CERAMIC CLAYS AND SHALES OF BRITISH COLUMBIA

By J. G. Brady** and R. S. Dean**

Introduction

Canada, in general, lacks good-quality clays and shales useful to the ceramic industry, particularly high-quality kaolin and fire clay deposits. British Columbia is no exception, but there is a wider variety of clays there than in many of the other provinces. Common brick, facing brick, drain tile, building tile, flower pots, pottery, sewer pipe, flue liners, and conduits are all manufactured from British Columbia's common clays and shales. Some local fire clays are used in the manufacture of refractories, brick, tile, sewer pipe, conduits or flue liners, and a few stoneware clays are available. There are also useful deposits in certain areas where the potential market is now limited, and in the northern areas of the province where transportation charges are high.

Several earlier publications have dealt with the ceramic properties of the clays and shales of British Columbia. Between 1912 and 1920, Ries and Keele (1,2), Ries (3) and Keele (4,5,6,7,8) contributed greatly to a knowledge of their drying and fired characteristics. In 1924 and 1932, further data on British Columbia clays and shales were provided by Frechette (9) and McMahon (10). Cummings and McCammon (11) in 1952 discussed the location and properties of many B.C. clays and shales useful to the ceramic industry.

For purposes of this report, twenty-two samples were selected as being typical of B.C. clays and shales available to the ceramic industry of that province. The samples include common clays or shales, stoneware clays, and fire clays. Some of these materials are being used commercially, and all can probably be used for the manufacture of ceramic products, some with difficulty.

In the present study, ceramic properties and mineralogical composition are investigated, problems associated with processing are discussed, and the results of differential thermal analysis and X-ray diffraction analyses are correlated with ceramic properties.

Materials Investigated

The source and type of each sample are listed in Table 1. Their approximate locations are shown in Figure 1.

Samples 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 16, 17 and 20 were collected by J. G. Brady of the Ceramic Section of the Mines Branch, Ottawa. Sample 11 from Blue Mountain was sent to the Mines Branch by Mr. J. Hadgkiss, Manager, Haney Brick and Tile Company Limited. Samples 2, 14 and 15 were forwarded to the Mines Branch by private individuals for evaluation. Samples 18, 19, 21 and 22 were collected by the B.C. Department of Mines and evaluated by the Mines Branch.

** Head, Ceramic Section, and Scientific Officer, Mineral Processing Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa.

TABLE 1

Type and Location of Samples

Sample	Location and Type
	Vancouver Island
1. Bazan Bay	Surface clay from pit of Bazan Bay Brick and Tile Ltd. at Saanichton, used for manufacture of brick and tile.
2. Wellington	Grey cretaceous shale from site of former Nanaimo Brick and Tile Co., East Wellington, formerly used for brick.
3. Victoria Brown	Top 6 ft. of surface clay from pit of Evans, Coleman and Evans Limited (Brick Division), Victoria, used for brick and tile.
4. Victoria Blue	Blue clay from below Victoria Brown, used for brick and tile and washed for flower pots.
	Lower Mainland
5. Sumas Mountain A	Tertiary fire clay from Sumas Mountain, near Kilgard, used for firebrick manufacture by Clayburn-Harbison Ltd.
6. Sumas Mountain Red	Red Tertiary shale from Sumas Mountain, used for sewer pipe, conduits, flue liners and face brick by Clayburn-Harbison Ltd.
7. Sumas Mountain No. 9	Grey Tertiary shale from Sumas Mountain, used for same products by Clayburn-Harbison Ltd. as Sumas Mountain Red.
8. Bear Creek	Surface clay from Bear Creek near Surrey, B.C., used for flower pot manufacture by B.C. Clay Products Limited.
9. Haney Brown	Brown surface clay, top 6 ft., near Haney, used for brick and tile by Haney Brick and Tile Limited.
10. Haney Blue	Blue clay occurring below Haney Brown, used for brick and tile manufacture by Haney Brick and Tile Limited.
11. Blue Mountain	Red shale from Blue Mountain, 7 miles north of Whonnock (near Haney); probably location 6 on Fig. 8 of Bulletin 30, British Columbia Department of Mines (11).
12. Barnet	Soft shale near Barnet from pit of Mainland Clay Products Ltd.; used for face brick manufacture.
	Southern Interior
13. Whipsaw Creek	Princeton shale on Hope-Princeton highway, near Whipsaw Creek.
14. Enderby	Surface clay, 10 ft. section, southwest of old Enderby Brick and Tile Company plant, Enderby.
15. St. Eugene	Kaolinized Material, near St. Eugene Mission (north of Cranbrook), close to south bank of St. Mary River.
16. Cranbrook	Cambrian red shale, near Eager and close to the junction of Highway 3 and the Fort Steele Road.

17. Fernie	Very calcareous grey surface clay, along Elk River, adjacent to the highway on the western outskirts of Fernie.
	Northern Interior
18. Baker Creek	Schistose shale 400 ft. south of Baker Creek (at Quesnel), about 3 miles upstream from the highway bridge.
19. Quesnel	Light-coloured clay on Lot 9973, at the "Big Bend" of the Fraser River, 8 miles north of Quesnel, beneath the diatomaceous earth.
20. Giscome Rapids	White sandy clay, probably Tertiary; centre 5 ft. of a 30-ft.-deep outcrop along the west bank of the Fraser River near Giscome Rapids, below Mile 19 from Prince George on the Hart Highway.
21. Prince George	White clay, at Giscome Rapids deposit on west bank of Fraser about 100 ft. west of highwater mark.
22. Coal River	White clay from the right bank of the Coal River, 1½ miles above the Alaska Highway, close to the B.C.-Yukon boundary.

PROCEDURE

Ceramic Properties

The drying and fired properties of all samples were determined from hand-moulded briquettes. The laboratory procedures employed in the ceramic laboratories of the Mines Branch at Ottawa, for this part of the work have previously been described by Brady (12, 13).

Special absorption and shrinkage curves of the Bazan Bay, Sumas Mountain No. 9, Fernie, Giscome Rapids and Coal River samples were obtained by the temperature gradient method. This method has been described by Stone (14) and its use for determining color, hardness, absorption and shrinkage of Canadian clays by Brady (13, 15, 16).

The relative plasticities of the Bazan Bay, Sumas Mountain No. 9, Blue Mountain, Whipsaw Creek, Cranbrook, Fernie and Giscome Rapids samples were determined by the Brabender Plastograph. The use of this apparatus with clays or clay bodies has been discussed by Thies (17), Marshall (18), West and Lawrence (19); and its application to Canadian clays or shales, by Brady (15, 16) and Bell (20).

Temperature conditions were maintained as constant as possible, and the beam weight on the plastograph was the same for all measurements. Water was added at the rate of 5 cc per minute to a 200-gram dry batch. A Dundas (referred to occasionally in the literature as "Lorraine") shale that had just sufficient plasticity for the production of brick and tile was used as a standard. Curves were obtained on which the peak heights and the areas under the curves indicate relative plasticities: the higher the peak and the greater the curve area, the greater is the plasticity. The peak of each curve indicates the water content required for maximum resistance to pugging action, i.e., in effect, the maximum plasticity.

Differential Thermal Analysis

The application of differential thermal analysis (DTA) to Canadian clays has been discussed previously by Brady (12, 15, 16) and Brady et al (21). The thermal curves were obtained on air-dried samples in an air atmosphere

Figure 1. Map Showing Locations of Samples.

at a heating rate of 12°C per minute. A scale sensitivity of 40 was used above 450°C for clays having a high kaolinite-group mineral content, to keep the large peaks on the chart. A scale sensitivity of 10, which produces a peak four times as large as scale 40 for a given reaction, was employed for obtaining the smaller peaks of the illitic (hydrous mica), chloritic and montmorillonitic (montmorillonoids) clays, and for the lower portion of the kaolinitic clay curves below about 450°C. Scale 10 was useful for comparing the amounts of oxidizable material in the samples in the 300 to 400°C temperature region.

No quantitative estimate of the amount of clay minerals was made, although the approximate amount of kaolinite-group mineral in clays containing a high percentage of it can be obtained. The area under the quartz (SiO_2) peak at approximately 570C — which was obtained after eliminating the 580°C clay mineral peak by calcining the clay to 700°C in the DTA furnace — was measured to determine the approximate amount of quartz in each sample. With increasing temperature, the quartz peak is produced during the inversion from the low to the high form of quartz. Potter's flint was used as a standard for the quartz determinations.

X-Ray Diffraction Analysis

A portion of each sample was brought into suspension in distilled water. Most of the silt-size (or coarser) particles, which consisted largely of non-clay minerals, were separated by low-speed centrifugation. The clay remaining in suspension was flocculated with glacial acetic acid, which was added until a 2 per cent acetic acid solution was obtained. The flocculated clay was recovered by centrifugation.

A small quantity of distilled water was added to the centrifuged clay and the resultant slurry was brought into contact with ion exchange resin (Amberlite IR-120) saturated with Ca^{++}. Oriented aggregates of the layer silicates were prepared by evaporating thin films of Ca^{++}-saturated clay slurry upon the surface of two slides, one of which was composed of borosilicate glass.

The borosilicate glass slide was scanned with a North American Philips High-Angle X-ray Diffractometer following heat treatment for ½ hour at 600°C. The remaining oriented aggregate was scanned before and after saturation with ethylene glycol.

Montmorillonoids were identified by their characteristic reflections at about 17Å following glycol saturation, while the basal reflections of the Kaolinite-group minerals disappeared after the 600°C heat treatment. The basal spacing of hydrous mica (10Å) was unaffected by either treatment.

Detection, in the heated samples, of reflections having interplanar spacings exceeding 10Å indicated the presence of complex interlayers within mica-type material. The nature of this material was determined with the aid of the differential dissolution technique of Hashimoto and Jackson (22). In accordance with the procedure outlined by these authors, dried 200-mg portions of the centrifuged clay were heated at 400°C for 4 hours and subsequently boiled for 2.5 minutes in 200 ml of 0.5N sodium hydroxide solution. Following the sodium hydroxide treatment, free iron oxides were removed, by the method of Mehra and Jackson (23), from samples which appeared reddish in colour when dry.

