barrels of water (oral commun., U.S. Geol. Survey, Oil and Gas Operations Casper, Wyoming).

A log of the J. Ray McDermott No. 10 Trusler well in the NW ¼, ¼, SW ¼, Sec. 19, T. 58 N., R. 84 W., Sheridan County, Wyoming, shows the depths in feet to formation tops: Lewis, 2,948; Teapot, 3,100; Mesa Verde, 3,253; Parkman, 3,592; Claggett, 3,799; Shannon, 4,160; and Ash Creek, 4,422 (Magill and others, 1966, p. 21).

Snyder Oil Field

The Snyder oil field was discovered in October 1952 by the drilling of the George Greer-Kendrick No. 2 well in Sec. 6, T. 1 S., R. 35 E., after seismic exploration. Sulfurous oil of 21° API gravity was found in the Tensleep Sandstone at a depth of 4,600 feet; the initial pumping potential was 150 barrels per day (Perry, 1960).

TABLE 16
Oil Production from Indian Leases, Ash Creek Field.

Year	Barrels	Year	Barrels
1953	16,178	1964	24,667
1954	57,753	1965	37,101
1955	61,649	1966	72,609
1956	40,501	1967	54,431
1957	37,858	1968	38,747
1958	34,311	1969	30,149
1959	31,578	1970	26,783
1960	30,656	1971	21,146
1961	28,119	1972	13,254
1962	26,768	1973	10,797
1963	25,510	1974*	9,161

*Cumulative production to January 1, 1975 is 729,726 barrels. Reserves as of January 1, 1974 are 80,000 barrels.

Source: 1953-1964, inclusive, Magill and others, 1966, p. 25; 1965-1974, inclusive, Cumulative production and reserves, Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division.

TABLE 17

Oil Production from Snyder Oil Field.

Year	No. wells producing	Barrels
1965	4	8,775
1966	4	9,468
1967	4	9,489
1968	4	8,704
1969	4	7,691
1970	4	9,633
1971	4	9,125
1972	4	8,795
1973	3	5,911
1974*	3	8,079

*Cumulative to January 1, 1975 is 395,770 barrels.

Source: Department of Natural Resources and Conservation of the State of Montana; Oil and Gas Conservation Division and Phillips Petroleum Co., Bartlesville, Oklahoma.

Transportation and Markets

Four pipelines cross the reservation; two are refined products pipelines and two are natural gas lines (Magill and others, 1966, p. 20-21). The Continental Pipeline Co. 8-inch refined products line from Billings, Montana, to Sinclair, Wyoming, follows a northwest to southeast route. A Shoshone Pipelines Ltd. 6-inch refining products line from Billings, Montana, to Cody, Wyoming, crosses the extreme western section of the reservation. The Montana-Dakota Utilities Co. 12-inch gas transmission line from Worland, Wyoming, to Hardin, Montana, continues eastward after crossing the reservation from southwest to northeast. The Montana Power Co. 8-inch gas transmission line crosses through the extreme western part of the reservation.

With the many local refineries (Table 18), marketing will be no problem.

Environmental Aspects

The discovery and production of petroleum and natural gas involves some disruption of the landscape, has created some pollution of the immediate area, and in some instances, careless planning has promoted some waste of these commodities. It is possible to explore for and produce oil and gas without waste or contamination. Some landscape will be disturbed, but with proper concern this can be held to a minimum.

Most of the landscape disturbance is caused by road building and trails to drilling and storage sites. When roads are poorly designed, they often erode, creating more land disturbance than necessary. Reclamation including revegetation is possible but in dry areas it may take many years to complete restore the land surface.

Pollution can be caused by salt water and oil spills invading the ground water table directly from the well, or through spillage or improper impounding at the surface. Wells can be cased or plugged to prevent direct contamination of the ground water and surface or underground storage facilities can be used to prevent surface contamination.

TABLE 18
Local Refineries and 1973 Production
(Barrels of crude oil refined, -, no production)

Company	Barrels Montana oil	Barrels Canadian oil	Barrels Wyoming oil	Total barrels oil refined
Big West Oil Co.	1,469,405	-	-	1,469,405
Continental Oil Co.	1,045,780	5,001,117	10,441.424	16,488,321
Diamond Asphalt	3,069	-	-	3,069
Exxon Corp.	1,089,447	5,568,127	10,010,707	16,668,281
Farmers Union	1,671,569	5,298,748	4,951,636	11,921,953
Jet Fuel Refinery	6,982	-	-	6,982
Phillips Pet. Co.	2,219,519	-	-	2,219,519
Tesoro Pet. Corp.	668,318	-	-	668,318
Westco Ref. Co.	1,521,538	-	-	1,521,538
Totals	9,696,627	15,867,992	25,403,767	50,967,386

Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation, Division

In some cases, natural gas is burned as gas flares at refineries or at some oil wells because of the cost of storing or transporting it to a market. Because of the need to develop and conserve these resources, this practice should be eliminated. Petroleum and natural gas production from lands controlled by the Crow Tribe of Indians will have a positive effect on their standard of living through leasing and royalty revenues.

Uranium

Geologic Setting and Controls

Uranium has not been found on the Crow Indian Reservation; however, uranium has been found in the Pryor Mountains immediately south of the reservation. The deposits were discovered beginning in 1955, and all occur in the upper cavernous part of the Madison Limestone mainly along a north-trending fault near the crest of the Pryor Mountains or on the flanks of an anticline into which the fault passes laterally (Jarrard, 1957). Other deposits have been found in the upper, cavernous part of the Madison on the south side of the Porcupine Creek anticline (also known as Little Mountain) in Wyoming (Stewart, 1958). The ore bodies consist of mineralized collapse breccia of limestone and claystone, or partly replaced and recrystallized limestone mineralized in streaks or bands generally parallel to the bedding (Jarrard, 1957, p. 36-37). Tyuyamunite, $Ca(UO_2)_2(VO_4)_2 5\text{-}8.5H_2 0$, is the only uranium mineral that has been identified in the deposits. Most of the deposits in the Pryor Mountains contained 100 to 1,500 tons of ore; however, one deposit on Little Mountain in Wyoming contained an estimated 10,000 tons of ore (Jarrard, 1957, p. 37). The richest ore assayed about 6 percent $U_3 0_8$ for one shipment of 20 tons (Jarrard, 1957, p. 37). Uranium production from Montana totaled 6,075 tons of ore from 1958 to 1961, most of which was from the Pryor Mountains.

Uranium in the Pryor Mountains is thought to have been deposited from meteoric or surface waters (Jarrard, 1957, p. 37). The host rock for all the known deposits is the upper, cavernous part of the Madison, which provided ample drainage ways for moving water. Uranium was deposited where mineralizing fluids moved laterally away from faults into and through the cavern breccias. Much, if not all, the uranium apparently was extracted from solution soon after reaching the Madison. Most of the deposits are on the high parts of the range, which would have been reached earliest by downward moving groundwater. Outcrops of the Madison low on the flanks of the Pryor and Bighorn Mountains are not known to be mineralized.

The source of the uranium is presumed to be mid-Tertiary volcanic ash deposits (Elliott, 1963, p. 5) which once extensively covered southeastern Montana and adjacent regions. The nearest representatives of these deposits are now a few erosional remnants on the high parts of the Bighorn Mountains in Wyoming (Darton, 1906).

Occurrences on Reservation

In 1952, the Atomic Energy Commission made an airborne radiometric survey over portions on the east flank of the Bighorn Mountains covering about 250 square miles, including part of the Crow Reservation. Areas of Paleozoic rocks were not included because they were considered lithologically unfavorable.

The only anomaly found on the Crow Reservation by the aerial survey was in the Morrison Formation in sec. 34, T. 4 S., R. 29 E., and sec. 3, T. 5 S., R. 29 E. (about 27 miles southeast of Billings). Investigation on the ground revealed a very weak radioactive zone within the shales of the Morrison Formation. Jones (1952) states:

> "It is possible that this radioactivity is due to radon gas or other daughter products of minerals buried beneath the outcropping sandstones and shales. A slight increase was noted in several pits dug by the ground investigation party, but very low assays were obtained from samples taken in these pits. Chemical assays were from nil to 0.01 percent $U_3 0_8$.

Jones (1952) describes two other occurrences on the reservation as follows:

> "The first of these was a radioactive zone in the 1956). Precambrian granites which was examined at the request of Mr. Lyle Ramsbottom, a local rancher. A traverse was run with the hand scintillometer and samples were taken- Sub-sequent assays proved the zone of highest radioactivity to contain 0.06 percent U_30_8 and 0.04 percent chemical U_30_8. No megascopically visible uranium mineral was present and the extent of the deposit could not be determined by surface examination.
>
> "Radioactivity was also noted in dinosaur bone fragments embedded in a sandstone facies of the Morrison Formation. Radioactivity was confined solely to the bones, none was apparent in the adjacent sandstone. The fragments were small and inconsequential as a possible source of uranium. Chemical assays on samples of bones showing the highest radioactivity indicated 0.23 percent U_30_8."

Exploration increased in 1958, and there were 28 uranium leases, mainly along the Montana-Wyoming border. Records show that 21 holes, totaling 3,497 feet were drilled on the reservation. No ore was found, although some surface assays were as high as 0.77 percent U_30_8. The search for uranium diminished in the early 1960's, leases lapsed, and there were none on the reservation in 1964.

NONMETALLIC MINERAL RESOURCES

Bentonite

General

Bentonite is a clay material composed dominantly of montmorillonite. As used in industry there are two classes of bentonite--sodium bentonite, often referred to as Wyoming bentonite, that swells greatly in water and has sodium as its predominant exchangeable ion, and calium bentonite that has negligible swelling characteristics and has calcium as its principal exchangeable ion. Sodium bentonite occurs on the Crow Indian Reservation.

Sodium bentonite is an alteration product of airborne volcanic dust that settled out of sea water millions of years ago (Berg, 1969). The beds range in age from Early to Late Cretaceous (Knechtel and Patterson, 1956). Beds with the best possibility for use are in the Lower Cretaceous Mowry Shale and the Belle Fourche Member of the Cody Shale.

The unusual characteristics of sodium bentonite determine its many uses in industry. The capacity for swelling greatly when wet make it suitable for a water tight seal in irrigation ditches, soils, earth dams, and exploratory drill holes. When finely ground bentonite is mixed with water and is allowed to stand, it forms a gel that becomes a liquid again when agitated. This property, known for thixotropy, accounts for one of bentonite's largest uses, for drilling mud (in the petroleum industry) to keep heavy mud and drill cuttings in suspension. Its viscosity makes bentonite useful in sand bonding for metal casting molds and as a binder in iron ore pelletizing plants. The latter uses account for the largest tonnage of bentonite used in industry.

Bentonite consumption represents slightly less than 5 percent of all clay products, but when common clay is excluded--accounting for nearly 80 percent of all clay uses such products for brick, Portland cement and lightweight aggregate--bentonite represents about 21 percent of the remaining clay consumption.

According to the U.S. Bureau of Mines Minerals Yearbook for 1972, the production of bentonite from the United States was 2,766,998 tons, with a value of $29,330,517 or $10.50 per ton. Production from Montana was 233,390 tons valued at $1,489,361 or $6.40 per ton.

The Minerals Yearbook lists these uses of bentonite:

	Short tons
Animal feed	100,590
Animal litter	3,682
Drilling mud	537,357
Fertilizers	2,608
Filtering, clarifying and decolorizing	
Mineral oil	51,240
Vegetable oil	74,556
Firebrick, block, and shapes	6,596
Foundry sand	711,534
Pelletizing iron ore concentrate	707,187
Pesticides and related products	40,208
Waterproofing and sealing	39,350
Miscellaneous	27,286
Undistributed	41,710
Exports	423,094
Total	2,766,998

Chelini (1967) made a market study of industrial minerals in Montana with markets in Montana, Idaho, Oregon, and Washington. Responses by users of bentonite in this area indicated their sources of supply to be Utah, Idaho, Mississippi, and Wyoming. The delivered price per short ton ranged from 25 cents to $163 in 1967. The uses include:

Frozen fruits, fruit juices, vegetables, and specialties
Flour and other grain mill products
Wine, brandy and brandy spirits
Paper pulp mills
Chemicals and allied products
Alkalies and chlorine
Cellulosic man-made fibers
Soap and other detergents except specialty cleaners
Paints, varnishes, lacquers, enamels, and allied products
Agricultural pesticides and other agricultural chemicals not elsewhere specified
Glue and gelatin
Printing ink
Petroleum refining
Paving mixtures and blocks
Asphalt felts and coatings
Structural clay products
Concrete products except block and brick
Ready-mix concrete
Gypsum products
Mineral wool
Electrometallurgical products
Gray iron foundries
Steel foundries
Aluminum castings

Geologic Setting and Controls

Bentonite beds of commercial quality and minable thicknesses are widespread in Cretaceous rocks of the Crow Indian Reservation. The deposits in the eastern part of the reservation have been studied in detail by Knechtel and Patterson (1952, 1956). Information given here is largely summarized from their reports.

Bentonite beds represent beds of volcanic ash deposited on a level or nearly level sea floor in Cretaceous time, and subsequently altered to clay after burial. The bentonite beds in the Crow Indian Reservation generally range from less than an inch to more than 15 feet thick, although one bed (the Soap Creek bed) is locally 45 feet thick. Many of the bentonite beds are remarkably persistent rock layers that can be traced in outcrops and identified in drill holes for distances of many tens of miles. Others are broad lenses that pinch out into dark bentonitic shale within a few miles. Some are thickened or thinned locally by flowage. Thickening is common, for instance, on the crests of anticline or in the troughs of synclines. In the Crow Indian Reservation, abnormally thick sequences of bentonite are found in the Soap Creek bed on the flanks of the Soap Creek dome; these occurrences can be accounted for by flowage during the folding that produced the dome.

Kenechtel and Patterson (1952, 1956) specifically identified 24 bentonite beds in the Crow Indian Reservation, 22 of which they designated by the letters A to X, bed A being the oldest and bed X the youngest. The Clay Spur and Soap Creek beds are separately named, and are in the position of H and K, respectively, Stratigraphic relations of the beds are shown as follows:

Formation and Member		Bentonite Bed
Bearpaw Shale		X W V
Parkman Sandstone		
Cody Shale	Claggett Shale Member	U T S
	Shale Member equivalent to Eagle Sandstone	R
	Telegraph Creek Member	
	Niobrara Shale Member	Q P
	Carlile Shale Member	O N
	Greenhorn Calcareous Shale Member	M
	Lower Member	L
Frontier Formation		Soap Creek J I
Mowry Shale		Clay Spur G F E
Thermopolis Shale		D C B A

Potential Resources

Bentonite appears to have the greatest potential of the nonfuel minerals on the Crow Indian Reservation. Two beds of special importance are the Clay Spur and Soap Creek. The beds range in thickness from less than 1 inch to more than 15 feet with local thickness in the Soap Creek bed of as much as 45 feet. The eastern part of the reservation may contain an estimated 108 million tons of bentonite in minable thickness of more than 3 feet (Knechtel and Patterson, 19565 p. 48). These deposits lie in beds more than 50 feet thick and under less than, 30 feet of overburden.

The western part of the reservation lying west of the line that divides R. 29 E. from R. 30 E. has not been systematically examined for bentonite, although formations that contain beds A through O are present in the western part of the reservation, and most if not all of the bentonite beds are probably also present. The bentonite-bearing rocks dip gently in much of the western part of the reservation, which would provide sites where the bentonite would be under shallow cover and could be reached by strip mining. On this basis, 30-50 million short tons of bentonite in belts 50 feet or more wide and under less than 30 feet of overburden can be projected for the western part of the reservation.

Characteristics of Reservation Bentonites

Ninety-four samples were taken by Knechtel and Patterson (1956). The tests show that much of the bentonite is suitable for bonding foundry and. Also, bentonite slurries from the Clay Spur bed make good drilling mud and have substantial gel strength. These properties are present to a lesser extent in the material from the Soap Creek and W beds. The Soap Creek bed, and to a lesser extent the M, R, U, V, and W beds, are suitable for use as foundry sand-bonding clays. Undoubtedly some of the bentonite could be used for pelletizing of fine iron ore concentrates.

Quality enhancement methods include natural weathering, where the material is stockpiled for as long as 2 years before use (Skillings, 1974). Artificial means of weathering may be discovered as a result of experimentation by the U.S. Geological Survey (Knechtel and Patterson, 1956). Small amounts of chemical reagents or other material could be added to allow lower-grade material to meet specifications for use. For example, Berg (1970) determined that soda ash added to a sample increased the gel strength. If some high-quality bentonite horizons are found, material from lower--grade deposits could be mixed to provide a product of uniform quality.

The specifications for bentonite used in pelletizing iron ore concentrate is not as well defined as for foundry bonding sand and drilling mud. Slurry viscosity and gel strength are important properties when bentonite is used in pelletizing.

There is no record of any bentonite having been mined or sold from the reservation. Perhaps some has been used locally for water-proofing ditches and small dams.

Processing, Marketing, and Transportation

Skillings (1974) described a plant recently built by the Black Hills Bentonite Co. at Worland, Wyoming. The bentonite is stockpiled until the moisture content is reduced from 25 to 30 percent to 15 percent. It is trucked to the processing plant and segregated and blended to meet customer requirements. It is then conveyed to an 8 by 60 foot rotary dryer fired with natural gas to 150ºF. where the moisture is further reduced to 8 percent. The dried bentonite is fed to a 66-inch diameter Raymond roller mill for reduction to 85 percent minus 200 mesh. The finished product is either bagged or loaded into 80-ton covered hopper cars. Carload shipments usually go to iron ore pellet plants and bagged material to other users.

Recommendations

Bentonite crops out on the reservation so extensively that it would be unrealistic to sample the entire outcrop length in a preliminary study. Beds should be sampled at outcrops and some should be drilled to determine both the depth and effect of surface weathering. Blending of different bentonites should be done to produce a commercial product using both low-and high-yield bentonite. Addition of chemical reagents may improve the quality (Berg, 1970).

Two sites on the reservation are recommended for sampling. The first is in the eastern half of T. 9 S., R. 34 E. This tract has five different beds including the Clay Spur that was mined in the Northern Black Hills district and marketed as drilling-mud bentonite. Knechtel and Patterson (1956) estimate a reserve of 12.8 million tons of bentonite in this area. The area is 6 or 7 miles from the railroad at Aberdeen Siding.

The second locality is the west half of T. 2 S., R. 35 E. The bentonite beds with thicknesses ranging up to 22 feet crop out in a north-south direction across the entire township. Slightly less than 10 million tons of bentonite is estimated by Knechtel in this area. The southwest corner of this township is less than a mile east of the Crow Agency Station on the railroad.

If it is possible to produce a consistently satisfactory product meeting drilling-mud and other specifications, then a search should be made for exposures of the high quality bentonite that can be mined economically.

