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COMPOSITION AND CERAMIC PROPERTIES
OF SOME CLAYS
FROM NORTHEASTERN ALBERTA

by

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CONTENTS

ILLUSTRATIONS

Page

TABLES

COMPOSITION AND CERAMIC PROPERTIES
OF SOME CLAYS
FROM NORTHEASTERN ALBERTA

Abstract

Mineralogical analyses of five samples of clay from below
the oil sands near Fort McMurray, Alberta show quartz, minerals
of the kaolin group, chlorite, illite, and a swelling clay mineral
as dominant constituents. Ceramic tests showed firing ranges
similar to those of stoneware clay, but most samples had drying
or firing problems. Only one burned to a buff color.

A sixth sample, of glacial clay, is free of montmorillonite.
It consists mostly of quartz, chlorite, and illite. Although very
high in quartz, it appears to be more technically suitable for
some ceramic products than the other clays.

INTRODUCTION

Since reports by Ells in 1915 and 1926, and Hume in 1924, there
has been speculation on the possibility of economic deposits of stoneware or
higher grade clays along the lower Athabasca River. Some of these clays
were reported to be stratigraphically below the oil sands and are here
termed oil sand underclays. Production of oil from the Athabasca Oil Sands,
beginning in 1967, has resulted in improved access to the area generally;
also, it may permit direct access to some of these clays which otherwise
would be covered with prohibitive thicknesses of overburden. In order to
learn more technical details about these clays, samples from strata lying
between the oil sand and the Upper Devonian limestones were obtained
from three drill holes at the Abasand pit near Fort McMurray. Glacial
clay from the Firebag River northeast of Fort McMurray also was sampled.

The oil sand underclays near the Abasand pit consist mostly of
quartz, kaolinite, and illite. A swelling clay mineral somewhat like
vermiculite, an halloysite-like clay, mixed-layer clays, organic material,
and soluble salts, one or more of which are present in significant amounts
in some of the samples, caused drying or firing problems when these clays
were evaluated for their ceramic uses. However, they may have potential
for some ceramic products.

The glacial clay, which consists mostly of quartz, chlorite, and
illite, gave fewer drying problems and is suitable for the production of sewer
pipe, brick and tile.

Previous Work

The first published results of ceramic tests of the clays immediately overlying the Upper Devonian limestone near Fort McMurray are found in a report by Ells (1915). He collected 25 samples, most of which may be described as grab samples, from exposures in the valley of the Athabasca River and some of its tributaries, the Steepbank, Muskeg, MacKay, Ells, and Firebag Rivers, within 70 miles of Fort McMurray. Ceramic tests of these samples showed that, with or without the addition of sand to reduce shrinkage, and suitable care in drying and burning, 4 could be classed as stoneware clay, 4 were suitable for making sewer pipe, tile, or good quality face brick, 9 were suitable for common brick, and 8 had no ceramic value unless mixed with other clays because of high lime content, bloating, cracking, or excessive shrinkage. Slumping and the presence of overburden prevented Ells from learning stratigraphic variations in the clays, or much of their extent at most sample localities.

Ells (1926) collected five more samples of clay near Fort McMurray, three of which apparently are oil sand underclays, the other two being glacial clays. Two of the oil sand underclays were suitable for bricks, the third is a fireclay but not plastic enough for shaping. Although the two glacial clays developed scum, they were suitable for bricks.

Hume (1924) reported on three samples of clay collected along the Athabasca River near Fort McMurray. Two lay stratigraphically below the oil sands, and the third was interbedded with the oil sands. All three were found to be suitable for semirefractory purposes and bricks. Reserves under strippable thicknesses of overburden were not considered to be large. Hume concluded that the clay is a sedimentary deposit, not a residual one, being part of the McMurray Formation. He thought that it would be found in lenses of relatively small lateral extent.

Details of ceramic tests for these sets of samples are tabulated in appendix 1; sample locations are given in figure 1.

Acknowledgments

GEOLOGICAL SETTING

Fort McMurray lies in the valley of the Clearwater River at its confluence with the northward-flowing Athabasca River. The valleys of these rivers and their tributaries are as much as 250 feet deep. Between the valleys much of the area is covered by glacial drift. Lower Cretaceous formations form the youngest bedrock in the area; in order of increasing age are sandstones of the Grand Rapids Formation, marine shales and glauconitic sandstones of the Clearwater Formation, and the clays, shales, siltstones, sandstones, and oil sands of the McMurray Formation. Below the McMurray Formation lie limestones and shales of the Upper Devonian Waterways Formation. Buff and grey limestones of the Moberly Member of the Waterways Formation are the oldest rocks exposed in the river valleys near Fort McMurray. The distribution of these formations is shown in figure 1. In the subsurface below the Waterways Formation are shales, dolomites, anhydrite, gypsum, and salt of the Middle Devonian Elk Point Group. Underlying the Elk Point rocks, but separated from them by a thin layer of detrital sand known as "Granite Wash", are Precambrian granites and gneisses at a depth of about 900 feet at Fort McMurray.

Between the Devonian and Lower Cretaceous strata is a major break in the stratigraphic succession (Fig. 2). During the period of time represented by this break, the rocks in the area were subjected to at least one episode of subaerial erosion with all that this implies regarding the genesis of clays by weathering. Probably at least 800 feet of limestone and other strata were removed at Fort McMurray. The topography of the
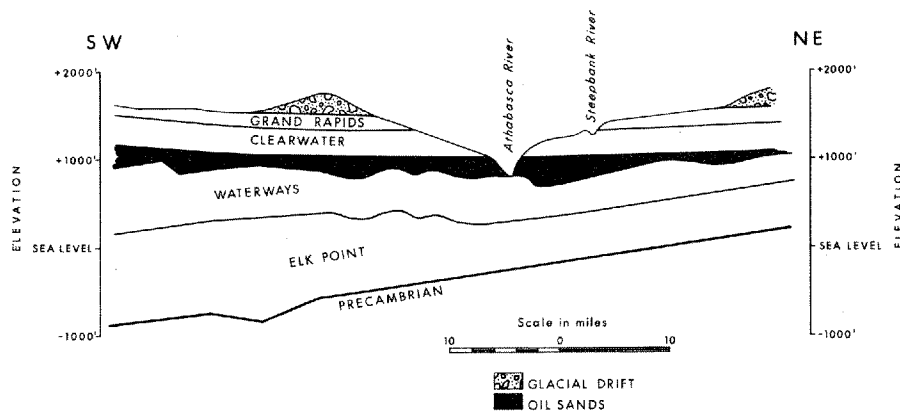
Figure 2. Cross section of the strata in the lower Athabasca River valley, near Fort McMurray.

Devonian erosional surface in northeastern Alberta has been mapped by
Martin and Jamin (1963). The irregularity of this surface is particularly
evident where it has been penetrated by closely spaced drill holes as at the
site of Abasand Oils Limited in Tp. 89, R. 9, W. 4th Mer., and the leases
of Great Canadian Oil Sands Limited in Tp. 92 and 93, R. 10, W. 4th
Mer. Clays lying on or near this surface are those with which this report
is chiefly concerned.

