Geology of the Otter Creek Quadrangle Montana

GEOLOGICAL SURVEY BULLETIN 1111-G

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By ROGER B. COLTON

CONTRIBUTIONS TO GENERAL GEOLOGY

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The engineering geology of some Tertiary and Quaternary rocks, with emphasis on lignite deposits

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GEOLOGY OF THE OTTER CREEK QUADRANGLE, MONTANA

By ROGER B. COLTON

ABSTRACT

The Otter Creek quadrangle, in northeastern Montana, is between long 105°30′ and 105°45′ W. and lat 48°30′ and 48°45′ N. The quadrangle was mapped as part of a program of the U.S. Department of the Interior for the development of the Missouri River basin.

Big Muddy Creek flows along the north and east edges of the quadrangle. Intermittent tributary streams in the quadrangle are Wolf, Otter, and Crazy Horse Creeks.

Three mesalike highlands, ranging from 2,500 to 2,600 feet in altitude, are in the western and northern parts of the area. Broad benches slope away from the highlands to the broad flood plain of Big Muddy Creek on the east side of the quadrangle; the altitude of the flood plain ranges from 1,940 to 2,000 feet.

Sedimentary Paleozoic and Mesozoic rocks, at least 8,700 feet thick, underlie the area but are not exposed. Overlying these rocks and partly exposed are about 1,200 feet of the Fort Union formation of Paleocene age. The Fort Union formation is unconformably overlain by the Flaxville formation of Miocene or Pliocene age that consists mainly of quartzitic gravel. Erosion of the Flaxville formation and redeposition of the gravel resulted in the formation of part of the Wiota gravels of Pleistocene age.

The Wiota gravels and their erratics are the only evidence of an earlier glaciation. The quadrangle was glaciated a second time during the Tazewell or Iowan(?) substages of the Wisconsin stage, and till was deposited. Outwash deposits and melt-water channels formed during the retreat of the Tazewell or Iowan(?) ice front.

During the Cary(?) substage of the Wisconsin, glacial ice advanced to within 5 miles of the north edge of the area and probably entered the southeast corner of the quadrangle. A valley train of outwash, the Plentywood formation, was deposited in the valley of Big Muddy Creek. As the ice sheet melted, the Plentywood formation was trenched to a depth of 170 feet.

In postglacial time the valley of Big Muddy Creek was filled with 150 feet of outwash and alluvium. Other deposits of Recent age include clay deposits in closed depressions in the ground moraine, colluvium, dune sands, and thin loess.

The chief structural feature of the area is a homocline dipping southeastward into the Williston structural basin. Many linear features in the area suggest the presence of small faults, fractures, or jointing in the bedrock.

Mineral resources consist of lignite, riprap, sand and gravel, till, and soil. No favorable structures for the accumulation of oil and gas were found.

Measured, indicated, and inferred reserves of several lignite beds in the Fort Union formation total 416 million short tons.

INTRODUCTION

The Otter Creek quadrangle (pl. 37 and fig. 21), in northeastern Montana, is 1½ miles south of Plentywood in Sheridan County. The southern half is in the Fort Peck Indian Reservation. The quadrangle has an area of about 200 square miles, and extends from lat 48°30′ to 48°45′ N. and from long 105°30′ to 105°45′ W.

The four 7½-minute quadrangles constituting the Otter Creek 15-minute quadrangle are the Shippe Canyon, Crazy Horse Creek, Flagstaff Hill, and Alkali Coulee quadrangles (fig. 22). Topographic maps were published for the Alkali Coulee and Shippe Canyon quadrangles in 1949 and 1950, respectively. The Flagstaff Hill quadrangle is covered by General Land Office township plat topographic maps (scale 1:31,680 and contour interval 20 feet). No published topographic map is available for the Crazy Horse Creek quadrangle.

The village of Medicine Lake (population 454, 1950 census) is in the southeast corner of the quadrangle (fig. 22). The villages of Reserve (population 200) and Antelope (population 142) are just east of the quadrangle. The town of Plentywood (population 1,862) is 1½ miles north of the quadrangle.

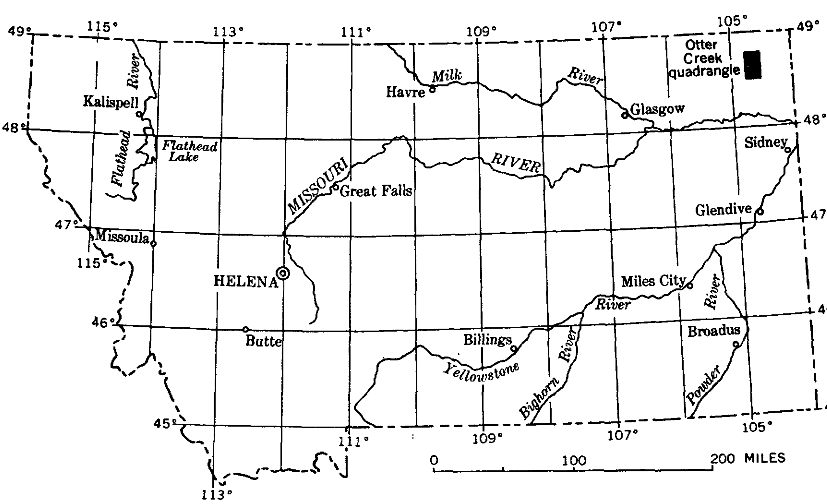

FIGURE 21.—Index map of Montana, showing location of the Otter Creek quadrangle.

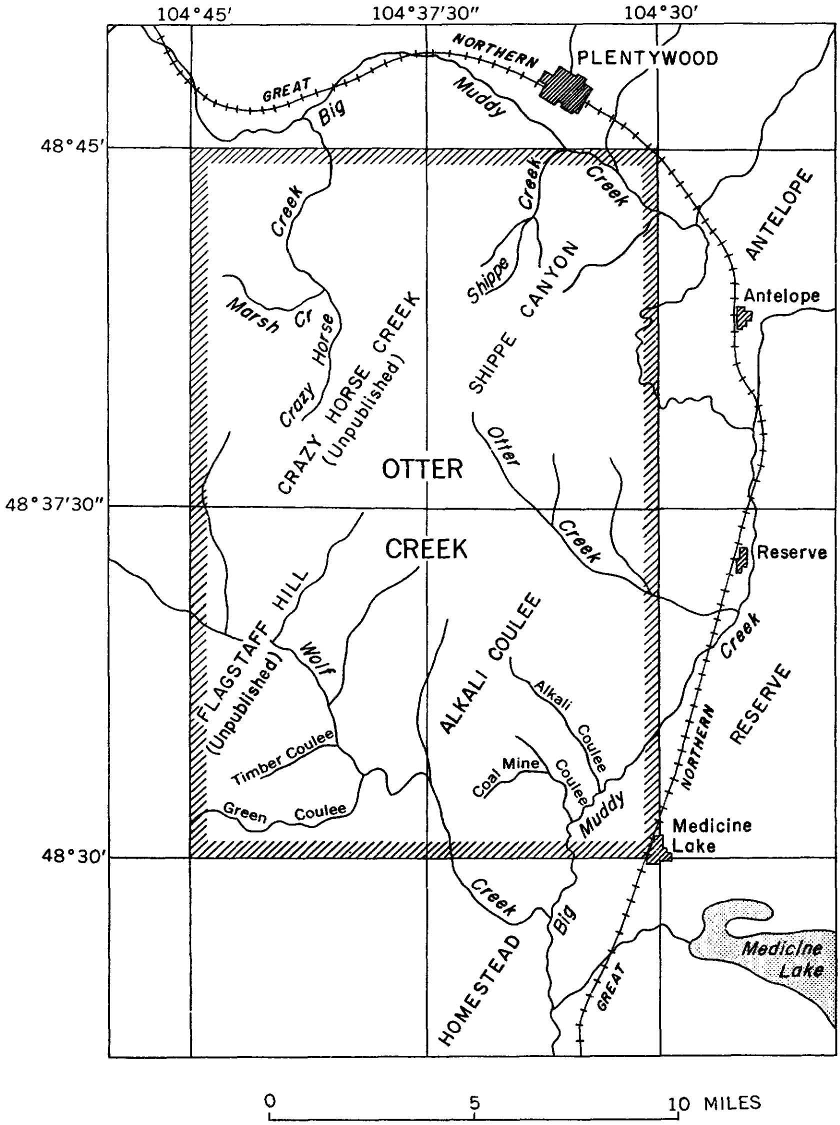

FIGURE 22.—Map showing the Otter Creek quadrangle, the four 7½-minute quadrangles within it, drainage, and nearby towns.

Cattle raising and wheat farming are the principal industries. A well-developed network of unsurfaced roads serves most of the region; the Great Northern Railroad crosses the southeast corner of the quadrangle. State Highway 16 is just east of and roughly parallel to the east edge of the quadrangle.

TOPOGRAPHY

The Otter Creek quadrangle is in the Missouri Plateau section of the glaciated northern Great Plains physiographic province and is mostly characterized by rolling prairie and broad gentle slopes. A few small badland areas are in the quadrangle. The highest point in the quadrangle is 2,650 feet and the lowest is 1,940 feet—a maximum relief of 710 feet.

The quadrangle is divisible into three physiographic areas characterized by surfaces having different average altitudes. The highest and oldest surface, at an altitude of about 2,600 feet in the north-central and northwestern parts of the quadrangle, consists of three small gravel remnants of a once-extensive surface known as the Flaxville plain. Somewhat younger broad benches slope away from these remnants, at altitudes ranging from 2,400 to 2,200 feet, toward Wolf Creek in the southwestern part of the area, and toward Big Muddy Creek in the eastern and northern parts. Wolf Creek is only slightly incised into these benches, but Big Muddy Creek is incised as much as 300 feet so that bluffs form its valley walls along the east and north sides of the quadrangle. The flood plain of Big Muddy Creek, the lowest surface in the area, occupies a glacial valley 1 to 2 miles wide. Big Muddy Creek is an underfit stream that occupies a valley made by a much larger glacial stream. The altitude of the flood plain ranges from 1,940 to 2,000 feet. Flagstaff Hill in the southwest corner of the quadrangle, reaches an altitude of 2,500 feet.

DRAINAGE

The principal streams in the quadrangle are Big Muddy, Crazy Horse, Wolf, and Otter Creeks (fig. 22). Big Muddy Creek, the only perennial stream, enters the northeast corner of the quadrangle and follows a sinuous course along the eastern border, leaving the quadrangle a few miles west of the southeast corner. Crazy Horse Creek, slightly more than 6 miles long, heads in the northwest-central part of the quadrangle and flows northward into Big Muddy Creek. A low divide separates the headwaters of Crazy Horse Creek from a southward-flowing unnamed creek. This unnamed creek is 5 miles long and flows generally southward and westward into Wolf Creek. Wolf Creek, in the southwest quarter of the quadrangle, and Otter Creek, which heads in the central part of the area, flow southeastward.

FIELD METHODS AND MAPPING

The area was mapped during the summers of 1948 and 1949. The geology was plotted on aerial photographs in the field and transferred by vertical sketchmaster to a planimetric base map which was constructed from topographic maps and township plats.

ACKNOWLEDGMENTS

The author was helped by several people not directly connected with the investigation. Christian Bafus and Gordon Holje of the U.S. Soil Conservation Service contributed pertinent information on soils. Mechanical analyses of samples from several formations in the quadrangle were made under the supervision of Roy H. Gagle, at the Materials Testing Laboratory, Montana State Highway Commission, Helena. T. C. Nichols, Jr., and Jean M. Roach of the U.S. Geological Survey laboratory at Denver, analyzed 21 samples.

PREVIOUS WORK

In 1862, Meek and Hayden proposed the name Fort Union or Great Lignite group for the strata exposed 40 miles south of the quadrangle around Fort Union They did not actually visit the Otter Creek quadrangle but named the sole bedrock unit that crops out in it.

Calhoun (1906, p. 7–62) probably was the first to describe the glacial geology of this part of Montana, but his study of the Montana lobe of the Keewatin ice sheet ended just west of the Otter Creek quadrangle. A geologic reconnaissance of the Fort Peck Indian Reservation coal field was made by Smith (1909, p. 36–55) in 1908. This area included the southern half of the quadrangle. Beekly (1912, p. 319–358) made a reconnaissance of an area to the east of the quadrangle in 1910. In 1911, Bauer (1914b, p. 3–25) examined the lignite deposits along the north border of the Fort Peck Indian Reservation. In 1912, Bauer (1914a, p. 369–372) worked in the area along Big Muddy Creek near Plentywood. Part of the Scobey lignite field, which Collier (1924, p. 157–230) and others mapped in 1915 and 1916, extends into the north end of the Otter Creek quadrangle. Collier (1919, p. 17–39) wrote a general description of the geology of northeastern Montana. The area discussed included the Otter Creek quadrangle. In connection with the coal mapping, Collier and Thom (1918, p. 179–184) mapped the Flaxville formation which occurs in the quadrangle.

Alden (1932) mapped the glacial geology and noted nearly all the major glacial features and problems in northeastern Montana. He began his reconnaissance work in northwestern North Dakota on the Coteau du Missouri and worked westward by making automobile traverses 8 to 10 miles apart across the area.

Geologic mapping in the area was resumed in 1946 to provide data for U.S. Bureau of Reclamation projects planned in the region. In 1947, Garland Gott mapped the adjoining Homestead quadrangle, and Irving J. Witkind mapped the adjoining Reserve quadrangle (fig. 22). Information on these and other quadrangles has been combined into a report by Witkind (1959) on the geology of the Smoke Creek–Medicine Lake–Grenoar area, Montana–North Dakota.

Arthur D. Howard (1961) made a reconnaissance study of the glacial geology of northeast Montana and northwest North Dakota during the summers of 1946–51.

A preliminary report on the area by the author (Colton, 1951) was released in 1951, and the southern part of the quadrangle was included in a preliminary map of the Fort Peck Indian Reservation by the author (Colton, 1953). Virtually the same map with structure contours was published in 1956 (Colton and Bateman, 1956).