Claystone and Shale

General

Clays are generally hydrous aluminum silicates which develop plasticity when mixed with a limited amount of water. The individual grains are less than 1/256 mm (4 microns) in diameter and may have either expanding or non-expanding characteristics. Shale is a fine-grained, laminated sedimentary rock composed of clay, silt, and chemical materials. Claystone is a fine-grained. Massive material which is somewhat harder than shale.

The plasticity of clays and their ability to become stonelike when fired (baked) are characteristics necessary to the ceramic industry. Some clay and shale will expand (bloat) when fired and can be used as a lightweight aggregate. The bloating is determined by impurities such as carbonaceous material, iron compounds, calcareous minerals and gypsum. Chelini (1956) reported that fine-grained parent material, to be bloated, must not weigh more than 55 pounds per cubic foot, or 70 pounds per cubic foot for coarse material.

The commercial value of the claystone or shale depends primarily on the mineralogic composition of it clay-mineral fraction. The higher the proportion of the clay mineral group kaolin, the more refractory will be the clay and the lighter will be the fired color. For uses such as for common brick and tile, red-firing low-refractory clays containing much illite and nonclay minerals are suitable. Clays that swell and bloat at fairly low firing temperatures are desired for light-weight aggregate used in concrete; these properties are found in bentonitic clays that contain the clay mineral group smectite.

Geologic Setting and Controls

Claystone and shale make up a large proportion of rocks in the Crow Indian Reservation younger than the Mississippian Madison Limestone. Kaolinitic clays tend to form under conditions of severe weathering and thus are most likely to predominate in deposits of continental origin, such as claystones in the lower part of the Cloverly Formation. Illitic clays are found in rocks deposited in diverse environments. Most claystones and shales, including most of those in the reservation, are mixtures of these clay mineral groups.

Considerable random sampling and testing of claystone and shale in Montana has been done by the Montana Bureau of Mines and Geology including the testing of 23 samples from 9 localities on the Crow Creek Reservation (Figure 16). Test results have been reported by Chelini and others (1966) and by Berg and others (1970) and are summarized in Table 19.

TABLE 19

Results of Tests on Claystone and Shale Collected in the Crow Indian Reservation

Formation	Number of Samples tested	Suitability for use: Common brick	Suitability for use: Light-weight aggregate
Bearpaw Shale	7	Poor or unsuitable	Suitable
Cody Shale	3	Poor or unsuitable	Suitable (1 sample)
Cloverly	3	Fair to good	Suitable
Thermopolis	1	Unsuitable	Not rated
Morrison	8	Poor to unsuitable	Not rated
Amsden	1	Fair	Not rated

Berg and others (1970) tested 33 samples of claystone collected from the Tongue River Member of the Fort Union Formation in the eastern part of Big Horn County, a few miles east of the reservation. The rocks tested are probably typical of claystones and shales in the Tongue River Member in the northern part of the Powder River basin, including the part of the member that underlies the eastern side of the reservation. The claystones are generally poor to unsuitable for common brick, but

19 of the 33 samples are bloating clays that are fair to excellent for light-weight aggregate (Berg and others, 1970, p. 10).

Potential Resources

Clay is a low price commodity, especially when used for common brick. For a deposit to be economic it must be amenable to low-cost mining and relatively near a market.

A clay pit on the reservation in secs. 11 and 12, T. 4 S., R. 26 E., has been operated intermittently since 1955 by the Lovell Clay Products Co. of Billings (Magill and others, 1966). The clay is used for brick and is trucked 29 miles to Billings. The pit produced 5,000 tons of material in 1956. Clay properties are listed in Table 20.

The Lovell pit is in the Lower Cretaceous Cloverly Shale which ranges in color from dark red to green. Clay beds are nearly horizontal with a maximum mining thickness of 15 feet. Soil and gravel overburden ranges in thickness from 5 to 15 feet.

The Montana Bureau of Mines and Geology has been sampling and testing clay and shale deposits in the state since 1958 (Sahinen and others, 1958; Chelini and others, 1965, 1966; Berg and others, 1968, 1970, 1973). Six samples from the Crow Indian Reservation indicated a potential for a lightweight aggregate production from Big Born County. Results of 26 samples taken on the reservation are shown in Table 21 and Table 22. Samples 468 through 477 (Table 22) were taken from bentonite beds which are unsuitable for ceramics or common brick, but indicate a possible source of bloating material for lightweight aggregate. Samples 660 through 674 (Table 21) show some material suitable for common brick

Processing, Transportation, and Marketing

All clay products, whether brick, ceramics, or lightweight aggregate, are processed by firing in a furnace. In view of the present and future energy situation, the Crow Indian Reservation has an economic advantage because of its coal resources. Conley and others (1948) concluded that it takes 248 pounds of coal or 33 gallons of oil to produce 1 ton of expanded aggregate. The coal and clays on the reservation could be developed together to form the basis of an industry.

The proximity of the deposits to railroads is another advantage in favor of the reservation deposits. Large areas of the Tongue River beds are within 10 miles of the railroad. No freight rate has been established for lightweight aggregate from the area, however the rate for bentonite clay from northeastern Wyoming to northern Minnesota is $17.35 per ton (John Nigro, oral commun., 1975). The retail price of lightweight aggregate (1,450 pounds per cubic yard) in Seattle, Washington, is about $25 per cubic yard (Pioneer Sand and Gravel Co., oral commun., 1975).

Gypsum

Gypsum is hydrous calcium sulphate and is used for plaster of Paris, wallboard, as a soil conditioner for decreasing alkalinity in soil, and as a setting retardant in Portland cement. Persistent beds of gypsum occur in the middle part of the Jurassic Piper Formation and in the basal part of the Chugwater Formation in the Crow Indian Reservation. Gypsum in the Piper Formation is well exposed for several miles along the base of the Bighorn Mountains.

A sample from the top of a Chugwater gypsum bed west of Wyola assayed 82.5 percent gypsum (West, 1957).

Several beds, ranging from 5 to 40 feet in thickness, occur near the head of Soap Creek in T. 7 S., R. 32 E. and the north-central part of T. 8 S., R. 32 E.

In the Piper Formation northwest of the Yellowtail Dam in T. 6 S. and Rs. 30 and 31 E., the deposit is about 40 feet thick, and composed of 4-foot-thick beds separated by 2 or 3 inches of red or green shale (Magill and others, 1966; Richards and Rogers, 1951).

Enough information is available from the work of Richards Rogers (1951) and from Richards (1955) to indicate that very large resources of gypsum are available on the reservation. Detailed measurements and sampling across the gypsum-bearing sequences are insufficient, however, for quantitative estimates of resources.

Limestone And Dolomite

General

Limestone is essentially calcium carbonate and is considered as high calcium limestone if it contains more than 95 percent $CaC0_3$. Impurities such as silica, alumina, and magnesium carbonate restrict its use for some products. If magnesium carbonate exceeds 45 percent it is classified as dolomite (Chelini, 1965).

Probably the largest tonnage of limestone is used in the manufacture of Portland cement. Paper manufacture, sugar refining, and soil conditioning, also require large amounts. In Montana, Portland cement and sugar refineries are probably the largest users. Reserves in Montana are extensive.

Limestone is abundant in the Crow Indian Reservation principally in the upper part of the Madison Limestone, and in lesser but substantial amounts in the Piper Formation (Richards, 1955, p. 87-88). The upper part of the Madison (the Mission Canyon Limestone of nearby areas) is the source of much of the high-purity limestone used in Montana (Chelini, 1965, p. 10). According to Chelini, the Mission Canyon Limestone commonly contains more than 95 percent calcium carbonate, less than 5 percent magnesium carbonate, and less than 3 percent total impurities.

Limestone in the upper part of the Piper Formation is in several beds that range from nearly pure to very clayey limestone according to Richards (1955, p. 88) who notes that the limestone is well exposed north of Grapevine Creek in the south part of T. 5 S., R. 30 E. A bed of limestone 5 feet thick about 100 feet below the top of the Chugwater Formation has been quarried in sec. 21, T. 6 S. R. 31 E. (Richards, 1955, p. 88).

Production and Potential

A 5-foot bed of hard, slabby limestone, about 100 feet below the top of the Chugwater Formation, has been quarried on Lime Kiln Creek about 1¼ miles northwest of the old site of Fort Smith in NW ¼ sec. 21, T. 6 S., R. 31 E. Another small quarry was opened in sec. 7, T. 6 S., R. 31 E.

Material from these quarries was calcined and used locally in early days (Magill and others, 1966).

It is unlikely that reservation limestone will be used commercially in the near future. The presence of local coal to fire kilns in an energy-short economy could change this, however. To promote future interest in the limestone and dolomite resources a thorough inventory of these beds should be made. This would include mapping, determining minable reserves, and quality.

Sand and Gravel

General

Major sand and gravel deposits in the Crow Indian Reservation occur north and northeast of the mountains in stream terraces deposits along the Bighorn River, and lesser but substantial amounts in terraces along the Little Bighorn River and Pryor Creek. The distribution of the deposits is shown by Thom and others (1935, pl. 3) and Richards (1955, pls. 1 and 7). Six main terrace levels and a few intermediate ones are recognized by Richards (1955, pl. 1, p. 80) who numbered them 1 to 6, level 1 being the lowest and youngest and level 6 the highest and oldest (Table 23). Terraces at level 1 are only a few feet above the present streams. They form most of the valley bottom of the Bighorn River in a band averaging about 2 miles wide between the Yellowtail dam and hardin- Remnants of older and higher terraces cover areas from s few acres to 10 or more square miles.

Terrace deposits along the Bighorn River are generally unconsolidated silt, sand, and gravel, and commonly are about 25 feet thick (Richards, 1955, p. 81). Near the mouth of the Bighorn Canyon, coarser rock fragments in the deposits measure as much as 40 inches across and are mostly limestone; finer fragments are chiefly volcanic rocks. Near Hardin, limestone is subordinate to volcanic rocks in all sizes of the gravel.

Potential Resources

Resources of gravel for road subgrade or road surfacing is practically unlimited. Because of the high proportion of basalt and andesite in all the deposits that have been described, the gravels at many places may not be well suited for use in concrete.

TABLE 23

Bighorn River Terraces below the Yellowtail Dam

[Richards, 1955, p. 81]

No.	Average height above river (feet)	Maximum diameter of gravel (inches)	Average diameter of gravel (inches)	Rock types of aggregate (most abundant named first)
6	650	10	3	Limestone, Sandstone, basalt andesite, chert, granite, and quartzite
5	550	12	4	
4	350	12	4	
3	250	13	3	
2	120-140	16	3	
1	20	40	5	

Pumicite

General

Pumice is a highly cellular, glassy froth-like rock generally found in the vicinity of volcanic cones. The material has a low density. Pumicite is used in concrete as a pozzolan material. It can also be used as a concrete aggregate and can be expanded to form and ultra light-weight aggregate. Wagner and Hogland (1964) describe samples of fresh pumice which were expanded as much as 110 percent and weighed about 15 pounds per cubic foot. Such a product could be used for lightweight plaster used in fireproofing members in structural steel buildings, as a carrier for insecticides, filtration, absorbent, and as a soil conditioner.

Potential Resources

A volcanic ash deposit is on the reservation in sec. 12, T. 4 S., R. 31 E., on the north side of Beauvois Creek about 25 miles north of the Yellowtail dam site (Magill and others, 1966). This ash has a minimum thickness of 5 feet where sampled and is covered with about 4 feet of overburden. Tests made by the Bureau of Reclamation determined that the pumicite met pozzolan specifications. Results of two samples taken by U.S. Bureau of Reclamation and one taken by the U.S. Bureau of Mines are shown in Table 24.

TABLE 24

Pozzolan Test on Three Samples Form a Volcanic Ash Deposit, Sec. 12, T. 4 S., R. 31 E., Crow Indian Reservation (Magill and Others, 1966). (--, not determined)

Test	USBR Sample M-3952	USBM Sample M-4027	Sample P-48
Retained on No. 325 mesh sieve	0.5	3.5	7.3
Specific surface Cm cc	17,978	18,893	--
Specific gravity	2.42	2.44	2.37
Compressive strength			
2 inch cubes, percent of control,			
7 days	89	92	--
28 days	98	97	85
2 inch by 4 inch cylinders			
7 days p.s.i.	889	840	890
Change of drying shrinkage, percent	0.012	0.018	--
Water requirement, percent of control	98	96	101
Reduction of reactive expansion, percent	78	78	--
Chemical composition, weight percent:			
$SiO_2 + Al_2O_3 + Fe_2O_3$	86.32	86.18	--
MgO	.79	.26	--
SO_3	.01	.07	--
Loss on ignition	3.52	2.82	--
Moisture	.44	.54	--
Exchangeable alkalies	1.54	1.08	--

The ash consisted of abundant (85 to 90 percent) light gray shards and pumiceous particles of acidic volcanic glass and from 10 to 15 percent feldspar, quartz, and other materials.

Work by the U.S. Bureau of Mines (Magill and others, 1966) determined that pumicite deposits on the reservation are much more extensive than had been previously known. Six separate deposits were found in a 40-mile-wide area. Additional work is needed to determine extent of these deposits as well as finding other deposits. The following are descriptions of the four deposits examined (Magill and others, 1966).

Location sec.	T.	R.	General description
SW¼ 22	5S	31E	Several feet of pumicite in a gully about 15 feet beneath the terrace surface.
SE¼ 34	4S	31E	Pit dug for construction of a power transmission line tower. A minimum of 5 feet of light colored pumicite covered by 4 feet of overburden.
NW¼ 30	2S	34E	White pumicite at least 7 feet thick covered by a few feet of soil.
SE¼ 6	3S	28E	Lovell Clay Products pit. Twelve feet deep and 200 feet in diameter. Bottom of bed not reached.

At the first three locations the pumicite is very fine grained, and is estimated to be 35 to 50 percent minus 325-mesh. The material in the Lovell pit was much coarser grained, and contains a few rounded pebbles of black and light gray pumice as much as several inches in diameter. The majority of the material, however, is uniform in size and consists of volcanic glass shards. The size distribution of a dry-screened sample from the Lovell pit is as follows:

Size fraction, mesh	Percent
+10	2.6
10-14	1.4
14-20	3.0
20-28	4.7
28-35	9.4
35-48	20.0
48-65	24.1
65-100	21.8
100-150	6.7
150-200	3.3
200-270	1.1
270-400	1.0
-400	.8

The "sand" produced from the pit was used to reduce plasticity of clay in brick manufacture.

Transportation and Marketing

Pumicite is a low price commodity and for most uses would not be profitable to ship any great distance unless it could be processed locally to increase its value.

Building Stone

Sandstone from several areas on the reservation has been used locally for building stone. The Big Horn County courthouse at Hardin was constructed in the 1930's using Jurassic sandstone quarried from sec. 21, T. 6 S., R. 31 E., 1½ miles south of the old site of Fort Smith. Although constructed more than 30 years ago, the sandstone shows no sign of deterioration. It is light gray and uniform in texture and color.

West of Fort Smith, on the opposite side of the Bighorn River in sec. 8, T. 6 S., R. 31 E., is another quarry in similar rock.

Several buildings at Crow Agency have been constructed from Cretaceous sandstone quarried about 1½ miles east of the Agency. Judging from the size and shape of the excavations, it was apparently difficult to obtain suitable stone.

The Pryor Mountain Stone Co. of Billings quarries a rock described as dolomitic siltstone, from five quarries in the Chugwater Formation (Triassic) west of the Yellowtail Reservoir in Carbon County (Berg, 1974). The stone is split and sorted in a stone yard in sec. 36, T. 7 S., R. 28 E., 3 miles south of the reservation boundary and is trucked to Lovell, Wyoming, for rail shipment. The Chugwater Formation underlies large areas of the reservation north of this quarry.

Two relatively flat-lying beds are quarried that have a total thickness of 6 to 7 feet and are reported to be approximately 100 feet below the top of the Chugwater Formation (Berg, 1974). The attractive color of this stone is caused by the iron-oxide content.

Minor amounts of clinkers, partially baked rock formed usually by heating from underlying burning coal beds, have been quarried and used as decorative stone in buildings. The varied bright colors and rough, uneven surfaces make this material attractive for some applications. Freezing and thawing may cause deterioration and precautions should be taken when exposing this material to the weather.

Undoubtedly, there are rock formations on the reservation where building stone can be quarried. Localities favorable to low-cost mining methods should be inventoried.

Silica Sand

Silica sands of exceptional purity are found in deposits where sandstone or quartzite have been weathered, reworked, and reconcentrated. Industrial specifications vary according to the use, and for many applications washing and sizing is the only treatment necessary. More refined methods may be used where high purity and specific physical properties are important.

Generalized requirements for several specialized uses of silica raw materials follow. Glass--melting and chemical sand must be pure (Murphy, 1960). Alumina and iron are the most common impurities; Al_2O_3 content of glass-melting sand should generally not exceed 0.2 percent and Fe_20_3 should not exceed 0.02-0.025 percent for flint quality glass and 0.05-0.08 percent for average amber glass. The maximum amount of CaO and MgO allowed is about 0.05 and for alkalies about 0.01 percent.

Hydraulic fracturing sand used in the petroleum industry, requires 1 rounded quartz sand with a high uniformity in grain sizes. The 20-40 U.S. standard mesh grade calls for 100 percent between 16 and 60-mesh with a minimum of 80 percent between 20 and 40-mesh. Highly rounded particles are desirable with a maximum particle density of 2.7.

The Tensleep Sandstone on the reservation has potential value for industrial sand, particularly where the rocks have been decomposed by weathering and have minimum iron staining.

A sandstone deposit in the NW¼ NW¼ sec. 34, T. 6 S., R. 32 E., leased to the Texas Calgary Co. of Abilene, Texas, in 1957. This deposit is in the Cloverly Formation (Lower Cretaceous) which has a .mum thickness of 10 feet and is covered by about 3 feet of over-burden. The company proposed to crush and screen the material for a to pack artificial openings in oil-producing rocks to increase recovery. The deposit was not developed because the sand grains were slightly smaller in diameter than normally used for this purpose. A screen analysis of a representative sample from the deposit is:

Size fraction, mesh	Percent
+20	0.12
20-28	.85
28-35	6.93
35-48	61.79
48-65	17.36
65-100	4.14
100-150	1.50
150-200	1.19
200-270	.57
-270	5.55
	100.00

Samples from a few of the best reservation sand deposits indicate that they have industrial potential. There is no record of any silica production from the reservation.

Clinker

The thicker coal beds in the Tongue River Member of the Fort Union Formation have burned at many places along their outcrops and the resulting heat has baked and fused the overlying rocks into masses of hard, stony clinker through thicknesses of a few to several tens of feet, depending primarily on the thickness and quality of the coal that has burned. The baked and hardened rock is generally shades of red and purple. It resists erosion and holds up buttes and divides or forms conspicuous red bands on hillsides along the eastern side of the reservation. Clinker has been widely used in the Powder River basin region for road-surfacing material and railroad ballast.