K^+-saturated ion-exchange resin was then utilized to convert the clay to the K^+ form. Oriented mounts prepared from the K^+-saturated clays were scanned before and after heating for ½ hour at 550°C. The collapse of all large spacings to approximately 10Å following this heat-treatment suggested that the interlayer material detected after the initial 600°C heating was aluminous rather than ferro-magnesian. Apart from the usual intensity modifications which accompany heating (Brindley and Ali (24)), structures with ferro-magnesian interlayers (i.e., normal chlorites) appear to be largely resistant to this treatment. Some doubt may still exist, however, regarding the effect of the previously described combined heat and chemical treatments on very poorly crystalline ferro-magnesian interlayer material, such as may be encountered in chlorites from surface clays.

When the presence of ferro-magnesian chlorite was suspected, a supplementary 10-minute treatment with boiling concentrated hydrochloric acid was employed, which resulted in complete or nearly complete disappearance of chlorite reflections.

When the preliminary scans indicated the presence of large quantities of kaolinite-group mineral, the centrifuged clay was heated for ½ hour at 600°C. Following removal of free iron oxide (if necessary), the dehydroxylated kaolinite-group mineral was dissolved in 0.5N sodium hydroxide, in the manner previously outlined. An oriented aggregate of the residual material was scanned, and further heating, ion-saturation or acid-dissolution procedures were undertaken when necessary.

The non-clay minerals occurring within the plus 325 mesh fraction of the samples were collected by wet sieving. Portions of the dried coarse fractions were ground to minus 200 mesh and the major non-clay minerals were identified from X-ray diffractometer scans of these powders.

Miscellaneous Properties

The clays and shales were wet-washed through a 200-mesh sieve and the percentage of plus 200-mesh non-clay particles was calculated. The shales were boiled in water for a sufficient period to break down the hard shale particles into clay and non-clay portions. Several washings were necessary for some of the harder shales.

The chemical analyses of certain samples were obtained. The chemical method reported by Trostel and Wynne (25) for determining the percentage of quartz (free silica) was used to obtain the amount of quartz in the samples. This value was used as a check on the DTA method for determining the approximate amount of quartz.

RESULTS

Ceramic Properties

The physical properties of the clay and shale samples are shown in Tables 2, 3, 4 and 5. Here the samples are grouped into four geographical locations: Vancouver Island, Lower Mainland, Southern Interior, and Northern Interior. Table 3 deals with samples on the Lower Mainland, which, in this report, refers to the area around Vancouver.

Bazan Bay, Victoria Brown, Victoria Blue, Bear Creek, Haney Brown, Haney Blue, Enderby, and Fernie are common clays with low fusion points (low pyrometric cone equivalents (PCE's)). With the exception of Fernie, these samples are plastic to very plastic and, consequently, difficult to dry. All samples, except Fernie, are salmon- to red-firing materials. Fernie is very calcareous; consequently, it has only fair plasticity and fires to a buff colour. The test briquettes of Fernie have a high absorption until a temperature close to the fusion point is reached.

Wellington, Sumas Mountain Red, Sumas Mountain No. 9, Blue Mountain, Barnet, Whipsaw Creek, Cranbrook and Baker Creek are common shales. With the exception of Wellington and Whipsaw Creek, they are more refractory than the common clays. Sumas Mountain No. 9 and Blue Mountain might be classed as low-duty fire clays. The plasticities of the shales are lower than

TABLE 2

Physical Properties of Some Clays and Shale from Vancouver Island

Sample	UNFIRED CHARACTERISTICS	P.C.E.	FIRED CHARACTERISTICS					REMARKS
			Cone No.	Fired Shrinkage %	Absorption %	Colour	Hardness	
1. Bazan Bay	Buff surface clay, very plastic, fair workability (sticky), water of plasticity 32.5%, cracks with rapid drying, drying shrinkage 8.4%.	4	06	2.0	15.4	Dark salmon	Fairly hard	Common red-firing clay, difficult to dry, very short firing range; with careful drying, may be suitable for drain tile, common brick, and building tile.
			04	5.7	8.4	Medium red	Hard	
			02	9.3	0.1	Dark red	Vitrified	
2. Wellington	Dark grey shale, fair plasticity and workability, water of plasticity 17.1%, safe in rapid drying, drying shrinkage 3.9%.	2	05	2.0	10.7	Dark salmon	Hard	Common shale, may have sufficient plasticity for extruding, easy to dry, firing range short; suitable for common brick.
			04	2.5	10.2	Light red	Hard	
			02	5.0	3.8	Dark red	Very hard	
3. Victoria Brown	Brown surface clay, very plastic, water of plasticity 31.7%, cracks with rapid drying, drying shrinkage 8.6%.	4½	06	1.8	15.3	Salmon	Fairly soft	Difficult-to-dry common clay, scums, very short firing range, tendency to warp in firing; with care in drying, may be suitable for high absorption products such as drain tile, building tile, and common brick.
			04	6.0	8.1	Medium red	Very hard	
			02	9.5	1.7	Poor red	Nearly vitrified	
4. Victoria Blue	Blue to brown clay below Victoria Brown, slightly calcareous, very plastic, water of plasticity 31.7%, cracks with rapid drying, drying shrinkage 7.9%.	2	06	2.5	15.9	Salmon	Fairly hard	Common clay, same comments as for Victoria Brown.
			04	6.8	7.1	Dark salmon	Hard	
			02	10.3	0.4	Poor red	Vitrified	

TABLE 3

Physical Properties of Some Clays and Shales from the Lower Mainland of British Columbia

Sample	UNFIRED CHARACTERISTICS	P.C.E.	FIRED CHARACTERISTICS: Cone No.	Fired Shrinkage %	Absorption %	Colour	Hardness	REMARKS
5. Sumas Mountain A	Grey clay, fairly good plasticity and workability, water of plasticity 16.4%, satisfactory drying properties, drying shrinkage 3.8%.	31½	02	2.7	10.4	Nearly white	Fairly hard	Open firing fireclay, suitable for intermediate and high duty refractories.
			5	4.0	8.8	Off white	Hard	
			10	5.0	6.1	Speckled buff	Very hard	
6. Sumas Mountain Red	Grey slightly calcareous shale, good plasticity and workability, water of plasticity 20.8%, safe drying, drying shrinkage 5.8%.	10	04	1.0	13.4	Salmon	Fairly soft	Common shale, has a tendency to bloat, scums slightly, good drying and firing characteristics; suitable for brick, tile, sewer pipe, flue liners, and conduits.
			01	2.4	10.7	Fairly light red	Fairly hard	
			2	3.0	9.5	Fair red	Hard	
			5	6.0	3.1	Very dark red	Very hard	
7. Sumas Mountain No. 9	Dark grey shale, fair plasticity, water of plasticity 18%, will dry under rapid drying conditions fairly well, drying shrinkage 7%, extrudes well.	19	1050°C* (04)	3.3	14.6	Light pink	Fairly hard	Common shale, or low-duty fireclay, good unfired characteristics; an open firing shale with a long firing range, suitable for brick, tile, sewer pipe, flue liners, and conduits.
			1104°C* (02)	4.9	12.2	Light pink	Hard	
			1148°C* (2)	6.1	9.7	Pink-grey	Hard	
			1183°C* (5)	6.7	8.1	Light grey	Very hard	
			1215°C* (7)	7.0	6.9	Light grey	Very hard	
8. Bear Creek	Grey-brown clay, very plastic, water of plasticity 32.5%, cracks with rapid drying, drying shrinkage 9.1%.	2	08	1.8	13.9	Salmon	Fairly hard	Common red-burning clay, difficult to dry, short firing range; with care in drying, suitable chiefly for common brick, building tile, drain tile, flower pots.
			06	5.1	8.7	Medium red	Hard	
			04	8.3	1.4	Dark red	Steel hard	
			02	8.0	0.1	Dark red	Overfired	
9. Haney Brown	Grey-brown surface clay, good plasticity and workability, water of plasticity 32.3%. Slight tendency to crack with rapid drying, drying shrinkage 7.9%.	3½	06	2.0	16.2	Salmon	Fairly hard	Common red-burning clay, some care needed in drying, short firing range; with care in processing, suitable for common brick, drain tile, and building tile.
			04	4.7	8.1	Medium red	Hard	
			02	9.5	1.2	Dark red	Nearly vitrified	
10. Haney Blue	Grey-blue clay, contains some fossils, slightly calcareous, good plasticity and workability, water of plasticity 25.9%, cracks with rapid drying, drying shrinkage 6.4%.	3	06	0.3	16.3	Light salmon	Fairly soft	Common clay, tendency to scum, difficult to dry, short firing range; with care in processing, suitable for common brick, drain tile, and building tile.
			04	1.7	14.0	Salmon	Fairly hard	
			02	5.0	5.6	Light red	Very hard	
11. Blue Mountain	Red shale, fair plasticity, inclined to be short, water of plasticity 18.3%, safe drying, drying shrinkage 2.9%.	20	06	2.5	15.0	Salmon	Fairly soft	Low-grade fireclay or refractory common shale, should extrude, difficult to vitrify; suitable for clay products, if mixed with a clay which will promote earlier vitrification.
			04	3.1	13.3	Salmon	Fairly soft	
			02	4.3	10.0	Pale red	Fairly hard	
			5	4.3	10.8	Medium red	Hard	
12. Barnet	Brown, soft shale, fairly plastic, good workability, gritty, water of plasticity 22.8%, satisfactory drying properties, drying shrinkage 6.5%.	13	05	2.0	12.6	Salmon	Fairly hard	Common shale, safe drying with reasonable care, requires a high firing temperature for dense products; long firing range, suitable for face brick, tile, and possibly sewer pipe.
			03	3.3	9.8	Light red	Hard	
			2	4.2	9.2	Light red	Hard	
			5	5.6	4.7	Dark red	Steel hard	

* Fired by temperature gradient method; numbers in brackets are approximate cone equivalents.