GEOLOGY

OLDER FORMATIONS (NOT EXPOSED)

At least 8,700 feet of sedimentary rocks underlies the quadrangle. Information concerning the subsurface stratigraphy has been gained through the drilling of several wildcat or test wells by oil companies in or near the quadrangle. In 1953, the Zach Brooks Co. drilled the No. 1 Larson in the southeastern part of the quadrangle in the center of the NW¼SW¼ sec. 2, T. 32 N., R. 55 E. The Texas Co. drilled a well just north of the quadrangle in sec. 27, T. 35 N., R. 54 E. in 1956 and also a well 4 miles east of the quadrangle in 1957 in the NW¼NE¼ sec. 5, T. 33 N., R. 56 E. The Williston Pioneer Co. drilled the No. 1 Pohle, 3 miles northeast of the quadrangle in the center of the NW¼SE¼ sec. 13, T. 35 N., R. 55 E.

Table 1, showing the thickness of the formations penetrated by these wells, has been prepared from electric logs, petroleum information cards, and a report of the American Stratigraphic Co. The table is based mainly on the Zach Brooks Co. No. 1 Larson electric log and petroleum information card and the American Stratigraphic Co. card No. B–247.

TABLE 1.—*Surface and subsurface strata in the Otter Creek quadrangle, based chiefly on data from Zach Brooks No. 1 Larson well, and American Stratigraphic Co. card No. B–247*

[Total depth, 8,760 feet]

System	Group	Stratigraphic unit or formation			Thickness (feet)
Tertiary		Flaxville formation			30–80
		Unconformity			
		Fort Union formation			1, 400±
Cretaceous		Hell Creek formation			220–280
		Unconformity			
	Montana group	Fox Hills formation			85–120
		Pierre shale	Bearpaw shale equivalent		1, 112
			Judith River formation equivalent		83
			Claggett shale member equivalent		233
			Eagle sandstone equivalent		705
			Telegraph Creek formation equivalent		
		Colorado shale	Niobrara shale equivalent		152
			Carlile shale equivalent		277
			Greenhorn limestone equivalent		159
			Graneros shale equivalents	Belle Fourche shale equivalent	268
				Mowry shale equivalent	
				Newcastle sandstone equivalent	88
			Skull Creek shale equivalent and "basal Colorado sand" equivalent		128
			Dakota sandstone equivalent		63–78
			Fall River sandstone equivalent and "first Cat Creek sand" equivalent		72–205

TABLE 1.—*Surface and subsurface strata in the Otter Creek quadrangle, based chiefly on data from Zach Brooks No. 1 Larson well, and American Stratigraphic Co. card No. B–247*—Continued

[Total depth, 8,760 feet]

System		Group	Stratigraphic unit or formation	Thickness (feet)
Cretaceous—Continued			Kootenai formation — Lakota formation equivalents	203
			Unconformity	
Jurassic		Ellis group	Morrison formation	110
			Swift formation	620
			Disconformity	
			Rierdon formation	170
			Piper formation	219
			Unconformity	
Triassic			Nesson formation of Nordquist (1955)	174
			Spearfish formation	300
			Unconformity	
Carboniferous	Pennsylvanian	Big Snowy group	Amsden(?) formation	69
			Unconformity	
	Mississippian		Otter formation	147
			Kibbey sandstone	131
		Madison group	Charles formation	771
			Mission Canyon limestone	553
			Lodgepole limestone	592–593
			Bakken formation	24–33
			Unconformity	
Devonian			Three Forks formation	92–124
			Nisku formation of Hadley and others (1952)	87

FORT UNION FORMATION

The Fort Union formation of Paleocene age underlies all the Otter Creek quadrangle. It consists of a thick yellowish-brown sequence of continental deposits of interbedded sand, sandstone, siltstone, silt, clay, clayey shale, and lignite. About 600 feet of these strata are exposed in the quadrangle. The formation was named by Meek and Hayden (1862) from exposures along the north side of the Missouri River 35 miles south of the report area.

The author has not subdivided the formation into members because facies changes made it impossible to recognize the subdivisions north of the Missouri River that have been used to the south and southwest such as the Tullock member, the Lebo shale member, the Tongue River member, and the Sentinel Butte member.

The formation is well exposed in the northeast, the northwest, and the southwest corners of the quadrangle. It is well exposed in a few places in the west-central part of the area. The sediments comprising the formation are generally soft, erode easily, and thus crop out only in areas of active erosion. Erosion of the strata tends to produce a rolling landscape but there are some definite benches formed by more resistant pseudoscoria or sandstone beds. Gentle slopes are covered with grass.

Weathered outcrops are lighter colored; unweathered yellowish-gray shale (5*Y* 6/2) weathers light yellowish gray (5*Y* 7/2) and unweathered dark-grayish orange sand (10*YR* 6/4) weathers pale yellowish brown (10 *YR* 7/2).

The formation has a maximum thickness of about 1,265 feet in the quadrangle; the maximum exposed thickness is about 600 feet. The thickness of the formation varies considerably throughout the area because the upper part of the formation has been removed by erosion, both before and after deposition of the Flaxville formation. As a result of the regional southeastward dip, the formation is thickest in the eastern part of the quadrangle. The log of a test well (Zach Brooks No. 1 Larson) drilled for oil in the southeastern part of the area in the center of the NW¼SW¼ sec. 2, T. 32 N., R. 55 E. indicates that the top of the Bearpaw shale of Cretaceous age is at a depth of 1,015 feet. Elsewhere in the Fort Peck Indian Reservation the author found the maximum total thickness of the Fox Hills and the overlying Hell Creek formations to be 400 feet. Both of these formations are Cretaceous in age, and both overlie the Bearpaw shale and underlie the Fort Union formation. This indicates that 615 feet of Fort Union formation underlies the southeastern part of the quadrangle. About 650 feet more of the formation underlies the higher parts of the area as determined from the altitude and the structure.

Thus the formation has a maximum thickness of 1,265 feet in this area. Collier and Knechtel (1939, pl. 3) report that the formation is also 1,265 feet thick about 40 miles south of the area.

The Fort Union formation is conformably underlain by the Hell Creek formation and unconformably overlain by the Flaxville formation of Miocene or Pliocene age and deposits of Quaternary age.

Sandstone and sand beds constitute more than half the total thickness of the strata. Clay beds account for about one-third, and carbonaceous shale, shale, lignite, siltstone, and limestone make up the rest of the section. A statistical analysis of the thickness and lithology of beds is presented in table 2 from two sections measured in the area.

The two partial sections used in table 2 are 496.2 and 210.1 feet thick, a total of 706.3 feet; but only 500 feet of the middle of the Fort Union formation is represented by these measured sections. Therefore, the relative percentages of the various lithologies shown in the last column of the table represent only the middle third of the formation and do not represent the rest of the Fort Union formation.

TABLE 2.—*Lithology and thickness of beds based on two partial sections measured in the southwest and northwest corners of the quadrangle*

Lithology	Number of beds measured	Range in thickness (feet)		Average thickness of beds (feet)	Percentage relative to total thickness measured
		Minimum	Maximum		
Sandstone and sand	25	0.2	45	14	52
Siltstone	1	1	1	1	Trace
Clay	30	.4	38	7.9	35
Shale	2	1.7	5.5	3.6	1
Carbonaceous shale	26	.1	7.5	1.7	6
Lignite	22	.1	8.3	1.6	5
Limestone	2	3	3	3	1
Total					100

The following section was measured at the north edge of the quadrangle. Color is expressed in terms of the Rock Color Chart of the National Research Council (Goddard and others, 1948).

Section of part of Fort Union formation below and north of the Plentywood triangulation station (altitude 2,652 feet) in NE¼ sec. 11. T. 34 N., R. 53 E.

		Color	Feet
Pleistocene:			
	Till, dark-brown		10. 0
Late Miocene or Pliocene:			
	Flaxville formation		15. 0
Covered interval			22. 0
Paleocene:			
Fort Union formation:			
	Limestone, light-olive-gray, concretionary, weathering to a buff color or light gray	5*Y* 6/1	3. 0
	Clay, light-brown to pale-yellow-brown, carbonaceous	10*YR* 6/2	1. 5
	Lignite, gray-black	*N* 2	. 1
	Shale, fissile	*N* 6	. 4
	Shale, olive-brown	10*YR* 6/2	1. 3
	Sandstone, buff, silty, contains small concretions	10*YR* 8/4	6. 0
	Lignite, gray-black	*N* 2	. 1
	Clay, light-pinkish-gray to brown, carbonaceous	5*YR* 8/1	1. 2
	Sandstone, yellow to brown, silty	10*YR* 8/4	7. 0
	Clay, gray	*N* 6	1. 4
	Clay, light-gray, silty, limonitic	10*YR* 7/2	4. 0
	Sand, gray; contains limonitic concretions	10*YR* 8/2	5. 4
	Clay, lignitic and carbonaceous	5*YR* 4/1	. 3
	Sand, light brownish-gray	5*YR* 6/1	1. 5
	Shale, gray, fissile, silty; contains limonitic concretions	*N* 6 or 10*YR* 6/6	11. 0
	Lignite, gray-black, poor quality	*N* 3 to *N* 2	. 4
	Clay, light-gray-brown, carbonaceous	5 *YR* 5/2	2. 8
	Sand, light-olive-gray, well-laminated; weathers to buff	5*YR* 6/1	9. 5
	Clay, light-gray, limonitic	10*YR* 6/2	4. 0
	Silt, light-brown, clayey	10*YR* 7/4	11. 0
	Clay, brown, carbonaceous	5*YR* 4/1	. 6
	Lignite, gray to black	*N* 2	. 7
	Clay, brown, carbonaceous	5*YR* 4/1	. 5
	Clay, light-gray; weathers buff	*N* 6	6. 5
	Clay, brown, lignitic, carbonaceous	5*YR* 4/1 to *N* 2	5. 0
	Sand, light-olive-gray; weathers to buff, fine grained, crossbedded	5*Y* 6/1 or 10*YR* 8/4	34. 5
Local bed *R*	Clay, brown, carbonaceous	*N* 3	. 6
	Lignite, black	*N* 2	. 1
	Clay, brown, carbonaceous	5*YR* 4/1	. 3
	Lignite, black, hard, woody	*N* 1	1. 8
	Clay, brown, carbonaceous	5*YR* 4/1	. 7
	Clay, gray, silty	*N* 6	4. 0
	Clay, light-gray, limonitic	*N* 5	5. 5

Section of part of Fort Union formation below and north of the Plentywood triangulation station (altitude 2,652 feet) in NE¼ sec. 11. T. 34 N., R. 53 E.—Con.

		Color	Feet
Paleocene—Continued			
Fort Union formation—Continued			
	Lignite, gray-black, containing one small clay parting near the top	*N* 2	1.5
	Clay, brown, carbonaceous	5*YR* 4/1	.3
	Clay, light-gray; changes downward into crossbedded sand	10*YR* 8/2	38.0
Local bed *P*	Lignite, bony	*N* 2	.8
Local bed *P*	Lignite, hard woody	*N* 1	3.0
Local bed *P*	Clay, brown, carbonaceous	5*YR* 4/1	.9
Local bed *P*	Clay, lignitic	*N* 3	.7
Local bed *P*	Clay, brown, carbonaceous	5*YR* 4/1	1.5
	Silt, yellow to brown, clayey	10*YR* 6/2	9.0
	Shale, brown, carbonaceous	5*YR* 4/1	2.3
	Shale, light-gray, fissile, thin-bedded	*N* 6	5.5
	Silt, light-gray, hard, clayey	*N* 3	11.0
	Clay, light-gray, silty	*N* 6	5.5
	Sand, light-olive-gray	5*Y* 6/1	45.0
	Clay, brown, carbonaceous	5*YR* 4/1	.4
	Lignite, slaked	*N* 2	.3
	Clay, light-yellow to gray; contains limonitic concretions, weathers to a light-buff color	*N* 6	13.0
	Clay, brown, carbonaceous	5*YR* 2/2	3.9
	Sand, gray to yellow	10*YR* 7/4	3.0
	Clay, light-olive brown, gray	5*Y* 6/1	2.0
Local bed *Q* (upper part)	Lignite, gray-black, hard, woody, with about eight clay partings	*N* 2	3.3
Local bed *Q* (upper part)	Clay, brown, hard, carbonaceous	5*YR* 2/2	2.2
	Sand and clay, olive-gray to yellow-brown	5*Y* 5/1 or 10*YR* 5/4	13.0
Local bed *Q* (lower part)	Lignite, black, hard, woody	*N* 1	1.0
Local bed *Q* (lower part)	Clay and lignite, brown, carbonaceous	*N* 2	.7
Local bed *Q* (lower part)	Lignite, black, hard, woody	*N* 1	1.0
	Clay, light-gray, very silty; containing crossbedded limonitic concretions	10*YR* 8/4	31.5
	Clay (Richardson lignite seam) gray-brown carbonaceous, hard, lignitic	5*YR* 3/2	3.0
	Sand, gray, hard, yellowish-orange, buff, silty, containing some clay	10*YR* 7/4	22.0
	Clay, gray, fissile	----------	2.5
	Lignite, gray-black	*N* 2	.3
	Shale, dusky-red-brown, gray, carbonaceous	10*YR* 3/2	2.0
	Sand, gray-orange to buff, silty	10*YR* 7/4	32.0
	Lignite, gray to black	*N* 2	.5
	Shale, dark-gray, carbonaceous	*N* 3	1.0
	Shale, silty, carbonaceous	*N* 6	3.0

Section of part of Fort Union formation below and north of the Plentywood triangulation station (altitude 2,652 feet) in NE¼ sec. 11. T. 34 N., R. 53 E.—Con.

