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GEOLOGICAL SURVEY

Preliminary study of the geotechnical properties of the Fort Union Formation from the White Tail Butte drill holes 76-103 and 76-108 near Recluse, Wyoming

By

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Contents

Illustrations

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Introduction

This report contains lithologic and geotechnical data on core samples from two drill holes. They are White Tail Butte drill holes 76-103 and 76-108, drilled by the U.S. Bureau of Reclamation (USBR) and U.S Bureau of Land Management (USBLM) in cooperation with the U.S. Geological Survey (USGS). The holes were drilled at White Tail Butte, in the Little Powder River coal field near Recluse, Wyo. (fig. 1). Hole 76-103 was drilled between July and September 1976, and is located in sec. 31, T. 56 N., R. 72 W. Hole 76-108, located in sec. 24, T. 56 N., R. 73 W., was begun in October 1976 and completed in the spring of 1977. Drilling for both holes was done solely within the Fort Union Formation and its surficial material.

This study is part of the Energy Lands Program effort to define the geotechnical characteristics of the Fort Union Formation in the Powder River Basin, Wyo. Its purpose is to provide information pertinent to the effects of mining in the formation and to help define characteristics of formation materials comprising spoil banks on reclaimed land.

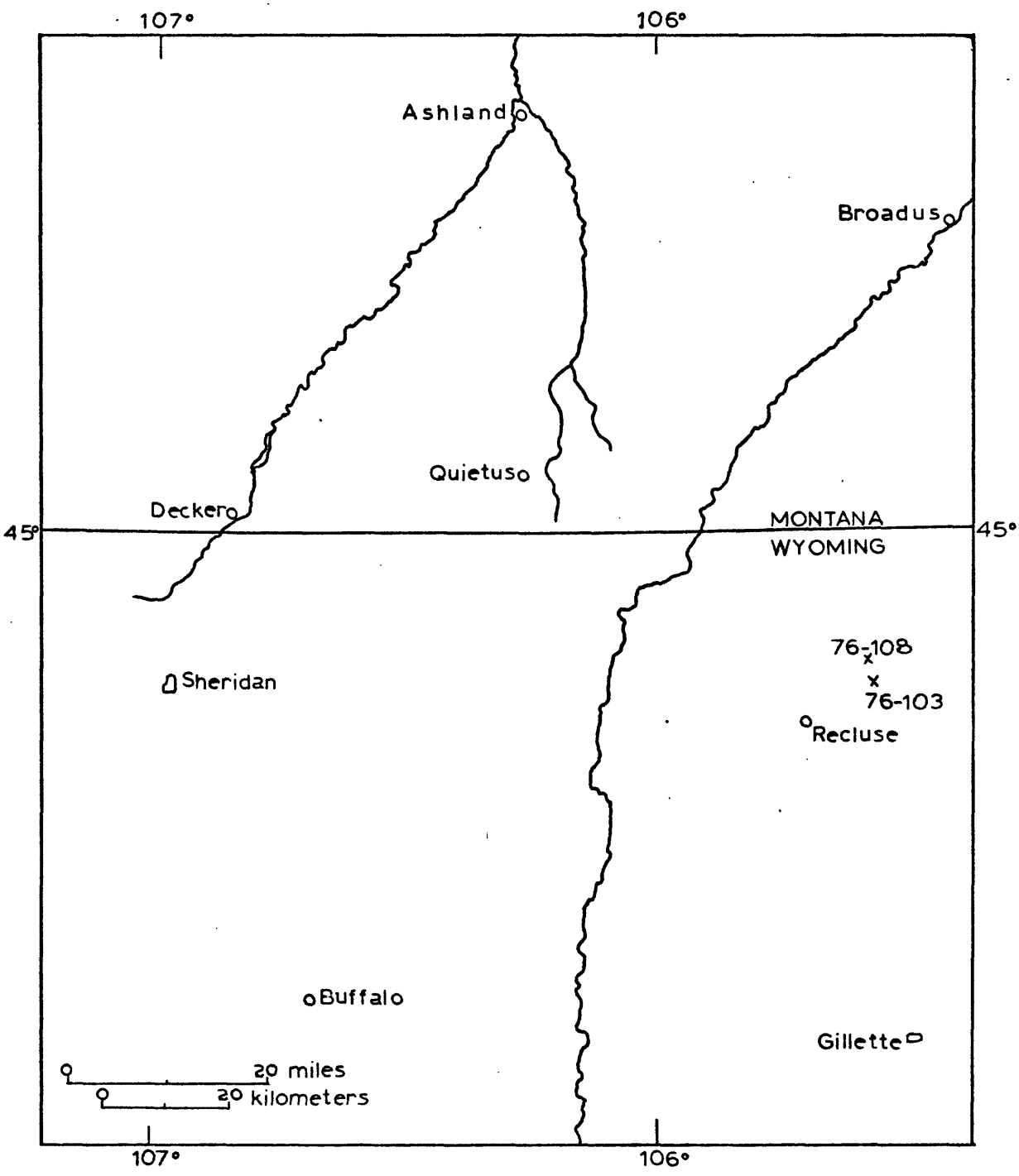


Figure 1.--Location of White Tail Butte drill holes 76-103 and 76-108, near Recluse, Wyo.

Scope of study

Except for the fracture pattern distribution count which was done at the drilling site, the analysis of core was carried out entirely in the U.S. Geological Survey's laboratory in Golden, Colo. Its scope included lithologic logging and the following geotechnical property analyses: Atterberg limits, grain-size distribution, as-received density, dry-bulk density (calculated after oven drying), slake durability, and the reaction to dilute hydrochloric acid. The results are summarized in Appendix 1. Because of moisture loss and exposure, the condition of the core received in the laboratory did not permit reliable measurements of natural density, natural moisture content, and strength characteristics. Where no core was available for laboratory study, lithologic information and some field data were obtained from the unpublished log kept in the field.

Hole 76-103 had a total depth of 216.5 m (710.2 ft); the core that was made available to the laboratory for testing represented approximately 60 percent of the cored interval from 71 to 216.5 m (232.9 to 710.2 ft). Hole 76-108 had a final depth of 239.4 m (785.5 ft) after resumption of drilling in the spring of 1977; the core that was made available to the laboratory for testing represented approximately 38 percent of the interval from 0 to 146.9 m (0 to 482 ft). Fracture-count data and samples for as-received density data were obtained for the interval of 36.2-143.3 m (118.7-470 ft) for hole 76-108 only. Competent samples were not generally available for study from either hole and data on total core recovery are not yet available for publication.

Acknowledgments

Natural gamma and gamma-gamma density logs were run by the U.S. Geological Survey on September 16 and 17, 1976, for hole 76-103, and on March 22, 1976, for hole 76-108 by R. N. Babcock of the USGS. Copies of these logs are on file with the U.S. Geological Survey, Denver, Colo. Physical properties testing was performed by M. H. Jones, H. A. Cloft, J. M. Leitner, and H. D. Gomez of the U.S. Geological Survey, Golden, Colo. Lithologic descriptions of core intervals removed for testing by other agencies were obtained from unpublished field notes of R. G. Hobbs, U.S. Geological Survey, Denver, Colo.

Field test program and procedures

The only test performed in the field was the determination of the fracture spacing of the core from drill hole 76-108. This was done immediately after the core was removed from the core barrel. The core was grouped into intervals of approximately evenly spaced fractures. The interval distance was divided by the number of fractures to get an average fracture spacing, which is graphically displayed as centimeters per fracture in the data sheets found in Appendix 1.

