

REPORT 77-A

STONEWARE AND LOW DUTY REFRACTORY CLAYS
ASSOCIATED WITH THE ATHABASCA OIL SANDS

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(11)

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ABSTRACT

Openpit mining of the Athabasca Oil Sands in the Fort McMurray area removes most of the overburden from basal McMurray Formation clays which have potential for use as stoneware and low heat duty refractories. These clays, interbedded with sands, form the lowest unit in the stratigraphic interval between the base of the mined zone and the underlying Devonian limestone. The clays have good plasticity and working properties, dry reasonably well, have a total drying and firing shrinkage averaging 10 percent, and have absorptions averaging 2.4 percent at the maximum recommended firing temperature. Pyrometric cone equivalent (P.C.E.) varies from 10 to 23 with 16 as the average from 70 samples. Chemical and mineralogical data suggest that a high content of potassium associated with abundant illite may be a significant factor in control of sample refractoriness. Fired colors are shades of yellow, brown, and gray. Thorough evaluation of these basal clays, to outline the most refractory portions of a deposit, would be necessary prior to extraction for stoneware and low duty refractory uses.

Clays from within the mined zone have characteristics similar to those of the basal clays and similar uses can be suggested for them. However, the clay material rejected as "oversize" from the feed material for the oil extraction plant because it remains in large cohesive chunks after mining generally contains enough oil sand, in variable amounts, to preclude the use of the clay for ceramic purposes. The intraformational clays that are subjected to the primary extraction process must be concentrated from the waste stream and they remain contaminated with a small amount of oil. Firing shrinkage is high and bars curl at high temperatures, but the P.C.E. of 23 and the easily accessible unlimited supply of this material suggests that further research to evaluate these clays might be worthwhile.

INTRODUCTION

Ells (1915, 1926), Hume (1924), and Halferdahl (1969) published data on the ceramic properties of clays from the Fort McMurray area which indicated that some of the materials might be of interest to producers of ceramic products. With the exception of Halferdahl, these workers only sampled outcrops near rivers and streams in the area. Since most of the desirable clays tested came from near the base of the McMurray Formation, below thick overburden, further investigation was curtailed. However, openpit mining of the Athabasca Oil Sands contained in the McMurray Formation removes most of this overburden and provides potential users with easy access to these clay resources. In view of the recently-developed availability of these potential resources it seemed desirable to augment with core samples the data of the earlier workers. It also seemed desirable to confirm the presence of the deposits from which Ells (1915, 1926) obtained the two samples that tested to a Pyrometric Cone Equivalent (P.C.E.) of 27. P.C.E., a measure of a clay's refractoriness, is expressed as a cone number relative to a series of standard manufactured cones. The higher the cone number the higher the temperature at which a standard cone will melt to the extent that it cannot support itself. The melting temperature of a clay sample is compared with that of P.C.E. cones by firing simultaneously the sample and a suite of cones of various melting temperatures. The refractory deposits described by the earlier workers contain the highest refractory materials reported in the area and potentially are the most valuable.

This preliminary report presents new test data, in only partially refined form, to make them accessible more quickly to potential users of ceramic clays. Subsequently, these data will form part of a more comprehensive report on the ceramic properties of Alberta clays. Recommendations for use are based upon the characteristics of individual samples as collected in the field rather than blends of numerous components that most commonly comprise bodies used in ceramic ware preparations.

GEOLOGICAL PERSPECTIVE

The geography, geology, and projected mineral potential of the Fort McMurray area is summarized in Carrigy and Kramers (editors, 1973). All published data concerning the ceramic properties of clays sampled in this area are found in the compilation by Hamilton and Babet (1975) and from this compilation a general outline of the clay resources can be made. A light to dark gray, noncalcareous, slightly laminated clay is usually found in the interval below mineable oil sand of the Cretaceous McMurray Formation and above the underlying Devonian Waterways Formation. At some localities a light gray to greenish gray clay or shale (sometimes calcareous) is present at a comparable stratigraphic position but its ceramic properties are much less attractive. Lenses and stringers of light gray to olive gray, noncalcareous clays are present within the oil sands. Above the oil sands is the olive gray to light brown, slightly silty shale of the Cretaceous Clearwater Formation. Overlying this shale are various Pleistocene age glacial deposits which generally are devoid of clays within the study area.

SAMPLING

Surface and core samples tested for this report were obtained from a number of sources within map areas 74D and 74E of the 1:250,000 National Topographic Series. Most samples were collected within the surface mineable area from clays below the oil sands (Fig. 1) because the work of previous investigators indicated that these clays are the most refractory, and because reasonable access is most likely upon removal of the overburden during mining of the oil sands.

Fifty-eight samples were obtained from 29 cores from the Athabasca Oil Sands Project drilling program of 1952-54 (Scotland and Benthin, 1954). The cores, stored at the Alberta Research Council, had been used in tests for bitumen content but the clay and shale sections were still intact. After consulting the driller's field logs, cores that contained clay or