Paleocene—Continued
Fort Union formation—Continued

		Color	Feet
	Clay, gray, fissile, containing limonitic concretions	*N* 7	9.0
	Sand, pale-yellow to orange-buff	10*YR* 7/2	6.9
	Sand, hard, gray, crossbedded, containing limonite	*N* 7	7.0
	Pale yellow brown carbonaceous zone	10*YR* 6/2	1.5
	Clay, yellowish-gray, hard, silty, gray	5*Y* 8/1	2.5
	Lignite, grayish-black	*N* 2	.1
White clay bed	Clay (top of Bauer's clay seam), pale-grayish-brown, hard, silty	5*YR* 4/2	4.1
White clay bed	Clay (Bauer's clay seam), hard, very light gray	*N* 8	2.5
White clay bed	Sand, buff, silty, containing limonite concretions	*N* 7	4.0
	Clay, hard, buff, very silty	*N* 7	7.0
	Limonitic concretionary layer, dark yellow orange	10*YR* 6/6	.2
	Silt, grayish-orange to buff	10*YR* 5/4	1.0
	Clay, light yellowish gray, hard, silty	5*Y* 8/1	3.0
	Dark-gray carbonaceous zone	*N* 4	4.8
	Clay, light-grayish orange, silty, hard, limonitic	10*YR* 7/4	3.0
	Clay, light-gray, hard, silty	*N* 7	1.0
	Shale, brown, carbonaceous	*N* 3	.3
	Clay, gray, hard, silty	*N* 7	.5
	Clay, light-grayish brown, very hard, silty	*N* 7	15.0
	Total		519.7

Correlation of strata within the quadrangle (fig. 23) is possible only through the tracing of lignite beds and a few other distinctive strata. One traceable stratum is the tough white clay bed mentioned by Bauer (1914a, p. 369–372), which has a maximum thickness of 22 feet in sec. 1, T. 34 N., R. 53 E. It is exposed along the north edge of the quadrangle, where it has a southeast dip of 16 to 18 feet per mile. The author traced it into Canada where it can be correlated with the Willowbunch member of the Ravenscrag formation (Fraser and others, 1935, map 267A). The bed is not exposed along Wolf Creek, hence, either there is a facies change from north to south, or the bed was not deposited in that area. It is thinner to the northwest as indicated by exposures along the north side of Big Muddy Creek west of Plentywood. Because of the regional dip, the bed dips under the alluvium south of Plentywood.

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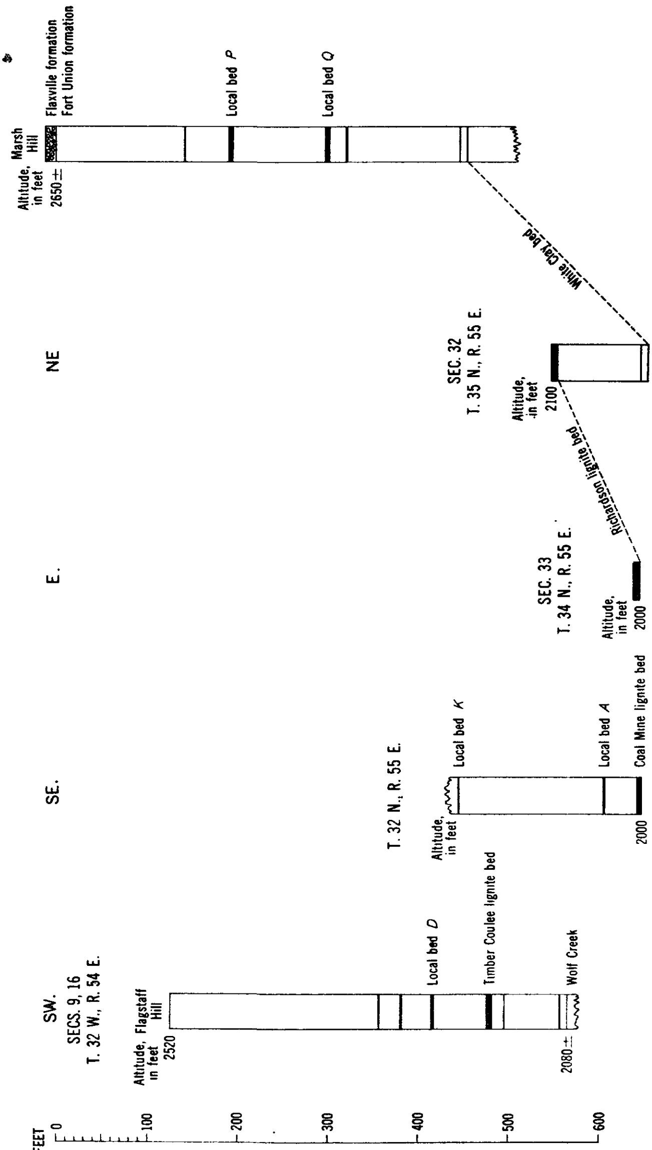

FIGURE 23.—Diagram of coal beds in Otter Creek quadrangle. Position of local beds *M*, *T*, *U*, and *V* not shown.

A distinctive gray bed, which is variable between two end members, a bentonitic clay and an olive-gray sand, is apparently the only bed recognizable throughout the quadrangle. The thickness of this bed ranges from 10 to 40 feet. It can be traced eastward along the north edge of the quadrangle and southward along the east edge in the west valley wall of Big Muddy Creek to a point a few miles north of Reserve where it is covered by gravel deposits. This bed also crops out in sec. 10, T. 32 N., R. 54 E.

Concretions are of five types: sandstone or sand cemented by calcium carbonate, siltstone, limonite, pyrite, and limestone.

Sandstone concretions are the main type found in the formation but limonite and pyrite concretions are fairly common. The weathered pyrite concretions are dark yellowish brown (10*YR* 4/2). The unweathered interior of the pyrite concretions is greenish gray (5*GY* 5/1). The limonite concretions are generally disk shaped and their thickness ranges from 3 to 7 inches. The limonite concretions are moderate yellowish brown (10*YR* 5/4) but they weather to blackish red (5*R* 2/2). The weathered sand concretions and sandstone concretionary beds range from yellowish gray (5*Y* 7/2) to medium olive gray (5*Y* 5/1) in color.

Large log-shaped sandstone concretions were found in several places in the quadrangle. In the SW¼NW¼ sec. 24, T. 33 N., R. 54 E., the long axes of the concretions are oriented N. 50° W. The concretions in that area are 15 feet long, 8 feet wide, and 3 feet high. At the corner common to secs. 13, 14, 23, and 24, T. 33 N., R. 54 E., the long axes of the concretions are oriented N. 85° W. Some of these concretions are 77 feet long, 5 feet wide, and 4 feet high. Many large cross-bedded sandstone concretions are in sec. 8, T. 33 N., R. 54 E. They are as much as 100 feet long, 25 feet wide, and 10 feet high. Their long axes trend S. 80° E.

Some of the limy concretions show cone-in-cone structure. The color of the limestone concretions is dark gray but weathers buff. The organic content in the carbonaceous shale and lignite beds is high. Otherwise, the formation is relatively free of organic matter.

The beds in the formation are well sorted and within any one bed there is little variation in grain size. Lateral facies changes are common, however, and gradual changes laterally are the rule. Contacts between beds range from sharp to gradational but most exposures show gradational contacts between beds. However, where channeling or short periods of nondeposition have occurred, there are sharp contacts.

The Fort Union formation was deposited by eastward-flowing streams on a broad swampy flood plain which slowly subsided until more than 1,200 feet of the formation accumulated in this area.

Locally, beds overlying lignite have been baked to a red rock (known as pseudoscoria or clinker) by burning of the underlying lignite beds. Such outcrops are in the southern part of the quadrangle along Wolf Creek near Timber Coulee and in the northeastern part of the area. The fire that burned the coal has been ascribed to lightning, prairie fires, man, or spontaneous combustion. Locally the heat was great enough to fuse the overlying strata and form a hard dark-colored ropy rock resembling pahoehoe lava. It is not known when most of the clinker was formed, but in 1911, E. K. Soper (field notes) reported that an outcrop of coal in the SW¼NE¼ sec. 17, T. 33 N., R. 53 E. was burning. He stated that all the outcrops of clinker examined in that township showed signs of recent burning.

Vertebrate fossils are very rare in the Fort Union formation. Parts of a skeleton and several teeth found in sec. 10, T. 32 N., R. 54 E. were identified by Louis Gazin of the U.S. National Museum as remains of the genera *Claenodon* and *Tricentes* (primitive carnivores) of middle Paleocene age Many fossil leaves and plants found in the formation were identified by Roland W. Brown of the U.S. National Museum as Paleocene in age.

The physical characteristics of the formation which are pertinent to engineering geology vary as the lithology, which ranges from fine plastic clay to sandstone.

Most of the concretionary masses of sandstone and limestone can be moved by power equipment, but some calcareous sand concretions may require blasting. Clays of high plasticity are difficult to handle when wet as they tend to stick to the equipment.

The fine-grained sands and silty sands compact fairly well under controlled conditions, but silts and clays compact less well and require moisture control to achieve maximum densities. Sheepsfoot rollers will probably be necessary to compact fills made of material from the Fort Union formation.

Nearly all the beds except sandstone have low shearing strength, and as a result, slope stability is poor particularly when the beds are saturated. Stability of slope is affected by ground-water conditions and seeps which commonly occur along the tops of clayey beds. Slopes are characterized by many small slips; a few large landslides have occurred outside the quadrangle. Small landslides have occurred in secs. 11, 13, 14, T. 32 N., R. 54 E. along cutbanks of Wolf Creek and in the SW¼NE¼ sec. 24, T. 32 N, R. 54 E. Landslides are more common in beds of clay than in beds of sand. Few near-vertical slopes are stable because vertical joints are close enough together that failure can be expected in most cuts.

Some units of the formation have been used for highway fills, but in general they are a fair-to-poor subbase. However, some of the more clayey sands can be used to make a fairly stable fill. Other sands are too fine and uniform to make a strong fill although some of them could be used where necessary. Nearly all of the sand is too fine and too uniform in grain size to be used as concrete aggregate. Clayey beds are a source of nearly impervious fill for dams and lining for irrigation ditches. Lignite should not be used in fill as it slakes and ignites spontaneously.

Some beds of concretionary sandstone are a limited source of riprap, but the quantity is small in any one area. Some of the clay beds in the formation may be usable as sources of clay for bricks. Clinker has been used as road metal where gravel is not easily available but not in the Otter Creek area.

The ease of excavation depends on the lithology. All beds except local ledges of concretionary sandstone and limestone can be excavated with hand tools and power equipment. Most materials are sufficiently compact so that excessive settlement under foundation load need not be anticipated.

Four samples of the Fort Union formation were collected in the SE¼SE¼ sec. 16, T. 34 N., R. 55 E. from a bentonitic clay bed, a hard clay bed, a friable siltstone, and a friable sandstone. About 68 percent of the bentonitic clay was clay sized and the remainder was all silt. The Atterberg limits on this sample were: liquid limit, 170; plastic limit, 41; plastic index, 129; specific gravity, 2.59.

About 54 percent of the hard-clay bed was of clay-sized material and the remainder was silt. The Atterberg limits of the hard-clay sample were: liquid limit, 39; plastic limit, 27; plastic index, 12; specific gravity, 2.75. The coefficient of sorting (Trask, 1932, p. 67) was 2.06.

About 16 percent of the sample of siltstone was clay-sized material, 76 percent was silt, and 8 percent was sand-sized material. The Atterberg limits of the siltstone sample were: liquid limit, n.d. (not determined); plastic limit, 27; plastic index, n.d.; specific gravity, 2.73.

The sample of sandstone was composed of 18 percent clay, 14 percent silt, and 68 percent sand. The Atterberg limits were: liquid limit, 38; plastic limit, 25; plastic index, 13; specific gravity, 2.54. The coefficient of sorting (Trask, 1932, p. 67) was 2.31.

One other sample was collected in SE¼SE¼ sec. 19, T. 33 N., R. 54 E. and was composed of 4 percent clay sized material, 16 percent silt, and 80 percent sand. It had a specific gravity of 2.68. The coefficient of sorting (Trask, 1932, p. 67) was 1.35.

SURFICIAL DEPOSITS

Surficial deposits include all materials younger than the Fort Union formation. The Flaxville formation, the oldest of the surficial deposits, is pre-Pleistocene in age. Several types of material were deposited during the Pleistocene epoch. The oldest of these are the Wiota gravels. Other deposits include till, outwash deposits, pond deposits, gravels along Big Muddy Creek (Plentywood formation), alluvium, colluvium, and dune sand.

FLAXVILLE FORMATION

The Flaxville formation of late Miocene or Pliocene age is composed of sand, clay, and gravel. West of the quadrangle it includes beds of marl and volcanic ash but none were found in the Otter Creek quadrangle. The formation consists of fluvial deposits reworked many times during a long period of tectonic quiescence and erosion when all but the most stable constituents were removed and were not replenished because of the low relief of the source area. Much of the formation has been eroded and redeposited several times at successively lower altitudes.

Collier (1917, p. 194–195) first described the formation; it has been discussed at length by Collier and Thom (1918, p. 179–184). It was named from exposures near the town of Flaxville, 20 miles west of the quadrangle. Collier first called the unit "the Flaxville formation" but a year later with Thom (1918) he renamed it "the Flaxville gravels." The author, as a result of his mapping, advocates that the unit be called the Flaxville formation because the supposedly distinctive gravel is actually a minor part of the unit.

The formation underlies a total area of 9 square miles in the quadrangle. Three areas of Flaxville formation occur at altitudes between 2,500 and 2,650 feet and underlie high level plateaus. They are the remnants of a once-continuous sheet of gravel which extended at least as far east as Alkabo, N. Dak. (A. D. Howard, written communication).

The formation is eroded slowly because of its permeability. The mesalike areas are being eroded only along the margins mostly by undercutting in the more easily eroded Fort Union formation. The typical outcrop is a rounded knob projecting through the mantle of till. The formation is well exposed at the following localities: Sec. 8, T. 33 N., R. 54 E.; NE¼ sec. 11, T. 34 N., R. 53 E.; sec. 30, T. 34 N., R. 54 E. It unconformably overlies the Fort Union formation and is overlain by glacial deposits.