DRILLING FOR CLAY AT ABASAND

In order to obtain samples of the oil sand underclay, drilling
was undertaken at the site of the Abasand Oils Limited pit in Lsd. 15,
Sec. 8, Tp. 89, R. 9, W. 4th Mer., east of the Horse River. This site was
chosen for the following reasons. At this location drilling conducted by the
Mines Branch (Canada, 1949) indicated thicknesses of clay ranging from 18
to 25 feet (Fig. 3). Thicknesses of overlying material consisting of uncon-
solidated glacial and alluvial deposits and oil sand ranged only from 38 to
57 feet because much of the oil sand originally overlying the clay has been
eroded by the Horse River, and some removed by excavations of Abasand
Oils Limited. The site is accessible by road from Fort McMurray.

Eight holes, the locations of which are shown on figure 3, were
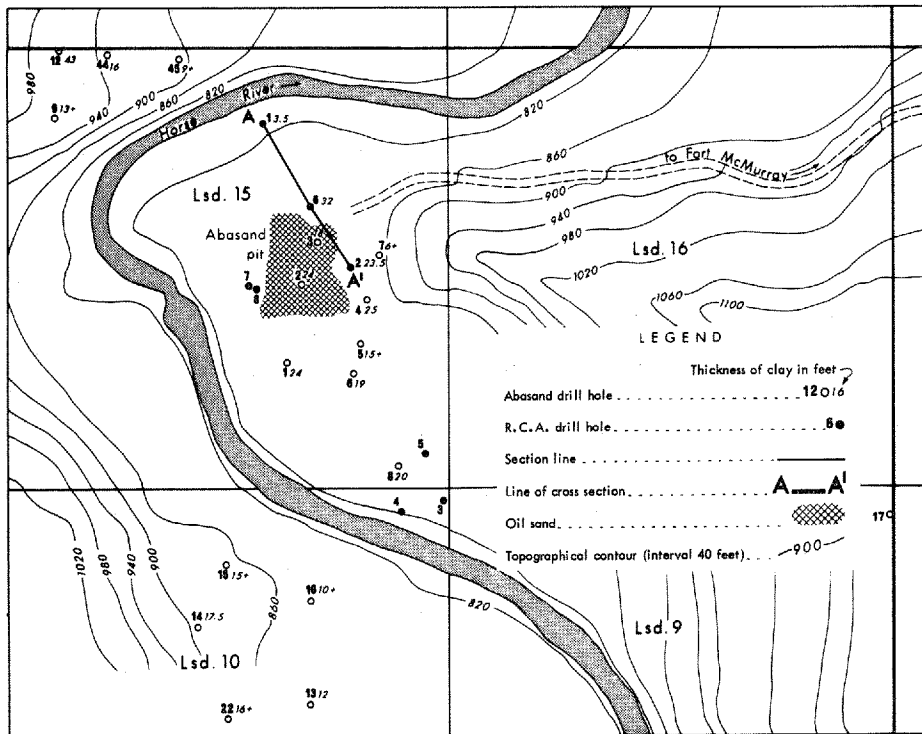
Figure 3. Map showing location of holes drilled to sample clay
in Sec. 8, Tp. 89, R. 9, W. 4th Meridian.

drilled with a Failing Model 1500 rig. Only three of these, numbers 1, 2, and 6, penetrated below the oil sand, the other five being abandoned at depths from 10 to 18 feet on encountering pea-size gravel which slumped into the hole. No casing was available to enable drilling below this gravel.

In Holes 1, 2, and 6, the oil sand was drilled and a total of 59 feet of clay cored in the three holes with 40 feet or 67 per cent of 2-inch diameter core recovered. Recovery was difficult in some intervals because of the presence of thin hard limey layers and ironstone layers or nodules. Because the oil sand was not cased off and fresh mud not used for the coring, all the core was coated with a mixture of oil and sand. This oil and sand was removed in the laboratory with toluene in a soxhlet apparatus, and by scraping off any sand still adhering to the cores. This involved heating the cores to about 100°C, a procedure which probably changed some of the clays significantly, as discussed in a succeeding section.

DESCRIPTION OF THE CLAY

Stratigraphy

Figure 4 is a cross section through the three holes that penetrated the clay. Three and one-half feet of clay were present in Hole no. 1 at a
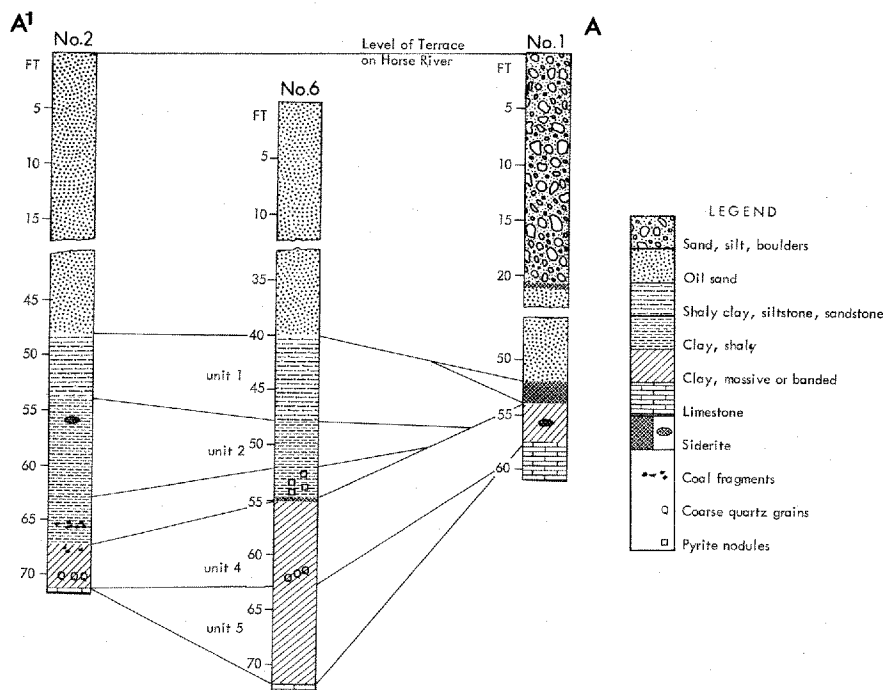
Figure 4. Cross section of three holes drilled to obtain samples of clay in this study.

depth of 54 feet; 32 feet in Hole no. 6 at a depth of 40 feet; and 23 1/3 feet in Hole no. 2 at a depth of 48 feet. As shown in the cross section, the oil sand underclay has been divided into 5 units. For tests and analyses, representative parts of each unit from each hole in which it was present were combined into a single sample, the number of each sample corresponding to the number of the unit.

Unit 1 consists of interbedded brownish-grey clay, some slightly fissile grey clay, thin siltstones, fine sandstone, and some hard limey layers. It is about 6 feet thick in Hole no. 2 and 8 feet thick in Hole no. 6. Clays similar to those in this unit are interbedded with oil sand near the base of the oil sand, so the division between the oil sand and the underlying clay is arbitrary to some extent.