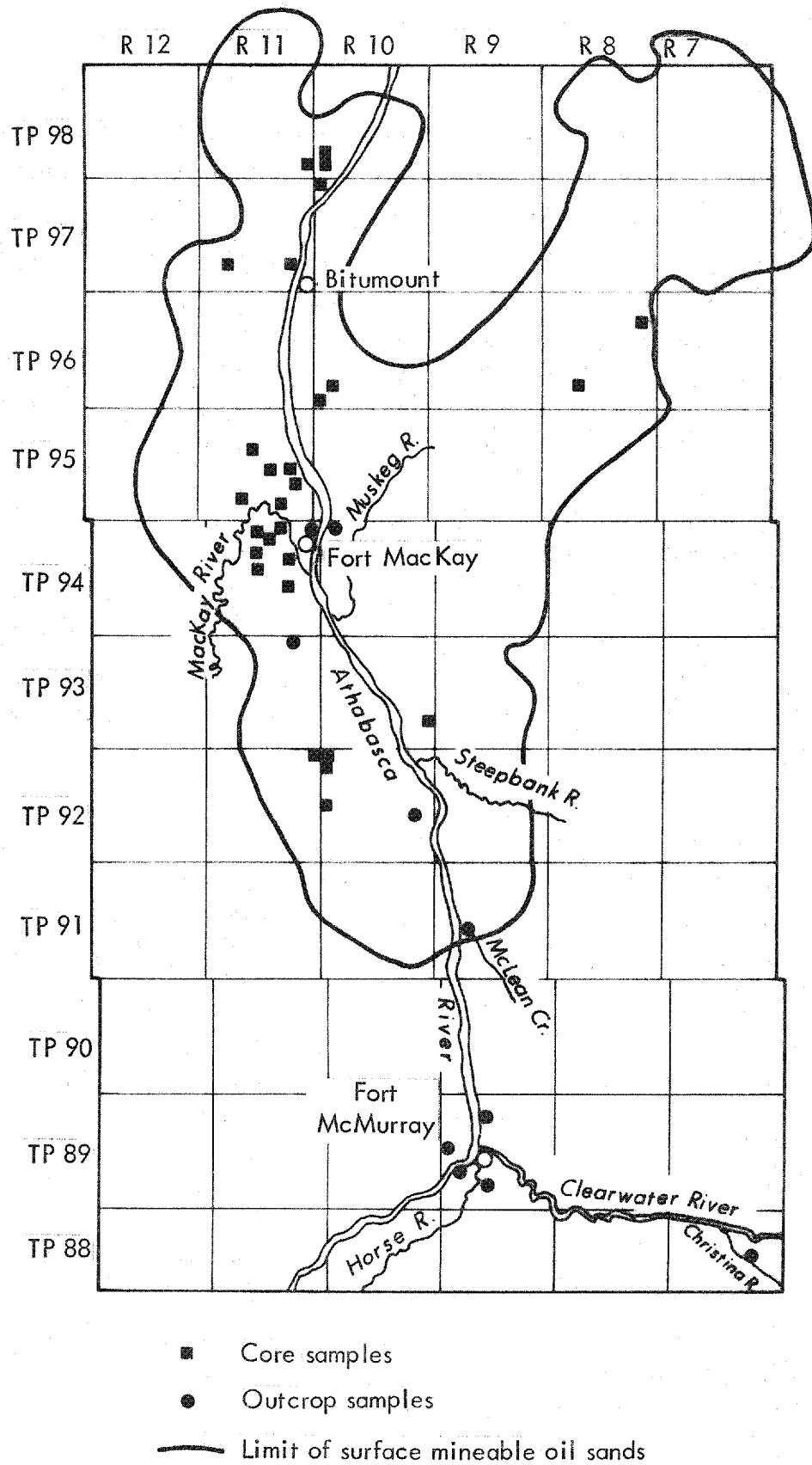


Figure 1. Sample Locations, Fort McMurray Area

shale material below oil sand at the base of the McMurray Formation were sampled. Also tested were similar clays from 17 samples of seven cores supplied by Syncrude Canada Ltd., and from three samples taken from the floor of the Great Canadian Oil Sands Ltd. (GCOS) openpit mine. Clay samples from the base of the McMurray Formation also were collected from outcrops along watercourses in the study area.

A sample of clay from within the oil sands was obtained from the GCOS "oversize" reject area. Further sampling of intraformational clay was considered unwarranted because present mining and processing practices preclude recovery of this material without contamination from oil sand. A sample of fine-grained material concentrated from tailings was obtained as an example of the homogeneous clay produced during processing of the oil sands.

Three samples were taken for analysis from the Clearwater Formation which overlies the McMurray Formation.

TESTING

All samples were tested for refractoriness by determining P.C.E. values. Twenty-nine samples were selected for further analyses which included determination of plasticity, workability, extrudability, drying characteristics at room temperature and 150°C, linear drying and firing shrinkage, water adsorption after firing, fired color at the point of steel hardness, firing range, and maximum recommended firing temperature. Ten samples were chosen for chemical analyses.

PROPERTIES OF THE BASAL MCMURRAY FORMATION CLAYS

In some topographic lows on the surface of the Devonian limestone, the stratigraphic interval between the base of the oil pay-zone (oil content 6 percent minimum) and the underlying limestone can be divided into two recognizable units. Interbedded oil-bearing sand, silt, and

Table 1. Criteria Used in Evaluating Clay Products

	Face Brick	Sewer Pipe	Stoneware	Artware
UNFIRED PROPERTIES				
Workability	good	good	good	good
% Water of Plasticity	15-40	0-35	not critical	not critical
Drying Characteristics	no warping or cracking	no warping or cracking	no warping or cracking	no warping or cracking
% Drying Shrinkage	0-12	0-8	3-8	0-15
FIRED PROPERTIES				
Maturing Temperature (°C)	980-1200	980-1150	1150-1300	980-1150
Hardness	steel hard	steel hard	steel hard	steel hard
% Absorption (unglazed)	0-15	0-8	0-2	not critical
% Shrinkage	0-10	0-10	1-8	0-20
Color	reds, buffs, creams, etc.	reds and buffs	buffs and grays	variety

clay commonly overlies lenticular beds of oil-free clay and sand. Thickness of the interbedded zone may vary from 1.5 m (5 ft) to 15 m (50 ft) while the underlying zone of clay and sand may be zero to 15 m thick. The clays from the oil-free zone vary from dark brownish gray to black, slickensided material that often contains lignite to light to dark gray, noncalcareous, slightly laminated clay. The clays from this lower zone are of interest for their ceramic properties and are termed "basal clays" in this report, as an indicator of their stratigraphic position. These clays probably are equivalent to the "oil sands underclay" of Halferdahl (1969).

