REPORT 80-A

POTENTIAL INDUSTRIAL CLAYS OF ALBERTA
PRELIMINARY ASSESSMENT PART II

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ABSTRACT

The oldest rocks tested in this study that have ceramic potential are the basal clays of the Lower Cretaceous McMurray Formation. Some of these clays can be used for low heat duty refractories but most of the material is more suitable for structural clay products or pottery. In the Peace River region pressed bricks made from shales of the Shaftesbury Formation probably could be fired successfully. From the same area, samples of Kaskapau Formation dry well, firing range is moderate to long, and the milk chocolate brown color could be acceptable in "earth color" pottery or structural clay products. A sample from the Bearpaw Formation in the Foothills has a long firing range and reasonable drying characteristics, which suggests that further testing of Foothills material may be desirable. Use of clays from the Eastend and Whitemud Formations for ceramic purposes is expected to continue. Shales from the Porcupine Hills Formation seem best suited for their present use as raw material for expanded aggregate production. Structural clay products could be produced from sediments of the Brazeau Formation if the good drying characteristics, moderate to long firing range, low fired absorption, and acceptable fired colors are maintained by active quality control methods. Clays and shales of the Paskapoo Formation have potential for use in the production of structural clay products if blended with grog, quartz or other clays to reduce the tendency to curl on firing.

INTRODUCTION

A summary report on the ceramic properties of Alberta clays and shales, published in 1975 (Hamilton and Babet), presents data from 233 sampling locations in the province. Supplementary information is contained in Scafe (1977) - Fort McMurray area, and Scafe (1978) - various locations in the Plains and Foothills.

During the field seasons of 1977 and 1978, samples of bedrock and surficial materials were collected from an additional 51 locations in the province (Fig. 1). The results of the ceramic tests on these final

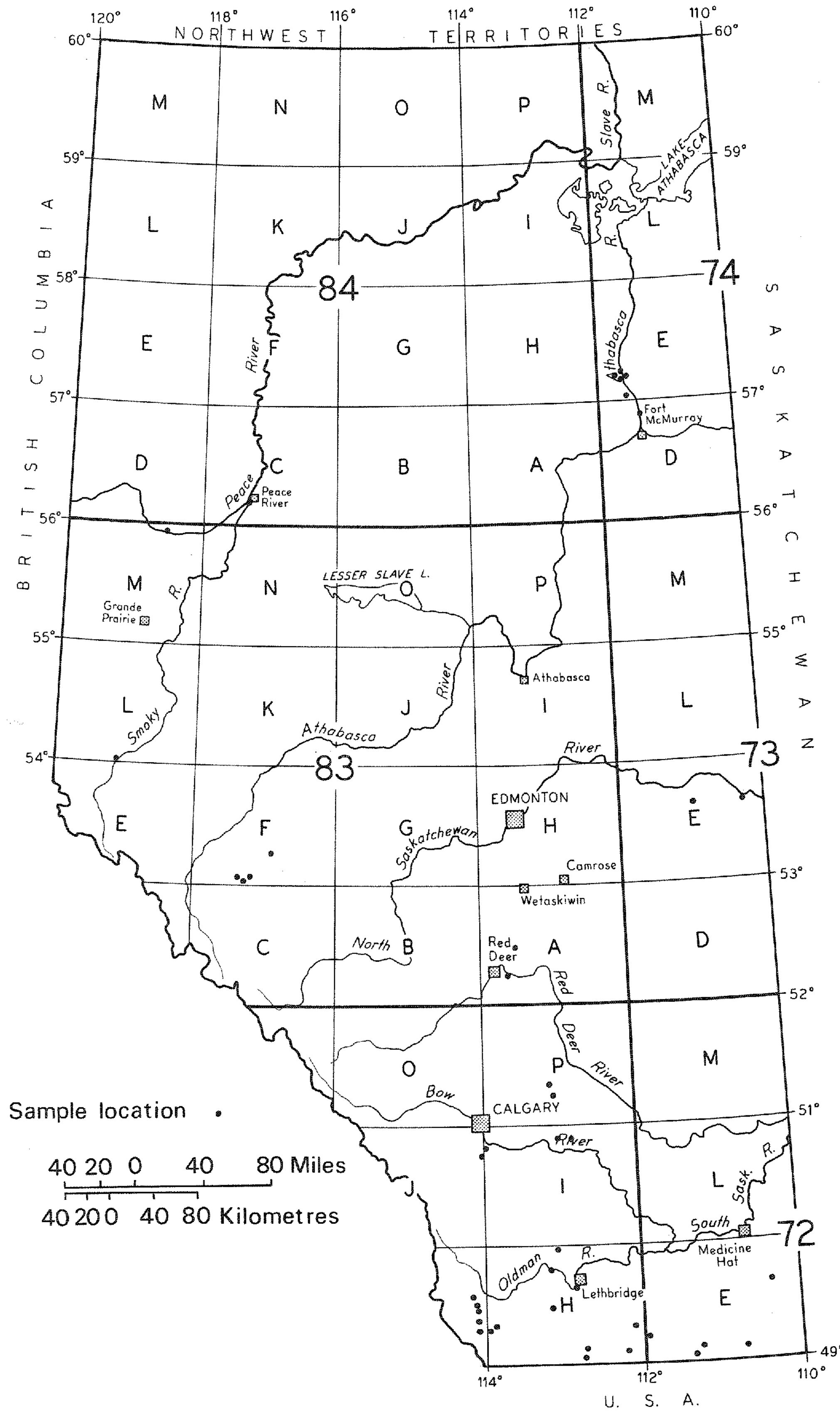


FIGURE 1. Sampling locations for the 1977-78 field seasons

samples in the project are given in this preliminary report. A final report will be published incorporating these data with data from earlier reports for a comprehensive, province-wide assessment of the ceramic properties of different geologic formations.

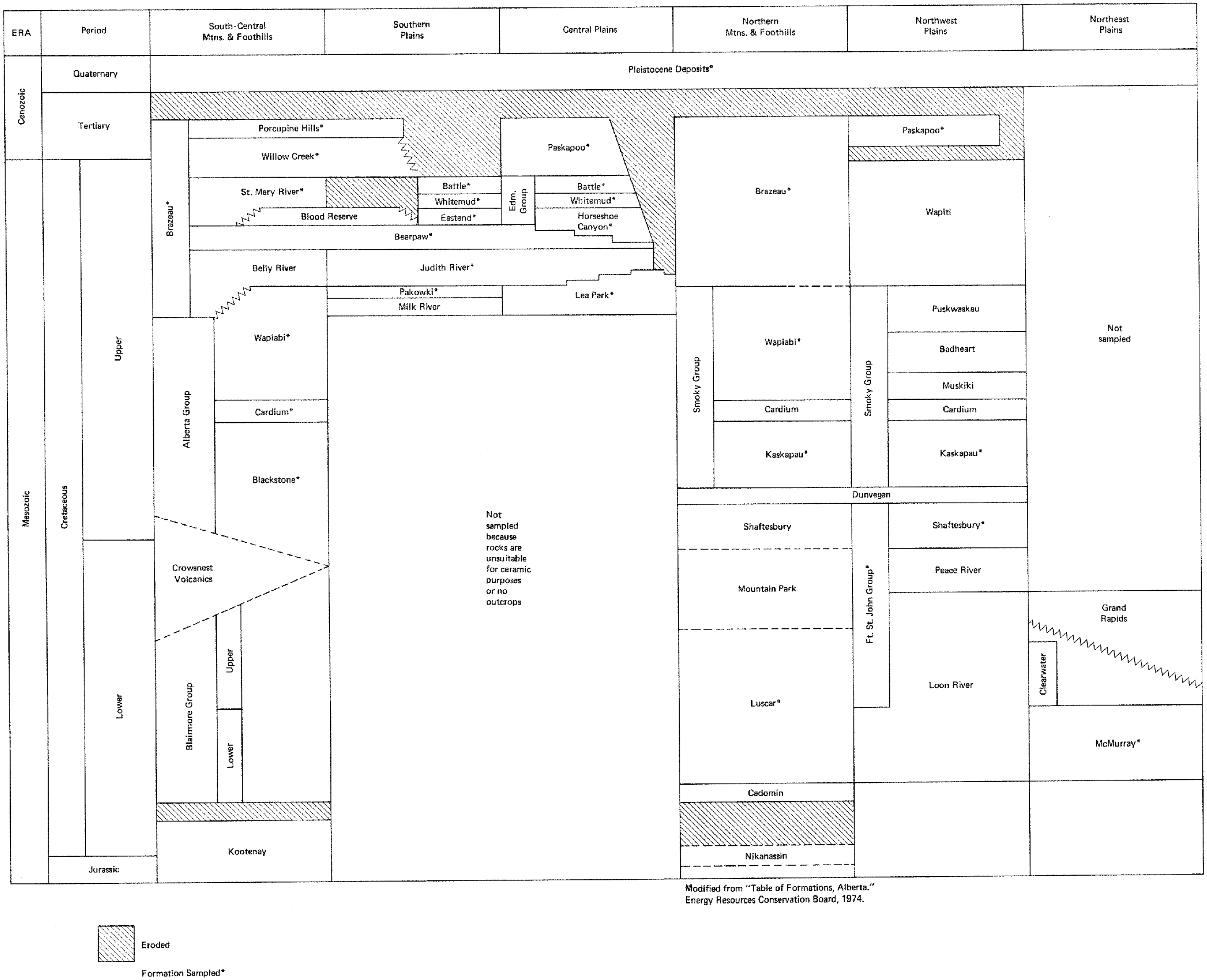
Recommendations for use of the tested materials are based upon the characteristics of individual samples as collected in the field, rather than those of blends of numerous components that most commonly comprise material used in ceramic ware preparations.

GEOLOGICAL PERSPECTIVE

A basic familiarity with general characteristics of the various geologic formations present in an area is necessary to eliminate superfluous field investigation and laboratory testing. Sandstone, siltstone, limestone, and highly montmorillonitic or calcareous shales can be rejected for most ceramic uses, although unconsolidated sands and silts that contain desirable clay minerals may be amenable to beneficiation.

In Alberta, most clay-bearing rocks older than Cretaceous age are unsuitable for ceramic purposes because of their coarse-grained, siliceous, or carbonate natures. Nevertheless, samples were taken from argillites of two formations of Precambrian age in the southwestern corner of the province. The Grinnell Formation consists of red argillite, white and light green quartzite, with zones of red argillite-pebble conglomerate, and red sandstone and quartzite. The Siyeh Formation is composed of a gray, fine-crystalline dolomite, sandy dolomite, green, red and black argillite.

Figure 2 illustrates the stratigraphic relationships of formations of Cretaceous and younger age discussed in the following paragraphs. In the Lower Cretaceous McMurray Formation of northeastern Alberta (Fig. 2), a light to dark gray, noncalcareous, poorly laminated clay is developed locally in the interval between mineable oil sand and the underlying Waterways Formation of Devonian age. This clay could become accessible during open-pit mining of the oil sand. In the



Modified from "Table of Formations, Alberta." Energy Resources Conservation Board, 1974.

FIGURE 2. Nomenclature and correlation of formations of Jurassic age and younger within the sampling area

northern Rocky Mountains and Foothills the lower part of the Luscar Formation is the age equivalent to the McMurray Formation. Gray and brown sandstones, and gray and greenish-gray shales are well exposed as a result of open-pit mining for coal in the Grande Cache area.

The gray to black marine shales of the Shaftesbury Formation are the oldest Lower Cretaceous rocks in the northwestern part of the province and are well exposed along the Peace River at the town of Peace River. In areas of the northwest, where it is difficult to differentiate between shales of the Mountain Park-Luscar Formation and the Dunvegan Formation, the rocks are called the Fort St. John Group.

The Dunvegan Formation includes, especially in the upper part, thin-bedded, dark gray shales, in addition to sandstones, siltstones, and minor coal beds. Directly above the Dunvegan Formation is the Kaskapau Formation, which consists of dark gray shale, silty shale, thin concretionary ironstone beds, and sandstones. The Dunvegan and Kaskapau Formations are present only in the northwestern and north-central parts of the province.

In the south-central Mountains and Foothills, the Blackstone Formation is age equivalent to the Shaftesbury, Dunvegan, and Kaskapau Formations. This formation consists of dark gray, fissile, silty shale and some thin-bedded, fine- to medium-grained cherty sandstone.

The Cardium is a formation that is present in all parts of the province except the northeastern Plains. This formation is characterized by sandstones, but contains both marine and nonmarine shales.

The Wapiabi Formation overlies the Cardium Formation and is composed primarily of dark gray, fissile to rubbly shales with minor siltstones and sandstones. This formation outcrops along the entire length of the Rocky Mountains and Foothills in Alberta and extends eastward beneath the Plains as well. The uppermost beds of the Wapiabi Formation in the south-central Mountains and Foothills are age equivalent to the dark gray shales and silty shales with minor sandstone of the Pakowki

Formation on the southern Plains as well as the gray, silty, marine shales of the Lea Park Formation in east-central Alberta.

Rocks of the Judith River Formation lie above the Pakowki Formation in southern Alberta and are drab, gray to brownish shales, siltstones and sandstones that grade upward into predominantly greenish-gray shales, silty shales and argillaceous sandstones.

Lying conformably and relatively abruptly on the Judith River Formation is the marine shale of the Bearpaw Formation. Although the montmorillonitic character of these rocks throughout the Plains indicates that they are unsuitable for ceramic use, a sample was taken in the Foothills near the most westerly extent of the outcrops to determine whether tectonic effects had changed the mineralogy of the sediments in comparison to a sample taken from the Plains.

The Eastend Formation is confined to the Cypress Hills area, where it comformably overlies the Bearpaw Formation. Gray, clayey sandstones, gray to dark-green silty shales and siltstones, black shale and coal beds are the characteristic lithologies.

In the Cypress Hills the white kaolinized sandstones and shales of the Whitemud Formation overlie the Eastend Formation. On the Plains, between Gleichen and Grande Prairie, the Whitemud Formation is more montmorillonitic and overlies the Horseshoe Canyon or Wapiti Formation. Conformably and abruptly overlying the Whitemud Formation are the dark brown to black montmorillonitic shales of the Battle Formation that extend over the same area as the Whitemud Formation.

In southwestern Alberta, the St. Mary River Formation is the age equivalent to the Eastend, Whitemud, and Battle Formations. This formation consists of a thick sequence of alternating sandstones and shales with a few thin coal beds.

The Willow Creek Formation overlies the Battle Formation on the Oldman River, the St. Mary River Formation elsewhere, and straddles the Cretaceous-Tertiary boundary. Sandstones and clays are soft, gray to maroon in color, and calcite is common. An erosional contact separates this formation from the overlying crossbedded, buff-weathering, gray sandstone with interbedded gray and dark gray clay shale of the Porcupine Hills Formation.

Near Nanton, the Willow Creek Formation passes laterally into the equivalent Paskapoo Formation, and farther north, near Airdrie, the Porcupine Hills Formation becomes indistinguishable from the underlying Paskapoo. The Paskapoo Formation is composed of gray and green siltstones and mudstones, sandstones, minor conglomerates, thin limestones, coals, and tuffs. Northwestward the Paskapoo is indistinguishable from the Brazeau Formation with its blocky, gray mudstones, sandstones, thin coal beds, and some tuffs.

The youngest materials sampled were lacustrine clays deposited during retreat of the Pleistocene glaciers. Two samples were taken from the "summer" and "winter" varves respectively of a calcareous clay. Although calcareous clays normally are rejected, interest in these particular clays was generated by a local attempt to use the clays for pottery.

Most of the rock units in Alberta that are considered potential sources of ceramic material were tested in this or in previous studies. Using the data presented in these publications, potential users will be able to determine which formations warrant further testing in their own laboratories.

SAMPLING

Samples for this report were taken from surface exposures of bedrock and surficial deposits within NTS map areas 72E; 73E, 74D and E; 82G, H, I, J, and P; 83A, F, L, and M; and 84C (Fig. 1). One hundred and eight samples of shale, mudstone, or clay were tested form 51 easily accessible locations. The relatively low market value of most ceramic products makes it imperative to obtain the raw materials as inexpensively as possible. Consequently, samples were taken from roadcuts, river cutbanks, open pit coal mines, or other excavations where it was possible to assess overburden thickness, clay thickness, access to transport, and the possibility of mining the clay in association with some other commodity such as coal or gravel.

TESTING

All samples were tested for refractoriness by determining the Pyrometric Cone Equivalent (P.C.E.) values. Two samples of Lea Park and one sample each of Wapiabi, McMurray, and Pleistocene material bloated so badly during P.C.E. firing that no further tests of these samples were performed. The remaining samples were analyzed to determine: clay mineralogy, plasticity, workability, extrudability, drying characteristics at room temperature and 150°C, linear drying and firing shrinkage, fired color at the point of steel hardness, firing range, 24 hour cool water absorption, and maximum recommended firing temperature. Maximum recommended firing temperature is determined from the shrinkage versus temperature curve plotted for each sample (Fig. 3); the temperature of maximum shrinkage was chosen as the maximum recommended firing temperature because higher temperatures cause bloating from overfiring. Firing range is considered to be the temperature range between the point of steel hardness and the maximum recommended firing temperature. The point of steel hardness is chosen as the lower end of the firing range because all commercial bodies are fired at least to this temperature so that the final product will not disintegrate during handling or use. The maximum recommended firing temperature is the temperature above which expansion begins at a predictable but unmanageable rate. Below this temperature firing shrinkage progresses at a predictable, manageable rate with temperature rise. In this report, a firing range of 5°C to 25°C is considered extremely short, 30°C to 50°C is short, 55°C to 100°C is moderate, and greater than 105°C is long.

