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

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SUMMARY AND CONCLUSIONS

The most important mineral resources on the Blackfeet Indian Reservation are oil and natural gas. Several productive fields occur on and near the reservation and continuing exploration will almost certainly discover others. Probabilities for new discoveries appear to be greater in the western and eastern parts of the reservation than in the central section. The expected costs for new discoveries in the western part of the reservation will be many times that for new discoveries in the eastern part, mainly because of the complex geology and depth to potentially producing formations. Gathering of additional surface and subsurface data, by geological mapping and geophysical surveys, is necessary to fully evaluate areas of greatest potential.

Thin beds of bituminous coal are in the north-central and southeastern part of the reservation. Coal for local consumption can be produced from these but they cannot be considered a source of large reserves that might compete with the thicker, more extensive coal beds in eastern Montana and elsewhere.

Titaniferous magnetite deposits occur in Cretaceous sandstones and might be sources of titanium metal in the distant future. Problems in their development as resources include beneficiation, smelting, and marketing. Further study of these deposits is recommended, even though their current value is very limited.

Large deposits of sand and gravel are along the drainages throughout the reservation. These are adequate for local usage but costs of transportation precludes their competing in markets distant from the reservation.

Some clays associated with coal beds might find local usages in pottery making or similar industries but none are known to have unique qualities to compete successfully in markets distant from the reservation.

INTRODUCTION

General

This report was prepared for the U.S. Bureau of Indian Affairs by the U.S. Geological Survey and the U.S. Bureau of Mines under an agreement to compile and summarize available information on the geology, mineral and energy resources, and potential for economic development of certain lands. Sources of information were published and unpublished reports as well as personal communication with various individuals. No field work was done.

Geography

The Blackfeet Indian Reservation includes about 2,400 square miles in Glacier and Pondera Counties, Montana (Figure 1). Of the total area, 81 percent is allotted, 13 percent is privately owned, 5 percent is non-Indian, and 1 percent is government owned (U.S. Department of Commerce, 1974, p. 269).

The reservation is bounded on the north by Canada, and on the west by Glacier National Park. The southern and eastern boundary is defined in part by Birch and Cut Bank Creeks.

The terrain slopes gently upward toward the west and is partly dissected, grassy, and nearly without a forest cover. The Rocky Mountains rise abruptly along the western edge without marked foothills. Elevations range from 3,800 feet along the eastern edge to about 9,000 feet on the northwestern boundary (Figure 2). Topographic relief of some lower valleys in the eastern area is as much as 350 feet; in the mountain foothills about 1,500 feet; and near the highest point about 4,000 feet.

The climate is typical of the Northern Great Plains with severe, cold winters, and warm-hot summers. Freezing temperatures are common from November to April. Precipitation averages about 15-20 inches.

The reservation drains north and east into two major geographic basins. Most of the drainage is into the Missouri River Basin by the Milk River, Cut Bank Creek, Two Medicine Creek and Birch Creek. The St. Mary River flows north from the northwestern corner of the reservation into Canada.

The Indian population consists of about 6,200 who reside on or adjacent to the reservation. Browning (population 1,700) (1970), the largest town and principal reservation supply center, contains the tribal headquarters.

The reservation is served by the Burlington Northern Inc. railroad which passes east-west through Cut Bank, Browning and East Glacier Park. A Burlington Northern spur heading is at Valier southeast of the reservation. U.S. Highway 2 is the main east-west route and U.S. Highway 89 is a major north-south route through the area. Secondary roads afford access to most of the other sections of the reservation.

Physiography

The reservation's west boundary crosses Chief Mountain, about 4 miles south of the Canadian border, then veers southeasterly toward St. Mary; from St. Mary the boundary trends generally south for about 4 miles, then southeasterly again to Heart Butte, then due south to Birch Creek (Figure 2). For this entire distance the boundary lies on or very nearly to the dividing line between the Great Plains on the east and the Rocky Mountains on the west. According to Stebinger (1916, p. 120-121), "The front range of the mountains rises with wall-like abruptness from the plains without marked foothills. . . . . the plains appear to extend indefinitely eastward as a single surface with monotonous regularity. On closer examination, however, the part of the plains in the area here treated proves to have considerable relief, with low plateau-like areas in places, together with extensive dissected tracts along the principal streams. . . the topographic types that give a distinctive character to the surface features in different parts of the region are 1) high-level plains, 2) low-level plains, 3) escarpments, two of which are continuous across the entire area, 4) badlands, 5) glacial moraines of considerable extent." To this group we might add the extensive area of glacial lake deposits of Lake Cut Bank (Colton, Lemke, and Lindvall, 1961). Figure 3 shows the western limits of the advances of the continental glaciers, portions of the eastern limits of the mountain glaciers, and the unglaciated areas. This entire area is shown in greater detail by Alden (1932, Plate 1). In the vicinity of Cut Bank the glacial lake deposits border the ground moraine and terminal moraines of the continental glaciers.

To the north of Cut Bank a distinct melt-water channel drains across an otherwise unglaciated area into Lake Cut Bank from a lobe of terminal moraine. Southwest of Cut Bank is a larger area of glacial deposits left by the mountain glaciers, as well as remnants of the three alluvial terraces that formerly maintained a continuous slope back toward the mountain front. In the northwest corner of the reservation are remnants of terminal moraines, ground moraines, and several stream-cut terraces. Remnants of early mountain glacial deposits partly cemented to tillite, lie on top of the number one terrace remnants.

With few exceptions, main streams on the Blackfeet Reservation flow east and northeast. Rocky Coulee and Little Rocky Coulee, north of Cut Bank, flow southeast into the Cut Bank to its junction with the Marias River a few miles to the south.

The Continental Divide lies a few miles west of the reservation in Glacier Park. The Hudson Bay Divide crosses the reservation in the northwest corner, and trends generally north, east of the St. Mary Lakes and Duck Lake, west of Goose Lake, and finally trending generally northeast into Canada on the ridge between St. Mary River and the North Fork of the Milk River.

GEOLOGY

Stratigraphy

The stratigraphic units exposed at the surface and known from oil wells are listed in Table 1. Figure 4 is a generalized geologic map showing outcrop areas of formations in the east half of the reservation.

In the unglaciated portions of the Blackfeet Indian Reservation, and in areas where erosion has removed the glacial deposits or alluvial terraces, the underlying Cretaceous formations are exposed. Surface exposures of the Virgelle Sandstone are limited to small areas along streams in T. 31 and 32 N., R. 5 W., south of Cut Bank in both Glacier and Pondera Counties.

Exposures of the Two Medicine Formation on the east side of the reservation are bordered by glacial deposits. The Two Medicine is succeeded toward the west by the Bearpaw Shale, the Horsethief Sandstone, the St. Mary River Formation, all of Cretaceous age and the Willow Creek Formation (Tertiary). West of the Willow Creek is the area called the "disturbed belt" with repeated exposures of Cretaceous formations.

From the eastern boundary of the "disturbed belt," westward to the Belt rocks of the Rocky Mountain Front, the Cretaceous formations are so disturbed that they are not differentiated on the geologic map. Not shown on the geologic map are small areas of the Cretaceous Colorado Group, the Kootenai, and Paleozoic rocks in the southwest part of the reservation near Heart Butte.

The formation descriptions for bedrock units on the Blackfeet Reservation are adapted from Stebinger (1914, 1916), Cobban (1955), and Weimer (1955).

The Virgelle is light gray, fine to medium grained, and commonly crossbedded. Over wide areas the formation contains large brown weathering calcareous sandstone concretions. At many places the top of the Virgelle is titaniferous-magnetite sandstone. Near the mouth of Birch Creek there is a sharp contact between the Virgelle and the Two Medicine next above.

The Two Medicine Formation is exposed at the surface in the northeast and southeast parts of the reservation and in the disturbed belt. This formation is almost entirely nonmarine and is about 2,125 feet thick at the south end of the reservation. The formation is composed of soft, calcareous mudstone containing hard calcareous nodules. Carbonaceous beds and sandstone layers occur within the formation, and thin coal beds are found near the base. The Two Medicine covers the greatest area of the Cretaceous formations exposed on the Blackfeet Reservation.

Above the Two Medicine are exposures of the Bearpaw Shale, a dark-gray marine shale containing clay-ironstone concretions, bentonite, and thin sandstone beds. In the south-central part of the reservation the Bearpaw is about 400 feet thick.

Overlying the Bearpaw is the Horsethief Sandstone, consisting of about 360 feet of gray to buff coarse sandstone, massive and cross bedded, and a lower part grading from slabby sandstone to shaly sandstone toward the base. The Horsethief is a marine and brackish-water formation. The sandstone layers near the top carry heavy concentrations of detrital magnetite.

Next above is the St. Mary River Formation, consisting mainly of greenish-gray clay and sand and thin, discontinuous, buff-weathering sandstone. Thin beds of red clay and a few lenticular beds of limestone are common, and coal beds occur both at the base and at the top of the formation. The St. Mary River Formation is about 980 feet thick on the Blackfeet Indian Reservation.

The youngest bedrock unit on the reservation is the Tertiary Willow Creek Formation, consisting of about 700 feet of clay and soft sandstone. The contact between the Willow Creek and the underlying St. Mary River Formation is placed on the color change from the grayish rocks to the dominantly red sediments of the Willow Creek Formation. The red Willow Creek rocks give rise to reddish soils that are easily recognized in tracing the limits of the formation.

On the west side of the reservation the boundary line crosses mostly Cretaceous rocks but occasionally the boundary crosses outliers of rocks of the Belt Series (Figure 4) over thrust toward the east over the Cretaceous formations. The Belt rocks in this area consist of as much as 10,000 feet of argillite, quartzite, and limestone beds.

In the southwest part of the reservation are exposures of the Colorado Group, the Kootenai Formation, and even a few small exposures of Mississippian, Devonian and Cambrian rocks (not shown on Figure 4). The Colorado Group consists of 1,500 to 2,000 feet of dark-gray shale and a few layers of concretionary limestone. The lower 600 feet is made up of dark marine shale alternating with gray siliceous sandstone layers 20 to 50 feet thick.

The Kootenai Formation consists of 900 to 1,200 feet of red and green shale and siltstone and lenticular beds of sandstone. At the base is a conglomeratic sandstone 90 feet thick, called the Cut Bank sand. The Kootenai Formation is mainly a continental deposit.

The Mississippian rocks are represented by the Madison Group, consisting of about 1,500 feet of limestone and dolomite.

The Devonian rocks consist of about 1,000 feet of limestone, dolomite, and shale, and the Cambrian is represented by between 1,000 and 1,500 feet of sandstone, limestone, and shale.

Structure

The regional structure of the Blackfeet Reservation is influenced by the Sweetgrass Arch (Figure 5) to the east and the Lewis Overthrust on the west. The shallow synclinal structure that underlies the central part of the reservation broadens into a more extensive feature to the north, where it is referred to as the Alberta Syncline. On the south the syncline flattens out and is not distinguishable beyond Cut Bank Creek. The Cretaceous beds dip gently to the west off the Sweetgrass Arch, then dip more steeply into the synclinal area. Complex folding and faulting mark the eastern boundary of the so-called disturbed belt. At the Rocky Mountain Front, Paleozoic rocks as well as rocks of the Belt Series are thrust over the Cretaceous rocks of the disturbed belt to the east and northeast. More details of the structure of the Blackfeet Reservation are discussed in the section on petroleum geology.

On the structure map (Figure 6) the contours depict the generally westward dip of the beds on the west flank of the Sweetgrass Arch. Several modifications of that generality appear; one of the most significant is the Reagan structure, which is a small closure in T. 37 N., R. 7 W. It has produced both oil and gas for many years and is indicative of the importance that local modifications of the regional structure may have. Close attention to the structure map shows several northwest-trending plunging noses (anticlinal features without closure). All of these may be important, if they continue to the depth of the potentially productive rocks. One large synclinal area is indicated between the disturbed belt and the contoured area in the northern part of the reservation.

It should be noted that the contours on the map were modified from the cited publications. Much of the information available was either shallow well data or surface information. The contours, therefore, reflect only the general structural picture at or near the ground surface. Typically, structural configuration at depth is only approximately followed by surface structure and may turn out to be much more complex.

The large area in the western half of the reservation that is labeled as having "sharp surface folds underlain by thrust faults" is in the disturbed belt. Geologic structure is much too complex to represent on a small scale map and is often difficult to show on a large-scale map. (For details see Weimer, 1955). In a broad way, the area represents the eastward "dying-out" of the overthrust faulting of the Glacier Park area. At depth, thrust faults and recumbent folds are commonly encountered in wells drilled for oil or gas. As many as 50 or 60 faults may be identifiable in a well before any Paleozoic rocks are reached.

Very important to an understanding of the structural geology is the fact that folded and faulted potentially productive Paleozoic rocks underlie structurally complex Cretaceous rocks. The very complexity of the Cretaceous structure adds to the difficulty of exploring for the underlying features that may contain oil or natural gasfields.

MINERAL RESOURCES

Energy Resources

Petroleum and Natural Gas

General

Before Glacier National Park was established, a prospector named Sand D. Somes was looking for copper along Swift Current Creek near what is now Many Glaciers Lodge (Douma, 1953). While cleaning out his workings after blasting, he found pools of oil. Those pools of oil soon became more exciting than rocks with no copper shows, and by 1902 Mr. Somes had started drilling. By the spring of 1903, he had drilled to a depth of 500 feet and found oil. He is thus credited with finding Montana's first commercial oil production. Most significant to this report is the fact that Somes' discovery was only a few miles from the Blackfeet Indian Reservation and is now covered by the waters of Sherburne Lake.

Although production from that oil field in the Swift Current valley didn't last, it marked the beginning of the development of an oil and gas industry of major importance to the state's economy. Since 1903, several fields have been discovered on the Blackfeet Indian Reservation, and it seems likely that several more fields will be found (Figure 7).

A summary of past drilling activity on or near the reservation is given in Table 2, which lists both wildcat and developmental drilling in Glacier County, Montana, from 1962 to 1974.

TABLE 2
Summary of Drilling in Glacier County, Montana

	Wildcat wells			Development wells			Total	Footage
Year	Dry	Oil	Gas	Dry	Oil	Gas	wells	drilled
1962	3	0	0	3	21		27	83,273
1963	0	0	1	5	10	2	18	59,912
1964	3	1	0	12	13	0	29	104,939
1965	4	2	0	14	19	0	39	124,671
1966	11	1	0	12	37	2	63	205,135
1967	5	0	0	9	12	2	28	87,028
1968	1	2	2	5	3	0	13	38,923
1969	3	0	0	3	35	0	41	133,826
1970	3	0	2	2	11	3	21	87,503
1971	8	0	0	4	16	1	29	108,740
1972	2	0	0	6	27	4	39	120,832
1973	2	1	0	2	13	1	19	52,978
1974	2	0	0	9	10	2	23	69,697

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

Stratigraphic units on the reservation that are productive of hydrocarbons include the carbonate rocks of the Madison Group (Table 1), sandstone beds of the Kootenai Formation, and to a small extent, sandstone beds of the Blackleaf Formation. These units are not the only potentially productive rocks, as significant shows have been found in additional zones on or near the reservation, and these zones should be regarded as prospective. In January 1976, for example, it seems that production from Devonian rocks has been established from a well only about 30 miles from the reservation. Oil shows were first seen in Devonian rocks of the area in the early 1930's, but production did not occur until more than 40 years later. Shows have also been found in Cambrian rocks (Flathead Quartzite) in the area, but production has never been established.

Each of the porous and permeable rock units of the area should be regarded as potentially productive of oil or natural gas. Units of particular importance are the Blackleaf Formation, Kootenai Formation, Madison Group, and Jefferson Group. As exploration proceeds, the increased geologic knowledge will permit a better evaluation of the characteristics of these units.

Stratigraphy of the Blackfeet Indian Reservation is moderately complex in detail but relatively simple in general. Most of the thick units as shown in the stratigraphy sequence (Table 1) are continuous throughout the area, but many of the thinner units are markedly lenticular. In some areas thickness variations take place over very short distances. If such short-range variations can be found in the proper structural attitudes, they may form stratigraphic traps for hydrocarbons, which should be one of the major objectives of the search for oil and gas on the reservation.

Two cross sections (Figure 8) show, in a general way, the major stratigraphic relations in the area. The wells for the cross sections were chosen to show the stratigraphy to as great a depth as possible and across areas of typical variability. The cross sections do not show details of stratigraphic variation, but they indicate typical thickness and structural variations.

Production and Reserves

Three oil, and two oil and gas fields have been discovered on or near the Blackfeet Reservation; and additional discoveries are probable (Figure 7). Several one-well and two-well pools that failed to develop into commercial ventures are not included in these fields.

Cut Bank Oil and Gas Field

The Cut Bank oil and gas field (Figure 1 and Figure 7) is about 30 miles long, 5 to 10 miles wide, and extends north and south of the town of Cut Bank. Most of this oil field is east of the reservation. In 1960, production was 2,077,933 barrels of oil, of which 438,957 barrels was from Indian land (Hubbard and Henkes, 1962, p. 27). Since that time oil may have been produced on the reservation, but specific production records have not been found.

Production through 1974 was 141,286,000 barrels. Yearly production, including present reserves, are listed in Table 3. Gas production from this and the Reagan field is listed in Table 4.

TABLE 3
Oil Production from the Cut Bank Field

	Production from Kootenai Formation		Production from Madison Group		
Year	Producing wells	Oil (barrels)	Producing wells	Oil (barrels)	Shut-in
1966	1,139	3,902,643	39	135,908	
1967	1,139	3,259,049	39	133,374	
1968	729	3,673,177	31	118,313	
1969	714	4,837,708	33	115,756	
1970	727	5,300,919	28	114,332	29
1971	830	5,441,493	27	99,568	29
1972	926	4,669,512	27	88,985	29
1973	844	3,916,348	27	89,256	29
1974	863	3,303,815	28	89,423	29

Kootenai cumulative production to 1-1-75 was 134,953,000 barrels. Madison cumulative production to 1-1-75 was 6,333,000 barrels. Kootenai reserves as of 1-1-75 were estimated to be 45,047,000 barrels. Madison reserves as of 1-1-75 were estimated to be 967,000 barrels.
Note: Cumulative production and reserves are given to closest 1000 barrels.
Source: Dept. of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Div., Annual Reviews, 1966-1974.
The production peaks in 1970 and 1971 were due to water flooding the Kootenai Formation (Dept. of Natural Resources and Conservation of the State of Montana, annual reviews, 1966 to 1973 inc.)

TABLE 4
Gas Production from the Cut Bank and Reagan Gas Fields

			Producing wells			
			Kootenai Formation		Madison Group	
Year	Production (Mcf)	Producing formation	Cut Bank field	Reagan field	Cut Bank field	Reagan field
1960	11,231,488	Kootenai*				
1961	12,377,473	Kootenai				
1962	8,618,812	Kootenai				
1963	7,198,429	Kootenai				
1964	7,484,591	Kootenai				
1965	8,292,024	Cut Bank & Sun River				
1966	8,253,797	Cut Bank & Sun River				
1967	9,497,010	Cut Bank & Sun River	N.A.***		N.A.	N.A.
1968	7,811,914	Cut Bank & Sun River	170	0	2	1
1969	7,308,722	Cut Bank & Sun River	133	0	2	1
1970	6,696,872	Cut Bank & Sun River	135	0	Shut-in	1
1971	11,072,365	Cut Bank & Sun River & Blackleaf**	135	0	Shut-in	1
1972	4,068,780	Cut Bank & Sun River	129	0	Shut-in	1
1973	3,274,900	Cut Bank & Sun River	129	0	Shut-in	1
1974	2,350,799	Cut Bank & Sun River	139	0	Shut-in	0

*Kootenai Formation includes Moulton, Sunburst, and Cut Bank sands.
**Blackleaf production is from West Reagan. Discovered in 1970. The gas is injected into the Reagan oil field as a secondary recovery agent. In 1971, there were eight Blackleaf gas wells.
***The number of wells producing gas before 1968 is not available(N.A.).
Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Review, 1960-1974.

According to Perry (1960, p. 38), the Cut Bank gas field was discovered in 1926 by a well drilled in sec. 1, T. 35 N., R. 5 W. Initial production was about 8 million cubic feet of gas per day from a depth of 2,780 feet. Since no pipeline was available, the well was plugged and abandoned. In 1929, a second well, 8½ miles to the southwest, found oil and gas in the same formation, although it was structurally 250 feet lower. Productive zones were found in the Cut Bank Sandstone at the base of the Kootenai Formation. Intensive drilling did not begin until 1931 when 20 wells were drilled northeast of Cut Bank. Only one hole was dry. Each well averaged 12,700,000 cubic feet of gas per day.