TABLE 4

Physical Properties of Some Clays and Shales from the Southern Interior of British Columbia

Sample		UNFIRED CHARACTERISTICS	P.C.E.	FIRED CHARACTERISTICS: Cone No.	Fired Shrinkage %	Absorption %	Colour	Hardness	REMARKS
13.	Whipsaw Creek	Light brown shale, short, poor workability, water of plasticity 14.4%, safe drying, drying shrinkage 1.0%	7	04	0.8	18.4	Light brown	Fairly soft	Common non-plastic shale, open firing; probably requires a plasticizer if used for extruded clay products such as brick.
				03	1.8	18.4	Light brown	Fairly soft	
				01	4.3	12.2	Brown	Fairly hard	
				2	4.5	7.7	Brown	Hard	
14.	Enderby	Brown calcareous clay, good plasticity and workability, water of plasticity 23.6%, safe drying, drying shrinkage 5.7%.	4½	06	+0.3*	15.8	Salmon	Soft	Common calcareous clay, scums, short firing range; suitable for drain tile, building tile, and common brick.
				04	0	15.1	Salmon	Soft	
				02	1.8	12.4	Light red	Fairly hard	
				1	6	2.9	Fair red	Very hard	
15.	St. Eugene	White kaolinized argillite, contains some dark coarse grains; fairly good workability, low plasticity (short), water of plasticity 23.8%, safe drying, drying shrinkage 3.2%.	18	06	0.0	14.4	Pale grey	Soft	Low-grade non-plastic refractory clay, long firing range, difficult to vitrify; may be suitable for sewer pipe or face brick if it can be extruded; may need a plastic additive.
				02	3.3	12.9	Pale grey	Fairly hard	
				2	5.0	9.8	Light grey	Hard	
				5	6.3	6.7	Grey	Very hard	
16.	Cranbrook	Red shale, contains trilobites; fair workability and low plasticity, water of plasticity 25.9%, safe drying, drying shrinkage 3.6%.	14	06	+0.5*	21.1	Light salmon	Very soft	Common shale, low plasticity, satisfactory firing range, high firing temperature for dense products; should be suitable for face brick.
				02	4.2	9.0	Medium red	Hard	
				2	4.7	8.6	Red	Very hard	
				5	9.8	0.5	Dark red	Steel hard	
17.	Fernie	Light grey clay, very calcareous; fair plasticity and workability, water of plasticity 22.5%, safe drying, drying shrinkage 3.7%.	4½	06	2.0	22.7	Light cream	Fairly soft	Common very calcareous clay, very short firing range; not recommended for clay products because of the very short firing range.
				04	1.7	22.7	Cream	Fairly soft	
				02	1.7	20.7	Cream	Fairly soft	
				2	7.0	5.8	Greenish buff	Very hard	

* A plus sign indicates expansion.

TABLE 5

Physical Properties of Some Clays and Shale from the Northern Interior of British Columbia

Sample	UNFIRED CHARACTERISTICS	P.C.E.	FIRED CHARACTERISTICS					REMARKS
			Cone No.	Fired Shrinkage %	Absorption %	Colour	Hardness	
18. Baker Creek	Soft, white shale, fair workability, low plasticity, water of plasticity 21.2%, safe drying, drying shrinkage 2.7%.	15½	02	1.1	12.6	Light buff	Fairly hard	Common shale, lacks plasticity unless an additive is added; open firing, requires an addition of a close firing clay to lower firing temperature for products such as brick and tile.
			3	2.1	9.7	Buff	Hard	
			8	3.0	5.0	Grey	Very hard	
19. Quesnel	White clay, good workability and plasticity, water of plasticity 31%, safe drying, drying shrinkage 6.5%.	18	02	2.3	15.3	Light buff	Fairly hard	Open firing stoneware-type clay, long firing range; requires the addition of a close firing clay to lower firing temperature of such products as brick and sewer pipe.
			3	3.7	12.2	Buff	Hard	
			8	5.8	6.7	Dark buff	Very hard	
20. Giscome Rapids	White clay, good workability and plasticity, water of plasticity 26.4%, safe drying, drying shrinkage 5.7%.	29	02	1.7	15.2	Cream	Fairly hard	Open firing fireclay, suitable for intermediate duty refractories or mixing with a more refractory clay for high duty refractories.
			5	3.0	12.6	Cream	Fairly hard	
			10	4.3	10.1	Cream	Hard	
21. Prince George	White clay, fair plasticity and workability, water of plasticity 27.7%, safe drying, drying shrinkage 4.5%.	16½	04	2.7	12.9	White	Fairly hard	Stoneware-type clay with a long firing range; suitable for face brick, pottery and possibly sewer pipe.
			02	4.7	9.7	Cream	Hard	
			3	6.3	6.0	Cream	Very hard	
22. Coal River	White clay, good workability and plasticity, water of plasticity 26%, safe drying, drying shrinkage 5.9%.	15	06	1.8	14.2	Cream	Fairly hard	Stoneware-type clay, long firing range.
			04	3.5	11.0	Cream	Hard	
			02	5.6	5.7	Cream	Very hard	
			1	7.5	4.0	Cream	Very hard	

the common clays. The range of fired colours includes pink, salmon, red, brown, buff, and grey.

The Quesnel, Prince George, and Coal River samples may be classed as stoneware clays having fair to good plasticities. They have pyrometric cone equivalents of about cones 15 to 18 and fire to a white, cream or buff colour. Quesnel has very open-firing properties for a stoneware clay.

The Sumas Mountain A and Giscome Rapids samples are open-firing; refractory fire clays; they fire to a light white, cream or buff colour.

The St. Eugene sample is difficult to classify; it has the properties of a low-duty, open-firing fire clay.

The Brabender Plastograph curves are shown in Figures 2 and 3, in which per cent tempering water is plotted against comparative resistance to pugging action (resistance to shear). The curve for Dundas shale standard (Figure 2) has a peak height of approximately 300 scale units under the laboratory conditions employed. Whipsaw Creek (Figure 2) has a dull, low curve which indicates that a plastic addition is necessary for extruding this shale. The Blue Mountain and Cranbrook curves (Figure 2) are similar to the Dundas standard curve and indicate that these shales probably can be extruded, although a plasticizer may be necessary.

The peak heights and the areas under the curves for Giscome Rapids (Figure 2), Sumas Mountain No. 9 (Figure 3), Fernie (Figure 3) and Bazan Bay (Figure 3) are greater than those for Dundas shale. Consequently, these four materials appear to have ample plasticity for extruding.

The curve for Bazan Bay indicates that this is a very plastic clay that may be sticky. Victoria Brown, Victoria Blue, Bear Creek and Haney Brown, clays similar to Bazan Bay, probably have curves of similar size.

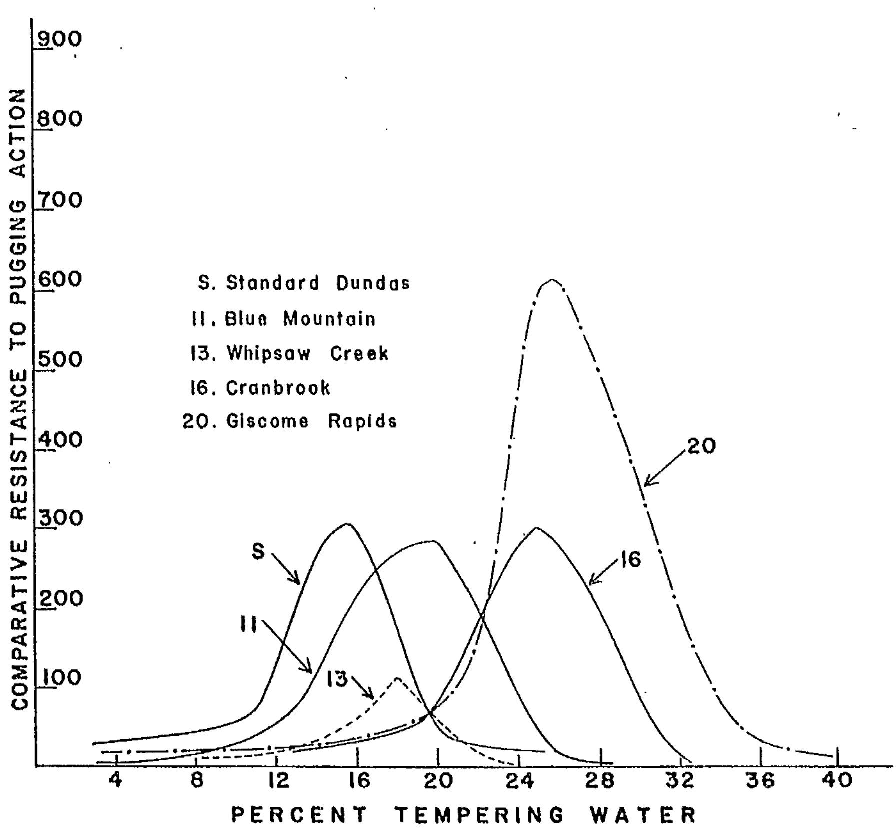

Figure 2. Plastograph Curves of Standard Dundas, Blue Mountain, Whipsaw Creek, Cranbrook and Giscome Rapids Samples.