Laboratory test program and procedures

Work performed at the laboratory included the logging of available core and the determination of: the Unified Soil Classification, grain-size distribution, Atterberg limits, presence of $CaCO_3$ as determined by the material's reaction to a weak hydrochloric acid solution, slake durability index, and dry bulk density. As-received bulk density values were determined for selected core samples from drill hole 76-108 that were sealed in airtight plastic containers.

The scope of the laboratory test program was limited by the condition of the core upon arrival at the laboratory. Part of the core was saturated because it had been covered with wet rags. Uncovered parts of the core were dried out. Along most sections of the core, drying resulted in separation along bedding planes and air slaking. As a result, few samples with the proper length-to-width ratio required for point load, Schmidt hammer, and unconfined compression tests were available for testing.

Brief explanation of the tests performed

Atterberg limits

Atterberg limits define the moisture contents at which a soil changes from a solid state to a plastic state and from a plastic state to a liquid state. The range is shown as a bar graph (Appendix 1). The standard test for the liquid limit of soils, ASTM designation D423-66, reapproved 1972 (American Society for Testing and Materials, 1978, p. 81-84), and the standard test for the plastic limit of soils, ASTM designation D424-59, reapproved 1971 (American Society for Testing and Materials, 1978, p. 85-86), were used.

The liquid limit (LL) is the water content of the soil at which it changes from a plastic to a liquid state, and the plastic limit (PL) is the water content of the soil at which it changes from a solid or semisolid state to a plastic state. These limits are reported as the water content in percentage of dry soil weight. The plasticity index is the difference between the liquid limit and the plastic limit and represents the range of water contents over which a soil is plastic (U.S. Bureau of Reclamation, 1974).

Grain-size distribution

The grain-size distribution analysis used in this study provides relative percentages of sand, silt, and clay according to the standard method for particle-size analysis of soils, ASTM designation D422-63, reapproved 1972 (American Society for Testing and Materials, 1978, p. 70-80).

Unified Soil Classification

A description of the symbols used in Appendix 1 can be found in the "Earth Manual" published by the U.S. Bureau of Reclamation (1974). This manual describes size, dry strength, dilatancy (reaction to shaking), consistency near the plastic limit, and other general characteristics according to group symbols.

Dry bulk and as-received density

Dry bulk densities were determined utilizing the techniques for measuring bulk volume as described by Chleborad, Powers, and Farrow (1975). It should be noted that dry bulk density (dry weight/dry volume) as defined here means that the sample was oven dried before any measurements were made. Samples for as-received density, collected at the drill site, were removed from their airtight containers and weighed immediately. These densities closely approximate natural state densities.

Slake durability

Slake durability testing followed the procedures of Franklin and Chandra (1972) and is a measure of a rock's resistance to weakening or disintegration due to cyclic wetting and drying. A standard 2-mm mesh cylinder containing 10 irregular specimens, dried to a constant weight of 40-60 g each, is partially immersed in distilled water, and rotated at 20 r/min for 10 minutes. All particles larger than 2 mm are retained within the mesh cylinder, dried, and weighed. The percentage ratio of the final to initial dry sample weight is the slake durability index. Slake durability results are for a one-cycle run only. An observation was made that some samples with high-clay contents tend to adhere to the mesh surface of the tumbling apparatus and therefore do not fall fairly during rotation. This observation suggests the quantitative significance of results on some dominantly clay rich material may be limited.

Test results

Appendix 1 presents, in tabular and graphical form, all physical properties (grain-size analysis, Atterberg limits, and densities) test results for drill holes 76-103 and 76-108, White Tails Butte, Wyo. As-received bulk density and fracture spacing tests were performed on samples from drill hole 76-108 only. A specific sample's test results are displayed horizontally, while the sample's depth and stratigraphic location to other samples are displayed vertically.

References

American Society for Testing and Materials, 1978, Natural building stones; soil and rock; peats, mosses and humus, Pt. 19 of Annual book of ASTM standards: American Society for Testing and Materials, 560 p.

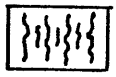
Chleborad, A. F., Powers, P. S., and Farrow, R. A., 1975, A technique for measuring bulk volume of rock materials: Association of Engineering Geologists Bulletin, v. 12, no. 4, p. 317-322.

Franklin, J. A., and Chandra, R. J., 1972, The slake-durability test: International Journal of Rock Mechanics and Mining Science, v. 9, no. 3, p. 325-341.

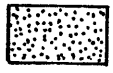
U.S. Bureau of Reclamation, 1974, Earth manual--A water resources technical publication [2d ed.]: U.S. Bureau of Reclamation, 810 p.

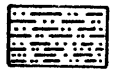
Appendix 1

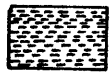
LITHOLOGIC SYMBOLS

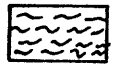

Soil horizons


Shale

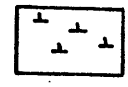

Sandstone

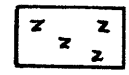

Siltstone

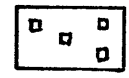

Claystone

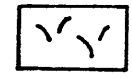

Mudstone

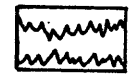

Coal


Calcareous


Plant fragments

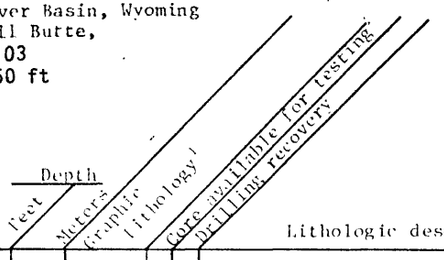

Pyritic


Slickensides


Washed-out zones, core loss

GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft



Depth (feet)	Depth (meters)	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm³) As-received	Density (g/cm³) Dry-bulk
	71	Mudstone, medium to dark gray, carbonaceous fragments, slickensides, becomes increasingly more sandy with depth		CH	3	34	63		(-)			1.92
	72			MH	11	12	77		(-)			1.92
	73			CL	3	53	44		(-)			1.86
				CH		32	68		(-)			1.94
	74											
		Coal, very low grade, brownish		MH	30	9	61		(-)			1.72
	75	Sandstone, gray, very fine grained to silty, scattered clayey zones, soft to slightly friable, plant fragments,		CL/ML	20	53	27		(-)			1.54
250	76			CH	1	35	64		(-)			1.97
		grades to mudstone		CL	11	57	32		(-)	72		1.92
	77											
	78	Shale, very dark gray to black, carbonaceous		CL	10	45	45		(-)			1.87
		black carbonaceous shale		CL	1	37	62		(-)			1.90
	79	Mudstone, gray, clayey		CH	20	15	65		(-)			1.93
				MH	2	24	74		(T)	30		1.96
	80	Coal, medium hard, vitreous, conchoidal to uneven fracture										
	81	sharp lower contact										
	82	Mudstone, gray, very silty, slightly carbonaceous, grades to sandstone		CL	21	47	32		(-)			1.91
	83	Sandstone, light gray to gray, very fine to fine grained, scattered plant fragments and pyritic nodules										
275	84											
	85			SM	37	44	32		(-)			1.57
		soft to crumbly		CL	10	50	40		(-)			1.84
	86			ML	19	53	28		(-)			1.83
	87	increasingly silty		CL	9	50	41		(-)			1.75
	88											
	89											