Firing range, as defined in this report, should not be confused with vitrification range (Grimshaw, 1971), which is the temperature interval between the commencement of fusion and the loss of shape due to the production of a large amount of vitrified material. The highest

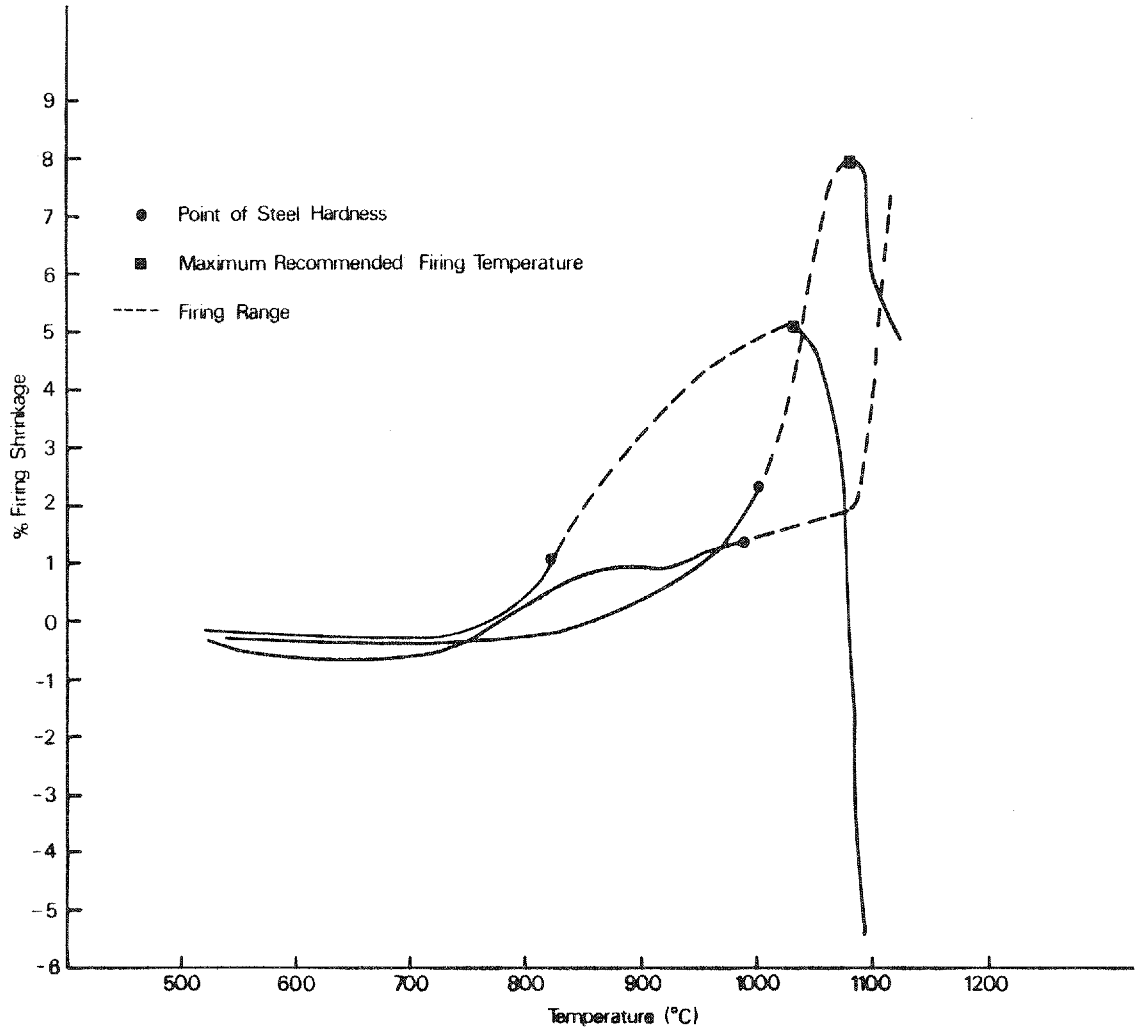


FIGURE 3. Representative percent firing shrinkage versus firing temperature curves

temperatures of each range should be similar, but vitrification can begin at temperatures as low as 450°C. Since all commercially produced bodies are fired at least to steel hardness, the temperature of steel hardness is considered the most practical and easily determined lower temperature point of reference for the potential user of the tested material.

Test data are grouped in the appendixes of this report by NTS map area as a convenience for future researchers wishing to use this information as part of a compilation to evaluate all resources of these map areas (Appendixes 1 to 6). Twenty three samples were chosen for chemical analysis and the results are given in Appendix 7.

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	1210-1330	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.	red and buffs	buffs and grays	variety

CLAY PRODUCT REQUIREMENTS

Typical requirements for structural clays and pottery clays are given in table 1. The most common method used in forming structural clay products is the "stiff mud extrusion process," for which good plasticity and workability are essential properties of the raw material, as is uniform drying without warping and cracking. Poor drying characteristics often can be improved by adding non-plastic material such as quartz sand or granular prefired clay, called "grog." Workability and fired color are the most important properties for pottery clays, with color particularly important for whitewares. Clays for pottery formed by throwing, jiggering, or slipcasting must have good plasticity, and the drying the firing shrinkage must be small enought to prevent warping and cracking. Firing ranges quoted in this report should overlap the maturing temperature values of clay products (Table 1) for which the clays may be used as raw materials.

The most important property to be considered in appraising refractory clays is refractoriness. Clays with P.C.E values from cone 15 to 29 (1430°C to 1660°C) are considered low heat duty refractory clays (A.S.T.M. Designation C27-70). Higher refractoriness designations exist but their quotation would be superfluous for the clays tested.

PROPERTIES OF THE GRINNELL FORMATION

The Grinnell Formation is one of eight formations of unmetamorphosed rocks of Precambrian age that form the Purcell Group in the Rocky Mountains of southwestern Alberta. The Purcell Group is exposed above the Lewis Fault, which thrusts Precambrian rocks over those of Cretaceous age.

The Grinnell Formation is composed mainly of bright red argillite, white and light green quartzite with zones of red argillite-pebble conglomerate, and red siltstone and quartzite (Price, 1965). Upper and lower contacts are gradational. Where sampled in the Beaver Miles map area, the formation attains a thickness of 230 m (Hage, 1943).

One sample of the red argillite that is interbedded with white quartzite was taken along Drywood Creek south of Pecten, in map area 82G. The data for that sample are listed in Appendix 4. The constant quest for red-burning clays prompted collection of the sample even though beneficiation of the material would be necessary to remove the quartzite.

With 15 percent tempering water, the material has poor plasticity and fair working properties. Bars dry well at room and elevated temperature but are very fragile until fired. The fired color is pale reddish-brown at steel hardness and grayish-red at maximum recommended firing temperature. Firing range is moderate and fired shrinkage is only 4 percent. Perhaps because the white quartzite is difficult to remove, this argillite does not burn as red as one would expect from field observations. The need to beneficiate, poor plastic properties, and distance from manufacturing complexes make this argillite undesirable as a source for ceramic raw material.

PROPERTIES OF THE SIYEH FORMATION

The Siyeh Formation overlies the Grinnell Formation and has a similar areal extent. Three lithostratigraphic units are recognizable in the formation. The lower unit, about 10 m thick, consists or green and black argillite with interbeds of green and gray argillaceous and arenaceous dolomite. The middle unit is approximately 300 m thick and is composed of fine-crystalline, thin-bedded, gray dolomite with thin interbeds of gray and black argillite, dolomitic sandstone and quartzite. The upper unit, which has a sharp upper contact with lava, is 30 m thick and consists of light green argillite and dolomitic argillite with a zone of red, mud-cracked argillite on top.

One sample of dark gray argillite was collected along Drywood Creek in map area 82G, not far from where the Grinnell Formation was sampled. Unfired and fired characteristics are listed in Appendix 4. Poor plastic and fair working properties are obtained with 15 percent tempering water. Bars dry well at both room and elevated temperatures and drying shrinkage is only 1 percent. Fired color is grayish-yellow for both steel hard and maximum fire. Absorption at maximum fire is very low (0.4 percent), fired shrinkage is high (14.7 percent) and the firing range is extremely short. Although the argillite does not appear to contain carbonate when tested in the field, the fired color and extremely short firing range suggests that dolomite is present in the material. This material is of little value for ceramic use.

PROPERTIES OF BASAL CLAYS OF THE MCMURRAY FORMATION

The McMurray Formation, primarily exposed along the Athabasca and Clearwater Rivers in the vicinity of Fort McMurray, is best known for its impregnation with bitumen. The formation consists of a complexly interbedded sequence of sandstones, siltstones, mudstones, and thin coals. The lower contact often is sharp with the underlying limestone of Devonian age. In some topographic lows on the surface of the Devonian limestone, the stratigraphic interval between the base of the oil "pay-zone" and the underlying limestone can be divided into two recognizable units. These are (1) a unit of interbedded oil-bearing sand, silt, and clay, commonly overlying (2) a unit of lenticular beds of oil-free clay and sand. Thickness of the interbedded zone varies from 1.5 to 15 m and of the underlying zone of clay and sand from zero to 15 m. The clays from the oil-free zone are dark brownish-gray to black,

Table 2. General Characteristics of Samples from the McMurray Formation Basal Clays

Description	PCE	Unfired Characteristics: Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
Various shades of light gray to black clay, non-calcareous, massive to thinly laminated, minor silt	8-30 15 average	17	fair-excellent	fair-good	good, minor warp	good, minor cracks	5.3

Fired Characteristics: Steel Hard: Color	Steel Hard: Temperature (°C)	Steel Hard: Absorption (%)	Maximum Fire: Color	Maximum Fire: Temperature (°C)	Maximum Fire: Absorption (%)	Maximum Fire: Shrinkage (%)	Remarks
Light shades of brown or yellow	1045 (cone 05)	5.1	Light to moderate shades of brown	1145 (cone 02)	1.6	5.3	moderate-long firing range, usually extrudes well

slickensided materials that often contain lignite or are light to dark gray, noncalcareous, poorly laminated clays. The clays from this lower zone are of interest for their ceramic and engineering properties and have been called "basal clays" (Scafe, 1977; Dusseault and Scafe, 1979).

Ten samples from map areas 74D and E were collected subsequent to those reported on by Scafe (1977). Table 2 summarizes the data from Appendix 3 for these succeeding samples. The three most refractory clays have P.C.E. values of 20, 27 and 30; most other samples tested in this series have values of 15 or less. With 17 percent tempering water, plasticity ranges from fair to excellent and working properties range from fair to good. Drying behaviour is good at room and at elevated temperatures, with only minor warping at room temperature and minor cracking at elevated temperatures. The average temperature at which bars reach steel hardness is 1045°C (cone 05). Light shades of brown are the most common colors at this temperature, changing slightly to moderate shades of brown at the maximum recommended firing temperature. Absorption at this temperature averages 1.6 percent and fired shrinkage and temperature versus absorption are shown in figure 4.

The average maximum recommended firing temperature of 1145°C (cone 02) would disqualify these materials for use in the production

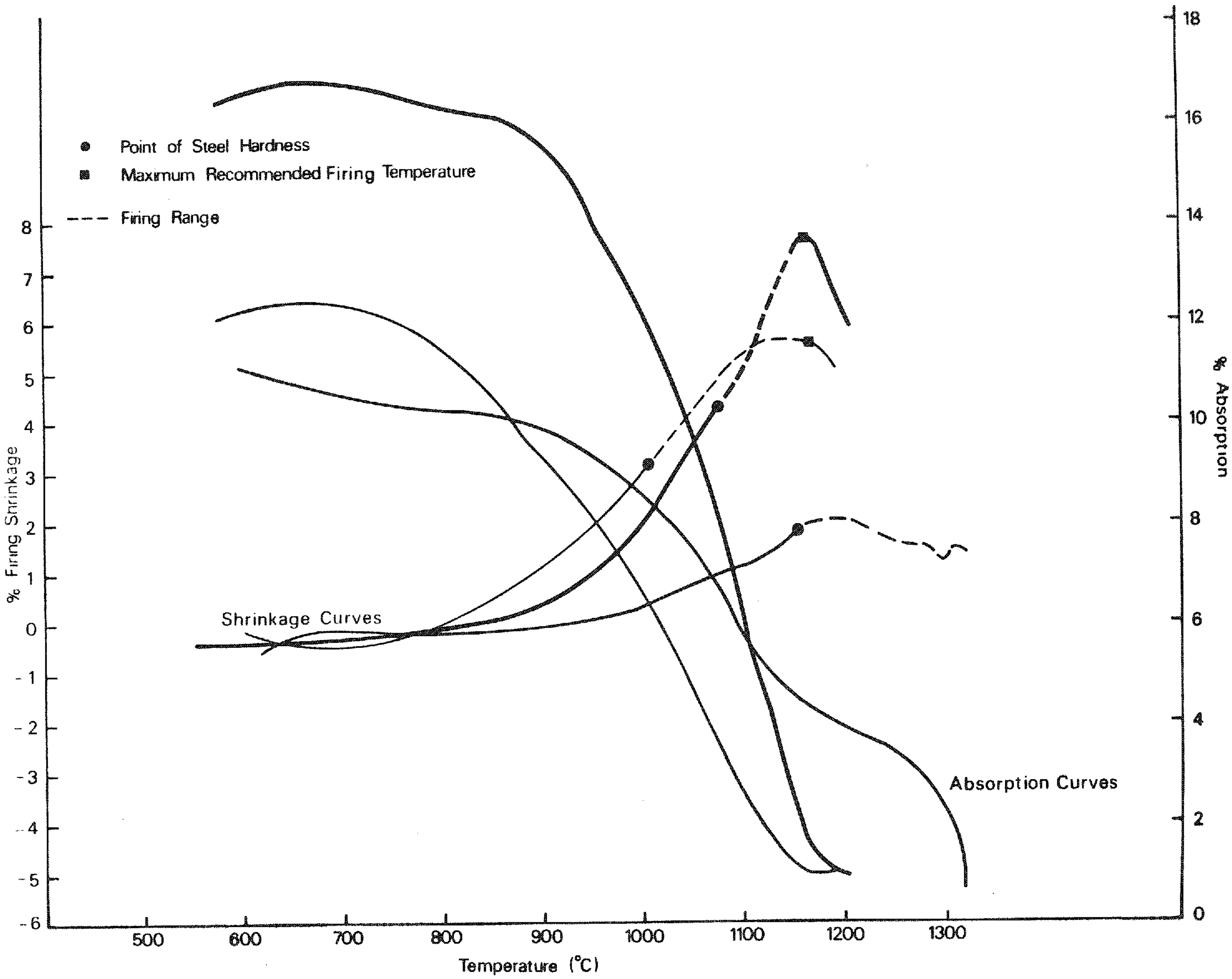


FIGURE 4. Typical temperature versus shrinkage and temperature versus absorption curves for McMurray Formation basal clays

of stoneware, which has a recommended vitrification range between cones 4 and 10 (1210°C to 1330°C) with 8 (1300°C) as the desired maturation temperature (Klinefelter and Hamlin, 1957). Clays with P.C.E values from cone 15 to 29 (1430°C to 1660°C) are considered low heat duty refractory clays (ASTM Designation C27-70); therefore, the most refractory clays tested could be used to produce low heat duty refractories, if care is taken to reject the low refractory material present. By eliminating material that bloats during firing (Appendix 3) little difficulty should be encountered with these clays for use in structural clay products or pottery. Since no sample fires to a white color, these materials cannot be used for the production of whitewares; however, items that will be covered with colored glazes should not encounter problems.

PROPERTIES OF THE LUSCAR FORMATION

In the Rocky Mountains and Foothills of west-central Alberta, the lower part of the Luscar Formation is the age equivalent to the McMurray Formation of the northeast Plains. The Luscar Formation extends northwest from the Red Deer River to the British Columbia border. Ceramic data from samples in the Nordegg area were reported by Scafe (1978) and the present report contains data from samples in the Cadomin-Luscar area and the Grande Cache area. Typical beds are fine to coarse-grained, gray and brown, buff and gray weathering sandstone and argillaceous sandstone, gray, greenish-gray, and dark gray shale, minor amounts of yellow weathering, concretionary ironstone associated with both shale and sandstone, and coal seams that range in thickness from 15 cm to 9 m. Lateral variations in lithology occur within relatively short distances in these nonmarine sandstones and shales but the general character of the sediments is maintained over a wide area (Irish, 1965). Maximum thickness of the formation is 670 m.

Data given by Scafe (1978) for samples from thin shale beds of Luscar Formation in the Nordegg area indicate that the material could have potential for producing an appealing chocolate colored brick after firing through a moderate firing range. Unfortunately, data from samples further north do not allow such a favorable recommendation. As shown in table 3, plasticity and working properties vary from nonexistent to only fair, which makes the material difficult or impossible to extrude and produces bars that are fragile before firing. Some samples did not reach steel hardness before firing was completed. With other samples, maximum recommended firing temperature coincides with the temperature for steel hardness (Appendix 5, Fig.5). Short or extremely short firing ranges are much more common than moderate or long firing ranges. Fired colors seldom are the appealing dark chocolate brown obtained from more southern samples. The lack of plasticity, poor fired colors, and short firing ranges make these more northern materials unappealing for ceramic use.