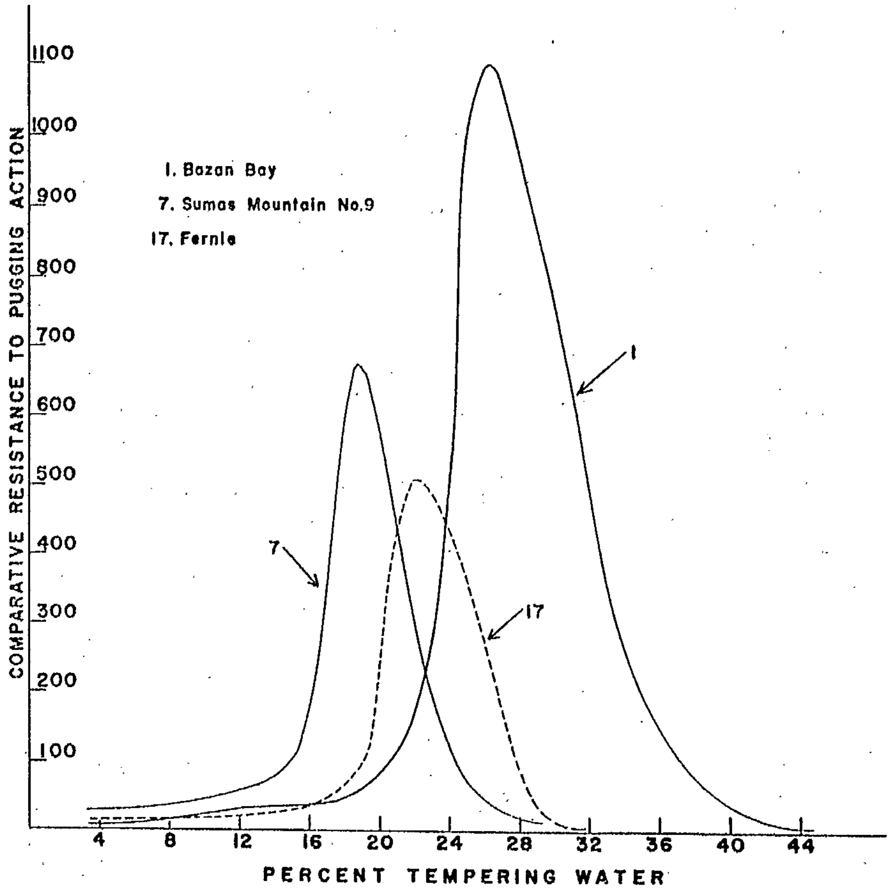

Figure 3. Plastograph Curves of Bazan Bay, Sumas Mountain No.9 and Fernie Samples.

The Haney Blue, Enderby, Quesnel, Prince George and Coal River samples have fairly good plasticity and workability. The work on the hand-moulded briquettes indicates that the plastograph curves of these samples would be similar to that of the Giscome Rapids sample.

Sumas Mountain A, Sumas Mountain Red, and Barnet probably have plastograph curves similar to that of Sumas Mountain No. 9, with Sumas Mountain A probably having the curve with the least height and area.

Indications are that Baker Creek and St. Eugene would have plastograph curves similar to Cranbrook, and that the curve for Wellington would likely be similar to that of Blue Mountain.

The temperature-gradient shrinkage and absorption curves are shown in Figures 4 and 5. Shrinkage values between 0 and minus 2 per cent indicate that there has been a residual expansion, while values greater than zero indicate that shrinkage has taken place. At the upper temperatures, where absorption is close to zero and shrinkage is a maximum, a sharp decrease in shrinkage indicates that the sample is over-fired and that bloating has occurred.

The curves for Bazan Bay (Figure 4) and for Fernie (Figure 4) show that these materials have short firing ranges at the upper temperatures where the fired product starts to get hard. Shrinkage and absorption change very rapidly, and difficulty is experienced in producing dense, hard products having uniform physical properties.

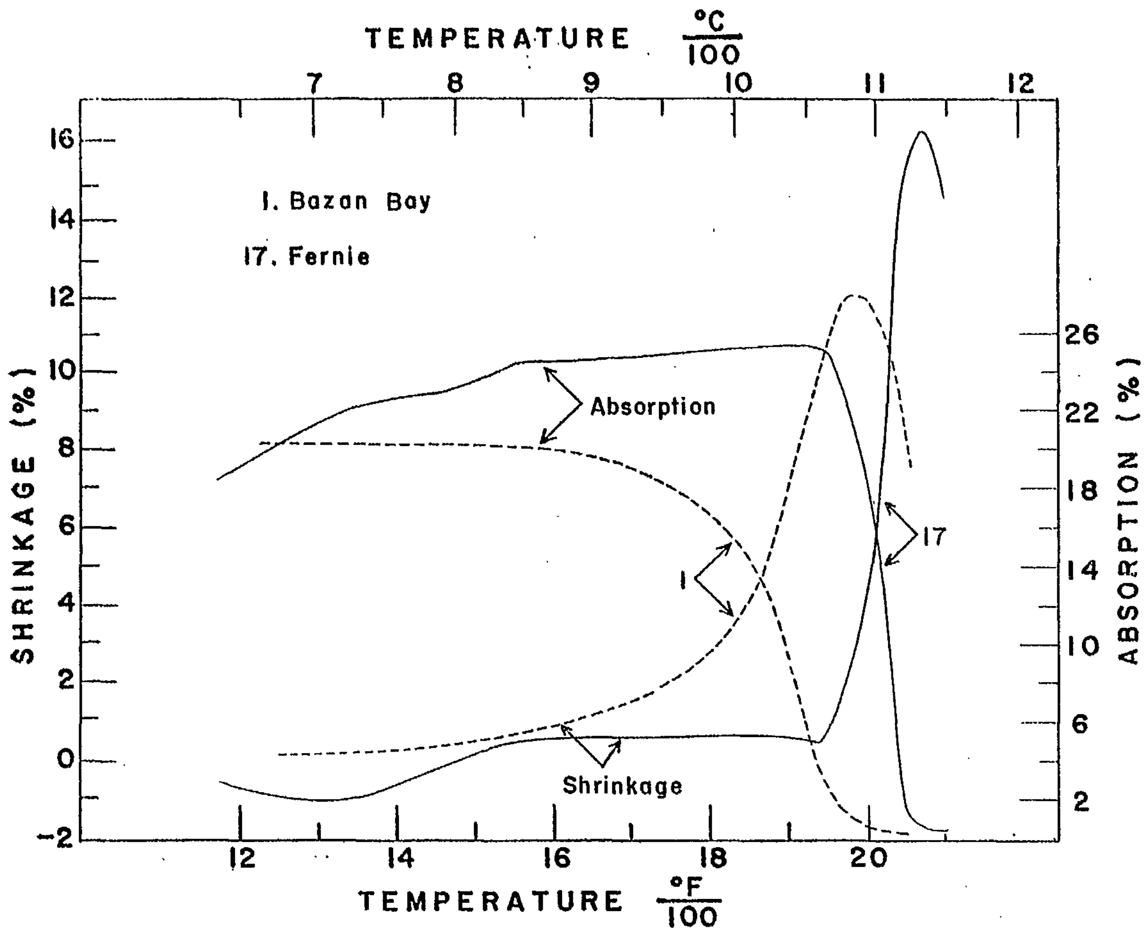

Figure 4. Temperature Gradient Curves of Bazan Bay and Fernie Samples.

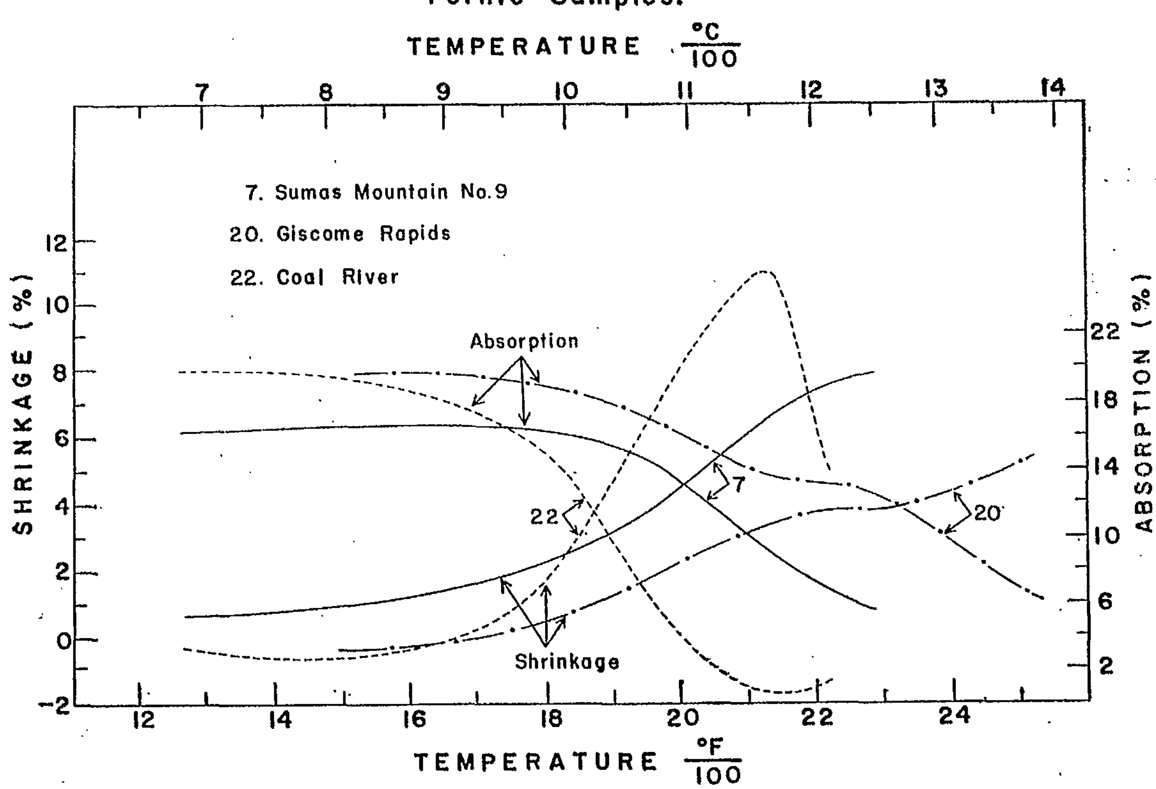

Figure 5. Temperature Gradient Curves of Sumas Mountain No.9, Giscome Rapids and Coal River Samples.

