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GEOLOGICAL SURVEY

Preliminary Study of the Geotechnical Properties of the Fort Union Formation From Drill Holes BH-166-76, BH-168-76, and BH-187-76 near Sheridan, Wyoming

By Jack K. Odum and Philip S. Powers

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ILLUSTRATION

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Introduction

This report summarizes the geotechnical properties obtained from tests run on core from exploration holes drilled for the Big Horn Coal Company. The holes designated BH-166-76 (sec. 23, T. 57 N., R. 84 W.), BH-168-76 (sec. 14, T. 57 N., R. 84 W.), and BH-187-76 (sec. 15, T. 57 N., R. 84 W.) are located near the Big Horn Coal Company strip mine about 15 km north of Sheridan, Wyo. (fig. 1). The three holes range in depth from 0 to 97.5 m and all three begin and end within the Fort Union Formation of Paleocene age. The formation includes mudstone, shale, carbonaceous shale, coal, siltstone, and relatively soft sandstone.

This study, a part of the Energy Lands Program, hopes to define the geotechnical characteristics of the Fort Union Formation in the Powder River Basin, Wyo. Its goal is to provide information helpful in predicting the effects of mining in the formation and to define the characteristics of formation material comprising spoil banks on reclaimed land.

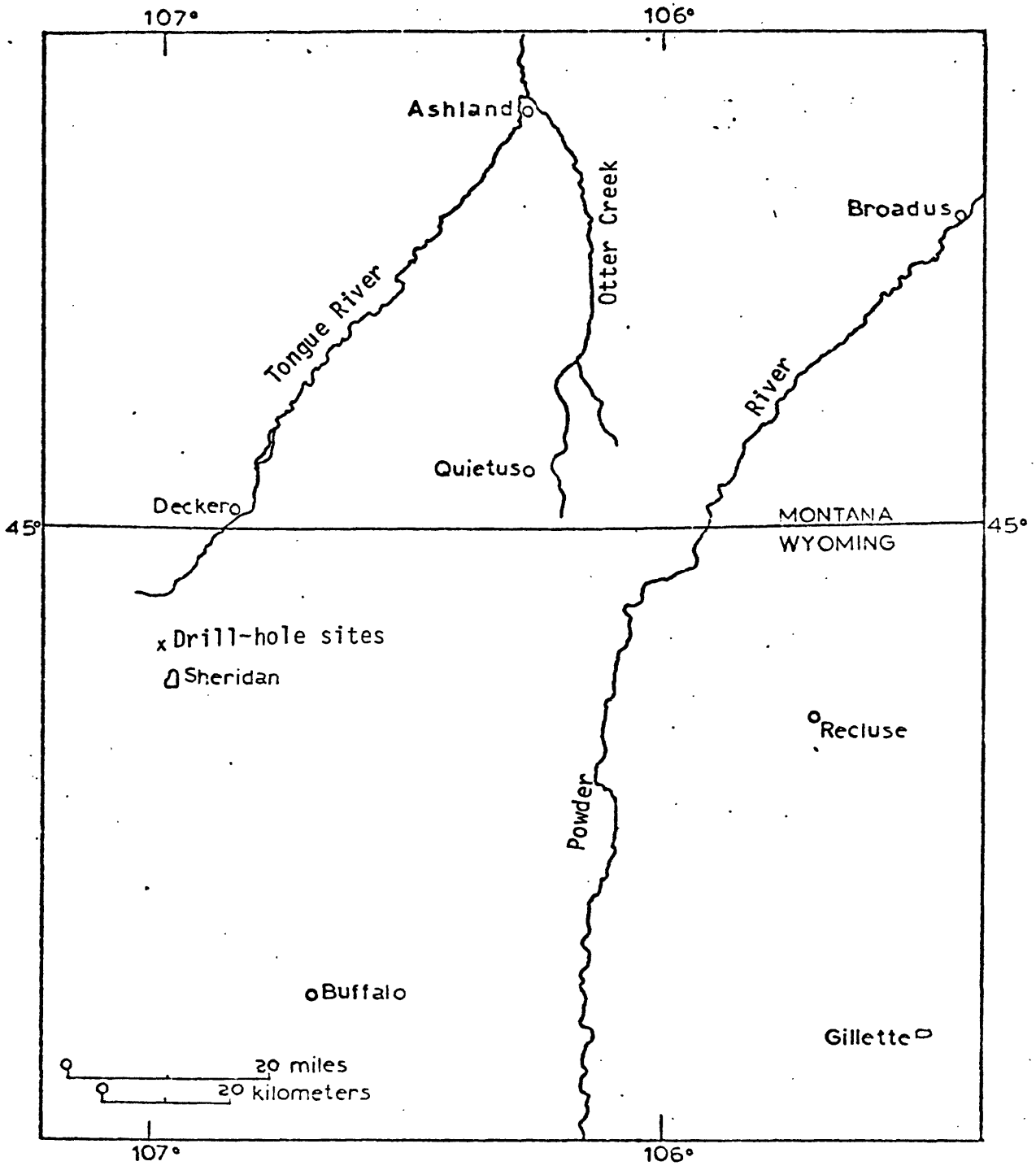


Figure 1.--Location of Big Horn drill-hole sites BH-166-76, BH-168-76, and BH-187-76 near Sheridan, Wyo.