Clinker is widespread and abundant in the Tongue River Member of the Fort Union Formation both in the reservation and in regions to the east and south. The amount available is perhaps several hundred times the amount needed for any foreseeable level of use.

METALLIC MINERAL RESOURCES

Gold and Copper

There are no vein deposits of gold on the reservation. Enough placer gold was found along Bighorn River, years ago, to stimulate some prospecting, but there is no record of any production. Yellowtail dam backwater now covers the gravels once thought to have the best potential.

No copper ore has been mined on the reservation, although copper occurs in the Bighorn Mountains, outside the reservation, associated with diabase dikes of Precambrian age (Darton, 1906, p. 114).

MINERAL LEASING AND PROSPECTING REGULATIONS

There are three types of land holdings on the Crow Reservation: (1) tribal land, (2) private land held in fee (by various owners), and (3) allotments (land allotted to individual Indians). Individuals were awarded the mineral rights on allotments made prior to 1920; since 1920 the tribe has reserved the mineral rights for a period of 50 years (until 1970) at which time they reverted to individuals.

Prospecting for minerals on reservation lands is authorized to holders of a prospecting permit approved by the Tribal Council and the Secretary of the Interior, and obtained from the Superintendent of the Crow Reservation. Prospecting permits are granted for a specific period of time, cover a designated area, and may or may not grant the exclusive right to prospect or give any preference right to a lease. To obtain a prospecting permit, a surety bond (amounts vary) must be posted. Numerous provisions are included to cover damages, forest protection, liquor, firearms, inspection, roads, rights of way, water wells, Indian labor, assignment, and reports.

Crow Reservation land leases are governed by the Code of Federal Regulations, Title 25, Indians, Part 173--Leasing of Lands in Crow Indian Reservation, Montana, for Mining. The Crow Tribal Council may also make resolutions imposing additional rules. The U.S. Geological Survey is responsible for monitoring and administering lease agreements and is powered to enforce Federal regulations. The U.S. Bureau of Mines as the responsibility of making inspections for the safety and welfare f miners. These are listed in the Code of Federal Regulations, Title 30, Chapter 2, Geological Survey, Part 231--Operating and Safety Regulations Governing the Mining of Metallic and Nonmetallic Minerals.

Lease offerings are generally advertised, and the highest bidder is awarded the lease subject to approval by the Tribal Council and the Secretary of the Interior or his authorized representative. Leases are made for a period of not longer than 10 years and are renewable upon such terms and conditions as may be prescribed by the Secretary of the Interior with concurrence of the Tribal Council.

RECOMMENDATIONS FOR FURTHER WORK

Coal has the greatest potential for development of any mineral resource on the reservation. Extensive drilling for coal has been done the northeastern and southeastern parts of the reservation by private companies, and much of their information presumably will become available. Additional work is not warranted in these areas by the U.S. Geological Survey or U.S. Bureau of Mines pending release of the existing data.

In contrast, the Crow Reserve Area in Tps. 4 and 5 S., Rs. 37 and 38 E. (Figure 17) has potential for valuable coal deposits, but the distribution of deposits is virtually unknown. The northern part of the area in T. 4 S., Rs. 37 and 38 E. has low relief, and coal near the surface would be amenable to surface mining. The Rosebud and stratigraphically lower coal beds are present in this area. Beds stratigraphically higher than the Rosebud coal bed can be expected in the more mountainous southern part of the Crow Reserve Area in T. 5 S., Rs. 37 and 38 E. Work recommended in the Crow Reserve Area should include geologic mapping at a scale of 1:24,000, accompanied by the drilling of 10 to 15 holes per township to depths of 200 to 500 feet. Purposes of the work would be to establish coal-bed correlations within the area and with adjoining areas to the north and south, refine estimates of resources, identify sites that have potential for surface or underground mining, and provide information on coal quality.

REFERENCES

Abelson, P. H., 1973, Underground gasification of coal: Science, v. 182, no. 4119, p. 1297.

___,1975, Mineral research in Turkey: Science, v. 187, no. 4179, p. 793.

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

Aldrich, H., 1969, Industrial water: Proceedings of the Montana coal symposium, Empire Printing, Billings, Montana, p. 89-93. American Foundrymen's Co., 1963, p. 81-83.

American Petroleum Institute, 1966, Specifications for oil-well drilling fluid materials: New York, 11 p.

Baker, A. A., 1929, The northward extension of the Sheridan coal field, Big Horn and Rosebud Counties, Montana: U.S. Geol. Survey Bull. 806-B, p. 15-67.

Balster, C. A., 1973, Structure contour map, Upper Cretaceous, southeastern Montana: Montana Bur. Mines and Geol. Spec. Pub. 60, map sheet.

Barnum, B. E., 1974, Preliminary geologic map and coal resources of the Ranchester quadrangle, Sheridan County, Wyoming and Big Horn County, Montana: U.S. Geol. Survey Open File Rept. 74-35.

Bass, N. W., 1932, The Ashland coal field, Rosebud, Powder River, and Custer Counties, Montana: U.S. Geol. Survey Bull. 831-B, p. 19-106.

Berg, R. B., 1969, Mineralogy and physical properties of some Montana bentonite, in Eastern Montana Symposium: Montana Geol. Soc., 20th Ann. Conf., 1969, p. 227-232.

___,1969, Bentonite in Montana: Montana Bur. Mines and Geol. Bull. 74,

___,1970, Bentonite deposits in the Ingomar-Vanada area, Treasure and Rosebud Counties, Montana: Montana Bur. Mines and Geol., Special Pub. 51, 5 p.

___,1974, Building stone in Montana: Montana Bur. Mines and Geol. Mines an Geol. Bull 94, 41 p.

Berg, R. B., Lawson, D. C., Jones, F. P., and Smith, R. I., 1968, Progress report on clays and shales of Montana, 1966-67: Montana Bur. Mines and Geol. Bull. 70, 74 p.

___, 1970, Progress report on clays and shales of Montana, 1968-1969: Montana Bur. Mines and Geol. Bull. 80, 27 p.

___,1973, Progress report on clays and shales of Montana, 1970: Montana Bur, Mines and Geol. Bull. 89, 18 p.

Bertine, K. K., and Goldburg, E. D., 1973, Fossil fuel combustion and the major sedimentary cycle: Science, v. 173, no. 3993, p. 233-235.

Biggs, C. A., 1961, Devonian stratigraphy of the Bighorn Canyon area: Billings Geol. Soc., 12th Ann. Field Conf. Guidebook, 1961, p. 41-46.

Blackstone, D. L., Jr., 1940, Structure of the Pryor Mountains, Montana: Jour. Geology, v. 48, p. 590-618.

Bleifuss, R. L., and Girod, F. X., 1971, Evaluation of western bentonites: 32d Annual Min. Symp., Duluth, 1971.

Bureau of Indian Affairs, 1974, Final environmental statement FES-74-8, Crow ceded area coal lease, Westmoreland resources mining proposal: Planning Support Group, Dept. of Interior, Billings, Montana, 253 p.

Chelini, J. M., 1965, Limestone, dolomite, and travertine in Montana: Montana Bur. Mines and Geology Bull. 44, 53 p.

___,1967, Market study and compendium of data on industrial minerals and rocks of Montana: Montana Bur. Mines and Geol. Bull. 62, 144 p.

Chelini, J. M., Smith, R. I., and Lawson, D. C., 1965, Progress report on clays and shales of Montana, 1962-1964: Montana Bur. Mines and Geol. Bull. 45, 43 p.

Chelini, J. M., Smith, R. I., and Jones, F. P., 1966, Progress report on clays and shales of Montana, 1964-1965: Montana Bur. Mines and Geol. Bull. 55, 38 p.

Clark, F. W., 1959, The data of geochemistry: U.S. Geol. Survey Bull. 770, 841 p.

Clausen, C. F., 1960, Cement materials-- Industrial Minerals and Rocks: Am. Inst. Mining Metall. Petroleum Engineers, p. 203-231.

Coal Age, 1971a, The Black Mesa plan--energy today, better land tomorrow: v. 76, no. 3, p. 78-82.

___, 1971b, Mine to market efficiency--Peabody Coalls strong point: v. 76, no. 10, p. 150-161.

___,1974, Economical new coal-to-gas process claimed by Garrett Co.: v. 79, no. 3, p. 86-87. Coates, D. F., Cochrane, T. S., and Ellie, G., 1972, Three mining methods for vertical, inclined, and thick coal seams used in France: Can. Inst. of Min. Trans., v. LXXV, p. 96-102.

Combo, J. X., Brown, D. M., Pulver, H. F., and Taylor, D. A., 1949, Coal resources in Montana: U.S. Geol. Survey Circ. 53, 28 p.

Combo, J. X., Holmes, C. N., and Christner, H. R., 1950, Coal resources of Montana: U.S. Geol. Survey Coal Inv. Map C-2.

Conley, J. E., Wilson, H., Klinefelter, T. A., and others, 1948, Production of lightweight concrete aggregates from clays shales slates and other materials: U.S. Bur. Mines Rpt. Inv 4401 121 p.

Cornforth, C. L., 1973, Reclamation proves successful in semi-arid Montana: Min. Cong. J., v. 10, no. 7, p. 40-42 .

Corriveau, M. P., 1974, Coal utilization: Mining Eng., v. 26, no. 2, p. 84-87.

Culfaz, A. I., Keisling, C. A., and Sand, L. B., 1973, A field test for molecular sieve zeolites: Am. Minera. v 58 p 1044-1047 .

Darton, N. H. 1906, Geology of the Big Horn Mountains U S Geol. Survey Prof. Paper 51, 129 p.

Deffeys, K. S., 1959, Zeolites in sedimentary rocks Journal of Sedimentary Petrology, v. 29, no. 4 p 602-609.

Dobbin, C. E., 1929, The Forsyth coal field, Rosebud, Treasure, and Big Horn Counties, Montana U.S. Geol. Survey Bull 812-A 55 p.

Doroshenko, J., 1961, Pre-cambrian relationships of the Bighorn and Beartooth Mountains: Billings Geol. Soc. 12th Ann Field Conf. Guidebook, 1961, p. 58-66.

Driggs, M. F., and Hobbs, J. F., 1974, Crow Indian Reservation, Big Horn County, Montana, Peabody Coal Company proposed coal leases Report submitted to Crow Indian Tribe by Peabody Coal Company St Louis, Mo., 22 p.

Duzy, A. F., 1967, Characteristics of high-moisture fuels in cyclone furnace applications; Symposium--Technology and use of lignite U.S. Bur. Mines Inf. Circ. 8376, p. 57-76.

Edmisten, Neil, 1961, Mississippian Madison Group in the Bighorn Canyon area: Billings Geol. Soc., 12th Ann. Field Conf. Guidebook, 1961, p. 36-40.

Elliott, J. M., 1963, Cave occurrences in the Mississippian Madison Limestone of the Pryor Mountains, Montana: Billings Geol. Soc., Paper 2.

Everhart, D. L., 1956, Tectonic control of uranium deposition in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Rocky Mt. Section Geol. Record, p. 87-97.

Eyde, T. H., 1974, Exploration for deposits of natural zeolite minerals in the western United States: Society of Min. Eng. of Am. Inst. Mining Metall. Petroleum Engineers, Preprint No. 74-N-336, 10 p.

Geer, M. R., and Yancey, H. F., 1955, Cleaning characteristics and cleaning tests of Montana coal: U.S. Bur. Mines Rept. Inv. 5103, 47 p.

Gillette, R, 1974, Energy "blueprint" sees little R & D import before 1985: Science, v. 186, no. 4165, p. 718.

___, 1974, Recent surface mining development in the Western States: Min. Cong. J., v. 60, no. 9, p. 18-21.

Glover, T. O., Hinkle, M. E., and Riley, H. L., 1970, Unit train transportation of coal: U.S. Bur. Mines Inf. Circ. 8444, 109 p.

Greenwalt, R. B., 1974, Pyrolysis and agglomeration: Min. Eng., v. 26, no. 2, p. 69,70.

Groff, S. L., 1966, Coal, first Montana coal resources symposium: Montana Bur. Mines and Geol. Spec. Pub. 36, p. iv-v.

___,1968, Montana's place in the Nation's coal energy picture; Symposium-- Technology and use of lignite: U.S. Bur. Mines Inf. Circ. 8376, p. 40-56.

Hanson, A. M., 1961a, Permo-Triassic of Bighorn Canyon area: Billings Geol. Soc., 12th Ann. Field Conf. Guidebook, 1961, p. 35-37.

___, 1961b, Cambrian System in the Bighorn Canyon area: Billings Geol. Soc., 12th Ann. Field Conf. Guidebook, 1961, p. 51-57.

Hadley, H. D., 1958, Mosser field, in Montana oil and gas fields--a symposium: Billings Geol. Soc. Symposium Committee, p. 183-184.

Hodder, R. L., 1970, Coal mine spoils research project located at Western Energy Company, Colstrip, Montana: Montana Agricultural Experiment Station Res. Rept., v. 8, 56 p.

Hogan, W. T., 1975, Iron and steel: Eng. and Min. J., v. 59, no. 12, p. 24-28.

Hucka, V., and Das, G., 1973, In situ gasification of coal--solving the energy crisis: Min. Eng., v. 25, no. 8, p. 49,50.

International Oil Scouts Association, 1965, International Oil and Gas Development: Yearbook (Review of 1964), v. XLI, pt. 1, p. 197.

Jarrard, L. D., 1957, Some occurrences of uranium and thorium in Montana: Montana Bur. Mines and Geol. Misc. Contr. no. 15, 90 p.

Joensuu, O. I., 1971, Fossil fuels as a source of mercury pollution: Science, v. 172, no. 3987, p. 1027-1028.

Jones, E. E., 1952, Airborne radiometric survey of the east flank of the Bighorn Mountains, Wyoming and Montana: Div. of Raw Materials, Atomic Energy Commission, Tech. Inf. Service, Oak Ridge, Tenn., RME-4006, 12 p.

Katell, S., and Hemingway, E. L., 1974a, Basic estimated capital investment and operating costs for coal strip mines: U.S. Bur. Mines Inf. Circ. 8661, 31 p.

___,1974b, Basic estimated capital investment and operating costs for underground bituminous coal mines: U.S. Bur. Mines. Inf. Circ. 8641, 31 p.

Kinard, J. C., 1961, Ordovician of the Bighorn Canyon area: Billings Geol. Soc., 12th Ann. Field Conf., Guidebook, 1961, p. 47-50.

Kinnison, P. T., 1971, Future petroleum potential of Powder River basin, southeastern Montana and northeastern Wyoming, in Future petroleum provinces of the United States--their geology and potential: Am. Assoc. Petroleum Geologists Mem. 15, p. 591-612.

Knappen, R. S., and Moulton, G. F., 1930, Geology and mineral resources of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana: U.S. Geol. Survey Bull. 822-A, p. 1-70.

Knechtel, M. M., and Patterson, S. H., 1952, Bentonite deposits of the Yellowtail district, Montana and Wyoming: U.S. Geol. Survey Circ. 150, 7 p.

___,1956, Bentonite deposits in marine Cretaceous formations of the Hardin district, Montana and Wyoming: U.S. Geol. Survey Bull. 1023, 116 p.

___,1963, Bentonite deposits of the Northern Black Hills district Wyoming, Montana and South Dakota: U.S. Geol. Survey Bull. 1082-M, p. 893-1030.

Kramer, W. E., and Youngs, R. W., 1968, Pelletizing iron ore with organic additives: 29th Annual Min. Symp., Duluth.

Magill, E. A., Hubbard, C. R., and Koch, C. A., 1966, Mineral resources and their potential on Indian lands, Crow Reservation, Big Horn and Yellowstone Counties, Montana: U.S. Bur. Mines

Prelim. Rept. 167, 54 p.

Major-Marothy, G., 1968, Pellet binders, bentonites versus substitutes: 29th Annual Min. Symp., Duluth.

Matson, R. E., 1969, The strippable coal fields in eastern Montana, in Eastern Montana Symposium: 20th Ann. Conf., Montana Geol. Soc., 1969, p. 219-225.

Matson, R. E., and Blumer, J. W., 1973, Quality and reserves of strippable coal, selected deposits, southeastern Montana: Montana Bur. Mines and Geol. Bull. 91, 135 p.

Maugh, T. H., II, 1972, Gasification--a rediscovered source of clean fuel: Science, v. 178, no. 4056, p. 44,45.

Mining Congress Journal, 1975, v. 61, no. 1, p. 5, 7-8.

Murphy, T. D., 1960, Silica sand and pebble: Industrial Minerals and Rocks, Third Edition: Am. Inst. Mining Metall. Petroleum Engineers, p. 763-772.

National Academy of Sciences, 1974, Rehabilitation potential of western coal lands: Ballinger, Cambridge, Mass., 198 p.

Obled, A. G., 1972, Molecular-sieve cracking catalysts: Oil and Gas J., March 27, 1972, p. 85-106.

Osborn, E. F., 1974a, Clean synthetic fluid fuels from coal--some prospects and projections: Min. Eng., v. 26, no. 9, p. 31-33.

___,1974b, Coal and the present energy situation: Science, v. 183, no. 4124, p. 447-481. Paulson, L. E., Cooley, S. A., and Ellman, R. C., 1974, Shipment, storage, and handling characteristics of dried low-rank coals: Symposium--Technology and use of lignite: U.S. Bur. Mines Inf. Circ. 8650, p. 49-75.

Perry, E. S., 1949, Gypsum, lime, and limestone in Montana: Montana Bur. Mines and Geol. Mem. 29, p. 28.

___,1960, Oil and gas in Montana: Montana Bur. Mines and Geol. Bull. 15, 70 p.

___,1962, Montana in the geologic past: Montana Bur. Mines and Geol. Bull. 26, pl. 1.

Perry, H., 1974, The gasification of coal: Sci. Am., v. 230, no. 3, p. 19-25. Persse, F. H., 1973, Strip-mining techniques to minimize environmental damage in the upper Missouri River Basin States: U.S. Bur. Mines Prelim. Rept. 192, 52 p.

Quilici, F. J., 1973, Characteristics and uses of Montana fly ash: Montana Bur. Mines and Geol., Bull. 90, 29 p.

Rawlins, J. H., 1973, Montana: Coal Age, v. 78, no. 5, p. 117-125.

___,1974a, Montana: Legislators give the State control over surface mining siting: Coal Age, v. 79, no. 5, p. 86-88.

___,1974b, Responses--Final environmental statement, Crow ceded area coal lease, Westmoreland resources mining proposal: Planning Support Group, Bur. of Indian Affairs, Dept. of Interior, Billings-, Montana, 83 p.