Unit 2 consists of slightly fissile, medium to dark grey clay with some limey layers and siderite, and a few thin layers of whitish-grey clay. It is about 9 feet thick in Hole no. 2 and 4 feet thick in Hole no. 6. The chief differences between units 1 and 2 are the presence of silty and sandy layers in unit 1 and the proportions of clay minerals.

Unit 3 consists of fissile, dark greyish-brown clay with specks of coal, and a thin layer of black shale. A few pyrite nodules up to 5 mm in size were noted. It is about 4 1/2 feet thick in Hole no. 2 and about 3 feet in Hole no. 6.

Unit 4 consists mostly of massive whitish-grey clay, mottled or stained yellowish or greenish in places, with some hard layers which were not recovered in the core. In the lower part of the interval, medium to coarse sand-sized grains of quartz are present in bands which dip 20° to 25°. Each quartz grain is well separated from the next by the fine clayey matrix. The unit is about 4 feet thick in Hole no. 2, 8 feet in Hole no. 6, and 3 1/2 feet in Hole no. 1.

Unit 5 consists of greenish-grey clay with thin bands of yellow-brown clay and irregular rusty-colored laminae in the upper part, becoming more massive in the lower part. Only 1 1/2 inches were found in Hole no. 2, but 9 feet are present in Hole no. 6.

The upper three units appear to be similar to the clays and shales interbedded with the oil sand, whereas the lower two appear more like residual clays. However, the presence of quartz grains in bands in unit 4 and the banded nature of part of unit 5 indicate that these also are transported or secondary clays. Support for this conclusion comes from the chemical data presented in a subsequent section and from spores which were separated from samples of the five units. The spores indicate an Early Cretaceous age for all units.

Sample 6 is pink glacial clay taken from a deposit of unknown

thickness and extent at a bridge site on the Firebag River in Lsd. 16,
Sec. 35, Tp. 99, R. 8, W.4th Mer.

Mineralogy

The minerals present in the samples of clay were determined
chiefly by the X-ray diffraction powder method, by standard diffractometer
techniques using cell mounts of a representative part of the whole sample
and also of the 5- and 2-micron size fractions, and oriented slides of the 5-
and 2-micron size fractions. The oriented slides were treated with ethylene
glycol and heated according to standard procedures for clay minerals.
Some of the X-ray diffraction powder patterns are shown in figure 5.

The amount of quartz was determined by a chemical method
described by Talvitie (1951), after an X-ray diffraction technique using an
internal standard was found to be unsatisfactory, possibly because of grain
size variations (Gordon and Harris, 1955).

In all five units of the Lower Cretaceous clays, minerals of the
kaolin group have been identified. The first three orders of the basal spacing
of 7.15Å for kaolinite are present in patterns of samples 1, 2, 3, and 5.
The pattern for sample 4 shows a spacing of 7.47Å in this region with what
may be a second order at 3.52Å . In samples 1, 2, 3, and 5, the (001) peak
shows varying amounts of asymmetry to higher spacings. In some samples the
asymmetry is enhanced by glycolation and is not changed by heating to 350°C.
It may be explained by the presence of a mixed-layer clay, by overlapping
with a higher order of a longer spacing clay, or by the presence of some of
the clay mineral which gives the 7.47Å spacing in sample 4. This 7.47Å
spacing is appreciably greater than that of kaolinite; it corresponds to
partially dehydrated halloysite. Little or no change is evident on heating
to 350°C, which agrees with the experiments of Brindley, Robinson, and
Goodyear (1948), who showed that heating to 400°C was required to reduce
the spacing of halloysite from 7.5Å to 7.2Å. Lowering the relative humidity
below about 30 per cent also will reduce the spacing to 7.2Å according to
Harrison and Greenberg (1962). Although the second order spacing of 3.52Å
is a little small for the first order of 7.47Å , the third order at about 2.50Å
being weak or absent agrees with data on halloysite. In the absence of
diagnostic criteria from electron micrographs, the mineral in sample 4 with
the 7.47Å spacing is tentatively identified as partially dehydrated halloysite,
the dehydration probably occurring when the oil was removed from the cores
in the soxhlet apparatus or while the sample was awaiting analysis at the low
humidities that prevail in the laboratory. The glacial clay, sample 6,
appears to contain no kaolinite.

Small amounts of chlorite also have been identified in all five
Lower Cretaceous clays. Although the (001) peak of chlorite only showed
in the 2-micron fraction of sample 2 and in the 5-micron fraction of sample
5 (and then only when heated), and the (002) peak of chlorite was marked
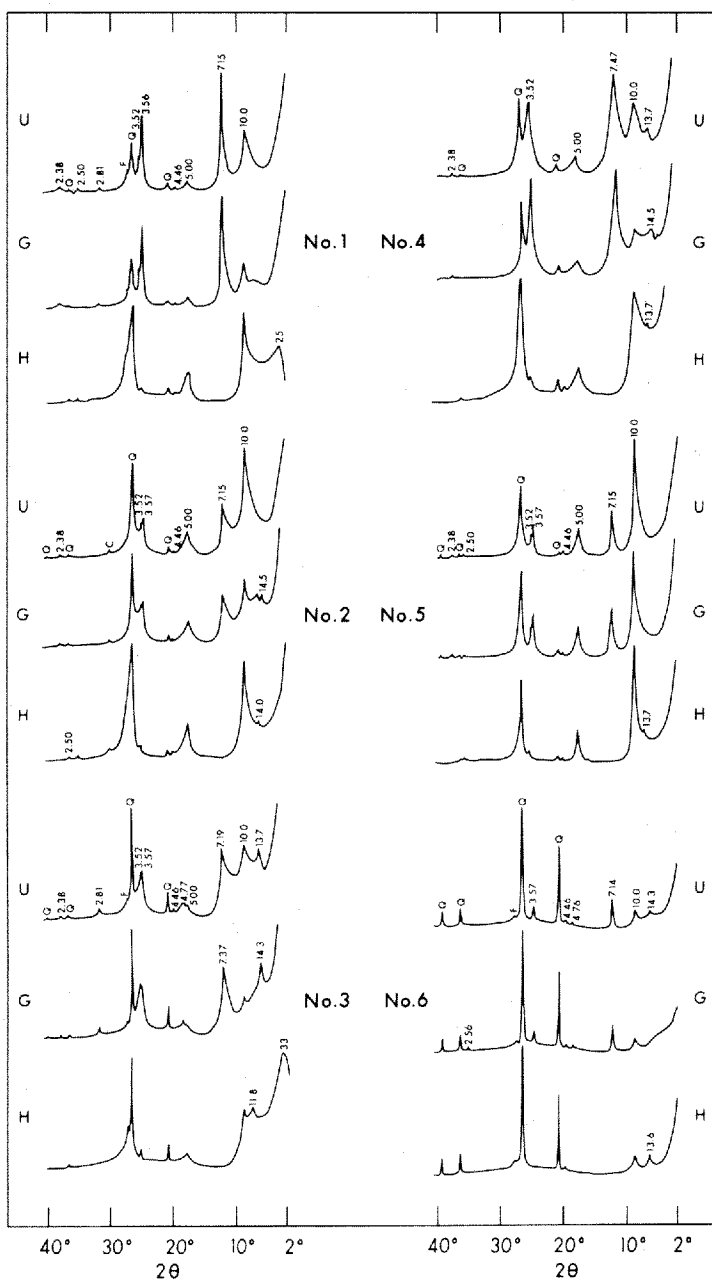
Figure 5. Smoothed traces of x-ray diffraction powder patterns
of the clay-size fractions from six samples of clay from
northeastern Alberta: U - untreated, G - glycolated,
H - heated at 550°C for 1 hour. The patterns were
obtained with CuK radiation, and the spacings are in
Angstroms; letters refer to nonclay minerals, Q - quartz,
F - feldspar, C - calcite.