Table 3. General Characteristics of Samples from the Luscar Formation

Description	PCE	Tempering Water (%)	Plasticity	Working Properties	Unfired Characteristics: Drying Behavior: Room Temperature	150°C	Drying Shrinkage (%)
olive gray mudstones and shales, organic impressions common, calcareous to non-calcareous, nonsilty to minor silt	6	14	none-fair	none-fair	good	good	2.3

Fired Characteristics: Steel Hard: Color	Temperature (°C)	Absorption (%)	Maximum Fire: Color	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
pale to moderate brown	1080 (cone 04-05)	7.8	pale to moderate brown	1130 (cone 03)	2.5	5.9	hard to extrude, short firing range

PROPERTIES OF THE SHAFTESBURY FORMATION

Covering a significant area of northwestern and north-central Alberta and well exposed along the Smoky and Peace Rivers are the marine shale and silty shale beds of the Shaftesbury Formation. This formation, which straddles the time boundary between Early and Late Cretaceous, can be divided into two members. The lower member consists of soft, black, fissile shale, which upon weathering forms an abundant pale yellow or whitish, powdery efflorescence on outcrop surfaces. The upper member consists of soft, dark gray fissile to blocky shale containing scattered siltstone beds a few tens of centimeters thick (Green and Mellon, 1962). From a maximum thickness of 488 m, the formation thins to the west, south and east and is transitional into the overlying Dunvegan Formation (Green and Mellon, 1962; Jones, 1966).

Three samples of the Shaftesbury Formation were collected from the river valley south of Peace River town. Two samples are from the lower member and one sample is from the upper member. Test data are given in Appendix 6 for map area 84C.

Plasticity and working properties are fair to very good with 20 to 25 percent tempering water. Minor warping occurs during drying at room

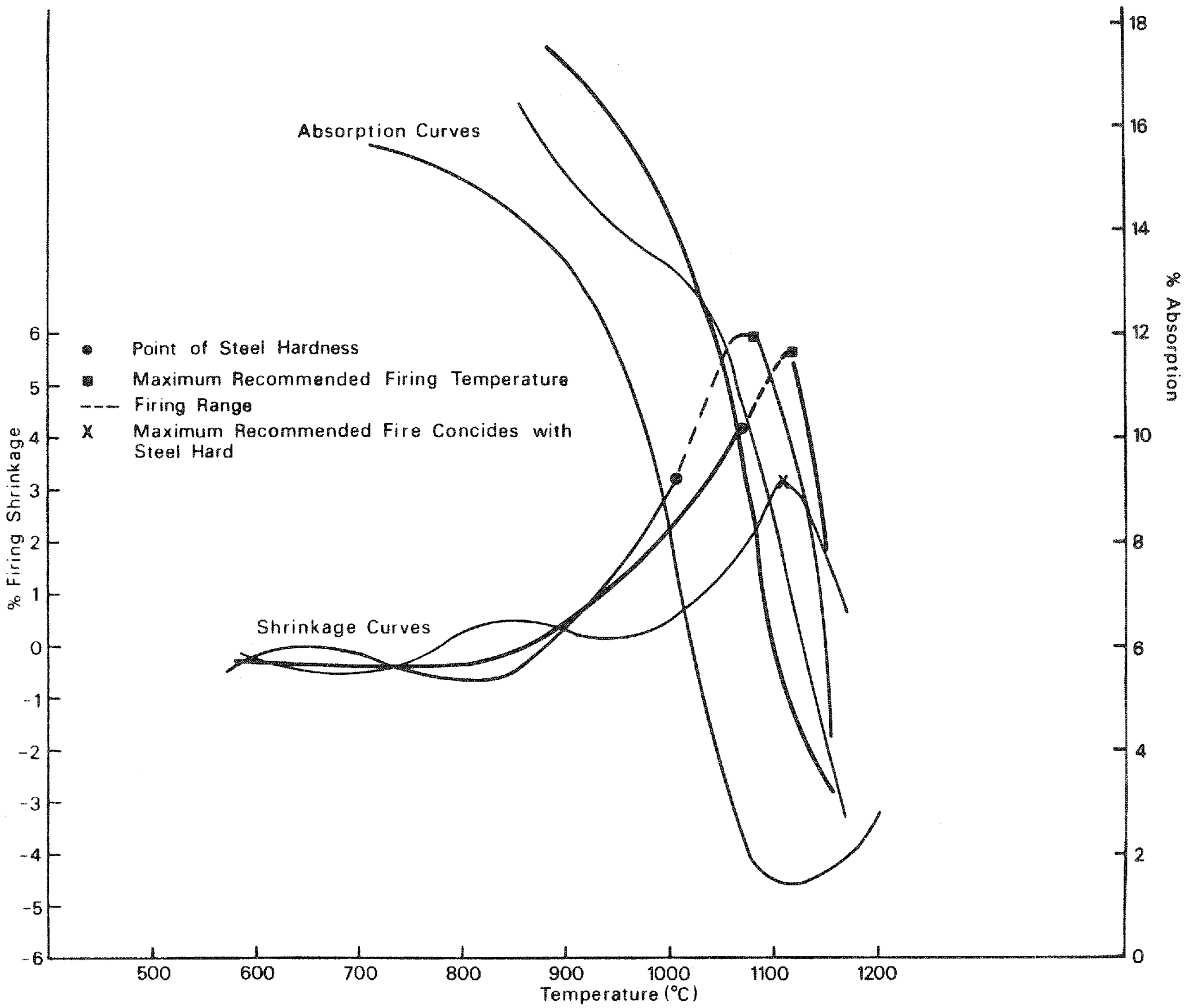


FIGURE 5. Typical temperature versys shrinkage and temperature versus absorption curves for Luscar Formation clays

temperature. Drying at elevated temperature is good but minor cracks can develop. Average drying shrinkage is 7.4 percent. At steel hardness samples from the lower member are reddish-orange or reddish brown and the sample from the upper member is light brown. Steel hard temperature averages 1055°C (cone 05). Color at maximum recommended firing temperature is moderate reddish-brown for the lower member samples and moderate brown for the upper member sample. At the average maximum recommended firing temperature of 1110°C (cone 04), absorption averages 1.5 percent and fired shrinkage averages 10.9 percent. Because extruded bars developed long, deep cracks or exploded in the furnace during firing, bars had to be hand molded in order to collect complete firing data. Unless this material is modified by the addition of clay, grog, or quartz, extruded bodies will be difficult to fire although pressed bodies, with their more open texture, might be fired successfully. The moderate reddish-brown color attained at maximum recommended firing temperature probably would be acceptable for brick manufacturing and would be of little consequence for pottery finished with colored glazes.

PROPERTIES OF THE FORT ST. JOHN GROUP

In the northwestern Rocky Mountains and Foothills, there are some dark gray, rubbly to platy shales, rusty weathering and with some argillaceous siltstones, that are stratigraphically equivalent to the Shaftesbury shales. These rocks are referred to in this area as the Fort St. John Group (Stott, 1963; Irish, 1965) and they grade upward, over an interval of 6 m into the shales, siltstones, and sandstones of the Dunvegan Formation. Total thickness of the unit is 150 m.

Only one sample of the Fort St. John Group shales was taken. The data for this sample, from the Grande Cache area, are in Appendix 5 (map sheet 83L). Fair plasticity and working properties are attained with 17 percent tempering water. Bars extrude and dry well. Drying shrinkage is 4.4 percent. At the steel hard temperature of 1030°C (cone 06), the color of the material is light brown with a pink cast. At the maximum recommended firing temperature of 1120°C (cone 04-03), the material is moderate (milk chocolate) brown, absorption is only 0.6 percent and fired shrinkage is 6.8 percent. Siltstone stringers noted at the outcrop may provide too much diluent unless some of it can be removed, but the good drying properties, moderate firing range and low absorption shown by this single sample suggests that further testing may be warranted.

PROPERTIES OF THE DUNVEGAN FORMATION

Extending from just north of the Athabasca River to the British Columbia border in the Foothills and on either side of the Peace River from the British Columbia border through about one-third of the river's length in Alberta are rocks of the Lower Cretaceous Dunvegan Formation. The formation is up to 310 m thick and is composed of light gray, fine-grained, feldspathic sandstone, thick, grayish-green, nonmarine, carbonaceous shale, dark gray, marine shale, and rare, thin coal seams (Stott, 1963). Upper and lower boundaries are transitional.

Two samples of shale were collected in map area 83M at Dunvegan Crossing, the type section for this formation. The test data are listed in Appendix 5. With 20 percent tempering water, plasticity and working properties are good. Bars tend to warp when dried at room temperature and to crack when dried at elevated temperature. Both extruded samples bloated so badly on firing that firing data could not be determined and it was possible to obtain firing data from only one sample after hand molding. Firing range is short, fired color is moderate (milk chocolate) brown, absorption at maximum recommended firing temperature is 1.1 percent, and fired shrinkage is 8.2 percent.

Shales have a maximum thickness of 15 m but do not constitute a large volume of the Dunvegan Formation at readily accessible locations, and this in combination with the poor drying and poorer firing characteristics suggest that the formation is not of much value for the ceramic industry.

PROPERTIES OF THE KASKAPAU FORMATION

Sediments of the Kaskapau Formation overlie the Dunvegan Formation conformably and gradationally and have a similar geographical distribution. The sediments consist of dark gray marine shales, fissile to thin bedded and in part silty, with numerous interbedded, thin, hard, gray, buff to yellow weathering, concretionary ironstone beds (Irish, 1965). These easily weathered shales generally are expressed in the topography by broad valleys with gentle, commonly grass-covered slopes above small canyons carved by Recent streams. Maximum thickness of the formation is 460 m (Stott, 1963).

Three samples of shale from the Kaskapau Formation were sampled from map areas 83L and 83M and the data are given in Appendix 5. With 17 percent tempering water, plasticity and working properties are fair

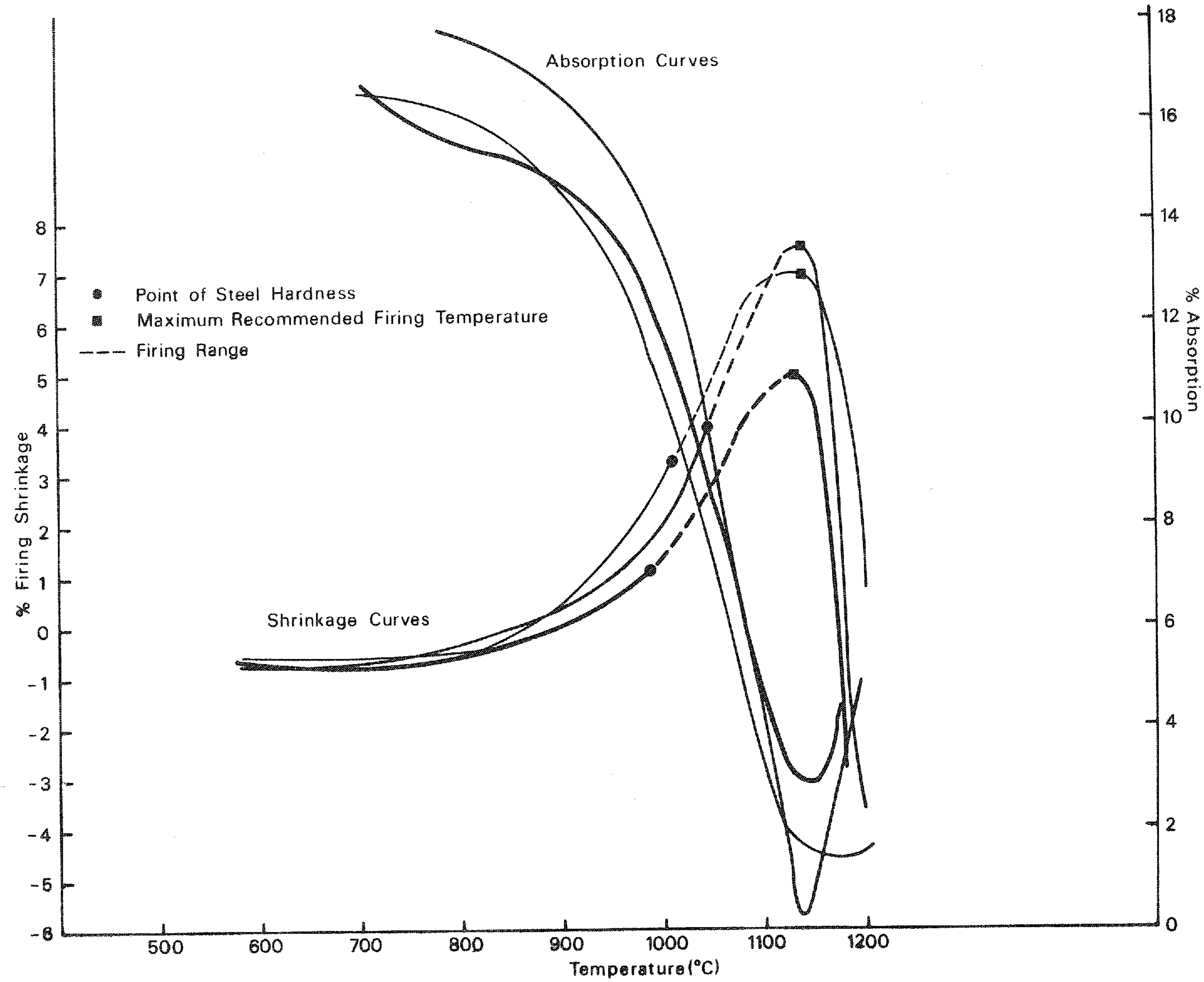


FIGURE 6. Typical temperature versus shrinkage and temperature versus absorption curves for Kaskapau Formation clays

to good. The material dries well but can show minor warping. Average drying shrinkage is 4.9 percent. Fired color at steel hardness is light brown with a pink cast. Average temperature for steel hardness is 1020°C (cone 06). Color at the maximum recommended firing temperature of 1140°C (cone 03-02) is moderate (milk chocolate) brown. Average absorption at maximum recommended firing temperature is 1.6 percent and average fired shrinkage is 6.5 percent. Unlike a sample tested previously from the Kaskapau Formation that shows a short firing range (Scafe, 1978), these samples have moderate or long firing ranges (Fig. 6). The moderate (milk chocolate) brown color at higher firing temperatures would be of no consequence in structural clay products, other than face bricks, or in pottery covered with colored glazes. The "earth color" of unglazed fired pottery ware also should be acceptable. Unlike most marine sediments in Alberta, shales from the Kaskapau Formation seem to show potential for ceramic use. Further testing would be useful.

PROPERTIES OF THE BLACKSTONE FORMATION

Extending northward from the Castle River in the southern Rocky Mountains and Foothills, rocks that are age equivalent to the combined Shaftesbury, Dunvegan, and Kaskapau Formations are called the Blackstone Formation. This formation is the lower of three units that form the Alberta Group in the south-central Rocky Mountains and Foothills (Fig. 2). It consists of a succession of marine shales and siltstones with some beds of dolomitic limestone, sandstone, bentonite, and ironstone concretions (Stott et al., 1968). The lower boundary is a well-defined disconformity and the upper boundary is transitional into the Cardium Formation sandstone. The formation thickens from southeast to northwest to a maximum thickness of 530 m. Four members are recognized (Stott, 1963) and are named, from lowest to highest, Sunkay, Vimy, Haven, and Opabin. Three of the four members (Sunkay, Vimy, Haven) were sampled for this study.

The Sunkay member is composed of noncalcareous, rusty weathering, fissile to platy shales, coarse-grained sandstones, and siltstones. The Vimy member is composed of silver-gray weathering, fissile to platy, calcareous shales, and yellow to buff weathering, argillaceous dolomite. The Haven member consists of dark gray to grayish-black shales containing abundant organic matter, thinly bedded siltstone, and a few large, buff to yellow weathering limestone concretions. The basal part of the Opabin member consists of dark gray, blocky shale or mudstone rich in organic matter, and the upper part contains considerable quantities of massive, argillaceous siltstone and some sandstone.

A total of five samples were collected of the Blackstone shale in map areas 82G and 83F, and data for these samples are listed in

Appendixes 4 and 5. A sample from the Haven member has a P.C.E. of 12, but 6 is a more common value for the other members sampled. With 15 percent tempering water, plasticity and working properties generally are poor to fair, although the sample from the Haven member has a very good plasticity and working properties. All samples dry well and maximum drying shrinkage is 4.6 percent.

It was possible to fire only the samples from the Sunkay and Haven members to completion. For the three other samples, either steel hardness was not reached before firing was terminated (to protect the furnace as the P.C.E. value was approached), or the bars curved so badly that the firing was terminated to protect the furnace from a bar sticking to the muffle. Both the Sunkay and Haven member samples fired to moderate (milk chocolate) brown after moderate and long firing ranges respectively. At maximum recommended firing temperature (1125°C, cone 03), absorption for the Haven member sample is 0.7 percent and firing shrinkage is 5.5 percent. For the Sunkay member, absorption is 2.1 percent and shrinkage is 6.8 percent at maximum recommended firing temperature (1105°C, cone 04). The absence of carbonate in the Sunkay and Haven member samples probably contributes most to their superiority over other samples from the Blackstone Formation.

The moderate to long firing range (Fig. 7), good drying characteristics, low absorption and firing shrinkage would make material from these members useful in pottery or structural clay products.