Reed, G. C., 1950, Preliminary investigation of cement materials in the vicinity of the Yellowtail-Hardin Dam site, Big Horn County, Montana: U.S. Bur. Mines, Miner. Res. Invest., Prelim. Rept. No. 37.

Richards, P. W., 1955, Geology of the Bighorn Canyon--Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026, 93p.

Richards, P. W., and Rogers, C. P., Jr., 1951, Geology of the Hardin area, Big Horn and Yellowstone Counties, Montana: U.S. Geol. Survey Oil and Gas Inv. Map OM-111.

Roby, R. N., and Kingston, G. A.3 1966, Feasibility study of mining and beneficiating of low-grade iron deposits in southwestern Montana: U.S. Bur. Mines Unpub. Rept., 66 p.

Rogers, G. S., and Lee, Wallace J 1923, Geology of the Tullock Creek coal field, Rosebud and Big Horn Counties, Montana: U.S. Geol. Survey Bull. 749, 181 p. Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geol. Survey.

Sahinen, U. M., 1957, Expandable shale in the Great Falls area, Montana: Montana Bur. Mines and Geol. Inf. Circ. 18, 16 p.

Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, Progress report on clays of Montana: Montana Bur. Mines and Geol. Inf. Circ. 23, 41 p.

Sand, L. B., and Regis, E. A., 1967, Mineral distribution in size fractions of Tertiary zeolite ores: Soc. of Min. Eng., Preprint 67-4-317, 6 p.

Sastry, K. V. S., 1975, Pyrolysis and agglomeration: Min. Eng., v. 27, no. 2, p. 60, 61.

Shell Oil Company, 1974, Youngs Creek coal mine plan, Crow Indian Coal Lease 14-20-0252-3848, Big Horn County, Montana, Sept. 1974: Shell Oil Co. Mining Venture Dept., on file U.S. Geol. Survey Conservation Division, Billings, Mont.

Skillings, D. N., Jr., 1974, Black Hills Bentonite Co. opens new mine and plant: Skillings Min. Rev., v. 63, no. 45.

Spicer, T. S., and Leonard, J. W., 1968, Utilization from the point of view of the preparation engineer: Coal Preparation, Am. Inst. Mining, Metall. Petroleum Engineers, New York, p. 3-3 through 3-24.

Stewart, J. C., 1957, The Stratigraphy, physiography, and structural geology of the Dryhead-Garvin basin, South-central Montana: PhD thesis, Princeton Univ., New Jersey.

____,1958, Geology of the Dryhead-Garvin basin, Big Horn and Carbon Counties, Montana: Montana Bur. Mines and Geology Spec. Pub. 17.

Symposium on the methods of working thick coal seams, 1966, United Nations, New York, v. 1, 35 p., v. 2, 134 p.

Thom, W. T.. Jr., 1923, Oil and gas prospects in and near the Crow Indian Reservation, Montana: U.S. Geol. Survey Bull. 736-B, p. 35-53.

Thom, W. T., Jr., Hall, G. M., Wegemann, C. H., and Moulton, G. F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana, with special reference to the water, coal and gas resources: U.S. Geol. Survey Bull. 856, 200 p.

Thom, W. T., Jr., and Moulton, G. F., 1921, The Soap Creek oil field, Crow Indian Reservation, Montana: U.S. Geol. Survey Press Memorandum, Dec. 5, 1921.

U.S. Bureau of Indian Affairs, 1973, Crow Ceded area coal lease-- Westmoreland Resources Mining Proposal: Draft Environmental Statement DES-73-59.

___,1975, Projected coal development Crow Indian Reservation: Draft Programmatic Environmental Statement DES-75-2.

U.S. Bureau of Mines, Minerals Yearbook for 1972.

U.S. Geological Survey and Montana Bureau of Mines and Geology, 1963, W Mineral and water resources of Montana: U.S. 88th Cong. 1st Sess. [Reprinted as Montana Bur. Mines and Geology Special Pub. 28].

___,1973, Preliminary report of coal bed drill-hole data and chemical analyses of coal beds in Sheridan and Campbell Counties, Wyoming and Big Horn County, Montana: U.S. Geol. Survey Open File Rept.

U.S. Geological Survey and U.S. Bureau of Mines, 1965, Mineral potential of eastern Montana, a basis for future growth: U.S. 89th Cong., 1st Sess., Sen. Doc. 12, U.S. Govt. Printing Office [Reprinted as Montana Bur. Mines and Geology Spec. Pub. 33.]

Van Voast, W. A., 1974, Hydrologic effects of strip coal mining in southwestern Montana--emphasis: one year of mining near Decker: Montana Mines and Geol. Bull. 93, 24 p.

Wagner, N. S., and Hogland, L. L., 1964, The residual expansibility of pumice: Oregon Ore Bin, v. 26, no. 4, p. 73-75.

Warren, W. C., 1959, Reconnaissance geology of the Burney-Broadus coal field, Rosebud and Powder River Counties, Montana: U.S. Geol. Survey Bull. 1072-J, p. 561-585.

Wasp, E. J., 1969, The importance of slurry pipelines for Western coal development: Proceedings of the Montana Coal Symposium, Empire Printing, Billings, Montana, p. 73-77.

Waterhouse, J. H., and Everett, F. D., 1951, Mineral resources (except fuels), Big Horn River Basin: U.S. Bur. Mines, Prelim. Rept. No. 58, 65 p.

Weir, J. P., 1973, Coal supply for gasification plants: Min. Cong. J., v. 59, no. 12, p. 24-28.

West, J. M., 1957, Montana gypsum resources and their utilization: U.S, Bur. Mines, Missouri River Basin Rept. 116, 31 p.

Williams, F. J., Elsley, B. C., and Weintritt, D. J., 1954, The variation of Wyoming bentonite beds as a function of the overburden: Clays and Clay Miner., Natl. Acad. Sci., Nat. Res. Council, Pub. 327, p. 141-151.

Winegartner, E. C., and Ubbens, A. A., 1974, Understanding coal ash quality parameters: Exxon Res. and Eng. Co., Baytown, Texas, 11 p.

Wood, C. L., and Vollmer, H. M., 1962, Provisional overall economic development program, Crow Reservation Area: SRI Project IE-3998, Stanford Res. Inst., Menlo Park, California.

Woodson, R. D., 1971, Cooling towers: Sci. Am., v. 224, no. 5, p. 70-78.

Zachar, F. R., and Gilbert, A. G., 1968, The economics of coal preparation: Coal Preparation, Am. Inst. Mining, Metall. Petroleum Engineers, New York, p. 5-3 through 5-45.

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Table 2.--Anticlines, domes, and uplifts in the Crow Indian Reservation

Map No. Fig. 3	Name	Location	Oldest formation exposed on crest	Approximate structural closure at surface, in feet
1	Plum Creek anticline	T. 4 S., R's. 25 and 26 E.	Swift Formation	150
2	Shively Hill dome	South part T. 5 S., R. 27 E.	Madison Limestone	500
3	Birdhead dome	South part T. 3 S., R. 27 E.	Cloverly Formation	50
4	Boundary dome	North part T. 2 S., R. 27 E.	Frontier Formation	50
5	Mifflin anticline	East part T. 2 S., R. 28 E., and west part T. 2 S., R. 29 E.	Eagle Sandstone Member, Cody Shale	None
6	Crescent dome	East part T. 4 S., R. 29 E.	Cloverly Formation	70
7	Point Creek dome	Southwest part T. 4 S., R. 30 E.	Thermopolis Shale	50
8	Beauvais Creek uplift	T. 4 S., R's. 29 and 30 E.; includes the Crescent and Point Creek domes as local culminations	Cloverly Formation	70
9	Grapevine dome	Southwest part T. 5 S., R. 29 E.	Madison Limestone	50
10	Sport Creek anticline	East part T. 9 S., R. 33 E.	Chugwater Formation	None
11	Willow Creek dome	West part T. 8 S., R. 33 E.	Chugwater Formation	None
12	Reed dome	North line T. 8 S., R. 32 E.	Piper Formation	None
13	Fort Smith anticline	North part T. 7 S., R. 31 E.	Amsden Formation	250
14	Soap Creek dome	South part T. 6 S., R. 32 E.	Morrison Formation	500
15	Rotten Grass dome	Southwest part T. 7 S., R. 33 E.	Mowry Shale	150
16	Soap Creek anticline	East part T. 5 S., R. 31 E. to south part T. 7 S., R. 33 E.; includes the Soap Creek and Rotten Grass domes as local culminations	Morrison Formation	500+
17	Woody Creek dome	South part T. 3 S., R. 31 E.	Mowry Shale	200
18	Two Leggin uplift	T. 2 S., R. 31 E.; along north line	Carlile Shale Member, Cody Shale	None
19	East Tullock Creek anticline	Corner common to T's. 1 and 2 S., R's. 37 and 38 E.	Hell Creek Formation	None
20	Black Gulch dome	East part T. 9 S., R. 34 E.	Thermopolis Formation	500
21	Aberdeen uplift	East part T. 9 S., R. 35 E.	Carlile Shale Member, Cody Shale	100
22	Ash Creek anticline	South part T. 9 S., R's. 37 and 38 E.	Fort Union Formation	None
23	Porcupine Creek	South part T. 9 S., R's. 28 and 29 E. (unsurveyed)	Jefferson and Three Forks Formations	None

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Table 3.--Geologic occurrences and potential for development of rock and mineral resources, Crow Indian Reservation

[H, high potential; M, moderate potential; L, low potential, ----, not applicable or unevaluated]

	Sand and gravel	Clay and shale	Clinker	Coal	Bentonite	Gypsum	Oil and gas	Limestone	Uranium
Alluvium	M	----	----	----	----	----	----	----	----
Terrace deposits	H	----	----	----	----	----	----	----	----
Wasatch Formation	----	----	----	----	----	----	----	----	----
Fort Union Formation:									
Tongue River Member	----	L	H	H	----	----	----	----	----
Lebo Shale Member	----	----	----	L	----	----	----	----	----
Tullock Member	----	----	----	L	----	----	----	----	----
Hell Creek Formation	----	----	----	----	----	----	----	----	----
Bearpaw Shale	----	----	----	----	M	----	----	----	----
Parkman Sandstone	----	----	----	L	----	----	M	----	----
Cody Shale:									
Claggett Shale Member	----	----	----	----	M	----	----	----	----
Shale Member equivalent to the Eagle Sandstone	----	----	----	----	M	----	M	----	----
Telegraph Creek Member	----	----	----	----	----	----	----	----	----
Niobrara Shale Member	----	----	----	----	L	----	----	----	----
Carlile Shale Member	----	----	----	----	L	----	----	----	----
Greenhorn Calcareous Shale Member	----	----	----	----	M	----	----	----	----
Lower Member	----	----	----	----	----	----	----	----	----
Frontier Formation	----	----	----	----	H	----	M	----	----
Mowry Shale	----	----	----	----	M	----	----	----	----
Thermopolis Shale	----	----	----	----	L	----	M	----	----
Cloverly Formation	----	L	----	L	----	----	M	----	----
Morrison Formation	----	----	----	----	----	----	L	----	----
Swift Formation	----	----	----	----	----	----	L	----	----
Rierdon Formation	----	----	----	----	----	----	----	----	----
Piper Formation	----	----	----	----	----	L	----	----	----
Chugwater Formation	----	----	----	----	----	M	----	----	----
Tensleep Sandstone	----	----	----	----	----	----	H	----	----
Amsden Formation	----	----	----	----	----	----	L	----	----
Madison Limestone	----	----	----	----	----	----	M	M	L
Jefferson Limestone and Three Forks Shale, undivided	----	----	----	----	----	----	L	----	----
Beartooth Butte Formation	----	----	----	----	----	----	----	----	----
Bighorn Dolomite	----	----	----	----	----	----	M	----	----
Gallatin Limestone and Gros Ventre Formation, undivided	----	----	----	----	----	----	----	----	----
Flathead Sandstone	----	----	----	----	----	----	----	----	----
Precambrian rocks	----	----	----	----	----	----	----	----	----

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Table 4.—Analyses of coal, as received, from the Tongue River Member of the Fort Union Formation in in and near the Crow Indian Reservation.

[Composite samples of drill cores; in percent]

Bed name	Location			Moisture	Volatile matter	Fixed Carbon	Ash	Sulfur	Heat value Btu	Source
	Sec.	T.	R.							
Roland	20	8 S.	39 E.	29.54	30.12	36.95	3.39	0.46	8,130	1
Anderson	30	9 S.	39 E.	24.83	30.18	40.65	4.34	.37	9,074	1
Dietz	36	8 S.	38 E.	25.91	31.62	39.61	2.86	.30	9,305	1
Canyon	16	6 S.	39 E.	27.47	29.16	40.02	3.35	.22	8,780	1
Wall	1	7 S.	40 E.	25.08	30.89	39.31	4.72	.29	9,010	1
Rosebud	—	1-2 S.	37-38 E.	24.44	28.79	34.73	11.10	.94	8,353	2
McKay	—	1-2 S.	37-38 E.	24.61	29.62	33.25	11.60	.92	8,243	2
Robinson	—	1-2 S.	37-38 E.	24.96	26.35	38.22	9.38	1.09	8,486	2
D	—	9 S.	38 E.	26.8	—	—	12.0	.84	7,843	3
G	—	9 S.	38 E.	27.0	—	—	4.4	.22	8,736	3
M	—	9 S.	38 E.	23.4	—	—	3.9	.26	9,462	3

Source of analyses as follows: 1. Composite analyses, Matson and Blumer, 1973, p. 20, 29, 34, 38-39. 2. Average analyses, Peabody Coal Co. 3. Composite analyses, Shell Oil Co.

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Table 6.--List of coal mines and prospects, coal thicknesses and analyses - Crow Indian Reservation, Montana (Magill and others, 1966)

Location figure 6	Name	Sec.	T.	R.	Formation	Bed thickness	Form of sample 1/	Sample analysis						Description
								Moisture	Volatile, percent	Fixed carbon, percent	Ash, percent	Sulfur, percent	Btu/lb	
1	Roadcut exposure	5	4 S	38 E	Fort Union	+5 ft	A	19.3	32.5	36.1	12.1	0.5	7,550	Lower part of bed not exposed. Sampled 10/5/64, sample thickness 5 ft.
							B	-	40.3	44.7	15.0	.6	9,360	
							C	-	47.4	52.6	-	.7	11,010	
2	Unnamed prospect	-	4 S	38 E	do---------	6 ft			No sample record					Working inaccessible.
3	do--------------	-	4 S	38 E	do---------	5 ft			do--------------					Do------------------
4	Keasling mine	35	4 S	37 E	do---------	15 ft to 2 in			do--------------					Do------------------
5	Wagon mine	-	5 S	36 E	do---------	Unknown			do--------------					Do------------------
6	Shaw mine	8	6 S	37 E	do---------	9 ft to 11 ft 6 in	A	20.1	35.3	40.4	4.2	.3	9,000	Dump sample east entry. Sampled 9/28/64. Mine was inaccessible. Dump sample main entry. Sampled 9/28/64. Entry was caved.
							B	-	44.2	50.5	5.3	.4	10,690	
							C	-	46.6	53.4	-	.4	12,500	
							A	18.0	34.5	41.5	6.0	.7	8,770	
							B	-	42.1	50.6	7.3	.9	10,700	
							C	-	45.4	54.6	-	.9	11,540	
7	Lodge Grass mine	13	6 S	35 E	Parkman	8 ft			No sample record					Working inaccessible.
8	Dow mine	-	6 S	37 E	Fort Union	Unknown			do--------------					Do-----------------
9	Jones mine	-	6 S	38 E	do--------	do------			do--------------					Do-----------------
10	Johnson mine	-	7 S	37 E	do--------	25 ft			do--------------					Do-----------------
11	Glen Leming mine	16	7 S	36 E	do--------	4 ft 2 in			do--------------					Do-----------------
12	Walter Miller lease	-	7 S	37 E	do--------	Unknown			do--------------					Do-----------------
13	Unnamed prospect	33	7 S	37 E	do-------- (Carney bed)	8 ft 1 in	A	22.5	32.2	40.2	5.1	.3	9,090	Sampled 8/31/16. Reference USBM Tech. Paper 529, p. 36.
							B	-	41.6	51.9	6.5	.4	11,730	
14	do-------------	33	7 S	37 E	do--------	8 ft	A	24.2	31.3	39.4	5.1	.4	8,940	Sampled 10/4/17. Reference USBM Tech. Paper 529, p. 36.
							B	-	41.2	51.2	6.7	.5	11,790	
							C	-	44.2	55.8	-	.5	12,630	
15	do-------------	-	9 S	38 E	(Roland bed)	5-13 ft			No sample record					Working inaccessible.
16	do-------------	-	9 S	38 E	do--------	5-13 ft			do--------------					Do------------------
17	do-------------	-	9 S	34 E	Cloverly	7 ft 3 in			do--------------					Do------------------
18	Unnamed mine	-	9 S	35 E	Bearpaw	3 ft			do--------------					Do------------------
19	Unnamed prospect	-	9 S	36 E	Fort Union	3 ft			do--------------					Do------------------
20	Trembath lease	-	9 S	37 E	do-------	Unknown			do--------------					Do------------------

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1/ A - Sample as received. B - Moisture free. C- Moisture and ash free.

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Table 8.--Oil and gas fields in and immediately adjacent to the Crow Indian Reservation.

[Data as of September, 1974 from Petroleum Information, Denver, Colo.]

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, Amsden, 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

[1] Barrels

[2] Thousand cubic feet

[3] One mile north of the reservation

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Table 9.--Wells drilled to Ordovician or older rocks in the Crow Indian Reservation

[Data from Petroleum Information, Denver, Colorado]

Name of well	Location Township, Range quarter, and section	Year completed	Surface elevation feet	Total depth feet	Oldest formation tested
Carter Oil Co., 1 Crow Tribal	1S 34E C NE SE 27	1953	3,157	5,464	Bighorn Dolomite
Mobil Producing Co., T-44-10-1	1S 36E SE SE NW 10	1954	3,500	8,335	Cambrian rocks, undivided
Stanolind Oil and Gas Co., 3-1 Crow Tribal	3S 30E C NW NE 30	1953	3,463	4,718	Cambrian rocks, undivided
Farmers Union, 1 Tribal	3S 31E C SW NW 34	1955	3,494	4,309	Bighorn Dolomite
Humble Oil and Refining, 1 Crow Tribal	3S 35E SW SE SE 2	1964	3,383	7,570	Cambrian rocks, undivided
Tidewater Associated, 1 Crow Tribal	3S 37E C SW NW 3	1956	3,638	8,801	Winnipeg Sandstone
Inland Empire, 52-34 Crow Tribal	6S 32E SW NW NE 34	1948	3,613	4,470	Precambrian rocks
Tennison Drilling Co., 1 Spear	8S 33E NE NE NW 30	1956	5,134	2,086	Bighorn Dolomite
Shell Oil Co., 11 Crow Tribal	9S 37E NE SE SE 26	1957	4,414	10,445	Bighorn Dolomite

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Table 20.--Properties of clay samples from Lovell clay pit.