In 1932, the presence of oil in one of the wells (Drumheller-Yunck) led to downdip drilling and the Cut Bank oil field was discovered (Perry, 1960, p. 38 and 39). As of January 1936, development drilling had proven a gas-producing area 18 miles long and 3 to 5 miles wide, and an oil-producing area 20 miles long and 3 to 22 miles wide. Oil production peaked during 1942, 1943, and 1944 at about 5½ million barrels of oil annually (about 15,000 barrels daily). In December 1950, there were 1,171 oil wells and 162 gas wells.

The Carter-Brindley well No. 1 (sec. 12, T. 36 N., R. 6 W.) discovered oil and gas in the upper part of the Madison Group at a depth of about 3,090 feet in the summer of 1945. Within two years approximately one-tenth of the Cut Bank oil production was from the Madison Group (Sun River Dolomite) (Perry, 1960, p. 39).

Now that several hundred wells have been drilled, it is known that the Cut Bank field is a stratigraphic trap. The oil and gas were trapped in sandstone bodies and in limestone layers that showed distinctly limited areas of porosity and permeability. Structure contributes to the trap only because it tilts the limited sand bodies and affords a completed trapping mechanism.

The main producing zone at Cut Bank is at or near the base of the Kootenai Formation. The Kootenai has a total thickness of about 500 feet on the east side of the field and as much as 650 feet on the west, within a horizontal distance of about 10 miles. The formation is an intermingled series of river-laid, flood-plain, and near-shore deposits consisting of mudstones and shales with lenticular siltstones and sandstones. Most of the sandstones are in the lower third of the formation.

The three producing sandstone zones, in the lower 150 to 200 feet of the Kootenai Formation, are the upper Moulton, the middle Sunburst, and the basal Cut Bank zones, with the latter being the most important oil and gas reservoir (Perry, 1960, p. 40).

The Cut Bank sand zone is present throughout the field. The thickness averages about 45 feet, the porosity about 15 percent, and the permeability about 115 millidarcys. However, the characteristics of the sand vary from well to well, and dry holes and poor wells are found throughout the field. Initial production of the wells was as much as 300 barrels of oil per day (Perry, 1960, p. 40, 41)

Reagan Oil and Gas Field

The Reagan oil and gas field lies about 10 miles northwest of the north end of the Cut Bank field and 1 mile south of the Canadian border (Figure 1 and Figure 7). It is about 5 miles long and 1 mile wide (Perry, 1960, p. 43) and is completely within the reservation.

Surface geologic mapping provided the basic information for locating the discovery well of Reagan field. Core drilling was used to supplement and verify the presence of the small anticlinal closure that forms the trapping mechanism. Later, seismic information showing that the structure extended northward encouraged the drilling that expanded the field almost to the Canadian border.

The Reagan field is recognized as an accumulation of oil and gas that is trapped in an anticlinal closure. The eastern edge of the anticline, however, is modified by a normal fault, and the field seemingly is bounded by the fault.

The discovery well, Reagan Associates Tribal 194-1 in sec. 22, T. 37 N., R. 7 W., was completed March 29, 1941. Initially it produced 6 million cubic feet of gas per day from a total depth of 3,869 feet. One of the deepest wells in the field penetrated Cambrian strata. No production was found below the Madison Group. The Cambrian test well (Figure 8--Blackfeet Tribal 194-12) was drilled to a depth of 6,258 feet by the Union Oil Co. The field has a combination gas and water drive. A pressure maintenance project was started in August 1961 by injecting gas into the oil reservoir (Dept. of Natural Resources and Conservation of the State of Montana, 1965, p. 32).

The following field data are from Perry (1960, p. 43): "An active drilling campaign got underway in 1947 after the Montana Power Company Tribal 335 No. 1 (sec. 10, T. 37 N., R. 7 W.) flowed 50 barrels of oil and 12 million cubic feet of sulfurous gas per day. By the end of 1948, eight more wells had been drilled. After being acidized, each flowed from 25 to more than 400 barrels of oil per day. Gas pressure was about 1,100 pounds per square inch. Depths varied between 3,745 feet and 3,810 feet. The producing zone, about 20 feet of porous limestone or dolomite, is from 30 to 60 feet below the top of the Madison Group. Sulfurous water occurs beneath the productive zone. Total production in 1950 was 182,334 barrels of oil from 18 wells. Production peaked in 1953 at 250,890 barrels of oil per year. In 1958, 45 wells produced only 166,634 barrels of oil. The specific gravity of the oil is from 31º to 36º A.P.I."

Production from the Reagan field through 1974 was 5,666,364 barrels of oil. Yearly production and estimated present reserves, are given in Table 5. With the help of secondary repressuring, ultimate recovery is estimated to be about 7 million barrels. In other words, there should be about 1.3 million barrels of oil remaining to be produced from the Reagan field after 1974.

Blackfoot Oil Field

The Blackfoot field is in T. 37 N., R. 6 W. and covers all or part of secs. 2, 3, 10, 11, and 14 (Figure 1). The field is east of the reservation and underlies about 480 acres (Hubbard and Henkes, 1962, p. 29).

Surface mapping checked by detailed seismic mapping led to the discovery of the Blackfeet field in October 1956. Union Oil No. 1 Muntzing was completed at a depth of 3,542 feet, producing 15 barrels of oil per day from the uppermost part of the Madison Group. It was recompleted about a year later, producing 55 barrels of oil per day from the Cut Bank Sandstone.

A dozen or more wells were drilled in a square mile area. Ten were producers from either the Cut Bank sand or the Madison Group (Sun River Dolomite). Initial flows from the wells in the Madison were about 100 barrels of oil per day with rapid declines to about 30 barrels per day. Initial production of wells in the Cut Bank was about 40 barrels per day and slowly declined to about 30 barrels per day. In 1958, 11 Madison Group wells and four Cut Bank sand wells produced 97,781 barrels of oil (Perry, 1960, p. 43).

The Cut Bank pay zone is about 18 feet thick with a porosity of about 15 percent. The Madison zone averages about 10 feet thick with a porosity of about 14 percent (Dept. of Natural Resources and Conservation of the State of Montana, 1974).

Cumulative production from the Blackfoot field through 1974 was 1,026,547 barrels of oil. Yearly production, including present reserves are given in Table 6.

The Blackfoot field is another example of an accumulation trapped by a faulted anticlinal closure, but either stratigraphic characteristics of the Madison Group or hydrodynamic components cause the oil field to the displaced northward from the top of the closure. Both the Cut Bank sandstone and the Madison Group show great variation in porosity and permeability, and the field should probably be regarded as a combination stratigraphic-structural trap.

The Blackfoot field is small, only 160 acres productive from the Cut Bank Sandstone and 480 acres productive from the Madison Limestone. Oil from the Cut Bank Sandstone is 30º A.P.I. gravity; and that from the Madison Limestone, 25º A.P.I. gravity. Estimated ultimate recovery is about 1.2 million barrels; more than a million barrels having been produced since 1956, a little less than 130,000 barrels of oil probably remains to be produced. It must be concluded that the field is about depleted.

TABLE 5
Oil Production from the Reagan Field, Madison Group Production

Year	Oil (barrels)	Producing Wells	Year	Oil (barrels)	Producing wells Oil	Producing wells Shut-in
1960	190,334	50	1968	266,539	48	?
1961	152,764	50	1969	270,257	48	?
1962	210,584	43	1970	255,426	50	?
1963	231,624	47	1971	223,986	46	19
1964	223,451	48	1972	212,167	44	19
1965	208,110	51	1973	186,958	44	19
1966	208,668	46	1974	170,261	44	19
1967	250,923	47				

Cumulative production to 1-1-75 was 5,666,364 barrels.
Reserves as of 1-1-75 were estimated to be 1,335,000 barrels.
Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Reviews, 1960-1973.

TABLE 6

Oil Production from the Blackfoot Oil Field

Year	Production (barrels)	Cut Bank Formation producing wells	Sun River Formation producing wells
1966	50,278	5	7
1967	41,849	5	8
1968	33,423	Shut-in	6
1969	29,653	Shut-in	7
1970	29,212	Shut-in	6
1971	25,218	6	Shut-in
1972	19,812	5	Shut-in
1973	16,217	3	Shut-in
1974	13,509	4	Shut-in

Cumulative production to 1-1-75 was 1,026,547 barrels.
Reserves as of 1-1-75 were estimated to be 123,000 barrels.
Source: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Reviews 1966-1974.

Red Creek Oil Field

The Red Creek oil field, near the Canadian border, is about 7 miles east of the reservation (Figure 1). Production is from a stratigraphic trap in the Cut Bank sand and a structural trap in the Madison Group (Sun River Dolomite) (Dept. of Natural Resources and Conservation of the State of Montana, 1974, p. 23).

The discovery well, G. S. Frary #1 Morberly, was completed in January 1958, in sec. 1, T. 37 N., R. 5 W. The wells initially produced 1,500,000 cubic feet of gas per day from a total depth of 2,656 feet.

In June 1965, a waterflood project was started in the Cut Bank sand using water from Madison strata which has a natural water drive (Dept. of Natural Resources and Conservation of the State of Montana, 1965, p. 32). The waterflood started yielding results in 1967 (Table 7).

Cumulative production from the Red Creek field through 1974 was 4,742,000 barrels. Yearly production, including present reserves, are given in Table 7.

Graben Coulee Oil Field

The Graben Coulee oil field, near the Canadian border, is about 6 miles east of the reservation (Figure 1). Production is from the Sunburst, Cut Bank Formations, and the Madison Group. All the reservoirs are structural-stratigraphic traps and have depletion drives (Dept. of Natural Resources and Conservation of the State of Montana, 1974, p. 15). The discovery well, Cardinal Petroleum #1 McAlpine, was completed December 7, 1961 in sec. 3, T. 37 N., R. 5 W. Initial production of 56 barrels of oil per day was from the Sunburst Formation at a total depth of 2,816 feet (Dept. of

Natural Resources of the State of Montana, 1965, p. 22).

Cumulative production from the Graben Coulee field through 1974 was 1,043,092 barrels of oil. Yearly production, including estimated present reserves, are given in Table 8.

TABLE 7
Oil Production from the Red Creek Field

	Cut Bank Formation			Sun River Formation		
	Production	Number of wells		Production	Number of wells	
Year	(barrels)	Producing	Shut-in	(barrels)	Producing	Shut-in
1963	165,648	N.A.	N.A.	343,789	N.A.	N.A.
1964	150,710	N.A.	N.A.	322,282	N.A.	N.A.
1965	127,534	N.A.	N A.	216,224	N.A.	N.A.
1966	121,473	16	N.A.	178,629	20	N.A.
1967	151,162	10	N.A.	175,106	20	N.A.
1968	152,622	9	N.A.	153,348	17	N.A.
1969	139,648	9	N.A.	114,967	14	N.A.
1970	117,977	9	N.A.	97,877	12	N.A.
1971	94,866	8	2	98,328	12	9
1972	60,649	7	2	105,181	12	9
1973	64,790	7	2	111,252	12	9
1974	64,935	7	2	83,600	12	9

Cut Bank cumulative production to 1-1-75 was 1,983,000 barrels.

Madison cumulative production to 1-1-75 was 2, 759, 000 barrels.

Cut Bank reserves as of 1-1-75 were estimated to be 1,017,000 barrels.

Madison reserves as of 1-1-75 were estimated to be 741,000 barrels.

Note: Cumulative production and reserves are given to closest 1000 barrels. N.A. (information not available).

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

TABLE 8

Oil Production from the Graben Coulee Oil Field

Year	Production (barrels)	Number of wells, formation: Cut Bank Formation	Sunburst Formation	Madison Group	Dual wells, Cut Bank-Madison
1966	190,100	20	0	22	0
1967	139,266	20	0	22	0
1968	100,394	20	1	7	17
1969	68,800	18	2	7	17
1970	53,061	18	2	7	2
1971	45,628	23	1	0	3
1972	45,729	17	1	0	3
1973	80,188	17	1	0	3
1974	101,386	28	1	0	3

Cumulative production to 1-1-75 was 1,043,092 barrels.

Reserves as of 1-1-75 were estimated to be 1,457,000 barrels.

Note: No secondary recovery has been attempted.

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

Landslide Butte Field (Figure 7)

Early in 1968, the Montana Power Company completed the No. 1 Thelen as an oil well at a depth of 4,725 feet in the Sun River Dolomite. It is in sec. 13, T. 37 N., R. 9 W., and is the discovery well for Landslide Butte field. The field has had only two productive wells, and records of production and reserves are not readily available. The oil is 41° A.P.I. gravity, and productivity of the wells is small.

Other Fields

A one-well gas field located in T. 31 N., R. 11 W., has never been named. It is capable of gas production from rocks of the Madison Group but has never been extended. No reserve or production data are available.

Future Possibilities

Exploration Techniques

Modern technology is capable of marvelous accomplishments, but it has never developed a method of successfully finding oil or gas with a high rate of success. This fact is not surprising if we realize the complexity of the subsurface structure and lithologic characteristics of the rocks involved.

Basically, a hydrocarbon trap is composed of (1) a porous reservoir rock, (2) a structural position that allows the oil and gas to rise to a position of higher elevation (lower pressure environment), and (3) a nonpermeable barrier having a configuration that prevents escape of the hydrocarbons upward. Structural configuration may be mapped by various methods, and the lithologic character of the rocks may be predicted to a degree, but errors in both techniques lead to many failures when the exploratory test is drilled.

Geologic structure may be mapped by using surface geologic information, well data, or seismic data. Each method has limitations. Structure as expressed in surface beds may not extend to the depth of the prospective zones and cannot be relied upon to define accurately structural conditions where the explorationist needs to know them. Information from wells already drilled is obviously a hindsight method because when the information is available the presence or absence of hydrocarbons is already known. Subsurface data are very useful, but accurate interpretation between control points is usually difficult. Seismic data are often useful, but it must be remembered that the method is an indirect one and involves the measurement of travel times of energy through the rock complex and does not show the rock configuration directly. When someone prepares to spend money to drill an exploratory well, he is usually well advised to use all the data available to him at a reasonable cost. "Reasonable cost" is usually defined by the degree of risk that the explorationist is willing to take.

The search for prospective hydrocarbon traps is tempered by the characteristics of the area under study. If the prospective trap is mostly likely to be of a purely stratigraphic nature, well data, regional trends, and drilling are used in exploration. If the conjectured trap is estimated to be entirely of the structural type, surface geology and seismic information are usually used. Very often the evidence suggests that traps may be combination stratigraphic and structural, and all methods are used. On the reservation, stratigraphic, structural, and combination traps are known to exist. The Cut Bank field is a good example of a stratigraphic trap, the Reagan field is a structural trap, and the Blackfoot field seems to be a combination type of accumulation.

As a generalization, some parts of the reservation are more likely to have a particular type of trap. By no means should such a generalization be taken to mean that the other type of traps are not likely to be found in an area characterized as being a likely environment for one type of trap. The western part of the reservation, for example, is most likely to have strictly structural traps. Figure 9 illustrates the structural configuration that develops where an overthrust fault displaces beds and results in what is known as "drag folding." Distortion of the bed probably begins as a fold (anticline), which increases in displacement as compressional stress results in deformation. Ultimately, the deformation becomes so great that the beds are no longer competent to withstand breaking, and a fault occurs. The result is folding along the fault surface that gives the appearance of being caused by dragging along the broken surface.

After an overthrust fault occurs, subsequent folding is very likely to cause deformation of the displaced beds as shown in Figure 10. In a sense such a structure is an anticlinal trap but not a simple one. In this situation multiple traps may develop in the same formation because the thrust faulting causes repetition of beds, which the drill penetrates vertically. These types of folding are important in the western part of the Blackfeet Reservation because they are the most likely type of trap in the disturbed belt. The large gas fields of the disturbed belt of Alberta are in traps of these types, and it is worthy of note that fields such as Waterton Lakes and Pincher Creek in Canada contain more recoverable gas than Montana's entire proven gas reserves. Those fields should indicate the great potential for finding gas in Montana's disturbed belt.

Although the disturbed belt is most likely to be characterized by structural type accumulations, the probability is great that some stratigraphic influences will be apparent in many of the traps. Carbonate reservoirs such as in the Madison Group typically have variable porosity and permeability. It may be that many of the traps, when discovered and analyzed, will have stratigraphic changes as part of the trapping mechanism.

Most of the rest of the reservation (other than the disturbed belt) will be likely to have both stratigraphic traps and combination structural-stratigraphic traps. The area just southwest of the Cut Bank field is likely to be dominated by stratigraphic accumulations. It is fairly certain that all of the purely structural traps have been found, but there may be unknown structures in Devonian or Cambrian rocks. Updip porosity "pinchouts" will probably account for most of the oil and gas found on the reservation outside of the disturbed belt.

It must be pointed out that exploration for new hydrocarbon reserves is no longer a simple and easy task. The brief, and consequently simplified, discussion of the probable trapping situations on the reservation should serve to illustrate the point. Additional discoveries are almost a certainty, however, if exploration continues.

Probability Areas

Any attempt to assign probabilities of discovering significant reserves of oil or gas must be subjective. Such probabilities are someone's educated evaluation, and only a means of transferring integrated information beyond that which can be put on a few printed pages.

Figure 11 attempts to rate the various areas of the reservation as to the probability of discovering significant hydrocarbon reserves. Probability of directional porosity and permeability changes and structural conditions throughout the entire section of sedimentary rocks were considered. Much of the area is characterized by scarcity of data, so interpretation of trends must be utilized. The resulting map shows five categories, of which category "1" represents the greatest probability of discovery, and category "5" represents the least.

Nationally, the success rate in wildcat drilling is about one discovery in 13 attempts, and one discovery of economic reserves in about 22 attempts. This means that only a little more than half of the discoveries pay out. These success rates may be used to consider the probability ratings on the map in this way. If the area rated "3" is about equivalent to the national average for discovery rates, one might expect that 22 exploratory wells would need to be drilled (on the average) before an economic discovery was made. By the same reasoning, the areas rated as "1" should have a considerably higher probability of a significant discovery, but there is no way of putting an accurate number on that likelihood. It may be in the vicinity of one discovery in about 15 attempts. On the other end of the scale, wells in the areas rated "5" may have about one chance in 40 of being successful. In the final analysis, the actual numbers are unimportant, it is the relative chance of success that is meaningful for this report.

Exploration Costs

There are many ways of calculating exploration costs. The map showing relative exploration costs does not reflect dollars and cents per barrel of oil, but is only an attempt to rate each part of the reservation as related to other parts (Figure 12).

It is obvious that some types of traps should be easier to find than others. Structural traps, for example, in a structurally simple province, are relatively easy to identify. As the structures become more complex, they become harder to find. Stratigraphic variations that lead to trapping of hydrocarbons are typically difficult to find and require more exploratory holes to discover a new accumulation of hydrocarbons.

Let us assume that exploration investigations were begun by mapping surface geology, supplemented with all of the subsurface data available from previous drilling, then progressed through seismic work, and resulted in the decision to drill a test well. Total investment to that point would be different across the reservation by a factor of, perhaps, two. Investigations up to the point of drilling a test well in the disturbed belt might cost twice as much as the same techniques would cost in the vicinity of the Cut Bank field. The cost of drilling the test well, however, is vastly different. A well drilled to test the Madison Limestone in the vicinity of the Cut Bank field may cost only about one percent of the cost of a well in parts of the disturbed belt.

These factors were all considered in constructing the map of relative exploration costs (Figure 12). No actual costs should be applied to the areas, but the area rated as "1" should be least expensive to explore and the area rated as "5" should be the most expensive.

Recommendations

Exploration Philosophies

Generally speaking, exploration is governed by many factors. Availability of funds, governmental attitudes, marketing considerations, taxation, personnel, and other factors need not be extensively considered here. Of particular importance here is the relationship of the prospector to the land-owner and holder of the mineral rights.

Investment of money in a risk venture such as the search for oil or gas is a type of business totally unfamiliar to most people. For someone to be willing to spend large sums of money in hopes of a one in 20, or less, chance of receiving any return seems totally unreasonable to most people. It is the chance of a very large return that encourages such an investment. At the same time the investor can scarcely be careless in considering all factors involved or he would be foolish and would rapidly be reduced to the state of no longer having money to invest.