The basal clays are potentially the most valuable for use in the production of structural clay products, pottery, and refractories. Typical requirements for structural clays and pottery clays are given in table 1. The most common method employed in forming structural clay products is the stiff mud extrusion process, and in this process good plasticity and workability are very important properties of the raw material. Uniform drying without warping and cracking is also important, although poor drying characteristics often can be improved by adding fine quartz or granular, nonplastic, prefired clay called "grog". Workability and fired color are the most important properties for pottery clays, with color particularly important for whitewares. Pottery formed by throwing, jiggering, or slipcasting must have good plasticity, and the drying and firing shrinkage must be small enough to prevent warping and cracking. Table 2 summarizes the data from Appendix 1 and shows that the basal clays generally have good plasticity and working properties and that most samples dry well, although warping of the body during drying is not uncommon. Total drying and firing shrinkage averages about 10 percent. Water absorption at the point of steel hardness averages 7.4 percent but drops to an average of about 2.4 percent at the maximum recommended firing temperature. Maximum recommended firing temperature was determined from the shrinkage versus temperature curve plotted for each sample (Fig. 2); the temperature of maximum shrinkage was chosen as the maximum recommended firing temperature because higher temperatures cause bloating

Table 2. General Characteristics of Samples from Basal Clays

Unfired Characteristics							
Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
					Rm Temp	150°C	
various shades of light to dark gray clay, often laminated, minor silt	10-23 16 average	18	good	good	good, minor warp	good, minor warps and cracks	5

Fired Characteristics							
Color	Steel Hard		Color	Maximum Fire			Remarks
	Temperature (°C)	Absorption (%)		Temperature (°C)	Absorption (%)	Shrinkage (%)	
light shades of brown or shades of olive gray	1090 (cone 04)	7.4	moderate shades of brown or shades of olive gray	1210 (cone 4)	2.4	5.4	fires well especially when fired slowly