The temperature gradient curves for Bazan Bay are typical of many red-burning, common clays and some shales in British Columbia. Victoria Brown, Victoria Blue, Bear Creek, Haney Brown, Haney Blue and Enderby would probably have curves somewhat similar to those for Bazan Bay.

The temperature gradient curves for Fernie are typical of common clays which contain a substantial proportion of calcite or dolomite. Many such clays are found in British Columbia.

The curves for Coal River (Figure 5) indicate it has a medium firing range for production of fairly dense products. Shrinkage becomes excessive at low absorptions. Sumas Mountain Red, Whipsaw Creek, Wellington and Cranbrook would likely have similar curves.

The curves for Sumas Mountain No. 9 (Figure 5) indicate it has a long firing range with high shrinkage at the upper temperatures. The curves for Baker Creek, Quesnel, St. Eugene, Barnet, and Prince George are probably similar to Sumas Mountain No. 9, although Baker Creek has less shrinkage at comparative temperatures.

The curves for Giscome Rapids (Figure 5) indicate that this material is open-firing, and consequently difficult to vitrify at reasonable firing temperatures. Sumas Mountain A and Blue Mountain would have similar curves, although the Blue Mountain sample is the least refractory, and could not be fired to so high a temperature as the other two.

Differential Thermal Analysis

Standard DTA curves for API kaolinite H-4, API illite H-36, API montmorillonite H-23, and a chlorite from Mattawa, Ontario, are shown in Figure 6. The DTA curves of the British Columbia clays are shown in Figures 7, 8, 9 and 10. In these figures endothermic peaks point down and exothermic peaks point up.

The API standards are discussed by Kerr et al (26), and Molloy and Kerr (27). Examination of the curves shows that kaolinite has a large endothermic peak at 580°C, caused by the loss of combined water, and an intense exothermic peak at 980°C. The illite standard has a small endothermic peak at 580°C (the scale sensitivity of 10 is four times as great as scale 40 used for kaolinite) and small peaks making up an endothermic-exothermic doublet at 940°C and 980°C. The montmorillonite standard has a medium-sized endothermic peak at 710°C and a prominent endothermic-exothermic doublet at 875°C and 925°C. The chlorite sample has a sharp endothermic peak at 650°C, two small endothermic peaks at 810°C and 850°C, and an intense exothermic peak at 870°C.

The illite standard, according to Molloy and Kerr (27), probably contains a mixed-layer montmorillonite-illite. The intense exothermic peak shown on the illite curve indicates the presence of organic material, pyrite, and siderite.

The standards have absorbed water peaks at approximately 150 to 200°C. Montmorillonite has a very large peak here, which, in the case of H-23, is a large double peak typical of a calcium montmorillonite. The illite standard curve has a prominent adsorbed water peak, smaller than that of montmorillonite. The kaolinite and chlorite standard curves have a small adsorbed water peak.

The DTA curves of the British Columbia clays vary considerably, and many of them suggest that the samples contain mixtures of clay minerals. Bazan Bay, Bear Creek, Haney Brown and Enderby have similar curves. The large adsorbed water peaks at approximately 150°C suggest the presence of a montmorillonoid. The remainder of the clay mineral peaks are relatively small and suggest the presence of a hydrous mica (illite) or of illitic and

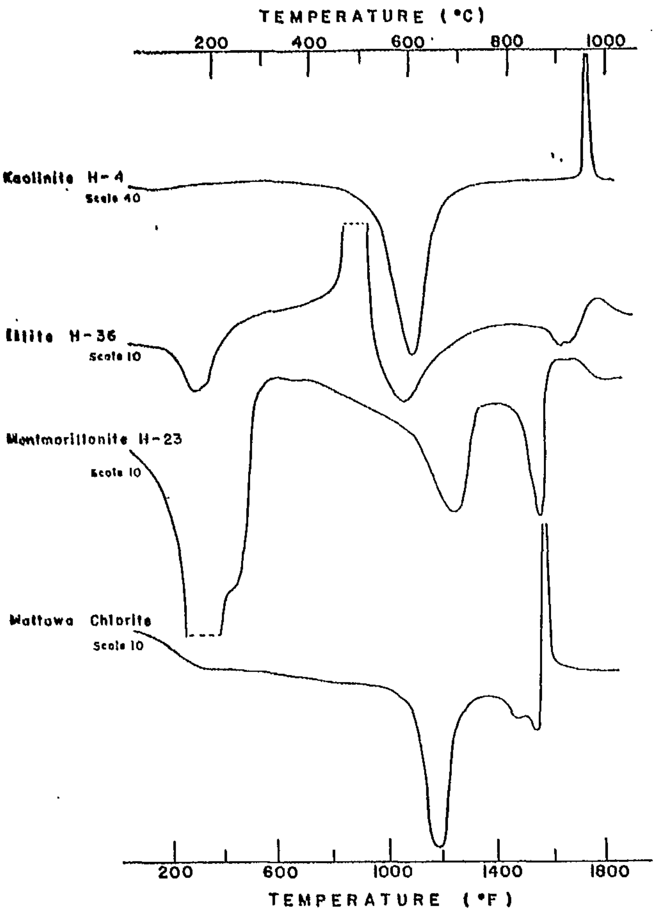

Figure 6. DTA Curves of Standards.

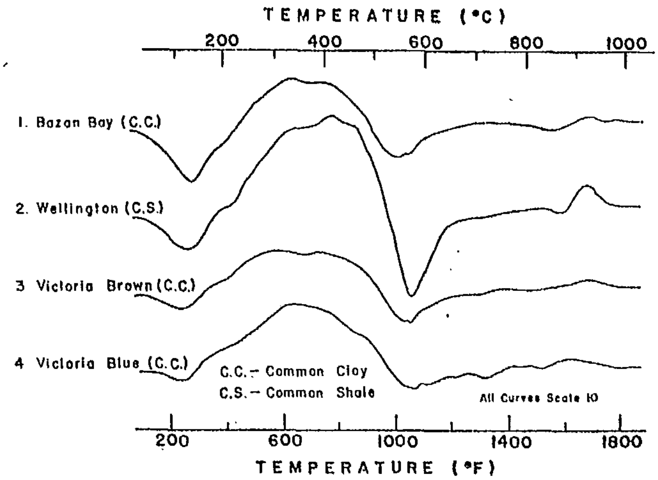

Figure 7. DTA Curves of Clays and Shales from Vancouver Island.

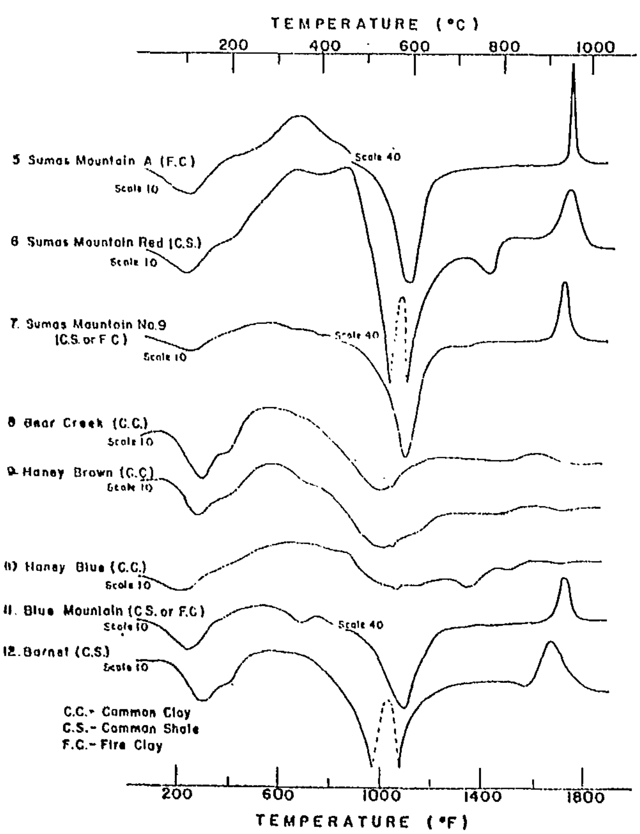

Figure 8. DTA Curves of Clays and Shales from Lower Mainland of British Columbia.

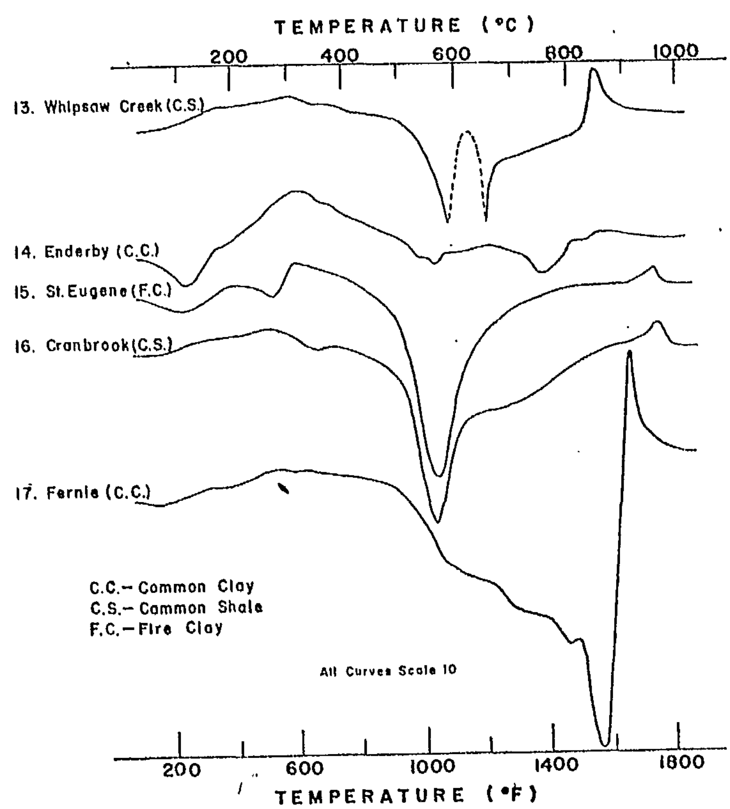

Figure 9. DTA Curves of Clays and Shales from the Southern Interior of British Columbia.