			Unfired properties						Fired properties			
Sample No.	Location	Color	Water of plasticity percent	Dry shrinkage (linear), percent	Dry modulus of rupture pounds per square inch	Fusion	Cone	Color	Weight loss, percent	Shrinkage (linear), percent	Absorption percent	Modulus of rupture, pounds per square inch
CR-10	Lovell claypit					10		Reddish brown				
CR-11	do-------------					11+		Purple brown				
CR-12	do-------------					9+		Medium brown				
CR-16A	do-------------	Pearl gray	18.27	7.1	2,438	8+		Dark brown				
							04	Medium orange	7.69	1.9	7.48	4,458
							3	Reddish brown	7.50	3.6	4.15	5,862
							7	Brownish gray	7.26	1.7	11.96	3,375
CR-13	Roadcut 500 feet S of Lovell pit	Medium gray	18.77	7.0	1,977	11		Grayish black				
							04	Dark orange	5.44	.3	12.95	1,645
							3	Orange red	5.60	1.4	11.13	2,253
							7	Grayish brown	5.61	2.5	4.60	3,555
CR-14	do------------					11		Purple brown				
CR-10 CR-11	50 percent of each	Chocolate brown	20.73	7.3	2,079		04	Reddish brown	6.39	3.9	2.28	6,498
							3	Brick red	6.47	3.5	.34	6,614
							7	Dark red	6.53	.8	18.35	3,348
CR-10 CR-11 CR-16A	33-1/3 percent of each	Chocolate brown	19.16	7.2	2,247		04	Reddish brown	7.07	3.6	3.51	5,959
							3	Brick red	7.01	3.6	.58	6,761
							7	Dark red	6.89	.9	17.02	2,756

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TABLE 21. Ceramic properties of samples of clay and shale on the Crow Indian Reservation (Berg and others, 1970).

Sample No.	Formation	Section	T.	R.	Water of Plasticity 1/	Drying Shrinkage, Percent 2/	P.C.E. 3/	Firing Range °F 4/	Firing Temperature °F	Firing Shrinkage, Percent	Fired Color	Hard-ness	Remarks
660	Cloverly	NE 1/4, 6	6S	31E	L 29 H 33	4.5	11	2000 to 2100	1850 2050 2250	0.0 3.1 7.5	red red dark red	SS S HS	Fair common brick
661	Cloverly	NE 1/4, 6	6S	31E	L 29 H 35	5.5	12	2000 to 2200	1900 2100 2300	0.0 5.2 7.0	red red dark red	SS S HS	Fair common brick
662	Cloverly	NE 1/4, 6	6S	31E	L 30 H 37	11.0	12	2150 to 2300	1900 2100 2300	1.9 6.2 7.0	buff buff buff	S S HS	Good common brick
663	Thermopolis shale	SE 1/4, 6	6S	31E	L 27 H 32	7.2	11	None	1850 2050 2250	2.3 o.f. o.f.	red red red	SS HS HS	Not suitable
664	Thermopolis shale	SW 1/4,18	4S	30E	L 38 H 45	6.9	12	None	1900 2100 2300	0.6 9.8 9.4	red red dark red	SS HS HS	Not suitable
665	Kootenai (Cloverly)	NW 1/4,23	4S	29E	L 41 H 52	10.00	12	2000 to 2200	1900 2100 2300	0.0 7.4 7.5	red red Chocolate	S HS HS	Poor common brick
666	Kootenai (Cloverly)	NW 1/4,23	4S	29E	L 44 H 54	--	10	None	Not fired, brick cracked on drying.				
667	Morrison	NE 1/4,25	4S	25E	L 22 H 26	3.9	4	None	1650 1850 2050	0.0 0.0 0.0	light red light red light red	SS SS SS	Not suitable
668	Morrison	NE 1/4,25	4S	25E	L 21 H 24	3.0	3	None	1600 1800 2000	0.0 0.0 0.0	light red light red light red	SS SS SS	Not suitable
669	Morrison	NE 1/4,25	4S	25E	L 24 H 27	4.0	3	1950 to 2000	1600 1800 2000	0.0 0.6 2.0	red red red	SS SS S	Poor common brick
670	Morrison	NE 1/4,25	4S	25E	L 21 H 24	4.2	2	None	1600 1800 2000	0.0 0.0 0.0	red red red	S S S	Not suitable
671	Morrison	NE 1/4,25	4S	25E	L 27 H 30	5.1	4	1950 to 2050	1650 1850 2050	0.6 2.5 9.6	tan tan brown	SS SS S	Poor common brick
672	Morrison	NE 1/4,25	4S	25E	L 20 H 23	4.8	4	1900 to 2050	1650 1850 2050	0.0 0.0 1.8	red red red	SS S HS	Not suitable
673	Morrison	NE 1/4,25	4S	25E	L 30 H 37	11.0	3	1850 to 2000	1600 1800 2000	0.0 6.1 9.4	red red red	S S HS	Poor common brick
674	Morrison	NE 1/4,25	4S	25E	L 26 H 31	7.1	6	1900 to 2000	1700 1900 2100	0.0 0.0 over fired	red red red	S S HS	Poor common brick

1/ L, Lower limit; H, Upper limit.
2/ Drying shrinkage is linear.
3/ Pyrometric cone equivalent.
4/ Firing range is linear.
5/ S, steel hard; HS, harder than steel; SS, softer than steel.

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TABLE 22.-- Results of expandability tests made on samples of clay and shale by Montana Bureau of Mines and Geology, Chelini (1966).

Sample No.	Formation	Location	Section	T.	R.	Expansion Range °F	S.G. after firing	Firing behavior	Remarks
468	Soap Creek bentonite bed	SW Hardin	SE 1/4 19	3S	32E	2200-2300	0.70	Fair bloat at 2200	Narrow range not suitable.
469	do----------	do--------	SE 1/4 19	3S	32E	2100-2300	1.1	Fused at 2400	Fair bloat narrow range.
470	Bentonite bed "L"	do--------	SE 1/4 19	3S	32E	None	-	Fused at 2300	Not suitable.
471	Bentonite bed W	E of Hardin	E 1/2 8	1S	35E	2000-2100	1.3	Fused at 2300	Fair bloat, but narrow range.
472	Bentonite bed "V"	do--------	E 1/2 8	1S	35E	None	-	Fused at 2200	Not suitable.
473	do-----------	do--------	E 1/2 8	1S	35E	2200-2400	-1.0	Fused at 2400	Fair bloat.
474	Bearpaw shale	do--------	NE 1/4, SW 1/4 20	1S	35E	2000-2300	-1.0	Fused at 2400	Good bloat, medium range.
475	Bentonite bed "V"	do--------	NE 1/4, SE 1/4 20	1S	35E	2200-2300	-1.0	Fused at 2300	Fair bloat, but narrow range.
476	Bentonite bed "W"	SE of Hardin	Center 4	3S	35E	2000-2300	1.0	Fused at 2300	Fair bloat, medium range.
477	do----------	do---------	Center 4	3S	35E	None	-	Fused at 2300	Not suitable.
478	Clay Amsden Formation.	Yellowtail Dam	SE 1/4 18	6S	31E	2200-2400	-	Slight bloat	Not suitable.

The above samples were tested for ceramic properties, but all except No. 478 were unsuitable for common brick. No. 478 was capable of making fair common brick.

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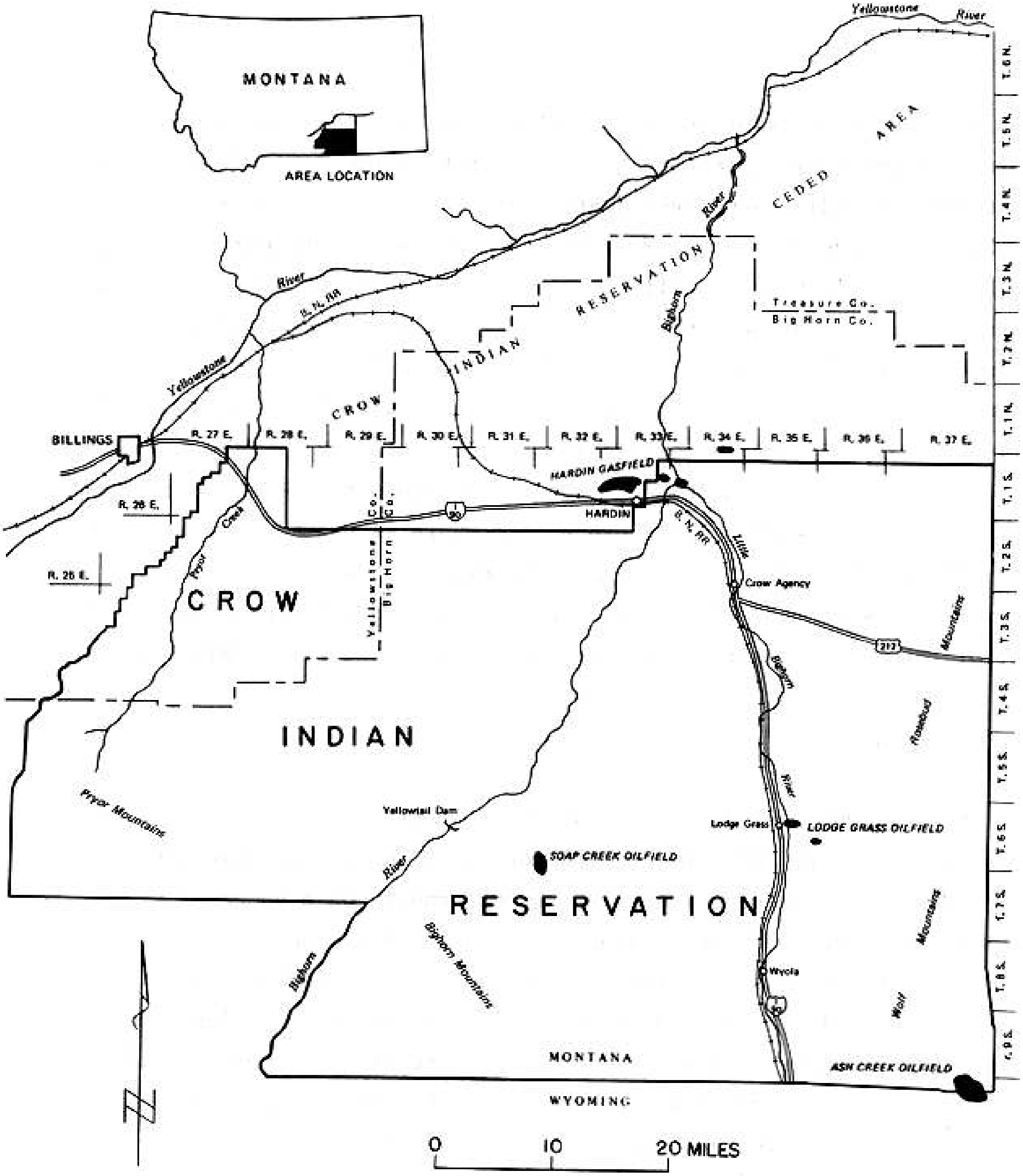

Figure 1. Index map of Crow Indian Reservation, Montana.

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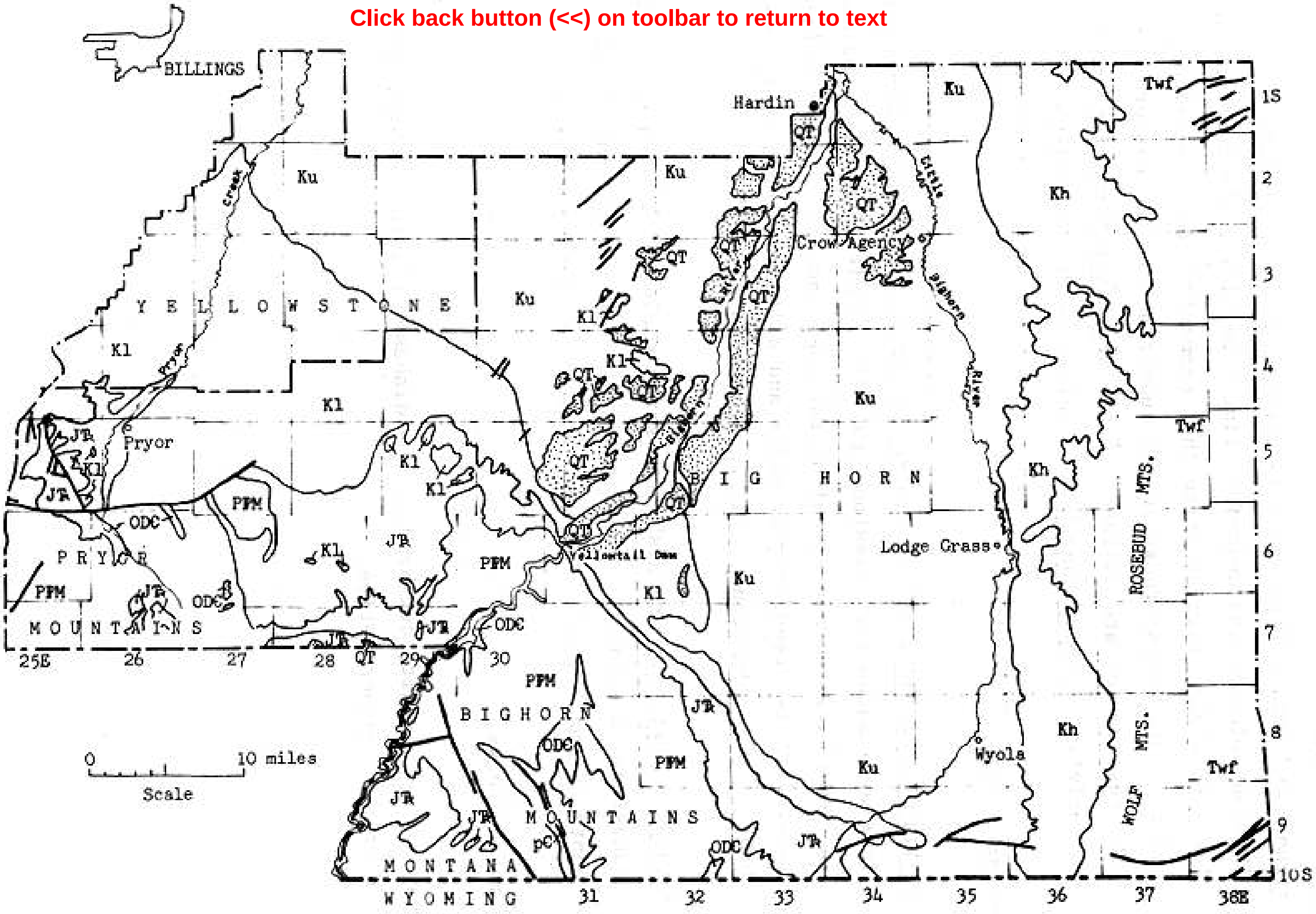

Figure 2. Generalized geologic map of the Crow Indian Reservation.

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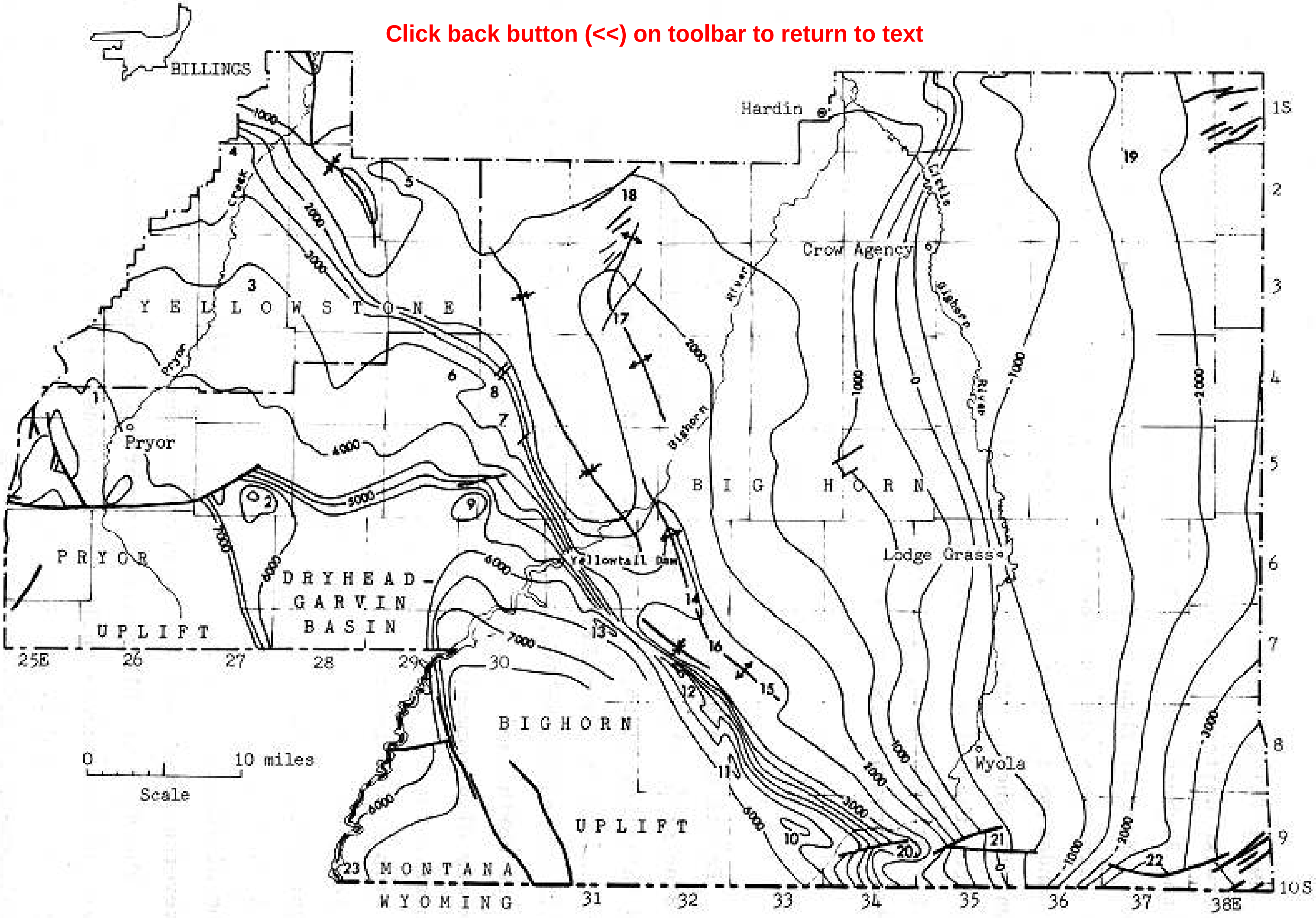

Figure 3. Structure contour map of the Crow Indian Reservation.

