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Preliminary Study of Geotechnical
Properties of the Fort Union Formation
near Recluse, Wyoming

By E. E. McGregor and J. K. Odum

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

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Preliminary Study of Geotechnical Properties of the

Fort Union Formation near Recluse, Wyoming

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Introduction

This report contains the results of selected physical-properties tests of rocks from the Fort Union Formation near Recluse, Wyo. The rocks were obtained from drill holes cored by a contractor for the U.S. Geological Survey (see figs. 1, 2, and appendix for locations and legal descriptions). Testing was done at the drill hole sites by E. E. McGregor and J. Sebesta and in the laboratory by J. K. Odum and J. Sebesta of the U.S. Geological Survey, Golden, Colo. The purpose of this study is to gather data on the physical properties of the Fort Union Formation that relate to coal mining operations in this area and to make these data public; this study is part of an engineering geologic research program on rock properties in the Powder River Basin, and is part of the Energy Lands Program.

Testing of the rock samples has followed ASTM (Am. Soc. Testing and Materials, 1964) procedures wherever possible. The ASTM test designations are discussed in section called "Explanatory Notes." The other tests that are not ASTM standards are included in this report as research and experimental information.

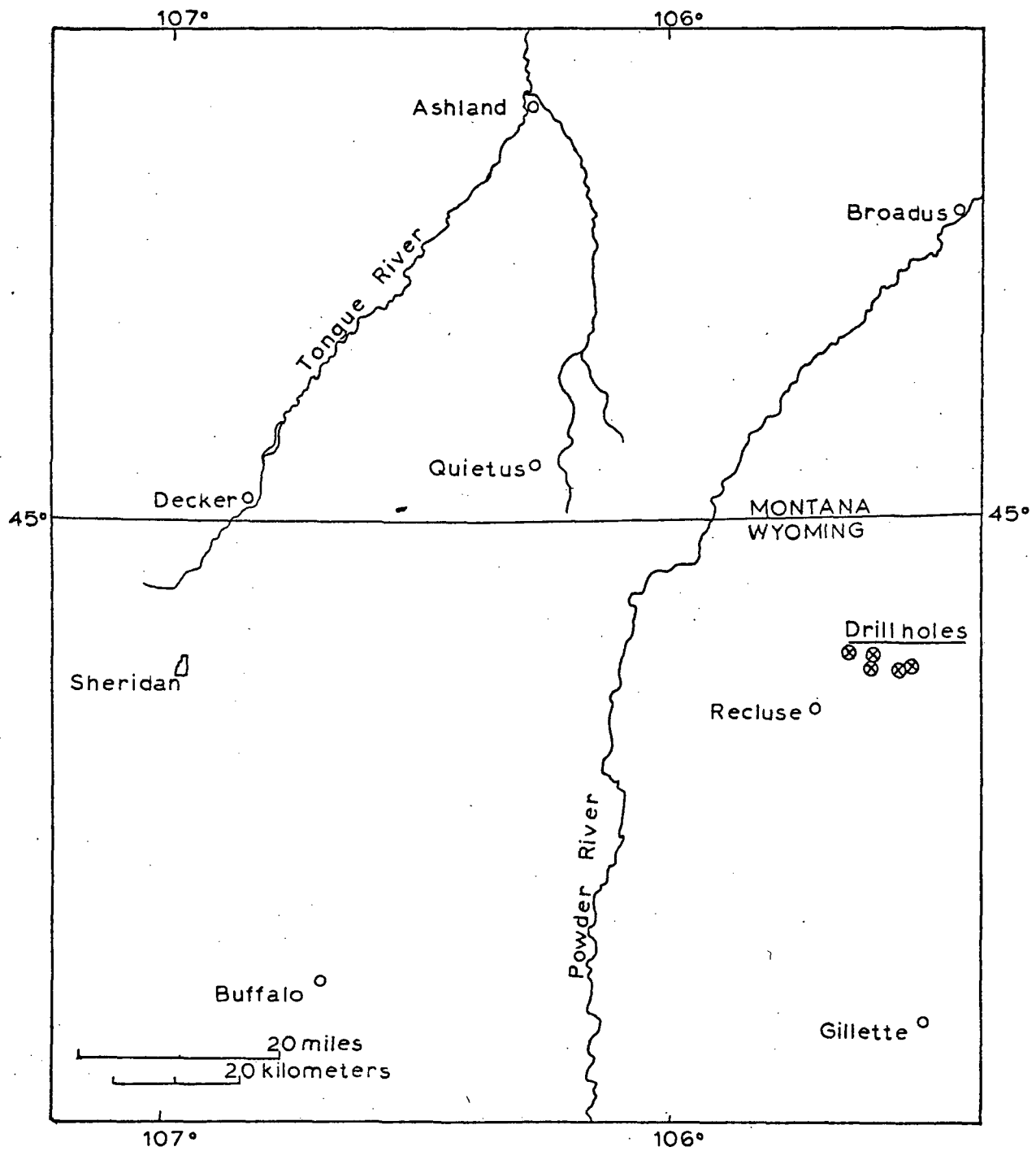


Figure 1. Index map of Northern Powder River Basin, showing locations of drill holes from which cores were tested. Drill hole numbers shown on figure 2.

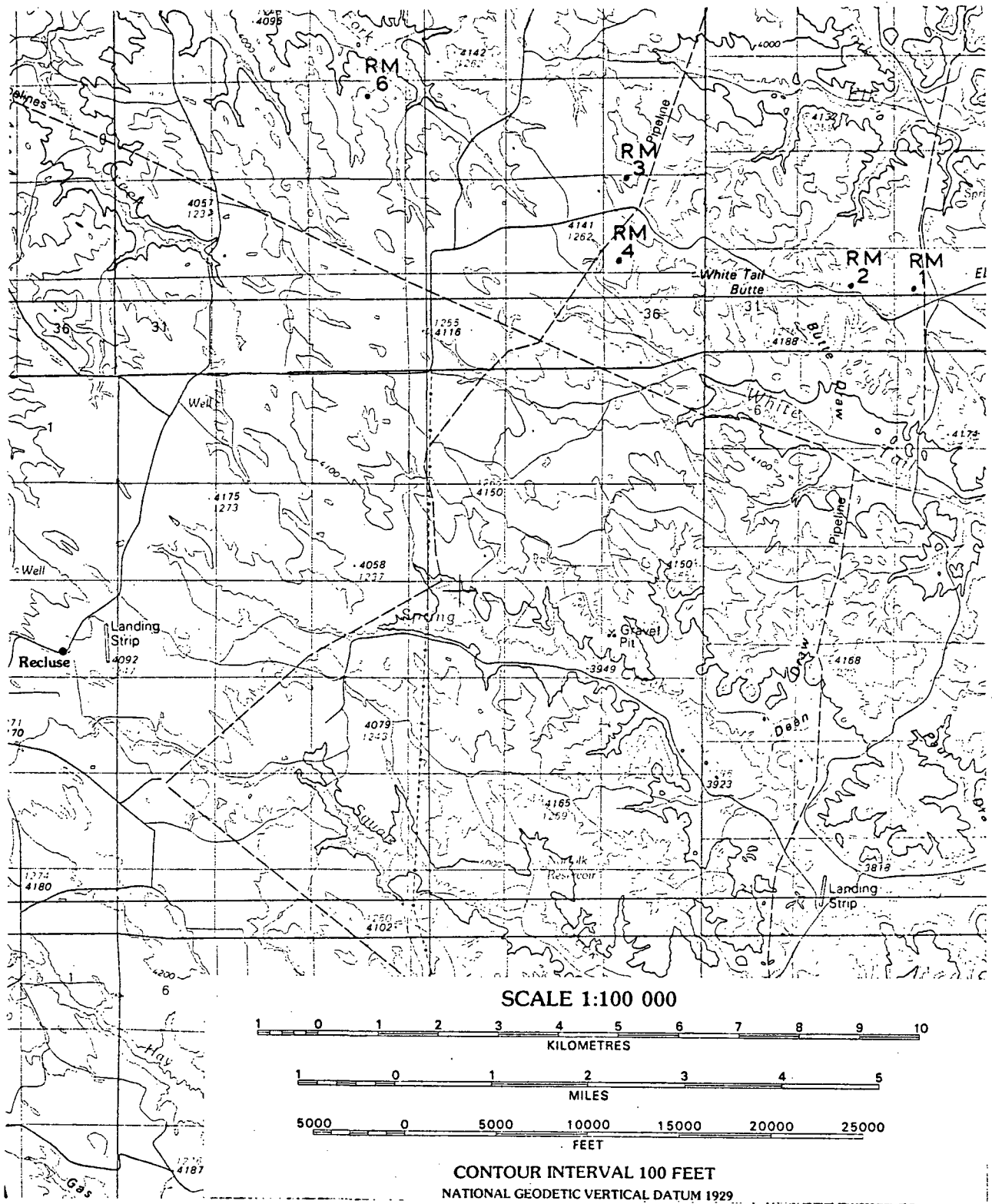


Figure 2. Map of Recluse-White Tail Butte area, showing locations of drill holes included in this report. Legal descriptions are in Appendix.