or overlapped by the (001) peak of kaolinite, the presence of chlorite was revealed by the partial resolution of the (004) peak of chlorite from the (002) peak of kaolinite, and by its persistence after the sample was heated to 550°C. The (003) peak of chlorite was present in sample 3 in which a spacing expanded from 13.7Å to 14.3Å on glycolation. The (005) peak of chlorite was present only in samples 1 and 3 and disappeared on heating. The spacings of these peaks in samples 1, 2, 3, 4, and 5 indicate a basal spacing of 14.5Å for these chlorites. This corresponds to a molecular ratio of alumina to silica of 0.74 in the chlorite, a ratio which is close to the alumina to silica ratio in kaolinite (0.67). There is no thermodynamic reason why this ratio should be identical in co-existing chlorites and kaolinites, but the similarity of the structures of these minerals suggests that the chemical activities of alumina and silica as shown by their ratio should not differ too much in co-existing chlorite and kaolinite. The r patterns from the glacial clay, sample 6, show the first four orders of the chlorite basal spacing of 14.28Å, which corresponds to an alumina to silica ratio of 0.29, a value very different from that of the Lower Cretaceous clays. All the orders but the first disappear on heating, which contracts to 13.60Å.

Peaks with a spacing of about 10Å are present in all five Lower Cretaceous clays and in the glacial clay. The shapes of these peaks vary considerably from sample to sample; some change markedly when the samples are treated with ethylene glycol. In both size fractions of sample 1, the 10Å peak shows moderate asymmetry to higher spacings when untreated. On glycolation the intensity at 10Å decreases and a broad band to about 14Å appears. On heating, the asymmetric 10Å peak reappears as well as a broad hump at about 25Å. In sample 2 the 10Å peak behaved in a similar manner. In sample 3 a broad band with two maxima at about 10Å and 13.7Å is present in the pattern of the untreated material. Glycolation substantially reduces the intensity of the 10Å maximum and expands the spacing of the other to 14.3Å, whereas heating partly restores the intensity of the 10Å peak, contracts the spacing of the other to 11.8Å, and seems to produce a peak at 33Å. In sample 4, the 10Å peak is very asymmetric to higher spacings and includes a small peak at 13.7Å. On glycolation, the 10Å peak is much reduced in intensity and the spacing of the other is expanded to 14.5Å. The patterns of the heated material are similar to those of the untreated clay. Sample 5 has a 10Å peak which is slightly asymmetric, becoming more so when glycolated. The 10Å peak in the glacial clay, sample 6, is weaker and broader than in the Lower Cretaceous clays and shows little or no change when glycolated or heated. These observations indicate that samples 1, 2, 3, and 4 of the Lower Cretaceous clays contain an expanding or swelling clay constituent. Three possibilities are that it is part of a mixed-layer clay with the other layer being illitic in nature, or that it is a distinct mineral phase mechanically mixed with illite, or both. No data were obtained that permit a definite choice between these possibilities or a reliable identification of the expanding constituent. If the asymmetry is interpreted as due to the presence of a 12Å component, then the expansion with ethylene glycol to 14.5Å bears some resemblance to the behaviour of some vermiculites described by Walker (1958), in which case

the swelling component of these clays may be identified tentatively as vermiculite. The long spacings on the patterns of samples 1 and 3 after heating could not be resolved from the direct beam even by employing narrower slits in the untreated and glycolated clays. They may be due to mixed-layer clays or possibly some new phases produced by heating and oxidation of organic carbon. The 10Å clays in samples 5 and 6 appear to be ordinary illite.

Table 1 summarizes the mineralogical compositions of the six samples. Quantitative determinations of the minerals other than quartz were not attempted but some indication of the relative amounts of kaolinite, halloysite, chlorite, and illite was obtained from the X-ray patterns of the less than 2-micron fractions. Kaolinite is a major constituent of samples 1 and 5, more being present in the clay-size fraction of sample 1 than sample 5. It was not detected in the glacial clay, sample 6. Halloysite is tentatively identified as a major constituent of sample 4 and may be present in small amounts in the other Lower Cretaceous clays, but not in the glacial clay. Chlorite is a minor constituent in the five Lower Cretaceous clays and a major constituent in the glacial clay. Illite is a major constituent of sample 5, the clay immediately overlying the Devonian limestone, and a minor constituent in the other clays. A mineral showing some of the characteristics of vermiculite is present in the four upper units of the clays, and spacings of 25Å or 33Å indicate mixed-layering in samples 1 and 3.

The other minerals noted are siderite, feldspar, muscovite, and calcite.

Chemical Composition

Results of chemical analyses of the six samples are given in table 2.. All are average to high in silica, and average to low in alumina with the Lower Cretaceous clays having about 50 per cent more titania than the average shales tabulated by Pettijohn (1957, p. 334). These data are further evidence that the oil sand underclays near the Abasand pit are transported or secondary clays, not residual. The iron content of sample 4 is lower than the others. The high carbon content of samples 1, 2, and 3 prevented determination of ferrous iron in them. The higher lime content of sample 2 is reflected in the presence of calcite. The higher K_2O content of sample 5 is reflected as a greater amount of illite. Samples 2 and 3 contain the highest concentrations of organic carbon.

Ceramic Tests

The clays were dried, ground, and tempered with water to a stiff plastic condition. Test briquettes were hand-moulded in a steel mould 4 by 4.5 by 1.25 inches in size from the prepared materials. One freshly made briquette of each sample was dried rapidly at 185°F; the balance of

Table 1. Mineral Composition of Clay Samples Determined from X-ray Diffraction Powder Patterns

CONSTITUENTS	SAMPLES					
	1	2	3	4	5	6
Quartz (weight per cent)	45.0	35.1	52.0	56.0	31.8	69.5
Kaolinite	major	minor	minor	minor	major	-
Halloysite	minor	minor	minor	major	trace	-
Chlorite	minor	minor	minor	minor	minor	major
Illite	minor	minor	minor	minor	major	minor
Vermiculite	present*	present	present	present	-	-
Mixed-Layer Clays	present?	-	present?	-	-	-
Others	siderite feldspar muscovite	calcite	siderite calcite feldspar	-	siderite	muscovite feldspar

* No attempt has been made to estimate the relative proportions of vermiculite and mixed-layer clays.

