

**The Battle Formation
in Central Alberta
as a Source of
Low Alkali Clay for Cement**

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Abstract

The Battle Formation recently has been recognized as a potential source of the low alkali clay (<1.6 %) needed to produce low alkali cement.

Exposures of the formation in central Alberta are evaluated as sites for further prospecting. Twelve localities between the Oldman River in the south and the Athabasca River in the north are recommended for further testing.

Introduction

For many years, the Kneehills Tuff Zone, consisting of the Battle and Whitemud Formations, has been recognized, both at the surface and in the subsurface, as a very important stratigraphic marker in a thick sequence of predominantly nonmarine, deltaic and floodplain sandstones, shales and coal beds (Campbell, 1967, 1974; Campbell and Almadi, 1964; Gibson, 1977; Irish 1970; Irish and Havard, 1968; Ower, 1960). Recently, the upper, black to mauve weathering, highly smectitic component of the zone, the Battle Formation, also has been recognized as having considerable economic potential because of its chemical composition. In the clay rocks of this unit total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) concentration commonly is lower than the 1.6 % maximum allowed in low alkali cement production. Low alkali cement is used in concrete construction to counter the expansion reactions of certain aggregates with normal portland cement.

Battle Formation materials are mined and stockpiled in the Cypress Hills area by I-XL Industries Ltd. as a byproduct of mining the underlying Whitemud Formation materials which are used in production of brick and tile in Medicine Hat. Because of the high smectite content of the Battle Formation, only minor amounts of the material are used in ceramic production to increase plasticity of the mix. Some of this stockpiled material has been used for cement production in Edmonton and Exshaw. In order to determine whether the chemical characteristics of the Battle Formation are similar throughout its surface extent, and to make a reconnaissance survey of potential mining localities less distant than the Cypress Hills source from current cement plant sites, the Alberta Geological Survey performed a survey of reported localities of Battle Formation outcrops in central Alberta from the Oldman River in the south to the Athabasca River in the north.

Surface distribution of the Battle Formation

Furnival (1950) first separated the mauve weathering, dark brown to

purplish black, smectitic mudstones or shales of the Battle Formation from the Whitemud Group. The group, named in 1918 by N.B. Davis, consists primarily of white weathering, kaolinized, feldspathic sandstones, siltstones and shales that form a prominent marker over a large part of southern Saskatchewan and southeastern Alberta. Allan and Sanderson (1945) considered similar sediments in the Red Deer River area to be equivalents of the sediments in the Cypress Hills area. Irish and Havard (1968) show that the combination of Battle and Whitemud formations forms a distinctive marker wherever it is exposed and give locations for many of the outcrops in central Alberta. Even though many of these localities are given as precisely as the section designation in the Alberta Township System, several were difficult or impossible to locate after the 25 year interval since publication of that study. Similar problems exist with some localities given by Campbell (1967, 1974) and Ower (1960). Localities described in this study are defined to the legal subdivision (LSD) if possible (Table 1). Field descriptions of the localities visited for this study are in Appendix 1.

The most southern exposures of the Battle Formation are in the banks of the Oldman River northwest of Monarch (Locality 1, Figure 1) and these are the only known exposures of the formation south of the Bow River. The formation has thinned to ~3.6 m in this outcrop from the common 10 m thickness further north.

Between the Bow River valley in the vicinity of Gleichen, and Alix, north of the Red Deer River valley (Localities 2 to 18, Figure 1), there are numerous outcrops in the valleys of the Red Deer River, Kneehills Creek, Threehills Creek, Ghostpine Creek, and on the north slope of the Wintering Hills and the west slope of the Hand Hills.

North of the Alix area, outcrops are sparse. A section on Strawberry Creek north of Telfordville (Locality 19, Figure 1), an outcrop on Lakeshore Road west of Wabamun (Locality 20), and an outcrop beneath heavy overburden in the north bank of Athabasca River east of Whitecourt (Locality 21) are the only confirmed *in situ* outcrops of the Battle Formation. Ower (1960) reports an outcrop on the Pembina River in NW13-54-7-W5 but this author was unable to find any trace of that outcrop. Campbell (1972) reports outcrops in the vicinity of Fox Creek but these outcrops are either slumped or badly distorted from glacial action and may not be in place. These localities reported by Campbell were not

Table 1. Battle Formation outcrops visited in 1990-'91. Outcrop localities listed from south to north and located according to the Alberta Township System (ATS). Samples are placed in their relative stratigraphic position.

Locality	Field ID	NTS Map	ATS Location	Samples
1	DS91-21	82H/14	~11-25-10-25-W4	DS91-21-1
	DS91-20	82H/14	~15-25-10-25-W4	DS91-20-1
2	DS91-19	82I/14	3-25-22-23-W4	DS91-19-3 DS91-19-2 DS91-19-1
3	DS91-18	82I/14	4-23-22-24-W4	DS91-18-1
4	DS91-17	82I/14	~8-26-23-23-W4	DS91-17-2 DS91-17-1
5	DS91-13	82P/7	7-35-26-19-W4	
6	DS91-12	82P/7	16-3-27-19-W4	DS91-12-1
7	DS91-11	82P/6	5-23-27-23-W4	DS91-11-2 DS91-11-1
8	DS91-16	82P/7	~6-27-28-21-W4	DS91-16-4 DS91-16-3 DS91-16-1 DS91-16-2
9	DS91-14	82P/8	13-10-29-17-W4	
10	DS91-15	82P/8	~11-24-29-18-W4	DS91-15-1
11	DS91-10	82P/6	4-23-29-23-W4	
12	DS91-9	82P/11	12-18-30-22-W4	

13	DS91-8	82P/11	14-9-31-22-W4	
14	DS90-4	82P/15	8-29-34-21-W4	DS90-4-2 DS90-4-1
	DS91-6	82P/15	14-33-34-21-W4	
15	Unnumbered	83A/2	15,22-35-20-W4	
	DS91-4	82P/15	10-9-35-20-W4	DS91-4-4 DS91-4-3 DS91-4-2 DS91-4-1
16	DS91-7	82P/15	7-3-35-21-W4	
	DS91-5	83A/2	~5-21-35-21-W4	
17	Unnumbered	83A/2	1,11,12,14-37-21-W4	
18	DS91-3	83A/6	3-3-39-22-W4	
	DS91-2	83A/6	16-3-39-22-W4	
	DS91-1	83A/6	4-22-39-22-W4	DS91-1-3 DS91-1-2 DS91-1-1
	DS90-2	83A/6	12-23-39-22-W4	DS90-2-1
19	DS90-8	83G/8	4-5-50-1-W5	DS90-8-1 DS90-8-2 DS90-8-3 DS90-8-4 DS90-8-5 DS90-8-6 DS90-8-7 DS90-8-8
			1-6-50-1-W5	DS90-8-11 DS90-8-10 DS90-8-9
20	DS90-12	83G/10	13-8-53-4-W5	DS90-12-1
	DS90-11	83G/10	5-9-53-4-W5	DS90-11-1
21	Unnumbered	83J/4	14,15-1-60-12-W5	