Engineering Geology

Approximately 250 tests were performed on 72 samples of core, 82.6 mm in diameter, to determine geotechnical properties. An average of 14 rock samples was taken from each drill hole for testing, both in the field and in the laboratory. The results of these tests indicate weak rocks that can pose engineering geologic problems associated with the in-place material and the disturbed material.

With only a few exceptions, compressive- and tensile-index tests performed on the rock samples have low values similar to those test results obtained on rock samples from drill holes at Ashland, Mont. (McGregor, 1975). These data and the physical-properties data, Atterberg limits, and gradation (grain-size distribution) suggest the need for careful design in slopes, open mine faces, and open-pit floors. Some of the rocks were so weak that they could not be tested as rocks and had to be considered as soils for geotechnical testing.

Testing of rocks from other areas in the Powder River Basin, near Quietus, Mont., Sheridan, Buffalo, and Monarch, Wyo., is in progress at this writing. It is hoped that results from this testing, along with those in this report, will give more definitive answers to some of the engineering geologic problems of the rocks in the Fort Union Formation.

Explanatory Notes

The Unified Soil Classification, gradation, and Atterberg limits are from the "Earth manual--A water resources technical publication" (U.S. Bureau of Reclamation, 1974):

1. Unified Soil Classification System.
2. Gradation (grain-size distribution): ASTM designation D-422-63. Material finer than a No. 200 sieve is subdivided as follows--silt, 0.074-0.004 mm; clay-size is less than 0.004 mm, according the Wentworth classification (1922).
3. Atterberg limits: ASTM designation D-423-66, liquid limit of soils. ASTM designation D-424-54T, plastic and plasticity index of soils.

The following field index tests are described in Aufmuth (1974):

1. The Schmidt rebound hammer is essentially a nondestructive, portable, and inexpensive test device that expends a definite amount of energy stored in a spring (approximately 0.54 ft/lb) in impelling a steel hammer of uniform weight and cross-sectional area against the material's surface. The amount of rebound of the hammer after striking the surface is indicated on a graduated scale. This number has been designated as "R," and has been correlated with the compressive strength of concrete and rock. Values shown in the column are in "R's".
2. The slake durability test is a measurement of the resistance of a rock to weakening and (or) disintegration resulting from cyclic wetting and drying. Values shown in the column are the percentages of material larger than 2 mm remaining after the test. Ten rock specimens, each weighing 40-60 g and oven-dried at 43°C to constant weight, are placed in a 2-mm standard mesh cylinder. The cylinder is placed in a water tank containing distilled water as the slaking fluid and is rotated at 20 r/min \pm 1 r/min by a motor assembly for 10 minutes. Then the mesh drum is removed from the slaking fluid tank, and the remaining material is removed from the drum, dried to constant weight, and weighed. The slake durability index is calculated as the percentage ratio of the final to initial dry-sample weight. Data for one cycle are shown in this report.

3. The point-load strength test is intended to measure the strength of rock samples in the form of specimens of regular geometry. Testing was done on natural core in the field and as received in the laboratory. Data obtained consist of failure load in psi (pounds per square inch) at time of failure, and the core diameter and (or) cross-sectional area at initial loading. From this, the point-load tensile strength of the rock may be calculated. Values shown in the column by the triangles are the tensile strengths parallel to bedding, and, by the circles, normal to bedding. These values are expressed in MN/m^2 (meganewtons per square meter). The test procedure was described in detail by Broch and Franklin (1972).