Explanatory notes:

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

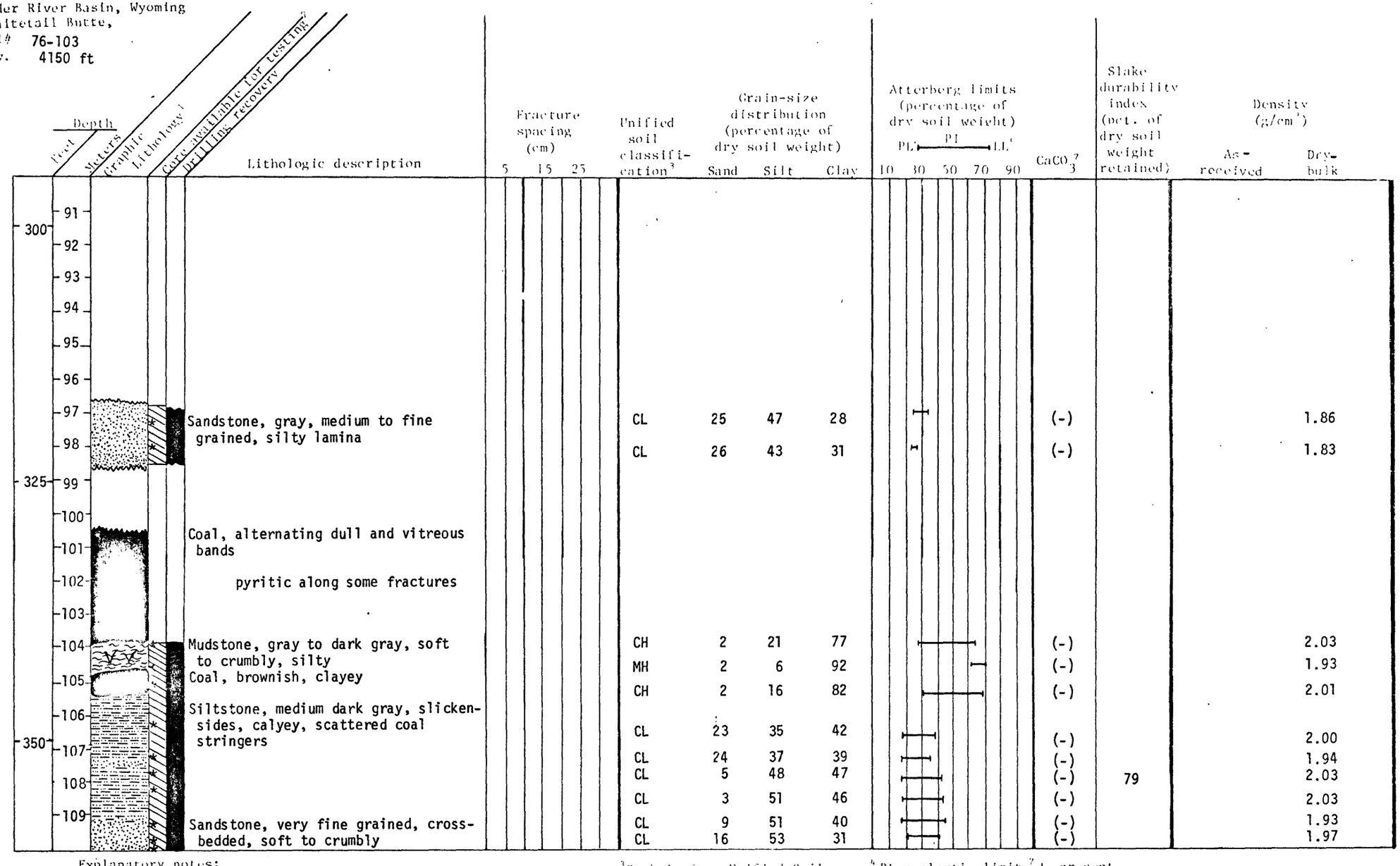
[3]Symbols from Unified Soil Classification Chart by U.S. Bureau of Reclam. (1974)
S= sand, M= silt, C= clay
L= low plasticity
H= high plasticity

[4]PL = plastic limit
[5]LL = liquid limit
[6]PI = plasticity index

[7]+, present
-, not present
T, trace

GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft



Depth (Feet)	Depth (Meters)	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4]	PI	LL[5]	$CaCO_3$[7]	Slake durability index (oct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
	91													
300	92													
	93													
	94													
	95													
	96													
	97	Sandstone, gray, medium to fine grained, silty lamina		CL	25	47	28				(-)			1.86
	98			CL	26	43	31				(-)			1.83
325	99													
	100													
	101	Coal, alternating dull and vitreous bands												
	102	pyritic along some fractures												
	103													
	104	Mudstone, gray to dark gray, soft to crumbly, silty		CH	2	21	77				(-)			2.03
				MH	2	6	92				(-)			1.93
	105	Coal, brownish, clayey		CH	2	16	82				(-)			2.01
	106	Siltstone, medium dark gray, slickensides, calyey, scattered coal stringers		CL	23	35	42				(-)			2.00
350	107			CL	24	37	39				(-)			1.94
				CL	5	48	47				(-)	79		2.03
	108			CL	3	51	46				(-)			2.03
	109	Sandstone, very fine grained, cross-bedded, soft to crumbly		CL	9	51	40				(-)			1.93
				CL	16	53	31				(-)			1.97

Explanatory notes:

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GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft

Depth Feet	Depth Meters	Graphic Lithology[1]	Core available for testing[2] / Drilling recovery	Lithologic description	Fracture spacing (cm) 5 15 25	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[5] PI[6] LL[5] 10 30 50 70 90	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
	111			Sandstone, light to medium gray, very fine to fine grained, friable, poorly cemented		CL/ML	27	41	32		(-)	75		1.67
						SM	51	31	18		(-)			1.88
	112													
	113			highly carbonaceous lamina		SM	67	19	14		(-)			1.94
						SM	72	17	11		(-)			1.45
	114					SM	80	11	9		(-)			
375	115					SM	75	13	12		(-)			1.78
						ML	33	30	37		(-)			1.56
	116			scattered limonitic stain		SM	38	31	31		(-)			1.88
						CL	28	32	40		(-)			
	117			thin regular bedding		SM	70	18	12		(-)			1.81
	118					SM	54	22	24		(-)			
	119													
	120													
	121													
400	122			Sandstone, as above		CH	8	46	46		(T)			1.99
	123					CH	18	36	46		(-)			1.84
						SM	38	30	32		(-)			1.58
	124			clayey laminae and pockets		SM	80	12	8		(-)			1.49
	125					SM	62	20	18		(-)			1.65
	126			scattered mudstone layers		CL	37	33	30		(-)			1.95
	127													
	128													
	129			Mudstone, gray, massive, grades to sandstone, friable, porous, uncemented		CL	30	37	33		(-)			1.57
						SM	81	12	7		(-)			1.73

Explanatory notes:

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

[3] Symbols from Unified Soil Classification Chart by U.S. Bureau of Reclam. (1974). S= sand, M= silt, C= clay L= low plasticity H= high plasticity