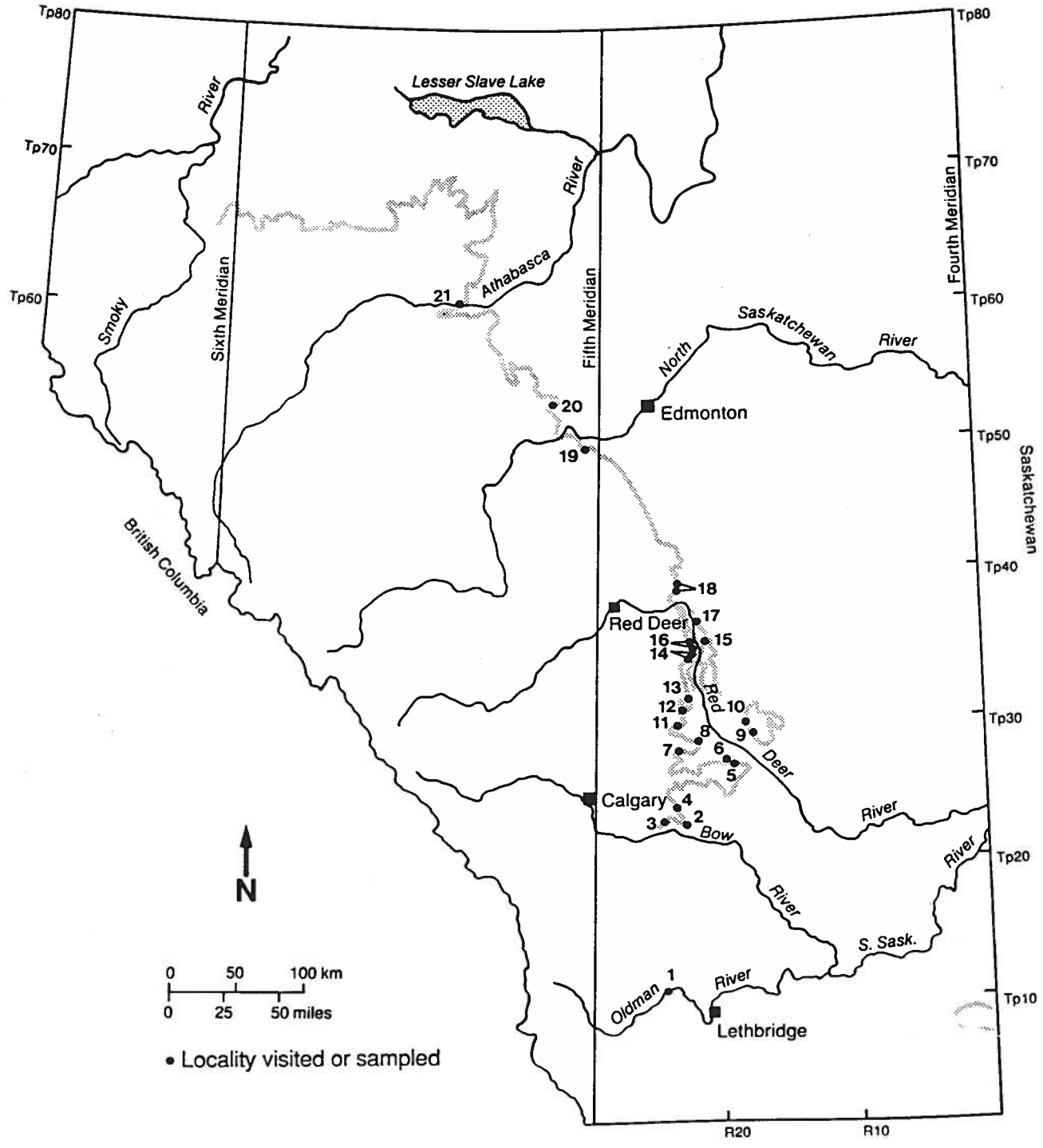


Figure 1 Outcrop localities of Battle Formation visited for this study.

visited by this author.

Lithology

The formation, commonly 10 m thick, is predominantly 10YR2/2 (dusky yellowish brown) and 5YR2/1 (brownish black) mudstone. Silt seldom is present in more than minor amounts and the fissility of a shale is uncommon. Slickensides are common on the surfaces of material that exhibits blocky texture below the weathered surface. Conchoidal fracture is common on the surfaces of material that exhibits tabular texture. A weathered surface 10 to 20 cm thick exhibits "cauliflower" or "alligator skin" texture from wetting and drying. The higher the amount of smectite clay present, the more the surface texture tends to be "cauliflower". Small pockets, rosettes or single crystals of white calcite are common. An olive gray bentonite ~30 cm thick is present at or slightly above the base of the formation at a few localities. The lower contact with the Whitemud Formation appears conformable at most localities but the upper contact may be conformable or an erosion contact with overlying bedrock or till may be present. Up to four hard, gray tuff beds from 7 to 30 cm thick may be present in the upper part of the formation. The uppermost tuff bed, commonly ~30 cm thick, is the Kneehills Tuff.

Laboratory Methods

Chemical analyses were performed on 32 samples, from 14 localities. The samples were dried and fused with lithium metaborate. Elements were determined on the dissolved melt by ICP. Results are reported as percent by weight in the oxide form. X-ray analyses were performed on the same samples as above on the <2 μm fraction of disaggregated samples smeared on glass slides mounted in a Philips X-ray diffraction unit. A slide was sprayed with ethylene glycol and another was heated to 550°C to determine the presence of expansive clay minerals and chlorite respectively.

Results

The results of chemical analyses are shown in Table 2 and total alkalis are shown in Table 3. Total alkalis range from 0.75 to 2.16 % and average 1.32 % for the 32 samples tested. This average is less than the 1.6 % maximum set for production of low alkali cement. If the values are deleted for the three bentonites that occur at the contact with the Whitemud Formation (Localities 2, 8, 15), the two samples from Dry Island Buffalo Jump Provincial Park (Locality 14), and the six samples

Table 2. Chemical analyses of the Battle Formation in central Alberta. Samples are placed in their relative stratigraphic position.