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-1

Powder River Basin
Recluse area
Hole RM-1
Collar elevation: 4204'

Depth		Lithologic description	Fracture spacing (cm)			Unified Soil Classification ³	Grain size distribution (percentage of dry soil weight)					As received water content & Atterberg limits (percentage of dry soil weight)		Slake Durability index ⁵ (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Anisotropy index ⁸
Feet	Meters		5	15	25		Sand	Silt	Clay	PL	LL ⁴	CaCO ₃ ⁵	20		40	0.2	0.6		
96	24	Mudstone, gray to dark gray, slightly silty, some mottling				CH	25	75				(+)					1.2		
	25																		
100	30	Mudstone, as above				CH	51	49				(-)	88				1.4		
	31	Shale, brown, numerous silty streaks, highly carbonaceous, coal streaks and stringers																	
	31	Coal, dark brown, highly fractured																	
120	36	Mudstone, dark brown to black, highly carbonaceous				CH	32	68				(T)					0.9		
	37	less carbonaceous, silty streaks, becomes more grayish in color																	
	38																		
	39	massive and hard																	
136	40																		
	41	Shale, dark brown to black, some silty streaks				CH	41	59				(T)	93				1.0		
	42	slightly laminated																	
140	43	becomes browner in color with depth																	
	44	carbonaceous streaks				MH	1	46	53			(T)					0.18		
	45	Coal, dull, woody, shaly streaks																	
	66	Mudstone, brown grading to gray, silty																	
150	67	Sandstone, gray, very fine to fine grained, some bedding thin carbonaceous zones					53	47				(T)	94				2.1 0.62		

Explanatory notes:

¹See Graphic Lithology Key in Appendix
²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

PL = plastic limit
LL = liquid limit
PI = plasticity index
O = natural water content
⁵+, positive
-, negative
T, trace

⁶Dimensionless

⁷Δ = value recorded parallel to bedding R units
O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-2

Powder River Basin
Recluse area
Hole RM-2
Collar elevation: 4238'

Depth Feet Meters	Graphic Lithology Drilling Recovery Core Intervals Tested	Lithologic description (Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durabil- ity index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{\circ}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	PI	CaCO ₃ ⁵	20		40	0.2	0.6		
1		Mudstone, brown to gray																		
2		scattered sandstone laminae and beds																		
3																				
4																				
5																				
6		Sandstone, brown to buff, silty, scattered carbonaceous flakes and fragments				CL		53	47											
7																				
8		friable				CL		51	49											
9																				
10		Mudstone, yellowish brown, oxidized coloration changing to gray and brown				CL		42	58											
11																				
12																				
13		silty				CH		38	62											
14																				
15		dark gray, slightly carbonaceous fractures common scattered siltstone zones				CH		7	93											
16																				
17		Shale, dark brown, highly carbonaceous to coaly				CH		29	71											
18		Mudstone, gray to light gray, carbonaceous streaks				CH		38	62											
19		Sandstone, medium to light gray, very fine to fine grained, subangular				ML		40	28	32										

Explanatory notes:

¹See Graphic Lithology Key in Appendix
²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

⁴PL = plastic limit
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O = natural water content
⁵+, positive
-, negative
T, trace

⁶Dimensionless

⁷ Δ = value recorded parallel to bedding R units
O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-2--Continued

Powder River Basin
Recluse area
Hole RM-2
Collar elevation: 4238'

Depth Feet	Graphic Lithology Drilling Recovery Core Intervals Tested	(Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					⁵ CaCO ₃	Slake Durabil- ity index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{\sigma}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	10	30	50			70	90	20	40	
21		Sandstone, light gray, becomes harder downward.				CH		33	67												
22																					
23		scattered mudstone laminae				CH	8	62	30												
24																					
25		Mudstone, light gray, alternating bands of light and dark gray mud- stone and very fine grained sand- stone				CH		51	49												
26																					
27																					
28		scattered shaly zones, carbona- ceous, pyritic fossiliferous				CH		15	85												
29																					
30																					
31		Siltstone, brown to gray, very hard																			
32		Mudstone, gray to light gray, silty, fractured																			
33		Sandstone, gray, very fine grained																			
34		Mudstone, as above scattered silty laminae				CL		68	32												
35		Siltstone, light gray to gray, sandy laminae and zones																			
36		fractured																			
37		light brown silty and sandy zones				CH		35	65												
38						CH		57	43												
39		fossiliferous																			

Explanatory notes:

See Graphic Lithology Key in Appendix
Asterisk, *, shows sample depth

³Symbols from Unified Soil
Classification Chart (from
U.S. Bureau of Reclamation,
1974).