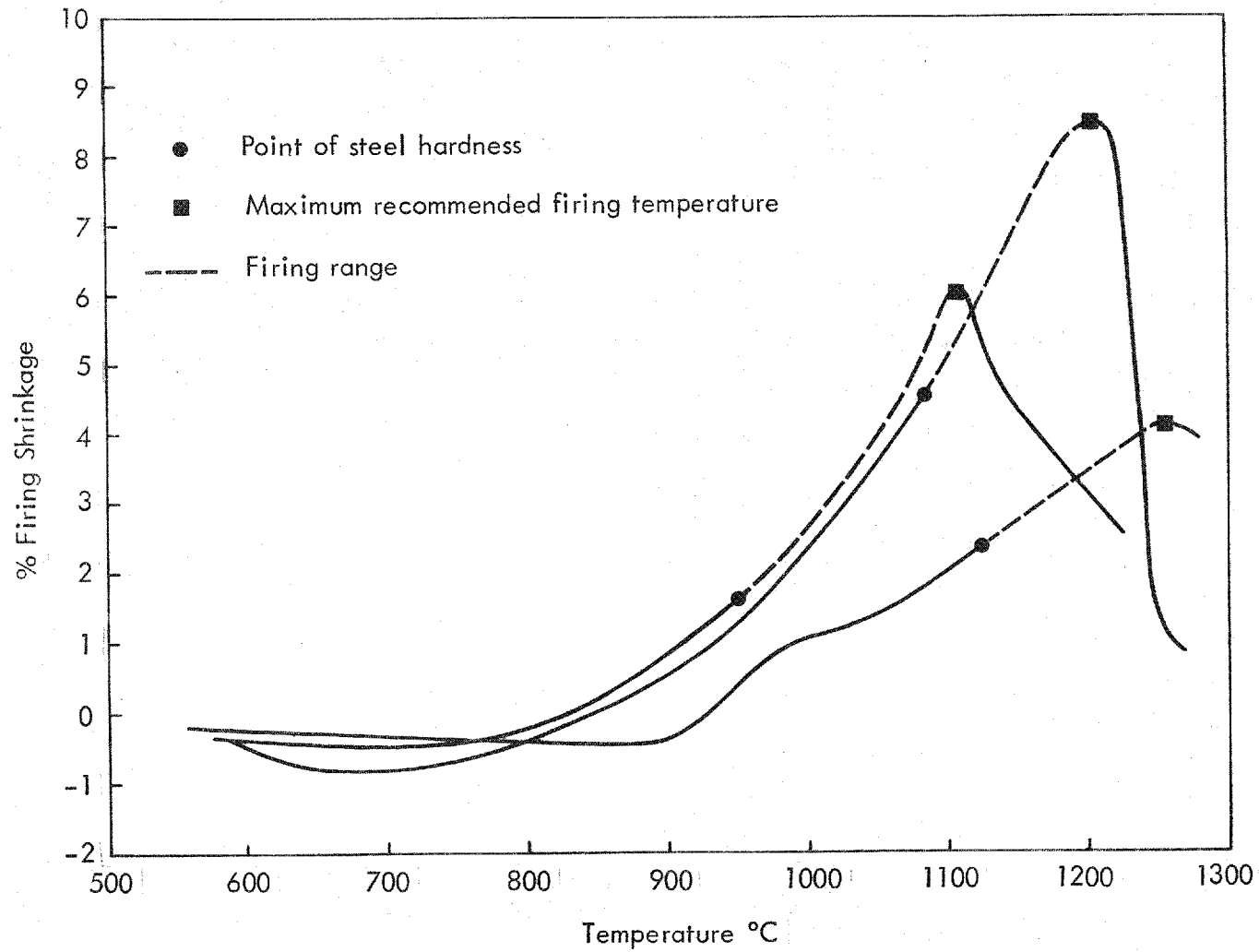


Figure 2. Representative Percent Firing Shrinkage versus Firing Temperature Curves for Basal Clays

from overfiring. The average firing temperature needed to reach steel hardness is 1090°C (cone 04) and the average maximum recommended firing temperature is 1210°C (cone 4). Fired colors are shades of yellow, brown, and gray.

Assuming that the clay properties listed in table 1 are typical of clays used in the structural clay products and pottery industries (excluding whitewares), the conclusion is, based on the data given in table 2, that basal clays can be used by both industries. However, these clays have some properties restricting their use: because no basal clay sample burned to a white color these clays cannot be used for the production of whiteware in the pottery industry; also the average water absorption at maximum recommended firing temperature is slightly above the 2 percent maximum allowable for unglazed stoneware. The recommended vitrification range for stoneware products is between cones 4 and 10 (1210-1330°C) with cone 8 (1300°C) as the desired maturation temperature (Klinefelter and Hamlin, 1957). The average maximum recommended firing temperature of cone 4 (1210°C) for the basal clays places these clays at the lower end of the recommended vitrification range, but judicious blending of basal clays from different areas of a mine might upgrade the maturation temperature to cone 8. An increase in the maturation temperature also might reduce the water absorption at maximum fire by producing enough vitreous material to further decrease the number of voids in a fired body and thus reduce water absorption below the 2 percent maximum allowed for unglazed stoneware articles.

Although the market in Alberta for refractory clay products is substantial, the best basal clays could be used to produce only low heat duty refractories. Clays with P.C.E. values from cone 15 to 29 (1430-1660°C) are considered low heat duty refractory clays (ASTM Designation C27-70). The most refractory basal clays (Appendixes 1 and 2) test to cone 23 (1605°C) and the average of all samples tested is cone 16 (1490°C). Because the average P.C.E. barely surpasses the minimum requirement for low heat duty fireclay brick, judicious monitoring of samples during

mining and stockpiling would be necessary to obtain the quantity of higher refractory material necessary to maintain consistent production.

If development of the clays were planned, a detailed drilling program to delineate the basal clays prior to mining would expedite the continuous monitoring program necessary during mining because it would be possible to locate clays with very low refractoriness and other less desirable properties that occupy a similar stratigraphic position at the McMurray Formation-Waterways Formation contact (Appendix 3). Although it is not possible to predict with certainty whether a core or outcrop sample of basal clay will have the desired characteristics, samples that contain carbonate, limonite, or carbonaceous material are less likely to be desirable as shown by the P.C.E. values and driller's log in Appendix 2. Cores AOP-20, -85, -96 (Appendix 4) illustrate that in some cores refractoriness of samples from a sequence of clay can deteriorate from high to low as samples are taken closer to the limestone. However, this trend in refractoriness is not universal and cannot be used in a predictive manner.

Factors controlling refractoriness are mineralogy and the carbonate, limonite, and carbonaceous material content. X-ray diffraction techniques show that less refractory clays contain from 15 to 35 percent less kaolinite, and a commensurate 15 to 35 percent greater illite content than the typical more refractory basal clay.

Characteristics of the less desirable clays from above the McMurray-Waterways formational contact are shown in table 2 which summarizes data given in Appendixes 3 and 4. The poor drying characteristics, short firing range, and bloating tendencies of these samples reduces their value considerably.

Chemical analyses of nine basal clays and one "lower quality" clay presented in Appendix 5 show that silica content and alumina content are within the general limits of 40 to 80 percent and 10 to 40 percent, respectively, given by Grimshaw (1971) for fireclays. With two exceptions, iron oxide content is less than the 5 percent maximum for a fireclay.

The lime and magnesia totals satisfy the less than 5 percent maximum for those fluxes; however, most samples exceed the less than 3 percent total recommended for potassium and sodium. The high potassium content probably is associated with the significant presence of the clay mineral illite, because feldspars generally are not sufficiently abundant to be identified in X-ray patterns from these samples. The fluxing power of potassium may be one of the main causes of the moderate refractoriness of these samples. The particularly high potassium content of the lower quality (P.C.E. = 6) clay sample included among the typical higher refractory basal clays supports this suggestion.

The quest to duplicate the two basal clay samples reported by Ells (1915, 1926) that tested to cone 27 was only partly successful. His description of the sampling location on the Muskeg River (Ells, 1915, sample 190) as, "From a point on northwest shore of Muskeg River, between head of portage and mouth of river," is imprecise at best. A traverse along the lower 3 miles of the Muskeg River during the course of this investigation revealed only one locality where clay is exposed and a sample from that locality tested to cone 6. The traverse was performed during the season of low water in the river and no slumping was observed over areas where basal clays might be expected, so it is unlikely that a basal clay deposit was obscured. This author is not convinced of the existence of a clay deposit that tests to cone 27 on the Muskeg River, and suggests that the laboratory test results of Ells are suspect.