The cores from the drill holes were stored without sealing for a number of weeks before logging and testing were done. During this storage period, they experienced several cycles of freezing and thawing in addition to normal drying. The effects were evident in the form of scaling and bulking along the exterior surfaces of the cores and some sections were totally reduced to a rubble of flakes and wedges. We believe, therefore, that the results of the tests run on these core will more closely approximate the physical properties of excavated rocks than rocks in situ.

Acknowledgments

Physical properties testing was performed by M. H. Jones and H. A. Cloft, and uniaxial unconfined compressive strength tests were conducted by D. M. Worley, all of the U.S. Geological Survey.

Field program

Core for drill holes BH-168-76 and BH-187-76 were obtained from Peter Kiewit Sons' Co. laboratory in Sheridan, Wyo. The core was photographed, lithologically logged, and strength index tests (point load and Schmidt hammer) were performed in a mobile field laboratory by the authors. Representative core was taken to the U.S. Geological Survey laboratories in Denver, Colo., for additional physical properties and strength testing; the results of the logging and tests on core from these two drill holes are summarized in Appendix 1.

Core from drill hole BH-166-76 had already been sampled, crushed, and chemically tested at 3 m intervals or at lithologic breaks by Peter Kiewit Sons' Co. laboratory, for chemical testing and only pieces that were too small for core testing remained. Representative pieces of core were obtained and taken to the Denver laboratory, where soil properties were determined using tests that do not require whole core samples. The results of these soils tests are summarized in Appendix 2.

Testing procedures

Aufmuth (1974) described the point-load test used in determining an index value for tensile strength. A segment of core is compressed across its diameter between two rounded metal points until it fails. The index value is calculated by the formula P/d^2, where P is the applied force at failure and d is the diameter of the core. The results were multiplied by $4/\pi$ to determine the force per unit area on the failed surface. Values are reported in meganewtons per square meter ($1 MN/m^2 = 145$ lb/in.^{2}).

The Schmidt hammer is usually a nondestructive index of compressive strength for elastic materials. The handheld instrument propels a spring-loaded hammer against a sample and records a relative rebound number. The dimensionless rebound numbers (R) are compared to a calibrated spring standard. The test requires a coherent segment of core which has a length that exceeds the diameter. If the sample failed before three hammer impacts, the data for that depth were discarded; otherwise recorded values were averaged. Most rock and soil units tested for this report either failed during testing or were near the lower limits of measurability.

Laboratory testing program

Subsequent tests in the laboratory were performed to determine properties of the soils and rocks. The weak materials were tested for grain-size distribution, Atterberg limits, and densities. For the most part, only minimal effort was required to disaggregate the materials so tested. More competent layers were subjected to unconfined compressive strength tests. Preparation of suitable specimens was difficult because of the friable and fissile materials; therefore, only limited numbers of rock strength tests were performed.

Testing procedures

Atterberg limits

Atterberg limits define the range of moisture contents at which a soil is plastic. 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 where it changes from a plastic to a liquid state, and the plastic limit (PL) is the water content of the soil where it changes from a solid or semisolid state to a plastic state. These limits are reported as the water content in percent of dry soil weight. The plastic index is the difference between the liquid limit and the plastic limit and represents the range of water content at which a soil is plastic (U.S. Bureau of Reclamation, 1974, p. 4-8).

Grain-size distribution

The grain-size distribution analysis used for 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, approved 1972 (American Society for Testing and Materials, 1978, p. 70-80).

Unified Soil Classification

A description of the symbols used in Appendix 1 and 2 can be found in the "Earth Manual" published by the U.S. Bureau of Reclamation (1974). These group symbols describe size distribution, dry strength, dilatancy (reaction to shaking), consistency near the plastic limit, and other general characteristics.

Dry bulk and as-received density

Dry bulk density was 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 air-tight 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 are a measure of the 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 rpm 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. An observation was made that some samples with a high-clay content 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 materials may be limited.

Unconfined compressive strength tests were run on a 50 K BLH press (Baldwin-Emery SR-4 testing machine built by Baldwin-Hamilton Corp.). Each sample was milled to an average value of 0.005 mm of true-face end parallelism and a length-to-diameter ratio of 2:1. Each sample was loaded in increments of 2 MN/m^2 until failure.

Test results and lithology for boreholes BH-168-76 and BH-187-76

Appendix 1 is a table of the physical properties (grain-size analysis, Atterberg limits, and densities) and strength (point-load, Schmidt hammer, uniaxial unconfined compressive strength, and slake durability) test results, as well as the lithologic log for each borehole.

Test results for borehole BH-166-76

Appendix 2 is a table of the physical properties for the borehole. The core from this borehole had already been crushed at 3-m intervals or at lithologic breaks and these crushed samples were used for chemical analysis by Peter Kiewit Sons' Co. laboratory. Samples of the pulverized material were obtained in sealed plastic bags and grain-size analysis and Atterberg limits tests were performed.