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O = natural water
content

⁵+, positive
-, negative
T, trace

⁶Dimensionless

⁷ Δ = value recorded parallel
to bedding R units
O = value recorded perpendicular
to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-2--Continued

Powder River Basin
Recluse area
Hole RM-2
Collar elevation: 4238'

Depth Feet Meters	Graphic Lithology 1 Drilling Recovery Core Intervals (USBR)	(Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					⁵ CaCO ₃	Slake Durabil- ity index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{O}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	10	30	50			70	90	20	40	
-200	61	Shale, dark grayish brown, silty carbonaceous and coal stringers				MH		58	42							(-)					
	62	Coal, bright to dull, semi-banded, fractured and blocky																			
	63																				
	64	highly pyritic																			
	65																				
	66																				
	67																				
	68	highly fractured zones																			
-225	69																				
	70	Shale parting, dark gray to black, carbonaceous, grades to claystone																			
	71	Claystone, light gray to black, carbonaceous to coaly, grades to shale																			
	72	Coal, dark brown to black, silty																			
	73	fractured pyritic shale parting as above																			
	74																				
	75																				
-250	76	some banding and occasional woody material																			
	77																				
	78																				
	79	less fractured																			

Explanatory notes:

¹See Graphic Lithology Key in Appendix
²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

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PI = plasticity index
O = natural water content
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-, negative
T, trace

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⁷ Δ = value recorded parallel to bedding R units
O = value recorded perpendicular to bedding

Powder River Basin
Recluse area
Hole RM-2
Collar elevation: 4238'

(Description of lithology taken from Hobbs and others, 1977)

Depth Feet	Graphic Lithology 1 Drilling Recovery Cont. Intervals Tested	Lithologic description	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durabil- ity Index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{\circ}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	CaCO ₃ ⁵	20	40		0.2	0.6			
-81		Coal, dull to shiny																		
-81	*	Mudstone, light gray, coaly streaks				CL	8	58	34											
-82		Sandstone, gray fine grained																		
-82	*	Siltstone, gray, shaly and coaly				CL	9	57	34											
-83		Sandstone, as above																		
-275																				
-84																				
-85																				
-86																				
-86		Sandstone, as above																		
-87																				
-88																				
-89																				
-90																				
-91	*	Sandstone, as above				CL	2	51	47											
-300																				
-92																				
-93																				
-94		Sandstone, petroliferous				CL	3	50	47											
-95		Shale, dark gray to brown, carbona- ceous																		
-96		Coal, dark brown, clayey pyritic fractures																		
-97																				
-98		low grade - poor quality																		
-325																				
-99																				

Explanatory notes:

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²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

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O = natural water content

⁵+, positive
-, negative
T, trace

⁶Dimensionless

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O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-3

Powder River Basin
Recluse area
Hole RM-3
Collar elevation: 4195'

(Description of lithology taken from Hobbs and others, 1977)

Depth Feet Meters	Graphic Lithology Drilling Recovery Core Intervals Tested	Lithologic description	Fracture spacing (cm)			Unified Soil Classification ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)			⁵ CaCO ₃	Slake Durability index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Anisotropy index $\frac{\Delta}{O}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	20			40	0.2	0.6		
6		Siltstone, light yellow brown				CH		31	69	○	—		(T)				△	○	0.51
30		Mudstone, reddish brown																	
10		Mudstone, bluish gray, carbonaceous stringers								○	—								
11		Mudstone, light brown, scattered laminae of silt				CH		50	50		—		(T)				△	○	0.57
40		Shale, gray, carbonaceous and sandy stringers																	
18		Shale, gray, silty and sandy				CH	4	51	45	○	—		(+)				△	○	0.59
19		Siltstone, light gray, very calcareous															○	△	1.46
23		Shale, gray slightly carbonaceous																	
24		Coal, silty stringers																	
24		Mudstone, gray brown, scattered sandy laminae				CH	12	53	35		—		(T)				△		
25		Shale, brown, slightly carbonaceous, fractured zones																	
26																			
27		very sandy streaks				CH-MH		19	81		—		(T)						
40		Mudstone, light gray increasingly more silty with depth																	
41		Siltstone, light gray, fractured				CL		30	70		—		(T)						

Explanatory notes:

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²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

⁴PL = plastic limit
LL = liquid limit
PI = plasticity index
○ = natural water content

⁵+, positive
-, negative
T, trace

⁶Dimensionless
⁷△ = value recorded parallel to bedding R units
○ = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Powder River Basin
Recluse area
Hole RM-4
Collar elevation: 4142'