When it is considered that the cost of drilling an exploratory test to the Madison Limestone in the disturbed belt may cost a million to several million dollars, it quickly becomes apparent that large companies, with large financial resources will be involved. The shallower areas with less structural complexity will more likely be the area in which the smaller investor will be willing to explore.

Whoever the explorationist may be, large company or small independent, he must be able to see the possibility of a satisfactory return on his investment.

Leasing Philosophies

When a lease is issued for oil or gas exploration, there may be no implication that a test well will be drilled on any particular tract, because leases are usually purchased to cover, as completely as possible, all of the probable producing area if a discovery is made. More often than not, there are no discoveries and many leases remain undrilled.

Any owner may include such provisions as he desires when the lease is purchased, but he should be careful that what he requires does not unreasonably discourage exploration. The real income from a lease comes when oil is discovered, not from the rentals or bonuses on the lease itself, and dollars spent for bonuses cannot be spent for drilling. In general, it is desirable to append clauses that will assure (1) satisfactory care and reclamation of the land surface both at the well site and on all access roads; (2) satisfactory care of the well site if a discovery is made; and (3) provision for the landowner to acquire information that may be useful to him, such as ground-water data or information on other mineral resources not included in the lease. Some companies are willing to assist the landowner in the completion of a well as a water well if it is not capable of hydrocarbon production.

An operator should always be willing to discuss and negotiate with the landowner on any points that may be questionable. It is important that both parties understand the desires of the other and attempt to reach an agreement that is satisfactory to both that will lead to exploration. Oil or gas can be found only by drilling and does not become a resource until discovered.

When a lease is executed, the rate of the landowner's royalty is usually established. In the past, it has almost universally been a constant rate, with no change throughout the productive life of the wells. This practice may make a productive well uneconomic during the last years that it is capable of giving up oil or gas.

Whenever a landowner has the opportunity, he should use his efforts to encourage wise production practices. Secondary recovery practices can sometimes be encouraged or discouraged by the landowner. On the other hand, he should be careful that water disposal problems, or use of water for injection do not jeopardize his water resources.

Potential Resources

A new oil field similar to the Cut Bank field would produce about 200 million barrels of oil. A new oil field similar to the Reagan field would produce about 7 million barrels and one similar to the Blackfoot field would net about 1.25 million barrels. The discovery of a Cut Bank-sized field on the reservation is unlikely, but immense volumes of oil may be in small and subtle stratigraphic traps sandwiched between otherwise undistinguished layers of impervious rock (Gillette, R., 1974, p. 68). Five-to 25-million-barrel fields will likely be discovered in relatively small traps on the reservation.

Transportation and Markets

The reservation is adequately served by pipelines, and refineries are nearby. There is both a local and a national market for oil and gas. Westco Refining Co. and Big West Oil Co. have refineries in the immediate area. The Reagan and Cut Bank fields have pipeline connections for oil. Continental Oil Co. has two oil pipelines (8 and 12 inches in diameter) crossing the reservation from the northwest to the southeast (Figure 1). Montana Power has a 16-inch diameter gas pipeline crossing the reservation from the northwest to the southeast and an 8-inch gas pipeline crossing the reservation from the southwest to the northeast.

Environmental and Social Effects

Oil and natural gas are closely associated natural resources occurring in sandstone and limestone reservoirs below the surface of the earth. Both are in short supply and can be obtained without adversely affecting the environment.

Government and private experts have warned that the domestic effort to solve the energy shortage may trigger an even worse national water crisis (Tulsa Daily World, 1975, p. 20). Virtually every proposed method for boosting domestic energy production places heavy demands on local water supplies. Most synthetic fuels require great quantities of water in their production. However, finding and producing oil and gas require very little water.

Oil and gas production could downgrade the local environment, but proper planning can hold decline in living space, wildlife, vegetation, topsoil, water resources, and air quality to a minimum.

Royalty payments will help improve the economic base of the reservation. Also, employment possibilities will be enhanced if additional oil and gas resources were discovered and developed.

Oil Shale

Oil shale is known to occur within the lower 150 feet of the Colorado Group which underlies the entire reservation east of the Disturbed Belt (Alpha, 1955, p. 137). An oil shale bed has been reported about 10 miles south of the reservation on Dupuyer Creek (Stebinger, 1918, p. 162, 163). This bed, about 10 feet thick, is described as "highly bituminous." Whether this or other oil shale beds extend laterally onto the reservation is not known.

No significant amount of oil is expected to be extracted from oil shale deposits before 1985, but by the year 2000 oil shale is expected to supply 2 million barrels of oil per day (Dupree and Corsentino, 1975, p. 45). Initially the highest-grade and more easily mined deposits will be developed. Oil shale on the reservation may eventually be a valuable future source of oil.

Coal

General

Coal deposits of bituminous rank on the Blackfeet Reservation were examined by Stebinger (1916) and the discussion given here is from his work.

Coal is found at three levels in the Two Medicine Formation--at the base, about 250 feet above the base, and at the top, below the overlying Bearpaw Shale (Figure 13). The coal at the base of the Two Medicine Formation was mined in the Valier coal field (Figure 13). The coal in the bed 250 feet above the base was prospected but seemingly never successfully mined because the coal is either too thin (little more than 1 foot thick) or too dirty (as much as 30% ash). The coal at the top of the Two Medicine was investigated at three sites in and near T. 37 N., R. 8 W., and, although the coal is clean, it is only about 1 foot thick and is not minable.

Coal also is found at two levels in the St. Mary River Formation--at the base and at the top. The coal at the base is the only coal mined in the Blackfeet coal field (Figure 14 and Figure 15). The coal at the top of the St. Mary River Formation is known from one locality only where it is reported as 10 inches thick and therefore unworkable. These brief descriptions show that of the five coal zones in the two coal-bearing formations only two seams are of any real significance, the coal at the base of the Two Medicine, above the Virgelle Sandstone, and the coal at the base of the St. Mary River Formation, overlying the Horsethief Sandstone.

Valier Coal Field

The Valier coal field lies in T. 31 N., R. 5 W., about 6 miles north of Valier (Figure 14 and Figure 7). Several underground mines formerly were worked in this area. Stebinger referred to a coal bed 2 ft. 10 in. thick, but this measurement includes one bed of coal 1 ft. 6 in. thick, one 2 in. thick, and one 4 in. thick, and two partings of clay 8 in. thick and 2 in. thick. It would probably be best not to plan on salvaging any of the 2 in. or 4 in. layers of coal, and perhaps only a part of the 1 ft. 6 in. layer. A lower coal bed in this field is judged too dirty to be worked, consisting of two layers of dirty coal more than 1 foot thick and an 8 in. layer of good coal. The coal in the Valier field thins out to the north and does not extend beyond the south line of sec. 21, T. 31 N., R. 5 W. To the south the coal goes below creek level in section 31 of the same township. No other significant coal deposits are known from this zone. In T. 35 N., R. 4 W., about 12 miles north and 11 miles east of Cut Bank, exposures of the coal near the top of the Virgelle, and thus from the same zone as that of the Valier coal field, show as much as 9 inches of dirty coal.

Blackfeet Coal Field

The Blackfeet field (Figure 7 and Figure 15) lies north and west of Browning in Townships 35 to 36 North, Ranges 11 to 12 West. The field is about 12 miles long and 1 mile wide and the coal lies mainly in a northwest-trending syncline. On the west a reverse fault has carried Two Medicine rocks up against the coal at the base of the St.

Mary River, thus limiting the field to the west. The field is limited on the east by the steep dip of the coal-bearing beds, which carries the coal below minable depth in sec. 15, T. 34 N., R. 11 W., 3½ ft. of good clean coal is exposed. This is the thickest bed of coal known in the field. In section 9 of the same township, an exposure of 2½ ft. of good coal was measured. In section 4 of the same township, a coal bed about 2 ft. thick dips east, parallel to the slope of the ground. Stebinger reported many exposures of coal in this area, and a thick layer of coal smut over many acres. These last two localities lie on the south slope of the Milk River Ridge, a gravel-covered divide between Milk River and Cut Bank Creek. Gravel deposits obscure the bedrock formations in this area.

On the north side of the Milk River Ridge in sec. 18, T. 35 N., R. 11 W., two good beds of coal 2 ft. 4 in. and 1 ft. 10 in. thick are exposed, separated by about 10 ft. of clay and sandstone. Other exposures to the north show coal thicknesses of l½ to 2 ft. of clean coal, but one exposure shows only 7 in. to 1 ft. 4 in. of dirty coal. In sec. 35, T. 36 N., R. 12 E., a seam of coal about 2 ft. 6 in. thick was mined for many years by a rancher for his own use. This coal has been somewhat crushed because of its location in the disturbed belt, and a large percentage of the coal is reduced to small fragments.

Coal at the base of the St. Mary River Formation is exposed at numerous locations just west of the main outcrop of Horsethief Sandstone, which lies almost entirely in Townships 28 to 37 North, Range 9 West. These deposits are generally flat lying but are either too thin or too dirty to be workable. Several of the deposits contained 9 to 11 in. of clean coal or 2 to 5 ft. of dirty coal. Farther west in the disturbed belt, coal from this same zone is the only coal mined in the Blackfeet field.

Numerous other exposures of coal are known in the disturbed belt but they are generally too fractured and crushed to warrant development.

The coal deposit in sec. 4, T. 34 N., R. 11 W., may well be worthy of further investigation. Concerning the coal exposure Stebinger stated, "The dip of the bed parallels the slope of the ground wherever the coal is exposed at this point, and the surface is therefore covered with a thick layer of coal smut over many acres." An area such as this one may be amenable to stripping, and other similar areas may be found through field examination. This area, Stebinger added, is on the south slope of Milk River Ridge, the divide between Milk River and Cut Bank Creek. Stebinger suggested that it was not improbable that at least a part of this ridge is coal land. A similar feature exists farther north in the southeast corner of T. 36 N., R. 12 W., where a gravel-covered plain is at the same altitude as the Milk River Ridge. All three of these areas deserve field examination, and a follow-up program involving some test drilling may be in order.

Coal Characteristics

The rank of the reservation coal is high-volatile bituminous C. Heat values range between 11,500 and 13,000 Btu on an air-dried, mineral-matter-free basis. Analyses of two samples, one from the Blackfeet field and the other from the Valier field, are listed in Table 9. Although the moisture contents of 5 to 6 percent are high for bituminous coals (typically 1 to 3 percent), reservation coal is reported not to slack or disintegrate when exposed to the weather (Stebinger, 1916, p. 137, 153). Coal from the Valier field is hard and blocky whereas coal from the Blackfeet field is extensively fractured and will produce a large proportion of fine-sized coal. The fractured nature of the coal from the Blackfeet field is a consequence of the extensive tectonic action that has occurred to the west of the reservation.

The ash and sulfur contents are moderate to high; the sulfur content of the sample from the Valier
field is particularly high. Coal from the reservation would generally require extensive upgrading to meet market requirements.

TABLE 9
Analyses of Coal from the Blackfeet Indian Reservation, Montana
(From Stebinger, 1916, p. 138)

	Proximate				Ultimate					Heat Content	
Locality	Moist.* (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulfur (%)	Hydrogen (%)	Carbon (%)	Nitrogen (%)	Oxygen (%)	Calories per lb.	Btu. per lb.
Stone prospect, Blackfeet field	5.8	36.2	45.3	12.74	1.02	5.03	64.40	1.49	15.32	6,280	11,310
Blair mine, Valier field	5.3	40.9	39.7	14.07	3.12	5.09	61.51	1.14	15.07	6,150	11,070

*Analyses were made after the sample had been dried at a temperature a little above normal until its weight became constant.
Moist, mineral-matter-free heat content is 12,960 Btu/lb. for coal from the Stone prospect and 12,880 Btu/lb. for coal from the Blair mine.

Coal Preparation

Reservation coal is not suitable for most markets (with the possible exception of the cement industry) unless the ash and sulfur contents are reduced. Modern coal preparation techniques can lower the ash and sulfur contents of run-of-mine coal by removing non-combustibles such as rock, shale partings, sandstone inclusions, pyrite lenses, sulfur balls, and other high density materials. Neither finely disseminated pyrite nor organic sulfur can be removed by mechanical cleaning. Coarse pyrite is easily removed.

Costs range from about $1.20 to $2.50 per ton for cleaning both the coarse (plus one-fourth to three-eighths inches) and fine sizes of coal. These costs assume that the cleaning plant operates two shifts a day and five days a week. This operating schedule is rarely attained and therefore coal cleaning costs are more realistically estimated to range from $2.50 to $3.50 per ton.

Potential Resources

The coal resources on the reservation are estimated to range from 30 to 50 million tons (Hubbard and Henkes, 1962, p. 25). Most are in the Blackfeet field. The Valier field contains at least 2 million tons and possibly 5 million tons of minable coal, although the lateral extent of the beds in the southwestern direction is unknown.

The Kootenai Formation is exposed only in the disturbed belt, and although the rocks are severely folded and faulted, exposures are good and the formation is reportedly noncoal-bearing (Stebinger, 1916, p. 125). However, it does contain significant coal resources north of the reservation in British Columbia and Alberta as well as in the Great Falls region to the southeast. According to Zubovic and others (1961, p. A40), the coal beds in Montana were deposited in many small shallow basins rather than large basins as is common in the Eastern United States. Hence, the Kootenai Formation, which underlies the remainder of the reservation where the rocks are essentially flat-lying, could contain significant coal resources. This possibility can be explored by a drilling program, or possibly by examining oil and gas well logs and geophysical surveys of oil and gas wells that penetrate the Kootenai Formation. However, a hole drilled 15 miles off the east edge of the reservation in the NW¼ sec. 25, T. 34 N., R. 4 W. penetrated the entire Kootenai Formation and did not intersect any coal beds (Stebinger, 1917, p. 305).

Mining Methods

Underground Mining

Most of the coal that has been mined in the United States has been mined by underground methods--particularly by room and pillar. Coal is also mined by the longwall method, with the retreating longwall the most popular in the United States.

Underground mining in the Blackfeet field will present more formidable problems. The coal beds are thin, steeply inclined, folded, and faulted. Continuous mining machines and other mobile equipment are not practical for beds that are inclined more than 10 to 14 percent (5.7º to 8.0º).

Consequently, much of the coal in the Blackfeet field cannot be mined using equipment and mining techniques that have been developed for flat-lying coal beds. However, coal beds dipping as much as 50º are being mined in the Lorraine basin, France, by using a modified longwall system (Coates, et al., 1972, p. 97).

Steeply inclined coal beds in the Blackfeet field might be mined by cutting the working face with high pressure water jets. The efficacy of water jets in breaking coal from the working face has been demonstrated on a limited scale in the United States by the Bureau of Mines, but detailed plans for hydraulic mining were not developed (Price and Bada, 1965). The shortwall mining method, a modification of the longwall method, has recently been introduced into the United States by the U.S. Bureau of Mines (Palowitch and Brisky, 1973, p. 16-22).

The general thinness of the coal beds on the reservation limits the applicability of underground mining. For example, the best minable coal bed in the Valier field averages only about 38 inches thick. Coal beds as thin as 36 inches and under the most favorable conditions as low as 30 inches (Coal Age, 1975, p. 250) can be mined. Conventional mobile mining equipment (loading machines, cutting machines, drills, and shuttle cars) as well as longwall equipment are available for mining thin beds.

Mining costs in the Valier field can be roughly estimated from a recent Bureau of Mines cost study (Katell and Hemingway, 1975, p. 5). The coal selling price from a mine with an annual capacity of 1.03 million tons per year from a 48-inch bed is estimated to be $14.83 per ton. The life of the mine is assumed to be 20 years and require 254 employees. The coal resources in the Valier field now appear insufficient to support a mine of this size although an exploratory drilling program could increase resources if additional deposits are found in the Two Medicine and Kootenai Formations. Known resources will only support smaller mines. Therefore, mining costs will be higher because many of the economies associated with large-scale production will be lost.

Surface Mining

An advantage of surface mining is that the mining cost is only one-fourth to one-third that of underground mining. Furthermore, coal recovery is high, i.e., about 90 percent. This method is applicable only to shallow coal beds. The ratio of overburden thickness to coal thickness averages about 11 to 1 in the United States. By using this stripping ratio as a guide, the depth of overburden for the best coal bed in the Valier field would be limited to about 33 feet. Stripping ratios as high as 30 to 1 are technically feasible but are practical only under specially favorable mining and economic conditions.

Some flat-lying coal beds on the reservation might be mined by the area method. It is applicable to the gently rolling and relatively flat topography on the reservation. At an area surface mine, the overburden is drilled and broken by explosives. It is then removed and deposited in an adjacent cut where the coal has been removed. Next, the coal is drilled, blasted, loaded into trucks, and removed from the pit.

Contour surface mining may find some application where the coal beds crop out on the sides of ravines and valleys. Mining proceeds along the side of a valley or hill at the elevation of the outcrop. The width of coal that is mined extends from the outcrop into the hillside to where the overburden thickness becomes excessive. As originally practiced, the spoil was simply cast downhill to uncover the coal. This method of overburden removal is now prohibited in most states, including Montana. To overcome the shortcomings of this overburden disposal method, a haulback system has recently been developed in which the overburden is trucked to areas where the coal has been removed. This method of controlled overburden placement greatly reduces the adverse effects of contour surface mining.

Auger mining has gained wide acceptance in the Eastern United States. With it an auger machine bores horizontal holes as small as 19-inches in diameter and up to 250 feet deep into the exposed coal bed. Capital costs are low and productivity is high, but recovery is low, about a maximum of about 50 to 60 percent. Auger mining may find some application on the reservation where flat-lying beds of sufficient thickness are readily exposed.

An interesting adaptation of a fine grading machine has been successfully applied to mining an 18-inch-thick coal bed in Oklahoma (Coal Mining and Processing, 1975, p. 58-60). A rotating toothed auger cuts the coal from the bed and transports it to a central conveyor. This conveyor discharges the coal into trucks. Thus the machine acts as an excavator/crusher/loader. It makes cuts 6 inches deep and 10 feet wide as it moves along the coal bed. The production rate is about 100 tons per hour. It is particularly adaptable to mining thin beds and therefore may find some application on the reservation.

The reservation's coal resources are insufficient to support large-scale surface mining as practiced in the thick subbituminous coal beds in eastern Montana. Small-scale surface mining would be applicable for the thin flat-lying coal beds on the reservation if suitable areas can be found where the overburden thickness is not excessive.

The applicability of surface mining on the steeply inclined coal beds in the Blackfeet field is less definite. Techniques have been developed for surface mining in inclined beds, but only an extensive field study will reveal whether suitable areas are present here (Phelps, 1973, p. 390-392).

Environmental Aspects.--The environmental aspects of surface mining, especially the rehabilitation of mined land, recently has received a large amount of attention from scientists and engineers as well as the general public. Much of this concern originated from past practices, particularly in the Eastern United States. Objections have centered mainly around contour surface mining where the spoil was cast over the hillside and caused stream silting and acid drainage from the exposed pyrite-bearing rocks. Much more acceptable methods for overburden disposal have been developed, and technology for rehabilitating mined lands has progressed remarkably in the past few years.

A study by the National Academy of Sciences (1974, p. 53) concluded there "presently exists technology for rehabilitating certain western sites with a high probability of success."These include sites with over 10 inches of annual precipitation. The annual precipitation at Browning is about 15 inches, and therefore rainfall should not be a limiting factor in rehabilitating mined areas on the reservation. However, the rehabilitation of surface mined lands is essentially site specific and depends on many factors other than precipitation; some of which are soil composition, topography, vegetation, and projected land use.

Rehabilitation of surface mined land includes top soil removal, spoil grading, top soil placement, surface manipulation to trap rain and snow, revegetation, and possibly fertilizing and irrigation. The cost of rehabilitation at a mine in eastern Montana according to a recent Bureau of Mines study is about $4,300 per acre (Bitler and others, 1976).

Coal beds in Montana are commonly aquifers and often used by farmers and ranchers as underground sources of water. Surface mining may disrupt flow patterns. Fortunately, the amount of disturbed land at any time will be small so only local dislocations will occur. Therefore, no extensive or long term damage to the water resources on the reservation is expected. Furthermore, the small quantity of water required by a mining operation, e.g., for coal processing, road sprinkling, sanitary purposes, etc., should not seriously deplete present aquifers.