PROPERTIES OF THE CARDIUM FORMATION

A formation that is recognized everywhere in Alberta except the northeast Plains, the Cardium Formation is characterized by sandstones but does contain both marine and nonmarine shales. Six members are recognized in the formation (Stott, 1963) but only the Moosehound Member (2nd from top) was encountered and sampled in this study. This member, recognized in outcrop from the Muskeg River near Grande Cache southward to the North Saskatchewan River, is thick (40 m) in the north and along the Front Range, but thins eastward. Along the Front Range, it consists of greenish to brownish rubbly shale with beds

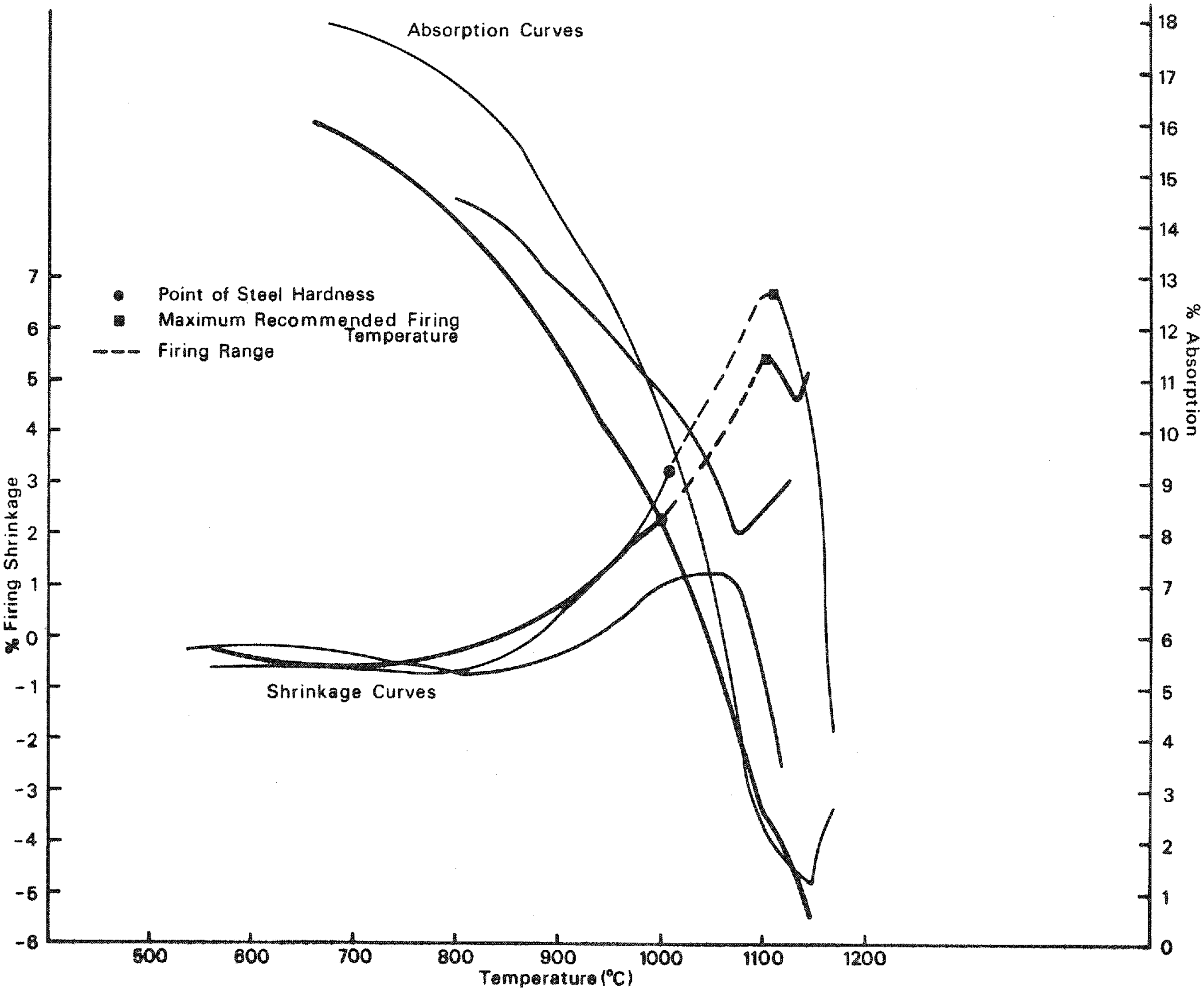


FIGURE 7. Typical temperature versus shrinkage and temperature versus absorption curves for Blackstone Formation clays

of carbonaceous sandstone. The shales are generally soft and crumbly and contain nonmarine invertebrate fossils.

One sample from the Moosehound Member was collected in map area 83F and the data for this sample are in Appendix 5. With 14 percent tempering, water plasticity is fair, working properties are good, but the member is difficult to extrude. Drying properties are good and drying shrinkage is 3.6 percent. At the temperature of steel hardness (1010°C, cone 07) the bars are a light brown color and absorption is 0.6 percent. At the maximum recommended firing temperature (1100°C, cone 04), the color is a pleasant moderate reddish-brown, absorption is 3.2 percent, and shrinkage is 6.4 percent. The moderate firing range, reddish fired color, low shrinkage and acceptable absorption suggest that further testing of material from this member is warranted.

PROPERTIES OF THE WAPIABI FORMATION

The Wapiabi Formation is the upper of three units that form the Alberta Group in the south-central Rocky Mountains and Foothills and the Smoky Group in the northern Rocky Mountains and Foothills. The formation outcrops in the Front Ranges from the International to the British Columbia boundary and extends east beneath the Plains. Maximum thickness is 655 m (Stott, 1963) and only a slight disconformity separates it from the underlying Cardium Formation.

The predominantly dark gray, soft, fissile to rubbly and platy shales do not outcrop well (Irish, 1965). Interbedded with the shales are dark gray siltstones, minor amounts of fine-grained sandstone and bands or individual concretionary bodies of ironstone.

None of the three samples collected from the Wapiabi Formation is of value for ceramic purposes. The P.C.E. cones of one sample bloated so badly that no further testing was warranted, steel hardness never was reached for the second sample, and the third sample had a firing range of only 25^{o}C.

PROPERTIES OF THE PAKOWKI FORMATION

In southern Alberta, the Pakowki Formation is well exposed in the eastern Milk River valley and continues in an arc to the International Boundary west of Coutts. The formation consists of dark gray, marine shale and sandy shale with some interbedded, thin, gray sandstones and irregular zones of fossiliferous ironstone concretions. Maximum thickness is 275 m. The base of the formation is marked by a chert-pebble conglomerate 15 to 30 cm thick (Russell and Landes, 1940).

With 22 percent tempering water, plasticity is fair to good and working properties are good in the five samples taken from map area 72E (Appendix 1). Bars warp when dried at room temperature and crack when dried at elevated temperatures. Average drying shrinkage is 8.7 percent. The common color at steel hardness is light brown. Steel hardness temperatures vary from 975°C to 1115°C (cone 08-04) and absorption varies from 2 to 11.3 percent. Color at maximum recommended firing temperature is moderate brown, maximum recommended firing temperature varies from 1080°C to 1120°C (cone 05-03), absorption averages 1.6 percent and firing shrinkage averages 7.9 percent. Firing ranges extend from zero to moderate, drying properties are poor, extrusion is difficult, and soft white blebs often are present on fired bars. Material from this formation is of little value for ceramic purposes unless it is mixed with ameliorating material.

PROPERTIES OF THE LEA PARK FORMATION

The upper part of the Lea Park Formation in central and eastern Alberta is age equivalent to the Pakowki Formation of the southern Plains. The formation is a uniform series of marine, gray, silty shales with local intercalations of sandy shale, ironstone concretionary bands and bentonite (Shaw and Harding, 1954). Thickness is 137 to 247 m, increasing northeastward. The lower boundary is at the top of the "First White Speckled Shale" zone of the Colorado Group marine shales and the upper boundary is gradational into the sands of the Judith River Formation. The Judith River Formation formerly was called the Belly River Formation in this area (McLean, 1977).

Five samples from the upper part of the formation were taken in map area 73E (Appendix 2). However, two of these samples bloated so badly during P.C.E testing that they were not tested further. With 23 percent tempering water, the three other samples have good plasticity and good working properties. Extruded bars warp when dried at room temperature and crack badly when dried at elevated temperatures. Drying shrinkage averages 8.4 percent. To obtain bars for firing that did not warp or crack on drying, hand molded bars were made. One sample bloated so badly on firing that it was discarded, and firing data are available from only two samples. Color at steel hardness is light to moderate brown and absorption averages 5.9 percent. Color at maximum recommended firing temperature is moderate brown, absorption is 2.7 percent and average firing shrinkage is 7.4 percent. Firing range is extremely short to short. It is unlikely that material from this formation could be used for any ceramic purpose.

PROPERTIES OF THE JUDITH RIVER FORMATION

Stratigraphically above and underlying a large area geographically north of the outcrop limits of the Pakowki Formation in southern Alberta are rocks of the Judith River Formation that formerly were the Foremost Formation (McLean, 1977). The upper and lower contacts are gradational (Irish, 1967), the sediments are nonmarine and up to 80 m thick (Russell and Landes, 1940). Ironstone beds are common within interbedded green and gray shales, dark gray carbonaceous shales, gray siltstones, and gray to pale brown sandstones. In some places the carbonaceous shales grade into coal seams.

The most common P.C.E value for the Foremost shales is 4. With 19 percent tempering water, plasticity varies from fair to very good, and working properties vary from poor to very good. Bars warp on drying at room temperature and usually crack when dried at elevated temperature. Drying shrinkage averages 7.6 percent. Of the six samples tested (Appendixes 1 and 4), one sample had no bars survive drying, bars disintegrated before steel hardness was reached for another, and bars cracked just beyond the point at which steel hardness was reached for two others. For the two samples that survived firing, steel hardness color is light to moderate brown, steel hardness temperature is 1040°C to 1050°C (cone 05), and absorption is 7 to 8 percent. Firing range is short to moderate, absorption ranges from 0.9 to 4 percent, and firing shrinkage ranges from 2.5 to 8.2 percent.

The extremely poor drying and firing characteristics of material from this section of the Judith River Formation make it of no value for ceramic purposes.

Rocks of the Judith River Formation that formerly were called the Oldman Formation (McLean, 1977) are present in a horse shoe-shaped area, with one limb extending from the International Boundary through Lethbridge, Brooks, and Empress and the other limb extending from the International Boundary through Medicine Hat to Empress. Outcrops of these rocks along the Red Deer River form the badlands of Dinosaur Provincial Park. Typical rocks in the 180 m thick sequence are light colored, with greenish-gray the dominant tone as seen from a distance (Russell and Landes, 1940). Sediments are interbedded and interlensed green, gray and light gray shale, silty shale, soft gray and light gray weathering argillaceous sandstone (Irish, 1967). Coal seams are confined to the Lethbridge coal member at the top of the sequence.

With 20 percent tempering water plasticity is good to excellent and working properties are fair to very good (Appendixes 1 and 4). Warping of bars is common during drying at room temperature and cracking is usual during drying at elevated temperature. Drying shrinkage averages 8.5 percent. One sample was impossible to fire because bars warped too severely during drying even after hand molding. Color at steel hardness is light to moderate brown and is reached near 1070°C (cone 05). Absorption at steel hardness averages 7.8 percent. Maximum recommended firing temperature is 1100°C (cone 07), color is moderate brown, absorption averages 2.1 percent, and firing shrinkage averages 3.5 percent. Ameliorating material, to compensate for the poor drying properties and short firing ranges, is added to clays from this section of the Judith River Formation before use in the production of pressed bricks in Redcliff.

PROPERTIES OF THE BEARPAW FORMATION

The almost exclusively marine shales of the Bearpaw Formation extend in a long arc from the International Boundary near Del Bonita to as far north as Edmonton. This arc widens to touch the Saskatchewan border east of Oyen. The formation surrounds the Cypress Hills and is present north of Irvine. An outlier is present in the Foothills north of Lundbreck on the Crowsnest River. The rocks are dark gray or brownish-gray shales that tend to weather into small angular fragments with rusty stains (Russell and Landes, 1940). Spheriodal ironstone concretions are present in irregular zones and thin bentonite beds have wide lateral persistence. Maximum thickness of the formation is 260 m (Irish, 1967).

These shales are known to have a high montmorillonite content, so only two samples were tested from this formation. One sample was collected from the outlier on the Crowsnest River in the Foothills (map area 82G) to determine whether tectonic forces associated with mountain building may have changed the ceramic characteristics of the shales. The second sample, from near Del Bonita on the Plains (map area 82H), should be unaffected by tectonic forces. As shown in Appendix 4, there are some differences in characteristics of the two samples. The P.C.E. of the Foothills sample is 8 whereas it is 5 for the Plains sample. The Foothills sample requires 19 percent tempering water to produce fair plasticity and good working properties, and the Plains sample requires 23 percent tempering water to give good plasticity and fair working properties. The Foothills sample dries well at room temperature but minor cracking is caused by drying at elevated temperatures. Drying shrinkage is 7 percent for the Foothills sample and 8.4 percent for the Plains sample.

At steel hardness temperature (Fig. 8), absorption is higher (9.3 percent) for the Foothills sample than for the Plains sample (7.2 percent). However, steel hardness temperature is considerably lower (925°C, cone 08). Maximum recommended firing temperature is similar for the two samples, at 1050°C (Foothills) and 1040°C (Plains). Absorption and firing shrinkage for the Foothills sample are 0.8 percent and 6.9 percent whereas the values for the Plains sample are 1.2 and 8.4 percent.

An undesirable characteristic shown by the Foothills sample is the tendency for bars to curl upward at the hot end. However, this tendency may be due to overfiring and could be reduced by not exceeding the maximum recommended firing temperature. Addition of small amounts of ameliorating material also would be beneficial. In addition to the warping and cracking on drying of the Plains sample, a large crack is present parallel to the base of the bar at the hot end. This cracking may be corrected in similar ways to those suggested for the Foothills sample. The Foothills material is superior to the Plains material in these limited tests and the long firing range and reasonable drying characteristics suggest that further testing of this Foothills material may be worthwhile.

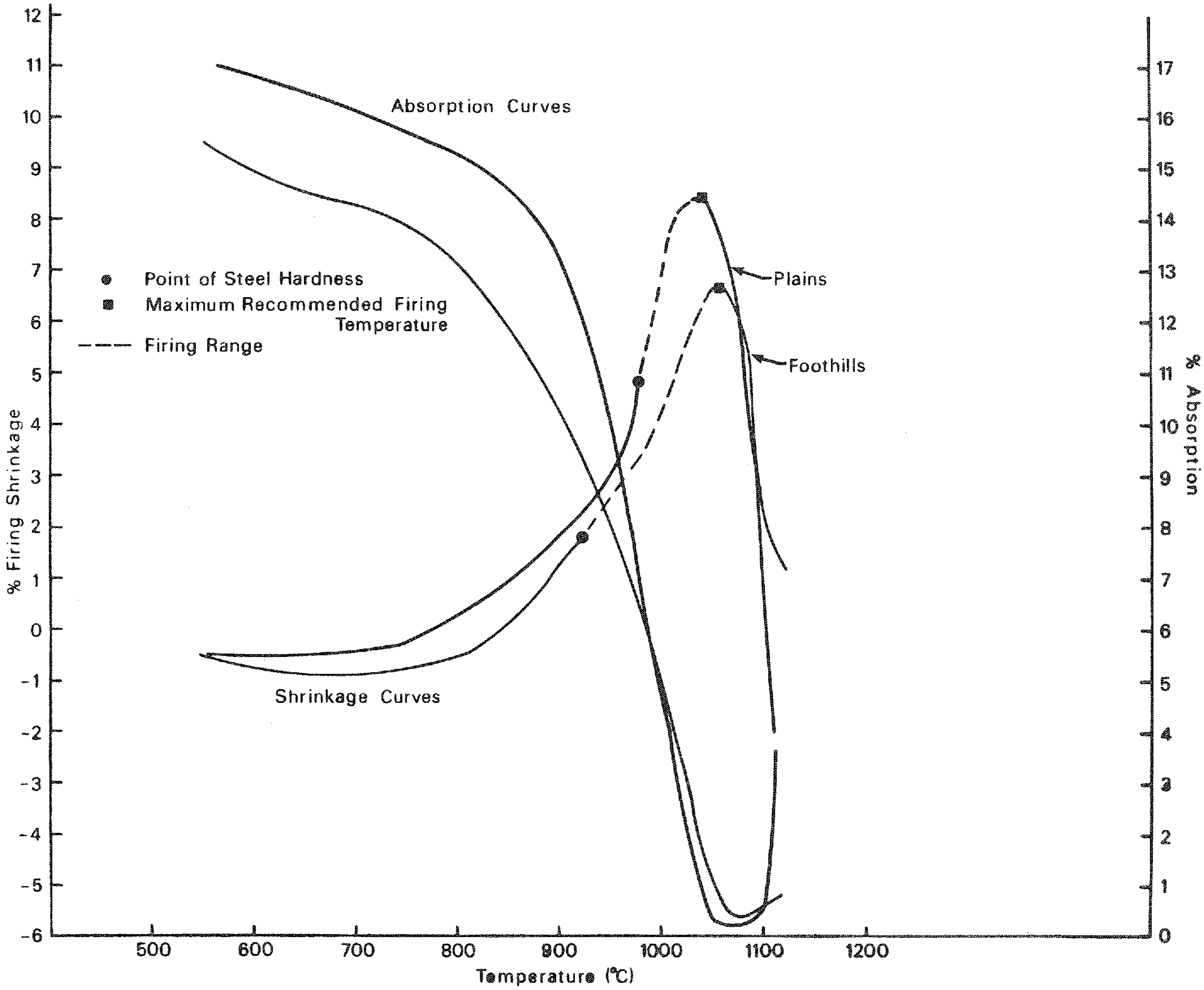


FIGURE 8. Typical temperature versus shrinkage and temperature versus absorption curves for Bearpaw Formation clays

PROPERTIES OF THE EASTEND FORMATION

Confined to the Cypress Hills area of Alberta and occupying a belt at the foot of the main escarpment are the sediments of the Eastend Formation. Outcrops are not common because the sands, silts, and soft shales tend to form gentle slopes covered with soil and vegetation (Lindoe, 1965). Maximum thickness is 100 m and sediments change from marine at the base to nonmarine at the top (Irish, 1967). Sediments above the coal seam 21 m from the top of the formation are feldspathic sands, silty sands, and minor silty shales. An upper shale is mined for use in the manufacture of red face brick (Lindoe, 1965).