The thickness ranges from 0 to more than 100 feet. The maximum thickness can only be estimated from the topography because no well records are available and no exposures show the total thickness; the average is probably 50 feet.

The formation is composed of several different lithologic units. The basal unit, which is 20 to 50 feet thick, is nearly everywhere composed of quartzitic gravel and sand.

Sandy and clayey strata, 20 to 40 feet thick, overlie the gravel and sand unit. Seventy miles west of the quadrangle, in secs. 19 and 20, T. 35 N., R. 43 E., volcanic ash was found by Collier and Thom (1918, p. 182). They presented a generalized section of that locality and gave the following approximate thicknesses:

	Feet
Flaxville formation:	
Marl, containing scattered quartzite pebbles	15
Sandstone, cemented with calcite	30
Volcanic ash, white to yellow, very pure but mixed with the underlying gravel at the base	15
Gravel, more or less cemented	20
Total thickness	80
Fort Union formation.	

About 70 percent of the pebbles in the gravel members of the formation consists of fine- to medium-grained quartzite. The average diameter of the pebbles is 1½ inches; boulders as much as 1 foot in diameter are a minor component of the gravel. The pebbles, cobbles, and boulders are smooth and well rounded. Most are moderate yellowish brown (10*YR* 5/4). Broken pebbles show a thin rind of weathering about one-eighth of an inch thick. Some broken pebbles are distinctly stratified; the darker parts are dark yellowish brown (10*YR* 4/2). Twenty percent of the pebbles are moderate red (5*R* 4/4) when dry but are dark reddish brown (10*R* 3/4) when wet. Grayish-red quartzite pebbles (10*R* 4/2) become dark reddish brown (10*R* 3/4) when wet. A minor percentage of the pebbles are dusky yellow green (5*GY* 5/2) or grayish green (10*GY* 5/2); when wet, they are one value darker. A small number of pebbles are olive gray (5*Y* 3/2) to black argillite, whereas others are chert and agate. A minor but distinctive lithologic type consists of green tinguaite porphyry whose feldspar phenocrysts are distinctly zoned. These pebbles apparently came from the Sweetgrass Hills 200 miles west of the area (C. P. Ross, oral communication, 1949).

Locally, the formation has been cemented by calcium carbonate to form concretionary sandstone and conglomerate.

The organic content of the Flaxville formation is low. However, Russell (1950, p. 58) found two gravel beds separated by a weathered zone and 3 inches of fossil soil a few miles north of Flaxville. No lignite beds were found but thin discontinuous carbonaceous beds were noted.

Many vertebrate fossils have been found in the formation. Those found by Collier and Thom were examined by Gidley (*in* Collier and Thom, 1918, p. 180–181) who concluded that "* * * the beds from which these fragments were collected cannot be older than Miocene or younger than lower Pliocene." Only a few unidentifiable waterworn vertebrate remains were found by the author in the Otter Creek quadrangle.

The following sequence of events is indicated in the deposition of the Flaxville formation: The coarse basal gravels were deposited on a planation surface by streams of varying velocities which flowed northeast across northeastern Montana. The lower gravelly part of the formation was deposited by streams occasionally capable of moving cobbles and boulders. The overlying sandy and clayey strata were deposited by streams of low velocities or in ponded waters. Information from outside the Otter Creek quadrangle indicates that volcanic ash fell, was washed, concentrated, and preserved during the deposition of the upper part of the Flaxville formation. Fifteen to twenty feet of marl formed from a soil developed on the uppermost part of the formation.

Uplift caused streams to erode 200 feet below the upland surface. Gravels were eroded and redeposited at this lower level. A second uplift occurred and streams were rejuvenated and eroded. The gravels were reworked to a level approximately 350 feet lower than the upland surface, and it was at this common level that the gravels around the type locality, Flaxville, were deposited. About 100 feet of downcutting occurred subsequent to the formation of the Flaxville surface and the 2,600-foot level of gravels near Lundville (20 miles southwest of the quadrangle) was formed. Subsequent uplift and downcutting by the streams formed a level of gravels having a present altitude of 2,500 feet. This is the common level of remnants in the Otter Creek quadrangle. However, one remnant is at 2,650 feet. Big Muddy Creek was incised into the 2,500-foot level about 550 feet but is now only 500 feet below this level owing to valley filling.

Two areas east of outcrops of the Flaxville formation have a protective veneer of gravel similar to the Flaxville formation over the Fort Union formation. In these areas, the gravel remnant is slightly lower than present outcrops of Flaxville formation. One area, in the NE¼NE¼ sec. 22, T. 33 N., R. 54 E. and at an altitude of 2,400 feet, may be the result of preglacial erosion of a gravel deposit from a higher altitude. The other locality, where the lower altitude is more clearly the result of the removal of the upper part of the Flaxville formation by erosion, is in the NW¼SE¼ sec. 16, T. 33 N., R. 54 E. No erratic pebbles were found in this area. The altitude of the lag concentrate in this area is 2,500 feet which correlates with the base of the Flaxville formation further to the west at an altitude of slightly over 2,520 feet. The crest of Flagstaff Hill, at an altitude of slightly more than 2,520 feet, in the NW¼NW¼ sec. 17, T. 32 N., R. 54 E., was probably capped by the Flaxville formation; it is now so thoroughly covered with till that no gravel crops out.

The physical properties of the Flaxville formation vary as the lithology of the different parts. A mechanical analysis of a sample of the Flaxville formation from NW¼NW¼ sec. 24, T. 34 N., R. 54 E. showed the following size distribution: 2 percent silt, 36 percent sand, 4 percent granules, and 58 percent pebbles. This sample is probably representative of the formation and indicates it is a sandy gravel. The formation, except where cemented, is easily worked by hand and power tools. The cemented gravel can be broken easily by power machinery but occasionally blasting may be necessary. The presence of quartzite, chert, and agate suggests that the gravel is a poor concrete aggregate for high-alkaline cements. However, for lack of a more alkaline material, it is used even though the resulting concrete spalls. The basal part of the formation is used as pervious fill or backfill, or as a fairly pervious outer zone for earthfill dams. The formation is used extensively as a source of road metal. Good road bases can be constructed from those parts of the formation which contain, in addition to gravel, sand, silt, and some clay which acts as a binder.

The formation commonly provides a good foundation material. The gravelly parts also have good slope stability. The hard smooth surfaces of the well-rounded pebbles and cobbles result in fairly low internal friction and slopes that result are the natural angles of repose for pebbles and cobbles (30° to 35°).

Few pits have been dug in the formation in this area because more accessible deposits of a younger gravel are found at lower altitudes. Only two pits were found, one in the SW¼SE¼ sec. 8, T. 33 N., R. 54 E., and the other in the NE¼SW¼ sec. 24, T. 34 N., R. 54 E. Both are about 15 feet wide, 20 feet long, and 10 feet deep.

Mechanical analyses were made from three samples of the Flaxville formation collected at the following localities: (a) SE¼ sec. 8, T. 33 N., R. 54 E.; (b) SW¼SE¼NW¼ sec. 11, T. 34 N., R. 54 E.; and (c) from the top of a hill in the NE¼ sec. 11, T. 34 N., R. 53 E. The results were not identical but have been averaged as follows: 2 percent clay, 3 percent silt, 31 percent sand, 3 percent granules, 60 percent pebbles, and 1 percent cobbles. The coefficient of sorting (7.28) shows

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that this is a poorly sorted deposit. One sample had a plastic limit of 28. Specific gravity was 2.65.

WIOTA GRAVELS

Preglacial gravels exposed 65 miles southwest of the area near the railroad station at Wiota and similar in composition to the Flaxville formation, have been defined by Jensen (written communication, 1951) from areas to the southwest, as follows:

> Wiota gravels is the name here applied to gravels and associated sediments deposited by streams and rivers prior to glaciation of the sites of deposition of the gravels. The materials are predominantly of western provenance and discontinuously mantle a plain that forms the upland areas of the quadrangle. Wiota gravels underlying this upland are at altitudes ranging from about 2,100 feet to about 2,400 feet above sea level, but further east altitudes are 2,000 feet or less.
>
> The Flaxville gravel, similar in lithology and mode of deposition but older, is at altitudes of 2,600 feet or more, near the quadrangle, and is generally separated from adjacent Wiota gravels by slopes 100 to 200 feet high.

In the Frazer quadrangle, Jensen found pebbles similar to Canadian igneous and metamorphic rock types in these gravels (Jensen, written communication, 1951) which indicate they are Pleistocene in age.

In the Otter Creek quadrangle, many pebbles which closely resemble Canadian igneous and metamorphic rock types were found in pretill gravel deposits which seem to be identical in overall appearance, altitude, and lithology with those at Wiota.

The several outcrops of Wiota gravels can be grouped according to altitude. The altitude of the highest (oldest) remnant is 2,300 feet. Locally, it is necessary to be arbitrary as to which gravel deposits are part of the Flaxville formation and which belong to the Wiota gravels, but regionally there is a gradation between the two. The lowest (youngest) level is at 2,200 feet.

Nearly all deposits of the Wiota gravels are in terraces along Crazy Horse Creek in the valley walls where erosion has cut through the till and exposed the buried terraces of gravels in T. 34 N., R. 54 E.

Outcrops of Wiota gravels are marked by small benches because the gravels are more resistant to erosion than the overlying and underlying formations. Till nearly everywhere overlies the formation.

The range in thickness of the gravels is considerable. Nowhere is the total thickness exposed. At least 25 feet of gravel are exposed at the corner common to secs. 31, 32, T. 35 N., R. 54 E., and 5, 6, T. 34 N., R. 54 E; 20 feet are exposed in the SE¼NW¼ sec. 28, T. 34 N., R. 54 E.

The Wiota gravels overlie the Fort Union formation and are overlain by younger Pleistocene deposits such as till. They were derived by erosion of the Flaxville formation in Pliocene and throughout most of Pleistocene time. Subsequently, these gravels were buried under till.

The Wiota gravels are commonly reddish brown. They range laterally from deposits consisting entirely of sand to those containing coarse gravel.

The part of the formation that is of preglacial origin consists entirely of reworked gravels of the Flaxville formation. The gravels are composed of gray, pink, green, and brown, smooth, well-rounded, percussion-marked argillite and quartzite pebbles as much as 7 inches long. The part of the formation that is partly of glacial origin is similar to the preglacial gravels but includes a small percentage of granite gneiss, schist, limestone, and dolomite pebbles. Physical properties of both parts of the formation are similar to those of the Flaxville formation.

The pebbles and cobbles of the Wiota gravels are about 98 percent quartzite; about 1½ percent consists of amorphous and cryptocrystalline silica. The remaining one-half percent consists of green porphyry (tinguaite) and glacial erratics. The quartzite stones are smooth and well rounded; the larger pebbles and cobbles have abundant shallow crescentic percussion fractures. Most of the quartzite in the pebbles is medium to fine grained, but some is very fine grained or finely conglomeratic. Red, brown, gray, and green pebbles are common, but predominance of the first two imparts a reddish-brown color to exposures.

Mechanical analyses were made of two samples of the Wiota gravels. About 5 percent of the samples consisted of clay, 5 percent silt, 15 percent sand, 5 percent granules, and 70 percent pebbles. The two samples had liquid limits of 19.7 and 26. Both samples were nonplastic. One sample analyzed in the Engineering Geology Laboratory in Denver had the following Atterberg limits: liquid limit 22; plastic limit 13; plastic index 9. The specific gravity was 2.70.

The range in size of particles in the coarse fraction is from granules to 8-inch cobbles, but the average is about 10 mm in diameter. The great range in size indicates that the strata were deposited by both high- and low-velocity streams.

The Wiota gravels are a source of road metal and concrete aggregate. All pebbles are strong and the percentage of deleterious reactive material is small. The stones are well rounded and crushing is necessary to obtain angular material. Careful exploration along outcrops is necessary when searching for usable gravel deposits because of lateral facies changes and the variable ratio in thickness of gravel to thickness of overburden.

In building water-retaining structures such as canals and dams, the high permeability of the formation should be considered. Many stock dams built in the deposits have failed to retain much water.

The materials composing this formation and the overlying drift can be worked with hand tools. The Wiota gravels can be easily excavated by power tools, and the overburden of till can usually be removed with little difficulty by a bulldozer.

The Wiota gravels commonly provide a good foundation material. The coefficient of friction between the round pebbles and cobbles is low and the gravelly parts of the formation have poor slope stability above the natural angle of repose (30° to 35°). The hard smooth surfaces of the well-rounded pebbles and cobbles result in low friction and slopes that result are the natural angles of repose for pebbles and cobbles. The Wiota gravels can be used as a fairly pervious fill or backfill and as shell material for earthfill dams.

TILL

Most glacial deposits in the area consist of till deposited as a blanket over older deposits except where removed by postglacial erosion. The till surface is characterized by gently sloping swells, sags, closed depressions, and a few linear ridges.

The till is tough and compact when dry, but plastic when wet. It is a highly impermeable, calcareous, unstratified and unsorted, unconsolidated to moderately consolidated, heterogeneous mixture. It is predominantly clay, but also includes silt, sand, pebbles, cobbles, and boulders. Some of the erratic boulders from Canada are several feet in diameter.

The till is oxidized in most exposures and is commonly yellowish brown; the unoxidized till is bluish gray. Thin lenses of sand and sandy gravel are intercalated within the till. Some exposures of till show an indistinct to distinct horizontal layering or fissility. Vertical, prismatic, contraction-type jointing is well developed in many of the larger exposures.

The average thickness is about 15 feet, but deposits more than 30 feet thick have been observed in several places. The maximum thickness is estimated to be in excess of 80 feet.

Till overlies the Fort Union formation, the Flaxville formation, and the Wiota gravels. It is overlain by outwash, the Plentywood gravels, alluvium, colluvium, lake deposits, and dune sand.