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

Some trace elements in coal may also cause a health hazard by their liberation during combustion. Arsenic and mercury, for example, are exceptionally dangerous pollutants highly toxic to humans and animals. The volatility of both is relatively high in the elemental and combined forms. Mercury and arsenic would therefore be mobilized into the atmosphere by combustion (Bertine and Goldberg, 1971, p. 234). New arsenic standards have been proposed by the Occupational Safety and Health Administration. These will reduce the minimum permissible 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 values are unusually high and were among the highest of 36 coal samples analyzed. Clearly, future investigations of reservation coals must include analyses for mercury and arsenic as well as other elements, e.g., lead, that could possibly cause a health hazard.

Markets

Local

Small quantities of coal have been mined on or near the reservation to supply local needs. However, the local market has been largely captured by oil and natural gas. The recent rising costs and shortages of these fuels may stimulate a return to coal for domestic heating and as a fuel for small local industries. Nevertheless, the local market for coal will probably be small and would not support any large-scale development of the resources on the reservation.

Electrical Power Generation

The electric utility industry is the largest user of coal in the United States, consuming about 419 million tons or 70 percent of production in 1973. The electrical power generated in the United States has been increasing by almost 7 percent a year while the rate of increase of all forms of energy is about 4 percent a year. Nearly all of the coal that is currently mined in Montana is used for generating electrical power. The electric utility industry could form a large and viable market for coal from the reservation if it met their specifications.

Generally, contracts for the sale of coal to electrical power plants specify limits on moisture, ash, and sulfur contents; penalties are assessed for exceeding these limits. Similarly, a minimum heat content is specified. Ash and sulfur can usually be reduced and the heat content increased by mechanical cleaning. Assuming the heat content of clean coal is about 12,000 Btu per pound, the maximum allowable sulfur permitted by present Environmental Protection Agency regulations is 0.8 percent. Therefore, the sulfur content of reservation coal must be reduced to this level, but coal with a higher sulfur content could be blended with low sulfur coal from an off-reservation source. Low sulfur coal from eastern Montana is the most likely candidate for this purpose.

Additional coal characteristics important in power plants are related to the ash composition. The fluidity of the ash is an important factor in the design of boilers particularly with regard to ash removal equipment. For example, coal with an ash softening temperature above 2,600ºF cannot be used in cyclone furnaces (Slicer and Leonard, 1968, p. 3-22).

Coal commonly contains trace elements which may have future resource importance. These are gallium, germanium, selenium, tellurium, thallium, and vanadium. The reservation coals should be analyzed for them.

Each boiler manufacturer through experience has developed empirical methods for evaluating coal ash fluidity characteristics. These have not been standardized between manufacturers. They commonly depend on the amount of Fe_2O_3, CaO, MgO, Na_2O, K_2O, SiO_2, $A1_2O_3$, and TiO_2 in the ash.

Most modern power plants are designed to operate with steam temperatures above 1,000ºF. This recent development has caused a new type of fouling deposit to occasionally form on the boiler tubes. The source of these deposits are some sodium and potassium compounds in the coal, particularly the chlorides. Coal ashes containing 2 to 5 percent Na_2O are considered medium fouling for Western coals; higher Na_2O contents may cause severe fouling (Winegartner and Ubbens, 1974, p. 6). Some boiler manufacturers, recognizing that most of the alkali associated with fouling problems is in the form of chlorides, evaluate fouling potential by analyzing the coal for total chlorine content.

Grindability is an important physical property in pulverized coal firing, and is dependent on specific properties such as hardness, toughness, strength, tenacity, and fracture. It is measured by the Hargrove grindability test which is a standard of the American Society for Testing Materials. Coal from the Blackfeet field should be easy to grind because of its friable nature.

Modern power plants are commonly rated at about 1,000 Mw with an expected life of 35 years. The reservation's coal resources, estimated to be 30 to 50 million tons, would supply the power plant for only 10 to 20 years; it is unlikely that a power plant will be built on the reservation.

Metallurgical Applications

Coke has been manufactured from Montana coal in the past and used in local copper smelters. Modern copper smelting methods, however, do not require coke as a reducing agent. However, it is the most common reducing agent for the manufacture of steel. A resource investigation by the Bureau of Mines has established that substantial but low grade iron ore resources are present in southwestern Montana (Roby and Kingston, 1966), which can be upgraded to meet industry requirements. Coal from the reservation could be used in the future development of a local iron and steel industry.

If reservation coal is to be used by the iron and steel industry, it must be upgraded to not more than 8 percent ash and 1.2 percent sulfur. Washability tests are required to determine the degree of upgrading that is possible. If used in blast furnaces, blending with low volatile bituminous coal will probably be required. The blend must form a strong, well fused coke. Carbonization tests are necessary to determine coking characteristics. If the coal can be upgraded to satisfy the ash and sulfur limits but cannot be made into suitable coke, it can still be used by the iron and steel industry in the form of carbonized coal briquettes (formed coke) or as material for direct reduction processing.

Cement

Shortages of fuel oil and natural gas, as well as the sharp increase in their costs have forced nearly all cement manufacturers to consider coal as a primary fuel. Many manufacturers have acquired coal reserves or signed long-term contracts to assure a reliable fuel supply.

The amount of Portland cement consumed in Montana in 1972 was 241,720 tons (Minerals Yearbook, 1972, p. 432). Two plants are currently operating near Helena. High volatile bituminous coal with a heat content above 10,000 Btu per pound and with an ash content ranging from 6 to 22 percent is commonly used in cement plants (Leonard and McCurdy, 1968, p. 3-25). Reservation coal would readily meet these specifications.

Uranium and Thorium

Both the Virgelle Sandstone and the Horsethief Sandstone are possible sources of radioactive minerals which are associated with the magnetite and titaniferous magnetite beds. Both formations appear favorable for the occurrence of uranium, but the abnormal radioactivity of one sample from the Virgelle Sandstone was thought to be due to thorium in the associated monazite (Armstrong, 1957, p. 215, 222).

Metallic Mineral Resources

Titaniferous Magnetite

Geology

Concentrations of titaniferous magnetite formed as beach deposits during deposition of the Horsethief and Virgelle Formations. Although the host rocks for the deposits are relatively widespread on the reservation, the deposits are more restricted geographically.

Three deposits on the reservation were examined by the Burlington Northern Company (1970). The location of these deposits is shown in Figure 7, and the following description is condensed from the Company's 1970 report.

On the Blackfeet Indian Reservation, many exposures near the top of the Horsethief Sandstone are rich in iron and titanium. In these areas the rock is dark greenish brown to black on fresh exposures and dark reddish brown to black when weathered.

The titaniferous magnetite deposits originated as beach placer concentrations. They are hard, lenticular sandstones, medium to coarse grained, generally with calcareous cementing material.

Normally the deposits consist of two to four zones, rich in titaniferous magnetite intercalated with lean sandstone layers.

The individual rich zones range from a few inches to about 20 feet in thickness. The rich zones are commonly finely banded with distinct layers of rich material alternating with layers of lean material consisting chiefly of quartz and feldspar. Most layers are less than ¼ inch thick.

The most obvious effect of this banding is to make sampling difficult, and the most truly representative samples have been obtained from test pits. Core drilling recovers a greater proportion of either the rich or the lean, depending on which layer is harder at a particular site.

The samples of the iron-titanium beds all contained the same suite of minerals, but with differences in the proportions. The titanium content is greater than can be accounted for by the ilmenite, indicating that in much of the magnetite, titanium has replaced iron in the crystal lattice.

The opaque minerals consist of magnetite, hematite, magnetite-ilmenite intergrowths, hematite-ilmenite, and magnetite-hematite, and usually minor amounts of hematite-goethite-limonite. The samples also contain iron-stained quartz and feldspar and minor carbonates and silicates.

Deposits

The reservation's titaniferous magnetite deposits were first described in 1914 (Stebinger, p. 329-337). Twenty-one titaniferous magnetite deposits have been identified (Hubbard and Henkes, 1962, p. 9-19) and are listed in Table 10.

Lower Milk River District

The Kennedy Coulee deposit (Figure 16) is exposed for 1,000 feet along the upper edge of the bluff on the north side of Kennedy Coulee. Average thickness is about 8 feet. About 130,000 tons of titaniferous magnetite are estimated to be minable at a stripping ratio of 3 to 1. The deposit may extend beneath the southeast end of the bluff.

The Radar Station deposit is exposed for 2½ miles south-southeast from the Milk River. It contains about 330,000 tons of titaniferous magnetite in a bed averaging 10 feet thick. An additional 1,500,000 tons is inferred and it could be more. This may be the largest minable deposit on the reservation.

The Buffalo Lake deposits are about 2 miles northwest of Buffalo Lake. Outcrops average about 3 feet thick. An estimated 60,000 tons are minable at a stripping ratio of 3 to 1 but the deposit may be substantially larger.

Rimrock Butte District

The Rimrock Butte district (Figure 17) contains three deposits that lie along two low parallel ridges on top of a butte. The beds average about 2 feet thick. About 1 million tons of titaniferous magnetite are present with little or no overburden.

Kiowa Junction District

Seven small deposits are present in the Kiowa Junction district (Figure 18). These are the Lower Kiowa, East Kiowa No. 2 extension, Kiowa Junction, South Fork, High Knob, Two Medicine, and Cut Bank Ridge. They are relatively small. The two largest are the Two Medicine with estimated minable resources of 50,000 tons and the Kiowa Junction with 44,000 tons. Each of the remaining deposits contain minable resources of 16,500 tons or less.

Milk River Ridge District

The Milk River Ridge district (Figure 19) contains several widely scattered deposits 10 to 20 miles northwest of Browning. These are the Livermore Creek, Horse Lake, North Browning, and Star School. The Star School deposits are the most important; about 60,900 tons of titaniferous magnetite are minable by surface methods. The Livermore Creek and Horse Lake each contain about 10,000 tons of indicated resources.

Potential Resources

The potential resources of titaniferous magnetite in the Horsethief Sandstone suitable for surface mining have been estimated to range from 10 to 15 million tons (Hubbard and Henkes, 1962, p. 18). These deposits vary from a few thousand tons to a million or more.

The Virgelle Sandstone underlies the entire reservation to the east of the Disturbed Belt and is reported to contain locally abundant magnetite and titaniferous magnetite as well as small amounts of zircon, monazite, and garnet (Armstrong, 1957, p. 125). The extent of the iron resources in the Virgelle Sandstone on the reservation is not known.

An aeromagnetic survey indicates the presence of a large mass of magnetic material in the southwestern part of the reservation at a depth of 8,000 feet (±4,000 feet) (Mudge and others, 1966, p. B133). The magnetic anomaly is believed to be caused by a mass of iron-rich rock of moderate density and regional extent. Even if the magnetic anomaly is caused by an iron deposit, its depth probably rules out any possibility of being mined economically at this time.

Beneficiation

The iron content of the titaniferous magnetite samples listed in Table 10 ranges from 10.6 percent to 55.6 percent. Therefore, ore from the reservation will not be "direct shipping ore" because the iron content is too low and consequently beneficiation will be necessary.

Titaniferous magnetite from the Choteau area approximately 30 miles southeast of the reservation, which is probably similar to that on the reservation, has been investigated at the Albany Metallurgy Research Center of the U.S. Bureau of Mines (Wilmer, 1946, 12 p.).

The results of this test, Table 11, indicate that a concentrate with an iron content of 61.3 percent was obtainable (Holmes and Stickney, 1969, p. 3, 4). This is of sufficient grade to satisfy industry requirements.

Results of a Davis Tube magnetic beneficiation test of the titaniferous magnetite sands from the Kennedy Coulee deposit are as follows (Burlington Northern Inc., 1970, table 2):

Crude Ore		Davis Tube Test products at -150 mesh					
Fe%	TiO_2%	Product	Weight%	Fe%	TiO_2%	SiO_2%	Al_2O_3%
36.19	10.71	Conc.	27.0	51.10	20.48	2.28	1.22
		Tails	73.0	30.68	7.11		

TABLE 10

Analyses of Titaniferous Magnetite (Hubbard and Henkes, 1962, p. 11, 12)

Sample No.	Deposit / Location	Thickness (feet)	Average grade Iron (%)	Average grade TiO_2 (%)	Remarks
1	Kennedy Coulee, NE¼ sec. 30, T. 37 N., R. 9 W.	8.0	29.1	8.77	Channel sample
2	Radar station, SW¼ sec. 29, T. 37 N., R. 9 W.	8.8	37.4	12.6	Do.
3	Radar station, SW¼ sec. 29 T. 37 N., R. 9 W.	11.3	32.9	10.2	Do.
4	Radar station, NW¼ sec. 3 T. 37 N., R. 9 W.	19.0	33.7	10.31	Do.
5	Buffalo Lake, SE¼ sec. 16, T. 36 N., R. 9 W.	19.0	35.9	5.47	Do.
6	Buffalo Lake, NE¼ sec. 27, T. 36 N., R. 9 W.	1.1	29.5	9.30	Do.
7	Rimrock Butte, SW¼ sec. 4, T. 34 N., R. 9 W.	1.9	37.7	12.7	Do.
8	Rimrock Butte, NW¼ sec. 15, T. 34 N., R. 9 W.	2.1	45.5	14.5	Do.
9	Lower Kiowa, SW¼ sec. 1, T. 32 N., R. 13 W.	4.0	10.6	2.30	Channel sample bottom section of bed
10	Lower Kiowa, SW¼ sec. 1, T. 32 N., R. 13 W.	3.0	46.4	9.14	Channel sample top section of bed
11	East Kiowa No. 2 Ext., NE¼ sec. 1, T. 32 N., R. 13 W.	2.0	31.5	5.46	Channel sample
12	Kiowa Junction, NW¼ sec 10, T. 32 N., R. 13 W.	4.0	33.4	5.03	Do.
13	South Fork, NE¼ sec. 12, T. 32 N., R. 13 W.	1.8	19.4	4.16	Do.
14	High Knob, NE¼ sec. 18, T. 32 N., R. 12 W.	5*	50.8	--	Character sample of outcrop
15	Two Medicine Ridge, NE¼ sec. 21, T. 32 N., R. 12 W.	3*	47.8	--	Character sample of float
16	Cut Bank Ridge, SE¼ sec. 31, T. 33 N., R. 12 W.	1*	54.5	--	Grab sample of high-grade float
17	Livermore Creek, SE¼ sec. 30, T. 35 N., R. 12 W.	2*	36.2	--	Chip sample
18	Horse Lake, SE¼ sec. 1, T. 34 N., R. 13 W.	2.5	55.6	--	Channel sample of best outcrop
19	North Browning, SE¼ sec. 18, T. 34 N., R. 11 W.	1.0	10.5	2.01	Chip sample
20	Star School, NE¼ sec. 11, T. 33 N., R. 12 W.	3.4	25.2	4.86	Channel sample
21	Star School, SW¼ sec. 13, T. 33 N., R. 12 W.	7.5	37.0	5.86	Do.

*Estimated

TABLE 11

Analysis of Concentrate from Beneficiated Choteau Titaniferous Magnetite (from Holmes and Stickney, 1969, p. 4)

Element or compound	Percent
Iron	61.3
TiO_2	5.6
Al_2O_3	1.4
SiO_2	4.3
CaO	.4
MgO	1.0
Chromium	.3
Vanadium	.3
Manganese	.2
Sulfur	.05
Phosphorous	.03

Note: Concentrate yield was 75 percent of the ore.

Smelting

Iron

Titaniferous magnetite is not a source of iron in the United States at the present time although iron was made from New York deposits in the 1800's (Rossi, 1892-93, p. 835). The objections to smelting titaniferous magnetite ores in a blast furnace are that the fuel requirements are excessive, the slag is pasty and not free flowing, and accretions form which cause scaffolding in the furnace and clogging in the hearth.

The problem of high-fuel consumption originates in part from the dilution effect of the titanium in the ore--the higher the titanium content, the lower the iron content. Furthermore, magnetite ore is characteristically hard, dense, and resistant to reduction which in turn causes high-fuel consumption. However, titaniferous magnetite ore is amenable to magnetic concentration, and a large part of the non-iron-bearing material can be removed. If the magnetic concentrate is pelletized, attack by the reducing gasses in the furnace is greatly facilitated. By adopting modern beneficiating methods, the underlying factors leading to high-fuel consumption are largely eliminated.

The Albany Metallurgy Research Center has demonstrated that a free flowing slag can be obtained when smelting Choteau titaniferous magnetite concentrate by proper manipulation of the slag composition (Holmes and Stickney, 1969, p. 21.) Unfortunately, titaniferous magnetite ore and concentrate are best smelted under acid conditions to promote the formation of a fluid slag. The sulfur content of iron ore is characteristically low, but coke used as a reducing agent commonly contains a much higher sulfur content. If the sulfur content of the iron obtained from reservation titaniferous magnetite is excessive, additional desulfurization will be necessary. The technology for smelting under acid conditions followed by external desulfurization of hot metal is well established; but if this additional treatment is necessary, an additional expense will be added (Ross, 1958, p. 410, 411).

Titaniferous magnetite ore has been smelted successfully in an electric furnace at the Salt Lake City Metallurgy Research Center of the U.S. Bureau of Mines (Fuller and Edlund, 1960, 11 p.). Coal was a more satisfactory reducing agent than coke because coal promoted a more fluid and less foamy slag. Power requirements are estimated to range from 1,300 to 1,500 kilowatt hours per ton of ore.

The recent emphasis on the elimination of pollution from smelters has caused renewed interest in hydrometallurgical processes. A soda sinter process for treating low-grade titaniferous magnetite ore has been developed by the College Park Metallurgy Research Center, U.S. Bureau of Mines, College Park, Md. (MacMillan, et al., 1952, 62 p.).

Titanium

About 90 percent of the titanium that is used in the United States is imported. The price of rutile, a major source of titanium, has been rising sharply because of decreased world supply. Attention is now being directed to other sources including titaniferous magnetite ores. Titanium or titania can be recovered from blast furnace slag, electric furnace slag, or directly by hydrometallurgical processes. In 1974, about 250,000 tons of titanium slag were imported into the United States, largely from Canada by titania pigment producers (Commodity Data Summaries, 1975, p. 74). Electric furnace slag obtained from smelting Choteau titaniferous magnetite concentrate contained about 40 percent TiO_2 (Hubbard and Henkes, 1962, p. 13). The titaniferous magnetite on the reservation could become an important future source of titanium.

Nonmetallic Mineral Resources

General

The Bearpaw Shale, exposed along a narrow belt extending in a north-south direction across the entire reservation (Figure 4), commonly contains a bentonite zone. Also, the clay and shale may be suitable for the manufacture of common brick, tile, and sewer pipe (Hubbard, et al., 1966, p. 84).

Bentonite

No commercial beds of bentonite are known within this area. The Bearpaw Shale contains bentonite, but impurities in bentonite from this area are more abundant than in the beds farther east where bentonite is being mined from the Bearpaw (Berg, 1969, p. 28). It is unlikely that bentonite from the reservation is of commercial quality.

Clay

Clays that are associated with coal beds in the Two Medicine Formation and the Saint Mary River Formation are often suitable for the manufacture of ceramic products. Also, the shale associated with coal beds has been used for the manufacture of expanded aggregate (Harris, et al., 1962, p. 2-32).

Sand and Gravel

The extensive deposits of sand and gravel on the reservation (Figure 20) indicate they are sufficient to supply future local needs. About 58 gravel pits are located on the reservation but only four or five are operated. Most of the gravel is used for road construction and repair.

Transportation

The Burlington Northern railroad crosses the central part of the reservation in an approximately east-west direction. In addition, rail service is available at Valier, about 4 miles southeast of the reservation. The cost of transporting large quantities of coal or other bulk solids for long distances (over 400 miles) by unit train ranges from 0.4 to 0.9 cents per ton mile (Campbell and Katell, 1975, p. 24). The freight cost for shipping smaller quantities, i.e., smaller than full train loads, is about 30 percent higher (Zachar and Gilbert, 1968, p. 5-8).

Trucking costs depend on volume hauled, the nature of the terrain, and the capacity of the trucks. Transportation of coal by truck over 100 miles is considered impractical (Zachar and Gilbert, 1968, p. 5-9). The cost of shipment by truck for a one way haul and empty return ranges from 5.0 to 8.0 cents per-ton-mile (Campbell and Katell, 1975, p. 24).