References

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

Aufmuth, R. E., 1974, Site engineering of rock, in Field testing and instrumentation of rock--a symposium: American Society for Testing and Materials Special Technical Publication 554, p. 81-99.

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. H., 1972, The slake-durability test: International Journal of Rock Mechanics and Mining Sciences, 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.

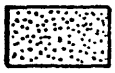
Appendix 1

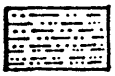
Lithologic and geotechnical logs for drill holes BH-168-76 and BH-187-76

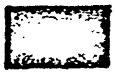
LITHOLOGIC SYMBOLS

 Soil horizons

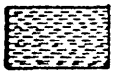
 Shale

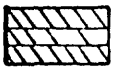
 Sandstone

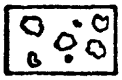
 Siltstone

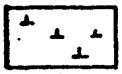
 Coal.

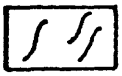
 Carbonaceous shale

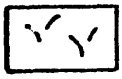
 Claystone

 Dolomite

 Gravel

 Calcareous

 Carbonaceous laminae

 Slickenside

 Gradational contact

Lithologic and Geotechnical log for Drill Hole BH-168-76

Depth in meters	Recovery	Drill Hole: BH-168 Lithologic Description	Atterberg Limits PL ⊢ LL (10 30 50 70 90)	Grain Size Distrib. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Indices Strength ⊥	Strength ∥	Penetration ⊥	Penetration ∥	Schmidt Hammer Index	Unconfined Compress. Strength	SLAKE DURABILITY
1		Top soil															
2		Unconsolidated sand and gravel															
3		Sandstone, buff to tan, friable, soft to medium soft, shaly lenses grading to shale, buff to gray, with sandy zones															
4		No core recovered 0-10 m															
5																	
6																	
7																	
8																	
9																	
10		Shale, light yellowish brown silty, calcareous to limy, small dolomitic lenses									0.05	0.60	1.0	1.2			
11				4	60	36			+	CL	.40	1.00	1.0	1.5			
12							2.33	2.08			.25	.45	1.0	1.5	12.5 30		85
13		Shale, gray, **slightly silty, calcareous, mottled tan very silty zones, carbonaceous inclusions**					2.32	2.15			.30	1.10	1.0	5.5	12.5		
14							2.25	2.13			.30	.70	1.0	2.5	16		90
15				1	31	68			-	CL	.60	1.00	1.0	1.5			
16				1	62	37	2.28	2.17	+	CL	.65	.70	1.5	1.5	15		
17		Dolomite, dark gray Crystalline, very hard, carb. inc.					2.66	2.62			.60	.85	1.0	3.0	17.5 12.5	20.7	
18		Shale, buff to gray, calcareous very silty, thinly laminated, argillaceous laminae shows disturbed structure, mottled with silty zones 1-4 cm thick, carbonaceous inclusions, 0.5 cm gypsum layer		5	71	24	2.12	2.06	+	CL-ML	.50	.55	1.0	3.0			
19							2.25	2.11			4.48		.6	1.2	34	218.5	
20							2.38	2.19			.50 .80 .70	60 85 .90	1.2 1.5 1.0	2.5 3.0 2.0	15 13 18	24.0	87
21											.25	.50	1.5	2.0	10		
22				7	56	37	2.29	2.17	+	CL	.70	.90	1.5	2.0	13	28.9	87
23		Carbonaceous shale, dark gray limonitic stain.		0	42	58	2.21	1.64	+	CL	.50 .60 .60 .60 .55	.60 .70 1.00 .65 .85	1.0 1.5 1.0 1.5 2.0	2.0 1.5 2.5 2.0 5.0	12 17 15 15 20	33.5 31.1	77
24		Shale, medium gray, clayey, carbonaceous laminae		5	45	50	2.30	2.15	-	ML					10		
				2	46	52			-	CL	.15	1.25	.7	2.0			
		Units:	Water content of dry soil weight	% finer by weight			g/cc		+ pos. - neg. T trace		MN/m^2		mm			MN/m^2	Retained % of dry soil weight

Explanation of symbols: PL = plastic limit; LL = liquid limit; ∥ = tested parallel to core axis; ⊥ = tested perpendicular to core axis.
(+)= positive reaction to a 25 percent HCl solution, (-)= no reaction, (T)= trace or faint reaction

Log for Drill Hole BH-~~186~~168-76 cont.