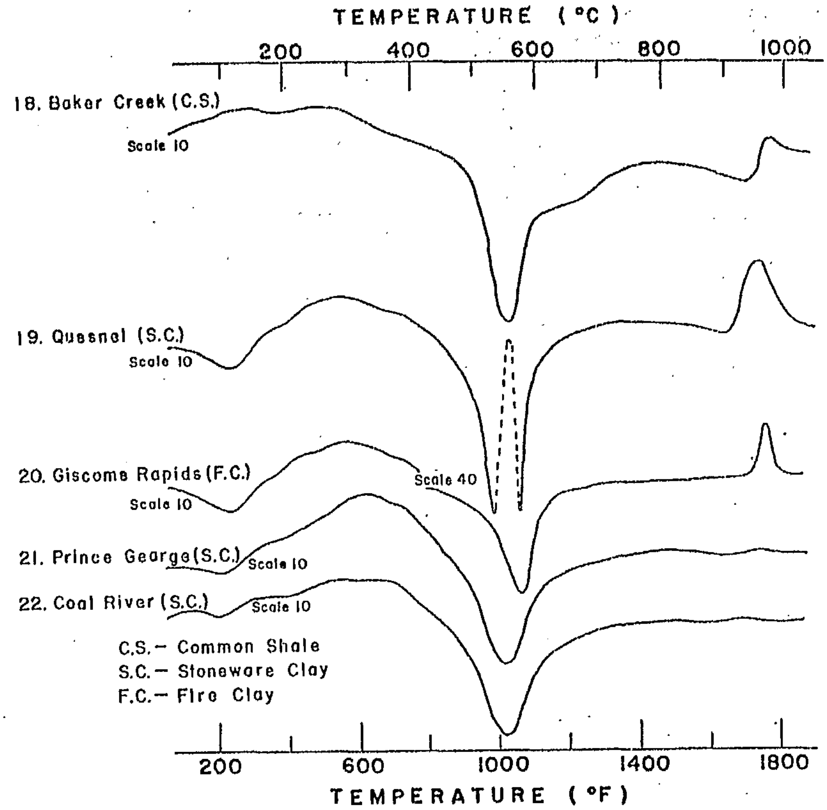

Figure 10. DTA Curves of Clays and Shales from the Northern Interior of British Columbia.

chloritic clay minerals. Enderby has an endothermic peak at 800°C, indicative of calcite and a broad exothermic peak at 350°C caused by oxidizable material.

Victoria Brown, Victoria Blue and Haney Blue are, in general, alike and the majority of the peaks suggest that the principal clay mineral is a hydrous mica or illitic and chloritic clay minerals. In Victoria Blue and Haney Blue, a small endothermic peak at 750°C suggests the presence of a very small amount of calcite.

For Sumas Mountain A, Sumas Mountain No. 9, Blue Mountain and Giscome Rapids, the large endothermic peak at 580°C and the exothermic peak at about 960°C, obtained at scale 40, suggest that the principal clay mineral is of the kaolinite group. For the same reasons, the presence of smaller amounts of a kaolinite-group mineral is indicated in Barnet, Sumas Mountain Red, Cranbrook, St. Eugene, Quesnel, Baker Creek, and possibly Wellington, although other clay minerals are also present, judging by the smaller reactions (scale 10) and the size of the adsorbed water peaks. The large, adsorbed water peak at 200°C suggests the presence of a montmorillonoid in Barnet and in Wellington. The shape of the same peak in Sumas Mountain Red, which is interfered with by oxidizable material, also suggests that there is a montmorillonoid in that sample.

The curves for Prince George and Coal River suggest that the principal clay minerals are illitic and chloritic. The curve for Whipsaw Creek indicates that the principal clay mineral in the sample is chloritic. The curve for Fernie has little indication of clay mineral reactions. The major peaks on the Fernie curve in the 800 to 950°C region are produced by dolomite and calcite.

The Sumas Mountain Red curve has a peak at 780°C, caused by a small amount of calcite.

The curves of most of the samples have dull exothermic peaks in the 300 to 400°C region which are indicative of a small amount of organic material. The Wellington and Sumas Mountain Red curves have a large exothermic peak at this temperature. The size of the latter peaks shows that these samples have an appreciable amount of oxidizable material — probably organic material and possibly pyrite or siderite — which could cause bloating during firing.

The Bazan Bay, Victoria Brown, Victoria Blue, Bear Creek, Haney Brown, Haney Blue and Enderby have very small peaks at 573°C caused by the inversion of quartz from the low to the high form. In the other curves this reaction is completely masked by the endothermic clay peak.

The curves for Blue Mountain, St. Eugene and Cranbrook have a small endothermic peak at 300-350°C which is probably caused by goethite. Several of the other curves have a very small peak in this area which could also be caused by this mineral.

The curves for Bazan Bay, Victoria Brown, Victoria Blue, Bear Creek, Haney Brown, Haney Blue and Enderby have very small peaks in the 800 to 1000°C region. This feature could be caused by a low percentage of clay mineral in the sample, but is probably the result of a mixture of clay minerals whose endothermic-exothermic reactions are interfering with each other in this temperature range.

X-Ray Diffraction Analysis

The minerals identified in the fine fractions of each sample by X-ray diffraction are shown in Table 6. Those identified by X-ray diffraction and microscopic examination are shown in Table 7. For the latter work the coarse fractions from the X-ray sample centrifugation were used in some cases; but in most instances, particularly for the shales, the plus 200 mesh fractions from the washing tests were used to establish the major minerals in the coarse fraction.

Miscellaneous Properties

The chemical analyses of thirteen samples are shown in Table 8. The amount of plus 200 mesh non-clay material, and the percentage of quartz determined by DTA and by the Trostel and Wynne chemical method, are shown in Table 9.

In most instances, the percentage of quartz determined by the chemical method is greater than that by the DTA method. There may be at least two reasons for this. Firstly, the chemical method may also include amorphous silica in addition to free quartz, whereas the DTA method is based on a peak produced by the inversion of quartz from the low to the high form. Secondly, the DTA results are based on potter's flint as a standard, which may be considerably coarser than the quartz in some of the samples.

TABLE 6

X-Ray Diffraction Analysis of Fine Fractions

Sample	Hydrous Mica (Illite)	Kaolinite Group	Montmorillonoid	Chlorite	Mixed Layer Minerals	Quartz	Feldspar
1. Bazan Bay (C.C.)	D				(A) Montmorillonoid - Intergradient chlorite	C	D
2. Wellington (C.S.)	D	C		A	(B) Illite - Montmorillonoid	C	
3. Victoria Brown (C.C.)	B	D		B	(B) Chlorite - Vermiculite	C	D
4. Victoria Blue (C.C.)	C		B	A		C	D
5. Sumas Mountain A (F.C.)		A			(C) [1]Vermiculite - Intergradient chlorite	B	
6. Sumas Mountain Red (C.S.)		B	B		(C)[1]Montmorillonoid - Chlorite	C	C
7. Sumas Mountain No. 9 (C.S.)		A	D			D	
8. Bear Creek (C.C.)	D		A		(B) Chlorite - Montmorillonoid (C) Illite - Montmorillonoid	D	D
9. Haney Brown (C.C.)	D				(A) Montmorillonoid - Chlorite (C) Illite - Montmorillonoid	C	D
10. Haney Blue (C.C.)	A			B		B	A
11. Blue Mountain (C.S.)	D	A					
12. Barnet (C.S.)	D	B	A			D	
13. Whipsaw Creek (C.S.)	C			A		C	D
14. Enderby (C.C.)	C	D	A	D	(C) Chlorite - Montmorillonoid	C	
15. St. Eugene (F.C.)	A	A				D	
16. Cranbrook (C.S.)	B	B				B	
17. Fernie (C.C.)	B				(B) Chlorite - Vermiculite	D	
18. Baker Creek (C.S.)	B	B				B	
19. Quesnel (S.C.)	D	A	B		(C) [1]Vermiculite - Intergradient chlorite	C	
20. Giscome Rapids (F.C.)	D	A	D		(C) [1]Vermiculite - Intergradient chlorite	C	
21. Prince George (S.C.)	B	B			(C) [1]Vermiculite - Intergradient chlorite	B	
22. Coal River (S.C.)	A	B				C	

A Abundant
B Moderate
C Minor
D Trace

C.C. Common Clay
C.S. Common Shale
F.C. Fire Clay
S.C. Stoneware Clay

[1] Identification of collapsing phase uncertain.