Locality	Sample ID	Alta. Twp. Sys. Location	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	MnO	CaO	MgO	Na ₂ O	K ₂ O	S	L.O.I.
1	DS91-21-1	11-25-10-25-W4	68.68	14.54	3.92	0.52	0.04	0.02	0.81	1.40	1.35	0.50	0.12	8.10
1	DS91-20-1	15-25-10-25-W4	62.91	17.81	5.23	0.53	0.04	0.03	1.24	1.49	1.06	0.81	0.02	8.83
2	DS91-19-3	3-25-22-23-W4	65.30	15.98	4.23	0.50	0.03	0.01	0.80	1.45	0.96	0.75	0.02	9.97
	- 2		69.15	15.68	2.54	0.39	0.04	0.01	0.71	0.65	0.61	0.22	0.02	9.98
	- 1		64.71	17.98	3.62	0.59	0.04	0.01	0.85	0.90	1.22	1.02	0.20	8.86
2	DS77-70-3	3-25-22-23-W4	64.71	17.20	2.88	0.40	0.04	0.01	0.81	0.56	0.69	0.25	0.02	6.79
3	DS91-18-1	4-23-22-24-W4	73.84	13.85	2.92	0.51	0.08	0.02	1.19	0.99	0.73	0.45	0.04	5.38
4	DS91-17-2	8-26-23-23-W4	66.58	18.33	3.98	0.42	0.06	0.02	1.18	1.32	1.03	0.39	0.02	6.67
	- 1		63.14	20.57	4.72	0.50	0.04	0.02	1.12	0.92	0.91	0.13	0.10	7.83
6	DS91-12-1	16-3-27-19-W4	73.85	15.07	2.50	0.60	0.04	0.01	0.75	0.61	0.70	0.36	0.07	5.44
7	DS91-11-2	5-23-27-23-W4	72.64	15.51	2.79	0.47	0.25	0.02	0.92	0.90	0.70	0.39	0.02	5.39
	- 1		70.04	17.45	2.83	0.61	0.07	0.01	0.92	0.84	0.83	0.64	0.02	5.74
8	DS91-16-4	6-27-28-21-W4	73.05	15.00	3.01	0.53	0.03	0.01	0.92	0.73	0.73	0.30	0.02	5.67
	- 3		68.82	17.39	4.15	0.46	0.04	0.01	0.74	0.65	0.78	0.18	0.02	6.76
	- 1		65.90	21.29	2.66	0.65	0.05	0.01	0.56	0.62	0.71	0.42	0.02	7.11
	- 2		72.97	16.08	1.89	0.77	0.07	0.01	0.40	0.66	0.70	1.49	0.02	4.94
10	DS91-15-1	11-24-29-18-W4	67.31	18.99	3.44	0.47	0.04	0.02	1.03	1.08	0.93	0.40	0.06	6.23
14	DS90-4-2	8-29-34-21-W4	64.63	20.52	4.17	0.45	.	.	1.20	1.65	1.66	0.32	.	5.40
	- 1		69.91	17.39	3.68	0.48	.	.	0.94	1.39	1.55	0.46	.	4.20
15	DS91-4-4	10-9-35-20-W4	68.31	17.59	4.18	0.52	0.04	0.00	0.93	1.00	1.01	0.37	0.02	6.03
	- 3		64.73	20.53	4.48	0.74	0.03	0.00	0.78	0.65	0.79	0.16	0.03	7.08
	- 2		63.54	22.08	3.33	0.70	0.04	0.01	0.58	0.72	0.75	0.91	0.02	7.32
	- 1		68.16	17.41	4.82	0.67	0.05	0.01	0.64	0.73	0.78	1.54	0.02	5.17
18	DS901-1-3	4-22-39-22-W4	70.39	16.52	3.43	0.48	0.06	0.01	0.76	0.98	1.04	0.79	0.03	5.51
	- 2		66.86	18.09	5.49	0.55	0.03	0.01	0.68	0.68	0.92	0.24	0.02	6.43
	- 1		62.46	20.14	6.76	0.64	0.11	0.01	0.62	0.48	0.72	0.66	0.02	7.38
18	DS90-2-1	12-23-39-22-W4	62.63	23.38	3.81	0.77	.	.	0.74	0.62	0.71	0.34	.	7.10
19	DS90-8-1	4-5-50-1-W5	68.05	16.46	3.36	0.59	.	.	0.74	0.87	1.40	1.15	.	7.38

	- 3		60.86	20.54	4.13	0.39	.	.	1.02	1.14	1.41	0.58	.	9.92
	- 5		61.60	20.35	4.38	0.45	.	.	0.97	1.03	1.66	0.35	.	9.21
	- 8		64.86	17.97	4.41	0.46	.	.	0.84	1.09	1.28	0.39	.	8.70
20	Wab. N. Shore	5-9-53-4-W5	62.01	23.25	3.16	0.58	.	.	0.94	0.73	0.71	0.20	.	8.42

Table 3. Percent total alkalis in the Battle Formation in central Alberta. Samples are placed in their relative stratigraphic position. Total alkalis = $\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O}$

Locality	Sample ID	ATS Location	Na_2O %	K_2O %	Total %
1	DS91-21-1	11-25-10-25-W4	1.35	0.50	1.68
1	DS91-20-1	15-25-10-25-W4	1.06	0.81	1.59
2	DS91-19-3	3-25-22-23-W4	0.96	0.75	1.45
	- 2		0.61	0.22	0.75
	- 1		1.22	1.02	1.89
2	DS77-70-3	3-25-22-23-W4	0.69	0.25	0.85
3	DS91-18-1	4-23-22-24-W4	0.73	0.45	1.03
4	DS91-17-2	8-26-23-23-W4	1.03	0.39	1.29
	- 1		0.91	0.13	1.00
6	DS91-12-1	16-3-27-19-W4	0.70	0.36	0.94
7	DS91-11-2	5-23-27-23-W4	0.70	0.39	0.96
	- 1		0.83	0.64	1.25
8	DS91-16-4	6-27-28-21-W4	0.73	0.30	0.93
	- 3		0.78	0.18	0.90
	- 1		0.71	0.42	0.99
	- 2		0.70	1.49	1.68
10	DS91-15-1	11-24-29-18-W4	0.93	0.40	1.19
14	DS90-4-2	8-29-34-21-W4	1.66	0.32	1.87
	- 1		1.55	0.46	1.85
15	DS91-4-4	10-9-35-20-W4	1.01	0.37	1.25
	- 3		0.79	0.16	0.90
	- 2		0.75	0.91	1.35
	- 1		0.78	1.54	1.79
18	DS91-1-3	4-22-39-22-W4	1.04	0.79	1.56
	- 2		0.92	0.24	1.08
	- 1		0.72	0.66	1.15
18	DS90-2-1	12-23-39-22-W4	0.71	0.34	0.93
19	DS90-8-1	4-5-50-1-W5	1.40	1.15	2.16
	- 3		1.42	0.58	1.79
	- 5		1.66	0.35	1.89
	- 8		1.28	0.39	1.54
20	Wab. N. Shore	5-9-53-4-W5	0.71	0.20	0.84

from Oldman River (Locality 1) and Strawberry Creek (Locality 19) that are below heavy overburden, then the average for the remaining 21 samples is reduced to an even more appealing 1.08 %.

Samples of a bentonite bed (in the Battle Formation) that is present at or near the contact with the Whitemud Formation at some localities, were taken at three localities. This was done to determine whether this material could be included while mining or whether it should be used as a lower limit for mining wherever it is present. In all cases, total alkali content from the bentonite bed exceeded the 1.6 % limit for low alkali cement production.

No chemical analyses were made of the Kneehills Tuff bed or of any other tuff beds present in some outcrops because it was considered that such indurated material may be removed and discarded during mining. However, chemical analyses of eight samples of the Kneehills Tuff bed in central Alberta by Irish and Havard (1968) are similar in total alkali content to the surrounding shale. Should the higher silica content and induration of the tuff be acceptable, then that material would not have to be discarded.

In order to ascertain whether there is any obvious trend in total alkali percentage, either stratigraphically or geographically, within the Battle Formation in central Alberta, the data from Table 3 are plotted in Table 4 in their relative stratigraphic positions within the formation along the outcrop trend from south to north. No trend in total alkali percentage is apparent either stratigraphically or geographically. A similar plot, from Table 5, of the clay mineral smectite percentage data in Table 6 reveals that smectite, the dominant clay mineral present in the Battle Formation in central Alberta, generally is less abundant in the lower 1 m of the formation. Its concentration varies from 55 to 100 % in this interval. Kaolinite is the next most common clay mineral and illite is present in only seven of the 31 samples subjected to x-ray diffraction analysis. Six of those seven samples containing illite are from the lower 1 m of the formation. Generally, total alkali percentage is high (>1 %) in the lower 1 m of the formation but there seems to be no consistent relation to the clay mineralogy assemblage. Other than the altered proportions of the clay mineral suite in the lower 1 m of the formation there is no apparent trend in clay mineral composition geographically or stratigraphically in central Alberta.

Table 4. Percent total alkalis in a cross section of the Battle Formation in central Alberta. Values in brackets are from bentonite beds. Samples are placed in their relative stratigraphic position.