One sample of clayey silt considered to be from the Eastend Formation was sampled in the floor of I-XL Quarry 34, northeast of Fly Lake in map area 72E (Appendix 1). With 18 percent tempering water, plasticity is fair and working properties are good. Drying properties are good at room and elevated temperatures and drying shrinkage is 3.5 percent. Steel hardness is reached at 1100°C (cone 04), color is moderate brown and absorption is 10.8 percent. Maximum recommended firing temperature is 1175°C (cone 01), color is an appealing chocolate brown, absorption is 1.3 percent, and firing shrinkage is 8.2 percent. The bars curl on firing but this deficiency could be corrected easily with grog or quartz additions. This material is used for ceramic purposes at present.

PROPERTIES OF THE WHITEMUD FORMATION

In Alberta the economically important portions of the Whitemud Formation lie above the sediments of the Eastend Formation around the Cypress Hills. Between Gleichen and Grande Prairie equivalent beds occur above the Horseshoe Canyon Formation, but so far these beds are not of economic importance. Whitemud Formation sediments are nonmarine, white-weathering, fine- to medium-grained, feldspathic, argillaceous sandstone, white to cream-weathering, gray, white, and pale green clays and silty clays (Irish, 1967). Maximum thickness is 8 m.

Studies of the ceramic properties of the Whitemud Formation in Alberta and Saskatchewan have tended to be performed near areas where the formation already is quarried for the concentrations of higher quality clays, and Lindoe (1965) points out that data from these reports tend to give a false impression of the quality of most clays in the formation. He believes that typical Whitemud deposits are of low quality and too high in sand for ceramic use. Results of the tests published by Crockford (1951) on samples from many outcrops of Whitemud Formation material in the Cypress Hills area support this belief.

Three samples of Whitemud Formation were taken from a face in I-XL Quarry 34 northeast of Fly Lake in map area 72E and one sample

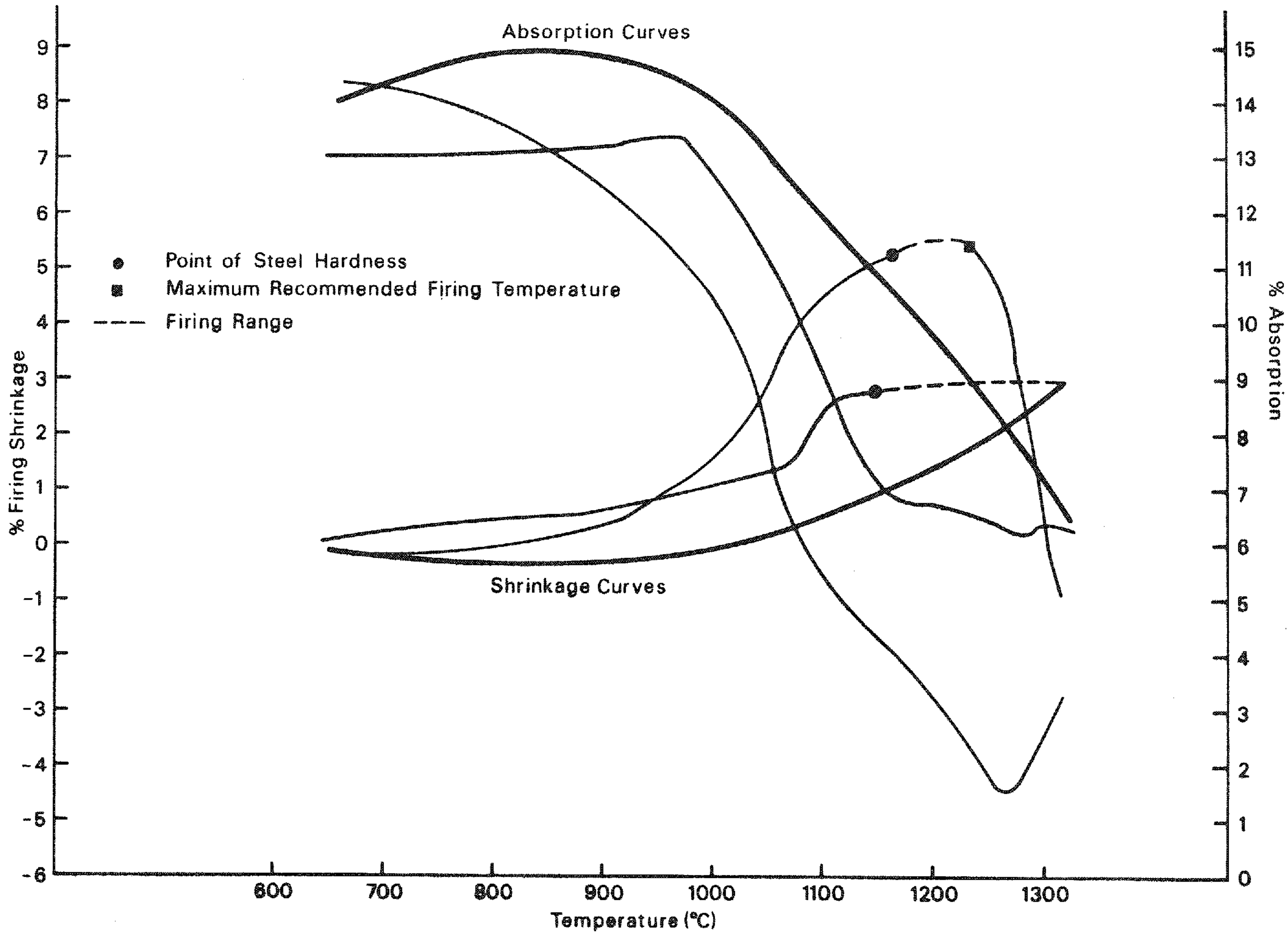


FIGURE 9. Typical temperature versus shrinkage and temperature versus absorption curves for Whitemud Formation clays

each in map areas 82I and P. The two latter samples are from the beds above the Horseshoe Canyon Formation. Test results for the three samples from Quarry 34 are given in Appendix 1 and illustrate the diversity of characteristics from different beds within the formation. With 12 to 16 percent tempering water, plasticity ranges from nil to good and workability ranges from nil to very good. Drying properties are good to excellent with the exception that one sample cracks on drying at elevated temperature. Drying shrinkage varies from 0.5 to 7.3 percent and the sample with the greatest shrinkage is the one that cracks during rapid drying. The normal maximum firing temperature of 1325°C (cone 10) for the temperature gradient furnace was insufficient to produce steel hardness in the sample with a P.C.E. of 26 (Fig. 9). The two other samples burned to steel hardness colors of pale yellowish-brown and very pale orange at 1250°C (cone 6) and 1150°C (cone 02) respectively. These same samples have maximum recommended firing temperatures of 1270°C (cone 7) and greater than 1325°C (cone 10) respectively for extremely short and long firing ranges. Absorption and shrinkage for the short firing range sample are 1.5 percent and 4.4 percent and for the long firing range sample are 6.5 percent and 3 percent. These materials form part of blends for production of ceramic products in Medicine Hat and the results listed above show why blending is so important to maintain consistency during production of ceramic bodies.

The two samples from the equivalent beds above the Horseshoe Canyon Formation also show diverse characteristics (Appendix 4). With 19 or 23 percent tempering water, plasticity is good to very good and working properties are good and fair to good. Both samples warp or crack when dried at room or elevated temperatures because drying shrinkages are 8.7 to 9.3 percent respectively. Steel hardness color is yellowish-gray at 1165°C (cone 01) in one sample and light brown at 1100°C (cone 04) in the other sample. Color does not change at the maximum recommended firing temperature of 1235°C (cone 5) for the first sample, absorption is 1.9 percent, and firing shrinkage is 5.5 percent. Maximum recommended firing temperature of the second sample coincides with the steel hardness temperature. Neither sample dries successfully. One has no firing range and the other has a moderate firing range. The potential for use of material from the Whitemud Formation in the central areas of the province seems limited.

PROPERTIES OF THE BATTLE FORMATION

Sediments of the Battle Formation overlie those of the Whitemud Formation. On large-scale maps the two formations often are undivided because their combined thickness is less than 20 m and they have the same areal extent. The light colors of the Whitemud Formation contrast with the mauve-gray weathering, dark brown to purplish-black, montmorillonitic shales with fine silt of the Battle Formation (Irish, 1967). Lindoe (1965) suggests from evidence gained from firing samples that the Whitemud-Battle contact is gradational. Within the upper part of the Whitemud Formation feldspar and mica decrease upward toward the contact with the Battle, kaolinite remains high, but montmorillonite appears and modifies the drying characteristics. Montmorillonite increases upward and becomes the dominant clay mineral in the Battle Formation.

Four samples of dark brown or black material that was assumed to be from the Battle Formation were tested from map areas 72E, 82I and P (Appendixes 1 and 4). P.C.E. values range from 12 to 19 and these values are high for true Battle Formation clays (Crockford, 1951; M. Shayna, personal communication). Three of the four samples need 28 percent tempering water to give plasticity and working properties that range from fair to very good. Bars crack upon drying at room and elevated temperatures and two bars could not be fired because of severe cracking or crumbling. One sample required only 18 percent tempering water for good plasticity and fair working properties. Drying at room temperature produces warped but uncracked bars, and drying at elevated temperatures produces cracked bars. Drying shrinkage is 8.5 percent. A pale reddish-brown color is reached at steel hardness temperature of 1150°C (cone 02) and absorption is 7.5 percent. At maximum recommended firing temperature of 1300°C (cone 8), color is light brown, absorption is 3.2 percent, and fired shrinkage is 8.8 percent. The long firing range of this sample supports the observation of Lindoe (1965) that "after drying the remaining ceramic properties are fairly acceptable." The severe cracking characteristics of the other samples tested also support his observation that "they have no normal ceramic application."

PROPERTIES OF THE ST. MARY RIVER FORMATION

The St. Mary River Formation is present in a narrow band from the International Boundary to the vicinity of Carmangay where it becomes indistinguishable from the Horseshoe Canyon Formation. The formation consists of a series of alternating sandstones and shales that change stratigraphically upward from marine to fresh water deposits (Russell and Landes, 1940). Maximum thickness is 365 m. The predominantly greenish-gray shales are friable, poorly bedded, and commonly highly sandy.

Two samples were collected from each of two locations in map area 82H (Appendix 4). Both samples from the location nearest to where the St. Mary River Formation becomes indistinguishable for the Horseshoe Canyon Formation dried poorly and bloated before steel hardness was reached and are of no value for ceramic purposes. The two samples from the banks of Oldman River produced poor to fair plasticity and fair to very good working properties with 15 and 11 percent tempering water respectively. Drying properties are good to very good at room temperature and good to fair at elevated temperature. Drying shrinkage is 4 to 5.7 percent. Color at steel hardness is light to moderate brown and is reached at 1000°C to 1055°C (cones 07 to 05). Color at maximum recommended firing temperature is moderate brown to dark yellowish-brown and is reached at 1080°C to 1100°C (cone 04). Absorption at maximum recommended firing temperature is zero and firing shrinkage is 7.8 percent.

Although the material extrudes well, and has a short to moderate firing range, bars have a tendency to curl upward on firing and problems with drying and firing are likely to occur whenever material from this formation is used for ceramic purposes.

PROPERTIES OF THE WILLOW CREEK FORMATION

The outcrop pattern of the Willow Creek Formation extends northward from the International Boundary southeast of Cardston and opens into a "Y" configuration with the characteristics of the formation in the wider eastern arm distinguishable to the vicinity of the Little Bow River north of Stavely where it becomes indistinguishable from the Paskapoo Formation. Rocks in the narrower western arm pinch out along the Foothills north of Cowley in Township 13.

The general color of the formation is pink with gray and yellow bands (Russell and Landes, 1940). Sediments are interbedded, soft, gray-weathering, medium-grained, argillaceous sandstone, and gray, maroon, and light brick red-weathering clay (Irish, 1967). The lower part of the formation is predominantly montmorillonitic shale containing small white calcite concretions, with sandstone beds becoming more numerous and thicker in the upper part (Carrigy, 1971). The formation overlies the Battle Formation on the Oldman River and the St. Mary River Formation elsewhere. The upper contact with the Porcupine Hills Formation is erosional (Carrigy, 1971).

There are no persistent lithologic horizons, but four clay samples were collected in map area 82H (Appendix 4) from a thick section on Mokawan Butte east of Stand Off on Blood I.R. 148. Tempering water required for poor to excellent plasticity is 17 to 20 percent and working properties are poor to good. One set of bars warped when dried at room temperature but the three other sets dry well. All bars crack when dried at elevated temperatures. Temperature of steel hardness varies from 823°C (cone 016) to 1100°C (cone 04), colors range from light to moderate brown, and absorption varies from 9 to 13.5 percent. Three of the four samples have a maximum recommended firing temperature of 1120°C (cone 03) and colors are mostly drab, yellowish-browns. With one exception, absorption at maximum recommended firing temperature is low (0 to 1.3 percent). Firing shrinkage is approximately 7 percent. The presence of small calcareous grains in the sediments causes flaking from the surface of most bars (lime blowing) during firing. The noncalcareous sample has an extremely long firing range (200°C) but cracks badly on firing. Other firing ranges vary from extremely short (20°C) to long (125°C). The nonpersistence of the beds, poor drying and firing characteristics, and drab fired colors are not assets for potential ceramic production.

PROPERTIES OF THE PORCUPINE HILLS FORMATION

The Porcupine Hills Formation occurs in a band approximately 30 km wide from the southern border of Peigan I.R. 147 to Airdrie. Lithologically, this formation consists of cross bedded, buff-weathering, gray sandstone with interbedded gray and dark gray, calcareous, montmorillonitic clay shale (Irish, 1967). Maximum thickness is 915 m. Abundant freshwater molluscs of Paleocene age are present in the formation (Carrigy, 1971). On its eastern erosion limit north of the Little Bow River in the vicinity of Stavely, the formation overlies the Paskapoo Formation and to the south it overlies the Willow Creek

Formation. North of Airdrie rocks of the formation are indistinguishable from those of the Paskapoo Formation.

Five samples were collected in map area 82J (Appendix 4) from two locations. Four samples come from a quarry operated by Consolidated Concrete for production of expanded aggregate, and one sample comes from an abandoned quarry at Sandstone where bricks were produced in the past. With 16 to 22 percent tempering water, plasticity is poor to fair and working properties poor to good but mostly poor. With one exception, drying properties are good at room temperature but all bars crack upon drying at elevated temperatures. Drying shrinkage is 7.3 to 8.7 percent. Even after hand molding, one sample bloated so badly during firing that firing data are unavailable. Color at steel hardness is light brown, steel hardness temperature varies from 950°C to 1005°C (cone 09 to 07) with 1005°C most common, and absorption is 10.5 percent. A moderate brown color is reached at a maximum recommended firing temperature of 1080°C to 1100°C (cone 04), absorption is zero, and firing shrinkage is 6.5 to 9.9 percent.

The moderate to long firing range and consistent brown color are assets for this material; however, the poor drying characteristics and the tendency for bars to warp during firing are liabilities. Perhaps the present use as a source of material for production of expanded aggregate is the best choice of all ceramic uses.

PROPERTIES OF THE BRAZEAU FORMATION

The Brazeau Formation, extending northward from the International to the British Columbia boundary in the Foothills, is a thick wedge of continental sediments that is homologous to Upper Cretaceous rocks of the Plains above the base of the Judith River Formation or its equivalents (Fig. 2). The formation is composed of sandstones and conglomerates, gray to greenish-gray shales, and thin bentonite beds, with some coal seams near the base (Stott, Gibson, and Ollerenshaw, 1968). Defining the top of the Brazeau Formation can be a problem north of the North Saskatchewan River and commonly the Brazeau and overlying Paskapoo Formations are mapped as one unit

(Jones and Workum, 1978). Over 3350 m of Brazeau sediments are present in the Hinton area and more than 1500 m of this thickness are considered to be of Tertiary age (Lang, 1947). Lesser thicknesses of Brazeau sediments are present elsewhere.

Six samples were tested from the abandoned Bryan Mountain Coal Company pit near Robb in map area 83F (Appendix 5). Fourteen to 16 percent tempering water gives poor to good plasticity and fair to good working properties. Drying behavior is good to very good at room temperature and mostly good to very good at elevated temperatures. Drying shrinkage varies from 4.5 to 6.4 percent. Upon firing, the sample with the highest drying shrinkage bloated and cracked so badly that no firing data are available for that sample. All other samples fired to light brown colors at steel hardness temperatures between 1005°C and 1075°C (cone 07 to 05). Absorption at steel hardness varies from 6 to 11 percent. A variety of shades from light through moderate to dark yellowish-brown are produced when the maximum recommended firing temperature is reached between 1090°C and 1190°C (cone 04 to 1). At the maximum recommended firing temperature maximum absorption is 0.4 percent and firing shrinkage varies from 7.7 to 8.4 percent. The lowest P.C.E. obtained is 8 and the highest is 15.

The good drying characteristics and, with one exception, the good firing characteristics (moderate to long firing range, variety of brown colors) suggest that Brazeau Formation clays could be used successfully for structural clay products if the usual raw material quality control testing is maintained.