TABLE 7

X-Ray Diffraction of Coarse Fractions

Sample	Minerals Identified
1. Bazan Bay	Quartz, feldspar
2. Wellington	Quartz, feldspar
3. Victoria Brown	Quartz, feldspar
4. Victoria Blue	Quartz, feldspar
5. Sumas Mountain A	Quartz, kaolinite group mineral
6. Sumas Mountain Red	Quartz, kaolinite group mineral
7. Sumas Mountain No. 9	Quartz,
8. Bear Creek	Quartz, feldspar
9. Haney Brown	Quartz, feldspar
10. Haney Blue	Quartz, feldspar, mica
11. Blue Mountain	Quartz, minor mica
12. Barnet	Quartz, feldspar
13. Whipsaw Creek	Chlorite, mica, quartz, feldspar
14. Enderby	Quartz, feldspar, mica
15. St. Eugene	Quartz, goethite, rare mica
16. Cranbrook	Quartz, mica, kaolinite group mineral, feldspar
17. Fernie	Quartz, perhaps feldspar
18. Baker Creek	Quartz, minor mica
19. Quesnel	Quartz
20. Giscome Rapids	Quartz, mica, kaolinite group mineral
21. Prince George	Quartz, minor mica
22. Coal River	Quartz, gypsum

TABLE 8

Chemical Analyses of Selected Clays and Shales from British Columbia

Sample	SiO_2 %	FeO %	Fe_2O_3 %	TiO_2 %	Al_2O_3 %	CaO %	MgO %	Organic Carbon %	CO_2 %	S %	Na_2O %	K_2O %	H_2O at 110°C (Moisture) %	H_2O +110°C %	L.O.I. %
1. Bazan Bay	57.80	1.66	5.61	0.82	17.20	2.45	2.79	0.19	0.26	0.018	2.44	1.69	1.85	5.27	7.47
5. Sumas Mountain A	54.88	1.28	1.00	1.85	27.18	0.78	0.44	0.34	0.82	0.060	0.23	0.88	0.56	10.16	11.65
6. Sumas Mountain Red	56.08	5.40	2.15	0.99	18.67	1.70	1.71	0.56	2.52	0.022	1.26	1.16	0.78	7.14	8.81
7. Sumas Mountain No. 9	52.12	5.08	2.22	1.09	24.52	0.59	0.23	0.12	3.72	0.019	0.13	0.55	0.72	8.48	12.90
8. Bear Creek	55.72	1.29	6.64	0.83	17.27	2.06	3.56	0.15	0.24	0.016	2.48	1.65	2.58	5.83	8.41
9. Haney Brown	55.88	1.10	6.61	0.86	17.55	3.00	4.06	0.14	0.56	0.015	2.60	1.74	1.86	4.28	6.54
10. Haney Blue	57.64	3.25	3.34	0.73	16.65	4.50	4.18	0.15	0.80	0.035	3.05	1.69	0.71	2.88	4.41
12. Barnet	61.48	0.07	4.65	0.74	19.35	1.35	0.60	0.11	n.d.	0.014	1.52	1.75	2.23	6.51	8.96
15. St.Eugene	59.20	7.79		0.86	21.33	0.50	0.42	-	-	-	1.04	2.94	-	-	6.74
16. Cranbrook	56.84	n.d.	5.46	0.77	24.74	0.28	0.55	0.04	0.33	0.007	0.67	4.67	0.17	5.01	5.42
18. Baker Creek	78.16	0.90	0.57	0.68	12.28	0.10	1.13	0.06	n.d.	0.022	0.11	2.75	0.10	3.26	3.60
19. Quesnel	75.76	0.26	1.57	0.81	13.40	0.10	0.94	0.05	0.22	0.030	0.078	0.95	0.70	5.48	6.29
20. Giscome Rapids	67.72	n.d.	1.36	1.19	19.60	0.16	0.62	0.04	n.d.	0.012	0.06	0.73	0.73	7.54	8.19

TABLE 9

Miscellaneous Properties of Some British Columbia Clays and Shales

Sample	Plus 200 Mesh Material %	Quartz by DTA %	Quartz by Chemical Method %
1. Bazan Bay	3.35	19	26.48
2. Wellington	0.85	18	*
3. Victoria Brown	4.05	15	*
4. Victoria Blue	3.45	13	*
5. Sumas Mountain A	10.55	17	21.58
6. Sumas Mountain Red	25.95	18	30.46
7. Sumas Mountain No. 9	13.40	15	21.6
8. Bear Creek	1.10	15	20.88
9. Haney Brown	2.65	16	26.48
10. Haney Blue	1.70	16	31.68
11. Blue Mountain	8.35	13	*
12. Barnet	28.45	22	33.24
13. Whipsaw Creek	60.00	14	*
14. Enderby	26.40	18	*
15. St. Eugene	*	28	*
16. Cranbrook	1.45	25	27.80
17. Fernie	0.35	18	*
18. Baker Creek	7.05	48	64.9
19. Quesnel	1.25	58	55.5
20. Giscome Rapids	23.50	39	43.72
21. Prince George	*	44.5	*
22. Coal River	1.60	54	*

* Figures not available.

Discussion and Conclusions

The effect of various clay and non-clay minerals on the properties of clays and shales, and their effect on ceramic products, have been investigated by many authors. Grim (28) has recently reviewed this subject and Brady (15, 16) has discussed the effect of various minerals on some Canadian clays. Minerals of the kaolinite group are refractory and white-firing. Hydrous or coarse particle micas, montmorillonoids, chlorites, vermiculites, or mixed-layer minerals of these materials, are less refractory and usually fire to a dark buff, salmon, red, or brown colour.

Quartz, a refractory mineral by itself, when present in normal quantities in heterogeneous mixtures, forms low-melting silicates particularly with non-refractory constituents. Feldspar, a common constituent of clays and shales, acts as a flux. Various carbonates such as dolomite and calcite, and iron-bearing minerals such as goethite, siderite and pyrite, help to reduce the refractoriness of a clay or shale and often have a great influence on the fired properties and firing curves.

Bazan Bay, Victoria Brown, Victoria Blue, Bear Creek, Haney Brown, Haney Blue, and Enderby are common clays consisting mainly of heterogeneous mixtures of non-refractory clay minerals, quartz, and feldspar. The clay minerals in them are mainly hydrous micas, montmorillonoids, chlorites, or mixed-layer minerals. The refractory clay minerals of the kaolinite group are either absent or present only in trace amounts. The combination of these non-refractory clay minerals with quartz, feldspar and minor amounts of other minerals usually produces a low-melting mixture, such as Bazan Bay (Figure 4), which has a short firing range. As a result, the above clays have pyrometric cone equivalents (PCE's) of cones 2 (approximately 1142°C), to 4½ (approximately 1172°C). It is usually difficult to fire successfully such products as dense face brick or sewer pipe from these clays, which are usually more suitable for the production of drain tile, building tile, flower pots, or common brick. Clays of this type are usually salmon- to red-firing.

Fernie is a special type of common clay which is frequently encountered. It contains hydrous mica and a mixed layer chlorite-vermiculite which, together with quartz, possibly feldspar, and a substantial amount of dolomite and calcite, produce a low-fusion material with a very short firing range (Figure 4). It is very difficult to produce a dense products, with uniform properties, from such a clay unless extremely close temperature control is maintained during the high-fire period. Materials such as this usually fire to a cream, buff, or greenish-buff colour.

Wellington, Whipsaw Creek and Sumas Mountain Red are non-refractory common shales which have PCE's of cone 10 or less, for much the same reasons as the above clays (except Fernie). Sumas Mountain Red is slightly more refractory because it contains a moderate amount of kaolinite.

Sumas Mountain No. 9, Blue Mountain, Barnet, Cranbrook and Baker Creek are common shales having PCE's between cones 13 (approximately 1321°C) and 20 (approximately 1542°C). These samples contain a moderate to abundant amount of kaolinite-group mineral which makes them more refractory and helps to produce a longer firing range than a common clay such as Bazan Bay. The samples also contain mica, (either in the hydrous mica clay mineral form or as coarse mica) and quartz. In addition, Cranbrook and Barnet contain feldspar, and Barnet contains a montmorillonoid. Cranbrook contains 24.74% Al_2O_3, which is a high content of aluminum for a shale of this type.

The stoneware clays Quesnel, Prince George and Coal River have approximately the same refractoriness as the above shales. Each of them contains a moderate to abundant amount of kaolinite-group mineral which, along with a high quartz content, makes them more refractory than the common clays. They also contain substantial quantities of non-refractory clay minerals. They fire to a white, cream, or buff colour because of low FeO or Fe_2O_3 percentages and because they contain substantial amounts of kaolinite-group mineral and quartz. The kaolinite-group mineral and the quartz are mainly responsible for a medium to long firing range.

St. Eugene has properties similar to those of the stoneware clays, although it is less plastic than conventional stoneware materials. It is probably best classified as a low-grade fire clay. It contains abundant kaolinite and hydrous mica, along with quartz; this composition results in a light fired colour.

Sumas Mountain A and Giscome Rapids are refractory fire clays whose principal constituents are kaolinite and quartz plus minor or trace amounts of non-refractory clay minerals. They have a long firing range and fire to a light colour.

The British Columbia clays are more plastic than the shales, as would be expected. The clay minerals are the plastic ingredients of these materials; according to Marshall (18) and Grim (28), the plasticity is enhanced most by the minerals of the montmorillonite group, followed by kaolinite and hydrous mica (illite). Chlorite and vermiculite clay minerals probably behave like the hydrous micas. Mixed-layer clay minerals containing a montmorillonite are probably very plastic and, according to Grim (28), all mixed-layer clays might have higher plasticities than those of the individual minerals making up the mixed-layer unit.

A montmorillonoid or a mixed-layer mineral containing a montmorillonoid was identified in Bazan Bay, Victoria Blue, Bear Creek, Haney Brown, Barnet, Sumas Mountain Red and Quesnel in abundant or moderate amounts. Such minerals would have a great effect on increasing the plasticities of these materials.

A montmorillonoid was identified in all the very plastic clays of the Bazan Bay type (Figure 3) except Victoria Brown. In these clays the montmorillonoid, in addition to making the clay very plastic, increases the drying shrinkage and causes difficulty in drying. Clays of this type must be dried under carefully controlled conditions or a portion of the clay should be calcined to reduce plasticity and drying shrinkage.

An abundant to moderate quantity of a montmorillonoid was identified in Enderby and Quesnel clays. The adverse drying effect of the montmorillonoid is probably offset by the substantial quantity of plus 200 mesh non-clay material contained in Enderby (Table 9) and the high percentage of quartz in Quesnel (Table 9).

The plasticities of Sumas Mountain Red and Barnet shales are good because they contain a moderate quantity of a montmorillonoid. The non-plastic nature of the other components of these shales minimizes drying difficulties.