Depth in meters	Recovery	Drill Hole: BH-168 Lithologic Description	Atterberg Limits PL ⊢ LL (10 30 50 70 90)	Grain Size Distrib. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Indices Strength ⊥	Point Load Indices Strength ‖	Point Load Indices Penetration ⊥	Point Load Indices Penetration ‖	Schmidt Hammer Index	Unconfined Compress. Strength	Slake Durability
26		Shale, gray, calc., carb. inclusions					2.29	2.15			0.20	1.00	1.0	4.0			
		Coal, black, conchoidal fractures, semibanded, pyritic and bicarbonate flakes, rosin inclusions, brittle					1.43	1.12			.20	.35	.5	1.0			
27		(DIETZ #2)															
28																	
29		Coal, brownish-black, as above, argillaceous					1.61	1.31			.10	.75	.5	.8			
30																	
31		Shale, gray, silty, carbonaceous laminae															
32																	
33																	
34		Mudstone, grayish-brown, slickensides, coal and rosin inclusions		0	5	95			-	CH	.05	.25	.5	.5			
35		Shale, lt. brown gray, coal incl., some sandy stringers					2.32	2.17			.05	.15	.5	2.0			
36		Coal, brown black, rosin					1.49	1.24			.15	.50	.5	2.5			
37		No core recovered															
38		Coal, black, brittle					1.60	1.22									
		Shale, gray, scattered carbonaceous inclusions, worm burrows filled with $CaCO_3$									.10	.20	.5	2.0			
39											.05	.20	.5	2.0			
40				2	41	57			-	CL	.05	.10	.5	2.0			
41		Increasingly sandy near base									.05	.15	.5	1.0			
42											.10	.30	.5	1.5			85
		Sandstone, light gray, very fine grained, subangular, argillaceous binder, friable in places		60	22	18	2.10	2.03	-	SC	.70	1.00	.5	5.0			
43											.10	.30	.5	1.5		9.5	43
44							2.10	1.88			.10	.30	.5	1.0			
45											.05	.05	.5	1.0			
		Fine to medium grained, carbonaceous stringers 1 mm thick angled 30° to horizontal		80	11	9	2.11	1.92	-	SM							
46							2.34	2.24							17.5	31.1	27
		Shale, light gray, argillaceous to silty, becomes darker gray with depth, carbonaceous inclusions									.65	1.00	.5	2.0		27.4	
47											.60	.80	1.0	3.0	16.0	23.8	
											.90	1.15	1.5	4.0	15.0		
48							2.43	2.26			.65	.80	1.5	7.0	19.0		
49											1.30	2.15	1.0	3.0	18.0	50.0	
											.75	1.10	1.0	1.5			
							2.49	2.40									
		Units:	Water content % of dry soil weight	% finer by weight			g/cc	+ pos. - neg. T trace			MN/m^2		mm			MN/m^2	Retained % of dry soil weight

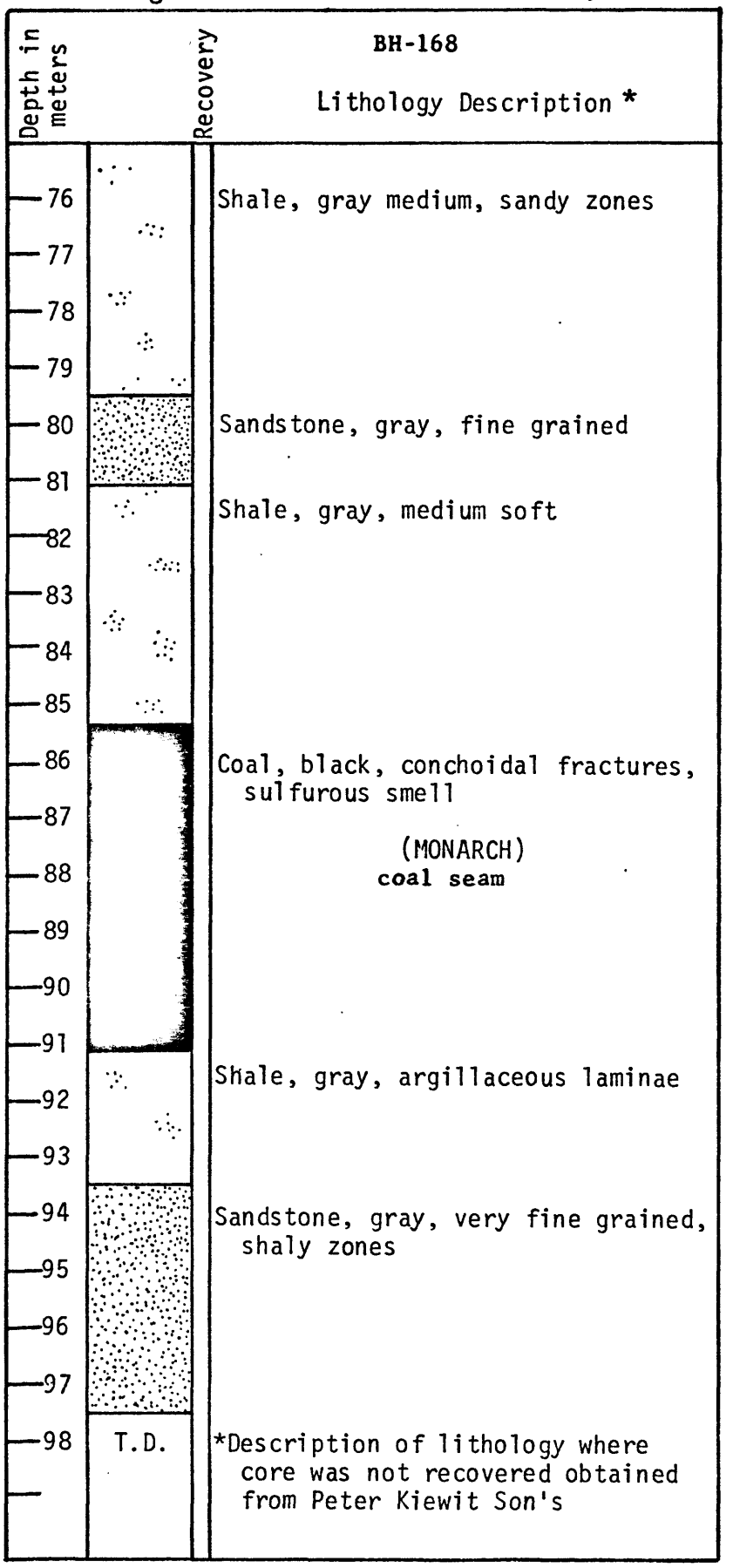
Explanation of symbols: PL= Plastic limit; LL= liquid limit: ‖= tested parallel to core axis; ⊥= tested perpendicular to core axis. (+)= positive reaction to a 25 percent HCl solution, (-)= no reaction, (T)= trace or faint reaction