11

Table 2. Chemical Analyses of Six Clay Samples
near Fort McMurray, Alberta

CONSTITUENTS	SAMPLES					
	1	2	3	4	5	6
SiO_2	68.42	61.49	67.18	74.69	61.89	84.53
TiO_2	0.92	1.06	1.29	1.25	1.09	0.30
Al_2O_3	16.20	16.01	10.12	13.38	18.01	7.41
Fe_2O_3	3.16	4.00	4.87	0.85	2.57	1.64
FeO	–	–	–	0.96	2.32	0.47
MnO	0.07	0.10	0.12	0.02	0.06	0.02
MgO	0.65	1.09	0.74	0.59	1.45	0.86
CaO	0.50	2.02	0.84	0.31	0.42	0.67
Na_2O	0.33	0.49	0.37	0.35	0.42	0.28
K_2O	1.37	2.14	0.66	0.96	3.45	1.12
H_2O^+	5.45	5.21	5.11	4.24	4.71	1.62
H_2O^-	0.74	1.16	1.13	0.66	0.68	0.58
CO_2	0.96	2.15	2.42	0.32	1.14	0.00
C	0.95	1.32	4.00	0.12	0.18	0.28
S	0.00	0.16	0.00	0.00	0.00	0.00
P_2O_5	.0.04	0.09	0.06	0.01	0.08	0.02
	99.76	98.49	98.91	98.71	98.47	99.80
Quartz	45.0	35.1	52.0	56.0	31.8	69.5
Combined SiO_2 (by difference)	23.4	26.4	15.2	18.7	30.1	15.0
Al_2O_3 : Combined SiO_2 ratio	0.69	0.61	0.66	0.72	0.60	0.49

Analysts: Chemical composition – H. Oikawa, Research Council of Alberta
Quartz determinations – H. A. Wagenbauer, Research Council
of Alberta

the briquettes was air-dried for about 24 hours and finally at 185°F in a laboratory drier. The pyrometric cone equivalent (PCE), which is the heat-softening point, was determined. Then duplicate test briquettes were fired at temperatures indicated in table 3. The fired shrinkage, color, hardness, and absorption after soaking 24 hours in cold water were obtained. The results are given in table 3.

All the clays except sample 6 are difficult to dry; they have fairly high to high drying shrinkages. Sample 6 is moderately difficult to dry with rapid drying conditions.

Samples 1, 3, 4, and 6 have long firing ranges similar to stoneware clay. Their firing temperatures were not high enough to determine whether they would vitrify. Sample 2 contains impurities which made firing difficult. The briquettes made from this clay have a decided tendency to form a black cone and bloat so that a much longer burn is required to fire them properly; it would be difficult to fire this material commercially. To overcome this problem would require a very long oxidizing period or dilution of this sample by the others.

Sample 5 has an overly high drying shrinkage and cracked during rapid drying. Upon drying, some of the soluble salts contained in the clay are deposited at the exposed surface of the product forming a scum, which fuses rather early during firing and might adversely affect the appearance and the laying properties of the product. Additions of nonplastic material, such as sand or grog, probably would be necessary to improve drying. The sample by itself has a fairly good firing range for the production of face brick with a firing temperature between cone 08 and cone 05. The clay matures at relatively low temperatures, probably owing to the fluxing action of the salts. Consequently, this material, with an addition of low grade nonplastic material, might be suitable for the manufacture of brick tile and sewer pipe, provided the drying difficulties can be eliminated.

Samples 1, 4, 5, and 6 appear suitable for the production of sewer pipe, brick, and tile by the stiff mud process, provided that extrusion and de-airing lower their drying shrinkage and provided that drying problems can be eliminated, possibly by blending with less plastic or nonplastic materials. Sample 3 likely could be blended with the more easily vitrified samples in the manufacture of the above products by the stiff mud method. Alternatively, these materials may be suitable for making dry-pressed brick; this procedure might eliminate the drying problem.

DISCUSSION OF RESULTS

The stratigraphic position of the five clay samples on the Devonian erosion surface below the oil sands of the Lower Cretaceous McMurray Formation suggests that they are residual clays. Although the

Table 3. Ceramic Tests of Six Clay Samples from the Fort McMurray area

Clay No.	UNFIRED CHARACTERISTICS	PCE	FIRED CHARACTERISTICS					REMARKS
			Cone No.	Fired Shrinkage %	Absorp-tion %	Color	Hardness	
(No. 1)	Brownish grey, non-calcareous clay, good workability, very plastic, somewhat tough, water of plasticity 25%, cracks badly with rapid drying (85°C) drying shrinkage 8.0%.	Cone 18 approx 1500°C 2732°F	010 (1629°F)	0.0	13.9	pale brown (buff specks)	fairly soft	High drying shrinkage, difficult to dry, long firing range. The buff specks showing on the fired briquettes have a pleasant effect.
			06 (1816°F)	1.3	12.4	pale brown	fairly hard	
			04 (1922°F)	2.0	10.0	light brown	hard	
			02 (2014°F)	3.1	7.6	medium brown	very hard	
			2 (2088°F)	3.1	3.9	medium brown	very hard	
(No. 2)	Dark grey, calcareous clay, good workability, very plastic, tough, water of plasticity 28.9%, cracks badly with rapid drying, drying shrinkage 7.8%.	Cone 14 approx 1388°C 2530°F	06	1.8	5.7	light brown	very hard	Briquettes made from this clay bloated in firing, forming a black cone. They would be very difficult to fire properly.
			04	+0.3 (expansion)	5.2	brown	very hard	
			02	+2.0	5.4	brown	very hard	
(No. 3)	Brownish black, non-calcareous clay, good plasticity and workability, tough, water of plasticity 24.7%, cracks badly in drying, drying shrinkage 7.3%.	Cone 15 1/2 approx 1439°C 2623°F	010	0.3	17.9	pale greyish brown	fairly soft	Fairly high drying shrinkage, difficult to dry, long firing range, difficult clay to vitrify, buff specks.
			06	0.9	16.6	light greyish brown	fairly hard	
			04	1.2	15.2	light brown	fairly hard	
			02	1.7	14.0	medium brown	hard	
			2	2.3	12.6	medium brown	hard	
			5	2.3	11.2	brown	very hard	

14

(No. 4)	Creamy grey, non-calcareous clay, good workability, very plastic, water of plasticity 23.6%, cracks badly in drying, drying shrinkage 7.8%.	Cone 17 1/2 approx 1493°C 2711°F	010	0.0	11.6	light pinkish buff	fairly soft	Light buff to buff-burning clay with red specks, long firing range, difficult to dry, high drying shrinkage.
			06	0.5	11.5	light pinkish buff	fairly hard	
			04	1.0	10.6	light buff	hard	
			02	2.0	9.2	light buff	very hard	
			2	2.0	7.7	light buff	very hard	
			5	2.3	6.9	buff	very hard	
(No. 5)	Light grey buff, non-calcareous clay, good workability and plasticity, water of plasticity 30.8%, cracks badly in drying, drying shrinkage 8.0%.	Cone 14 1/2 approx 1406°C 2562°F	010	0.3	12.1	salmon	fairly hard	High drying shrinkage, difficult to dry, satisfactory firing range for face brick. The dry briquettes showed a white scum on surface.
			06	3.7	6.9	pale red	very hard	
			04	5.8	2.7	medium red	steel hard	
			02	6.7	0.0	brownish red	nearly vitrified	
			2	6.3	0.0	brownish red	nearly vitrified	
(No. 6)	Pink, non-calcareous clay, good workability and plasticity, water of plasticity 27.8%, cracks moderately with fast drying, drying shrinkage 7.1%.	Cone 16 approx 1455°C 2651°F	06	0.9	15.5	pale salmon	fairly hard	Slight tendency to crack in drying, satisfactory firing range, fairly high drying shrinkage.
			04	2.2	12.2	light salmon	hard	
			02	4.9	6.7	dark salmon	very hard	
			2	6.3	4.2	light red	steel hard	
			5 (2131°F)	6.3	2.3	red	steel hard	