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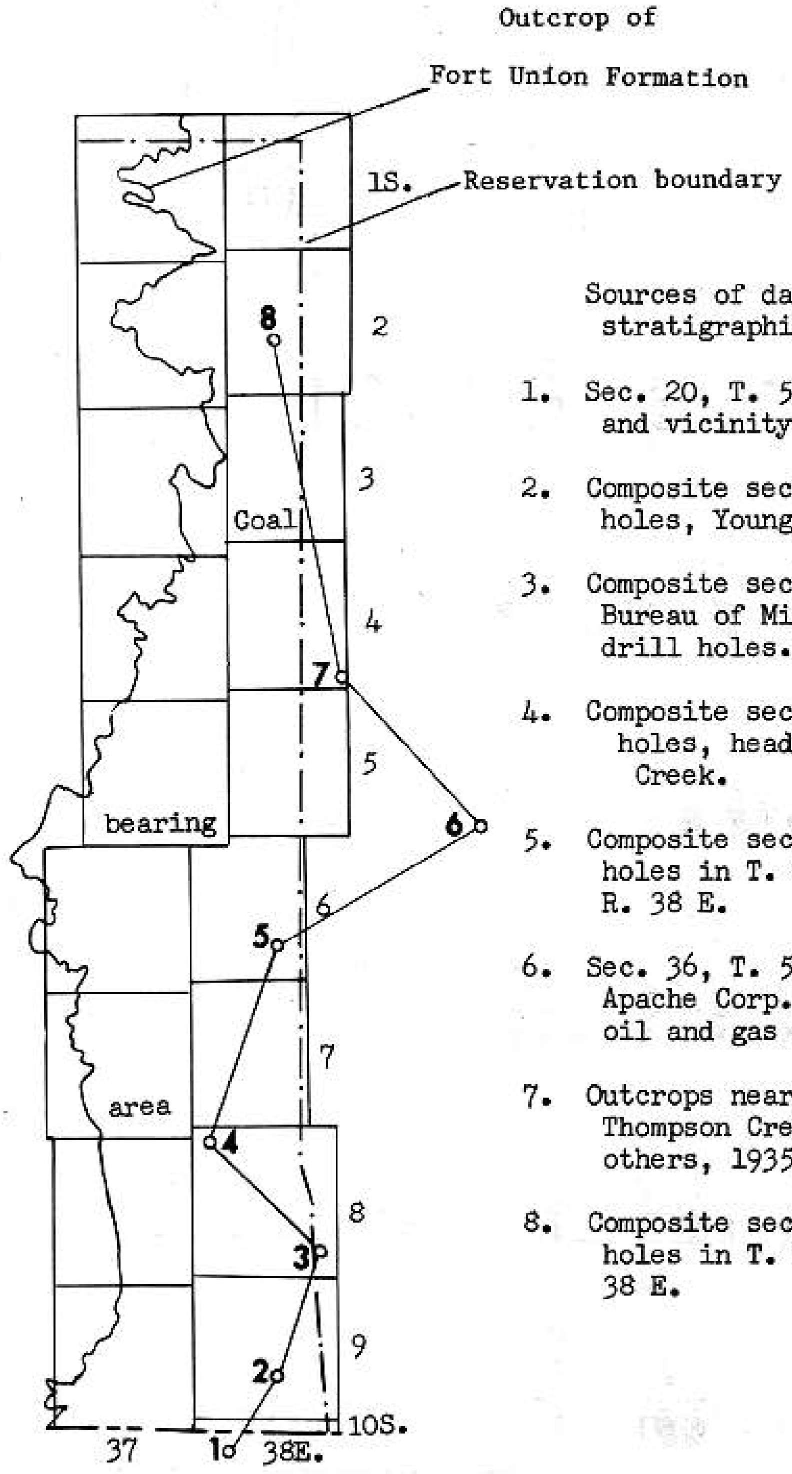

Sources of data for stratigraphic sections:

1. Sec. 20, T. 58 N., R. 85 W. and vicinity (Barnum, 1974).
2. Composite section from drill holes, Youngs Creek area.
3. Composite section, Montana Bureau of Mines and Geology drill holes.
4. Composite section from drill holes, head of Squirrel Creek.
5. Composite section from drill holes in T. 6 and 7 S., R. 38 E.
6. Sec. 36, T. 5 S., R. 39 E., Apache Corp., 1 Cheyenne Tribal oil and gas well.
7. Outcrops near the mouth of Thompson Creek (Thom and others, 1935, pl. 14).
8. Composite section from drill holes in T. 1 and 2 S., R. 38 E.

Figure 4. Map showing outcrop of Fort Union Formation in eastern part of the Crow Indian Reservation and line of diagrammatic section shown on Figure 5.

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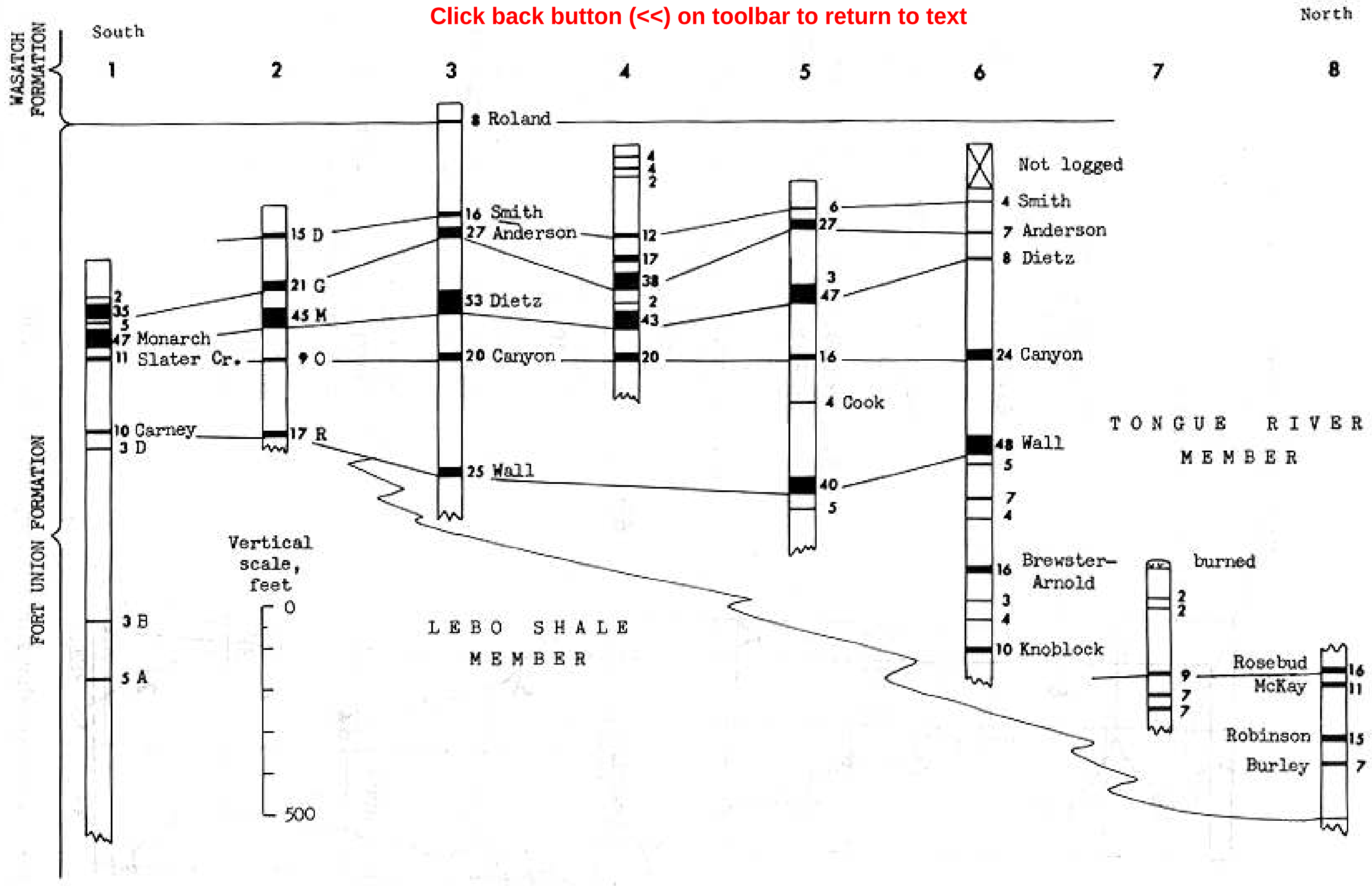

Number beside column is thickness of coal in feet.

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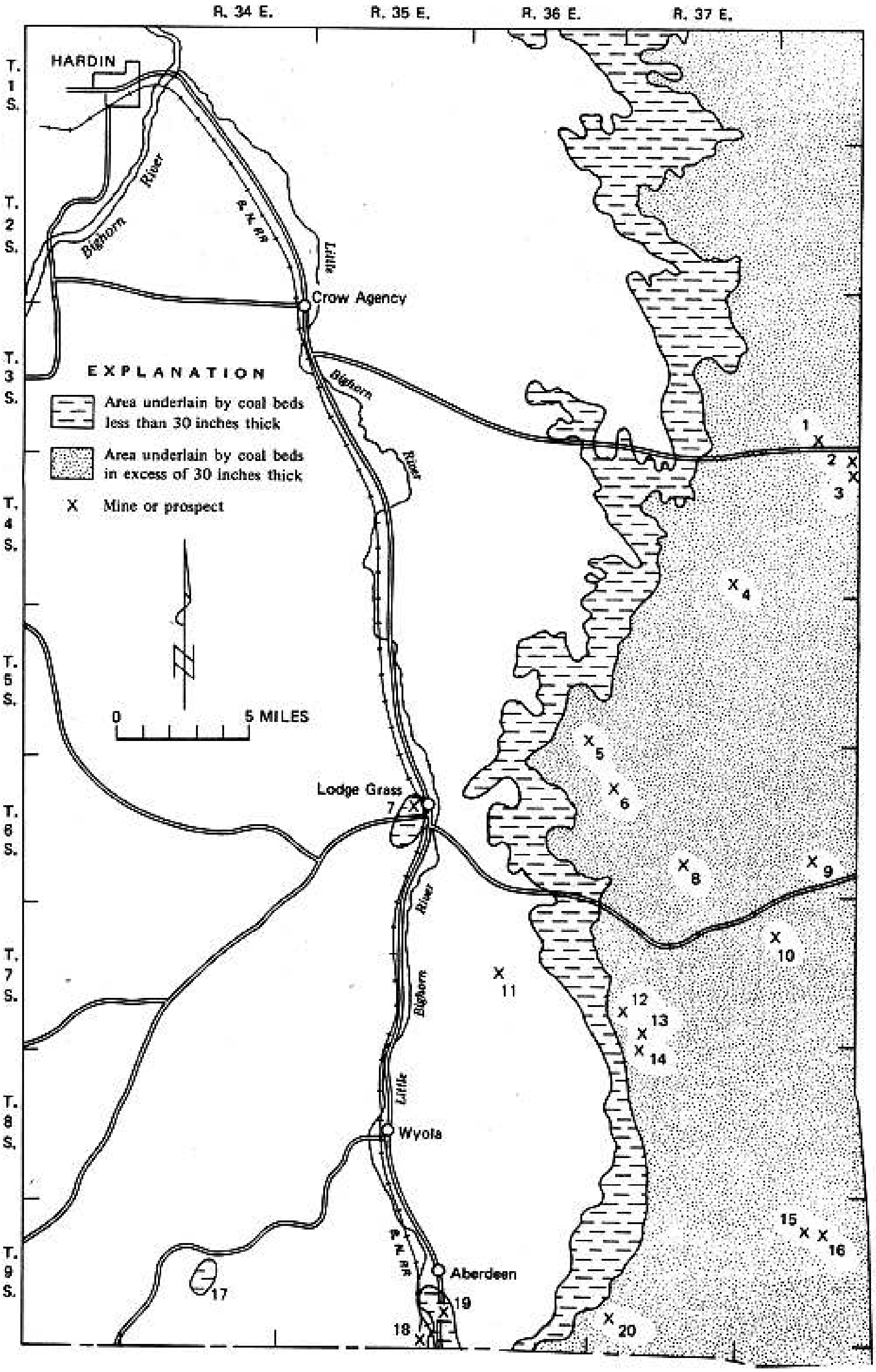

Figure 6. Coal deposits and coal areas, Crow Indian Reservation. See Table 6 for list of numbered coal mines and prospects. (Modified from U.S. Geol. Survey map C-2).

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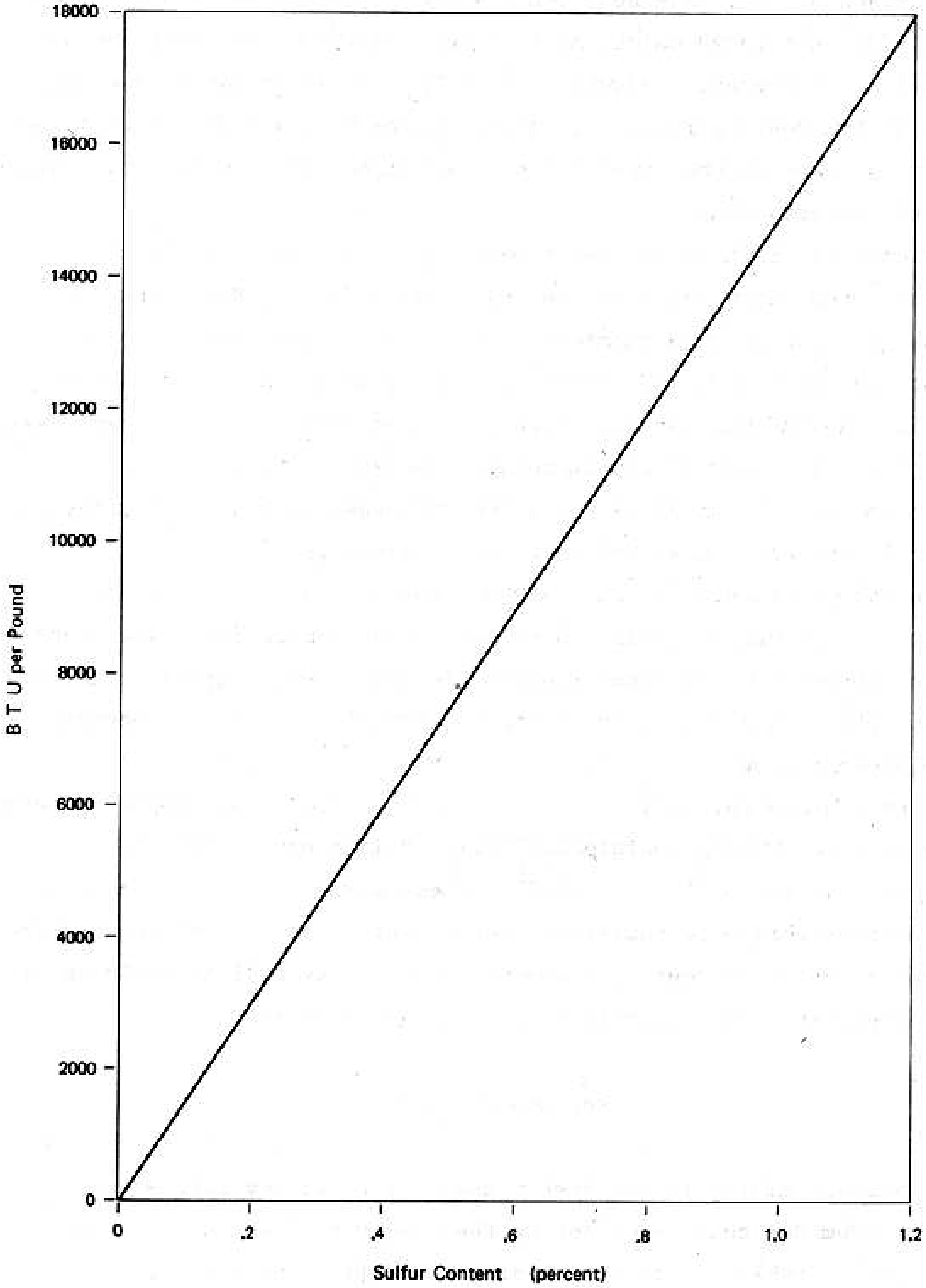

pounds SO_2/million Btu.

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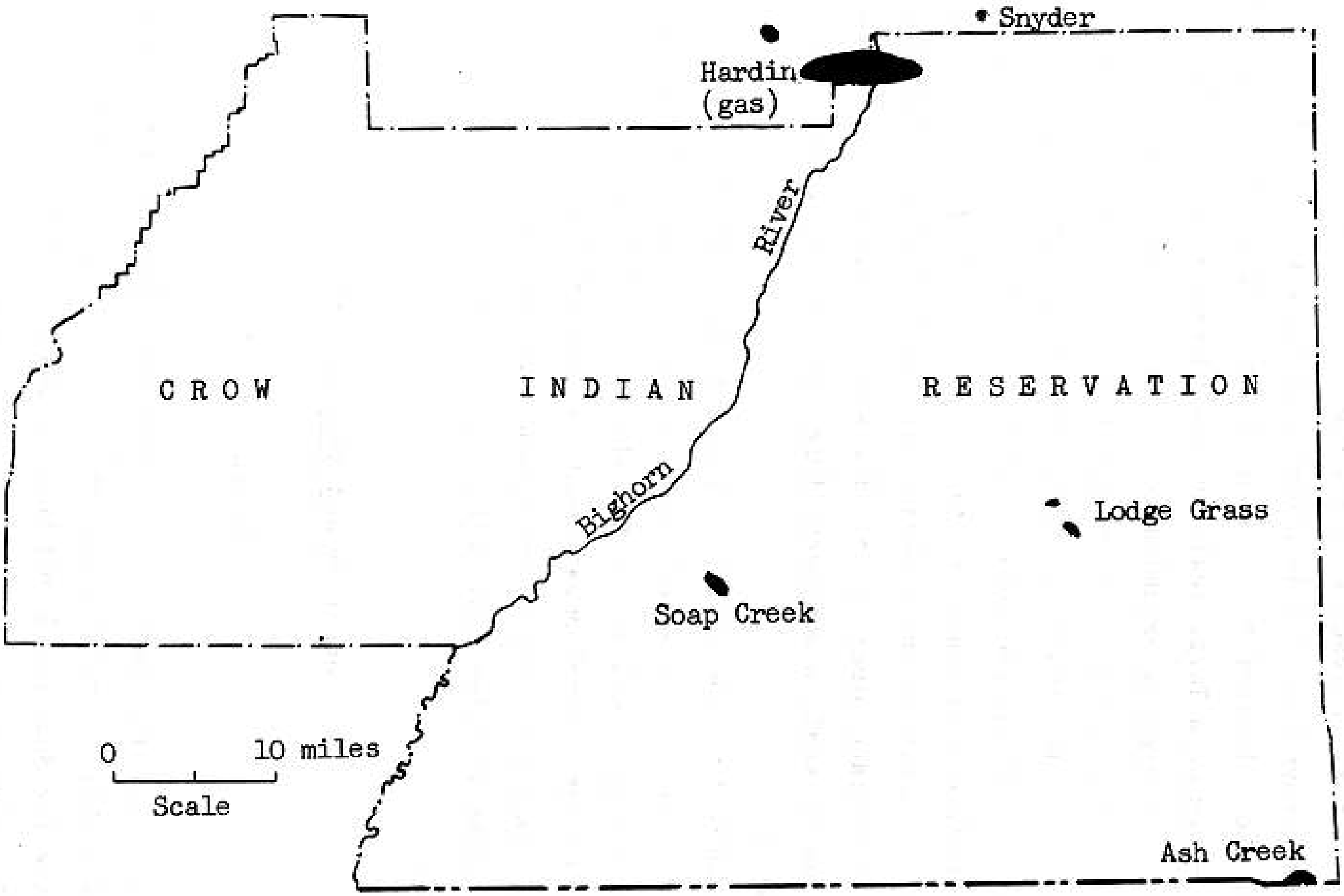

Figure 8. Oil and gas fields in and adjacent to the Crow Indian Reservation.