Thickness (m)	Locality													
	1	2	3	4	6	7	8	10	14	15	18	19	20	
10													2.16	
9													1.79	
8				1.29			0.93							
7		1.45										1.56	1.89	
6														
5									1.87	1.25			1.54	
4		0.85				0.96	0.90							0.84
3				1.00					1.19			1.08		
2	1.68													
2	1.59		1.03		0.94						0.90			
1							0.99						0.93	
1							(1.68)						1.15	
0		(1.89)					1.25		1.85	1.35	(1.79)			

Table 5. Semi-quantitative estimates of clay minerals in the Battle Formation in central Alberta. Samples are placed in their relative stratigraphic position.

Locality	Sample ID	ATS Location	Smectite %	Illite %	Kaolinite %
1	DS91-21-1	~11-25-10-25-W4	100		
1	DS91-20-1	~15-25-10-25-W4	<95	5	trace
2	DS91-19-3	3-25-22-23-W4	90		10
	-2		>95		trace
	-1		85	5	10
3	DS91-18-1	4-23-22-24-W4	100		
4	DS91-17-2	~8-26-23-23-W4	100		
	-1		90		10
6	DS91-12-1	16-3-27-19-W4	85		15
7	DS91-11-2	5-23-27-23-W4	95		5
	-1		80	5	15
8	DS91-16-4	~6-27-28-21-W4	>95		trace
	-3		90		10
	-1		60		40
	-2		60	25	15
10	DS91-15-1	~11-24-29-18-W4	>95		trace
14	DS90-4-2	8-29-34-21-W4	100		
	-1		100		
15	DS91-4-4	10-9-35-20-W4	>95		trace
	-3		95		5
	-2		65	5	30
	-1		70	15	15
18	DS91-1-3	4-22-39-22-W4	95		5
	-2		90		10
	-1		55	10	35
	DS90-2-1	12-23-39-22-W4	60		40
19	DS90-8-1	4-5-50-1-W5	100		
	-3		100		
	-5		100		
	-8		100		
20	Wab. N. Shore	5-9-53-4-W5	80		20

Table 6. Semi-quantitative estimates of smectite clay mineral percentage in a cross section of the Battle Formation in central Alberta. Values in brackets are from bentonite beds. Samples are placed in their relative stratigraphic position.

Thickness (m)	Locality												
	1	2	3	4	6	7	8	10	14	15	18	19	20
10												100	
9												100	
8				100			>95						
7		90									95	100	
6													
5									100	>95		100	
4		100				95	90						80
3		>95		90				>95			90		
2	100 <95		100		85						95		
1							60 (60)				60		
0		(85)					80		100	65 (70)	55		

No mechanical analyses were made of samples in this study. Irish and Havard (1968) performed analyses on nine samples from central Alberta and report sand and silt ranging from 3.3 to 44.5 % and 0.6 to 10.1 % respectively. Assessment of samples in the field by this author (Appendix 1) suggests that the lower figure is the most common value for either size fraction.

Discussion

The wide distribution, and usefulness as a correlation horizon of the Battle Formation in central Alberta is well established. The results presented in this study indicate that the formation is an excellent source of the low alkali clay needed for production of low alkali cement. Some practical problems exist, however, in the search for suitable mining locations. The high smectite content of the Battle Formation makes it extremely vulnerable to slumping when exposed to sources of water. The formation also was a common plane of weakness for glacial deformation during continental glaciation. This instability makes it difficult to find outcrops in place.

The usual 10 m maximum thickness of the formation limits the search to outcrops beneath reasonable overburden. Richardson et al. (1988) indicate that the formation dips ~5 m/km from the erosional edge. South of Tp 35 dip is to the west; between Tp 35 and 60, to the southwest; and north of Tp 60, to the south. Assuming a stripping ratio of 1:1, any drilling program aiding the search for the formation should be limited to a corridor no more than 2 km wide in a westerly or southerly direction from the erosional edge.

Recommended Localities

Several localities are recommended for prospecting. Total alkalis are below the 1.6 % maximum required for low alkali cement and field observations suggest that sufficient volume of the formation underlies reasonable thickness of overburden.

Locality 2 at 3-25-22-23-W4 has ~9 m of Battle Formation exposed along an outcrop ~100 m long beneath thin or acceptable overburden. Overburden is a combination of buff shales, sandstone and till to the west. Along the the southeast arm of the coulee overburden appears to be till and Battle Formation material is found at the entrance of animal burrows. The area is grassland and to the southeast there is likely to be abundant material

beneath thin overburden.

Locality 3 at 4-23-22-24-W4 on the north side of the Bow River has acceptable material but unacceptable overburden. The Battle Formation apparently does not outcrop on the south side of the river, but a bench is present at approximately the same level as the outcrops on the north side. If the formation is present on the south side of the river there is the possibility of a large volume of material beneath thin overburden. Drilling is required to confirm the presence of the formation.

Locality 4 at 8-26-23-23-W4 is a coulee that has ~10.8 m of Battle Formation with two tuff beds in the interval. The area is grassland and a good volume of material is below thin overburden and more is below acceptable overburden.

Locality 6 at 16-3-27-19-W4 is a coulee outcrop of Battle Formation ~5 m thick. The formation probably is present to the west and southwest in Section 3. The most accessible material is to the northeast but drilling is required to determine how much the formation thins in that direction. The area is grassland.

Locality 7 at 5-23-27-23-W4 has ~5.5 m of Battle Formation below ~5.5 m of till in the bank of the Rosebud River. If drilling confirmed the presence of the Battle Formation to the east in this bench, there would be a large volume of material below an acceptable thickness of easily mineable overburden. The field on the bench was growing a cereal crop when visited.

Locality 8 at 6-27-28-21-W4 is a side coulee on the southeast arm of Horseshoe Canyon and exposes ~9 m of Battle Formation beneath ~1.5 m of till overburden. There are two, thin tuff zones in the section. A drilling program on private land to the southwest is suggested, as the topography rises gently in that direction, whereas it drops in all northerly directions and the formation is likely to be missing. A quarrying operation to the south will have less negative visual impact for the Horseshoe Canyon Recreation Area lookout nearby.

Locality 9 at 13-10-29-17-W4 has a partly covered outcrop of Battle and Whitemud Formations near the base of the southeast wall of a coulee on the west flank of the Hand Hills. The thickness of the Battle Formation

present is unknown. It would be necessary to drill to the southeast to determine its presence and thickness but the topography suggest the result could be favorable. The area is grassland.

Locality 10 at 11-24-29-18-W4 is in a series of badlands-type outcrops in grassland on the west flank of the Hand Hills that expose ~9 m of Battle Formation. Overburden increases to the east but the area is slumped so the overburden may not be too thick over an extensive area north and south of the outcrop zone. Drilling is necessary to delineate the area of acceptable overburden. A tracked drill might be the best unit for traversing the several coulees between the nearest access road and the first outcrop to perform the An alternative is to test in the more easily accessible area near an abandoned Caterpillar tractor hulk at 2-25-29-18-W4.

Locality 15 at 10-9-35-20-W4 has ~6 m of Battle Formation exposed along a bluff ~1 km long. Till overburden is ~6 m thick. Topography increases gently to the west so the Battle Formation thickness also may increase to its usual 10 m as it dips in that direction. This locality appears very favorable for mining.

Locality 16 at 5-21-35-21-W4 west of McKenzie Crossing of the Red Deer River on Tp Rd 354, was viewed only through binoculars from the east side of the river. There appears to be a good thickness of Battle Formation under reasonable overburden at the top of the valley wall. Further to the south in the same township at 7-3-35-21-W4 is 3 to 4 m of Battle Formation under a similar depth of till overburden beneath a very large expanse of grassland.