15

presence of kaolinite, probably halloysite, and a titanium content somewhat higher than in average shales are characteristic of some residual clays, the presence of laminations, layering, silica and alumina contents about the same as in average shales, and the presence of Lower Cretaceous spores indicates that the oil sand underclays at the Abasand pit are transported clays. Irregular hollows containing residual clay in pockets of unknown extent would be expected to develop on the Devonian erosion surface (Carrigy, 1959, p. 36). At the beginning of deposition of the McMurray Formation, some of these clays undoubtedly were transported short distances at least and mixed with material moved in from farther away. Some residual clays from hollows or pockets in the Precambrian Shield to the east also may have been transported and deposited near the base of the McMurray Formation. Such an explanation accounts for the "residual" characteristics found in these clays.

Halloysite has been tentatively identified in some of the oil sand underclays at the Abasand pit. It is well known in residual clays from the southern Appalachian area (Sand, 1956), from the weathering of basic vol-canic rocks (Bates, 1962), and in both residual and transported clays from the weathering of basalt and granodiorite in eastern Washington and Idaho (Hasterman et al., 1960). Its presence in the Gardner Mine Ridge, Indiana, has been well described by Callaghan, (1948). There, it is found at an unconformity between a sandstone of Pennsylvanian age and limestone and shale of Mississippian age, a geologic setting strikingly similar to that of the oil sand underclays in the Fort McMurray area. Callaghan (1948, p. 40-42) concludes that much of the endellite (halloysite) is a residual clay, but some has been reworked by solutions so that it is now present in cracks and cavities in the sandstone and as nodules. These occurrences of halloysite indicate that its presence in the oil sand underclay would not be unusual.

The ceramic tests on the oil sand underclays have shown that they are difficult to dry. The drying problems are considered to be caused chiefly by the expanding vermiculite-like mineral and by the halloysite-like mineral. The high drying shrinkage of halloysite has been noted by Grim (1962, p. 76) and has been ascribed to the collapse of the tubular particles. This is probably one of the reasons that halloysitic clays are not used extensively for ceramics, but find their chief use as cracking catalysts (Grim, 1962, p. 310) and in the production of alum (Murray, 1960, p. 290). Another reason is their firing shrinkage and cracking into small pieces (Grim, 1962, p. 121). One of the clays tested by Hume (1924) was difficult to dry and cracked into small bits on firing. The fired shrinkages of the oil sand underclays range from 2.3 to 6.3 per cent at the highest temperature fired, except for sample 2, which expanded. This expansion could be ascribed to the presence of organic material, but sample 3, which did not expand, contains three times as much organic carbon. Thus, the explanation appears to be due to the higher calcite content and the presence of sulfur, possibly in pyrite. Apparently these minerals decomposed at a temperature

when the fired material was able to retain some of the gases being given off.

The color of the fired product is most important for marketing purposes. Only sample 4 fired to a buff color, the others burning red to brown. This buff-burning sample had an iron content of 1.81 per cent, the lowest of the samples tested. Several of the samples tested for Ells and Hume fired to a buff or cream color.

Samples 1 and 4 had PCE values of 18 and 17 1/2, respectively, the highest of the six samples. These values are related in sample 1 to the amount of kaolinite, and in sample 4 to the halloysite-like mineral. The lower PCE values in samples 2 and 5 apparently are related to the amount of calcite and CaO, and to the amount of illite and K_2O, respectively. Figure 6 shows the relation between PCE values and the ratios by weight of alumina to total silica less quartz, i.e. the ratio of alumina to combined silica. The oil sand underclay values show a linear trend, whereas the glacial clay value is quite different. The reason for the linear trend is uncertain, but its existence suggests that the alumina: silica ratio in these clay minerals is important in controlling the refractoriness of the oil sand underclays. At higher PCE values one might expect the refractoriness to be affected by quartz as well. Of the clays tested by Ells and Hume, only 3

LOWER CRETACEOUS CLAY SAMPLE..●
GLACIAL CLAY SAMPLE.................o

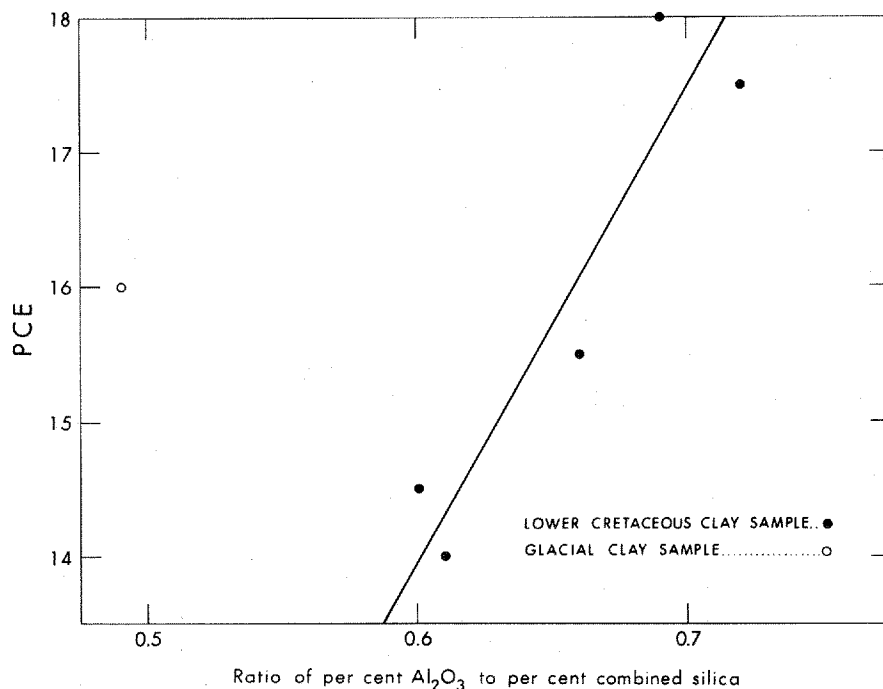Ratio of per cent Al_2O_3 to per cent combined silica

Figure 6. Scatter diagram showing the relation of PCE to the ratio of alumina to combined silica in six clay samples.

had PCE values higher than 18: two of 27 and one of 20 according to their scale of PCE values. This indicates that more refractory clays than those sampled at the Abasand pit are present at some places as oil sand underclays. Such clays might be expected to have more of the characteristics of residual clays than those from the Abasand pit.