SOCIAL EFFECTS FROM MINERAL RESOURCE DEVELOPMENT

The coal resources appear at this time to be of insufficient size to support large-scale development such as those now underway in eastern Montana, Wyoming, and Arizona. Consequently, no large industrial complexes are likely to be built on the reservation, and thus no serious disruptions to the traditional life style of the residents is expected. On the other hand, the coal resources are adequate to support relatively small-scale development with the attendant advantages of providing income as well as employment. The social impact from development of the iron resources, insofar as can be predicted at this time, would probably also be similar. If the mineral resources are developed by surface mining, relatively short-term training for mine employees would be required. However, underground mining would require the employment of highly skilled personnel and a comprehensive training program.

RECOMMENDATIONS

General

The disturbed belt of the Blackfeet Indian Reservation has a petroleum and titaniferous iron potential, but surface and subsurface geologic data are necessary to assist in evaluating the areas of greatest potential. Such data have not been compiled for all of the area.

Oil and Gas

Geologic and geophysical studies of the reservation are recommended to locate areas favorable for oil and gas.

The disturbed (faulted and folded) belt encompasses the western part of the Blackfeet Indian Reservation (Figure 4). At the International border it is about 18½ miles wide and maintains its width south to Browning. South of Browning the width of the belt thins to about 10½ miles at Birch Creek, the southern boundary of the reservation. Thus in the reservation, the belt encompasses about 1,113.5 sq mi (712,640 acres).

Petroleum, mainly gas, is potentially present in the disturbed belt. The belt is a southern extension of the Alberta foothills of which there are 4 major gas fields. It is also in a geologic setting similar to part of the Wyoming disturbed belt where large quantities of gas were recently discovered. Past petroleum exploration in this part of the reservation consisted mostly of seismic surveys. A few test wells have been drilled in the northern and southern parts of the area but vast areas remain unexplored. Some wells in the vicinity of East Glacier Park contain some gas.

Most of the area has not been mapped or studied geologically. Geologic studies were completed in 1976 in the foothills south of East Glacier Park along the western boundary of the reservation. Some broad reconnaissance geologic data are available in Two Medicine, Badger Creek, and Milk River drainages. Modern topographic maps (1:24,000 scale) cover the area.

The belt consists of closely spaced, westerly dipping thrust faults that repeat Upper Cretaceous strata. Much of the area is covered by glacial debris and stream gavels. Bedrock exposures, therefore, are sparse except along some major stream drainages. Detailed geologic knowledge of the Cretaceous strata are necessary to interpret the surface structure in the area. Geophysical studies (gravity and ground magnetometer) are necessary to aid in interpreting subsurface structures. Truck mounted magnetometer traverses would locate any titaniferous iron deposits beneath glacial debris and extensive gravel deposits.

A geologic and geophysical study of the disturbed belt in the reservation should consist of:

1. Geologically map the area at a scale of 1:125,000, depicting structure and formations, and where applicable, members of formations.

2. Geophysical studies (gravity and magnetometer) of the area. Gravity stations to be on 3 to 6 mile spacings depending on elevation control points. The spacing of truck mounted magnetometer traverses will be determined by northeasterly access roads or trails. Detailed geophysical traverses will be conducted in areas where anomalies are located.

3. A petroleum evaluation should be made for the area, based on all available surface and subsurface data.

Coal

Surface mining would be the best method for the initial development of coal resources on the reservation largely because of low mining costs; this applies to the Valier field, Blackfeet field, and possibly to some thinner beds outside of these fields. A comprehensive and systematic exploration program is recommended to determine the location and extent of the areas suitable for surface mining. The two most important technical factors in determining such areas are coal bed and overburden thickness.

An essential part of any investigation would be the determination of coal quality. This requires a complete analysis of representative samples including trace elements as well as ash analyses and ash fusion characteristics. Grindability, washability, and carbonization tests are also recommended.

Titaniferous Magnetite

Numerous small titaniferous iron deposits are known in sedimentary strata in parts of the belt. Together the deposits constitute a large tonnage of titaniferous iron. Geological and geophysical studies should determine the extent of these deposits under moderate cover of Quaternary deposits, and locate any buried deposits.

Beneficiation tests of the ores are recommended to determine the degree of upgrading that can be expected from established methods. The possible recovery of vanadium, uranium, thorium, and rare earth elements should be investigated.

Nonmetallic Minerals

The reservation contains clays and shales that might be used by the ceramic industry. A survey of the reservation to determine the extent and suitability of these deposits is recommended.

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Table 1.--Stratigraphic sequence on the Blackfeet Indian Reservation

(adapted from Balster, C. A., 1971)

Age	Group	Formation	Member	Lithology
Tertiary		Willow Creek Fm.		Soft shales and sandstones.
Cretaceous		St. Mary River Fm.		Gray-green shale, sandstone, mudstone, and coal.
Cretaceous	Montana Grp.		Horsethief Ss.	Gray, argillaceous sandstone.
Cretaceous	Montana Grp.		Bearpaw Shale	Dark gray shale.
Cretaceous	Montana Grp.	Two Medicine Fm.		Gray and green shale and sandstone. Thin coal beds near base.
Cretaceous	Montana Grp.		Eagle Ss.	White to buff sandstone.
Cretaceous	Montana Grp.	Virgelle Ss.		
Cretaceous	Montana Grp.	Telegraph Creek Fm.		Dark gray sandy shale.
Cretaceous	Colorado Grp.	Marias River Sh.	Kevin Sh. Mbr.	Dark gray shale.
Cretaceous	Colorado Grp.	Marias River Sh.	Ferdig Sh. Mbr.	Gray to dark gray shale.
Cretaceous	Colorado Grp.	Marias River Sh.	Cone Calc. Mbr.	Dark gray calcareous shale.
Cretaceous	Colorado Grp.	Marias River Sh.	Floweree Mbr.	Dark gray shale
Cretaceous	Colorado Grp.	Blackleaf Fm.	Bootlegger Mbr.	Gray sandstone, siltstone and shale.
Cretaceous	Colorado Grp.	Blackleaf Fm.	Vaughn Mbr.	Gray-green tuffaceous siltstone.
Cretaceous	Colorado Grp.	Blackleaf Fm.	Taft Hill Mbr.	Gray, glauconitic, shale and siltstone.
Cretaceous	Colorado Grp.	Blackleaf Fm.	Flood Mbr.	Brown, shaly sandstone.
Cretaceous		Kootenai Formation		Red mudstone, sandstone and shale.
Cretaceous		Kootenai Formation	Moulton Ss.	Gray sandstone.
Cretaceous		Kootenai Formation	Sunburst Ss.	White cherty sandstone.
Cretaceous		Kootenai Formation	Cut Bank Ss.	Coarse sandstone with dark chert grains.
Jurassic		Morrison Fm.		Green and gray shale and sandstone.
Jurassic	Ellis Grp.	Swift Fm.		Gray, glauconitic, shaly sandstone.
Jurassic	Ellis Grp.	Rierdon Fm.		Gray, limy shale.
Jurassic	Ellis Grp.	Sawtooth Fm.		White, calcareous sandstone.
Mississippian	Madison Grp.	Sun River Dolomite		Tan dolomite.
Mississippian	Madison Grp.	Mission Canyon Ls.		Gray limestone and dolomite.
Mississippian	Madison Grp.	Lodgepole Ls.		Gray, cherty limestone.
Mississippian		Bakken Fm.		Black shale.
Devonian	Three Forks Grp.	Three Forks Fm.		Green and red shale.
Devonian	Three Forks Grp.		Potlach Mbr.	Anhydrite and red shale.
Devonian	Jefferson Grp.	Birdbear (Nisku) Fm.		Brown dolomite.
Devonian	Jefferson Grp.	Duperow Fm.		Brown limestone and dolomite.
Devonian		Souris River Fm.		Brown limestone and dolomite.
Cambrian		Red Lion Fm.		Gray limestone and black shale.
Cambrian		Pilgrim Ls.		Gray, dense, shaly limestone.
Cambrian		Cambrian shale undivided		Gray-green, calcareous shale.
Cambrian		Flathead Quartzite		Pink, quartzose sandstone.
Precambrian				Igneous and metamorphic rocks.

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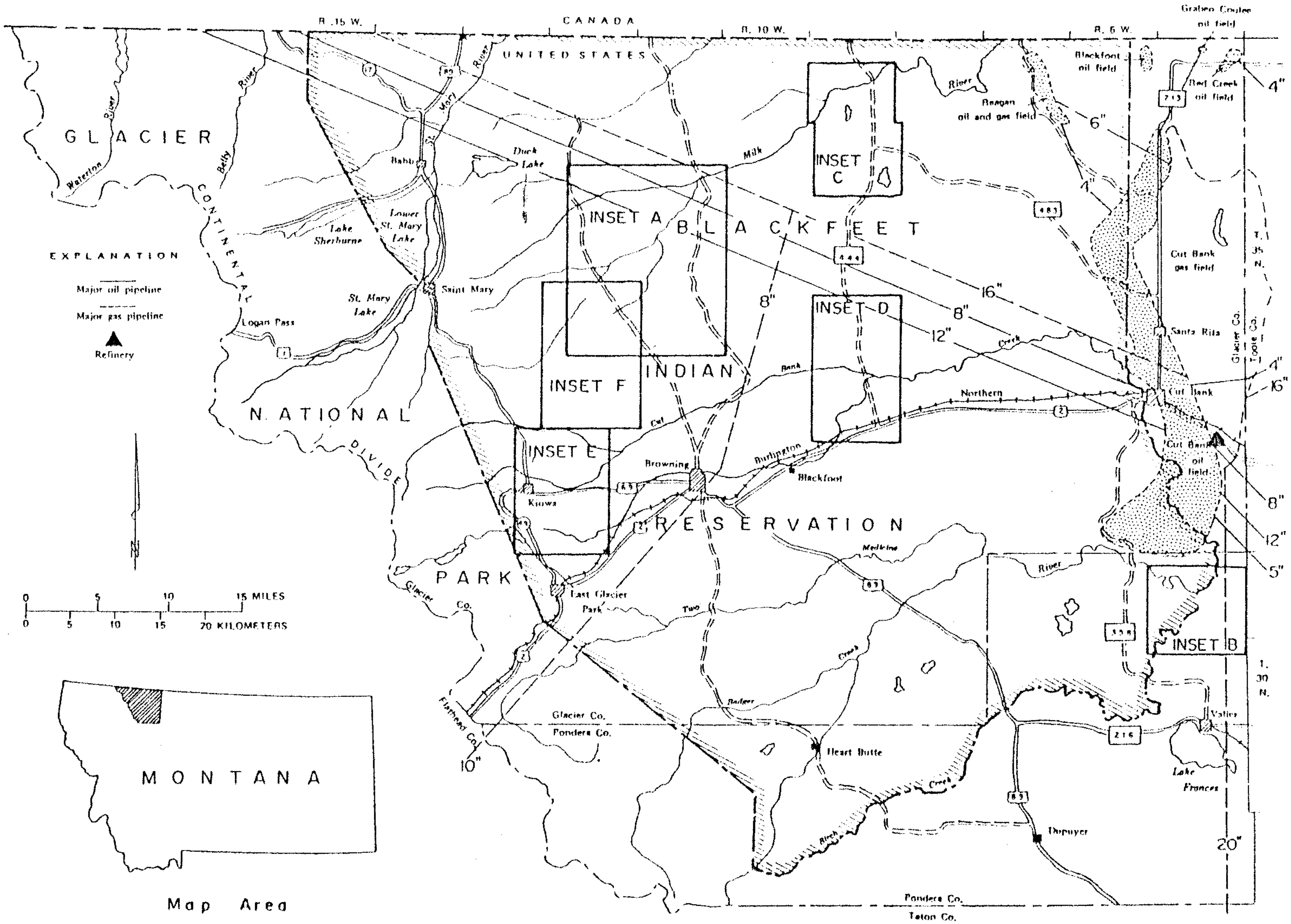

Figure 1. Index map of Blackfeet Indian Reservation, Montana (adapted from Hubbard and Henkes, 1962).

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Figure 2. Topographic map of the Blackfeet Indian Reservation, Montana (from U.S. Geological Survey State of Montana Map, 1966).

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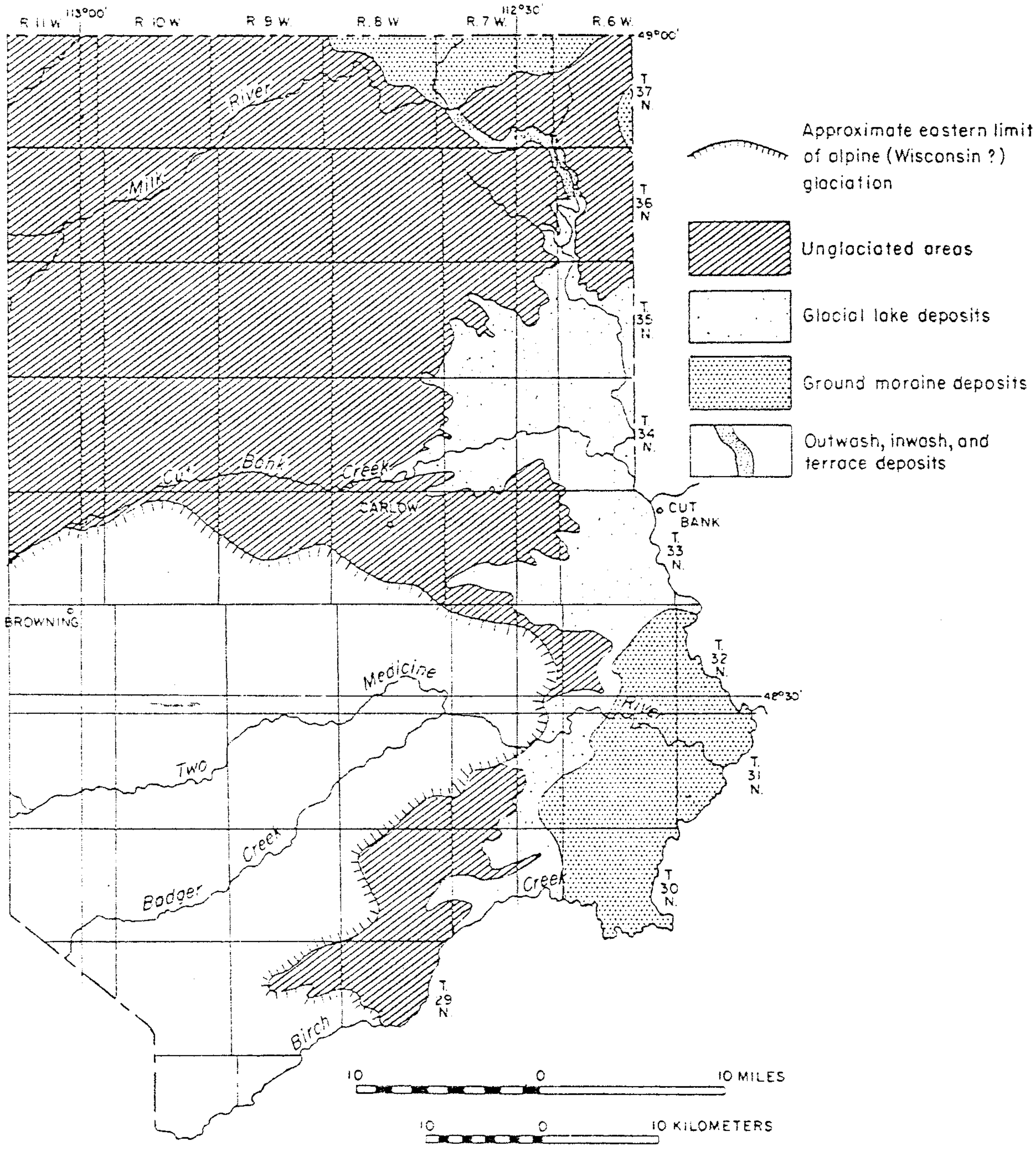

Figure 3. Map showing glacial deposits in eastern part of the Blackfeet Indian Reservation, Montana (adapted from Colton and Lemke, 1961).

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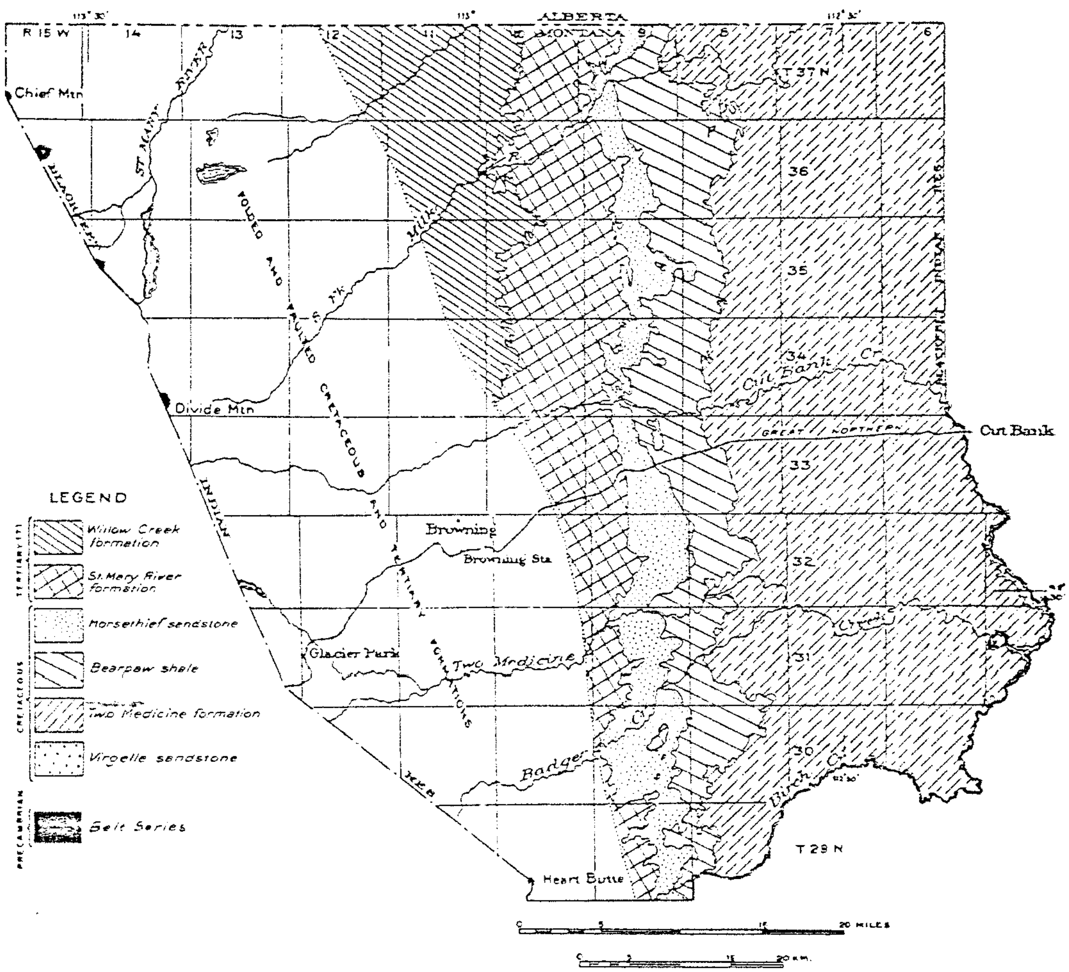

Figure 4. Generalized geologic map showing bedrock units on the Blackfeet Indian Reservation, Montana (adapted from Stebinger, 1916, pl XV).