[5] PL = plastic limit
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GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
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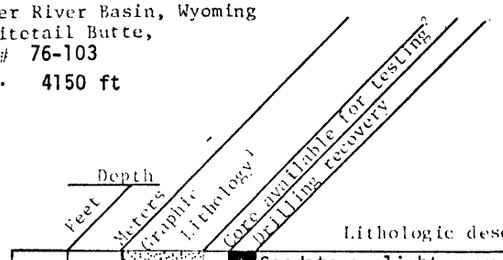
Elev. 4150 ft



Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
Sandstone, light gray, fine to medium grained, uncemented, massive, friable										
scattered and alternating mudstone laminae		CL	10	56	44		(-)			2.02
Sandstone, as above		CL	27	37	36		(-)			1.83
		SM	83	12	5		(-)			1.79
very friable		SM	85	10	5		(-)			
becomes increasingly more silty with depth		SM	83	11	6		(-)			
		CL	9	55	36		(-)	87		1.93
		CL/ML	32	48	20		(-)			2.01
scattered siltstone and clay laminae		CL	3	42	55		(-)			1.93
coal and carbonaceous shale stringers and laminea, small mudstone layer		CL/CH	3	40	57		(T)			2.01
		CH	4	48	48		(-)			1.95
		CL	5	60	35		(-)			1.97
Coal, black, vitreous, hard		SM	52	35	13		(T)	4		1.66
highly fractured										
Siltstone, light medium brown, calcareous, very hard, massive,		CH	2	40	58		(+)	85		2.01
interbedded laminea of mudstone,		CL	10	47	43		(T)			2.03
weaker		CL	11	57	32		(+)			1.92
Sandstone, gray, very fine grained		CL	4	63	33		(+)			2.03
Mudstone, dark gray, hard, silty, mottled, slightly calcareous		CL	7	70	23		(+)			1.93
		CL	3	65	32		(+)			2.00
		CL	5	62	33		(T)			1.86

Explanatory notes:

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

[3]Symbols from Unified Soil Classification Chart by U.S. Bureau of Reclam. (1974).
S= sand, M= silt, C= clay
L= low plasticity
H= high plasticity

[4]PL = plastic limit
[5]LL = liquid limit
[6]PI = plasticity index

[7]+, present
-, not present
T, trace

GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft

Depth (feet)	Depth (meters)	Graphic lithology[1]	Core available for testing[2] / Drilling recovery	Lithologic description	Fracture spacing (cm) 5 15 25	Unified soil classification[3]	Grain-size distribution (% dry soil wt.) Sand	Silt	Clay	Atterberg limits (% dry soil wt.) PL[4] PI[6] LL[5] 10 30 50 70 90	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm³) As-received	Dry-bulk
	151			Siltstone, light gray, massive, minor bedding, slightly, calcareous		CL	1	52	47		(-)	80		2.05
						CL	5	60	35		(T)			1.96
	152					CL	6	57	37		(-)			1.98
				iron oxide staining well cemented		CL	8	55	37		(-)			2.07
500	153			Sandstone, light gray, very fine grained, calcareous, very hard,		CL	18	49	33		(T)	84		1.97
	154			scattered clayey laminae										
						ML	30	51	19		(-)			1.91
	155			noncalcareous		SM	79	11	10		(-)			1.60
	156					SM	77	13	10		(-)			1.54
	157													
	158													
	159			thinly bedded		CL	5	50	45		(-)	84		1.98
525	160			scattered plant fragments grades mudstone										
	161			Mudstone, gray, hard slickensides, sandy, carbonaceous		CL	30	44	26		(-)			1.89
	162			Siltstone grading to fine grained sandstone, carbonaceous		CL	47	18	35		(-)			1.76
	163			Coal, black to brownish, dull to vitreous, clayey		CL	14	53	33		(-)			2.07
	164			Siltstone, gray, soft, abundant plant fragments, sandy		CL/ML	12	72	16		(-)			1.88
						CL	1	59	40		(-)			1.91
	165			Sandstone, medium gray, fine to medium grained, irregular bedding		SM	42	47	11		(-)	22		1.67
	166													
	167													
550	168			Mudstone, light gray, silty, soft										
	169													
				Mudstone, dark gray, as above		CL	1	59	40		(-)			1.91

Explanatory notes:

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

[3]Symbols from Unified Soil Classification Chart by U.S. Bureau of Reclam. (1974). S= sand, M= silt, C= clay, L= low plasticity, H= high plasticity

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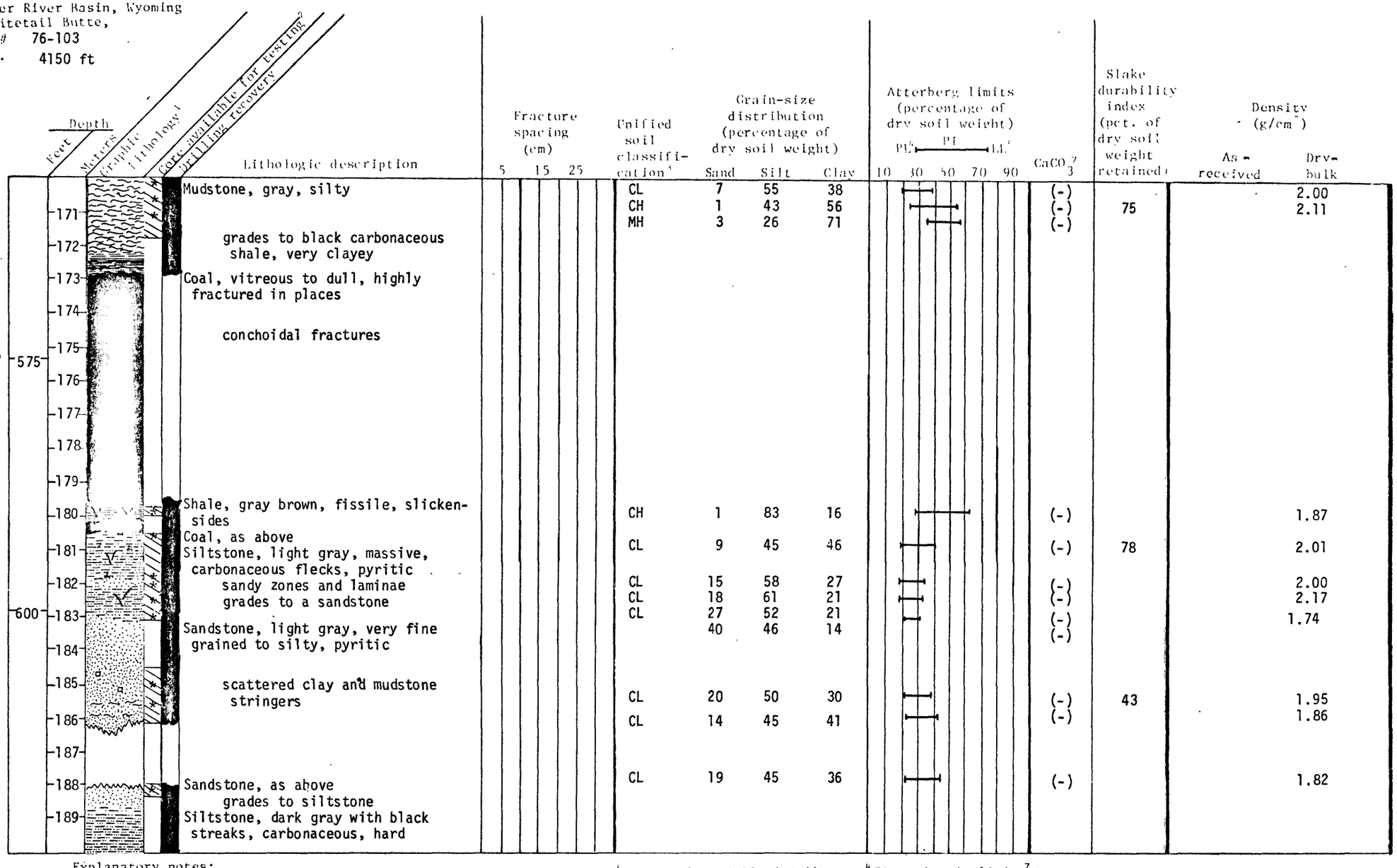
[7]+, present
-, not present
T, trace

GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft



Depth Feet	Depth Meters	Graphic Lithology[1]	Core available for testing[2] / Drilling recovery	Lithologic description	Fracture spacing (cm) 5 15 25	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5] 10 30 50 70 90	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm³) As-received	Density (g/cm³) Dry-bulk
	171			Mudstone, gray, silty		CL	7	55	38		(-)			2.00
						CH	1	43	56		(-)	75		2.11
						MH	3	26	71		(-)			
	172			grades to black carbonaceous shale, very clayey										
	173			Coal, vitreous to dull, highly fractured in places										
	174													
				conchoidal fractures										
575	175													
	176													
	177													
	178													
	179													
	180			Shale, gray brown, fissile, slickensides		CH	1	83	16		(-)			1.87
				Coal, as above										
	181			Siltstone, light gray, massive, carbonaceous flecks, pyritic		CL	9	45	46		(-)	78		2.01
	182			sandy zones and laminae		CL	15	58	27		(-)			2.00
				grades to a sandstone		CL	18	61	21		(-)			2.17
600	183					CL	27	52	21		(-)			1.74
				Sandstone, light gray, very fine grained to silty, pyritic			40	46	14		(-)			
	184													
	185			scattered clay and mudstone stringers		CL	20	50	30		(-)	43		1.95
	186					CL	14	45	41		(-)			1.86
	187													
	188			Sandstone, as above		CL	19	45	36		(-)			1.82
				grades to siltstone										
	189			Siltstone, dark gray with black streaks, carbonaceous, hard										

Explanatory notes:

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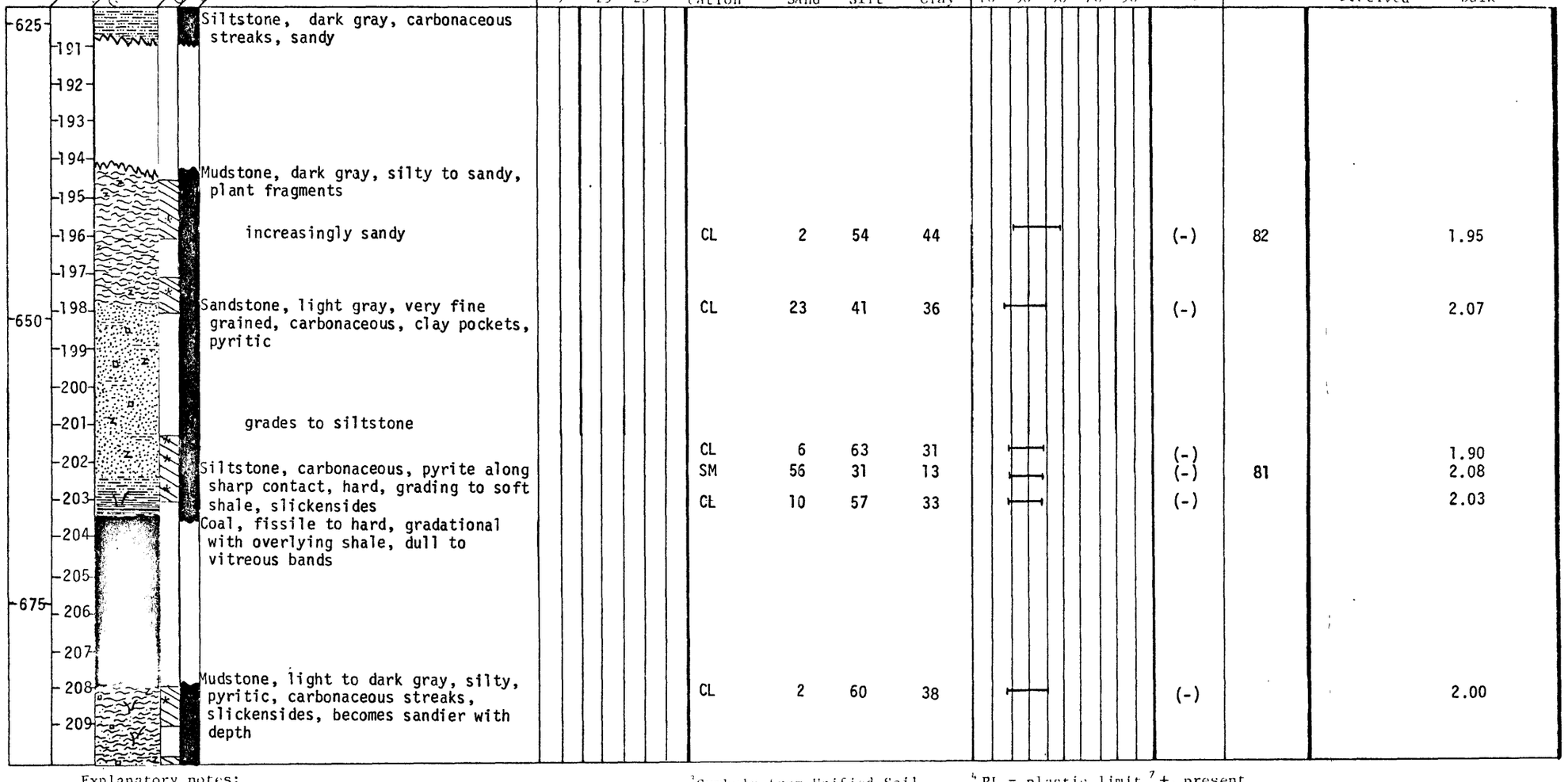
T, trace

GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft



Depth (Feet)	Depth (Meters)	Graphic lithology[1]	Core available for testing[2]	Drilling recovery	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
625	191				Siltstone, dark gray, carbonaceous streaks, sandy										
	192														
	193														
	194				Mudstone, dark gray, silty to sandy, plant fragments										
	195														
	196				increasingly sandy		CL	2	54	44		(-)	82		1.95
	197														
650	198				Sandstone, light gray, very fine grained, carbonaceous, clay pockets, pyritic		CL	23	41	36		(-)			2.07
	199														
	200														
	201				grades to siltstone										
	202				Siltstone, carbonaceous, pyrite along sharp contact, hard, grading to soft shale, slickensides		CL	6	63	31		(-)			1.90
							SM	56	31	13		(-)	81		2.08
	203						CL	10	57	33		(-)			2.03
	204				Coal, fissile to hard, gradational with overlying shale, dull to vitreous bands										
	205														
675	206														
	207														
	208				Mudstone, light to dark gray, silty, pyritic, carbonaceous streaks, slickensides, becomes sandier with depth		CL	2	60	38		(-)			2.00
	209														

Explanatory notes:

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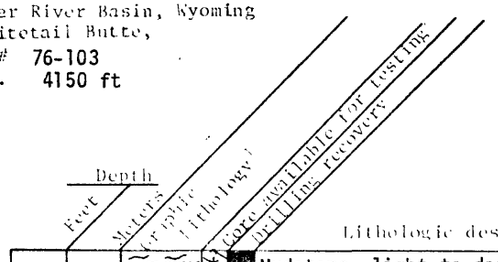
GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-103
Elev. 4150 ft



Lithologic description	Fracture spacing (cm)	Unified soil classification[2]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
Mudstone, light to dark gray, soft, silty, slickensides, scattered pyritic nodules, carbonaceous	5 15 25	CL	6	39	55	10 30 50 70 90	(-)	61		2.05
		CL	4	50	46		(-)	63		
		CL	7	36	57		(-)			2.08
		CL	10	41	49		(-)			2.02
Sandstone, light gray, very fine grained, clayey		CL	12	41	47		(-)			1.87
		CL	11	43	46		(-)	34		1.89
Coal, brownish, clayey										
Sandstone, light gray, very fine grained, carbonaceous streaks and plant fragments, pyritic		SM	58	29	13		(-)			
		CL	16	51	33		(-)			1.74
scattered clay laminae		CL	16	53	31		(-)			

700 211 212 213 214 215 216 217 T.D.

Explanatory notes:

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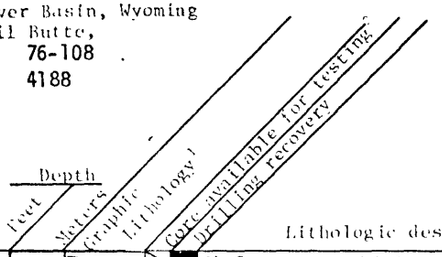
GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188



Lithologic description	Fracture spacing (cm)	Unified soil classification[4]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI[6] LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Dry-bulk
Shale, gray, thinly bedded, carbonaceous streaks		MH	3	41	56		(-)	93	1.70	1.65
Coal, black, moist										
core removed for sampling no description										
Shale, black, highly carbonaceous, scattered coal stringers, numerous slickensides								14	1.75	1.66
plant fragments and some slickensides		CH		14	86		(-)		1.92	1.87
increasingly more silty with depth		CH	2	48	50		(-)		1.95	1.90
grades to siltstone with scattered sandstone lenses										
Siltstone, light to medium gray, thinly bedded, cemented, weak to friable in places, pyritic along a few bedding planes								57		
		CL	20	48	32		(-)		1.82	1.79
grades to sandstone									1.94	1.90

Explanatory notes:

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GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188

Depth (Feet)	Depth (Meters)	Graphic Lithology[1]	Core available for testing[2]	Drilling recovery	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm³) As-received	Dry-bulk
	1				Topsoil, tan, clayey to silty Shale, tan with gray lenses, thin bedding, oxicized, gypsum along bedding planes, firm		MH	10	40	50		(+)		1.87	1.82
	2														
	3														
	4				Shale, as above, firmer		CH		45	55		(+)	29	1.76	1.71
							MH	2	35	63		(-)		1.67	1.62
	5														
	6				Sandstone, tan, uncemented, very fine grained to silty, washed out by drilling										
	7														
25	8				Shale, dark brown to light gray, very silty, thin irregular bedding, scattered clay lenses, very hard at places		CH	1	47	52		(-)		1.55	1.53
	9														
	10				increasingly more silty		CL	1	58	41		(-)		1.71	1.68
	11				Siltstone, tan, well cemented, very hard, thin bedding, sandy		CL/ML	25	49	26		(+)			1.81
	12				Sandstone, tan, very fine grained to silty, uncemented, friable, slightly oxidized,										
	13						ML	38	43	19		(-)		1.88	1.82
	14						ML	30	46	24		(-)			
	15				Shale, medium to dark gray, silty, thinly bedded, carbonaceous, coal seam, low grade		CH	1	47	52		(T)	51	1.84	1.79
50	16														
	17						MH	3	37	60		(-)	77	1.92	1.87
	18														
	19				Shale, as above, clayey zones and pockets										

Explanatory notes:

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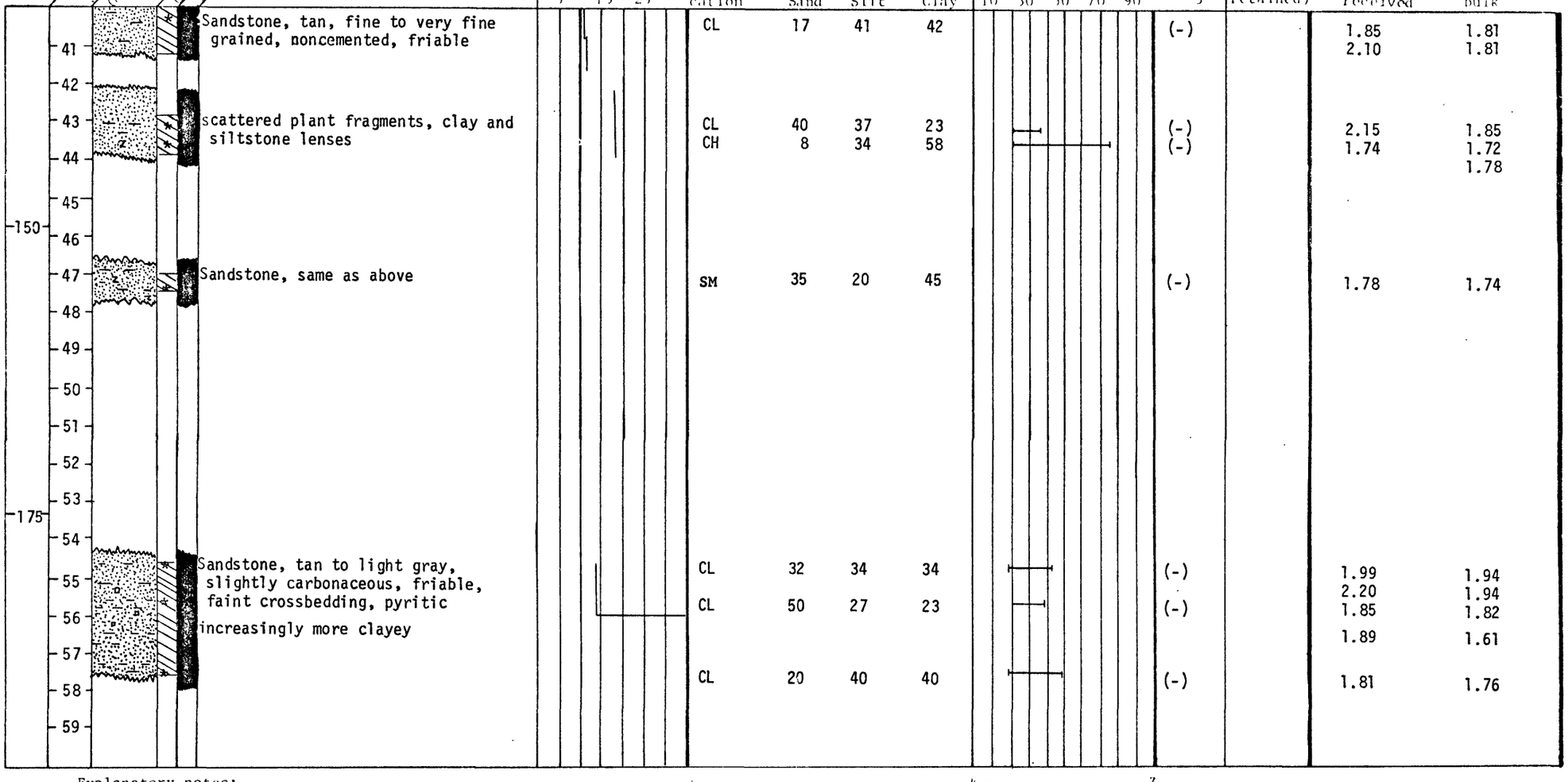
GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188