From the McLean Creek outcrop sampled by Ells (1926, sample 2) two samples for this study tested to cone 20. One of six samples from the same location tested for M. Dusseault (1977), yielded a value of cone 26. An average value for the six samples is cone 20. Although samples from the McLean Creek outcrop seem potentially more valuable than other basal clay samples because they consistently yield higher P.C.E. values, the assessment of Hume (1924), that, "the overburden of tar sands, except for a limited area, is so thick as to make this deposit unworkable," is still valid and conditions probably will not change in the near future.

PROPERTIES OF INTRAFORMATIONAL CLAYS

As stated at the beginning of this report, only one sample of intraformational clay was collected because of the impossibility of obtaining samples, during mining, that are uncontaminated with oil sand. The sample of intraformational clay that Hume (1924, Deposit 3) collected has properties similar to those of the sample collected for this study, so it is possible to describe a few general properties of these clays. The clay is olive gray in color and works well with good plasticity at 16 to 17 percent tempering water. Some bars warped during drying in this study, although Hume reported that his sample dried well. In both studies drying shrinkage is 5 percent. Fired test pieces reached steel hardness at 980°C for the sample tested by Hume, but not until 1195°C in this study. Maximum recommended firing temperature is 1240°C and the absorption at that temperature should be about 3 percent, with fired shrinkage about 6 percent. Fired color is dark yellowish brown (10YR4/2). The P.C.E. obtained in this study is 15 and that obtained for the sample collected by Hume is 16 (Table 3).

A comparison of properties quickly reveals that the intraformational clays and the basal clays behave similarly, so the intraformational clays could be used for purposes similar to those outlined for the basal clays. However, the uncontrollable contamination by oil sand during mining essentially precludes use of these clays for ceramic purposes.

A homogenized form of the intraformational clays is released during the primary extraction of oil from the oil sands. Good plasticity is obtained from these 5Y4/1 (olive gray) clays with 28 percent tempering water, but the residual oil content interferes with the even distribution of water during mixing for extrusion. Minor cracks appear during drying at room temperature, and cracking is more severe at 150°C. Drying shrinkage is 6 percent. A great deal of smoke is produced as the residual oil burns off during firing. Steel hardness is reached at 1075°C, the color is 5YR8/4 (moderate orange pink), and absorption is 9.5 percent.

Table 3. General Characteristics of Less Desirable Clays From the McMurray-Waterways Formation Contact

Unfired Characteristics							
Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
					Rm Temp	150°C	
various shales of gray to olive green, may be calcareous, limonitic or carbonaceous, but not always	5 or less	17	fair to good	good	may be good or may warp and crack		5
Fired Characteristics							
Color	Steel Hard		Color	Maximum Fire			Remarks
	Temperature (°C)	Absorption (%)		Temperature (°C)	Absorption (%)	Shrinkage (%)	
light brown	1045	7 or less	moderate brown	1100	3 or less	6	black core and bloating unless fired slowly, short firing range, body often warps during drying

Firing was halted at 1200°C because the bars were curving upward so severely that they almost reached the top of the muffle. Color after firing to 1200°C is 10YR6/2 (pale yellowish brown), absorption is 1 percent, and shrinkage is 12.5 percent. P.C.E. is 23.

Because these clays are mined, are unlimited in supply, and have a significantly higher P.C.E. than the average for basal clays, they are a potentially attractive source of ceramic clay; however, because the clays must be concentrated from the material obtained during primary extraction of the oil sand, crack upon drying, smoke badly during firing, and shrink and curl severely at high temperature, they are an unattractive source of ceramic clay. However, the addition of grog or sand probably could improve both the drying and firing characteristics, and under certain conditions the degree of concentration needed to produce ceramic clay from material released during the primary extraction process might be economically tenable.

PROPERTIES OF CLAYS OF THE CLEARWATER FORMATION

A bed of glauconitic sandstone at the base of the Clearwater Formation marks the boundary with underlying McMurray Formation. Above the glauconitic sandstone is an olive gray, massive, slightly silty marine shale, which commonly shows 10-foot thick iron-stained exposures littered with gypsum crystals.

The ceramic properties of samples from the marine shales tested during this study are listed in Appendix 6; it is apparent that at about 20 percent tempering water, plasticity is only fair to good, but the material does extrude well. Drying shrinkage is less than 8 percent, but to prevent the warping of pieces that commonly occurs during drying, it would be necessary to add fine sand or grog to any mixture. Shades of pale to moderate brown are the most common fired colors at steel hardness and at maximum recommended fire. The moderate brown is an attractive but unconventional color. The vitrification range average of 20-25°C is so short that temperature control in a kiln would be very critical. The

tendency to warp during firing and to show soft, white inclusions after firing combined with the short vitrification range make the shales of the Clearwater Formation undesirable for ceramic use.

CONCLUSIONS

1. The basal unit in the stratigraphic interval between the base of the zone mined for the Athabasca Oil Sands and the underlying limestone contains clays that have potential use for stoneware and low heat duty refractories:
 - (a) P.C.E. varies from 10 to 23 with an average of 16 from 70 samples.
 - (b) Plasticity and working properties are good.
 - (c) Samples dry reasonably well, total drying and firing shrinkage averages 10 percent, and absorption averages 2.4 percent at the maximum recommended firing temperature.
 - (d) Fired colors are shades of yellow, brown, and gray.
 - (e) The high content of potassium associated with the abundant clay mineral illite may be a significant factor in control of sample refractoriness.
 - (f) If these clays are considered for use, extensive exploration for the most refractory and largest concentrations of suitable material will be necessary.