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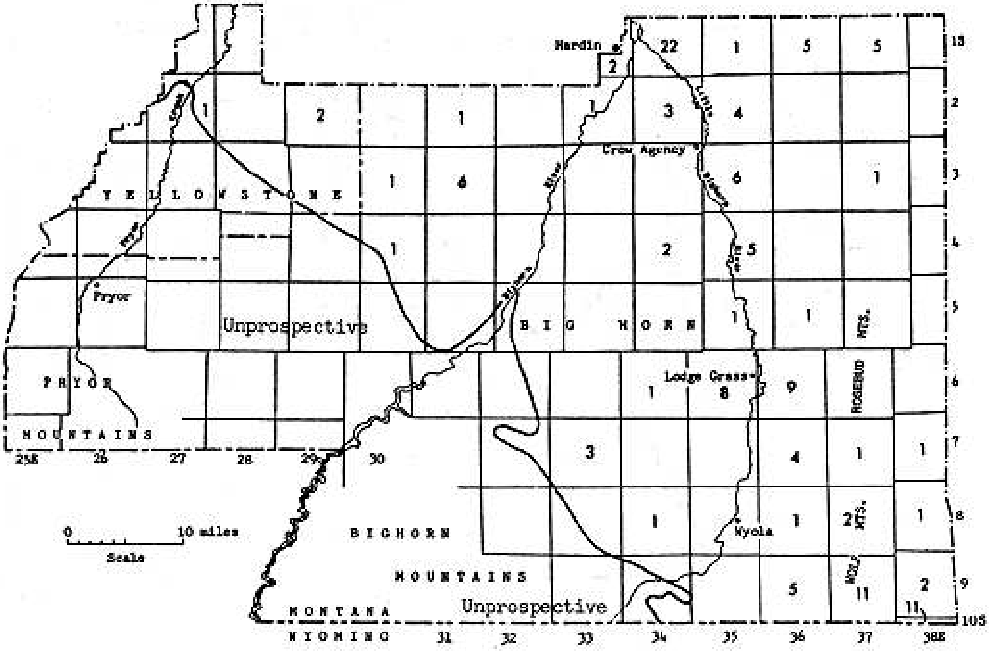
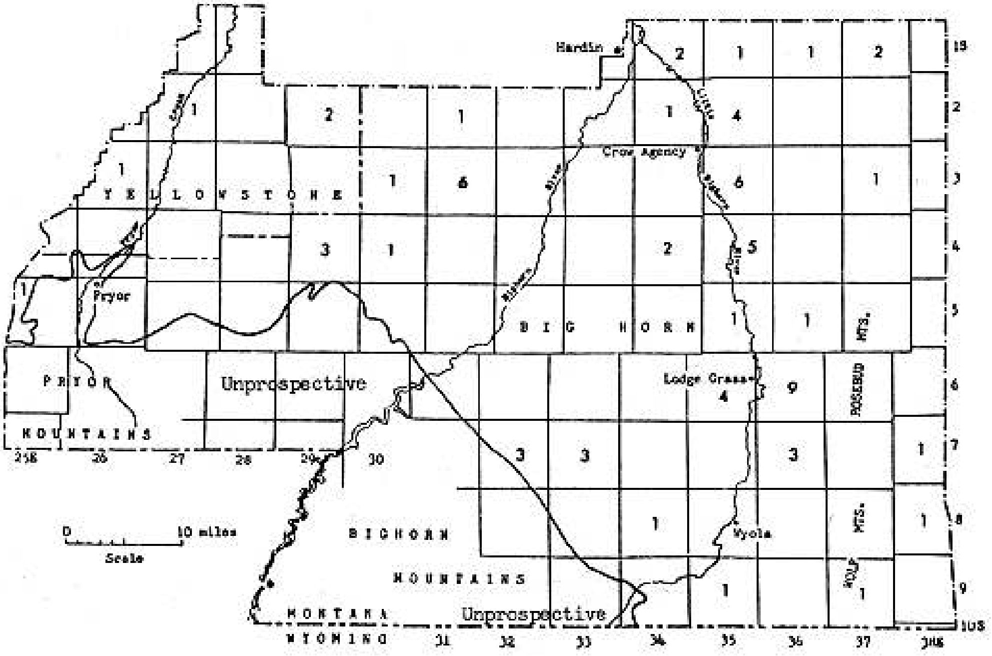


A. Upper Cretaceous rocks



B. Lower Cretaceous rocks

Figure 9. Prospective areas for oil and gas showing number of wells drilled in each township in Cretaceous rocks.

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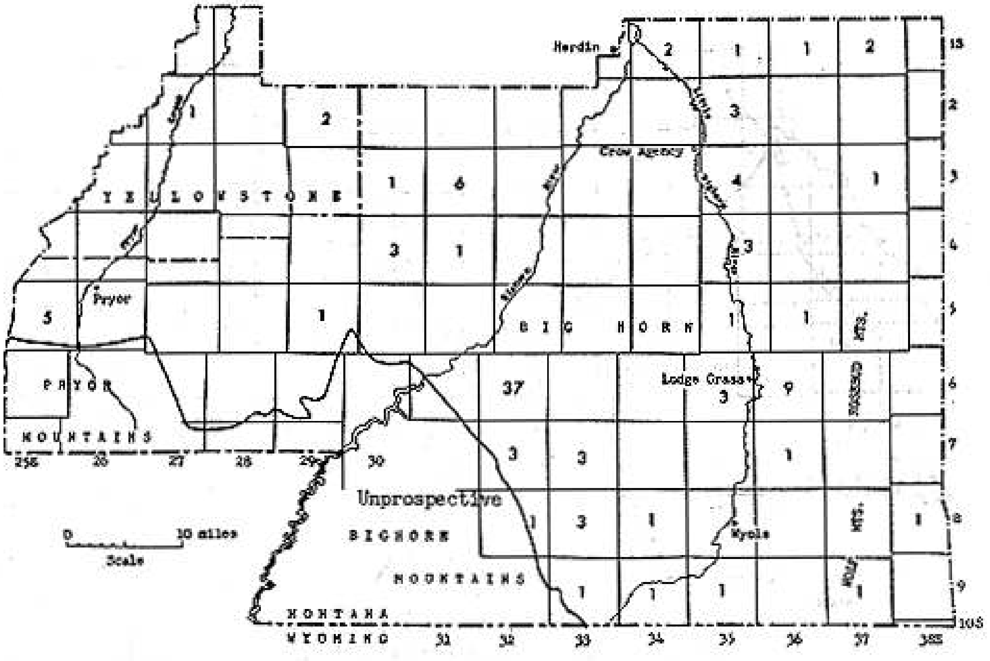
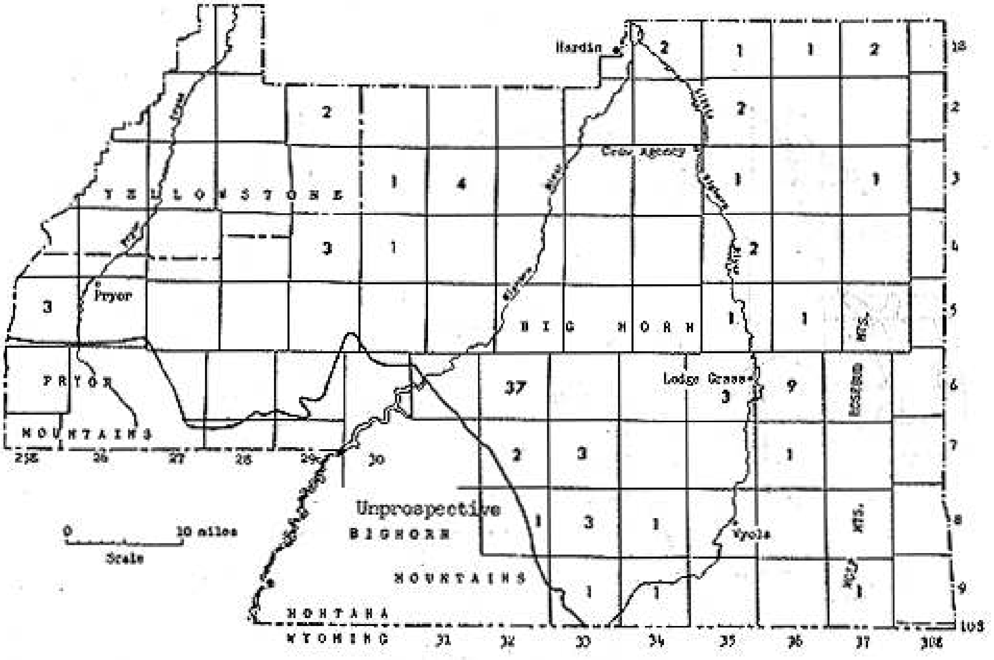


A. Jurassic, Triassic, and Permian rocks



B. Pennsylvanian rocks

Figure 10. Prospective areas for oil and gas showing number of wells drilled in each township in Jurassic, Triassic, Permian, and Pennsylvanian rocks.

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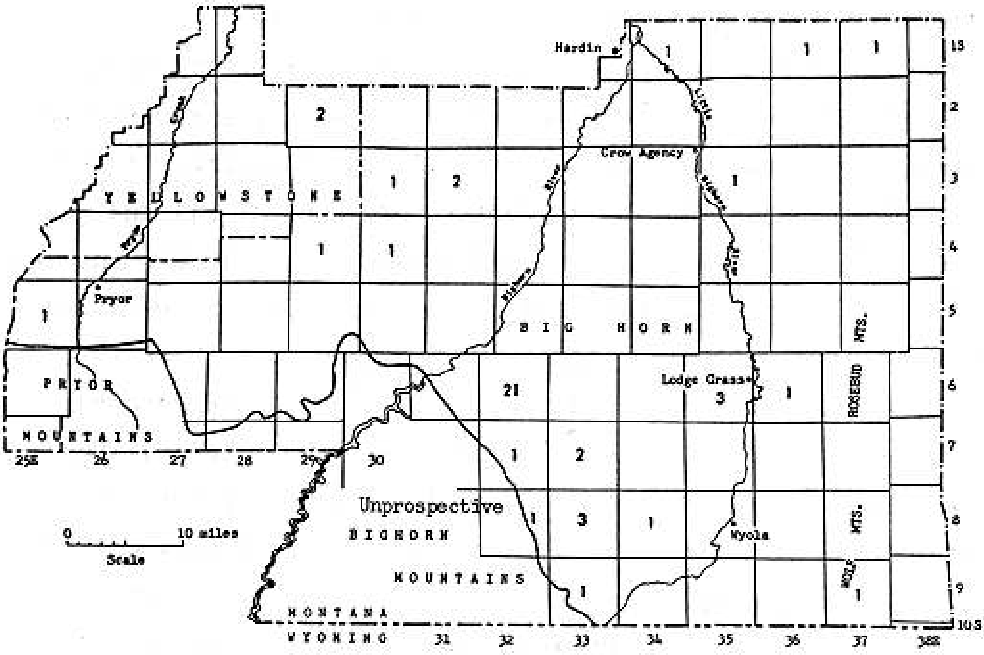
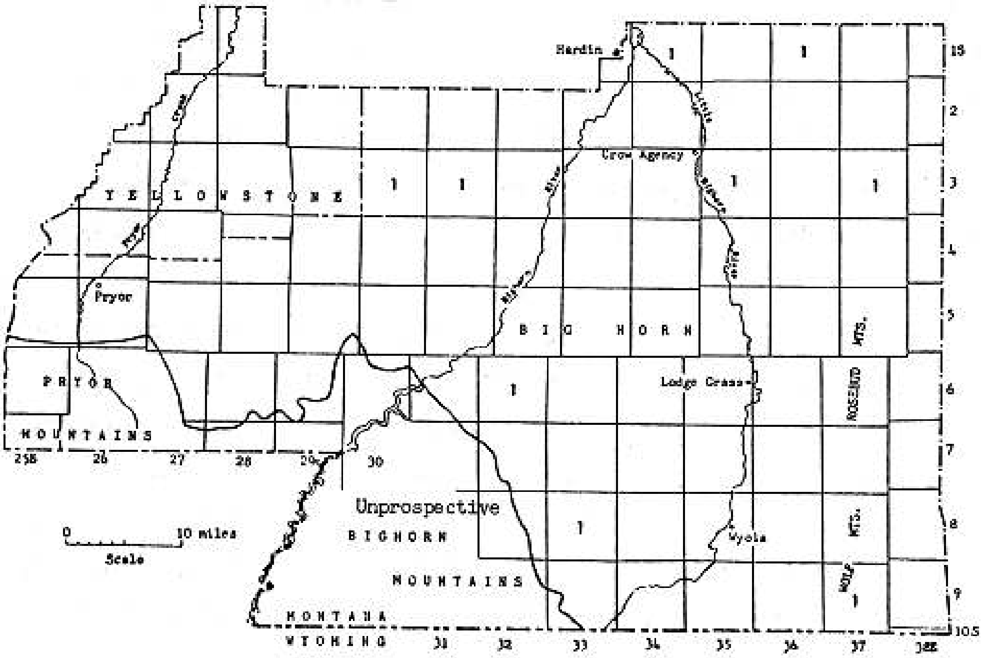


A. Mississippian rocks



B. Devonian rocks and older

Figure 11. Prospective areas for oil and gas showing number of wells drilled in each township in Mississippian, Devonian, Ordovician, and Cambrian rocks.

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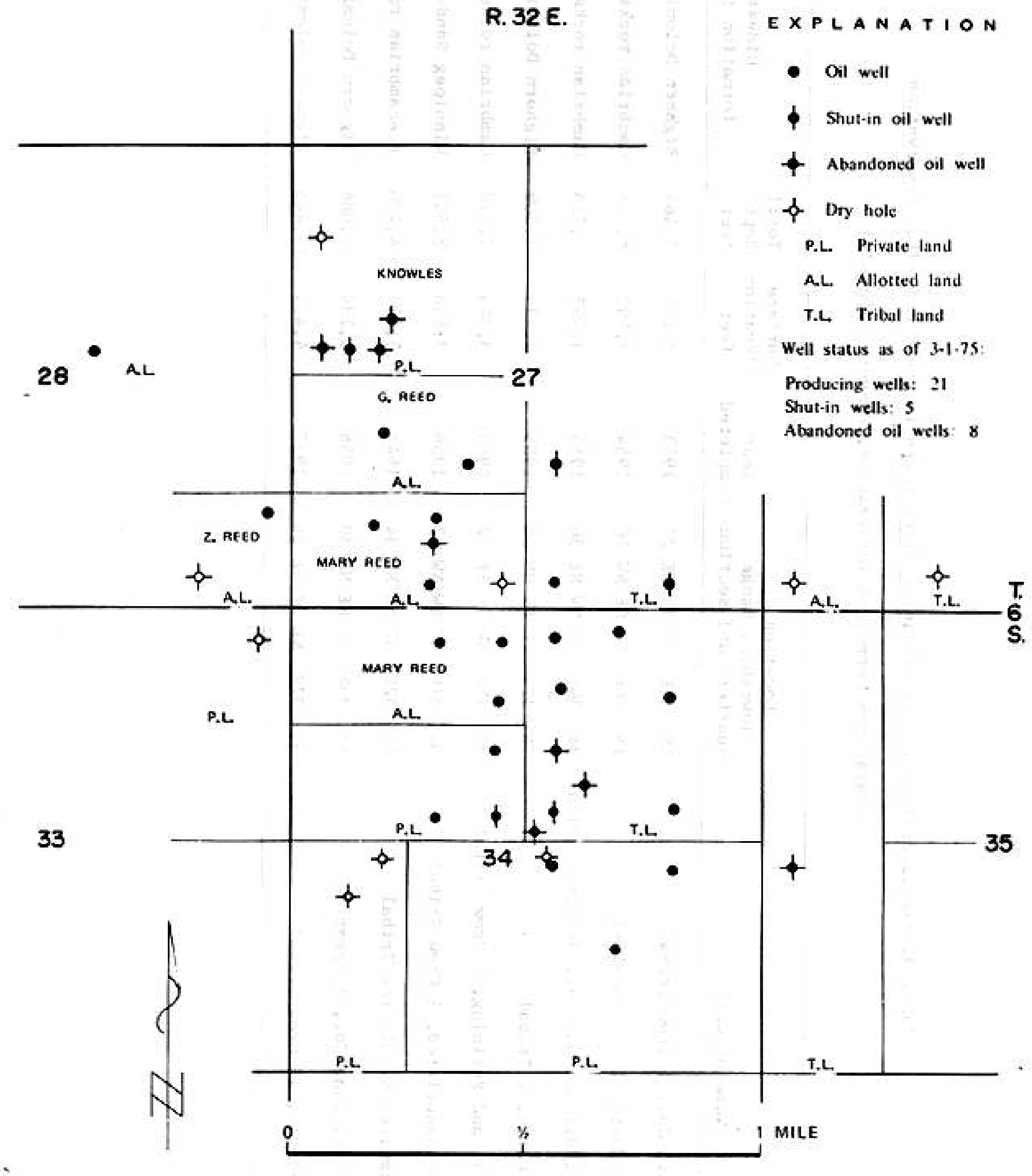

Figure 12. Soap Creek oil field, Big Horn County, Montana. (Modified from U.S. Geol. Survey Northwestern Region map No. 592).