Locality 18 at 4-22-39-22-W4 probably is the best of the three areas listed for this locality (Appendix 1) to prospect further. Approximately 7 m of Battle Formation is exposed beneath ~2 m of till overburden in the walls of a coulee just north of Tail Creek Raceway. There are three, faint, thin, light gray bands in the outcrop that could be tuff or bentonite. A large open expanse of grassland north of the coulee and south of Hwy 12 could be a good area to perform a drilling program. The location of pipelines to the abandoned gas plant nearby is not known.

There are no outcrops of the Battle Formation reported between Locality 19 at 4-5-50-1-W5 and Locality 20 at 5-9-53-4-W5, the

outcrops closest to Edmonton. Overburden exceeds 20 m at Locality 19 and there could be local resistance to a quarry at Locality 20 along Lakeshore Road that serves the resort homes on the north shore of Wabamun Lake. A drilling program north of Locality 19 and south of Lake Wabamun that follows within 2 km to the west of the projected formation edge is likely to be the best method of prospecting for the formation in that area.

Conclusions

1. The Battle Formation in central Alberta is an excellent source of low alkali (<1.6 %) clay.
2. Twelve localities from the Bow River in the south to Lake Wabamun in the north are recommended for prospecting.
3. If a 1:1 mining ratio is assumed, it is recommended not to search more than 2 km west of the erosion edge of the formation.
4. In those localities where a bentonite bed is present near the contact with the underlying Whitemud Formation, mine only material above the bentonite bed.
5. Tuff beds in the formation also are low in alkali and could be mined if their higher silica content and indurated nature are acceptable.

References

- Allan, J.A., and J.O.G. Sanderson. 1945. Geology of Red Deer and Rosebud sheets, Alberta. Research Council of Alberta Report 13, Edmonton, Alberta.
- Campbell, J.D. 1967. Ardley coal zone in the Alberta Plains: central Red Deer River area. Research Council of Alberta Report 67-1, Edmonton, Alberta.
- _____ 1972. Coal resources and related geology, Fox Creek area, Alberta. Research Council of Alberta Report 72-9, Edmonton, Alberta.
- _____ 1974. Coal resources, Hussar-Hanna area, Alberta. Alberta Research Report 74-8, Edmonton, Alberta.
- _____ and I.S. Almadi. 1964. Coal occurrences of the Vulcan-Gleichen area, Alberta. Research Council of Alberta Preliminary Report 64-2, Edmonton, Alberta.

- Davis, N.B. 1918. Report on the clay resources of southern Saskatchewan. Mines Branch, Canada Department of Mines Report 468, Ottawa, Ontario.
- Furnival, G.M. 1950. Cypress Lake map-area, Saskatchewan. Geological Survey of Canada Memoir 242, Ottawa, Ontario.
- Gibson, D.W. 1977. Upper Cretaceous and Tertiary coal-bearing strata in the Drumheller-Ardley region, Red Deer River valley, Alberta. Geological Survey of Canada Paper 76-35, Ottawa, Ontario.
- Irish, E.J.W. 1970. The Edmonton Group of south-central Alberta. Bulletin of Canadian Petroleum Geology 18(2):125-155.
- _____ and C.J. Havard. 1968. The Whitemud and Battle Formations ("Kneehills Tuff Zone") a stratigraphic marker. Geological Survey of Canada Paper 67-63, Ottawa, Ontario.
- Ower, J.R. 1960. The Edmonton Formation. Journal of Alberta Society of Petroleum Geologists 8(11): 309-323.
- Richardson, R.J.H., R.S. Strobl, D.E. Macdonald, J.R. Nurkowski, P.J. McCabe, and A. Bosman. 1988. An evaluation of the coal resources of the Ardley coal zone, to a depth of 400 m, in the Alberta plains area. Alberta Research Council, Alberta Geological Survey Open File Report 1988-02, Edmonton, Alberta.

Appendix 1. Battle Formation Outcrop Descriptions

Localities are listed from south to north and located according to the Alberta Survey System.

Locality: 1
Field ID: DS91-21
Location: 11-25-10-25-W4
Map Sheet: 82H/14 Monarch

General Locality Description:

This locality on the north bank of the Oldman River is the furthest south occurrence of Battle Formation in central Alberta reported by Irish (1967). The formation is ~3.6 m thick between grayish yellow beds and is exposed intermittently for ~100 m below ~15 m of till and bedrock overburden. The formation seems to dip southwest at more than the 5 m/km generally reported. There seems to be a thin tuff bed at the top of the dark material on the contact with the overlying grayish yellow beds. The formation should be present near the surface somewhere to the east of this locality but the interval is covered

Sample Description:

DS90-21-1 taken ~1 m below the upper contact is 10YR2/2 (dusky yellowish brown), silty mudstone that breaks into blocks <3 mm diameter.

Locality: 1
Field ID: DS91-20
Location: 15-25-10-25-W4
Map Sheet: 82H/14 Monarch

General Locality Description:

This locality, in an unnamed coulee draining into the Oldman River, was discovered while searching for the occurrence of the Battle Formation reported by Irish (1967). There are one or two outcrops <1.5 m thick and <4 m wide of dark purple mudstone overlying a thin bentonite bed over light olive, clayey sand, exposed through till covered slopes.

Sample Description:

DS91-20-1 is from immediately above the bentonite contact and is 10YR2/2 (dusky yellowish brown), very slightly silty mudstone that breaks into blocks <5 mm square.

Locality: 2
 Field ID: DS91-19
 Location: 3-25-22-23-W4
 Map Sheet: 82I/14 Gleichen

General Locality Description:

The Battle Formation is exposed in an outcrop >100 m long south of the Trans Canada Hwy and is ~9 m thick at the only spot where the underlying Whitemud Formation and the overlying Scollard Formation are exposed. The 20-30 cm thick Kneehills Tuff is present ~5.5 m above the base. At the base there is an ~30 cm thick bentonite bed similar to that present at Horseshoe Canyon and Big Valley. Overburden is a combination of buff shales, sandstones and till. Along the southeast arm of the coulee overburden appears to be till and Battle material is at the entrance of animal burrows. The area is grassland and to the southeast there is likely to be abundant material beneath overburden that is thin or of acceptable thickness.

Sample Description:

DS91-19-1 is from the bentonite bed at the base of the Battle Formation immediately above the contact with the Whitemud Formation and is 5Y3/2 (olive gray) and 5Y6/4 (dusky yellow), silty material with chunks of N1 (black) semi glossy carbon? to 2 cm diameter.

DS91-19-2 is from ~3.5 m above the base and is 5YR2/1 (brownish black), very slightly silty, blocky breaking mudstone. Conchoidal fracture on block faces that are commonly <2 cm square. Some white, calcareous crystals.

DS91-19-3 is from ~2 m above the tuff (~7.5 m above the base) and is 10YR2/2 (dusky yellowish brown), nonsilty mudstone that breaks into cubic blocks ~1 cm square. A few white, calcareous crystals.

Locality: 3
 Field ID: DS91-18
 Location: 4-23-22-24-W4
 Map Sheet: 82I/14 Gleichen

General Locality Description:

These Bow River sites of Irish (1967) are approximately two thirds of the distance up the river bank (~32 m below the top of the bank) on the north side of the river. Irish says that the Battle Formation is missing

from the south side of the river. However, there is a bench on the south side of the river at approximately the same level as the formation is exposed on the north side and overburden probably is thin if the formation is present. Any bench exposing Battle Formation on the north side is too narrow to mine economically.

Sample Description:

DS91-18-1 is from ~2 m above the contact with the Whitemud Formation on a bench with ~4 m thickness and ~5 m length exposed. The material is 10YR2/2 (dusky yellowish brown), silty mudstone that breaks into blocks <2 cm diameter. White, calcareous crystals are present.