2. Clays from the mining zone are similar to the basal clays. However, material rejected as "oversize" before the primary extraction of oil from the oil sands generally contains enough oil sand, in uncontrollable amounts, to eliminate these clays from consideration for use as raw materials for ceramic production. Material that is subjected to primary extraction is in a slurry and must be concentrated from the waste stream. This clay remains contaminated with oil and this probably contributes to the high firing shrinkage. However, the P.C.E. of 23 and the unlimited supply of readily accessible material suggest that further study to overcome these disadvantages would be valuable.

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APPENDIXES

Appendix 1. Ceramic Characteristics of Basal Clays

U n f i r e d C h a r a c t e r i s t i c s												
Location (W4)				Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)	
Lsd	Sec	Tp	R						Room Temperature	150°C		
9	1	98	11	AOP-58 220-225 gray, sandy clay	18	17	good	good	good	good	3.8	
8	11	97	11	AOP-40 223-230 gray-brown clay	15	23	fair to good	good	good	good	6.4	
14	9	96	8	AOP-96 205-210 dark clay, lignite	15	28	fair to good	good	good	good	6.0	
12	10	95	11	AOP-23 150-155 gray-green shale	14	21	fair to good	good	good	good	4.8	
6	34	94	11	AOP-17 110-115 green clay	23	19	fair to good	good	good	good	5.3	
9	15	94	11	AOP-90 220-225 dark clay, lignite	17	21	poor	poor	good	good	2.6	
16	36	92	11	medium gray clay	15	16	good	good, but sticky	good	good	5.2	
13	31	92	10	5Y4/1* clay, minor silt	16	19	good to very good	good	minor warp	warps	6.1	
13	31	92	10	N8 clay, minor silt	16	17	good	fair to good	good	good	4.6	
6	31	92	10	5Y4/1 clay, minor silt	17	9	fair	fair	good	good	0.8	
5	31	92	10	soft black clay, minor silt	15	17	fair to good	good, slightly stiff	warps	warps	4.5	
5	31	92	10	5Y5/1 clay, silty	14	18	very good	good	good	minor warp	4.5	
4	31	92	10	medium gray clay, minor silt	20	22	fair to good	fair, quite stiff	minor warp	minor warp, minor cracks	7.5	
13	30	92	10	medium gray clay	18	13	good	good	good	good	3.3	
16	19	92	10	5Y5/1 clay, silty	16	25	fair	poor to fair	warps	warps	8.7	
NW1/4	14	92	10	12 ft, 10YR4/2, minor lamination, minor silt	17	13	good	good but stiff	minor warp	minor cracks	4.7	
NW1/4	14	92	10	10 ft, 5Y4/1, thin lamination, minor silt	14	16	good	good, extrudes well	good	minor cracks	4.7	
NW1/4	14	92	10	10 ft, 5Y4/1, thin lamination, minor silt	15	13	good	good, extrudes well	minor warp	minor cracks	8.0	

Appendix I. (continued)

F i r e d C h a r a c t e r i s t i c s											
Location (W4)				Color*	Steel Hard		Color	Maximum Fire			Remarks
Lsd	Sec	Tp	R		Temperature (°C)	Absorption (%)		Temperature (°C)	Absorption (%)	Shrinkage (%)	
9	1	98	11	10YR7/4	1075	10	5Y7/2	1275	2.8	5.5	Fires very well
8	11	97	11	5YR6/4	950	9	5YR4/4	1100	2.9	7.3	much slag-like material
14	9	96	8	10YR7/4	1275	11		coincides with steel hard			weak body
12	10	95	11	10YR7/4	1085	11.7	10YR6/2	1200	1	8.5	fires well
6	34	94	11	5YR4/4	1025	11	5YR4/4	1100	3.3	6.3	short fire
9	15	94	11	10YR5/4	1225	19	10YR4/2	1260	18	13	bars fragile, warps badly on firing
16	36	92	11	10YR5/4	990	9.7	5Y5/2	1140	3	5.5	good when fired slowly
13	31	92	10	10YR7/4	950	13.5	10YR7/4	1100	6	6	black core, fire slowly
13	31	92	10	5Y7/2	1160	10	5Y7/2	1250	3.5	4	fires very well
6	31	92	10	-	-	-	5Y6/4	1350	3	5.4	many black slag-like inclusions no steel hard by 1350°C
5	31	92	10	10YR7/4	1125	9	5Y6/1	1235	1	5.5	fires very well
5	31	92	10	5YR5/6	1100	9	10YR4/2	1240	1	6	black core, fire slowly
4	31	92	10	10YR8/2	900	10.5	5Y6/4	1175	1	6	would fire well with minor grog
13	30	92	10	5Y5/2	1275	4.5	5Y5/2	1360	4	3.5	black slag-like inclusions
16	19	92	10	5YR6/4	940	5.5	5YR6/4	975	3	6	black core, fire slowly
NW1/4	14	92	10	5Y7/2	1100	7	5Y7/2	1200	2.5	4.5	black core, fire slowly
NW1/4	14	92	10	5YR5/2	1175	4.8	10YR4/2	1225	0.5	7.5	fires well
NW1/4	14	92	10	5YR5/2	1205	5.3	10YR6/2	1250	2	6	fires well

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 7.

Generally, 5Y's are shades of olive gray, 5YR's are light to medium browns, and 10YR's are light to dark yellowish browns.