The till was probably deposited during the Iowan or Tazwell(?) substages of the Wisconsin stage. The distribution and age relations of the drift sheets were worked out by the author elsewhere in the Fort Peck Indian Reservation.

Mechanical analyses of samples of till collected in the quadrangle show that it consists of 65 percent silt and clay, probably derived chiefly from the Fort Union formation, 30 percent sand-sized material, and 5 percent pebbles, cobbles and larger sizes. Seventy percent of the 5-percent fraction consisting of pebbles and cobbles is quartzite from the Flaxville formation. The remainder consists of various igneous, metamorphic and sedimentary rocks from Canada.

In the southeastern part of the quadrangle the surface of the till is characterized by many long narrow ridges that are as much as 1 mile long, 200 feet wide and 15 feet high. The author has mapped hundreds of these ridges elsewhere in the Fort Peck Indian Reservation (Colton, 1958, p. 99), and has called them ice-crack moraines after similar features mapped by Sproule (1939, p. 104). The term was first used by Sproule to describe narrow, generally sharp, ridges of sandy moraine trending across the country at right angles to the direction of ice movement in the Cree Lakes area, Saskatchewan, Canada. In that area, they are as much as 35 feet high, 3 miles long, and a few are more than 100 yards wide, but the majority are much narrower. In most areas, the ridges are parallel, although separate sets converge at acute angles. Swenson first described the ice-crack moraines in the Fort Peck Indian Reservation in an unpublished administrative report in 1946 and again in 1955 (Swenson, 1955, p. 27 and 28).

The pattern made by the ice-crack moraines is comparable to that seen in lateral crevasse patterns in many valley glaciers. Nye (1952, p. 89–91) discussed the theory of crevasse patterns and illustrated the theoretical positions and directions of crevasses and their relation to the direction of ice movement. He indicated that if lateral stresses were negligible, the principal axes of stress were everywhere at 45° to the edge of the ice.

The author came to the following conclusions from mapping in the Oswego, Wolf Point, Chelsea, Poplar, and Brockton quadrangles, 30 to 60 miles southwest of the Otter Creek quadrangle: The ice-crack moraines formed during the stagnation and retreat of the ice front; the crevasses in the ice were the result of shearing and therefore their long axes are at an angle of 45° to the westward direction of ice movement in the southeast part of the Otter Creek quadrangle just prior to stagnation.

The maximum thickness of the ice in the area at the time of stagnation where crevasses formed is indicated by the ice-crack moraines. At the time the ice-crack moraines were formed, the thickness of the ice could not have been greater than 100 feet or the ice would have plastically deformed under its own weight, closed and healed the crevasses.

The ice-crack moraines formed under the following circumstances: As the ice stagnated and became somewhat less than 100 feet thick, it broke along planes of weakness—somewhat regularly spaced vertical shear crevasses; the blocks of ice pressed down on the saturated soft plastic till, which was then squeezed up into the crevasses.

Till can be excavated with hand tools although its high plasticity (when wet), compactness, and cobble and boulder content make digging difficult. It can be easily worked, when slightly wet, with power tools, but it becomes hard and tough as it dries because of its clay content. It can be used to make impervious fill if well compacted under controlled moisture and density conditions.

Till makes a stable foundation material and settlement under heavy loads is negligible. Unsurfaced roads built of it are firm when dry but are slippery and rut badly when wet. Fair to good subgrades can be made of till except where drainage is poor. Local accumulations of stones may interfere with grading and excavation. Frost heaving is negligible.

Till has high slope stability when dry and commonly stands in nearly vertical slopes more than 35 feet high. However, in some cuts small slides are common owing mainly to a network of vertical fissures that characterize the upper part of the till and facilitate sliding. Road cuts in till with slopes of 1 to 1 are largely stable.

Compacted till has been used for lining of irrigation canals because of its near impermeability. Very little leakage can be expected from canals dug in this material.

Till is a source of boulders for riprap; the stones were concentrated on the surface of the till by erosion; in places they have been piled into heaps by farmers.

Mechanical analyses were made of two samples of till from sec. 17, T. 34 N., R. 54 E., and from NW¼NE¼NW¼ sec. 10, T. 32 N., R. 55 E. The results were nearly identical and showed that 35 percent was clay, 36 percent silt, 28 percent sand, and 1 percent granule size or larger. The Atterberg limits of these two samples were: liquid limit, 175 and 32; plastic limit, 22 and 20; plastic index, 153 and 12. Specific gravity of both was 2.69. One sample had a coefficient of sorting (Trask, 1932, p. 67) of 8.30 (poorly sorted).

OUTWASH DEPOSITS

Many glacial melt-water channels are floored with thin outwash deposits of sandy quartzite gravel containing many erratics (pebbles, cobbles, and boulders whose composition shows that they came from

Canada). The deposits are as much as 50 feet thick, commonly less than 100 feet wide, and as much as 5 miles long. Some outwash channels coincide with modern drainage, but most do not. Some are nearly normal to the slope of the ground surface, indicating they were formed between ice and the valley wall by ice-marginal streams.

All the outwash deposits were formed during the Wisconsin stage. Most were formed during the Iowan or Tazewell(?) substages, but a few in the southeastern part of the quadrangle may have formed during the Cary(?) substage. These age relations were established by the author elsewhere in the Fort Peck Indian Reservation.

Outwash deposits overlie till and older deposits and are locally overlain by alluvial, colluvial, and eolian deposits. Most of the outwash deposits are in the western half of the quadrangle along the large ice-marginal channel now occupied by Marsh Creek, the upper part of Crazy Horse Creek, Kampen Coulee, and the area near the northeastern end of Davis Gap (pl. 38). Other outwash deposits are grouped in the outwash channel that runs southward along the east side of T. 33 N., R. 54 E.

Terraces of outwash gravels are present along Wolf Creek in the western part of the quadrangle. A deposit in sec. 26 on the south side of the east-west road in T. 33 N., R. 53 E., has a maximum observed thickness of 20 feet but may be more than 50 feet thick in places. The only large pit in the deposits is in sec. 26, T. 33 N., R. 53 E., in a terrace at an altitude of 2,180 feet. Other deposits are in secs. 25, 26, 35, and 36 of T. 33 N., R. 53 E. Coarse gravels, in secs. 30 and 31, T. 33 N., R. 54 E., at about the same altitude, are probably contemporaneous.

Part of the outwash gravel along Wolf Creek was derived from the headwaters of the Wolf Creek drainage system, but most came from the north by way of the Crazy Horse Creek channel. The gravel is a fill in the valley of Wolf Creek above the Wolf Creek diversion and was deposited in the ponded waters of Wolf Creek when ice blocked the lower part of the channel (pl. 38, position 1). Wolf Creek, which normally flows into Big Muddy Creek, found a new outlet called Davis Gap, just west of the southwest corner of the quadrangle.

Several small outwash deposits are scattered along Wolf Creek in the southwestern part of the quadrangle. There are deposits too small and thin to show on the geologic map in many of the meltwater channel segments.

The lithology of the outwash deposits that cover the Flaxville formation cannot be distinguished easily from the underlying gravel from which they were largely derived. The presence of scattered erratics, however, indicates that the deposit is glacial outwash. Most of the deposits have been mapped on the basis of morphology and general relations to other glacial deposits and remnants of the Flaxville formation.

Most of the pebbles in the outwash deposits consist of fine- to medium-grained quartzite and are 1 inch in diameter. Boulders and cobbles are minor constituents. The pebbles, cobbles, and boulders are smooth and well rounded. Most are moderate yellowish brown (10*YR* 5/4) quartzite. Twenty percent of the pebbles are jasperlike argillites that are moderate red (5*R* 4/4) when dry but are dark reddish brown (10*R* 3/4) when wet. Dry grayish-red quartzite pebbles (10*R* 4/2) become dark reddish brown (10*R* 3/4) when wet. A minor percentage of the pebbles are dusky yellowish green (5*GY* 5/2) or grayish green (10*GY* 5/2) when dry. When wet, they are one value darker. A small number are olive-gray (5*Y* 3/2) to black argillites; some pebbles are chert and agate. Organic matter is a very minor constituent and no fossils were found.

The deposits are easily worked with hand and power tools. The presence of quartzite, chert, and agate suggest that the material is a poor concrete aggregate for high alkaline cements. Crushing is necessary to obtain angular material. The deposits have been used extensively as a source of road metal. Good road bases can be constructed from outwash deposits that contain enough sand, silt, and clay to act as a binder.

The outwash deposits generally provide good foundation material. The gravelly parts of the unit have poor slope stability owing to the low coefficient of friction between pebbles, and slopes that result are the natural angles of repose for pebbles and cobbles. Water-retaining structures should not be built in outwash deposits because of their high permeability.

Mechanical analyses of three samples of outwash gravel were made by the Materials Testing Laboratory of the Montana State Highway Commission. The results showed the following average size distribution: 6 percent silt, 44 percent sand, 10 percent granules, and 40 percent pebbles.

A mechanical analysis of a sample of outwash collected in the NW¼SW¼ sec. 10, T. 34 N., R. 54 E. showed that about 2 percent was silt, 36 percent sand, 8 percent granules, 53 percent pebbles, and 1 percent cobbles. The coefficient of sorting was 4.30.

PLENTYWOOD FORMATION

The Plentywood formation is here named for gravel deposits along Big Muddy Creek, which are conspicuously exposed in several pits just north of the quadrangle near Plentywood. In the quadrangle the formation crops out along Big Muddy Creek in secs. 4, 15, 27, T. 34 N., R. 55 E., in sec. 34, T. 33 N., R. 55 E., and in secs. 2, 11, 12, 22, T. 32 N., R. 55 E.

These gravel deposits are fairly extensive (pl. 38) outside the quadrangle and have been traced up the valley of Big Muddy Creek to a point 9 miles north of Daleview where the border of the Cary drift crosses the old abandoned valley of Big Muddy Creek.

The Plentywood formation overlies the Fort Union formation and till. It is overlain by alluvium, colluvium, pond deposits, and eolian deposits.

The thickness of the Plentywood formation ranges from 0 to an inferred 135 feet. A thickness of more than 20 feet was observed in many places. Drilling for shot holes a few miles northwest of the quadrangle indicated that a thickness of 70 to 120 feet is common. Some profiles are shown on plate 38.

A wide range in size of material occurs in this formation. Beds of boulders more than 1 foot in diameter were observed in some places. Cobble gravels were noted in sec. 34, T. 33 N., R. 55 E. Most of the formation is composed of sand and pea-sized material. In general, the formation is a sandy gravel.

Pebble counts indicate the following average percentage composition of the Plentywood formation:

	Percent
White quartzite pebbles	1
Granite pebbles (erratic)	9
Dark aphanitic pebbles	4
Chalcedony pebbles	4
Red sandstone pebbles	1
Calcareous sandstone fragments of the Fort Union formation	1
Dolomite and limestone erratic pebbles	25
Brown and yellow quartzitic pebbles of the Flaxville formation	55
Total	100

Irving J. Witkind (written communication, 1949) mapped gravel deposits in the Reserve 15-minute quadrangle, which adjoins the Otter Creek quadrangle on the east. He concluded that these deposits were formed prior to the deposition of early Wisconsin (Cary? substage) till and were later exhumed by erosion from beneath the till. The author agrees with Witkind that some of the gravel deposits in the Reserve quadrangle are overlain by till, but the author thinks that many of the gravel deposits were laid down after deposition of the till and can be correlated with the deposits at Plentywood.

The deposits of the Plentywood formation in the Big Muddy Creek valley are remnants of a gravel fill deposited during the retreat and melting of the Cary (?) ice sheet. The ice probably readvanced southward to a point about 5 miles from the northern boundary of the quadrangle and entered the southeast corner of the area (pl. 38). The gravel fill is younger than the older drift mantling the quadrangle and contemporaneous with the Cary (?) drift from which it is derived.

The drainage on the Plentywood formation is excellent and permeability is high. Water-retaining structures should not be built in the deposits without impermeable linings. The deposits are easily worked with hand and power tools. The presence of quartzite, chert, and agate suggests a poor concrete aggregate for high-alkaline cement, but it is used for concrete aggregate for lack of more suitable material; crushing is necessary to obtain angular material. Deposits of the Plentywood formation have been used extensively as a source of road metal. Good road bases can be constructed from deposits that contain enough sand, silt, and clay to act as a binder. The large areal extent of the deposits shown on the map indicates the large volume of gravel reserves available for use as aggregate and road metal and for other uses.

Deposits of the Plentywood formation generally provide good foundation material. The gravelly parts of the formation have poor slope stability owing to low coefficient of friction between pebbles. The hard smooth surfaces of the well-rounded pebbles and cobbles result in fairly low internal friction and the slopes that result (30° to 35°) are the natural angles of repose for pebbles and cobbles.

Mechanical analyses of reasonably representative samples were made by the Materials Testing Laboratory of the Montana State Highway Commission. The results showed the following size distribution: 6 percent silt, 23 percent sand, 12 percent granules, and 59 percent pebbles or larger.

A mechanical analysis of a sample of the Plentywood formation collected in the NE¼SW¼NW¼ sec. 27, T. 34 N., R. 55 E. showed the following size distribution: 4 percent silt, 18 percent sand, 18 percent granules, 59 percent pebbles, and 1 percent cobbles. The coefficient of sorting (Trask, 1932, p. 67) was 2.58.

ALLUVIUM

Flood-plain alluvium deposited by Big Muddy Creek underlies about 10 square miles of the quadrangle. Alluvial deposits of Wolf and Otter Creeks underlie another square mile or two. The alluvium is composed mostly of thin beds of fine sand, silt, and clay, and is rich in organic matter.

Moist alluvium is generally light yellowish gray (5*Y* 7/2) to medium brown (5*YR* 3/4), but many beds are tan; most of the moist clay beds are gray. Dry alluvium is commonly gray. The upper several feet contains a few dark-brown or black beds alternating with light grayish brown. Light-brown iron staining occurs as isolated blebs along rootlets and as irregular streaks in individual laminae.