Log for Drill Hole BH-168-76 cont.

Depth in meters	Recovery	Drill Hole: BH-168 Lithologic Description	Atterberg Limits PL—LL (10 30 50 70 90)	Grain Size Distrib.. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Strength ⊥	Point Load Strength ∥	Point Load Indices Penetration ⊥	Point Load Indices Penetration ∥	Schmidt Hammer Index	Unconfined Compress. Strength	Slake Durability
51		Shale, lt. gray, clayey to silty claystone, dark gray, eroded		5	45	50	2.39	2.23	-	CL	0.10	0.55	0.5	2.0			
52		Shale, gray, massive in places, silty, sandy lenses with carbonaceous stringers					3.19	3.16							37.0	66.0	
53							2.37	2.24			1.00	1.05	1.5	2.0	16.0		
54		Sandstone, light gray, fine grained subangular, argillaceous binder, 5-10 percent coal inclusions, friable, carbonaceous stringers inclined 20° to horizontal, increased carbonaceous laminae and plant impressions with depth, shale lenses									.60	1.00	1.0	1.5	17.5		
55											.50	.60	.5	1.5	12.0	27.9	89
56							2.23	2.13			.25	.70	1.0	4.0			84
57															15.0		
58											.15	.20	.5	1.5			
59							2.19	2.05			.30	.55	1.0	3.0			
60				61	18	21	2.26	2.16	-	SC							
61											.30	.40	1.0	2.0			
62							2.10	1.97			.60	.75	1.0	3.0			
63							2.40	2.22			.05	.35	.5	1.5	10.0	22.8	
64											.45	.70	1.0	3.0	18.0		
65											.25	.50	.5	1.5	15.0	22.8	92
66											.25	.55	.5	2.5			
67		Hard siliceous lenses, carbonaceous laminae and coal inclusions slickensides		58	20	22			-	SC-SM	.30	.95	1.0	4.0			
68				1	39	60			+	CL	.40	.50	.5	1.0			
69																	78
70		Coal, black, conchoidal fractures, semibanded, brittle, $CaCO_3$ scales					1.33	1.08									
71		(DIETZ #3)					1.40	1.11									
72																	
73							1.45	1.13									
74		Sandstone, light gray, very fine grained, friable, subangular, hard silty zones, weakly calcareous									.35	1.10	1.0	2.5	20.0		
		End of coring									.75	.80	1.0	1.0	13.0	17.2	93
		Shale, gray, medium soft															
		Sandy zones															
		Units:	Water content % of dry soil weight	% finer by weight			g/cc		+ pos. - neg. T trace		MN/m^2		mm		MN/m^2		Retained % of dry soil weight

Explanation of symbols: PL = plastic limit; LL = liquid limit; ∥ = tested parallel to core axis; ⊥ = tested perpendicular to core axis. (+) = positive reaction to a 25 percent HCl solution, (-) = no reaction, (T) = trace or faint reaction

Log for Drill Hole BH-168-76 cont.