Locality: 4
 Field ID: DS91-17
 Location: 8-26-23-23-W4
 Map Sheet: 82I/14 Gleichen
 General Locality Description:

Coulee outcrops of dark shales with two tuff beds but no Whitemud Formation exposed. The dark zone is ~10.8 m thick with the lower 10-15 cm thick tuff ~4 m above the base of the lowest dark shale exposure down the coulee. The upper tuff is ~7 m above the lower tuff. There is a belt of lighter material between the dark shale zones above the lower tuff and below the upper tuff.

Sample Description:

DS91-17-1 is from ~30 cm below the lower tuff and is 10YR2/2 (dusky yellowish brown) and 10YR4/2 (dark yellowish brown), nonsilty mudstone that breaks into blocks <5 cm square. Some white calcareous crystals are present.

DS91-17-2 is from ~2.5 m below the upper tuff and is 10YR2/2 (dusky yellowish brown) and 10YR4/2 (dark yellowish brown), blotchy, nonsilty to slightly silty mudstone that breaks into chips <1.5 cm diameter and ~5 mm thick.

Locality: 5
 Field ID: DS91-13
 Location: 7-35-26-19-W4
 Map Sheet: 82P/7 Drumheller

General Locality Description:

An exposure of ~10.5 m of Battle Formation is present on one large butte and the sides of two smaller knobs. The formation disappears to the south below rapidly thickening overburden under the Wintering Hills. Overburden to the east and west also is thick. This is unlikely to be a good prospect.

Locality: 6
 Field ID: DS91-12
 Location: 16-3-27-19-W4
 Map Sheet: 82P/7 Drumheller

General Locality Description:

A coulee outcrop of Battle and Whitemud Formations. The formations probably are present to the west and southwest in Section 3. The Battle Formation is ~5 m thick. Coal is present at the base of the outcrop and cross-bedded sandstone is 1.8 to 3.5 m thick from the top of the coal to the base of the Battle Formation. The surrounding area is grassland. The most accessible material is to the northeast but drilling is required to determine how much the formation thins in that direction.

Sample Description:

DS91-12-1 is from ~2 m above the contact with the cross-bedded sandstone below and consists of 5YR2/1 (brownish black), slightly silty mudstone that breaks with conchoidal fracture into chips <2.5 cm diameter by 1 cm thick. White, calcareous crystals are moderately abundant.

Locality: 7
 Field ID: DS91-11
 Location: 5-23-27-23-W4
 Map Sheet: 82P/6 Carbon

General Locality Description:

The Battle and Whitemud Formations outcrop in the bank of the Rosebud River. The Battle Formation is ~5.5 m thick under ~5.5 m of till overburden. If the Battle Formation is present to the east under this bench there is a considerable amount of material available.

Sample Description:

DS91-11-1 is from just above the contact with olive, argillaceous,

sandy material of the Whitemud Formation. The material is 10YR2/2 (dusky yellowish brown), slightly silty mudstone that breaks into <2 cm diameter by <1 cm thick, blocky fragments. A few carbonaceous, root-like impressions are present.

DS91-11-2 is from ~1 m below the contact with the till. It is 10YR2/2 (dusky yellowish brown), blocky, very slightly silty mudstone that breaks into <3 cm by 2 cm blocks. Some slickensides are present.

Locality: 8
Field ID: DS91-16
Location: 6-27-28-21-W4
Map Sheet: 82P/7 Drumheller
General Locality Description:

This side coulee on the southeast arm of Horseshoe Canyon exposes ~9 m of Battle Formation below ~1.5 m of till overburden at the top of the canyon wall. There are two tuff zones in the section. The upper zone is better developed and is ~5.5 m above the base and is ~15 cm thick. It probably could be screened out with little difficulty. Having regard for the Horseshoe Canyon Recreation Area lookout to the west and the most likely area for a complete section for mining, a drilling program to the southwest on private farmland probably would be most rewarding as the topography rises gently in that direction. Elevation drops in all northerly directions so the Battle Formation is not likely to be present too far in that direction.

Sample Description:

DS91-16-1 is from ~30 cm above the contact with an ~30 cm thick bentonite that, in turn, is ~30 cm above a dark shale interval overlying Whitemud Formation sand. The material is 5YR2/1 (brownish black), thinly laminated, slightly silty shale that breaks with conchoidal fracture into flat chips <3 cm diameter and 5 mm thick. A few carbonaceous imprints are present.

DS91-16-2 is from the ~30 cm bentonite below sample 16-1. The sample was taken to determine whether its chemistry is similar to the typical Battle Formation dark material above or whether the bentonite, where present, should be used as a base marker for mining. The material is 5Y4/1 (olive gray) with 10YR5/4 (moderate yellowish brown) stain on joints, slightly silty mudstone that breaks into blocky

pieces <4 cm diameter and 1.5 cm thick.

DS91-16-3 is from ~3.5 m above sample 16-1 and is 5YR2/1 (brownish black), slightly silty, blocky breaking mudstone with abundant slickensides. White, calcareous crystals are common. Blocks are <3 cm diameter and 1.5 cm thick.

DS91-16-4 is from ~3.5 m above sample 16-3 and is 5YR2/1 (brownish black), very slightly silty mudstone that breaks into thin chips <2 cm diameter and 5 mm thick. Some slickensides and some white, calcareous crystals are present.

Locality: 9
Field ID: DS91-14
Location: 13-10-29-17-W4
Map Sheet: 82P/8 Dorothy
General Locality Description:

A partly covered outcrop of Battle and Whitemud Formations is present near the base of the southeast wall of a coulee. It would be necessary to drill to the southeast to determine the presence and thickness of the Battle Formation but the view and map contours suggest the result could be favorable. The area is grassland.

Locality: 10
Field ID: DS91-15
Location: 11-24-29-18-W4
Map Sheet: 82P/8 Dorothy
General Locality Description:

On the west flank of the Hand Hills is a series of badlands-type outcrops exposing a coaly zone at the base, overlain with typical Horseshoe Canyon Formation sediments, thin (<2 m) Whitemud Formation sediments then ~9 m of dark Battle Formation. Two buttes expose Battle Formation sediments well and one has a small cap of Scollard Formation sediments. Overburden increases to the east but the area is slumped so the Scollard Formation or Pleistocene sediment cover may not be too thick over an extensive area north and south of the outcrop zone. Drilling is necessary to delineate the area of acceptable overburden. There may be some difficulty with access because of

several coulees between the first outcrop and the closest access road. A tracked drill might be the best unit. Initial drilling might be best in grassland near an abandoned Caterpillar tractor at 2-25-29-18-W4 (82P/9 Cragmyle).

Sample Description:

DS91-15-1 is from ~3.5 m above the contact with the Whitemud Formation on the south face of the butte with the Scollard Formation cap. The material is hard to dig and is 10YR2/2 (dusky yellowish brown), nonsilty mudstone that breaks into <3 mm diameter chips. Some small, white calcareous crystals are present.

Locality: 11
 Field ID: DS91-10
 Location: 4-23-29-23-W4
 Map Sheet: 82P/6 Carbon

General Locality Description:

The only outcrop of Battle Formation is ~9 m thick and the Whitemud Formation is not well developed. Overburden is till at the outcrop but overburden thickens rapidly in the valley wall so bedrock may overlie the formation in the valley wall. This area does not look promising for Battle Formation mining.