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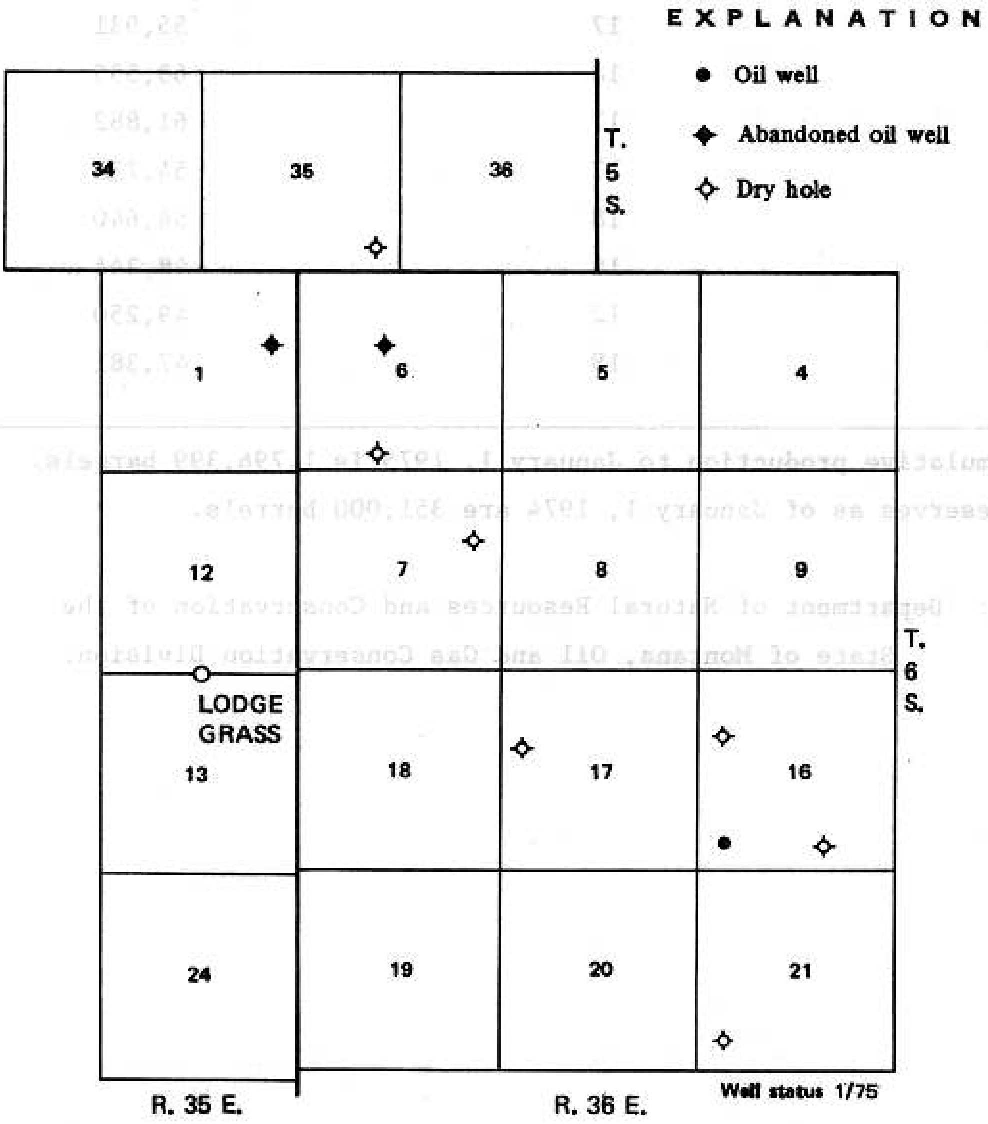

Figure 13. Lodge Grass oil field, Big Horn County, Montana. (Modified from Montana Oil and Gas Conservation Commission map).

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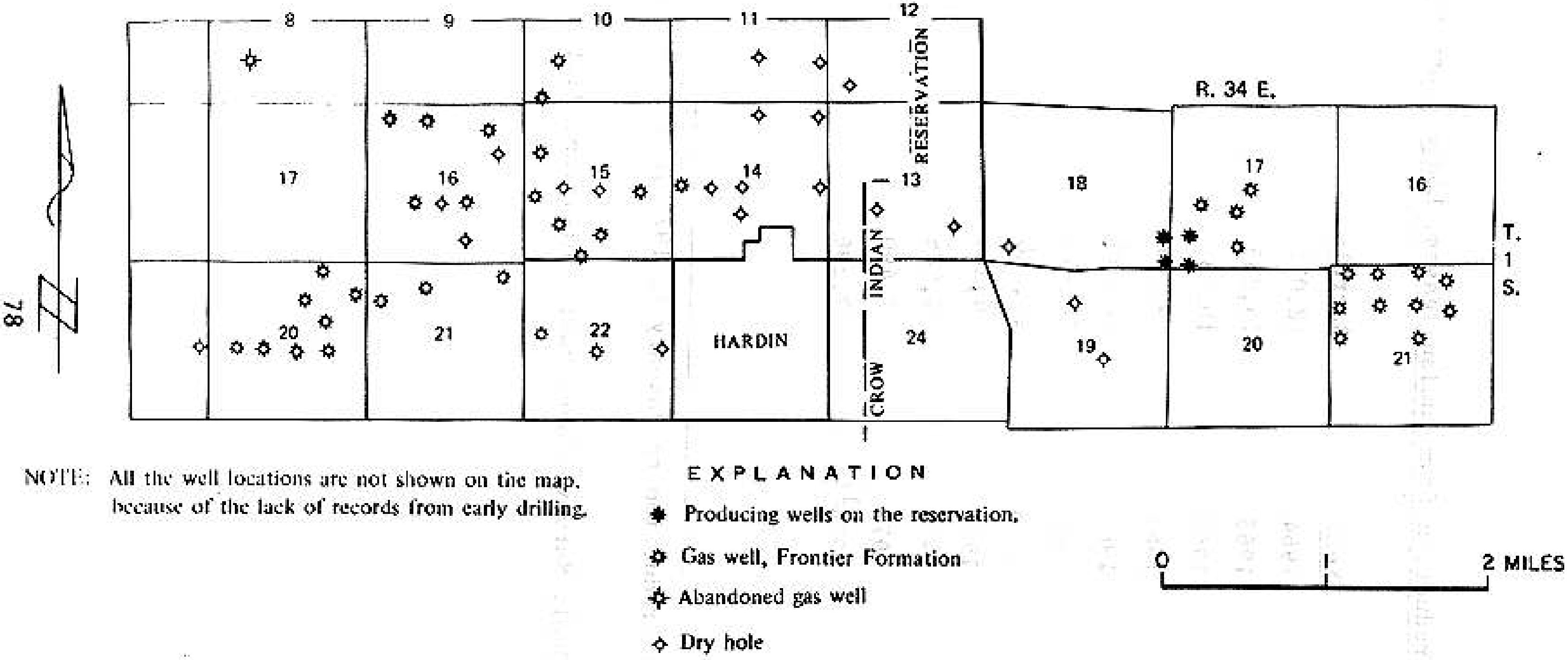

Figure 14. Hardin gas field, Big Horn County, Montana. (Modified from Magill and others, 1966, and data from Cities Service Oil Co., Tulsa, Oklahoma).

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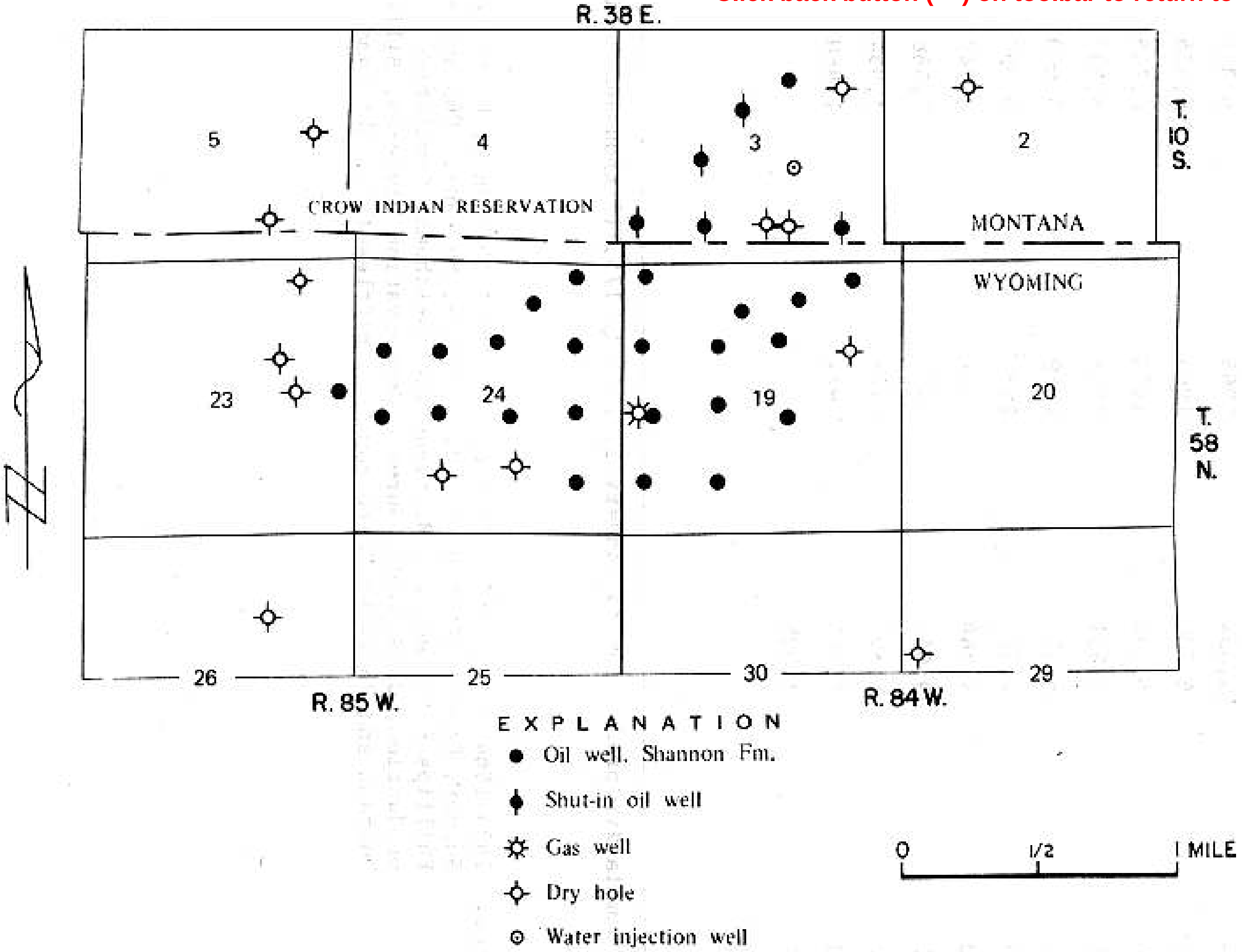

Figure 15. Ash Creek oil field, Big Horn County, Montana, and Sheridan County, Wyoming. (Modified from Magill and others, 1966, with data from U.S. Geol. Survey, Casper, Wyoming.

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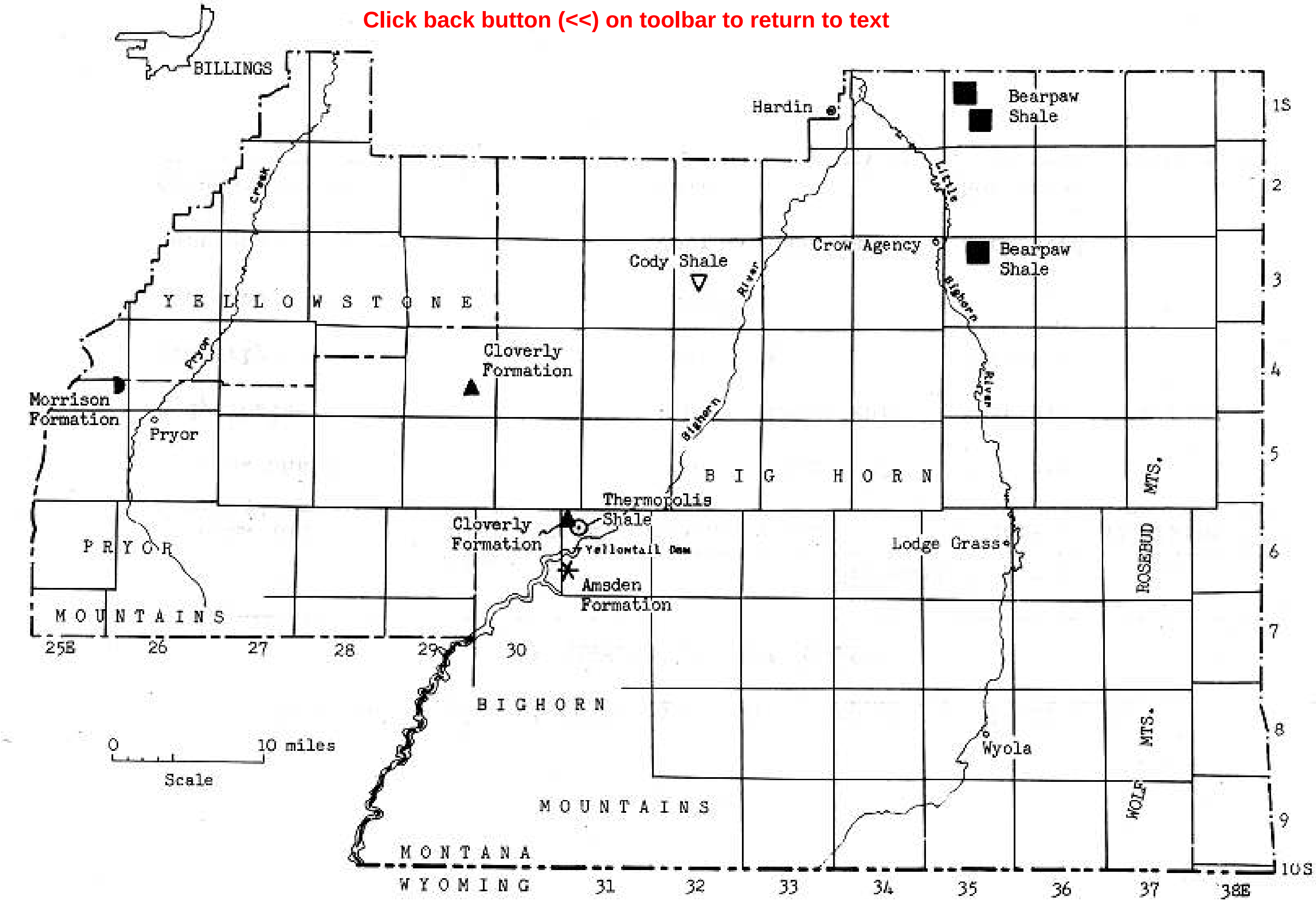

Figure 16. Sample localities for claystone and shale showing formation sampled.

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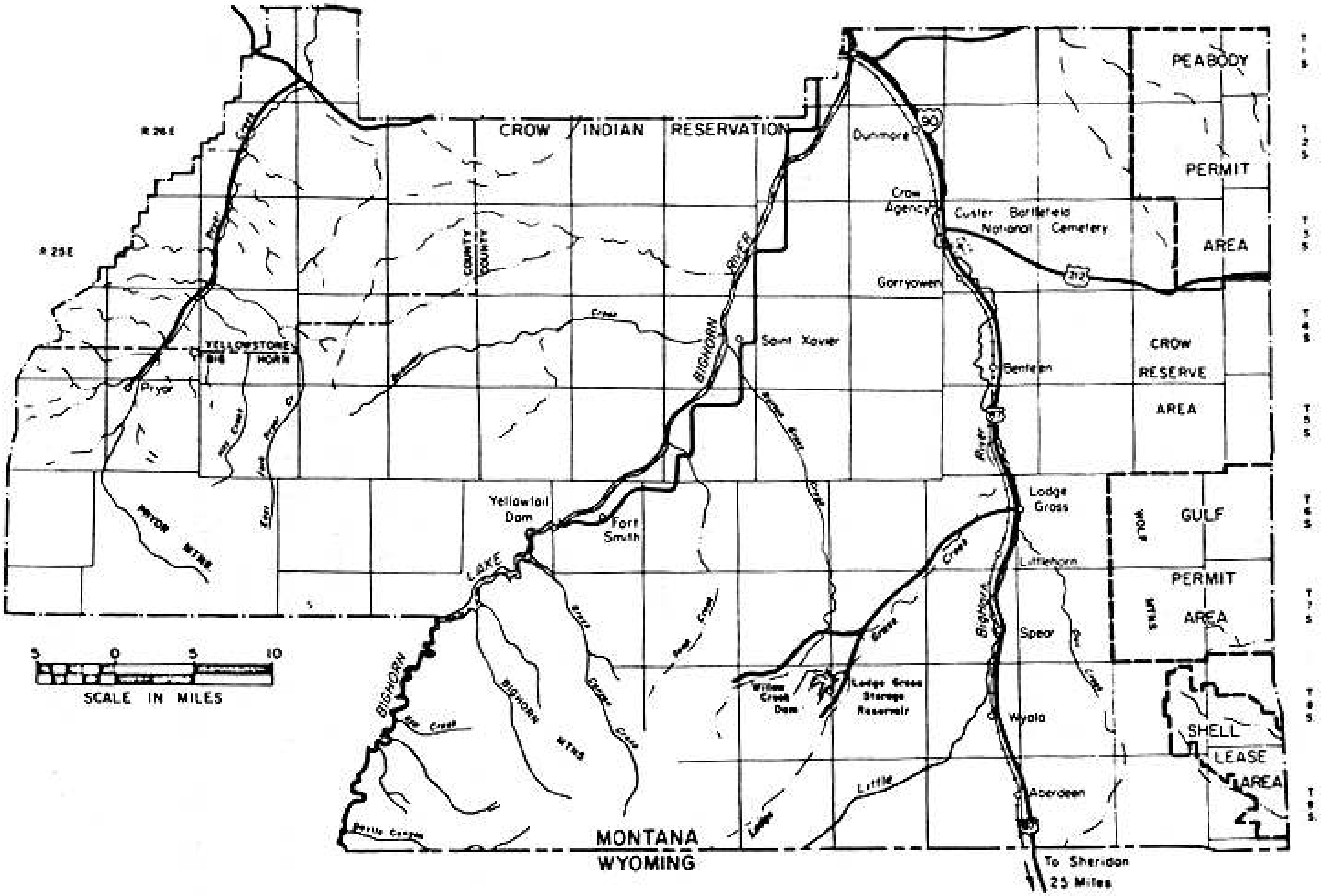

Figure 17. Coal leases and permit areas, Crow Indian Reservation.