Lithologic and Geotechnical Log for Drill Hole BH-187-76

Depth in meters	Recovery	Drill Hole: BH-187 Lithologic Description	Atterberg Limits PL—LL (10 30 50 70 90)	Grain Size Distrib. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Indices Strength ⊥	Strength ∥	Penetration ⊥	Penetration ∥	Schmidt Hammer Index	Unconfined Compress. Strength	SLAKE DURABILITY
1		Top Soil Sand and gravel mix															
2																	
3																	
4		Sand, nonindurated, tan, unconsolidated															
5																	
6																	
7																	
8		Shale, light gray to gray, calcareous to limy, carbonaceous laminae-plant impressions, slightly silty grading to sandy															
9																	
10				7	58	35	2.18	2.06	+	Cl							91
11		Siltstone-sandstone, brownish gray, very fine to fine-grained, 0.2 m quartzitic sandstone lens, very hard, shale zones		4	53	43			+	Cl	0.25	0.60	0.5	2.0			
12							2.20 2.54 1.86	1.99 2.53 1.82							32 29	156.5	99
13				38	47	15			T	Cl-Ml	.60	.60	1.0	1.0	14 15		91
14		Shale, light gray to gray, calcareous to limy, scattered sandstone lenses, very fine to fine grained, clay binder, friable in places, carbonaceous laminae common, less than 5 percent coal fragments					2.13 2.03	2.00 1.84			.05	.20	.5	1.0			
15											.05 .60	.25 .80	.4 1.0	1.0 1.0	12 13		
16							2.18	2.05								17.9	89
17							2.20	2.08			.50	1.25	1.0	5.0	13		
18				10	61	29			+	Cl							86
19							2.21 2.14	2.04 2.03			.10	.30	1.0	5.0	7 10	100.8	92 99
20				82	14	4	2.15	2.05	+	SC	.20 .50	.95 .75	.5 1.0	3.0 2.0	19 17		98
21											.15	.30	1.0	1.5			
22		Coal, black, brittle, conchoidal fractures, semi-banded, pyrite flakes, shale seams, gray (MONARCH) **coal seam**		16	61	23	2.29 1.76 1.50 2.15	2.11 1.60 1.18 1.86	+	Cl							
23																	
24							1.49	1.10									
		Units:	Water content of dry soil weight		finer by weight		g/cc		+ pos. - neg. T trace		MN/m²		mm			MN/m	Retained % of dry soil weight

Explanation of symbols: PL = plastic limit; LL = liquid limit; ∥ = tested parallel to core axis; ⊥ = tested perpendicular to core axis.
(+)= positive reaction to a 25 percent HCl solution, (-)= no reaction, (T)= trace or faint reaction

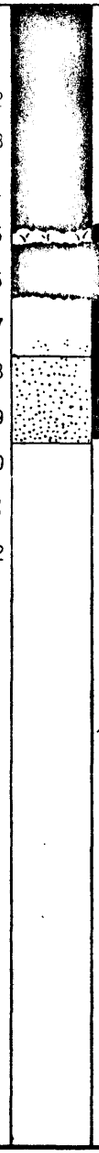
Log for Drill Hole BH-187-76 cont.

Depth in meters	Recovery	Drill Hole: BH-187 Lithologic Description	Atterberg Limits PL ⟷ LL (10 30 50 70 90)	Grain Size Distrib. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Indices Strength ⊥	Strength ∥	Penetration ⊥	Penetration ∥	Schmidt Hammer Index	Unconfined Compress. Strength	SLAKE DURABILITY
26		Coal, black, brittle, banded, conchoidal, fractures, pyrite flakes, shale seams, gray					1.52	1.10									
27							1.49	1.13									
28		(MONARCH) **coal seam**															
							1.52	1.13									
29							1.92	1.65									
30							1.93	1.68									
31		Shale, gray to dark gray, clayey to silty, carbonaceous zones, sandstone lenses, very fine to fine grained, coal and plant inclusions, scattered slickensides, becomes calcareous near base									0.10 .30	0.30 .85	0.5 1.0	1.0 3.5	25		
32				35	31	34	2.37	2.22	-	CL	1.00	1.90	1.0	5.0	20		88
33							2.39 2.38	2.27 2.23			1.40	2.10	1.5	2.0	18		
34				19	53	28			T	CL	.65 .80	.90 .90	.15 2.0	2.0 3.0	15 15		88
35				5	33	62	2.36 2.04	2.13 1.80	-	CH	.05	.15	1.5	3.0	18		76
36							2.20 2.33	2.04 2.16			.65	.70	2.0	4.5	18	15.3	94
37							2.07	1.83			.60	1.35	1.5	4.0	8		
38		Sandstone, light gray, very fine to fine grained, subangular, medium soft, calcareous and clay binder, carbonaceous laminae, coal inclusions, hard quartzitic zone at base	W	71	23	6	2.22	2.03	+	ML	.50 .45	.60 .55	1.0 .5	2.5 2.5	20 10	16.0	94
39							2.11	1.91			.05 .25	.65 4.30	1.5 .5	2.0 4.0	13 15	9.0	81
40							2.19 2.57	2.13 2.54			5.86	9.75	.5	3.0	35		
41		Shale, gray to dark gray, silty to very sandy, weakly calcareous, carbonaceous and sandstone laminae, coal and plant inclusions					2.13	2.08			.50 .65	.30 1.25	.5 1.0	.5 1.0	7 17		
42											.15	.65	.5	.5			
43				40	40	20	1.99	1.96	+	CL	.10 .60	.70 .95	.5 1.0	2.0 5.0	13		85
44		Sandstone, gray, fine to medium fine grained, subangular, weakly calcareous, carbonaceous laminae, shale zones, gray, faint cross bedding, clay binder, 1 m very hard cemented, sandstone, gray, contorted laminae					2.01	1.97			.25	.75	.5	4.0	15	12.6	94
45											.25	.65	1.0	3.0			
46				2	58	40			+	CL	.90	.75	1.0	3.0	25		92
47		Shale, as above, noncalcareous, more argillaceous									.15	.35	.5	.5	13		
48							2.26	2.18							10		
49		Coal, black, brittle, medium luster, conchoidal fractures, shale seams (CARNEY) **coal seam**					2.33 2.33	2.14 2.15									
				7	32	61			-	CL							90
		Units:	Water content of dry soil weight	finer by weight			g/cc	+ pos. - neg. T trace			MN/m²		mm			MN/m²	Retained % of dry soil weight

Explanation of symbols: PL = plastic limit; LL = liquid limit; ∥ = tested parallel to core axis; ⊥ = tested perpendicular to core axis.