Explanatory notes:

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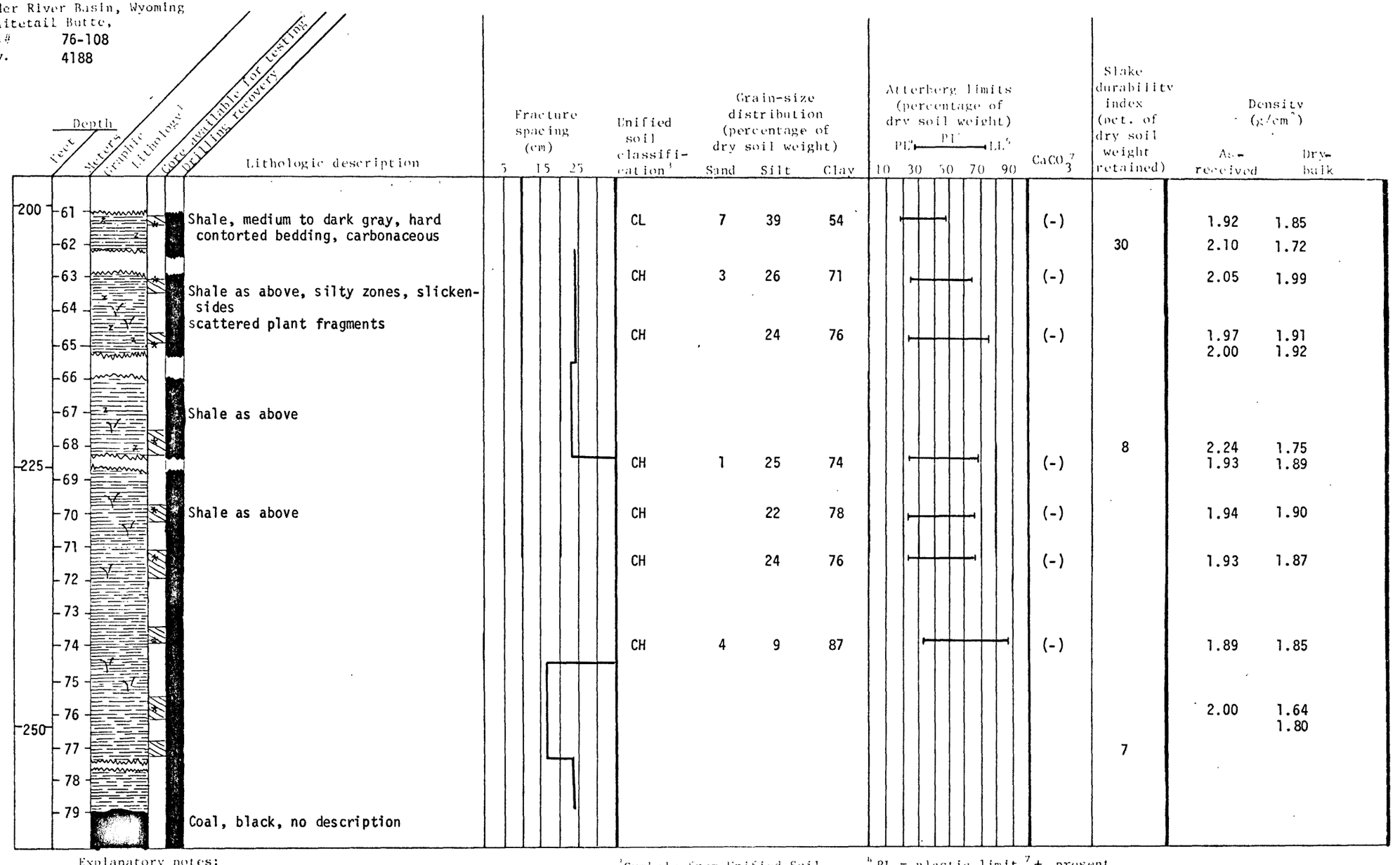
GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188



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Powder River Basin, Wyoming
Whitetail Butte,
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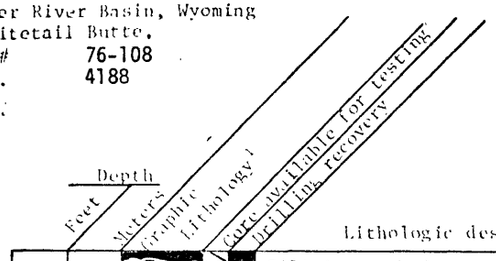

Lithologic description	Fracture spacing (cm) 5 15 25	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5] 10 30 50 70 90	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm³) As-received	Dry-bulk
Siltstone, dark gray, clayey lenses highly carbonaceous		CL		48	52		(-)		1.81	1.77
									1.70	1.68
Coal, black, no description										
Shale, dark gray, silty, very thin irregular bedding, calyey zones and pockes, pyritic		CH	8	33	59		(-)		1.97	1.93
		CL	14	54	32		(-)	78	1.95	1.93
		MH	1	45	54		(-)		1.96	1.93
increasing silt content with depth		CL		52	48		(-)			1.92
		CH		48	52		(-)			
scattered silt laminae		CL	22	46	32		(-)			1.93
Alternating thin laminae of silt and shale, burrowed		CL	5	55	40		(-)		2.18	1.91
		CL	1	57	42		(-)			
Shale, dark gray, thin irregular laminations, becomes highly carbonaceous and grades to coal		CH		26	74		(-)	78		
		MH	2	14	84		(-)		2.06	1.55
Coal, no description										

Explanatory notes:

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Powder River Basin, Wyoming
Whitetail Butte,
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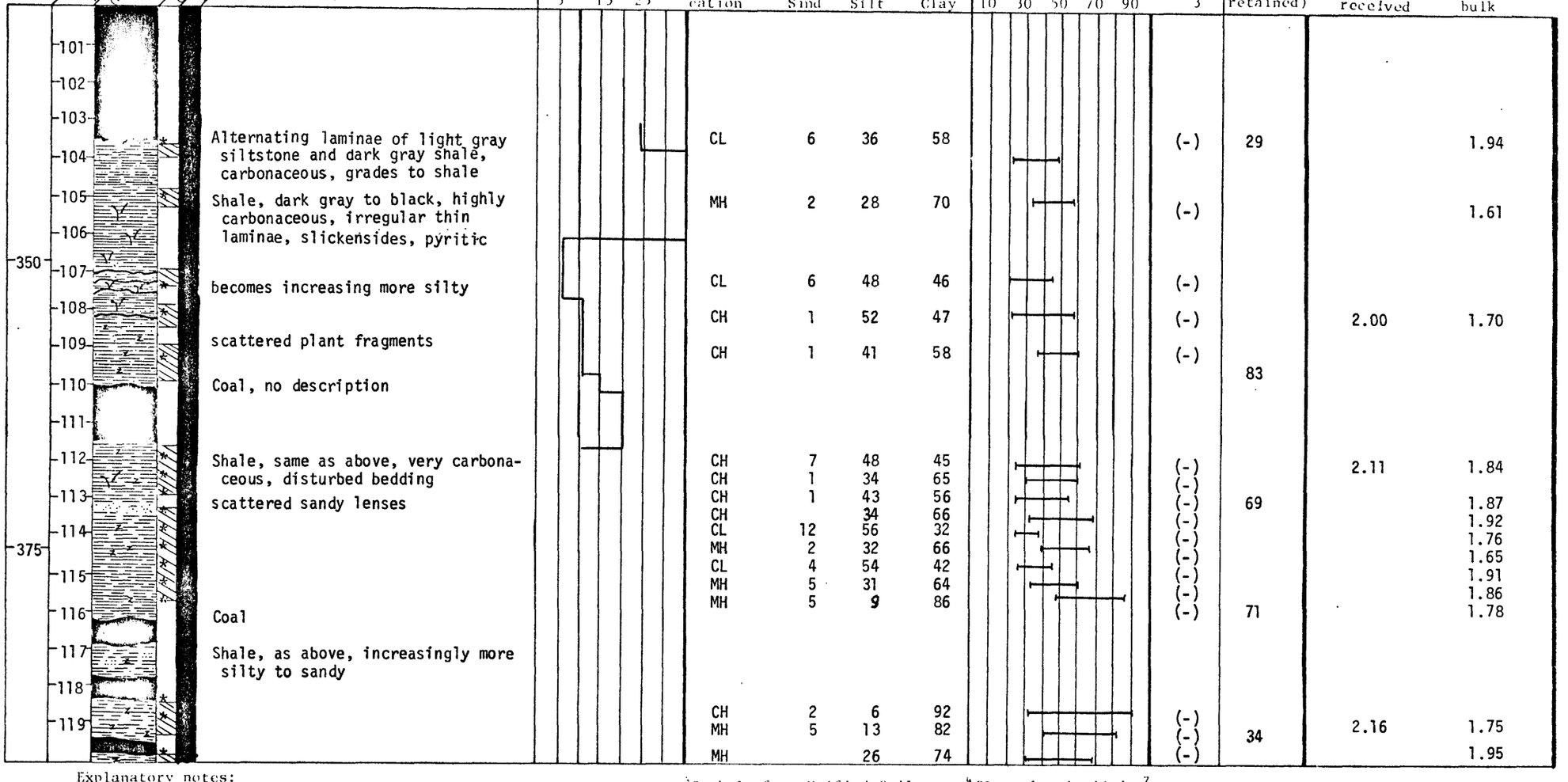

Depth (Feet)	Depth (Meters)	Graphic Lithology[1]	Core available for testing[2]	Drilling recovery	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI[6] LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Density (g/cm^3) Dry-bulk
	101														
	102														
	103														
	104				Alternating laminae of light gray siltstone and dark gray shale, carbonaceous, grades to shale		CL	6	36	58		(-)	29		1.94
	105				Shale, dark gray to black, highly carbonaceous, irregular thin laminae, slickensides, pyritic		MH	2	28	70		(-)			1.61
	106														
350	107				becomes increasing more silty		CL	6	48	46		(-)			
	108						CH	1	52	47		(-)		2.00	1.70
	109				scattered plant fragments		CH	1	41	58		(-)			
	110				Coal, no description								83		
	111														
	112				Shale, same as above, very carbonaceous, disturbed bedding		CH	7	48	45		(-)		2.11	1.84
							CH	1	34	65		(-)			
	113				scattered sandy lenses		CH	1	43	56		(-)	69		1.87
							CH		34	66		(-)			1.92
	114						CL	12	56	32		(-)			1.76
375							MH	2	32	66		(-)			1.65
	115						CL	4	54	42		(-)			1.91
							MH	5	31	64		(-)			1.86
							MH	5	9	86		(-)	71		1.78
	116				Coal										
	117				Shale, as above, increasingly more silty to sandy										
	118														
	119						CH	2	6	92		(-)			
							MH	5	13	82		(-)	34	2.16	1.75
							MH		26	74		(-)			1.95

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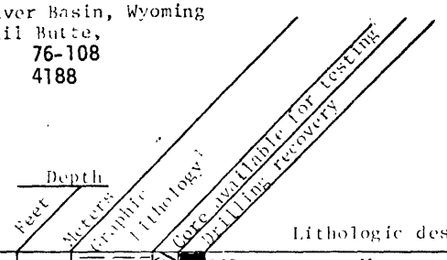
GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188



Depth Feet	Depth Meters	Graphic lithology[1]	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI[6] LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Density (g/cm^3) Dry-bulk
			Siltstone, medium gray, clay, plant fragments		CH	1	27	72		(-)		2.26	2.00
					MH	4	36	60		(-)			1.98
	121		grades to shale		CL	19	47	34		(-)	65		2.15
					CH	1	29	70		(-)			1.97
400	122		Shale, medium to dark gray, scattered slickensides, plant fragments, silty,		CH	3	13	84		(-)		2.15	1.81
	123		firm										
					CL	2	50	48		(-)			1.99
	124												
	125		scattered coal lenses and seams, black, highly fractured		CH	1	38	61		(-)			1.95
					ML	2	43	55		(-)	48		1.92
	126				CH	4	16	80		(-)		2.13	1.80
	127		increasingly more silty and sandy		CH	10	8	82		(-)		1.94	1.51
					CH	2	13	85		(-)			1.88
	128				CH		26	74		(-)		2.17	1.93
					CL	27	41	32		(-)			1.96
	129				CL	8	40	52		(-)			2.00
425					CL	2	22	76		(-)			
	130		slickensides										
	131												2.52
	132				CL	4	44	52		(-)	74		2.05
					CH	4	6	90		(-)			
	133		Coal, no description										
	134												
	135												
	136												
	137		Shale, light to medium gray, hard, fractured by drilling, slightly carbonaceous, scattered slickensides, plant fragments		MH	11	17	72		(-)			1.72
450					CH		20	80		(-)			1.79
	138												
	139												

Explanatory notes:

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[2]Asterisk, *, shows sample depth

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GEOLOGIC AND GEOTECHNICAL LOG

Powder River Basin, Wyoming
Whitetail Butte,
DH# 76-108
Elev. 4188

Depth (Feet)	Depth (Meters)	Graphic Lithology[1]	Core available for testing / Drilling recovery	Lithologic description	Fracture spacing (cm)	Unified soil classification[3]	Grain-size distribution (percentage of dry soil weight) Sand	Silt	Clay	Atterberg limits (percentage of dry soil weight) PL[4] PI LL[5]	$CaCO_3$[7]	Slake durability index (pct. of dry soil weight retained)	Density (g/cm^3) As-received	Density (g/cm^3) Dry-bulk
					5 15 25					10 30 50 70 90				
	141			Shale, light to medium gram, silty with scattered silt laminae		CH		18	82		(-)			1.90
	142													1.78
														2.01
	143			scattered plant fragments and slickensides		CH		14	86		(-)			1.93
	144													
475	145			numerous slickensides										
	146					CH	T	21	78		(-)			1.98
	147			T.D.										

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