Beds range from less than 1 inch to 2 feet in thickness. Bedding is virtually horizontal with little conspicuous channeling. Some irregularities in bedding are due to irregularities in the surface of deposition. Individual channels in some cutbanks are a few feet deep and 10 to 15 feet wide.

Shells of fresh-water clams (*Anodonta*) occur in the alluvium. Plant fragments are abundant.

The total thickness of the alluvial deposits in the quadrangle is not known. The only data which indicate the thickness of alluvial deposits are from well logs and resistivity tests north of Medicine Lake. Wells drilled into the alluvium of Big Muddy Creek have penetrated lenses of gravel (Plentywood formation?) at depths of 50 feet. This suggests that the alluvium is 50 feet thick. Resistivity tests made along the road north of the town of Medicine Lake and on the west side of the railroad tracks in sec. 13, T. 32 N., R. 55 E., by the U.S. Bureau of Reclamation indicate that bedrock is at a depth of 150 feet.

Saturated alluvial deposits have low stability and heavy losses of fill can be expected across swampy areas through lateral and vertical displacement of clayey alluvium. Sandy alluvium makes more stable fill if it is well compacted and drained.

Alluvial deposits are commonly saturated with water owing to the high water table and, therefore, are difficult to work, but good compaction can be achieved. In abandoned meanders, former oxbow lakes, and other depressions that are poorly drained, the ground-water table is within a few feet of the surface or at the surface; it is at a similar height in irrigated areas. Permeability ranges from high in sandy beds to very low in silt and clay beds.

Sand, silt, and clay beds can be easily worked with hand and power tools. Cribbing, timbering, and other support is necessary for underground installations and large excavations. The sand and silt will stand in cuts up to 60° for short periods of time but soon erodes or slumps back to slopes of less than 45°.

A mechanical analysis of a sample of alluvium from the SW¼NE¼ sec. 14, T. 32 N., R. 55 E., showed that it consisted of 25 percent clay, 69 percent silt, and 6 percent sand. The coefficient of sorting (Trask, 1932, p. 67) was 2.84. The plastic limit was 25, and specific gravity was 2.69. A second sample from NE¼NW¼ sec. 22, T. 34 N., R. 55 E., indicated that alluvium in that area was 62 percent clay, 36 percent silt, and 2 percent sand. It had the following Atterberg limits: liquid limit, 62; plastic limit, 29; plastic index, 33; specific gravity, 2.71.

POND DEPOSITS

Depressions in the till plain and other areas are partly filled with dark plastic silty and sandy clay. Each deposit is of limited extent because of the small size of the depressions in which they were deposited; only a few extend over more than 1 acre.

The pond deposits have originated in several environments: (a) in closed depressions in swell and swale topography where glacial ice stagnated; (b) in closed depressions formed in ice-marginal channels; (c) in oxbow lakes cut in the alluvial plain; and (d) in valleys blocked by a rising fill or by a moraine. The composition of the pond deposits varies with the origin; however, most are clay but a few consist of silt or sand.

Examples of the many small pond deposits, which formed in morainic swell and swale topography, are in sec. 19, T. 33 N., R. 55 E. Nearly all the area, in the southwest part of T. 33 N., R. 55 E., between Alkali Coulee and Otter Creek is characterized by swell and swale stagnation-type topography; many small pond deposits in that area have not been shown on the geologic map. It seems that the ice sheet in this area stagnated and broke up into many small blocks which melted and left an irregular surface containing closed depressions.

The largest pond deposit, about one-half square mile in area, is in the topographic sag over the buried preglacial valley of Wolf Creek in secs. 11 and 12, T. 32 N., R. 54 E. A few of the pond deposits fill ice-marginal channels; for example, in the Alkali Coulee ice-marginal channel in the SW¼ sec. 13, T. 33 N., R. 54 E. They fill places which were scoured by a larger volume of water flowing through the channels.

The most recent pond deposits are in oxbow lakes on the alluvial plain of Big Muddy Creek; they are in the NW¼ sec. 14, T. 32 N., R. 55 E. One lake deposit in secs. 11 and 12, T. 32 N., R. 55 E., formed when sediments deposited by Big Muddy Creek across the mouth of a small tributary impounded a small body of water. The swampy depression in the SE¼ sec. 32, T. 33 N., R. 55 E., is dammed by a small northeastward-trending moraine which blocked a southeastward-flowing stream. Owing to artificial drainage, erosion is beginning to remove the lake deposits that formed in this depression. Most of the pond deposits are postglacial.

The high organic content gives the deposits their black color; no fossils were found.

Pond deposits can be excavated by hand and power tools. However, wet, tough, plastic, sticky clay is difficult to handle. Because of local high water tables, poor permeability, and the lack of surface drainage, water control will be a problem in excavations. The deposits have low slope stability in both artificial and natural cuts, but excavations will stand if the clay is dried with well points; otherwise cribbing and timbering will be necessary. Pond deposits in closed depressions provide poor foundation conditions unless the depression is properly drained.

Construction of roads across pond deposits should be avoided if possible. Roads across closed depressions have to be repaired frequently because of subsidence of the highway grade and heaving from frost action in the water-saturated deposits. During wet seasons many of the depressions containing the clays become ponds and are impassable.

Mechanical analyses were made of two samples of pond deposits. About 50 percent of the samples consisted of clay, 42 percent was silt, and 8 percent was sand. The two samples had liquid limits of 46 and 76 and plastic limits of 36 and 38. The plastic indices were 10 and 38. Specific gravity was 2.50 and 2.62.

COLLUVIUM

Slope wash and creep produce gently sloping poorly stratified deposits of sandy silt, silty clays, pebbly silts and clays, gravelly clays, and gravels. Some deposits form alluvial fans. There is a gradational series between alluvium and colluvium. Deposits showing meander scars have been mapped as alluvium.

Colluvial deposits cover large areas in sec. 13, T. 33 N., R. 54 E.; secs. 9, 16, 17, 18, and 19 of T. 33 N., R. 54 E.; and secs. 15, 16, 21, 28, 33, and 34 of T. 34 N., R. 55 E. Many small deposits also are scattered throughout the area. The thickness ranges from 0 to more than 40 feet, but where the colluvium is less than 3 feet thick it has not been mapped. Conspicuous exposures of colluvium can be seen at the following localities: SE¼ sec. 28, T. 34 N., R. 55 E.; NE¼ sec. 21, T. 34 N., R. 55 E.; NE¼ sec. 17, T. 33 N., R. 54 E.; and NW¼ sec. 36, T. 35 N., R. 55 E.

The composition and color of the deposits depends upon the source of the material. Colluvium derived from the Flaxville formation is a poorly sorted, slightly clayey, sandy gravel; the gravel content commonly decreases away from the source. Where till is the parent material, the colluvium is a silty and sandy pebbly clay. Colluvium derived from outcrops of sandy strata of the Fort Union formation is nearly 100 percent sand.

No fossils, other than cattle and buffalo bones, were found in the colluvium deposits.

Colluvium is easily excavated with hand and power tools. Shoring may be necessary in excavations deeper than 5 feet. It is a good to poor foundation material depending on the amount of gravel and sand present. It can be used for fill having moderate to high strength. Silty sand and sandy colluvium can be used to make fairly stable fill. The coarse sandy and gravelly types of colluvium can be used to make pervious fill.

A mechanical analysis of a sample of colluvium collected in SE¼SE¼SE¼ sec. 16, T. 34 N., R. 55 E. indicated that it was 43 percent clay-sized material, 42 percent silt, and 15 percent sand. The Atterberg limits were: liquid limit, 48; plastic limit, 23; and plastic index, 25. Specific gravity was 2.71.

DUNE SANDS AND OTHER EOLIAN DEPOSITS

Deposits of windblown sand were mapped in two small areas in the western part of sec. 11, T. 32 N., R. 55 E. A mantle of eolian silt too thin to map covers large parts of the quadrangle. The sand dunes are the result of wind action. Other eolian deposits have formed along fences where piles of tumbleweeds have trapped sand and silt blowing off fields.

Dune sand is composed of medium- to fine-grained sand and less than 10 percent silt; it is noncohesive. The color ranges from light tan to brown. The organic content is low but there are some humified layers. Fine sand and silt of windblown origin is similar to the dune sand but does not have the typical dune form. It forms a thin silty veneer overlying glacial till. The sand is dark brown owing to organic coatings on individual grains. No fossils have been found in the dune sands and other eolian deposits.

Dune sand and other eolian deposits are easily worked with hand and power tools, but slopes of excavations need to be graded to the angle of repose for sand. The sand has fair to good bearing strength and moderately poor to good strength in embankments and fills. Slight amounts of frost heaving occur in dune and other eolian sand. Sand-dune terrain drains rapidly, but thin sand deposits on till drain more slowly. The sand has fairly high permeability and can be used for pervious fill.

Some compaction can be expected; the sand requires the movement of equipment over it to produce vibrations for dense compaction. Sand of uniform size will not compact and cannot be used to make a stable fill without the addition of smaller sizes to act as a binder. The dune and other eolian sand makes a fairly good subgrade, but it is poor for unsurfaced roads. The sand will drift, and frequent maintenance is required.

The eolian sand is very poor for concrete owing to its uniformly fine grain size. A sample of eolian sand was collected from the NW¼NE¼SW¼ sec. 1, T. 32 N., R. 55 E., and from NW¼SE¼ NW¼ sec. 11, T. 33 N., R. 55 E. The results were nearly identical and showed that about 5 percent was clay sized, 7 percent was silt sized, and 88 percent was sand sized. The specific gravity of these two samples was 2.64. The coefficients of sorting were 1.31 and 1.86, respectively.

STRUCTURAL GEOLOGY

The chief structural feature in the area is a homocline dipping southeastward on the west side of the Williston basin. Beds dip 15 to 18 feet per mile southeastward along the northern edge of the quadrangle. Bauer (1914b, p. 24) stated that "* * * the strata dip southeastward about 16 feet to the mile as determined from altitudes on the Richardson lignite bed." Minor local flexures have dips of 3° to 4°.

Indirect indications of faults or joints in the bedrock are scattered throughout the quadrangle. They consist of rectilinear drainage patterns and colinear stream directions on opposite sides of a divide. One example in secs. 8 and 18 T. 33 N., R. 54 E., shows a northeastward-trending pattern paralleled by a similar pattern 2.5 miles to the southeast. In sec. 14, T. 33 N., R. 53 E., a northward-trending rectilinear drainage pattern seems to continue into sec. 11 and to parallel the stream pattern in sec. 13.

These linear elements in the drainage pattern are strikingly developed in other parts of the quadrangle as shown clearly on many aerial photographs. There are two main trends: N. 20° to 80° W., and N. 22° to 45° E. The dominant trend is about N. 45° E. The lineations have been plotted on figure 24.

Mollard (1957, p. 26 [18140]) found that several sets of minor intersecting linear features are discernible on good-quality small-scale photomosaics covering parts of southern Manitoba and Saskatchewan. His detailed studies indicated that the orientation and incidence of these minor linear elements of the landscape bear little relation to the age, origin, composition, or thickness of surficial materials or to the type of relief in which they are developed.

He believed the minor linear features are the surface reflection of a multiplicity of fracture lines in the underlying bedrock. He thought fracture patterns were related to tectonism in the sedimentary rock cover as well as in the underlying crystalline basement.

Length, direction, spacing, and relative prominence of individual lineaments appear to be the main variables of the linear pattern.

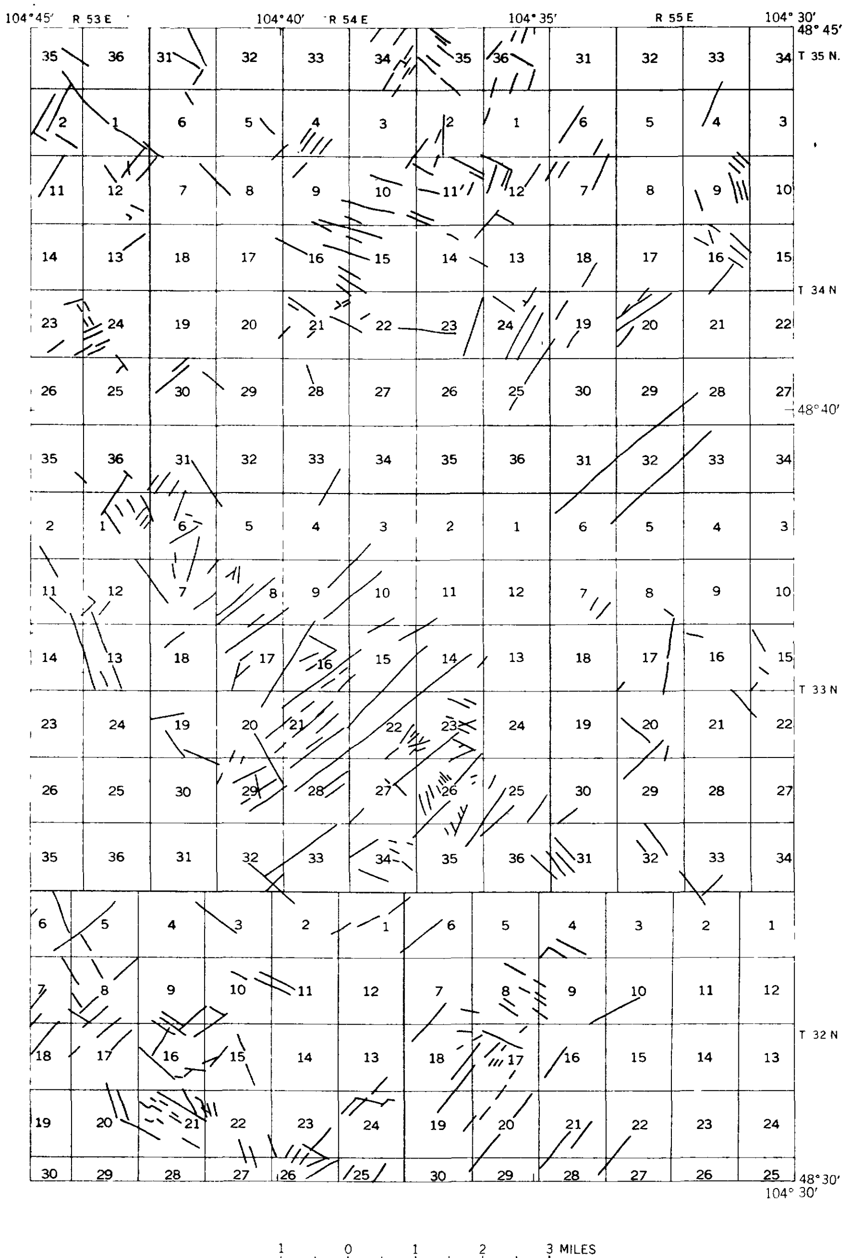

FIGURE 24.—Map showing the location and orientation of linear drainage in the Otter Creek quadrangle.