CONCLUSIONS

A maximum thickness of 32 feet of oil sand underclays was cored in three holes at the Abasand pit near Fort McMurray, Alberta. They have been divided into five stratigraphic units on the basis of lithology, mineralogy, and ceramic characteristics. All five units are lenticular, only unit 4 being present in all three holes. The clays are laminated. Four of the units contain an expanding vermiculite-like mineral, two appreciable amounts of kaolinite, and another appreciable amounts of an halloysite-like mineral. Other constituents are quartz, chlorite, illite, and mixed-layer clays. In ceramic tests, drying was difficult. This is probably due to the presence of the minerals tentatively identified as vermiculite and halloysite. The maximum PCE value is 18, but previous work has shown similar clays along the Athabasca River downstream from Fort McMurray to have PCE values of 27. Only one unit burned to a buff color; the others burned red or brown. Three of the units have long firing ranges similar to stoneware clays. The clays tested have been transported, but the geologic setting is one likely to contain pockets of residual clay. Although the thickness of the clays, their lenticular nature, their position below the oil sands, and their drying difficulties do not make them particularly attractive for development, the data from the many drill holes that have accompanied the oil sand exploration, development, and production, should allow other pockets of clay to be outlined. If samples of clay are still available from these holes, further data on their mineralogy and ceramic characteristics could be readily obtained. Possibly, kaolinitic clays may be found in pockets on the Precambrian Shield in northeastern Alberta, similar to those found in Quebec (Brady and Dean, 1966, p. 4).

The glacial clay from the Firebag River differs markedly from the oil sand underclays in its higher quartz and silica contents, and in the absence of kaolinite, halloysite, and expanding layer minerals. The ratio of Al_2O_3 to combined SiO_2 also is markedly lower than in the oil sand underclays. The absence of montmorillonite in this clay contrasts with its ubiquity in glacial clays from more southerly parts of Alberta, and is probably the result of its being so close to the Precambrian Shield and away from the montmorillonite-bearing Cretaceous bedrock which underlies so much of Alberta. This suggests that some of the glacial clays elsewhere in northeastern Alberta might be free of the drying problems common to montmorillonitic clays and hence suitable for ceramic use. However, only red-burning clays are to be expected.

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APPENDIX I

PREVIOUSLY PUBLISHED CERAMIC TESTS OF CLAY
FROM NORTHEASTERN ALBERTA

SAMPLE NO.	WATER OF PLASTICITY	WORKING PROPERTIES	DRYING SHRINKAGE	DRYING BEHAVIOUR	FUSION[1] TEMP. or PCE	CONE[1] or TEMP.	FIRED SHRINKAGE	ABSORPTION	COLOR	HARDNESS	REMARKS
E1 Ells, 1926	26	quite plastic, stiff	6.5		8 1290°C	010 06 03			pinkish buff pinkish brown dark brown	soft steel hard steel hard	From Clearwater Pit 1; showed some scum; suitable for brick. stratigraphic position unknown but Devonian limestone exposed nearby.
E2 Ells, 1926	23	slightly plastic, flabby			27 1670°C	010			light buff	fairly hard	Moderate heat duty fireclay
E3 Ells, 1926	24	fairly plastic	8		1280°C	06 03	low		reddish buff reddish buff	steel hard steel hard	Color unusual but suitable for bricks
H1 Hume, 1924	21	fairly good	6.3	difficult	1483°C	980°C			light buff	nearly vitrified	Cracks or shatters into small bits on firing; suitable for some bricks; 8 feet thick above Devonian limestone; extends 500 yards along river under 0 to 30 feet of overburden; laminated; noncalcareous.
302 Ells, 1915	28	highly plastic	8	requires slow drying		010 06	1.3 4.6	10 4		steel hard	Bloats above cone 06
303 Ells, 1915	27	good	5.3	fast drying	3 1190°C	010 06 03	0 0 0	25 25 23	salmon pink buff		Calcareous; suitable for common bricks
190 Ells, 1915		good, very plastic		good	27 1670°C	3	9		cream	steel hard	Stoneware clay; fireclay
305 Ells, 1915	27	good	8	fast drying	3 1190°C	010 06 03	0.7 4.0 4.0	11 4 0	light red red dark red		Suitable for brick
306 Ells, 1915	37	good	10			010	1.3	12	light red	steel hard	Requires 25 per cent sand for bricks

(E2, E3: Devonian limestone is exposed nearby)

(302, 303: Stratigraphically some distance above limestone)

(190, 305: Devonian limestone exposed nearby)