(+)= positive reaction to a 25 percent HCl solution, (-)= no reaction, (T)= trace or faint reaction

Log for Drill Hole BH-187-76 cont.



Depth in meters	Recovery	Drill Hole: BH-187 Lithologic Description	Atterberg Limits PL—LL (10 30 50 70 90)	Grain Size Distrib. sand	silt	clay	Density As Rec'd	Density Dry Bulk	$CaCO_3$	Unified Soil Class.	Point Load Indices Strength ⊥	Point Load Indices Strength ∥	Point Load Indices Penetration ⊥	Point Load Indices Penetration ∥	Schmidt Hammer Index	Unconfined Compress. Strength	SLAKE DURABILITY
51		Coal, black, brittle, medium luster, conchoidal fracture, bicarbonate along vertical fractures, claystone-shale partings, soft, slickensides					1.77	1.56									
52							1.56	1.09									
53																	
54							1.54	1.10									
55				23	49	28			-								
				6	33	61	2.36	2.16									60
56																	
57		Shale, gray, slightly silty becoming sandy with depth, coal inclusions		25	40	35			-	CL	0.05	0.50	0.5	0.5			58
							2.44	2.31			.05	.45	.5	1.0			
58				51	30	19	2.23	2.11	T	SC	.10	.20	.5	1.0			
59		Sandstone, light gray to gray, very fine to fine grained, small percent clay binder, friable, subangular to subrounded, coal fragments less than 10 percent									.15	.25	.5	1.5		8.8	55
60											.05	.25	.5	2.0			83
61																	
62																	
Units:			Water content of dry soil weight	finer by weight			g/cc		+ pos. - neg. T trace		MN/m²		mm			MN/m²	Retained % of dry soil weight

Explanation of symbols: PL = plastic limit; LL = liquid limit; ∥ = tested parallel to core axis; ⊥ = tested perpendicular to core axis.
(+)= positive reaction to a 25 percent HCl solution, (-)= no reaction, (T)=trace or faint reaction

Appendix 2

Test results for drill hole BH-166-76

Submitter:

Location: Big Horn Coal Pit - Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY

SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	0 - 3.3	3.4	4.8	6.6	9.5
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	19	81	1	1	5
Silt: 0.075 - 0.005 mm (% by weight)	52	14	62	54	59
Clay: <0.005 mm (% by weight)	29	5	37	45	36
Coefficient of uniformity: $C_u = D60 \div D10$					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	23	N.P.	36	38	35
Plastic limit [PL] (% of dry soil weight)	19	N.P.	20	21	17
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	4	N.P.	16	17	18
Unified soil classification	CL-ML	SM	CL	CL	CL
As received water content [w] (% of dry soil weight)					
Activity: A = PI ÷ % finer than 0.002 mm					
Liquidity index: $I_L = (w - PL) \div PI$					
$CaCO_3$	+	+	+	+	+

REMARKS: 0-3.3 m (+) Positive reaction to 25 percent HCl; sandstone, fine grained, soft
3.4 m N.P. = nonplastic material, magnetic particles detected in sample; sandstone, medium grained, hard
4.8 m shale; silty, soft
6.6 m shale; soft
9.5 m shale; silty, hard

Submitter:

Location: Big Horn Coal Pit - Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY

SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	10.1	12.5	15.5-18.6	18.6 - 20.8	20.8-21.7
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	5	4	6	4	7
Silt: 0.075 - 0.005 mm (% by weight)	60	39	66	48	68
Clay: <0.005 mm (% by weight)	35	57	28	48	25
Coefficient of uniformity: $C_u = D60 \div D10$					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	36	42	39	31	28
Plastic limit [PL] (% of dry soil weight)	21	17	23	21	21
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	15	25	16	10	7
Unified soil classification	CL	CL	CL	CL	CL-ML
As received water content [w] (% of dry soil weight)					
Activity: $A = PI \div$ % finer than 0.002 mm					
Liquidity index: $I_L = (w - PL) \div PI$					
$CaCO_3$	+	+	+	+	+

REMARKS: 10.1 m shale; soft
12.5 m shale; scattered silt lenses, moderately hard, shell fragments
15.5-18.6 m shale; scattered carbonaceous zones, moderately hard
18.6-20.8 m shale; with 0.3 m of sandstone, fine grained
20.8-21.7 m shale; silty with interbedded sandstone, fine grained, composing approximately 1/3 of volume

Submitter:

Location: Big Horn Coal Pit- Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY

SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	21.7-23.4	23.4	25.6	27.4 - 30.0	30.0 - 31.3
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	23	20	10	25	75
Silt: 0.075 - 0.005 mm (% by weight)	48	58	56	55	19
Clay: <0.005 mm (% by weight)	29	22	24	20	6
Coefficient of uniformity: C_u = D60 ÷ D10					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	26	27	26	28	N.P.
Plastic limit [PL] (% of dry soil weight)	21	21	22	20	N.P.
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	4	5	4	8	N.P.
Unified soil classification	ML	CL-ML	CL-ML	CL	SM
As received water content [w] (% of dry soil weight)					
Activity: A = PI ÷ % finer than 0.002 mm					
Liquidity index: $I_L = (w - PL) \div PI$					
$CaCO_3$	+	+	+	++	+

REMARKS: 21.7-23.4 m mainly sandstone, very fine to fine grained with interbedded shales, silty, random carbonaceous stringers

23.4 m sandstone; very fine grained, silty

25.6 m sandstone; fine grained, shaly, friable, carbonaceous laminae

27.2-30.0 m shale; silty, carbonaceous, medium hard--magnetic particles detected

30.0-31.3 m sandstone; fine grained, well-cemented, carbonaceous material--magnetic particles detected

Submitter:

Location: Big Horn Coal Pit - Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY

SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	31.3-33.8	33.8	37.0	41.9	44.8
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	22	12	15	7	5
Silt: 0.075 - 0.005 mm (% by weight)	60	60	40	19	31
Clay: <0.005 mm (% by weight)	13	28	45	74	64
Coefficient of uniformity: C_u = D60 ÷ D10					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	27	31	42	62	58
Plastic limit [PL] (% of dry soil weight)	21	17	21	27	23
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	6	14	21	35	35
Unified soil classification	CL-ML	CL	CL	CH	CH
As received water content [w] (% of dry soil weight)					
Activity: A = PI ÷ % finer than 0.002 mm					
Liquidity index: I_L = (w - PL) ÷ PI					
$CaCO_3$	+	+	T	T	-

REMARKS: 31.3-33.8 m shale; silty to clayey, medium hard to soft, carbonaceous
33.8 m shale; clayey lenses, abundant carbonaceous laminae
37.0 m shale; medium hard, grading to carbonaceous shale--(T)=weak to faint reaction with 25 percent HCL
41.9 m shale; medium hard, coal inclusions, grades to carbonaceous shale
44.2 m shale; silty, medium soft, carbonaceous, noncalcareous, parting in coal seam

Submitter:

Location: Big Horn Coal Pit - Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY
SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	52.1	55.2	64.5-67.1	67.4	70.4
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	1	7	17	37	14
Silt: 0.075 - 0.005 mm (% by weight)	25	19	63	52	66
Clay: <0.005 mm (% by weight)	74	74	20	11	20
Coefficient of uniformity: C_u = D60 ÷ D10					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	44	47	28	24	36
Plastic limit [PL] (% of dry soil weight)	21	24	20	22	21
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	23	23	8	2	15
Unified soil classification	CL	CL	CL	ML	CL
As received water content [w] (% of dry soil weight)					
Activity: A = PI ÷ % finer than 0.002 mm					
Liquidity index: I_L = (w - PL) ÷ PI					
$CaCO_3$	T	T	+	+	+

REMARKS: 52.1 m shale; thin silty zone, medium hard
55.2 m shale; carbonaceous to coaly
64.5-67.1 m shale; hard, base of coal seam
67.4 m sandstone; medium grained, hard
70.4 m siltstone; sandy, medium hard, carbonaceous laminae

Submitter:

Location: Big Horn Coal Pit - Acme, Wyoming

Project #:

Hole #: BH-166-76

ENGINEERING GEOLOGY LABORATORY

SOIL SAMPLE TEST RESULTS

Date:

Analyst: Cloft/Jones

Reviewed by:

	SAMPLE NUMBER				
Meters:	73.5-74.9	75.9	77.3	83.9	93
Gravel: 76 - 4.76 mm (% by weight)	0	0	0	0	0
Sand: 4.76 - 0.075 mm (% by weight)	23	53	70	33	35
Silt: 0.075 - 0.005 mm (% by weight)	60	37	24	41	34
Clay: <0.005 mm (% by weight)	17	10	6	26	31
Coefficient of uniformity: C_u = D60 ÷ D10					
Coefficient of curvature : $C_z = (D30)^2 \div (D60 \times D10)$					
Liquid limit [LL] (% of dry soil weight)	26	20	N.P.	24	40
Plastic limit [PL] (% of dry soil weight)	21	19	N.P.	18	25
Shrinkage limit [SL] (% of dry soil weight)					
Plasticity index [PI] (% of dry soil weight)	5	1	N.P.	6	15
Unified soil classification	CL-ML	SC	SM	CL-ML	CL-ML
As received water content [w] (% of dry soil weight)					
Activity: A = PI ÷ % finer than 0.002 mm					
Liquidity index: $I_L = (w - PL) \div PI$					
$CaCO_3$	T	T	T	T	T

REMARKS:
73.5-74.4 m sandstone; fine grained to silty, medium hard, carbonaceous laminae
75.9 m sandstone; very fine to medium grained, well compacted, hard
77.3 m sandstone; fine to medium grained, friable in places
83.9 m sandstone; fine to medium grained, clayey, carbonaceous
93.0 m shale; black soft, carbonaceous