PROPERTIES OF THE PASKAPOO FORMATION

Outcropping over a large area of central Alberta are the Paleocene nonmarine sandstones, siltstones, mudstones and lignites of the Paskapoo Formation. Sediments of the formation become indistinguishable from those of the Willow Creek Formation in the vicinity of the Little Bow River north of Stavely, and indistinguishable from those of the Porcupine Hills Formation near Airdrie (Carrigy, 1971). Maximum sediment thickness of 915 m is reached in the Foothills area where

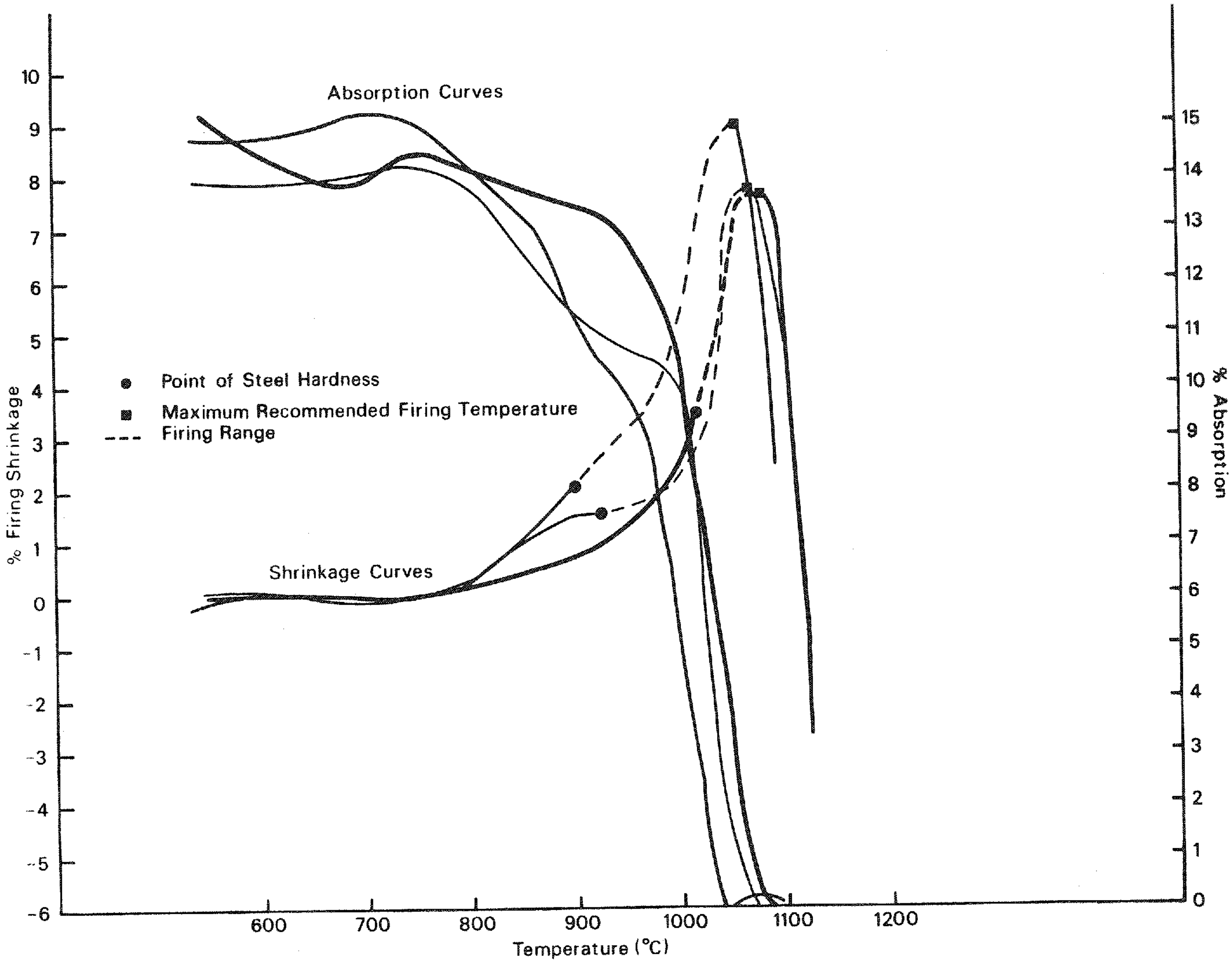


FIGURE 10. Typical temperature versus shrinkage and temperature versus absorption curves for Paskapoo Formation clays

sediments equivalent to the Paskapoo Formation form the upper part of the Brazeau Formation (Fig. 2). The northern limit of the formation reaches to approximately 80 km south of Grande Prairie. Sediments are characterized in the lower part by thick, buff-weathering, pale gray, cross bedded, cliff-forming sandstones. Sandstones of the upper part are soft, pale gray, and interbedded with blocky, green and gray siltstones and silty mudstone. Lignitic coal and carbonaceous shale beds also are present in the upper part (Kramers and Mellon, 1972).

Five samples were collected from map areas 82I and 83A (Appendixes 4 and 5) and P.C.E. values only range from 2 to 4. Tempering water averages 20 percent and produces fair to good plasticity and fair to very good working properties. Drying properties at room temperature are good but some cracking takes place when elevated temperatures are used for drying. Drying shrinkage ranges from 6.8 to 9.5 percent. The lowest temperature for steel hardness (Fig. 10) is 900°C (cone 012) and the highest is 1015°C (cone 07). Steel hardness color is light to moderate brown. Color at maximum recommended firing temperature is moderate brown and is reached between 1050°C and 1085°C (cone 05). Maximum absorption is 0.4 percent at these temperatures and firing shrinkage ranges from 7.6 to 10 percent.

The moderate to long firing range and appealing brown color at higher fired temperatures could make clays from this formation of interest to producers of structural clay products. The tendency of some bars to curve upward on firing could be eliminated by the addition of grog, quartz, or clays with lower firing shrinkage.

PROPERTIES OF PLEISTOCENE LACUSTRINE CLAYS

Of the common deposits left by the ice sheets that covered Alberta during the Pleistocene age (eolian, lacustrine, outwash, and till materials), the most useful as potential ceramic raw materials are the lacustrine deposits. Although bedded sands and silts are common lacustrine sediments, and unsuitable for ceramic use, the clays or silty clays cover sufficiently extensive areas of the province to warrant investigation.

Two samples of Pleistocene varved clay were collected in map area 82P (Appendix 4). Local potters had experienced mixed success when using the same material for glazing pottery. The light colored, thick, "summer" varve sample fired successfully but the dark colored, thin, "winter" varve bloated badly at temperatures as low as 850°C (cone 015) and is of no value. With 20 percent tempering water, the summer varve has excellent plasticity and excellent working properties. At room temperature, bars dry well but minor cracking occurs upon drying at elevated temperatures. Drying shrinkage is 9.4 percent. The firing range of 40°C between 1050°C and 1090°C (cone 05 to 04) is short. Fired color is a pleasant moderate brown, absorption at maximum recommended firing temperature is zero and fired shrinkage is 9 percent.

The short firing range due to high calcareous content and the impossibility of eliminating the valueless winter varve during mining would exclude this material from use in commercial ceramic production.

CONCLUSIONS

1. Argillites from the Precambrian Grinnell Formation are not suitable for use in production of ceramic products due to the fragile bars produced, the need to beneficiate the clays, distance from production plants, and less intense red-fired color than expected from the raw material.

2. The dolomitic nature of argillite from the Siyeh Formation gives an extremely short firing range and a grayish-yellow fired color. Little ceramic use is envisaged for this material.

3. Some basal clays of the McMurray Formation can be used for low heat duty refractories but most of the material is more suitable for structural clay products or pottery (excluding whitewares).

4. Samples of the Luscar Formation from the Cadomin-Luscar and Grande Cache areas lack plasticity, normally have a short firing range, and fire to undistinguished brown colors. This is in contrast to results from previously tested Luscar samples from the Nordegg area, which have moderate to long firing ranges and burn to an attractive chocolate brown.

5. Material from the lower member of the Shaftesbury Formation fires to a color probably acceptable for bricks. Pressed bricks rather than extruded bricks would dry and fire more successfully because of their more open texture.

6. The single sample from the Fort St. John Group in the Grande Cache area extrudes and dries well, has a moderate firing range,

and a moderate (milk chocolate) brown fired color. Beneficiation may be necessary to remove siltstone present as stringers at the outcrop sampled. Further testing may be valuable.

7. Poor drying and firing properties inherent in shales of the Dunvegan Formation are not beneficial for ceramic production.

8. Samples from the Kaskapau Formation dry well, firing range is moderate to long, and the moderate (milk chocolate) brown color could be acceptable in "earth color" pottery or structural clay products. Further testing may be valuable.

9. The Sunkay and Haven members of the Blackstone Formation have materials that dry and fire well and should be useful for production of structural clay products or pottery. Material from the Vimy member has no ceramic value.

10. The one sample tested from the Moosehound Member of the Cardium Formation extrudes with difficulty, but dries well and has a moderate firing range. The moderate reddish-brown fired color would be acceptable for bricks. Further testing or material from this member may be worthwhile.

11. Only one of three samples collected from the Wapiabi Formation could be fired successfully and its firing range is only 25^{o}C. Material from this formation has no ceramic value.

12. Pakowki Formation shales are difficult to extrude, dry poorly, have zero to moderate firing range, and commonly have small white blebs on the fired bars. Little ceramic value is placed on these shales.

13. It is unlikely that material from the Lea Park Formation could be used for any ceramic purpose because of warping and cracking on drying, extremely short or short firing range, and a strong tendency to bloat on firing.

14. Shales of the Judith River Formation that formerly were designated as Foremost Formation sediments are of no value for ceramic purposes because of the tendency for bars to disintegrate during drying or firing.

15. Shales of the Judith River Formation that formerly were designated as Oldman Formation can be used in ceramic production if ameliorating material is added to correct for warping and cracking during drying and for the short firing range.

16. A sample of shale from the Bearpaw Formation in the Foothills shows drying and firing characteristics superior to those shown by a sample typical of material from the Plains. Further testing of Foothills material may be desirable.

17. Good drying properties, moderate firing range, and pleasant fired color are sufficient reasons to continue using clays from the Eastend Formation for ceramic production.

18. Different beds within the Whitemud Formation in the Cypress Hills area have diverse characteristics that are favorable for use in various blends for ceramic bodies. The Whitemud Formation beds in the central part of the province have little potential for ceramic use.

19. The extremely poor drying properties of clays from the Battle Formation normally eliminate them from consideration for ceramic use.

20. Problems with drying and firing of shales from the St. Mary River Formation are likely to occur if they are used for ceramic purposes.

21. Clays of the Willow Creek Formation are hampered for use in ceramic production by nonpersistent clay horizons, poor drying and firing characteristics, and drab fired colors.

22. Poor drying properties and the tendency of bars to warp during firing offset moderate to long firing ranges in shales of the Porcupine Hills Formation. At present, the shales are quarried for production of expanded aggregate.

23. Maintenance of good quality control practices for raw materials from the Brazeau Formation would ensure that the good drying characteristics, moderate to long firing range, low fired absorption and acceptable fired colors would be used to advantage in the production of structural clay products.

24. Clays and shales of the Paskapoo Formation have potential for use in the production of structural clay products if blended with grog, quartz or other clays to reduce the tendency to curl upward on firing.

25. Varved lake clays of Pleistocene age are too calcareous in the lighter colored varves and contain too much organic matter in the darker colored varves to fire successfully.

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APPENDIXES

Appendix 1. Ceramic Characteristics of Samples from National Topographic Series 72 Map Areas

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
											Drying Behavior		
Lsd	Sec	Tp	R	Mer				Tempering Water (%)	Plasticity	Working Properties	Room Temperature	150°C	Drying Shrinkage (%)
		72E											
					Battle?	3 m 10YR2/2 shale, minor silt, slickensides, alligator weathering	15	28	very good	good	warps and cracks	cracks badly	10.2
					Whitemud?	1 m 5YR8/1 clayey sand, with small pods and stringers of 10YR2/2 slickensided material	23	16	fair	fair	very good	cracks	7.3
-	20	8	3	W4	Whitemud	1.5 m N9 clayey sand, dark slickensided material along joints	26	16	good	very good	excellent	excellent	6.9
I-XL Quarry 34													
					Whitemud	7 m N9 clayey sand, thin bedded	14	12	nil	nil	very good	good	0.5
					Eastend?	10 m 5Y7/2 clayey silt, worm burrows filled with dark slickensided material	9	18	fair	good	good	good	3.5
					Judith River	0.75 m 10YR2/2 shale, minor silt, 100 m below top of bank and first shale seen	5	22	excellent	fair	warps	warps and cracks	-
14	4	2	6	W4	Judith River	0.5 m 5Y4/1 shale, minor silt, ~1 m below sample above	4	23	very good	very good	warps	cracks badly	9.2
Down through 145 m of sediment along Milk River. Few shales													
					Judith River	1 m 5Y3/2 shale, minor silt, alligator weathering	5	18	fair	poor	warps	cracks badly	7.9
					Judith River	15 m 10YR2/2 shale, non-silty, alligator weathering	5	20	fair	poor	warps, cracks	cracks badly	-
10	20	2	10	W4	Pakowki	15 m 10YR2/2 shale, non-silty to minor silt, gypsum crystals on surface, 5YR3/4 stain on joints	7	27	good	good	warps	cracks	9.6

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 1. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
	72E											
					steel hardness not reached by 1335°C							poor drying characteristics
					10YR8/2	1150	7	10YR7/4	1325+	6.5	3	long firing range
-	20	8	3	W4	steel hardness not reached by 1325°C							extrudes well
I-XL Quarry 34					10YR6/2	1250	2.2	5Y6/1	1270	1.5	4.4	use as an extender?
					5YR4/4	1100	10.8	5YR3/4	1175	1.3	8.2	moderate firing range, pleasant brown color, bars curl on firing
					bars too warped to fire							no value
14	4	2	6	W4	5YR5/6	1065	8.3	5YR4/4	1100	1.3	4.8	short firing range
Down through 145 m of sediment along Milk River. Few shales					5YR5/6	1050	7.2	5YR4/4	1085	4	2.5	short firing range, hard to extrude
					no bars survived drying intact							no value
10	20	2	10	W4	5YR5/6	1000	7.2	5YR4/4	1080	0.8	10.4	poor drying properties, moderate firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics: Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer									
72E													
14	14	1	11	W4	Pakowki	5Y3/2 shale, 5Y3/4 stain on joints, nonsilty to minor silt, some gypsum crystals on surface	4	20	fair-good	good	minor warp	minor cracks	9.1
15 m shale in Miners Coulee					Pakowki	5Y3/2 shale, nonsilty, minor 5YR4/4 stain	3	24	good	good	warps	cracks	7.8
					Pakowki	5Y3/2 shale, 5YR4/4 stain prominent, nonsilty to minor silt	10	20	fair	good	warps	cracks	8.1
3	21	3	15	W4	Pakowki	3 to 7 m 5Y3/2 shale, sandy, 5YR4/4 stain on joints	4	20	fair	fair	warps	cracks	8.9

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Fired Characteristics: Steel Hard: Color*	Steel Hard: Temperature (°C)	Steel Hard: Absorption (%)	Maximum Fire: Color*	Maximum Fire: Temperature (°C)	Maximum Fire: Absorption (%)	Maximum Fire: Shrinkage (%)	Remarks
Lsd	Sec	Tp	R	Mer								
72E												
14	14	1	11	W4	5YR5/6	1000	9	5YR4/4	1100	2.2	8.9	sample would not extrude, soft white blebs in fired bar. moderate firing range
15 m shale in Miners Coulee					5YR5/6	975	11.3	5YR4/4	1080	1.1	9.6	hard to extrude, only hand moulded bars survived drying, fired bars warp severely
					5YR4/4	1115	2	coincides with steel hard				no firing range, soft white blebs in fired bar, no value
3	21	3	15	W4	5YR4/4	1080	9	10R4/2	1120	1.8	2.5	short firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 2. Ceramic Characteristics of Samples from National Topographic Series 73 Map Areas

Location					Group or Formation	Description*	Unfired Characteristics						
											Drying Behavior		
Lsd	Sec	Tp	R	Mer			P.C.E.	Tempering Water (%)	Plasticity	Working Properties	Room Temperature	150°C	Drying Shrinkage (%)
		73E											
					Lea Park	5Y3/2 shale, 5YR 4/4 stain on laminae and joints, minor silt, noncalcareous	PCE cones bloated so badly that further testing was not warranted						
16	11	54	3	W4	Lea Park	As above, slightly silty	5	23	good	good	minor warp	cracks	7.3
20 m shale on Vermillion River													
					Lea Park	As above, minor silt	PCE cones bloated so badly that further testing was not warranted						
					Lea Park	As above, slightly silty	5	23	good	good	warps	cracks badly	7.8
1	5	54	7	W4	Lea Park	2 m 5Y4/4 mudstone, 5 YR4/4 stain on joints, slightly silty	4	24	good	good	warps	cracks badly	10.2

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		73E										
					PCE cones bloated so badly that further testing was not warranted							
16	11	54	3	W4	5YR4/4	1055	5	5YR4/4	1075	2.8	7.9	extruded bars bloat badly
20 m shale on Vermillion River					PCE cones bloated so badly that further testing was not warranted							
					Bloats badly even when hand molded							no value
1	5	54	7	W4	5YR5/6	1035	6.8	5YR4/4	1080	2.6	6.9	extruded bars bloat badly

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 3. Ceramic Characteristics of Samples from National Topographic Series 74 Map Areas

Lsd	Sec	Tp	R	Mer	Location	Group or Formation	Description*	P.C.E.	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
					74D									
NW	17	91	9	W4	"Basal Clay" at mouth of McLean Creek	McMurray	5Y4/1 clay, slightly silty, noncalcareous, massive	PCE cones bloated so badly that further testing was not warranted						
						McMurray	5Y3/2 clay, nonsilty, non-calcareous, massive	27	18	fair	fair	good	good	6.7
						McMurray	5Y4/1 clay, very silty, massive, noncalcareous	20	12	excellent	good	minor warp	good	5.8
						McMurray	15 cm N1 clay, slightly silty, waxy, massive, coaly fragments	30	23	fair-good	fair	minor warp	minor cracks	6.1
					74E									
-	31	92	19	W4	Suncor pit	McMurray	5Y4/1 clay, slightly silty, noncalcareous, minor sand laminae with minor bitumen, ~2 m mineable oil sand below	15	15	very good	good	minor warp	minor cracks	4.7
						McMurray	5Y4/1 clay, thin-medium laminae, slightly silty, minor sand laminae with minor bitumen. Sample from a "rip up clast"	8	15	excellent	good	good	minor cracks	4.9
NW	31	94	10	W4	Shell Road-Athabasca River intersect	McMurray	5Y4/1 and 5GY6/1 clay, nonsilty, noncalcareous, massive	10	18	fair	fair	good	good	5.8
1	35	94	11	W4		McMurray	5GY6/1 clay, slightly silty, noncalcareous, massive, 30 cm	10	18	fair	fair	minor warp	good	5.8
4	2	95	11	W4		McMurray	5 m 5Y4/1 clay, noncalcareous, nonsilty	15	17	good	fair	minor warp	good	6.4
7	4	95	11	W4		McMurray	0.5 m 5Y3/2 clay, nonsilty, noncalcareous	15	19	good	good	minor warp	minor cracks	6.1

Columns from Tempering Water (%) to Drying Shrinkage (%) are grouped under the heading "Unfired Characteristics".