Locality: 12
 Field ID: DS91-9
 Location: 12-18-30-22-W4
 Map Sheet: 82P/11 Three Hills

General Locality Description:

An outcrop of Battle Formation(?) is present in the bank of Three Hills Creek but not on a tributary as reported in the literature. The outcrop is only ~1.5 to 2 m thick and the Whitemud Formation(?) is ~1 m thick. Bedrock and till overburden is from 3 to 15 m thick and thickens rapidly away from the cutbank. Prospects are not promising.

Locality: 13
 Field ID: DS91-8
 Location: 14-9-31-22-W4
 Map Sheet: 82P/11 Three Hills

General Locality Description:

Battle Formation outcrops on Ghostpine Creek reported in the literature were not found. The only outcrop seen was observed from across the creek. The material does not look like typical Battle Formation as there is no popcorn weathering nor is there typical Whitemud Formation below. The mauve Battle Formation(?) is overlain by ~6 m of bedrock plus ~12 m of till and glaciolacustrine sediments. This is not recommended as a good prospect.

Locality: 14
Field ID: DS90-4
Location: 8-29-34-21-W4
Map Sheet: 82P/15 Rumsey

General Locality Description:

Numerous outcrops of Battle Formation are present in Dry Island Buffalo Jump Provincial Park and one was sampled for comparison with exploitable material outside the park boundaries.

Sample Description:

DS90-4-1 is from ~50 cm above the contact with the Whitemud Formation in an outcrop ~5.5 m high with at least one tuff bed. The material is 5YR2/2 (dusky brown) mudstone that weathers to 5YR2/1 (brownish black) when damp. Blocky weathering to chunks 2 to 3 cm square. Scattered pockets of ~1 mm white, calcareous crystals.

DS90-4-2 is from above the tuff bed in 70 cm of 5YR2/1 (brownish black), nonsilty, thinly laminated shale that breaks into tabular flakes to 5 mm diameter and 1 to 2 mm thick. Scattered pockets of ~1 mm white, calcareous crystals.

Locality: 14
Field ID: DS91-6
Location: 14-33-34-21-W4
Map Sheet: 82P/15 Rumsey

General Locality Description:

Battle Formation ~1 to 2 m thick is present beneath 3 to 4 m of till. There could be a reasonable amount of material on both sides of the road allowance on this flat, wide bench but it is unlikely to be thicker than 2 m. Drilling is needed to confirm this observation.

Locality: 15
Field ID: Unnumbered
Location: 15,22-35-20-W4
Map Sheet: 83A/2 Big Valley

General Locality Description:

Occurrences of Battle Formation reported in the literature in these sections were not found.

Locality: 15
Field ID: DS91-4
Location: 10-9-35-20-W4
Map Sheet: 82P/15 Rumsey

General Locality Description:

Battle, Whitemud and Horseshoe Canyon Formations are exposed along a bluff ~1 km long. The Carbon-Thompson coal seam is exposed at the base of the bluff. The Battle Formation is ~6 m thick and is below ~6 m of overburden that increases in thickness gently to the west. This location appears very favorable for mining.

Sample Description:

DS91-4-1 is from the ~30 cm thick, 5Y5/2 (light olive gray), very slightly silty bentonite immediately above the contact with the Whitemud Formation argillaceous sand. The material breaks into conchoidally fractured chips <1 cm thick and <3 cm diameter. 5YR4/4 (moderate brown) stain is present on joints and laminae. Coaly fragments and many vertical carbonaceous forms that look like former rootlets are present.

DS91-4-2 is from ~15 cm above the contact with the bentonite and is 10YR2/2 (dusky yellowish brown) mudstone with 5YR4/4 (moderate brown) stain on vertical and horizontal planes. It breaks into conchoidally fractured chips <3 cm diameter and 0.5 cm thick that are very slightly silty. There are some dark, carbonaceous films of no definable shape.

DS91-4-3 is from ~2 m above the bentonite contact and is 10YR2/2 (dusky yellowish brown) mudstone that breaks into conchoidally fractured chips <3 cm diameter and <1 cm thick. It is very slightly silty with some slickensides and a few white, calcareous crystals.

DS91-4-4 is from ~3 m above the previous sample and ~1 m below what appears to be the contact with the overlying till. The 5YR2/1 (brownish black), very slightly silty mudstone is damp and breaks into <5 mm equidimensional chips. Some white, calcareous crystals are present.

Locality: 16
Field ID: DS91-7
Location: 7-3-35-21-W4
Map Sheet: 82P/15 Rumsey
General Locality Description:

Battle Formation is present under similar conditions to DS91-6 but appears to be 3 to 4 m thick below 3 to 4 m of till overburden. This bench, on the west side of the Red Deer River probably would be a good place to drill to confirm a sufficient volume of material for mining.

Locality: 16
Field ID: DS91-5
Location: 5-21-35-21-W4
Map Sheet: 83A/2 Big Valley
General Locality Description:

This location, west of McKenzie Crossing on Tp Rd 354, was viewed from the east side of the Red Deer River. There appears to be a good thickness of Battle Formation under manageable overburden at the top of the valley wall. There is a large slump area northeast of the house in LSD 4 that suggests Battle Formation may be just below the soil.

Locality: 17
Field ID: Unnumbered
Location: 1,11,12,14-37-21-W4
Map Sheet: 83A/2 Big Valley
General Locality Description:

Occurrences of Battle Formation reported in the literature in these sections were not found. The only outcrop observed is a relatively new one at 5-12-37-21-W4 which shows very contorted bedding in sandstone that probably is from glacial ice push.

Locality: 18
Field ID: DS91-3
Location: 3-3-39-22-W4
Map Sheet: 83A/6 Alix

General Locality Description:

An outcrop on the north bank of the Red Deer River. There appears to be ~11 m of Battle Formation below ~4 m of till. The till rests on ~15 cm of gray, chippy-weathering tuff. There is at least one other tuff bed at an undetermined distance below. There would be considerable material under similar thickness of till to the north below grassland and scrub trees. A new pipeline is present 200 to 300 m north of the crest of the river bank.

Locality: 18
Field ID: DS91-2
Location: 16-3-39-22-W4
Map Sheet: 83A/6 Alix

General Locality Description:

In the ditch on the south side of Tp Rd 39-1 at approximately the 2625' contour is an outcrop of mauve weathering mudstone with at least two hard, gray tuff beds ~1 m apart. In the grassy field ~40 m to the south is an outcrop of mauve weathering mudstone. No tuff beds were observed. The lower part of this east facing slope appears slumped. The vertical height from the top of the outcrop to the top of the bench capped by a tilled field is ~7 m. The Battle Fm probably is within 3 to 5 m of the surface under this bench. Considerable material could be present under grassland.

Locality: 18
Field ID: DS91-1
Location: 4-22-39-22-W4
Map Sheet: 83A/6 Alix

General Locality Description:

In the coulee that also is the location of Tail Creek Raceway, ~7 m of the Battle Formation outcrops in the coulee walls. The base of the formation probably is close to the coulee floor. There are three, faint, thin light gray bands in the outcrop that could be tuff or bentonite bands. There is no talus to indicate a tuff on the surface at any of the

band positions.

Sample Description:

DS91-1-1 is from the base of the outcrop and probably is close to the contact with the Whitemud Formation. The material is 10YR2/2 (dusky yellowish brown) with some 5YR4/4 (moderate brown) stain on joints, blocky breaking (to 3 cm diameter), slightly silty mudstone. Some slickensides are present and a few, ~2 mm diameter pockets of white, noncalcareous crystals.