Geologic and Geotechnical Log of Drill Hole RM-4

Face	Depth meters	Graphic Lithology 1 Drill Pipe Recovery Core Intervals Tested	Lithologic description (Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durabil- ity Index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{C}$
				5	15	25		Sand	Silt	Clay	PL	LL ⁴	PI	10	30		50	70	90	5CaCO ₃	
	8		Mudstone, gray, fractured				CH														
	9																				
	10		Sandstone, light gray, medium grained numerous carbonaceous stringers																		
	11		Mudstone, light gray brown				CH		42	58											
	12		Sandstone, light gray, fine to medium grained, numerous carbona- ceous streaks																		
	17		Siltstone, light gray, clayey, fissile				CH		58	42											
	18		Mudstone, gray to dark gray, silty and sandy partings, fissile																		
	19		Siltstone, light gray, very calcar- eous and hard				CH		45	55											
	35		Mudstone, black, carbonaceous, shaly				CH-MH		29	71											
	34		Mudstone, gray, silty				CH		30	70											
	55		carbonaceous streaks																		
	56						CL		51	49											
	60		Mudstone, dark brown to black, shaly, carbonaceous																		
	61		siltstone laminae and zones				MH CH-MH	15 6	7 10	78 84											
	62						CL CH	8 24	42 76	50 76											

Explanatory notes:

- ¹See Graphic Lithology Key in Appendix
- ²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

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LL = liquid limit
PI = plasticity index
O = natural water content

⁵+, positive
-, negative
T, trace

⁶Dimensionless

⁷ Δ = value recorded parallel to bedding R units
O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Powder River Basin
Recluse area
Hole RM-4
Collar elevation: 4142'

Geologic and Geotechnical Log of Drill Hole RM-4--Continued

Depth Feet Meters	Graphic Lithology Drill core recovery Core intervals tested	Lithologic description (Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durabil- ity index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{\sigma}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	CaCO ₃ ⁵	20	40		0.2	0.6			
		Mudstone, dark gray, carbonaceous																		
64																				
65	*	Mudstone, as above				CL	12	49	39											
66	*	Siltstone, gray, sandy																		
66	*	Mudstone, as above																		
220																				
67		silty				CL	6	54	40											
68	*	Sandstone, medium gray, fine grained				CL	2	40	58											
69																				
70		Mudstone, dark gray, silty, carbonaceous																		
71	*					CH		42	58											
72		coaly stringers																		
240																				
73	*	Siltstone, gray, very hard				CH	2	10	88											
74	*	Mudstone, medium to dark gray, carbonaceous				CL-CH		30	70											
75																				
76																				
77																				
78																				
260																				
79	*	coaly streaks				CH	3	16	81											
80	*					ML	1	8	91											
81																				
82																				

Explanatory notes:

¹See Graphic Lithology Key in Appendix
* Asterisk, *, shows sample depth

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LL = liquid limit
PI = plasticity index
O = natural water content

⁵+, positive
-, negative
T, trace

⁶Dimensionless

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O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-4--Continued

Powder River Basin
Recluse area
Hole RM 4
Collar elevation: 4142'

Depth Feet	Meters	Graphic Lithology Drilling Recovery Core Intervals Tested	(Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classifi- cation ³	Grain size distribution (percentage of dry soil weight)					As received water content & Atterberg limits (percentage of dry soil weight)					⁵ CaCO ₃	Slake Durabil- ity index (pct. of dry soil weight retained)	Schmidt hammer ⁶		Point-load strength indices ⁷ (MN/m ²)		Aniso- tropy index $\frac{\Delta}{\circ}$
				5	15	25		Sand	Silt	Clay	10	30	50	70	90	20	40			0.2	0.6			
84		*	Mudstone, dark gray, carbonaceous				CH		29	71						(T)								
85																								
86																								
87		*					CH		13	87						(T)								
88																								
89																								
90							CL-ML		29	71						(T)								
91																								
92			Coal, black, cleat fractures																					

Explanatory notes:

¹See Graphic Lithology Key in Appendix
²Asterisk, *, shows sample depth

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⁴ PL = plastic limit
LL = liquid limit
PI = plasticity index
O = natural water content

⁵+, positive
-, negative
T, trace

⁶Dimensionless

⁷ Δ = value recorded parallel to bedding R units
O = value recorded perpendicular to bedding

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RM-6

Powder River Basin
Recluse area
Hole RM-6
Collar elevation: 4106'