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 3. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
74D												
NW	17	91	9	W4 "Basal Clay" at mouth of McLean Creek	PCE cones bloated so badly that further testing was not warranted							no value
					10YR7/4	980	3	10YR7/4	1050	1.8	5.5	moderate firing range, extruded bars bloat severely, hand molded bars bloat less
					5Y8/4	1155	4.4	5Y7/2	1325	1	2	long firing range, low firing shrinkage
					steel hardness not reached because it exceeded upper firing limit of furnace							vugs left in bars as coaly fragments burn out
74E												
-	31	92	19	W4 Suncor pit	5YR6/4	1200	4.2	10YR6/2	1240	1.2	7.2	extrudes very well, short firing range
					10R4/2	1075	7.9	5YR3/4	1160	1.7	7.7	extrudes well, moderate firing range
NW	31	94	10	W4 Shell Road-Athabasca River intersect	bars begin bloating at point of steel hardness							no value
1	35	94	11	W4	5YR5/6	975	4.1	5YR5/6	1075	0.6	5.4	moderate firing range
4	2	95	11	W4	5YR8/4	1010	6.3	10YR6/2	1160	1	5.6	long firing range
7	4	95	11	W4	10YR7/4	930	6.1	10YR7/4	1000	4	3.5	moderate firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. Ceramic Characteristics of Samples from National Topographic Series 82 Map Areas

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
								Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer							Room Temperature	150°C	
		82G											
?	4	4	1	W5	Siyeh	N3 weathers 10YR7/4 argillite, noncalcareous, thin bedded	8	15	poor	fair	good	good	1
?	9	4	1	W5	Grinnell	5R4/2 weathers 10R5/4 argillite interbedded with N9 quartzite, only argillite sampled	4	15	poor	fair	good	good	3.5
13	7	6	1	W5	Blackstone	∿30 m 5Y2/1 with 5YR3/2 stain along laminae, shale, silty interbeds, sulfur smell when disturbed, noncalcareous	7	16	poor	fair	good	minor cracks	4.6
13	7	6	1	W5	Blackstone (Vimy mbr)	∿30 m 5Y2/1 weathers N6, shale, thin bedded to fissile, few silty interbeds, calcareous	5	17	fair	good	good	good	3.7
4	18	6	1	W5	Blackstone	∿15 m N3 weathers 5YR3/4 shale, low silt, noncalcareous	12	15	very good	very good	good	good	4.3
15	12	5	2	W5	Wapiabi	N3 shale, noncalcareous, minor silt to sandy bands, some ironstone concretions	PCE cones bloated so badly that further testing was not warranted						
NE	26	7	2	W5	Bearpaw	∿10 m 5Y3/2 shale, thin laminae, noncalcareous but has a few ironstone concretions, ∿5 m glacial overburden	8	19	fair	good	good	minor cracks	7
		82H											
9	17	4	16	W4	Judith River	∿3 m N1 shale, 5YR3/4 and 5YR4/4 stain on fissile planes, no silt, noncalcareous, small gypsum crystals on outcrop surface	4	23	poor	good	good	good	5.5

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Fired Characteristics: Steel Hard			Fired Characteristics: Maximum Fire				Remarks
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	
		82G										
?	4	4	1	W5	5Y8/4	1190	8.4	5Y8/4	1210	0.4	14.7	extrudes poorly, extremely short firing range
?	9	4	1	W5	10R5/4	975	7	10R4/2	1040	3.4	4	quartzite probably impossible to remove, bars very fragile until fired
13	7	6	1	W5	5YR5/6	1010	10	5YR4/4	1105	2.1	6.8	grind finely to improve workability and texture, moderate firing range
					bars curled so badly firing terminated before steel hardness reached							no value
4	18	6	1	W5	5YR6/4	1000	8.5	5YR4/4	1125	0.7	5.5	difficult to extrude, long firing range
15	12	5	2	W5	PCE cones bloated so badly that further testing was not warranted							no value
NE	26	7	2	W5	5YR6/4	925	9.3	5YR6/4	1050	0.8	6.9	long firing range, bars curl upward on firing
		82H										
9	17	4	16	W4	10R4/6	1040	bars crack severely immediately after steel hardness					soft blebs in fired bar, no value

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
								Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer							Room Temperature	150°C	
		82H											
9	17	4	16	W4	Judith River	∿1 m 5Y4/1 shale, 5YR5/6 stain, minor silt, noncalcareous, massive	12	22	very good	good	warp, crack	cracks	9.3
					Judith River	∿2 m 5Y5/2 clay, thin laminated, noncalcareous, minor silt	5	20	very good	very good	warps	cracks	9.1
4	3	2	17	W4	Judith River	∿3 m 5Y5/2 mudstone, massive, 5YR4/4 stain on joints, noncalcareous, a few carbon impressions	4	13	very good	very good	minor warp	minor warp	6.3
16	22	1	21	W4	Bearpaw	∿5 m 10YR2/2 shale, thin laminated, minor silt, noncalcareous, small gypsum crystals on surface, ironstone concretions, 5 cm band volcanic ash?	5	23	good	fair	minor warp	cracks	8.4
10	10	2	21	W4	Judith River	∿5 m 10Y4/2 shale, silty, medium laminated, noncalcareous	4	17	good	very good	minor warp	cracks	7.6
1	13	8	22	W4	Judith River	∿10 m 5Y5/2 shale, silty, thin laminae, calcareous, waxy	5	20	very good	very good	minor warp	cracks	8.7
10	4	12	23	W4	St. Mary River	∿3 m 5Y3/2 shale, slightly silty, thin laminated, calcareous	4	20	fair	fair	good	poor	7.6
					St. Mary River	∿0.5 m 5Y5/2 shale, silty, noncalcareous, 5YR5/6 on joints and laminae	4	20	poor	fair	cracks badly	crumbles	8.3

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		82H										
9	17	4	16	W4	5YR5/6	1000	bars crack severely immediately after steel hardness					extrudes poorly, no value
					5YR6/4	bars crack and bloat before steel hardness reached						soft blebs in fired bar, no value
4	3	2	17	W4	5YR4/4	1040	8	10R4/2	1125	0.9	8.2	hand moulding necessary, extruded bars bloated badly
16	22	1	21	W4	5YR5/6	980	7.2	5YR4/4	1040	1.2	8.4	moderate firing range, cracks at hot end
10	10	2	21	W4	5YR4/4	1075	8.8	5YR4/4	1110	2.6	3.4	low firing shrinkage, short firing range
1	13	8	22	W4	5YR6/4	935	6.5	5YR5/2	1100	2.5	2.3	does not extrude well, soft white blebs when fired
10	4	12	23	W4	bloated before steel hardness reached							no value
					bloated before steel hardness reached							no value

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Lsd	Sec	Tp	R	Mer	Group or Formation	Description*	P.C.E.	Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
		82H											
-	∿30	6	24	W4	Willow Creek	5R6/2 weathering clay, ∿30 cm, minor silt, calcareous	4	17	excellent	good	good	cracks	8.2
Mokowan Butte Blood I.R. 148					Willow Creek	N3 clay weathers N5, silty, thin bedded, noncalcareous	4	20	good	good	minor warp	cracks	9.1
					Willow Creek	5Y6/4 and 5R4/2 weathering clay, calcareous, no silt	3	18	good	fair	good	cracks	7.6
					Willow Creek	10R4/2 & 10R6/6 clay, no silt, calcareous	3	19	poor	poor	good	cracks	7.8
2	3	10	24	W4	St. Mary River	∿1 m 5GY4/1 shale, 10YR5/4 stain on joints, minor silt, thin laminated to massive, slightly calcareous	3	15	poor	fair	good	good	4
					St. Mary River	∿1.5 m 5GY3/2 shale, silty, noncalcareous, thin laminae	4	11	fair	very good	very good	fair	5.7
9	9	4	30	W4	Wapiabi	7 m 5Y3/2 shale, N6 weathering on joints, calcareous, thin bedded to fissile. ∿5 m till overburden	3	13	poor	poor	good	good	2.1
10	24	4	30	W4	Wapiabi	6 m 10YR4/2 and 10YR2/2 interbedded shale, minor silt to silty	6	18	fair	fair	good	good	5.7
		82I											
14	8	22	21	W4	Paskapoo	∿4 m olive shale, siltier laminae have yellow cast, noncalcareous	4	22	good-very good	very good	minor warp	cracks	9.5

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		82H										
					5YR4/4	1100	9	10YR4/2	1120	7	7	fine texture, lime blowing when fired
- Mokowan Butte Blood I.R. 148	~30	6	24	W4	5YR5/6	825	10.7	5YR4/4	1025	1.3	5	extrudes well, cracks badly on firing
					5YR6/4	995	13.5	10YR6/2	1120	0	7.3	some lime blowing when fired
					5YR6/4	1025	11.6	5YR5/2	1120	0	7	soft white blebs when fired
2	3	10	24	W4	5YR5/6	1055	10.6	10YR4/2	1100	0	7.8	extrudes well, short firing range
					5YR4/4	1000	10.6	5YR4/4	1080	0.2	7.8	extrudes well, bars curl on firing
9	9	4	30	W4	No steel hard							no value
10	24	4	30	W4	5YR3/4	1100	3.2	5YR3/4	1125	1.8	5.9	some spalling above white blebs, extremely short firing range
		82I										
14	8	22	21	W4	5YR4/4	1015	8.3	5YR3/4	1085	0	7.6	extrudes very well, moderate firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location: Lsd	Sec	Tp	R	Mer	Group or Formation	Description*	P.C.E.	Tempering Water (%)	Unfired Characteristics: Plasticity	Working Properties	Drying Behavior: Room Temperature	150°C	Drying Shrinkage (%)
		82I											
NW	18	22	22	W4	Whitemud	~0.75 m 5Y6/1 clay, massive, slightly silty, noncalcareous	18	19	good	good	cracks	cracks	8.7
					Battle	~1.5 m 10YR2/2 mudstone, slightly silty, slightly waxy, massive, noncalcareous, soft	12	29	very good	very good	cracks	cracks	11
					Battle	~4 m 5Y2/1 shale, thin laminae, slightly silty	16	18	good	fair	minor warp	cracks	8.5
		82J											
7	2	21	1	W5	Porcupine Hills	0.75 m 10Y6/2 mudstone parting in sandstone, slightly calcareous, massive to thin laminae	3	16	poor	poor	good	cracks	7.3
10	36	21	1	W5	Porcupine Hills	30 cm 5Y5/2 mudstone, massive, minor silt, noncalcareous, directly below till	3	16	poor	poor	good	minor cracks	7.4
Raw clay for Consolidated Concrete "Herculite" expanded aggregate					Porcupine Hills	2 m 5Y3/2 mudstone, massive to slightly laminated, noncalcareous	3	21	fair	fair	good	cracks	8
					Porcupine Hills	N3 mudstone, massive, calcareous, at bottom of pit	4	22	fair	poor	cracks	cracks	8.1
					Porcupine Hills	~3 m 5Y5/2 mudstone, massive, noncalcareous	4	18	fair	good	good	cracks	8.7
		82P											
2	25	26	23	W5	Pleistocene	8 m 5Y7/2 clay, nonsilty, calcareous, "summer" varve	4	20	excellent	excellent	good	minor cracks	9.4
					Pleistocene	5Y5/2 clay, nonsilty, calcareous, "winter" varve	Could not produce PCE cones because material bloated on calcining at 850°C						

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
82I												
NW	18	22	22	W4	5Y7/2	1165	4	5Y7/2	1235	1.9	5.5	dries poorly but fires well
					Bars cracked so badly they could not be fired							
					10R5/4	1150	7.5	5YR5/6	1300	3.2	8.8	excellent firing range, some glassy blebs above steel hard
82J												
7	2	21	1	W5	5YR5/6	1005	10.6	5YR4/4	1110+	0	7+	extruded with difficulty
10	36	21	1	W5	5YR5/6	1005	9.6	5YR4/4	1080	0	8	bars warp badly at hot end
Raw clay for Consolidated Concrete "Herculite" expanded aggregate					5YR5/6	1005	10.5	5YR4/4	1100	0	9.9	bars warp badly at hot end
					Bloats badly even when hand molded							no value
					5YR5/6	950	10.6	5YR4/4	1085	0	6.5	long firing range
82P												
2	25	26	23	W5	5YR4/4	1050	7.6	5YR4/4	1090	0	9	no value
					Could not produce PCE cones because material bloated on calcining at 850°C							no value

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 4. (continued)

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics			Drying Behavior		
Lsd	Sec	Tp	R	Mer				Tempering Water (%)	Plasticity	Working Properties	Room Temperature	150°C	Drying Shrinkage (%)
		82P											
12	23	27	23	W4	Whitemud	2 m 5Y4/1 clay, slightly silty, massive	10	23	very good	fair-good	warps	cracks	9.3
12	23	27	23	W4	Battle	6 m 5YR2/1 shale, minor silt, massive to medium laminae, slickensides	19	28	fair-good	fair	cracks	crumbles	

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Fired Characteristics: Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		82P										
12	23	27	23	W4	5YR6/4	1100	6.4	coincides with steel hard				bars enlarge and crack above steel hard
12	23	27	23	W4	cracked so badly on drying that bars could not be fired							

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 5. Ceramic Characteristics of Samples from National Topographic Series 83 Map Areas

Location: Lsd	Sec	Tp	R	Mer	Group or Formation	Description*	P.C.E.	Unfired Characteristics: Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	150°C	Drying Shrinkage (%)
		83A											
4	27	40	25	W4	Paskapoo	5Y3/2 shale, 5YR3/2 on joints and laminae, no silt, slightly calcareous, carbonaceous impressions	2	20	good	good	good	minor cracks	7.9
					Paskapoo	10Y4/2 shale, 10YR4/2 on joints, no silt, noncalcareous	3	18	fair	fair	good	minor cracks	6.8
4	3	38	26	W4	Paskapoo	As above	2	22	good	good	good	minor cracks	8.7
					Paskapoo	∿30 cm 5Y4/1 shale, no silt, noncalcareous, some carbonaceous material	3	23	fair	poor	good	good	7.4
		83F											
					Brazeau	5Y4/1 clay, slightly silty, noncalcareous, some 5YR4/4 on joints	15	16	good	good	very good	very good	5.5
					Brazeau	5Y5/2 clay, slightly silty, noncalcareous	12	14	fair	good	very good	very good	4.5
?	36	49	21	W5	Brazeau	5Y4/1 clay, 10YR4/2 stain on joints, slightly silty, noncalcareous	12	15	good	good	very good	minor cracks	6.2
Abandoned Bryan Mtn. Coal Co. pit					Brazeau	0.75 m shale, carbonaceous 5Y8/4 stain, thin laminae	10	16	poor	fair	good	fair-good	6.4
					Brazeau	2 m 5Y4/1 shale, slightly silty, massive, noncalcareous	10	15	fair	fair	good	good	5
					Brazeau	1 m 5Y4/1 shale, 5YR3/4 stain on joints, slightly silty, noncalcareous	8	14	poor	fair	very good	very good	4.6

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

FIRED CHARACTERISTICS OVERLEAF.

Appendix 5. (continued)

Location					Fired Characteristics: Steel Hard			Fired Characteristics: Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		83A										
4	27	40	25	W4	5YR5/6	975	13	10R4/2	1075	0	9.5	plasticity improves as material worked, moderate firing range
4	3	38	26	W4	5YR6/4	925	11	5YR4/4	1060	0.4	7.8	some upward curvature at hot end of bars, long firing range
					5YR6/4	900	11	5YR4/4	1050	0	9	extrudes well, bars crack during firing, long firing range
					5YR6/4	925	13	5YR4/4	1080	0.4	10	bars curve upward when fired, long firing range
		83F										
?	36	49	21	W5	5YR6/4	1075	6	10YR6/2	1190	0	8.4	extrudes well, long firing range
Abandoned Bryan Mtn. Coal Co. pit					5YR6/4	1010	11	10YR4/2	1150	0.4	8.3	extrudes well, long firing range, fired bars curve upward
					5YR6/4	1010	6.4	5YR5/6	1090	0	7.7	extrudes very well
					bloats and cracks badly							no value
					5YR5/6	1025	6.4	5YR4/4	1125	0	8.4	excellent plasticity with extra water, moderate firing range
					5YR5/6	1005	10	10YR4/2	1105	0	7.8	moderate firing range

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
								Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer							Room Temperature	150°C	
		83F											
6	30	47	22	W5	Cardium (Moosehound mbr.)	∿30 m 10YR2/2 mudstone, slightly silty, non-calcareous, 10YR2/2 and 5Y7/6 stain	7	14	fair	good	good	good	3.6
SE	5	47	23	W5	Luscar	50 cm 5Y3/2 mudstone, non-calcareous, non silty, carbonaceous stringers	8	12	fair	fair-good	good	good	2.7
"Luscar-type" beds across river from Cadomin					Luscar	2.5 m 5Y2/1 mudstone, non-silty, carbonaceous impressions	4	12	nil	nil	good	good	-
					Luscar	4 m 5YR2/1 shale, thin laminae, non silty, non-calcareous	14	15	poor-fair	poor	excellent	excellent	4.3
					Luscar	3 m 5YR2/1 shale, calcareous, thin laminae	4	14	poor	poor	good	good	0.6
8	8	47	23	W5	Blackstone (Vimy mbr.)	15 m 5Y2/1 shale, weathers N4, slightly calcareous, slightly silty, some silty and sand stringers	4	12	poor	fair	good	good	0.9
8	24	47	24	W5	Blackstone	10 m 5YR2/1 shale, slightly silty, thin laminae	7	13	poor-fair	poor	good	good	2.2
?	26	47	24	W5	Luscar	20 cm N3 mudstone, hard, some carbonaceous impressions, noncalcareous	3	12	nil	nil	good	good	0.7
		83L											
?	26	58	8	W6	Kaskapau	5Y2/1 shale, noncalcareous, some silt bands <10 cm thick	9	15	fair-good	fair	slight warp	good	3.5

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

FIRED CHARACTERISTICS OVERLEAF.