Appendix 2. P.C.E. Values of Basal Clays

Hole	Depth	Location (W4)	PCE	Driller's Description
AOP-12	190-195	11-21-94-11	12	clay, some poor oil sand clay
	195-200		10	
AOP-16	135-140	8-27-94-11	14	green shale
AOP-17	110-115	6-34-94-11	22	green clay
AOP-18	130-135	10-33-94-11	10	green-white clay, limy
AOP-23	150-155	12-10-95-11	14	gray-green shale black clay
	155-160		15	
AOP-25	165-170	5-14-95-11	14	green-black clay green clay
	180-185		12	
AOP-26	140-145	5-13-95-11	17	clay
AOP-28	130-135	12-22-95-11	14	clay
AOP-40	223-230	8-11-97-11	15	gray-brown clay gray-brown clay
	230-240		22	
AOP-55	200-210	14-6-98-10	17	sandy gray shale
AOP-56	215-220	14-7-98-10	20	dark sandy clay
AOP-58	220-225	9-1-98-11	18	gray, sandy clay gray, sandy clay gray, sandy clay gray, sandy clay gray, sandy clay gray, sandy clay gray, sandy clay dark clay and lignite gray clay gray clay gray clay dark clay
	225-230		18	
	230-235		23	
	235-240		19	
	240-245		20	
	245-250		18	
	250-255		18	
	255-260		18	
	260-265		18	
	265-270		18	
AOP-64	168-175	16-11-95-11	16	dark clay and lignite
	240-245		20	
AOP-67	255-260	2-23-95-11	18	clay and barren sand interbeds light greenish clay dense black clay and lignite
	260-265		18	
			18	
AOP-72	165-170	15-15-95-11	16	gray clay light sandy clay light greenish clay
	180-185		14	
	205-210		13	
AOP-74	185-190	2-9-95-11	12	green clay
AOP-80	145-150	7-28-94-11	12	gray-green clay, slightly limy
AOP-84	180-185	16-22-94-11	15	mottled greenish clay with abundant hematite and limonite streaks
	185-190		12	
	190-195		12	
AOP-90	220-225	9-15-94-11	17	dark clay, lignite, H ₂ S
AOP-97	205-210	6-24-96-8	16	black clay and lignite black clay and lignite black clay and lignite
	215-220		17	
	240-245		20	

Appendix 3. Ceramic Characteristics of Less Desirable Clays Near the McMurray-Waterways Formation Contact

U n f i r e d C h a r a c t e r i s t i c s												
Location (W4)				Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)	
Lsd	Sec	Tp	R						Room Temperature	150°C		
NW 1/4	31	94	10	3 ft, 5Y3/2*, slightly silty, slightly laminated	10	21	good to very good	good, extrudes well	warps	cracks	7	
Shell Road - Athabasca River intersect												
NE 1/4	25	94	11	5 ft, 5Y5/2, slightly silty	6	15	fair to good	good, extrudes well	good	good	5.1	
Fr. McKay - Athabasca River												
SW 1/4	17	94	10	3 ft, 5Y5/2, no grit, channel	6	22	good	fair, extrudes poorly	good	good	6.1	
West bank Muskeg River												
9	12	93	10	AOP-92 195-200 hard green limy shale	3	15	fair to good	good	good	good	1.6	
6	35	93	11	2-3 ft, 10YR2/2, slightly silty	6	17	fair to good	good, extrudes well	cracks, warps	cracks badly	7.1	
1 mile north of Beaver River Crossing												
NW 1/4	28	89	9	5 ft, 5GY8/1, slightly gritty, calcareous	4	17	good	very good	slight warp	slight warp	4.8	
Athabasca River - Clearwater River confluence												
NE 1/4	17	89	9	1 1/2 ft, N4, massive slightly silty	8	12	good	good, extrudes well	good	good	5	
West of Athabasca bridge												
10	22	88	7	small pocket 10GY5/2, slightly gritty clay	7	18	good	good	warps	warps & cracks	6.4	
North shore Christina River												

Appendix 3. (continued)

F i r e d C h a r a c t e r i s t i c s

Location (W4)				Color*	Steel Hard		Color	Maximum Fire		Shrinkage (%)	Remarks
Lsd	Sec	Tp	R		Temperature (°C)	Absorption (%)		Temperature (°C)	Absorption (%)		
NW1/4	31	94	10	5YR5/6	1042	6.3	5YR4/4	1100	0	5.5	black core, slight bloating
Shell Road - Athabasca River intersect											
NE1/4	25	94	11	-	-	-	-	-	-	-	no steel hard, hot end curls
Ft. McKay - Athabasca River											
SW1/4	17	94	10	10R6/6	970	13	5YR4/4	1050	3	9.5	some cracking
West bank Muskeg River											
9	12	93	10	-	-	-	-	-	-	-	no steel hard, hot end curls
6	35	93	11	5YR5/6	1000	7.2					cracks and bloats past steel hard
1 mile north of Beaver River Crossing											
NW1/4	28	89	9	-	-	-	-	-	-	-	many cracks, no steel hard
Athabasca River - Clearwater River confluence											
NE1/4	17	89	9	10YR7/4	1160	5.5	10YR4/2	1200	0	5.5	short firing range but good body
West of Athabasca bridge											
10	22	88	7	5YR5/6	1060	2.5	steel hard			4.5	black core
North shore Christina River											

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 7. Generally 5YR's are light to medium browns, 10YR's are light to dark yellowish browns, and 10R is a reddish orange.