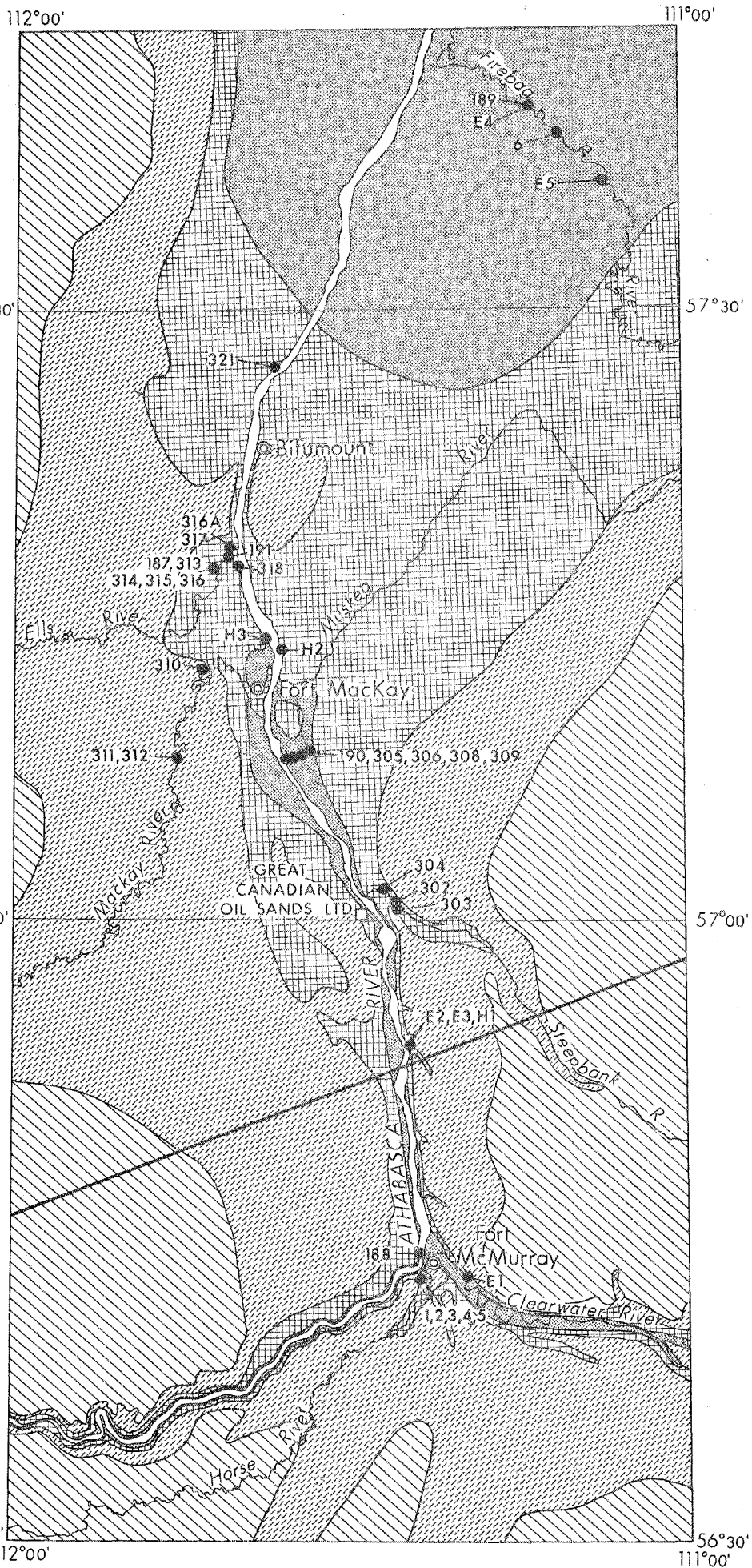|											
310 Ells, 1915	23	very plastic	7	requires slow drying	15 1430°C	010 06 03 1 5	0 1.4 3.0 3.4 2.0	10 8 3 2 0	buff buff buff dark buff grey		Requires slow burning; suitable for bricks
311 Ells, 1915	26	fairly good		dries fast		010			red		Low shrinkage; silty
H2 Hume, 1924	19	fairly plastic	6.2	good	1460°C	900°C 980°C 1040°C	0.0 1.0 1.0	11.0 8.9 8.1	light red brownish buff cream	steel hard nearly vitrified	Suitable for bricks and semirefractory uses; more than 6 feet thick; close to Devonian limestone.
H3 Hume, 1924	17	good, fairly plastic	5	good	1499°C	900°C 980°C 1040°C	0.6 0.0 0.3	11.6 10.2 8.9	light cream light cream light cream	 steel hard steel hard	Suitable for bricks and semirefractory uses; about 15 feet thick; interbedded with oil sand.
187 Ells, 1915		very plastic, stiff, sticky	6.5	dries slowly	20 1530°C	 5			light red buff grey	 vitrifies	Stoneware type but carbon causes difficulties; underlies oil sand.
191 Ells, 1915		very plastic			18 1490°C	3	high	dense	salmon		Stoneware type clay; between oil sand and Devonian limestone.
313 Ells, 1915	14	low plasticity, inferior	3		18 1490°C	010 06 03 5 14	0 0 0 0 softens	8 8 8 7	salmon buff buff buff grey		High concentration of fine sand; too sandy for use.
314 Ells, 1915		good, good plasticity	6	dries fast	14 1410°C	010 06 03 1 5	0 1.0 2.3 3.4 4.6	12 9 5 1 0	salmon salmon salmon buff grey		Suitable for face brick.
316 Ells, 1915	21	good plasticity	6	requires slow drying	13 1390°C	010 06 03 1	1.3 2.6 3.7 4.0	9 7 2 0	salmon salmon salmon grey	 vitrified	

Devonian lime-
stone exposed
nearby

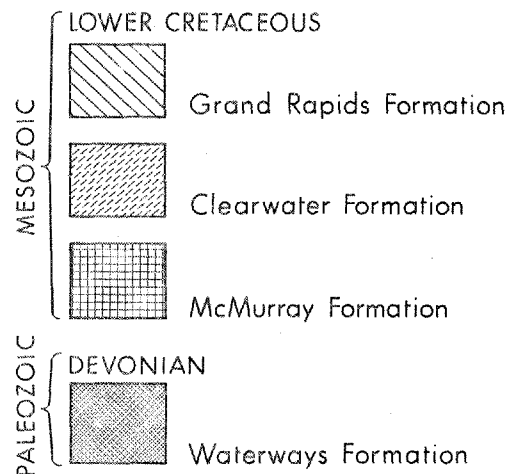| SAMPLE NO.	WATER OF PLASTICITY	WORKING PROPERTIES	DRYING SHRINKAGE	DRYING BEHAVIOUR	FUSION[1] TEMP. or PCE	CONE[1] or TEMP.	FIRED SHRINKAGE	ABSORPTION	COLOR	HARDNESS	REMARKS
317 Ells, 1915	17	good plasticity, stiff	5		16 1450°C	010 06 03 1 5 9	0 0 1 1 2 4	10 10 7 6 3 vitrified	salmon salmon buff buff grey		Stoneware type clay.
318 Ells, 1915	25	highly plastic, sticky	7.5	requires slow drying		010			salmon	steel hard	Swells above cone 010; at least 9 feet thick below 10 to 15 feet of oil sand; no limestone nearby.
319 Ells, 1915		highly plastic, good	5.5	requires slow drying	17 1470°C	010 06 03 1 5 9	0 0 0.6 1.3 2.0 4.0	11 10 8 6 5 vitrified	salmon salmon buff buff grey grey		Stoneware type clay; east side of Athabasca River near the southern boundary of the Murphy Claim.
320 Ells, 1915		high plastic, sticky, stiff, hard to work	9		4 1210°C	010			salmon	steel hard	High carbon renders this clay worthless.
189 Ells, 1915		very plastic, sticky			10 1330°C	3	high	vitrified	red		Suitable for sewer pipe; Ells states that this clay underlies the oil sand but it is probably glacial.
E4 Ells, 1926	33	quite plastic	6		16 1450°C	010 06 03			light pinkish buff dark pinkish buff dark red	quite soft steel hard steel hard	Briquettes show scum; suitable for brick if scumming prevented; glacial clay; slightly calcareous.
E5 Ells, 1926	21	not very plastic	6.3	dried well but with scum	3 1190°C	010 06 01	0.0 1.7 5.7	20.0 16.9	reddish brown dark reddish brown	steel hard nearly vitrified	Slightly calcareous; glacial clay; scum developed on burning; only suitable for bricks.

[1] All fusion temperatures have been converted to degrees Centigrade. Some of the cone points given by Ells are somewhat different from those given by Singer and Singer (1963).

[2] Total shrinkage.

Samples 188, 304, 309, 312, 315, 316A, 321 were other samples tested for Ells and found to be unsuitable for bricks.
Sample 308 is similar to sample 306.

LEGEND

LOWER CRETACEOUS

MESOZOIC

Grand Rapids Formation

Clearwater Formation

McMurray Formation

PALEOZOIC

DEVONIAN

Waterways Formation

———— Line of cross section (ref. Fig. 2)

● Clay sample location

187 - 191
302 - 306 } Ells, 1915*
308 - 321

E1 - E5   Ells, 1926
H1 - H3   Hume, 1924
1 - 6   R C A 69-3 (this report)

*The location of Ells, 1915 samples 319 and 320 is uncertain

Scale in Miles
4 3 2 1 0   4   8   12
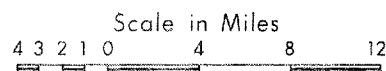
GEOLOGY OF LOWER
ATHABASCA RIVER VALLEY

To accompany R.C.A. Report
69-3 by L.B. Halferdahl