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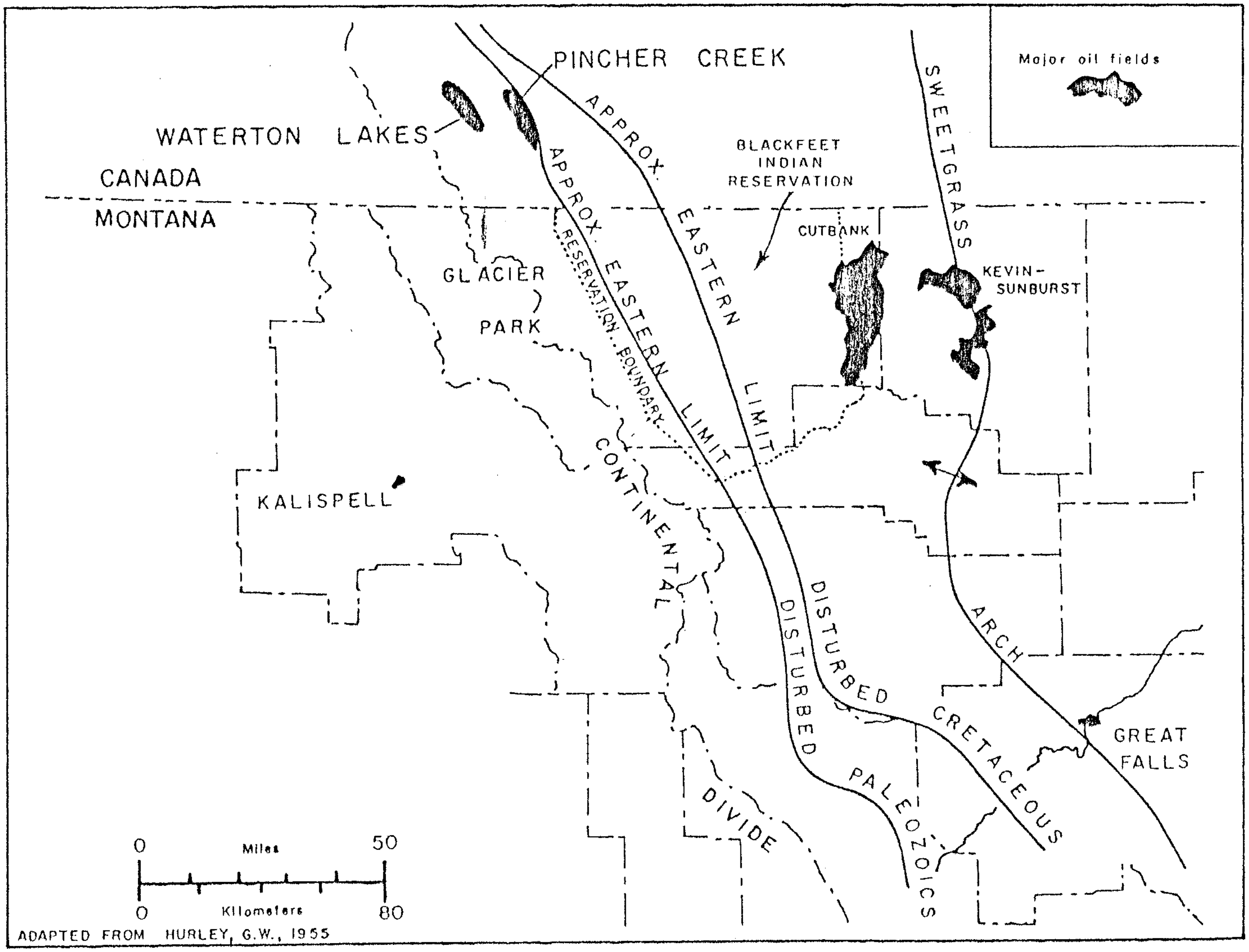

Figure 5. Map showing regional geologic structures of parts of northwestern Montana and southern Alberta, Canada.

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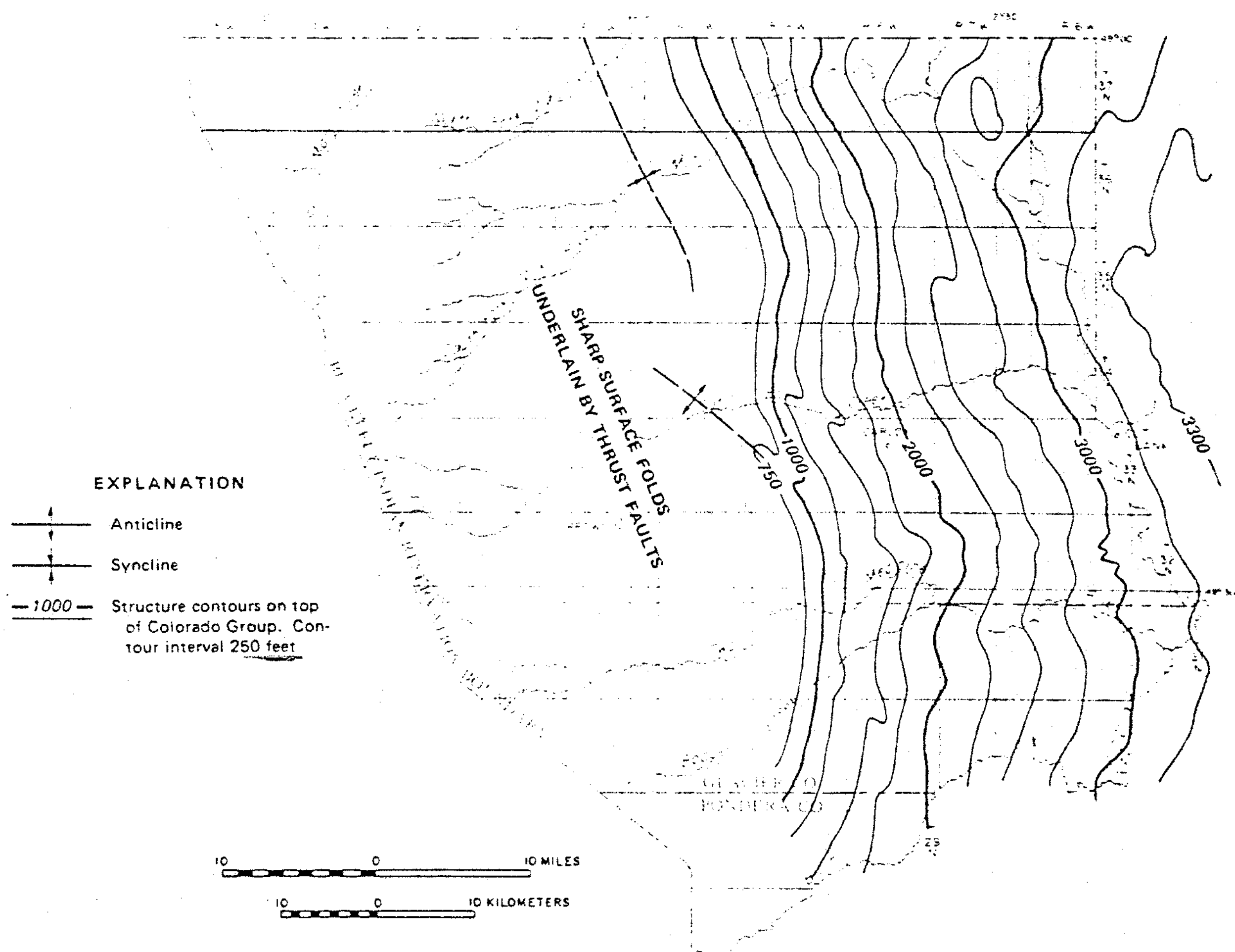

Figure 6. Map showing structure contours in eastern part of the Blackfeet Indian Reservation, Montana (adapted from Erdmann and others, 1946, and Dobbin and Erdmann, 1955).

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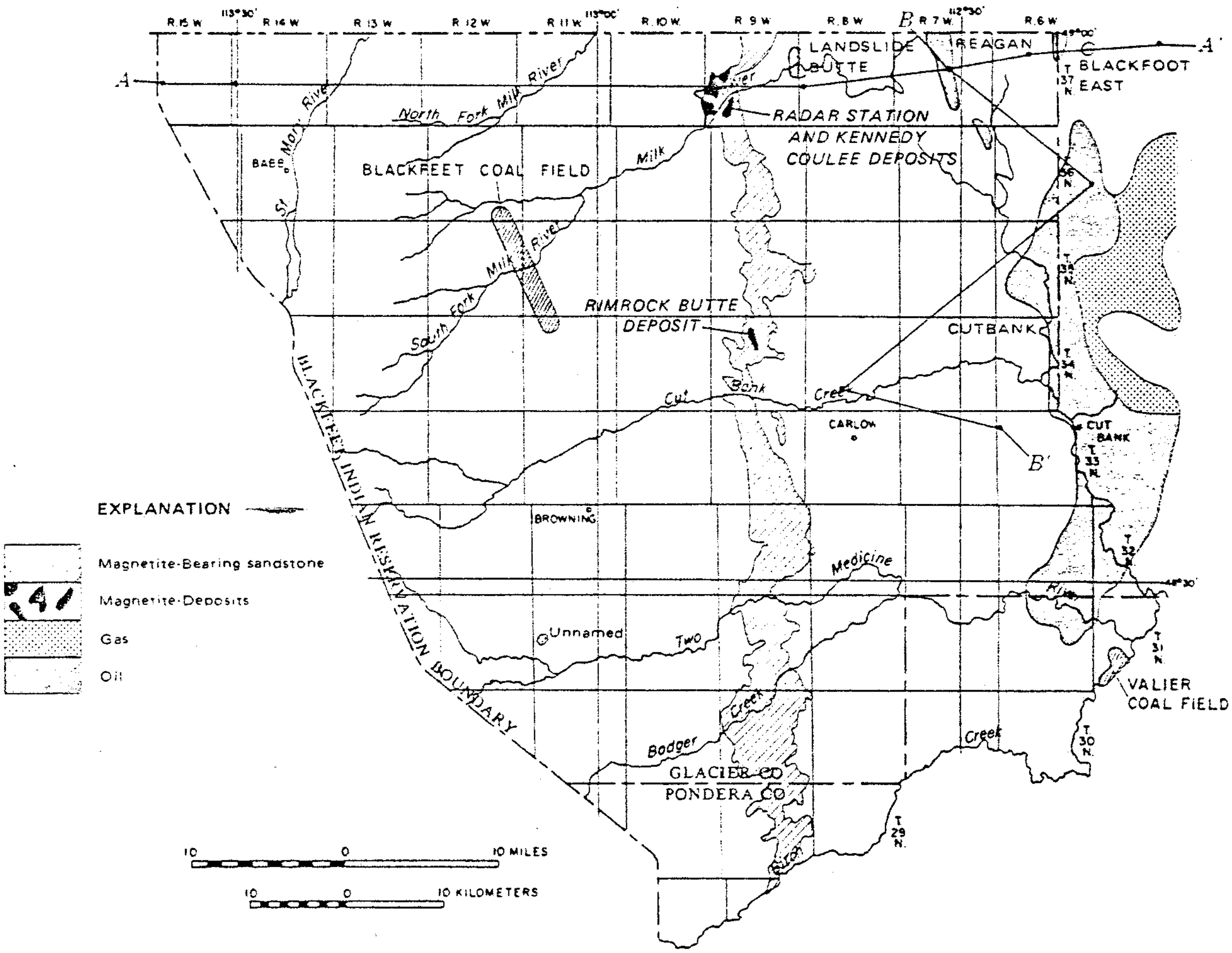
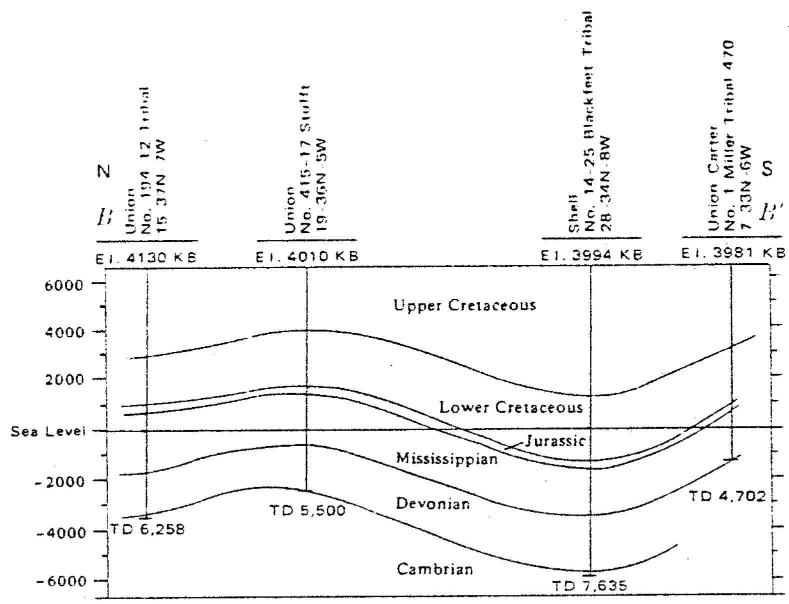


Figure 7. Map showing oil and gas fields, coal fields, and magnetite-bearing sandstone and magnetite deposits, Blackfeet Indian Reservation, Montana (adapted from Stebinger, 1914 and 1916).



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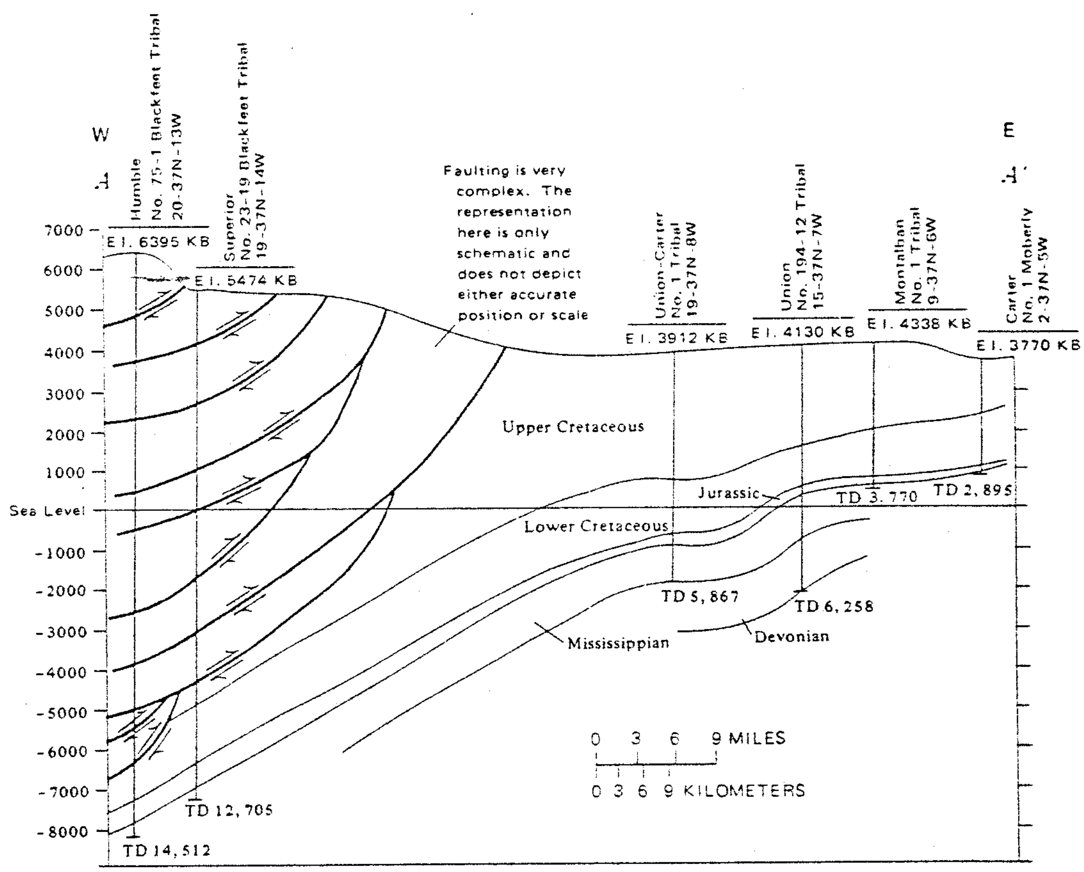

Figure 8. Cross sections through drill holes showing general structure and stratigraphic relations in parts of the Blackfeet Indian Reservation, Montana (for location of sections, see Figure 7).

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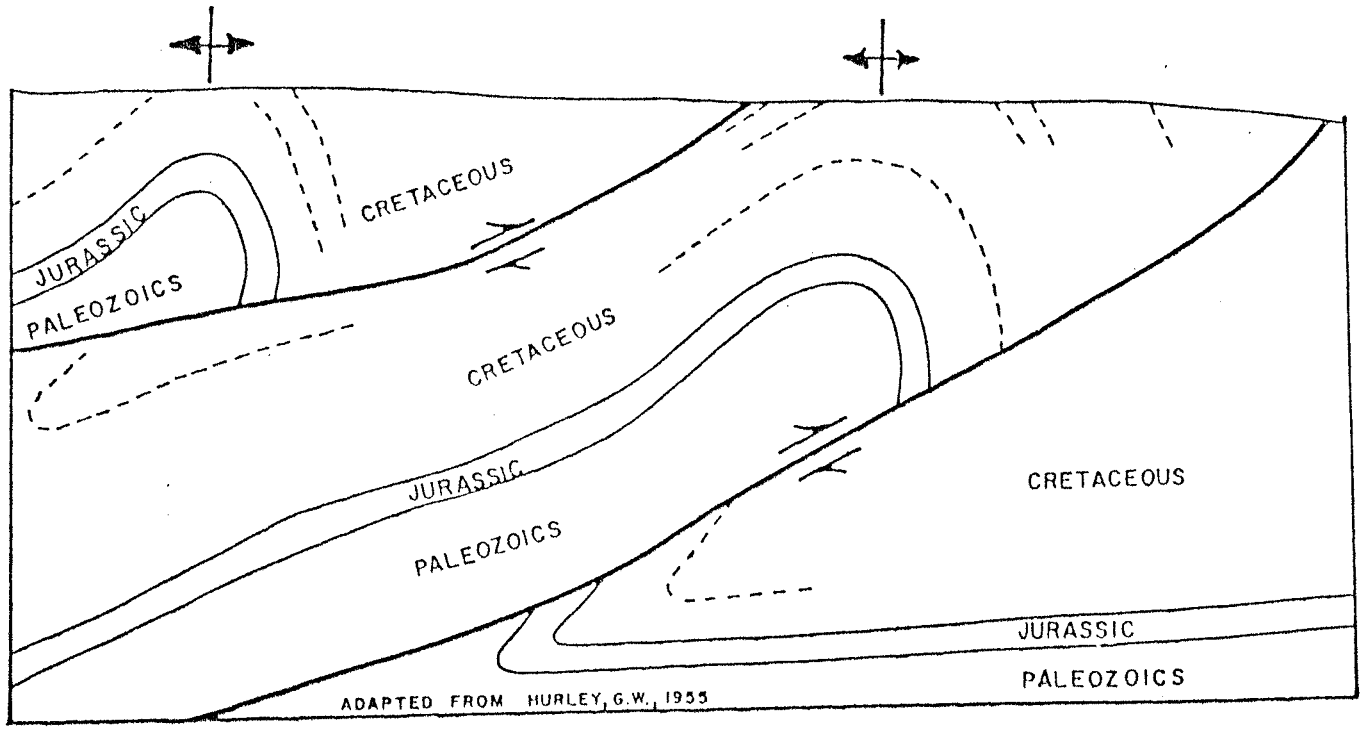

Figure 9. Diagram showing drag folds.

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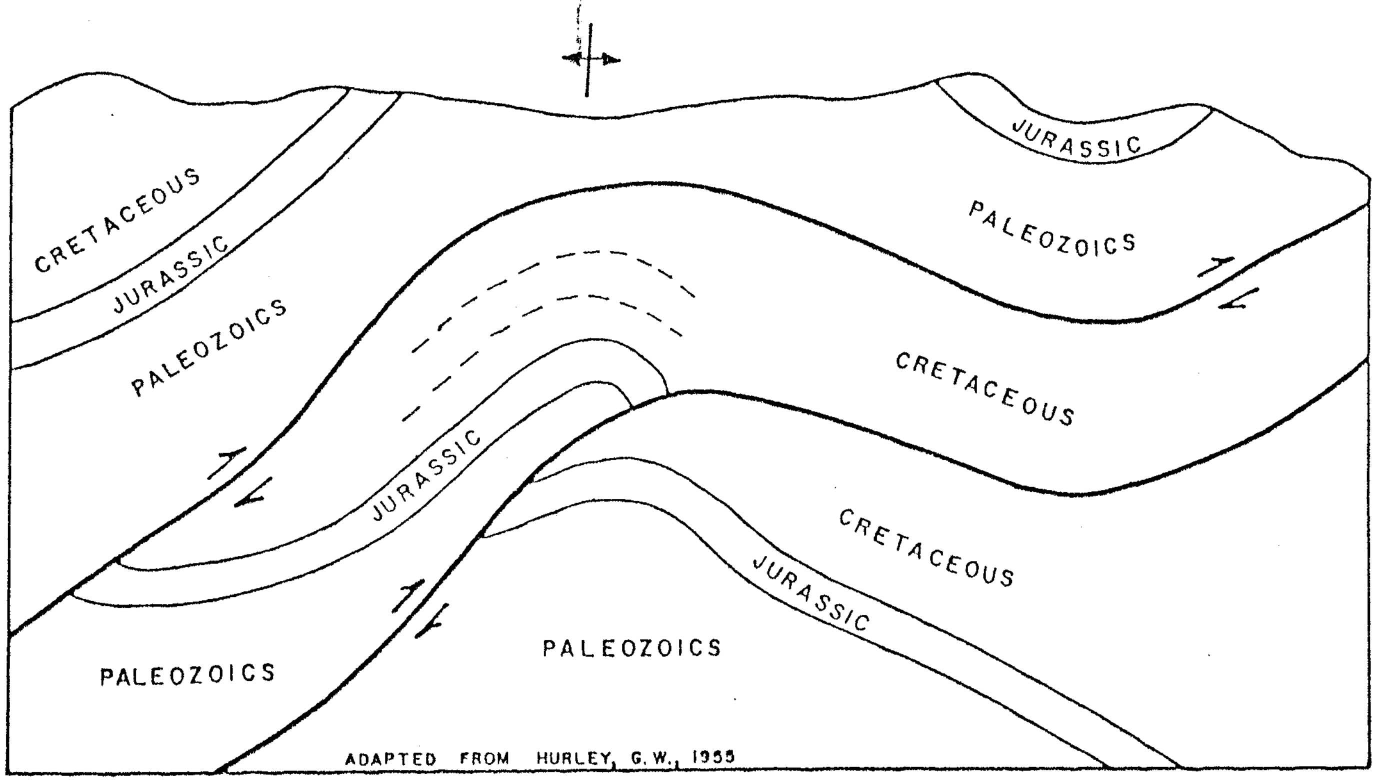

Figure 10. Diagram showing complex anticlinal traps.