Mollard (1957) indicated that two main processes, leaching and surface runoff, formed and accentuated the linear depressions:

Long continued leaching and settlement in the subsoil eventually caused slight depressions to form directly above fissures in the underlying rock. These faintly developed depressions may in turn be accentuated by surface runoff. Local differences in microrelief and subsoil permeability affect and localize soil moisture and plant growth. Both influence photo tones.

An attempt was made by the author during a short field check in 1958 to apply the methods of Mollard (1957). Measurements were made on jointing in several places. Fifty percent of the observed jointing was parallel to major linear features, and 50 percent could not be related to lineations observed on aerial photographs. Consequently, the author was unable to substantiate the validity of Mollard's methods.

GEOLOGIC HISTORY

At least 8,700 feet of sedimentary rocks, not exposed in the area, were deposited in Paleozoic and Mesozoic time. During early Cenozoic time (the Paleocene epoch) about 2,000 feet of the Fort Union formation were deposited on a broad slowly subsiding plain. Remnants of Eocene and Oligocene formations, 90 miles southeast of the quadrangle, suggest that rocks of these ages were deposited in the Otter Creek area but were eroded before the deposition of the Flaxville formation in late Miocene and Pliocene time.

The Flaxville formation was deposited on a broad planation surface. Parts of the formation were later eroded and redeposited on lower levels in Pliocene and early Pleistocene time. Continued erosion and redeposition in early Pleistocene time resulted in the formation of some pedimentlike surfaces veneered with Wiota gravels below and around remnants of the Flaxville formation. Bauer (1914b, p. 5) noted the following:

* * * the summits of the highest hills and ridges are approximately at the same altitude and are covered with quartzite gravel. The concordance of these hilltops suggests the existence of an old river plain at the close of the first stage in the development of the present topography * * *. A second stage in the development is represented by the general level of the country which has an altitude of about 150 feet above the flood plains of the present streams. The development of this second peneplain, presumably by erosion, was not complete when the country was covered by an ice sheet.

Preglacial drainage in the area consisted of three southeastward-flowing tributaries to the preglacial Missouri River (fig. 25). These tributaries were Wolf Creek, Otter Creek and Plentywood Creek. Wolf Creek still flows in about the same channel as it did in preglacial time. Only two changes have occurred along its course; the upper part of the stream west of the quadrangle has been captured

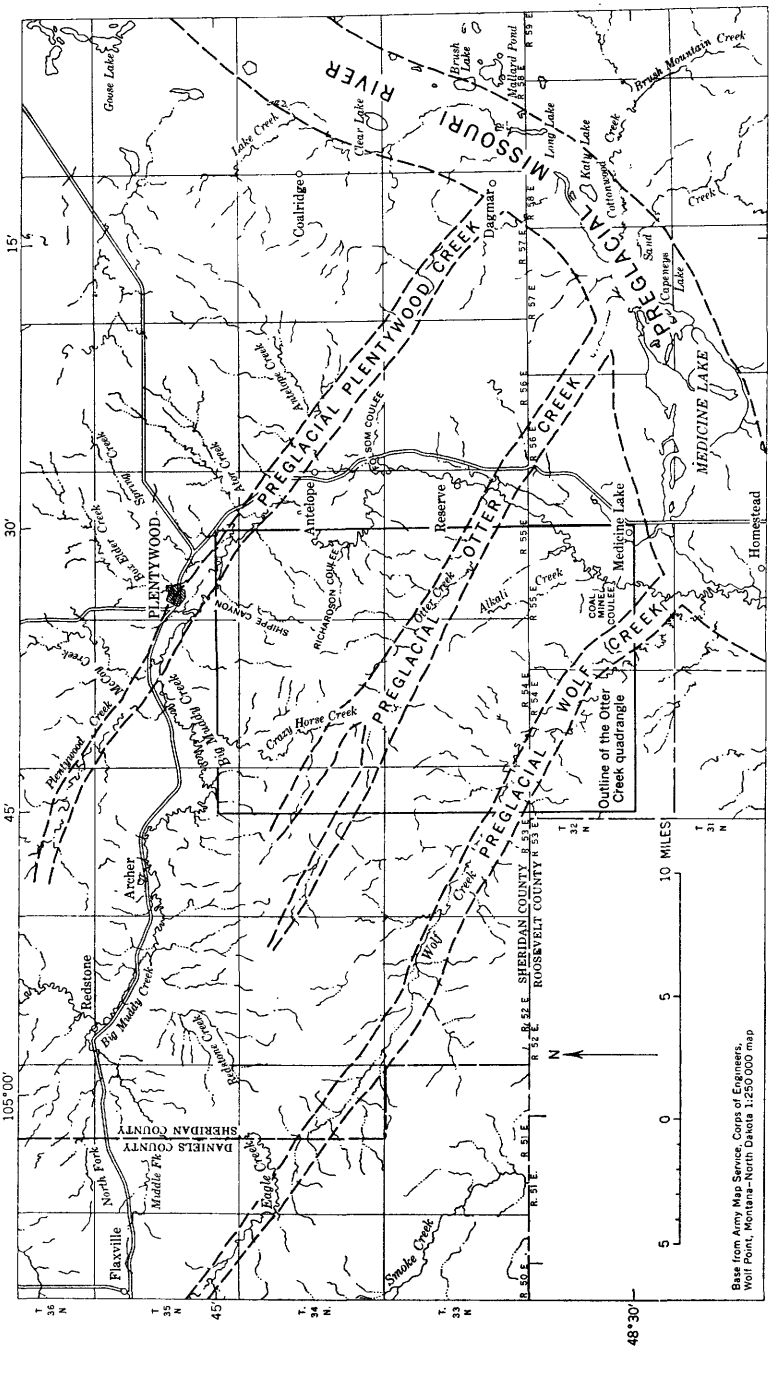

FIGURE 25.—Map of northeastern Montana showing the probable preglacial course of the Missouri River, Wolf Creek, Otter Creek, and Plentywood Creek. The outline of the Otter Creek quadrangle is also shown.

by Eagle Creek and a 3-mile reach has been diverted in the southwestern part of the quadrangle. Otter Creek probably flowed southeastward and joined the Missouri River near the east end of the present location of Medicine Lake. Plentywood Creek probably flowed southeast across the present sites of Plentywood and Antelope and joined the Missouri River near Dagmar.

The quadrangle was glaciated several times during Pleistocene time. Evidence of events that occurred during the advance of each ice front was not found in the quadrangle but undoubtedly drainage was blocked and rearranged. Nearly all the glacial deposits and features in the area were formed during the waning of the last ice sheet.

Terraces of Wiota gravels formed along Crazy Horse Creek after an early glaciation and before Cary(?) glaciation.

When Big Muddy Creek came into existence as a large ice-marginal channel, part of the course of Plentywood Creek was deepened, and the upper part of Otter Creek was separated from its lower part, which was completely buried. Also, the lower part of Plentywood Creek southeast of Antelope was buried and abandoned.

At least three periods of glaciation are believed by the author to be represented in this part of Montana. Witkind and Howard found a deposit of till along Smoke Creek (Witkind, 1959, p. 18) about 8 miles south of the Otter Creek quadrangle. This till seems to be the oldest evidence of glaciation in this part of Montana and may be older than the Wiota gravels which contain evidence of glaciation. The till that overlies the Wiota gravels is evidence of a second glaciation. Younger drift northeast of the quadrangle is evidence of a third pre-Wisconsin glaciation. Howard (1958, p. 585–587) thought that five periods of glaciation occurred in northeastern Montana and northwestern North Dakota. Evidence to confirm his conclusions was not found by the author in the Otter Creek quadrangle.

Mapping of drift borders on high-altitude aerial photographs of North Dakota in 1957 by the author has indicated that the till sheet which covers most of the Otter Creek quadrangle was deposited during the waning of the Iowan or Tazewell(?) substages of the Wisconsin glaciation. However, drift in the southeast corner of the quadrangle probably belongs to the Cary substage. The age of a log which was found in sec. 25, T. 138 N., R. 71 W., in Kidder County, N. Dak., was given as 11,480 years by Moir (1957). The next-oldest drift border in that area was probably formed at the maximum of the Cary substage. This drift border, which was mapped by photointerpretation westward across North Dakota and into Montana, is probably the same one which is in the southeast corner of the Otter

Creek quadrangle. Older melt-water channels, outwash deposits, ice-crack moraines, swell and swale topography, and till apparently formed during the recession of the Iowan or Tazewell(?) ice front.

The retreatal positions of the Iowan(?) or Tazewell(?) ice front are shown on plate 38. Generally, the Iowan(?) or Tazewell(?) ice front receded from southwest to northeast across the area, but topography influenced the actual position of the ice front. Ice melted from many high areas while the ice front was still many miles to the south. The succession of events that occurred during the melting of ice was probably as follows: First, the higher parts of the quadrangle, especially the remnants of the Flaxville formation whose average altitude is 2,500 feet, were uncovered. The remnants in the western part of the quadrangle probably were uncovered before the one in the northeastern part. At first these remnants probably were nunataks and ice flowed around them. As melting continued, the ice-free areas increased until remnants of the Flaxville formation were connected and the valley of Crazy Horse Creek became a large ice-marginal channel. This channel carried much of the melt water through Crazy Horse Gap and southwest across the valley of Wolf Creek (which was still filled with ice) and through Davis Gap. Some of the melt water spilled over through Ryan's Gap on the west side of the quadrangle. As the ice front receded further, more land was uncovered. At this time (pl. 38, position 2) the ice front probably was just south of the buried channel of Crazy Horse Creek and east of the west end of the buried channel of Wolf Creek. The small melt-water channels in the northeast part of the quadrangle and the long ice-marginal channel now partly occupied by Alkali Coulee suggest that the ice front stood for a time along a sinuous north-south line (pl. 38, position 3) a few miles west of the east border of the quadrangle. The next position of the ice front (pl. 38, position 4), suggested by glacial features, is a northeastward-trending line parallel to and just west of Big Muddy Creek. The last position (pl. 38, position 5) is a few miles west of Antelope along the east side of the quadrangle.

Drainage was rearranged in three areas in the quadrangle because preglacial valleys were blocked by ice, filled by debris, and new ice-marginal channels were cut so deeply that former drainage channels could not be reoccupied.

The most obvious example of stream superposition across a drainage divide is in the northeast part of the quadrangle just west of Antelope. Bauer (1914b, p. 5) mentioned this superposition in his report on the lignite of the northern part of the area, where Big Muddy Creek, which formerly flowed southward at the present site of Antelope, now flows through a semicircular 200-foot-deep channel 2 miles to the west (pl. 39).

Wolf Creek was diverted by ice from its preglacial course in the northeastern corner of T. 32 N., R. 54 E. The 3-mile-long diversion evidently began as an ice-marginal channel along the ice front. This new course is about 1 mile southwest of the old channel and is incised about 80 feet into the Fort Union formation. The old channel was blocked first by ice and then by a low moraine which formed in secs. 2 and 3, T. 32 N., R. 54 E.

In the northwest part of the quadrangle, in the northwest corner of T. 34 N., R. 54 E., Crazy Horse Creek was diverted westward about 1½ miles. The creek formerly flowed northward through sec. 8, T. 34 N., R. 54 E. It has been incised about 150 feet into the Fort Union formation. Preglacial stream gravels deposited by Crazy Horse Creek are overlain by the till along the north side of sec. 8 and in sec. 5.

The author agrees with Alden (1932, p. 129) that Big Muddy Creek was an important outlet for drainage while ice stood at the "Altamont" moraine or Coteau du Missouri (the Cary drift border on pl. 38). Alden further stated:

> Not only did it carry drainage from the ice front from regions far to the north but all the water from the South Saskatchewan River and its tributaries west of the ice front, and possibly also from the North Saskatchewan River, was diverted through this valley to the Missouri River.

During the Cary(?) substage of the Wisconsin stage of glaciation, the ice advanced to within 6 miles of the north edge of the quadrangle (pl. 38). Another lobe of the same ice sheet may have advanced into the quadrangle from the southeast. Witkind (1959, pl. 1) mapped a drift border trending westward to Big Muddy Creek in the adjoining Reserve quadrangle. He found large erratics and some till on the gravel terrace deposits in sec. 34, T. 32 N., R. 55 E., which indicate that the ice advanced onto the valley train of outwash gravel in the valley of Big Muddy Creek.

A lowering of base level throughout the area caused the dissection of the valley train represented by gravel of the Plentywood formation. This lowering was at least 100 feet as shown by shot-hole drilling along the north edge of the quadrangle; the author observed several profiles of holes drilled across the valley of Big Muddy Creek west of Plentywood. When the dissection occurred is not known, but it may have been during the Cary and younger glaciations.

Big Muddy Creek partly filled its valley in postglacial time so that the surface of the alluvial plain is now only 20 to 30 feet below the level of the Plentywood formation remnants (pl. 39, cross section). In Recent time, colluvial deposits formed as a result of continued erosion. Sand dunes formed and alluvium continues to be deposited by Big Muddy and other creeks.