Appendix 4. P.C.E. Values from Selected Samples at the McMurray-Waterways Formation Contact

Location (W4)				Core	Depth	PCE	Driller's Log
Lsd	Sec	Tp	R				
6	31	97	10	AOP-45	155-160	3	green clay, limy
14	9	96	8	AOP-96	205-210	15	dark clay with minor limonite
					215-220	10	dark clay with minor limonite
					240-245	3	green clay becoming limy
4	8	96	10	AOP-95	290-295	4	green clay
6	6	96	10	AOP-94	300-305	2	gray-blue limy clay
					305-310	2	gray-blue limy clay
					310-315	3	gray-blue limy clay
9	3	95	11	AOP-20	140-145	17	green and black clays
					155-160	8	green shale
4	3	95	11	AOP-19	145-150	6	chalk-like lumps, no HCl reaction
10	27	94	11	AOP-85	170-175	12	gray clay
					180-185	2	green clay, limonite streaks
8	22	94	11	AOP-87	190-195	3	olive green clay with limonite
9	12	93	10	AOP-92	195-200	3	hard green limy shales

Appendix 5. Chemical Analyses of Clays from Below Mineable Oil Sands

Location (W4)				Description	PCE	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	SO ₃	H ₂ O	L.O.I.	Total
Lsd	Sec	Tp	R																
9	1	98	11	gray, sandy clay	23	55.03	24.69	3.05	1.25	0.19	1.40	0.51	3.29	0.04	0.02	-	0.00	9.82	99.29
SW	35	94	11	olive gray clay, slightly silty	15	66.66	18.44	2.23	1.17	0.14	1.17	0.47	3.16	0.03	0.01	-	0.00	6.33	99.81
6	34	94	11	green clay	23	66.35	14.62	3.68	0.83	0.79	1.24	0.38	3.35	0.03	0.01	-	0.00	7.85	99.13
11	21	94	11	clay, some poor oil sand	12	62.56	11.30	9.80	0.91	0.13	1.55	0.47	4.14	0.00	0.01	-	0.00	8.32	99.19
13	31	92	10	very light gray clay, minor silt	16	76.56	11.34	2.87	1.39	0.16	0.46	0.48	0.84	0.02	0.02	-	0.00	5.33	99.47
13	31	92	10	olive gray clay, minor silt	16	67.51	15.74	2.24	1.13	0.19	0.93	0.56	2.55	0.05	0.02	-	0.00	8.77	99.69
NW	14	92	10	olive gray clay, slightly silty	15	65.71	13.99	6.36	1.06	0.24	0.72	0.39	2.34	0.02	0.09	-	0.00	8.30	99.22
SW	17	94	10	light olive gray clay, slightly silty	6	59.24	20.25	4.43	0.89	0.29	2.52	0.18	5.08	0.02	0.02	-	0.00	6.91	99.83
NW	17	91	9	grayish black clay, fairly silty	20	66.37	16.78	1.58	1.00	0.23	1.42	0.84	1.43	-	-	<0.01	2.82	7.58	100.05
NW	17	91	9	olive gray clay, no silt	20	51.59	24.68	3.07	0.85	0.24	0.78	1.43	2.78	-	-	<0.01	4.06	8.71	98.19

Appendix 6. Ceramic Characteristics of Clays from the Clearwater Formation

U n f i r e d C h a r a c t e r i s t i c s											
Location (W4)				Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R						Room Temperature	150°C	
SW1/4	9	89	9	20 ft, 5Y2/1*, massive, minor grit, gypsum crystals, iron stain	2	17	fair	fair, slightly stiff	warps	good	7.4
SW1/4	19	89	9	5Y5/2, massive, slightly silty, iron stain	3	23	good	good, extrudes well	warps	warps	8.6
				5Y4/1, massive, breaks into 1 in blocks	3	19	fair to good	good, extrudes well	warps	warps	7.5

Appendix 6. (continued)

F i r e d C h a r a c t e r i s t i c s											
Location (W4)				Color*	Steel Hard		Color	Maximum Fire			Remarks
Lsd	Sec	Tp	R		Temperature (°C)	Absorption (%)		Temperature (°C)	Absorption (%)	Shrinkage (%)	
SW1/4	9	89	9	5YR4/4	1040	7.5	5YR4/4	1075	3	7.5	very short firing range, soft white inclusions when fired
Cutbank, East side of road											
SW1/4	19	89	9	5YR5/6	1030	6	5YR4/4	1050	2.5	7.5	very short firing range, bars curl at hot end
Sewer cut, Thickwood subdivision											
				5YR5/2	1115	6	5YR5/2	1125	0	8	very short firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 7. Generally, 5 YR's are light to medium browns, and 5Y's are olive grays.

Appendix 7. Colors Encountered in Unfired and Fired Clays from the Ft. McMurray Area

Color designations based on the Munsell system as interpreted by the Rock-Color Chart Committee are used in this report to provide a standard to which any reader can refer.

5GY8/1	yellowish gray (lighter than 5Y7/2)
10GY5/2	grayish green
5Y7/2	yellowish gray
5Y5/2	light olive gray
5Y3/2	dark olive gray
5Y6/4	dusky yellow
5Y6/1	light olive gray (lighter gray than 5Y5/2)
5Y5/1	medium olive gray
5Y4/1	olive gray
5Y2/1	olive black
5YR5/2	pale brown
5YR6/4	light brown
5YR4/4	moderate brown
5YR5/6	light brown (with an orange cast)
10YR8/2	very pale orange
10YR6/2	pale yellowish brown
10YR4/2	dark yellowish brown
10YR2/2	dusky yellowish brown
10YR7/4	grayish orange
10YR5/4	moderate yellowish brown
10R6/6	moderate reddish orange
N8	very light gray
N4	medium dark gray