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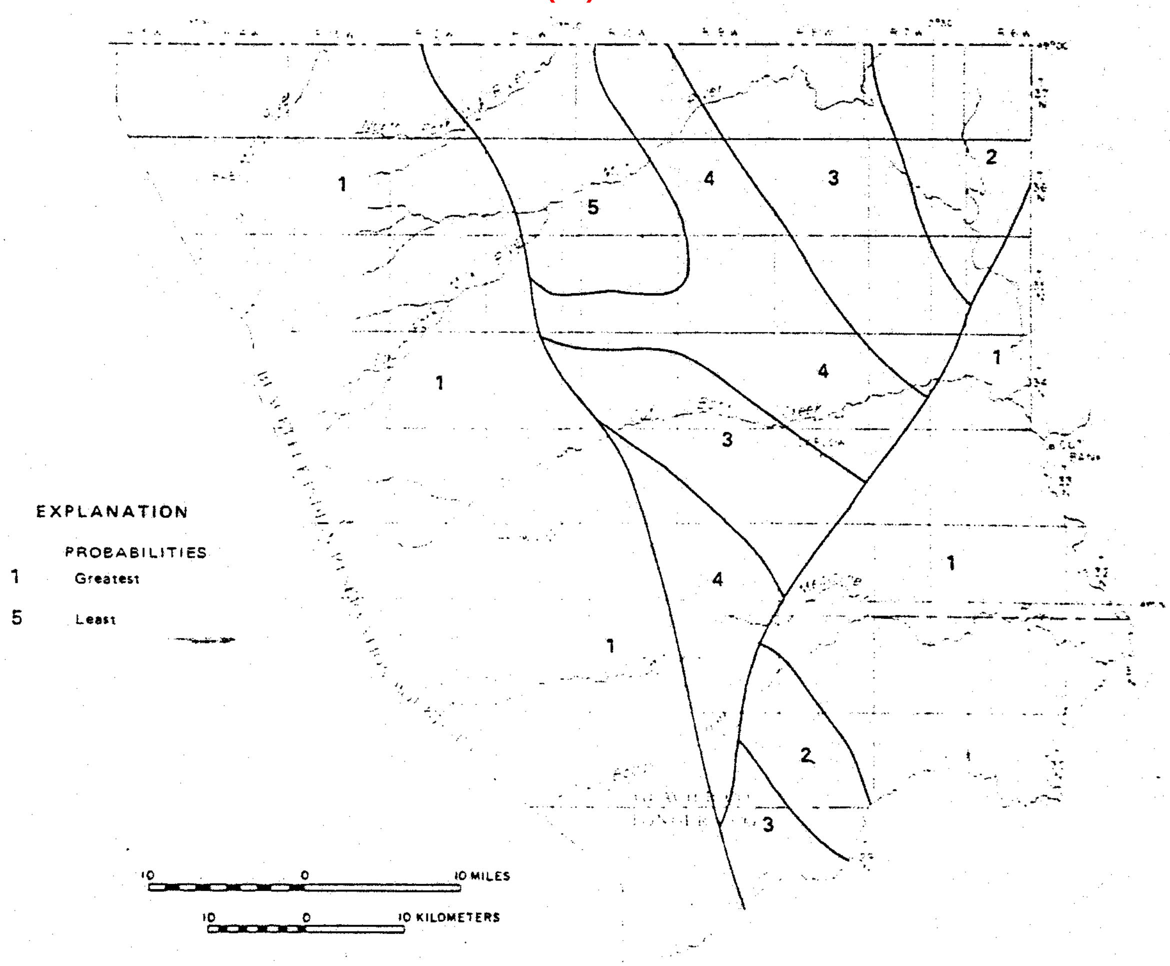

Figure 11. Map showing areas rated according to the probability of discoveries of significant oil and gas reserves, Blackfeet Indian Reservation.

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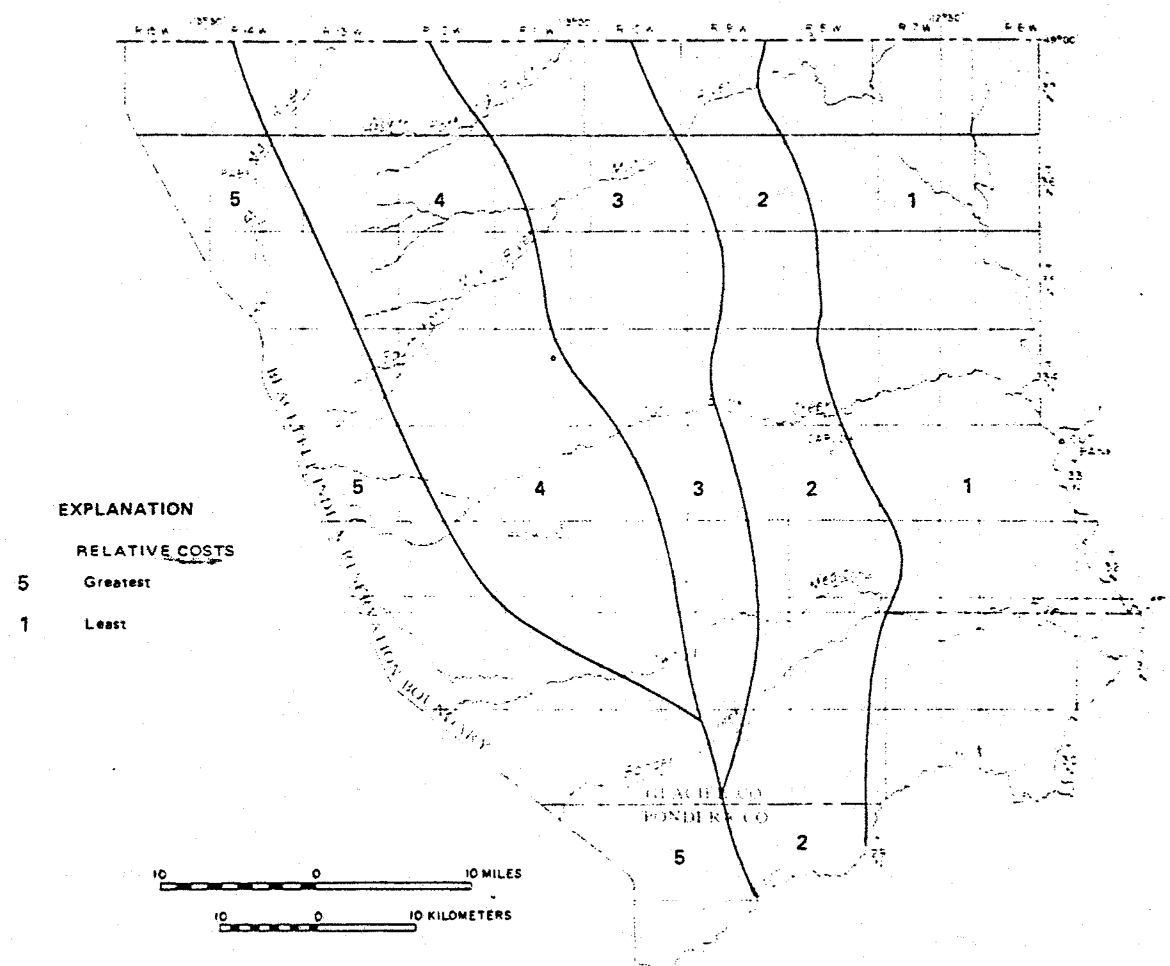

Figure 12. Map showing areas rated according to the probable costs of finding significant discoveries of oil and gas, Blackfeet Indian Reservation, Montana.

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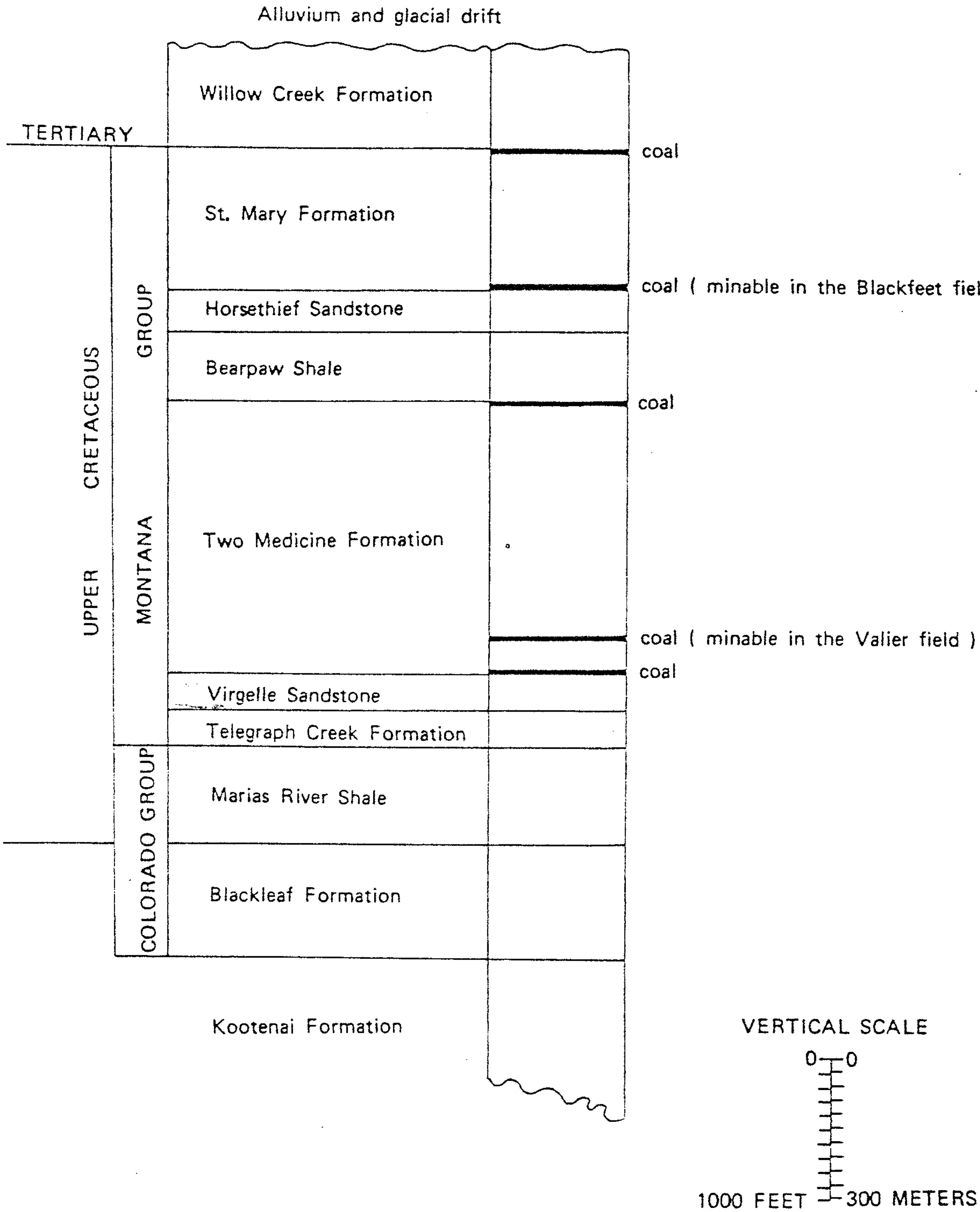

Figure 13. Partial stratigraphic section showing position of known coal beds, Blackfeet Indian Reservation, Montana.

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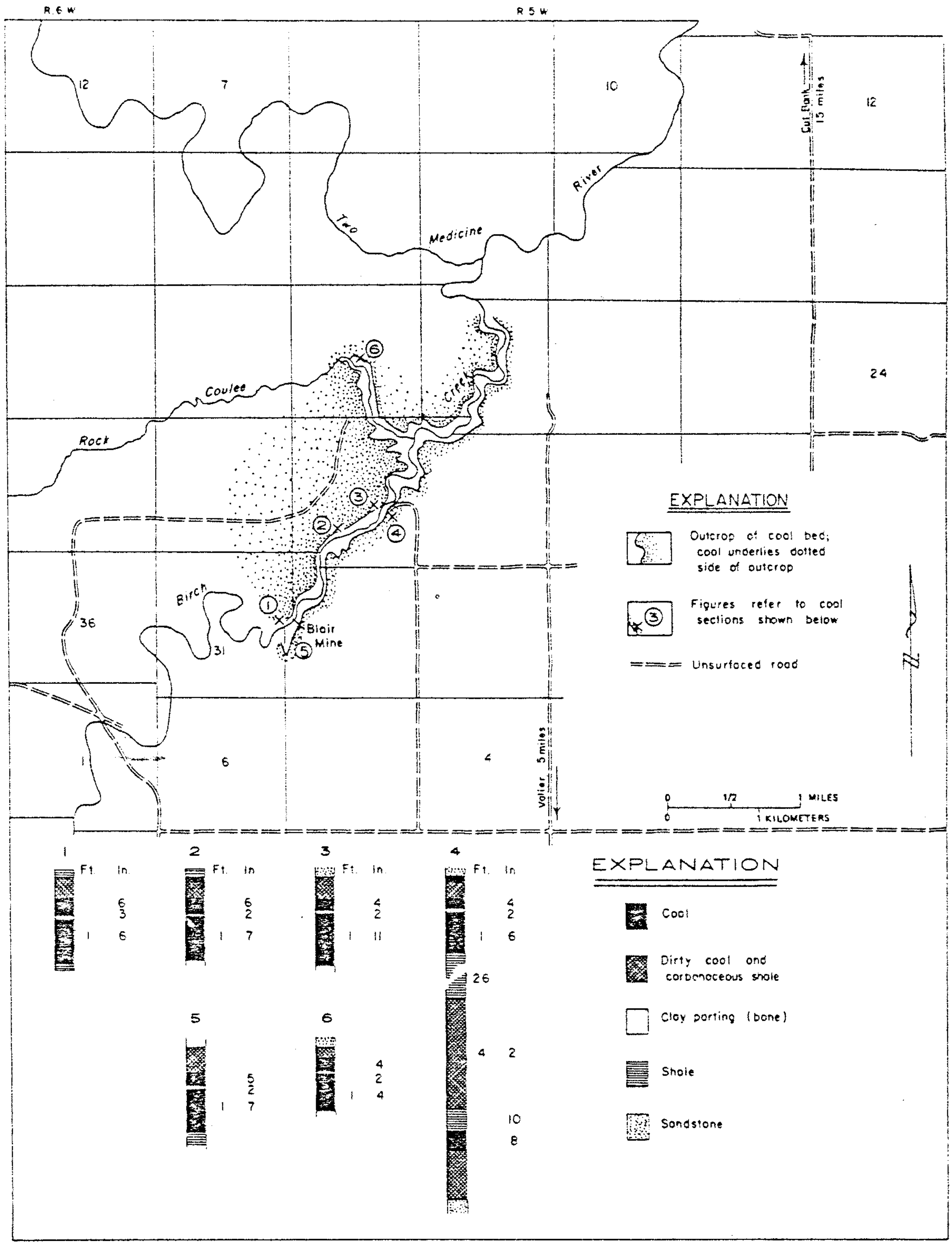

Figure 14. Map showing Valier coal field and sections through coal beds, Blackfeet Indian Reservation, Montana (adapted from Hubbard and Henkes, 1962); see index map (Figure 1) inset B for location.

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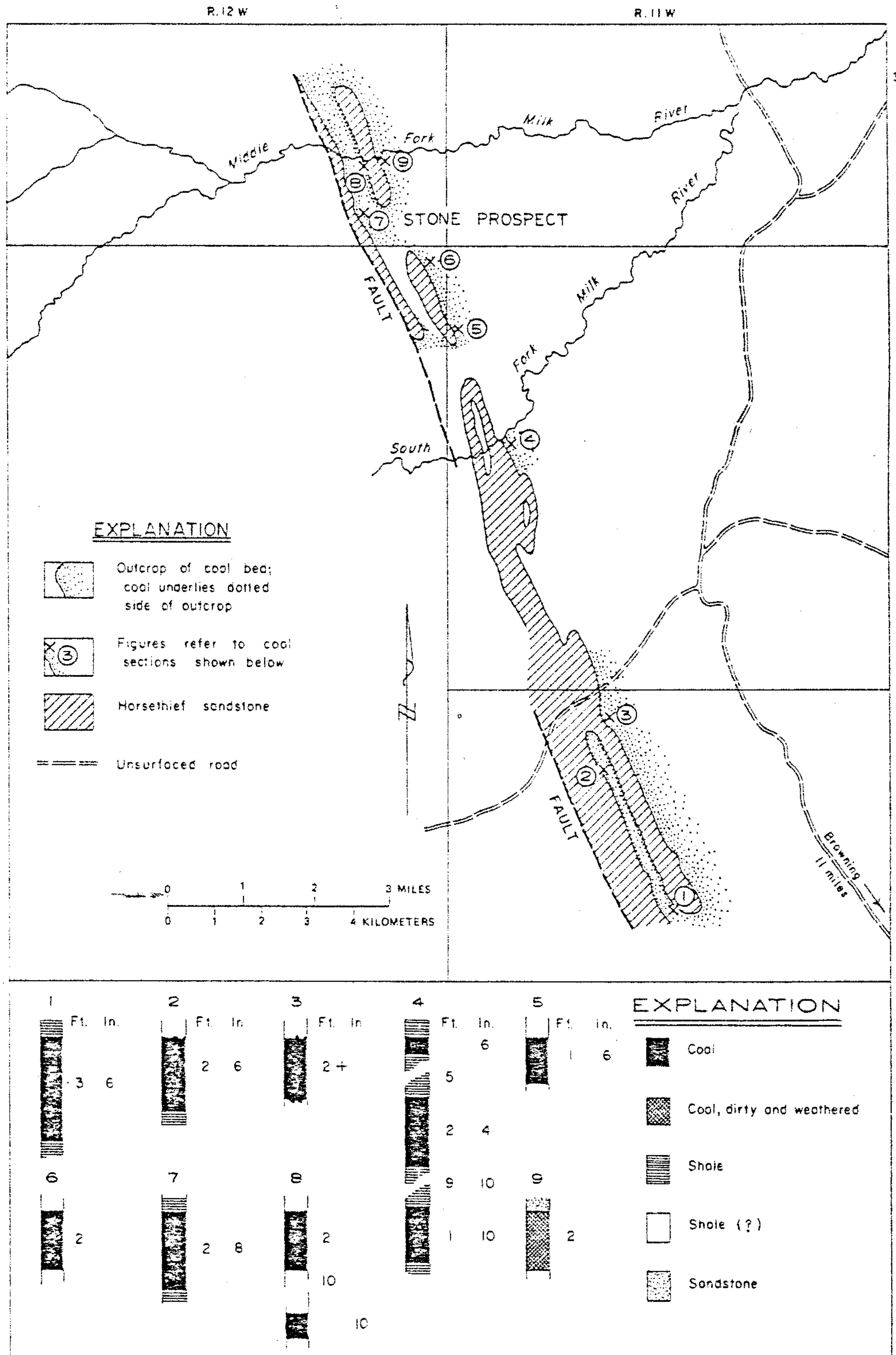

Figure 15. Map showing Blackfeet Coal Field, Blackfeet Indian Reservation, Montana (adapted from Hubbard and Henkes, 1962); see index map (Figure 1) inset A for location.