Depth		Lithologic description	Fracture spacing (cm)			Unified Soil Classification ³	Grain size distribution (percentage of dry soil weight)					As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durability index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Anisotropy index $\frac{\Delta}{\sigma}$
Feet	Meters		5	15	25		Sand	Silt	Clay	PL	LL ⁴	CaCO ₃ ⁵	20	40	0.2	0.6						
17		Sandstone, gray, fine grained, massive, faint carbonaceous streaks				SM	56	8	36													
18																						
22		Mudstone, gray to dark gray, carbonaceous				CH	4	20	76													
23																						
24		scattered slickensides																				
25		scattered fractured zones				CH		35	65													
26																						
27						MH		23	77													
38		Mudstone, as above, scattered plant fragments				CH	5	10	85													
39		impure coaly streaks and zones																				
40		coal with pyritic laminae, impure																				
41																						
42						CH	2	4	94													
43																						
44		Mudstone, as above				CL		13	87													
45		Sandstone, medium gray, very fine to fine grained, silty, coaly streaks																				
46		crossbedding near base																				
		Mudstone, gray, carbonaceous and pyritic																				
		Siltstone, light gray, sandy																				

Explanatory notes:

¹See Graphic Lithology Key in Appendix
Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

PL = plastic limit
LL = liquid limit
PI = plasticity index
O = natural water content

⁵+, positive
-, negative
1, trace

⁶Dimensionless

Δ = value of index parallel to bearing axis

σ = value of index perpendicular to bearing axis

Geologic and Geotechnical Log

Geologic and Geotechnical Log of Drill Hole RN-6--Continued

Powder River Basin
 Recluse area
 Hole RM-6
 Collar elevation: 4106'

Depth Feet Meters	Graphic Lithology Lithology I Drilling Recovery Core Intervals Listed*	Lithologic description (Description of lithology taken from Hobbs and others, 1977)	Fracture spacing (cm)			Unified Soil Classification ³	Grain size distribution (percentage of dry soil weight)			As received water content & Atterberg limits (percentage of dry soil weight)					Slake Durability Index (pct. of dry soil weight retained)	Schmidt hammer index ⁶		Point-load strength indices ⁷ (MN/m ²)		Anisotropy index $\frac{\Delta}{\circ}$
			5	15	25		Sand	Silt	Clay	PL	LL ⁴	CaCO ₃ ⁵	20	40		0.2	0.6			
48		Sandstone, light gray, very fine to fine grained, silty, scattered coaly streaks and pyritic nodules				CL	1	20	79											
49																				
50		Sandstone, as above																		
51						ML-CL	1	65	34											
52																				
53		Siltstone, light gray, irregular bedding, pyritic, scattered plant fragments and calcareous fossils				ML-CL		33	67											
54																				
55																				

Explanatory notes:

¹See Graphic Lithology Key in Appendix
²Asterisk, *, shows sample depth

³Symbols from Unified Soil Classification Chart (from U.S. Bureau of Reclamation, 1974).

⁴PL = plastic limit
 LL = liquid limit
 PI = plasticity index
 O = natural water content

⁵+, positive
 -, negative
 T, trace

⁶Dimensionless

⁷ Δ = value recorded parallel to bedding R units
 O = value recorded perpendicular to bedding

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Appendix

Legal Descriptions of Drill Holes

RM-1 SE1/4 SW1/4 NW1/4 sec. 33, T. 56 N., R. 72 W.
RM-2 SW1/4 SW1/4 NE1/4 sec. 32, T. 56 N., R. 72 W.
RM-3 NE1/4 NW1/4 NW1/4 sec. 25, T. 56 N., R. 73 W.
RM-4 NE1/4 SW1/4 SW1/4 sec. 25, T. 56 N., R. 73 W.
RM-6 NE1/4 NW1/4 NE1/4 sec. 21, T. 56 N., R. 73 W.

LITHOLOGIC SYMBOLS



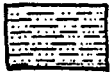
Soil horizons
and root zones



Shale



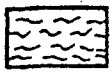
Sandstone



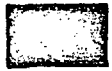
Siltstone



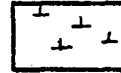
Claystone



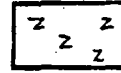
Mudstone



Coal



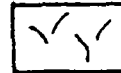
Calcareous



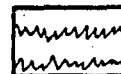
Plant fragments



Pyritic



Slickensides



Washed-out zones,
core loss