MINERAL RESOURCES

LIGNITE

Several coal beds crop out in the quadrangle. Analyses by the U.S. Bureau of Mines (Bauer, 1914b, p. 12) show that this coal is lignite. The most extensive outcrops are in the northeast quarter of the quadrangle along the west valley wall of Big Muddy Creek. A few are along the southwest wall of Wolf Creek, and some are in the northwest corner of the quadrangle.

The important lignite beds are shown graphically on plate 40. Reserves have been calculated for the following: Richardson lignite bed, Coal Mine bed, Timber Coulee bed, and local beds *A*, *D*, *K*, *M*, *Q*, and *T*. There are many local beds less than 2½ feet thick in the area, but they have not been mapped and reserves have not been calculated.

Topographic maps were not available when the lignite was mapped; hence, bed correlation was difficult in most areas. Correlation was impossible in a few areas owing to the cover of glacial deposits. For this reason, the stratigraphy of the north end of the quadrangle could not be correlated with that in the south end.

Bauer (1914b) mapped the lignite in the northeastern part of the quadrangle in parts or all of the following townships: T. 33 N., R. 54 E. and R. 55 E.; T. 34 N., R. 54 E. and R. 55 E.; and T. 35 N., R. 53 E., R. 54 E., and R. 55 E. Part of the data collected by him has been incorporated in this paper.

BASIS FOR CLASSIFICATION OF RESERVES

The reserves of lignite are separated into three classes—measured, indicated, and inferred—according to the relative reliability of available data. The basis of this classification was developed by the U.S. Geological Survey in recent years for calculations of coal reserves and is summarized below:

The tonnage of measured lignite reserves was computed from thicknesses revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement were closely spaced, and the thickness and extent of the lignite reserves was so well defined that the computed tonnage is accurate within 20 percent or less of the true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of lignite vary, they are generally not less than half a mile apart. The outer limit of a block of measured lignite, therefore, is about one-fourth of a mile from the last point of positive information.

Where no data are available other than measurements along the outcrop but where the continuity of the outcrop is measured in miles and suggests the presence of lignite reserves at great distances in from the outcrop, a smooth line drawn roughly half a mile in from the outcrop marks the limit of a block of lignite that can also be classed as measured. An additional line, drawn roughly 2 miles in from the outcrop will define, within the ½-mile and 2-mile lines, a block of lignite that can be classed as "indicated."

The tonnage of indicated lignite reserves was computed partly from specific measurements and partly from projection from an outcrop for a reasonable distance on geologic evidence. In general, the points of observation are about 1 mile apart but they may be as much as 1½ miles apart for beds of known geologic continuity.

Inferred lignite reserves are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region, and for which there are few if any measurements. The estimates are based on an assumed continuity for which there is geologic evidence. In general, inferred lignite reserves are outside the limits defined for measured and indicated lignite.

The figure 1,750 short tons per acre foot was used as the weight of lignite.

The amount of coal mined and lost in mining in the quadrangle is negligible and was not calculated.

LIGNITE BEDS

Richardson lignite bed.—The Richardson lignite bed consists of hard woody lignite 2 to 8 feet thick. It can be traced along the northeastern part of the quadrangle from where it first outcrops along the south side of Big Muddy Creek in sec. 34, T. 34 N., R. 55 E., to a point on the west side of Shippe Canyon. It thins west of Shippe Canyon to a seam of carbonaceous shale. Bauer (1914b) mapped this bed, and his measurements are shown on plate 41. This may be the thick lignite bed mentioned by many of the farmers when they discussed their well logs. Altitudes of the lignite in these wells were not available, so that it is not certain whether the same lignite was penetrated in each case. Thus calculation of reserves for this bed from well data was not possible.

There are several inactive mines along the outcrop of the Richardson lignite bed west of Antelope and on the west side of Shippe Canyon. Only a few small areas along the outcrop can be stripped.

Coal Mine lignite bed.—The Coal Mine lignite bed in the southeast part of the quadrangle is more than 6 feet thick in Coal Mine Coulee;

several abandoned adits are in that area. What is probably the same bed has been traced northeastward about 4 miles. The bed may be the same as the Timber Coulee, lignite bed, but no definite correlation could be made owing to the almost complete drift cover north of Wolf Creek.

Timber Coulee lignite bed.—The Timber Coulee lignite bed is best exposed in an abandoned strip mine on the west side of Timber Coulee and in the strip mine of the Wolf Creek Coal Co. along the north side of Green Coulee. The bed is 8.3 feet thick along the west side of Timber Coulee, and probably averages 9 feet in thickness in this area. Abandoned strip pits northwest of Timber Coulee indicate the presence of the bed beneath the till cover. Test drilling and the presence of large clinker areas north of Green Coulee indicate the continuity of the bed southeast from Timber Coulee.

Local bed A.—Local bed *A* crops out at an altitude of about 2,030 feet in T. 32 N., R. 55 E., in secs. 9 and 16. In sec. 9, measured sections 27, 28, and 29 (pl. 40) represent this bed. Probably sections 30 and 40 represent this bed in sec. 16 (pl. 40). An average thickness of 3 feet has been assigned to the bed; no inferred reserves are indicated because of lack of exposures over an extended lateral distance.

Local bed K.—Local bed *K* is exposed in two places at an altitude of about 2,200 feet in the central northwest part of the Alkali Coulee 7½-minute quadrangle. The measured sections are 24 and 25 (pl. 40). The bed has an average thickness of 2.8 feet. Probably the bed can be traced northward by test borings in secs. 23 and 14 of T. 33 N., R. 54 E. As no exposures were found, no reserves were calculated for that area.

Local bed D.—Although only one section was measured, the bed probably has the reserves indicated in table 3 because lignite beds in this area appear to have a wide lateral extent.

Local bed M.—Only measured reserves for this bed are given inasmuch as the outcrop of the bed can be traced around the side of the hill in secs. 7 and 8, T. 34 N., R. 54 E. A southward-trending till-buried former channel of Crazy Horse Creek in the western third of sec. 8, T. 34 N., R. 54 E., may have cut out the coal in that area because the channel bottom is below the supposed coal horizon. Reserves for that area have not been calculated.

Local bed P.—At present (1958) it is not feasible to strip such a thin seam, and hence no strippable areas have been plotted. If economic conditions should change, possible strippable areas are along the south side of the hill in secs. 11 and 12 in T. 34 N., R. 53 E (pl. 41). This bed probably extends westward because the lignite (measured

TABLE 3.—*Summary of lignite reserves*

Bed and township	Reserves, in acres			Average thickness of bed (feet)	Acre-feet			Short tons		
	Measured	Indicated	Inferred		Measured	Indicated	Inferred	Measured	Indicated	Inferred
Richardson lignite bed:										
T. 35 N., R. 55 E	765			6	4,590			8,032,500		
T. 34 N., R. 55 E	4,414	7,066	301	6	26,484	42,396	1,806	46,347,000	74,193,000	3,160,500
T. 34 N., R. 54 E	153	1,655	11,133	6	918	6,930	66,798	1,606,500	12,127,500	116,896,500
T. 33 N., R. 55 E	8	1,380	2,172	6	38	8,280	13,032	84,000	14,490,000	22,806,000
Coal Mine lignite bed:										
T. 33 N., R. 55 E	70	227		3	210	881		367,500	1,541,750	
T. 32 N., R. 55 E	1,204	1,533		4	4,816	6,132		8,420,000	10,731,000	
Timber Coulee lignite bed:										
T. 32 N., R. 54 E	1,147	1,917		9	10,323	17,253		18,065,250	30,192,750	
Local bed *A*:										
T. 32 N., R. 55 E	797	2,886		3	2,391	8,658		4,184,250	15,151,500	
Local bed *K*:										
T. 33 N., R. 54 E	203	205		2.8	568	574		994,000	1,004,500	
T. 33 N., R. 55 E	21			2.8	58			102,800		
Local bed *D*:										
T. 32 N., R. 54 E	56	216		3	168	648		294,000	1,134,000	
Local bed *M*:										
T. 34 N., R. 54 E	266			3	798			1,386,500		
Local bed *P*:										
T. 34 N., R. 53 E	320	354		3	960	1,062		1,680,000	1,857,500	
Local bed *Q*:										
T. 34 N., R. 53 E	683	225		3.3	2,254	743		3,834,500	1,300,250	
Local bed *T*:										
T. 33 N., R. 53 E	100	328		3	300	984		525,000	1,732,000	
Local bed *U*:										
T. 35 N., R. 55 E	354	630		3	1,062	1,890		1,858,500	3,307,500	
T. 34 N., R. 55 E		64		3		192			336,000	
Local bed *V*:										
T. 34 N., R. 55 E	212	370		6	1,272	2,220		2,126,000	3,885,000	
Total of all lignite reserves regardless of thickness								99,908,300	172,984,250	142,863,000
Grand total of all reserves										415,755,550

section 2, pl. 40, in sec. 2) at the west edge of the quadrangle correlates with bed *P*. The stratigraphic position of this bed is shown in the columnar description of the Fort Union formation (p. 248).

Local bed Q.—Only measured and indicated reserves are shown for local bed *Q*. No data were found on which to base any inferred reserves. This is a split bed and probably one or the other, if not both, lignite seams continue west of the quadrangle. It was not possible to trace this bed eastward into R. 54 E. The stratigraphic position of this bed is shown in the columnar section given in the discussion of the Fort Union formation. (See p. 248).

Local bed T.—Only measured reserves were calculated because this bed is known from only one outcrop. It is lenticular in places.

Local beds U *and* V.—Local beds *U* and *V* were mapped by Bauer (1914b) at a time when they were being mined. His thickness measurements of lignite (Bauer 1914b, pl. 17, secs. 45, 46, 47, 48) have been incorporated into plate 40 of this report. In 1948 and 1949 these beds were concealed.

RIPRAP

Many scattered glacial erratic boulders are a source of riprap. In many places where the land has been cultivated the boulders have been collected into large piles. Many of the piles contain more than 2 cubic yards, and some contain as much as 40 cubic yards. These boulders make suitable facings for dams. They consist of limestone and dolomite and a variety of igneous and metamorphic rocks.

CLAY DEPOSITS

Clay deposits of minor economic importance occur in the quadrangle. Clay beds of the Fort Union formation are commonly less than 20 feet thick and generally change to coarser grain sizes in less than a mile along the outcrop.

A rather complete discussion of a white clay bed in the Fort Union formation is given by Bauer (1914a).

SAND AND GRAVEL DEPOSITS

Extensive deposits of different ages occur at various altitudes in the quadrangle. The largest are in the alluvial plain of Big Muddy Creek and consist of interbedded silts, sands, and many gravel lenses. An area of 10 square miles is underlain by these deposits; they are as much as 100 feet thick.

A major source of gravel and sand are the valley train terrace remnants in the valley of Big Muddy Creek. These remnants have a combined area of 3 square miles. The volume of the terrace deposit in secs. 1, 11, and 12, T. 32 N., R. 55 E., which covers roughly 1 square mile and is at least 30 feet thick, is about 30,976,000 cubic yards.

Remnants of the Flaxville formation cap three large highland areas in the quadrangle. The average thickness is in excess of 50 feet, and the total volume is estimated to be about 50 million cubic yards.

The estimated volume of gravel and sand deposits in the Wiota gravels along Crazy Horse Creek, Marsh Creek, and Wolf Creek is several million cubic yards.

TILL

The sheet of till, which covers most of the quadrangle, is of engineering significance not only as a source of material for roads and buildings, but as a foundation for all types of construction. When properly compacted, it has fairly high strength. Usually there is very little settling of foundations. It makes a good, tough, hard base for unsurfaced graded roads when dry, but frequent regrading and removal of large erratics is necessary. During wet weather, roads built of till are very slippery and rut badly.

The till which is high in clay content and has high plasticity may be useful for nearly impervious lining for irrigation ditches dug through more permeable material. It should be considered for use as fills for earth dams. The surface of the till is characterized by swell and swale topography with many closed depressions. This lack of complete surface drainage and the highly impervious nature of the till may place severe limitations on the irrigability of the land.

SOIL

Most of the soil in the quadrangle is of glacial origin and has been developed on glacial deposits—mostly till. Nearly all of it has been classified as Williams loam, Williams sandy loam, and Williams stony loam (Gieseker, 1923, p. 17). The soil developed on the Plentywood formation was named the Cheyenne gravelly loam by Gieseker, (1923, p. 19). The Laurel loam has developed on the flood plain of Big Muddy Creek and its tributaries (Gieseker, 1923, p. 19).

OIL AND GAS POSSIBILITIES

Several test wells have been drilled in the area, but none had produced oil as of September 23, 1957. Some oil reportedly has been found during drill-stem tests. The No. 1 Pohle, drilled by the Williston Pioneer Oil Co., reportedly yielded 125 feet of heavily oil- and gas-cut mud from the Charles formation of the Madison Group of Mississippian age in a drill-stem test between 6,988 and 7,006 feet. This well, 2½ miles northeast of the quadrangle in the center of the

NW¼SE¼ sec. 13, T. 35 N., R. 55 E., was plugged and abandoned.

The Texas Co. drilled the No. 1 McNulty just north of the center of the north edge of the quadrangle. Drill stem tests at 6,318–6,397, 6,321–6,397, 6,330–6,397, 6,513–6,554, 6,513–6,589, 6,585–6,605, 6,605–6,663, 6,627–6,663, 6,663–6,675, 6,675–6,707, 6,611–6,707, 6,720–6,760, 6,832–6,879, 6,882–6,908 and 7,154–7,170 feet reportedly yielded only mud and a few rainbows and fluorescences of oil.

The Zach Brooks Co. drilled the No. 1 Larson in the southeast part of the quadrangle in the center of the NW¼SW¼ sec. 2, T. 32 N., R. 55 E. Data on drill-stem tests are not available; the well has been abandoned.

No favorable structures for the accumulation of oil and gas were detected during the mapping of the quadrangle. The regional dip of 15 to 18 feet per mile to the southeast is interrupted by only slight flexures of small areal extent.

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