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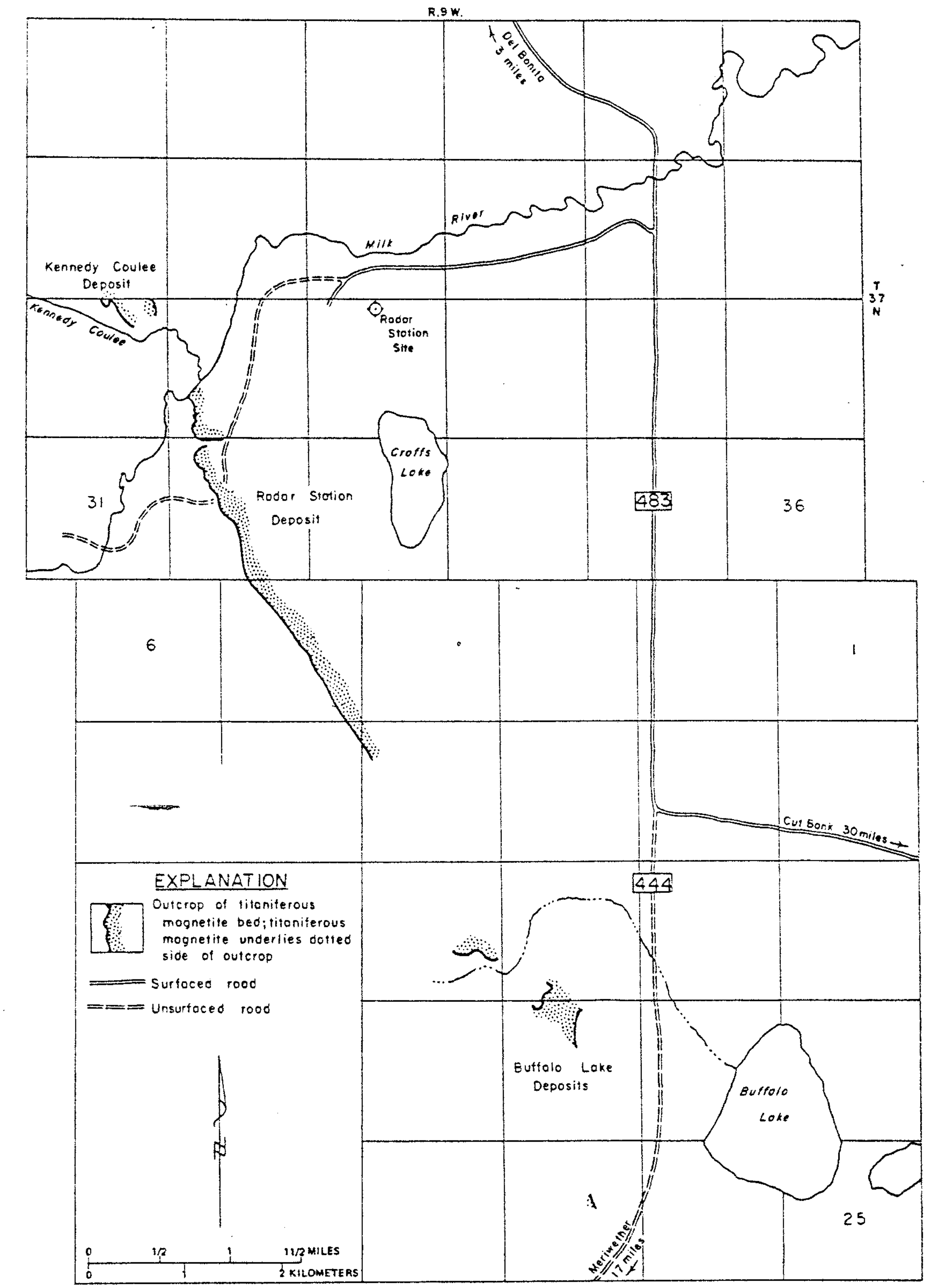

Figure 16. Map showing titaniferous magnetite deposits in the Lower Milk River district, Blackfeet Indian Reservation (adapted from Hubbard and Henkes, 1962). See index map (Figure 1) inset C for location.

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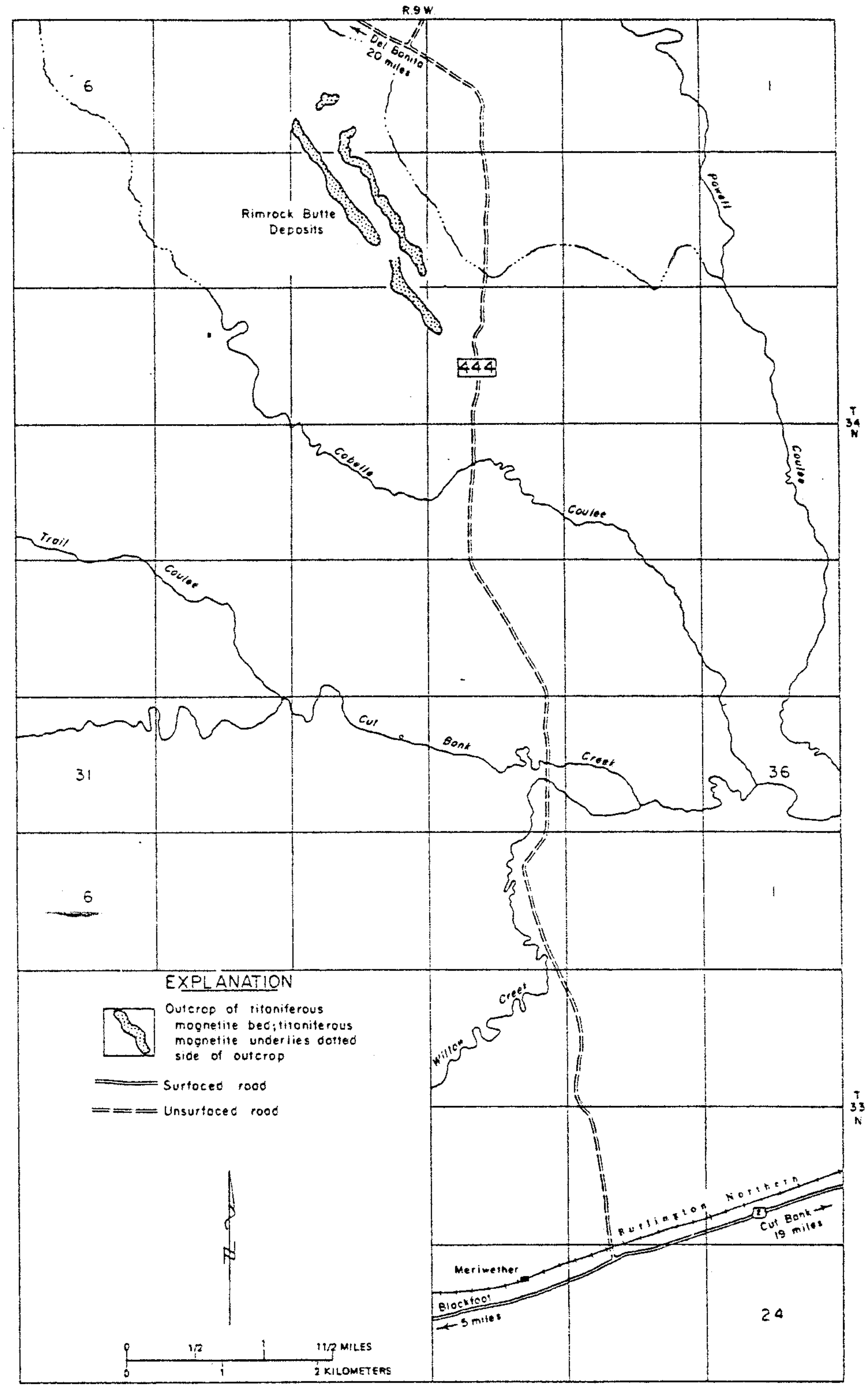

Figure 17. Map showing Rimrock Butte titaniferous magnetite deposits, Blackfeet Indian Reservation (adapted from Hubbard and Henkes, 1962). See index map (Figure 1) inset D for location.

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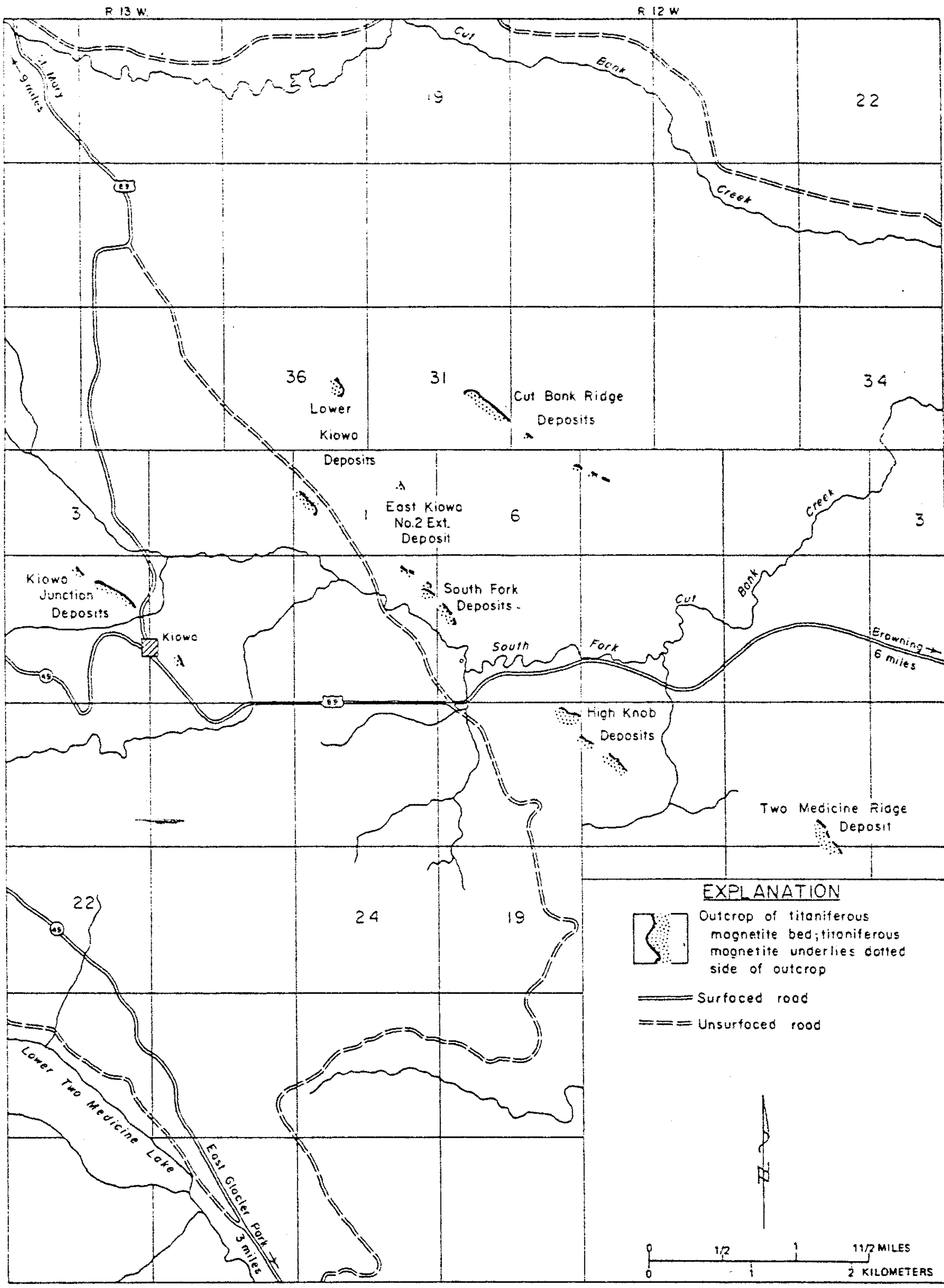

Figure 18. Map showing Kiowa Junction titaniferous magnetite deposits, Blackfeet Indian Reservation (adapted from Hubbard and Henkes, 1962). See index map (Figure 1) inset E for location.

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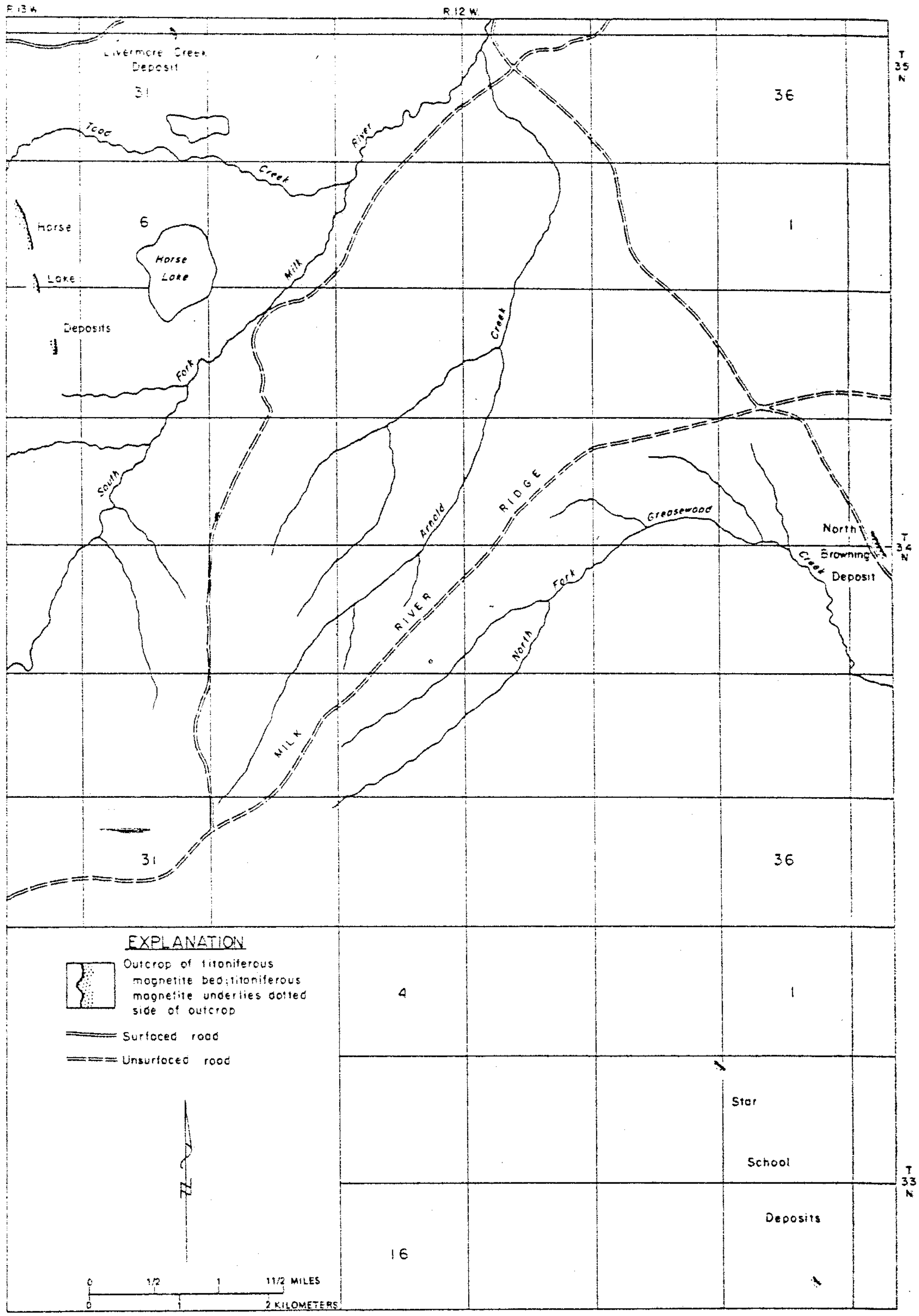

Figure 19. Map showing Milk River Ridge titaniferous magnetite deposits, Blackfeet Indian Reservation (adapted from Hubbard and Henkes, 1962). See index map (Figure 1) inset F for location.

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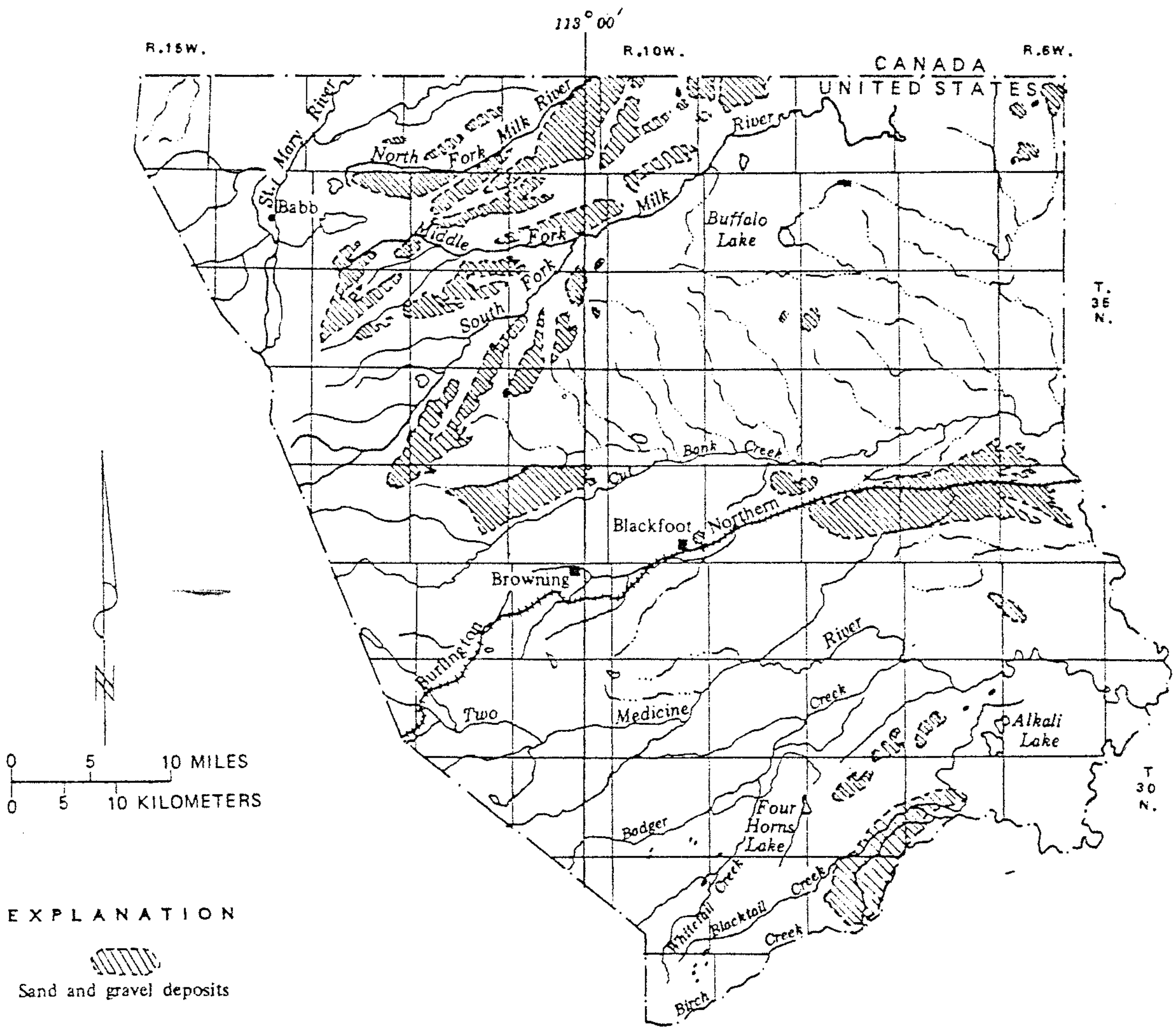

Figure 20. Map showing location of sand and gravel deposits, Blackfeet Indian Reservation (adapted from Larrabee and Shride, 1946).