DS91-1-2 is from ~3.5 m above the base of the outcrop and is 10YR2/2 (dusky yellowish brown), damp, blocky breaking, slightly silty mudstone. Blocks are ~5 mm diameter. Slickensides and conchoidal fracture are common. A few pockets of white, calcareous crystals.

DS91-1-3 is from ~7 m above the base of the outcrop and within 1 m of the till contact. The material is 10YR2/2 (dusky yellowish brown), damp, conchoidally fracturing, slightly silty to silty mudstone with abundant, scattered, white calcareous crystals. Blocks are <5 mm diameter.

Locality: 18
 Field ID: DS90-2
 Location: 12-23-39-22-W4
 Map Sheet: 83A/6 Alix

General Locality Description:

An outcrop of Battle Formation ~1.8 m thick is present below ~2 m of sandy till. The outcrop is slightly distorted from glacial forces.

Sample Description:

DS90-2-1 is from the center of the formation and is 5YR2/1 (brownish black), very slightly silty, thinly laminated shale that weathers 5YR4/1 (brownish gray) and breaks into ~1 cm diameter tabular pieces 2 to 3 mm thick. Alligator skin weathering texture.

Locality: 19
 Field ID: DS90-8
 Location: 4-5-50-1-W5, 1-6-50-1-W5
 Map Sheet: 83G/8 Telfordville

General Locality Description:

This locality is a combination of an outcrop on the south bank of Strawberry Creek downstream of the bridge that exposes the upper contact of the Battle Formation and an outcrop on the north bank upstream from the bridge, that exposes the lower contact. The downstream outcrop is a cutbank and major slumping, probably on the Battle Formation, is common. Only the upper ~5 m of the Battle Formation was accessible for sampling, even after extensive channeling with a shovel. The overburden of Scollard Formation and till exceeds 20 m. The upstream outcrop exposes ~6.5 m of Battle Formation below the contact with Pleistocene gravel. Total overburden exceeds 20 m.

Sample Description:

DS90-8-1 is taken from the downstream outcrop and is from a 1.1 m interval below the contact with the overlying Scollard Formation and consists of 5YR2/1 (brownish black) and 10YR4/2 (dark yellowish brown), interbedded, thinly laminated, nonsilty shale with a few small white calcareous crystals.

DS90-8-2 is from ~15 cm of 10YR2/2 (dusky yellowish brown), very slightly silty, thinly laminated shale in sharp lower contact with an ~15 cm band of hard gray tuff(#1). No calcareous crystals.

DS90-8-3 is from an ~0.8 m interval, below the gray tuff, of interbedded 5YR2/1 (brownish black) and 10YR4/2 (dark yellowish brown), thinly laminated, nonsilty to very slightly silty, noncalcareous shale that grades over 4 to 5 cm into sample DS90-8-4 below.

DS90-8-4 is from ~30 cm of 5Y4/1 (olive gray), thinly bedded, blocky, nonsilty shale. Some 5YR4/4 (moderate brown) stain on joints. Noncalcareous. Sharp lower contact with ~25 cm hard gray tuff (#2) seeps water.

DS90-8-5 is from ~0.6 m of interbedded 5YR2/1 (brownish black) and 5Y4/1 (olive gray), nonsilty, thinly laminated, slightly calcareous shale with sharp upper and lower contacts with tuffs #2 and #3. The lower contact is damp but does not seep.

DS90-8-6 is from ~0.55 m of 5YR2/1 (brownish black) and 5YR4/1 (brownish gray) with 10R3/4 (dark reddish brown) stain on joints, thinly laminated, nonsilty, noncalcareous shale. Sharp upper contact

with #3 tuff. Lower contact grades over ~5 cm into sample DS90-8-7.

DS90-8-7 is from ~0.4 m of 5Y5/2 (light olive gray), thinly bedded, blocky, nonsilty to slightly silty, calcareous shale. This material grades downward into a calcareous concretionary zone ~25 cm thick.

DS90-8-8 is from ~1.2 m of interbedded 5YR2/1 (brownish black) and 10YR4/2 (dark yellowish brown) with some 10YR6/6 (dark yellowish orange) stain on joints, thinly laminated, nonsilty, noncalcareous shale resting on a concretionary zone ~10 cm thick.

Talus was too thick to sample further at this location.

DS90-8-9 is from the upstream outcrop and is taken from an ~1.2 m interval above the contact with a white, massive sandstone that is considered to be the upper unit of the Whitemud Formation. The material consists of 10YR2/2 (dusky yellowish brown) with 5YR4/4 (moderate brown) stain on joints, slightly silty to silty, blocky to nodular weathering mudstone. Nodules are massive and can be to 15 cm diameter. The material surrounding the nodules is more chip-like with chips ~1 cm diameter. Noncalcareous.

DS90-8-10 is from ~3.5 m above the contact with the Whitemud Formation and consists of 5Y3/2 (olive gray) with 5YR4/4 (moderate brown) stain on joints and a few blotches of 5Y7/6 (moderate yellow), slightly silty, thin bedded, blocky weathering, noncalcareous shale.

DS90-8-11 is from ~5.5 m above the contact and ~1 m below the Pleistocene gravel and consists of 5Y3/2 (olive gray) with 10R4/6 (moderate reddish brown) stain on joints of slightly silty, slightly calcareous shale with thin, poorly developed bedding.

Locality: 20
 Field ID: DS90-12
 Location: 13-8-53-4-W5
 Map Sheet: 83G/10 Isle Lake
 General Locality Description:

An outcrop ~150 m long on the north side of Lakeshore Road exposes ~30 m of Battle Formation ~2 m thick below a 2 to 3 m covered

hillside.

Sample Description:

DS90-12-1 is from ~20 m east of a "Watch for Pedestrian on Road" sign and consists of interbedded 5Y4/1 (olive gray) and 5Y2/1 (olive black), nonsilty, massive to thinly laminated mudstone. Small calcareous, white crystals are scattered through the material.

DS90-12-2 is from ~20 m west of the sign and ~1.5 m stratigraphically above sample 12-1. Approximately 2.5 m of 5YR2/1 (brownish black), nonsilty, thinly laminated shale is exposed above ditch level. Small, white, calcareous crystals are scattered through the material.

Locality: 20
 Field ID: DS90-11
 Location: 5-9-53-4-W5
 Map Sheet: 83G/10 Isle Lake

General Locality Description:

Roadside outcrop of Battle Formation ~2 m high on the north side of Lakeshore Road (subsequent road upgrading "borrowed" the outcrop).

The material also is present in the ditch on the south side of the road.

Sample Description:

Lake Wabamun North Shore is from the upper 1 m of the outcrop and was sampled previously by a colleague. It is 5YR2/1 (brownish black), thinly laminated, nonsilty shale that breaks into <1 cm diameter flakes 1 to 2 cm thick. Well developed cauliflower weathering texture and a few, small white, calcareous crystals are present.

DS90-11-1 is from ~1 m of 5YR2/1 (brownish black), thinly laminated, slightly silty shale that weathers 5YR4/1 (brownish gray). The weathered surface is slightly alligator skin textured and has some scattered, white, noncalcareous powder.

Locality: 21
 Field ID: Unnumbered
 Location: 14,15-1-60-12-W5
 Map Sheet: 83J/4

General Locality Description:

This locality, on the north shore of the Athabasca River, was not

visited because vehicle access is nearly impossible but the outcrop was observed through binoculars from the south side of the river. The Battle Formation at this location is described by Ower (1960) to be 7 m thick with a 30 cm tuff bed 2.4 m from the top. Overburden is estimated to be in excess of 20 m. Much more accessible material is present further south in the province.