Substantial amounts of coarse, non-clay material, such as are found in the Sumas Mountain Red, Barnet, Whipsaw Creek, Enderby and Giscome Rapids samples, tend to reduce the plasticity and make drying less difficult. In the case of Whipsaw Creek, which has very low plasticity (Figure 2), the amount of coarse material is excessive.

Baker Creek, Quesnel, Giscome Rapids, Prince George and Coal River contain a large amount of quartz. Except in the Giscome Rapids sample, the quartz is mainly less than 200 mesh. Quartz is a non-plastic ingredient which reduces shrinkage and improves the drying quality of clays. Unreacted quartz frequently causes cracking of ceramic products during the cooling period, unless special precautions are taken. Frequently, clay products very high in quartz have a poor ring and are difficult to vitrify at normal firing temperatures. Baker Creek (Table 5) and Giscome Rapids (Table 5 and Figure 5) have some fired properties peculiar to a clay high in quartz.

The green and dry strengths of clay products manufactured from British Columbia clays or shales are probably enhanced whenever they contain a montmorillonoid or a mixed layer clay made up partly of a montmorillonoid. Non-plastic ingredients such as quartz, feldspar and coarse mica in these clays and shales reduce green and dry strength.

The small amount of calcite in some of the samples, provided it is not in the form of a large grains or pebbles, probably is not harmful. Calcite pebbles cause "lime popping" and so must be finely ground to avoid trouble with the fired product. A substantial amount of calcite imparts properties exhibited by Fernie (Table 4 and Figure 4).

According to the chemical analyses (Table 8), the Sumas Mountain samples contain small amounts of carbonates. DTA indicates Sumas Mountain Red has some calcite. Judging from the FeO content of the samples, each of them probably contains siderite. This mineral was indentified in Sumas Mountain No. 9. Siderite in excessive quantities could cause a problem during the oxidation period of firing, because the mineral breaks down into CO_2 and FeO at this time.

DTA shows that, of the samples selected, only Wellington and Sumas Mountain Red have excessive oxidizable material, which in the case of the latter is carbonaceous material and siderite. The former probably contains carbonaceous material and either pyrite or siderite. Clays of this type have a tendency to bloat; consequently, a prolonged oxidation period is required during firing. Materials of this type are often suitable for lightweight aggregate.

The chemical analyses of the thirteen samples show that the sulphur is very low and consequently, those samples contain very little or no pyrite. The analyses also show that the samples contain some carbon, most of it being in those from the Lower Mainland.

Acknowledgments

Helpful advice and assistance were given by R. M. Buchanan, Head, Ore Mineralogy Section, Mineral Processing Division. The chemical analyses were carried out in the chemical laboratories of the Mineral Sciences Division by D. J. Charette, R. Craig, Miss E. M. Penner, F. W. Brethour, and Miss F. E. Piercy.

Thanks are due to the individuals and companies who provided samples and information on them, and to J. M. McCammon of the British Columbia Department of Mines who collected some of the northern samples while on field work with his department.

References

1. Heinrich Ries and Joseph Keele, "Preliminary Report on the Clay and Shale Deposits of the Western Provinces", Memoir No. 24-E, Geological Survey Branch, Department of Mines, Canada (1912).
2. Heinrich Ries and Joseph Keele, "Report on the Clay and Shale Deposits of the Western Provinces (Part II)", Memoir No. 25, Geological Survey, Department of Mines, Canada (1913).
3. H. Ries, "Clay and Shale Deposits of the Western Provinces (Part IV)", Memoir 65, Geological Survey, Department of Mines, Canada (1915).
4. J. Keele, "Refractory Materials in Canada", Summary Report, Ceramic Division, Mines Branch, Department of Mines, Ottawa, 1916.
5. J. Keele, "Investigation of Clay and Shale Resources", Summary Report, Ceramic Division, Mines Branch, Department of Mines, Ottawa, 1917.
6. J. Keele, "Investigation of Clay and Shale Resources", Summary Report, Ceramic Division, Mines Branch, Department of Mines, Ottawa, 1918.

7. J. Keele, "Clays in British Columbia", Summary Report, Ceramic Division, Mines Branch, Department of Mines, Ottawa, 1919.
8. J. Keele, "Testing of Brick and Fire Clays from the Various Provinces", Summary Report, Ceramic Division, Mines Branch, Department of Mines, Ottawa, 1920.
9. Howells Frechette, "Laboratory Investigations", Investigations in Ceramics and Road Materials, Mines Branch, Report No. 645, Department of Mines, Ottawa, 1924.
10. J. F. McMahon, "Refractory Clays in Canada", Memorandum Series No. 57, Mines Branch, Department of Mines, Ottawa, Sept. 1932.
11. J. M. Cummings and J. W. McCammon, "Clay and Shale Deposits of British Columbia", Bulletin No. 30, British Columbia Department of Mines (1952).
12. J. G. Brady, "Physical Properties and Differential Thermal Analysis of Some Canadian Clays and Shales", J. Can. Ceram. Soc. 26, 71-89 (1957).
13. J. G. Brady, "Preliminary Evaluation of Clays and Shales for Clay Products", J. Can. Ceram. Soc. 29, 7-17 (1960).
14. R. L. Stone, "Temperature Gradient Method for Determining Firing Range of Ceramic Bodies", J. Am. Ceram. Soc. 36 (4), 140-142 (1953).
15. J. G. Brady, "The Nature and Properties of Some Western Canada Clays", J. Can. Ceram. Soc. 30, 72-86 (1961); Technical Bulletin TB21, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada, June 1961.
16. J. G. Brady, "The Effect of the Mineralogical Composition of Whitemud Formation Clays on Their Utilization", Research Report R90, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada, June 1962.
17. L. E. Thiess, "Method of Recording Plastic Properties of Porcelain Bodies", J. Amer. Ceram. Soc. 22, 286-289 (1939).
18. Claude L. Marshall, "A New Concept of Clay Plasticity", Bull. Amer. Ceram. Soc. 34, 54-56 (1955).
19. R. R. West and W. G. Lawrence, "The Plastic Behaviour of Some Ceramic Clays", Bull. Amer. Ceram. Soc. 38, (4), 135-138 (1959).
20. K. E. Bell, "Some Aspecets of the Plastic and Related Properties of Queenston Shale", J. Can. Ceram. Soc. 31, 106-119 (1962).
21. J. G. Brady, J. M. Humphreys and R. L. Eager, "Differential Thermal Analysis of Some Saskatchewan Clays", J. Can. Ceram. Soc. 22, 7-28 (1953).
22. Isao Hashimoto and M. L. Jackson, "Rapid Dissolution of Allophane and Kaolinite-Halloysite after Dehydration", pp. 102-113, Clays and Clay Minerals, Proceedings of the Seventh National Conference on Clays and Clay Minerals, Pergamon Press, London, 1960.
23. O. P. Mehra and M. L. Jackson, "Iron Oxide Removal from Soils and Clays by a Dithionite-Citrate System Buffered with Sodium Bicarbonate", pp. 317-327, Clays and Clay Minerals, Proceedings of the Seventh National Conference on Clays and Clay Minerals, Pergamon Press, London, 1960.
24. G. W. Brindley and S. Z. Ali, "X-ray Study of Thermal Transformations in Some Magnesian Chlorite Minerals", Acta Cryst. 3, 25-30 (1950).
25. L. J. Trostel and D. J. Wynne, "Determination of Quartz (Free Silica) in Refractory Clays", J. Amer. Ceram. Soc. 23, 18-22 (1940).
26. P. F. Kerr, J. L. Kulp, and R. K. Hamilton, "Reference Clay Minerals, API Research Project 49", published by Columbia University, New York, N.Y., 1951.
27. Martin W. Molloy and Paul F. Kerr, "Diffractometer Patterns of API Reference Clay Minerals", Amer. Mineralogist 46 (5 and 6), 583-606 (1961).
28. Ralph E. Grim, "Applied Clay Mineralogy", (McGraw-Hill Book Company, Inc., New York, N.Y., 1962), Chap. 3, pp. 52-140.

APPENDIX

Summary of Geological Data on Samples and some Geological-Mineralogical Relationships

The samples included two Palaeozoic marine shales (Cranbrook and Baker Creek) of Cambrian and Permian (?) age respectively. Both of these proved to be mixtures of illite, kaolinite and quartz. On the other hand, the Wellington sample from the marine Nanaimo group (Cretaceous) was rich in chlorite and mixed layer illite-montmorillonoid.

A large number of the samples were taken from non-marine strata of Tertiary age. These include Blue Mountain, Barnet, Whipsaw Creek, Quesnel, Giscome Rapids, Coal River, the three Sumas Mountain samples, and also probably those from Prince George and St. Eugene. With the notable exception of the Whipsaw Creek shale all Tertiary samples were rich in kaolinite minerals and deficient in chlorite. Hydrous micas, montmorillonoids, quartz and feldspars varied greatly. Most of the fire clay or stoneware clay samples within this group contained mixed-layer minerals with aluminous interlayer material (intergradient chlorite). "Chlorites" of this type typically occur as products of near-surface weathering in certain acid soils.

Enderby and Fernie are Recent non-marine clays.

The remaining samples were taken from marine clays of Pleistocene-Recent age. Victoria Blue and Haney Blue are relatively unweathered, whereas Bazan Bay, Victoria Brown, Bear Creek, and Haney Brown are weathered surface clays. The effects of weathering upon these clays are most readily observed in the Haney Blue and overlying Haney Brown samples, where chlorite and illite appear to have been partially altered to montmorillonoids within the weathered (brown) surface clay. In the case of the Bazan Bay sample, weathering has resulted in the formation of aluminous interlayer complexes within the expandable clay minerals.

The geological data on the Coal River, Quesnel and Baker Creek samples was provided by J. W. McCammon of the British Columbia Department of Mines and Petroleum Resources. Information on most of the remaining samples was provided by Dr. J. G. Fyles of the Economic Geology Division, Geological Survey of Canada.