Appendix 5. (continued)

Location					Fired Characteristics: Steel Hard			Fired Characteristics: Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		83F										
6	30	47	22	W5	5YR5/6	1010	10.6	10R4/6	1100	3.2	6.4	hard to extrude, moderate firing range
					5YR5/6	1010	8	5YR4/4	1080	1.6	6	hard to extrude, moderate firing range
SE "Luscar-type" beds across river from Cadomin	5	47	23	W5	bars too fragile to fire							no value
					5YR6/4	980	8.8	5YR5/6	1075	4.8	5	hard to extrude, rough surface on bars
					10R4/2	1125	1.3	coincides with steel hard				bars fragile, no firing range
8	8	47	23	W5	steel hardness not reached by 1120°C							no value
8	24	47	24	W5	steel hardness not reached by 1205°C							no value
?	26	47	24	W5	bars too fragile to fire							no value
		83L										
?	26	58	8	W6	5YR6/4	1010	10	5YR4/4	1150	1.7	7	tempering water critical for good extrusion, long firing range

*Color designation based on Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 5. (continued)

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
								Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer							Room Temperatures	150°C	
		83L											
SE	28	58	8	W6	Ft. St. John Group ?	5Y2/1 shale, silty, 5YR4/4 stain on joints, siltstone stringers <3 cm	7	17	fair	fair	good	good	4.4
NW (McIntyre #9 South Pit, sampled upward from #4 coal as 3 m combination samples unless noted otherwise)	24	58	9	W6	Luscar	5Y2/1 shale, organic impressions on laminae, nonsilty	4	11	none	none	good	good	3.4
					Luscar	As above, slightly silty, calcareous	3	13	none	none	good	good	0.8
					Luscar	17 m 5Y4/1 shaly siltstone, calcite along joints	5	16	none	poor	minor surface cracks	minor surface cracks	1.4
					Luscar	5Y2/1 silty shale, thin bedded, calcareous	-	12	none	none	good	good	0.2
					Luscar	N4 shale, organic impressions on partings, a few slightly calcareous mudstone bands, 0.5 m coaly material at top	4	14	fair	fair-good	good	good	3.2
					Luscar	2 m N5 sandstone							
					Luscar	5Y2/1 shale, silty, organic impressions on laminae, 0.5 m coal at top	13	14	none	none	good	good	0.8
					Luscar	2.7 m 5Y3/1 shale, nodular weathering	5	12	none	none	good	good	0.7
					Luscar	2.5 m coaly material							
					Luscar	5Y2/1 shale, minor silt, a few slightly calcareous nodules parallel to laminae	4	13	poor	poor	minor crazing	minor crazing	2.6
					Luscar	1.5 m siltstone							

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

FIRED CHARACTERISTICS OVERLEAF.

Appendix 5. (continued)

Location					Fired Characteristics							
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	Remarks
		83L										
SE	28	58	8	W6	5YR6/4	1030	9.1	5YR4/4	1120	0.6	6.8	extrudes well, moderate firing range
NW McIntyre #9 South Pit, sampled upward from #4 coal as 3 m combination samples unless noted otherwise	24	58	9	W6	steel hardness not reached by 1128°C							PCE cone collapsed suddenly, extrudes poorly
					steel hardness not reached by 1140°C							extrudes poorly, bars very fragile
					steel hardness not reached by 1140°C							extrudes poorly, bars very fragile
					bars too fragile to fire							
					10YR6/2	1115	7.3	maximum fire not reached by 1122°				minor cracks on surface
					steel hardness not reached by 1270°C even though bars are expanding and absorption is reduced to 3.5 percent							
					steel hardness not reached by 1170°C even though absorption is reduced to 2 percent							
					5YR4/4	1075	9.3	5YR3/4	1115	4.5	5.6	extrudes stiffly, short firing range

*Color designation based on Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 5. (continued)

Location (Lsd Sec Tp R Mer)	Group or Formation	Description*	P.C.E.	Unfired Characteristics: Tempering Water (%)	Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
83L									
NW 24 58 9 W6 McIntyre #9 South Pit, sampled upward from #4 coal as 3 m combination samples unless noted otherwise	Luscar	5Y2/1 shale, silty, a few slightly calcareous nodules	4	14	poor	poor-fair	minor crazing	minor crazing	2.8
	Luscar	2.2 m as above	4	14	poor-fair	fair	minor crazing	good	2.3
	Luscar	2.2 m 5Y3/2 shale, minor silt, noncalcareous, 0.3 m lensy sandstone in centre	10	18	fair	fair-good	minor crazing	good	4.9
	Luscar	4.2 m N6 sandstone							
	Luscar	3.5 m 5Y3/1 shale, prominent 5Y4/4 stain, minor silt, noncalcareous	5	13	none	none	good	good	1.5
	Luscar	21 m sandstone and covered interval to base of #10 seam							
NW 24 58 9 W6 McIntyre #9 South Pit Western Extension, Sampled down from #10 coal	Luscar	1.5 m 5YR2/1 shale, slightly silty, organic impressions on laminae	15	14	fair	fair-good	good	good	3.6
	Luscar	5.3 m siltstone							
	Luscar	3.4 m 5Y2/1 shale, organic impressions on laminae, noncalcareous, nonsilty	7	15	fair	fair	good	good	3.4
	Luscar	1.8 m sandstone							
	Luscar	3.5 m 5Y2/1 shale, mainly nonsilty but has a few silt bands 2-3 cm thick	5	12	none	none	good	good	0.6

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

FIRED CHARACTERISTICS OVERLEAF.

Appendix 5. (continued)

Location (Lsd Sec Tp R Mer)	Fired Characteristics: Steel Hard Color*	Steel Hard Temperature (°C)	Steel Hard Absorption (%)	Maximum Fire Color*	Maximum Fire Temperature (°C)	Maximum Fire Absorption (%)	Maximum Fire Shrinkage (%)	Remarks
83L								
NW 24 58 9 W6 McIntyre #9 South Pit, sampled upward from #4 coal as 3 m combination samples unless noted otherwise	5YR4/4	1100	8	5YR3/4	1140	1.8	5.8	short firing range
	5YR5/2	1125	8	5YR5/2	1150	2.2	5.7	finer grit, extrudes well
	5YR6/4	1030	13.7	5YR5/2	1150	0.7	8.2	extrudes well after fine grinding, long firing range
	5YR4/4	1100	9	coincides with steel hard				could not extrude
NW 24 58 9 W6 McIntyre #9 South Pit Western Extension, Sampled down from #10 coal	5YR7/2	1090	9.5	5Y6/1	1205	2.4	5.8	extrudes well, finer texture than samples above, long firing range
	5YR6/4	1030	10.2	5YR4/4	1110	1.4	6.4	extrudes stiffly, moderate firing range
	5YR3/4	1100	8.2	coincides with steel hard				could not extrude

*Color designation based on Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 5. (continued)

Location (Lsd Sec Tp R Mer)	Group or Formation	Description*	P.C.E.	Tempering Water (%)	Unfired Characteristics: Plasticity	Working Properties	Drying Behavior: Room Temperature	Drying Behavior: 150°C	Drying Shrinkage (%)
83L									
NW 24 58 9 W6 McIntyre #9 South Pit Western Extension, Sampled down from #10 coal	Luscar	1.5 m 5Y2/1 mudstone, non-silty, noncalcareous	4	12	none	none	good	good	0.9
	Luscar	0.4 m sandstone							
	Luscar	1.8 m 5Y2/1 shale, knobby weathering, nonsilty-minor silt	8	13	fair	fair	good	minor cracks	3
	Luscar	1.2 m siltstone							
	Luscar	3 m covered							
83M									
14 8 80 4 W6 North side of Peace River at Dunvegan Crossing	Dunvegan	3 m 5Y3/2 shale, nonsilty, becomes slightly silty near top, noncalcareous	4	20	good-very good	good	warps	cracks badly	7.8
	Kaskapau	Uppermost visible shale, 2m 5Y2/1 minor silt, noncalcareous	8	18	good	fair-good	good	minor warp	5.7
	Kaskapau	1.5 m as above, separated from above by 30 cm sand	9	17	good-very good	good	good	good	5.6
	Dunvegan	1.5 m 5Y2/1 shale, minor silt, noncalcareous, some 5YR5/6 stain on joints	7	19	good	good	good	cracks	7.6

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

FIRED CHARACTERISTICS OVERLEAF.

Appendix 5. (continued)

Location (Lsd Sec Tp R Mer)	Fired Characteristics: Steel Hard Color*	Steel Hard Temperature (°C)	Steel Hard Absorption (%)	Maximum Fire Color*	Maximum Fire Temperature (°C)	Maximum Fire Absorption (%)	Maximum Fire Shrinkage (%)	Remarks
83L								
NW 24 58 9 W6 McIntyre #9 South Pit Western Extension, Sampled down from #10 coal	5YR3/4	1150	3.5	coincides with steel hard				could not extrude
	5YR6/4	1110	4.8	5YR5/2	1135	2.7	4.8	extrudes well, extremely short firing range
83M								
14 8 80 4 W6 North side of Peace River at Dunvegan Crossing	5YR5/6	1040	9.7	5YR4/4	1090	1.1	8.2	extruded bars bloat badly, must be hand moulded
	5YR5/6	1050	9.8	5YR4/4	1135	0.2	7.5	extrudes well, moderate firing range
	5YR6/4	1000	12.5	5YR4/4	1140	2.9	5	extrudes very well, long firing range
	bars bloated too badly							

*Color designation based on Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 6. Ceramic Characteristics of Samples from National Topographic Series 84 Map Areas

Location					Group or Formation	Description*	P.C.E.	Unfired Characteristics					
								Tempering Water (%)	Plasticity	Working Properties	Drying Behavior		Drying Shrinkage (%)
Lsd	Sec	Tp	R	Mer							Room Temperature	150°C	
		84C											
2	19	83	21	W5	Shaftesbury	10 m 10YR2/2 shale, 5Y8/4 flecks, nonsilty, noncalcareous, gypsum crystals on surface	7	25	good-very good	good-very good	minor warp	good	6.7
7	20	83	21	W5	Shaftesbury	11 m 10YR2/2 shale, minor silt near bottom to silty near top, noncalcareous	5	20	very good	fair-good	minor warp	minor cracks	8.1
1	29	83	21	W5	Shaftesbury	5 m 5Y2/1 shale, 5Y8/4 flecks, a few ironstone nodules <30 cm diameter	8	22	fair-good	fair	minor warp	good	7.4

*Any color designations given are based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Location					Fired Characteristics							Remarks
					Steel Hard			Maximum Fire				
Lsd	Sec	Tp	R	Mer	Color*	Temperature (°C)	Absorption (%)	Color*	Temperature (°C)	Absorption (%)	Shrinkage (%)	
		84C										
2	19	83	21	W5	10R6/6	1020	18.2	10R4/6	1110	2.4	14.3	long cracks common on firing
7	20	83	21	W5	5YR5/6	1085	2.2	5YR4/4	1100	1	8.6	extruded bars exploded in furnace, hand moulding necessary
1	29	83	21	W5	10R4/6	1060	4.3	10R4/6	1125	1	9.7	extruded bars split on firing, hand moulding necessary

*Color designation based on the Munsell system. Numerical designations are interpreted in Appendix 8.

Appendix 7. Chemical Analysis of Clays from the Plains and Foothills

Location					Formation	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	CaO	MgO	Na_2O	K_2O	H_2O	L.O.I.	S
Lsd	Sec	Tp	R	Mer														
10	36	21	1	W5	Porcupine Hills	61.41	17.26	5.58	.78	.27	.03	0.90	2.08	1.22	2.41	2.68	5.18	0.04
10	36	21	1	W5	Porcupine Hills	62.29	16.48	5.72	.66	.18	.03	0.89	1.95	0.71	2.62	2.57	5.63	0.04
NE	26	7	2	W5	Bearpaw	64.66	16.87	5.07	.77	.11	.02	0.52	1.15	0.83	2.60	1.86	5.35	0.04
13	7	6	1	W5	Blackstone	68.21	14.32	4.24	.69	.36	.01	0.15	1.10	0.66	2.87	1.14	6.38	0.44
4	18	6	1	W5	Blackstone	68.15	15.42	3.95	.78	.31	.02	0.44	1.00	0.39	2.81	1.07	5.64	0.14
-	4	4	1	W5	Siyeh	41.47	5.91	2.03	.20	.07	.07	13.33	11.86	0.24	1.82	0.23	22.24	0.04
10	24	4	30	W4	Wapiabi	69.29	14.94	1.62	.65	.35	.02	1.44	1.07	0.33	2.62	0.98	6.08	0.31
-	30	6	24	W4	Willow Creek	59.34	16.59	4.33	.54	.05	.02	3.07	2.02	0.87	2.42	2.46	7.52	0.03
4	3	38	26	W4	Paskapoo	61.49	14.22	6.79	.65	.15	.03	0.81	1.81	0.99	3.31	2.52	6.06	0.06
-	18	22	22	W4	Battle	64.71	17.20	2.88	.40	.04	.01	0.81	0.56	0.69	0.25	5.45	6.79	0.02
14	8	22	21	W4	Paskapoo	57.38	21.07	4.30	.63	.11	.05	1.73	1.94	1.28	2.90	2.36	5.59	0.03
2	3	10	24	W4	St. Mary River	59.08	15.17	4.21	.53	.09	.03	4.01	2.93	1.20	3.43	0.88	7.60	0.05
2	3	10	24	W4	St. Mary River	66.12	15.63	4.65	.55	.08	.02	0.99	1.69	1.43	2.86	1.75	3.63	0.06
9	17	4	16	W4	Judith River	65.40	16.93	4.38	.76	.09	.01	0.31	0.96	0.80	2.13	2.14	5.69	0.18
10	10	2	21	W4	Judith River	60.35	12.22	3.79	.48	.14	.02	4.95	3.80	0.66	2.75	1.26	9.14	0.01
14	14	1	11	W4	Pakowki	58.06	17.69	6.21	.77	.21	.03	0.84	1.84	0.75	2.53	2.88	7.12	0.52
10	20	2	10	W4	Pakowki	55.82	17.47	6.72	.72	.18	.02	1.24	1.48	0.75	2.36	4.00	7.07	0.85
14	4	2	6	W4	Judith River	59.15	13.95	3.78	.56	.14	.05	3.98	3.26	1.56	2.72	1.30	8.66	0.02
14	4	2	6	W4	Judith River	58.14	17.95	6.26	.74	.21	.12	1.71	1.53	1.57	2.01	2.41	6.78	0.12
NW	17	91	9	W4	McMurray	51.12	28.07	2.84	.80	.33	.01	0.23	1.15	0.96	2.13	2.36	9.50	0.07
-	36	49	21	W5	Brazeau	64.68	18.14	4.61	.87	.05	.03	0.48	0.92	0.88	2.70	1.13	5.20	0.01
-	36	49	21	W5	Brazeau	64.31	17.55	3.66	.84	.18	.02	0.88	1.43	0.75	2.55	1.14	6.20	0.02
SE	5	47	23	W5	Luscar	60.06	20.04	3.91	.87	.50	.02	0.50	0.91	0.20	3.00	1.50	8.20	0.09

Appendix 8. Colors Encountered in Unfired and Fired Clays from the Plains and Foothills

Color designation 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

5R6/2	pale red
5R4/2	grayish red
10R4/2	grayish red (slight orange tint)
10R2/2	very dusky red
10R5/4	pale reddish brown
10R6/6	moderate reddish orange
10R4/6	moderate reddish brown
5YR8/1	pinkish gray
5YR2/1	brownish black
5YR7/2	grayish orange pink
5YR5/2	pale brown
5YR3/2	grayish brown
5YR8/4	moderate orange pink
5YR6/4	light brown
5YR4/4	moderate brown
5YR3/4	moderate brown (darker than 5YR4/4)
5YR5/6	light brown (more yellowish red than 5YR6/4)
10YR8/2	very pale orange
10YR6/2	pale yellowish brown
10YR4/2	dark yellowish brown
10YR2/2	dusky yellowish brown
10YR7/4	grayish orange
5Y6/1	light olive gray
5Y4/1	olive gray
5Y3/1	dark olive gray
5Y2/1	olive black
5Y7/2	yellowish gray
5Y5/2	light olive gray
5Y3/2	olive gray (greener than 5Y4/1)
5Y8/4	grayish yellow
5Y6/4	dusky yellow
5Y4/4	moderate olive brown
5Y7/6	moderate yellow
5Y5/6	light olive brown
10Y6/2	pale olive
10Y4/2	grayish olive
5GY6/1	greenish gray
5GY4/1	dark greenish gray
5GY3/2	grayish olive green
N9	white
N7	light gray
N6	medium light gray
N5	medium gray
N4	medium dark gray
N3	dark gray
N1	black