

TN
26
ESK
NO. 128
1954

CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
MINES BRANCH
OTTAWA

PRELIMINARY REPORT
ON COATED LIGHTWEIGHT CONCRETE AGGREGATE
FROM CANADIAN CLAYS AND SHALES

PART VI

BRITISH COLUMBIA

by

H. S. Wilson

Industrial Minerals Division

Price 50 cents

Memorandum Series No. 128

This document was produced
by scanning the original publication.

OCTOBER, 1954

Ce document est le produit d'une
numérisation par balayage
de la publication originale.

CONTENTS

	<u>Page</u>
Preface	
Introduction	
Definition of lightweight aggregate	1
Types of clay and shale lightweight aggregate	1
Desirable properties of a lightweight aggregate	2
Test Methods	4
Stationary furnace tests	4
Rotary kiln tests	6
Determination of physical properties	8
Relation of chemical properties to the bloating of clays and shales	9
Application of chemical analyses to problem of producing coated aggregate	13
Clays and shales in British Columbia	22
General distribution	22
Locations, descriptions and test results	23
Golden	23
Enderby	24
Kamloops	25
Chase	25
Falkland	26
Quilchena	26
Ferne	27
Kimberley	27
Grand Forks	28
Princeton	28
Hope	35
Kilgard	35
Bear Creek	36
Haney	37
Port Moody	37
Barnet	37
McNab Creek	38
Victoria	38
Saanichton	39
Hillbank	39
Somenos	39
East Wellington	40
Gabriola Island	40
Campbell River	40

	Page
References	42

ILLUSTRATIONS

Figure 1 - Effect of preheating on the specific gravity of bloated specimens of shale high in combustible carbon	15
Figure 2 - Composition diagram of major oxides in clays and shales showing proportions required to produce coated aggregate	17
Figure 3 - Diagram showing relationship of type of fluxes in clays and shales to width of vitrification range	19
Figure 4 - Summary of lightweight aggregate test results - British Columbia	21
Map - Southern British Columbia, showing approximate locations of clays and shales suited for coated aggregate, and those unsuited for coated aggregate due to agglomeration	41

PREFACE

In 1949 the Mines Branch began an investigation of possible sources of clays and shales in Canada suitable for the production of lightweight concrete aggregate.

For many years much of the need for lightweight aggregate was met by the use of industrial cinders. However, in the past few years the supply of cinders has diminished because many industries have switched from lump coal to oil, gas, and pulverized coal as fuels.

Clays and shales appear to be the most suitable materials for structural concrete aggregate owing to their widespread occurrence. A somewhat similar aggregate is produced by "foaming" blast furnace slag but it can be produced only in areas where steel plants or similar industries are located.

This report is the sixth of a series dealing with the possible production of lightweight concrete aggregate from Canadian clays and shales. The object of these reports is to make available to the public information on the location of clays and shales which show the most promise in this field and to assist in the elimination of those materials that are decidedly unsuited to lightweight aggregate production.

The aim of the laboratory test work has been to produce the highest quality aggregate, namely the "coated" type, at the lowest cost by using the raw materials in their natural state. Some of the materials described as being unsuited to "coated" aggregate production might be found satisfactory for a "sintered" product but owing to the limited quantity of the samples, tests were not made to determine that possibility.

The five preceding publications on the results of tests on materials from various provinces are;

- Part I - Alberta - Memorandum Series No. 117.
- Part II - Manitoba and Saskatchewan - Memorandum Series No. 120.
- Part III - Ontario - Memorandum Series No. 121.
- Part IV - New Brunswick, Nova Scotia and Prince Edward Island - Memorandum Series No. 122.
- Part V - Quebec - Memorandum Series No. 126.

John Convey,
Director,
Mines Branch.

COATED LIGHTWEIGHT CONCRETE AGGREGATE

FROM CANADIAN CLAYS AND SHALES

PART VI

BRITISH COLUMBIA

by

H. S. Wilson
Industrial Minerals Division

INTRODUCTION

by

J. G. Matthews*

Definition of Lightweight Aggregate

A lightweight aggregate may be defined as an aggregation of fine and coarse particles of a material which because of its light weight, strength, low absorption, and chemical stability, can be mixed with cement to form a concrete of pre-determined characteristics. Coated lightweight aggregate has a thin, hard, smooth, outer shell or coat which gives the aggregate improved properties of high strength, low absorption, and good workability.

Types of Clay and Shale Lightweight Aggregate

Two distinct types of lightweight aggregate are made from clays and shales namely, coated type aggregate and sinter type aggregate.

The first type is made by rapid firing in a rotary kiln. Gases released from within the clay or shale during the pyroplastic condition

*Those sections of the report preceding the section on Clays and Shales in British Columbia and a portion of the location, description and test results were prepared by J.G. Matthews who left the Government Service in May, 1952.

cause it to expand into light, cellular particles. The particles are usually well rounded owing partly to the bloating action and partly to the tumbling taking place in the kiln. The quantity and quality of the fluxes in the shale allow this expansion or bloating to take place at a temperature below that at which the particles become sticky so that the product is discharged from the kiln in individual, coated particles. An ideally coated aggregate requires no crushing after firing to supply the required grade sizes.

Sinter type aggregate may be made in either the rotary kiln or sintering machine. The rotary kiln process for producing a sinter type aggregate differs from that for coated aggregate in that the product is crushed to supply the required grade sizes. Owing to the quantity and quality of the fluxes present this material cannot be fired with sufficient expansion below the temperature at which sticking occurs, and as a result the individual particles agglomerate and are discharged as clinker. The sinter aggregate produced on the sintering machine except for being harsher, is similar to the sinter product from the rotary kiln. The raw material for the sintering machine process is finely ground and mixed with a pulverized fuel, pelletized, placed on a travelling grate and ignited. A lightweight product is formed by bloating or sintering or by a combination of both depending upon the raw material. The sintering machine type product may be made from a greater variety of raw materials than the rotary kiln sinter and coated types.

Desirable Properties of A Lightweight Aggregate

The raw material selected for the production of lightweight aggregate must be capable of giving a product possessing the following desirable properties:

(a) High Strength-to-Weight Ratio

The product must be light to effect a worthwhile saving in weight and at the same time be strong enough to meet strength specifications. Variations in both the strength and weight may be effected by modifying the processing technique. As the strength of a product is increased, the weight is also increased and vice versa. Because of their strong shell and spherical nature, coated lightweight aggregate particles tend to give a product with a higher strength-to-weight ratio than other types. The actual maximum weights specified for a properly graded aggregate under A.S.T.M. specifications, designation C130-42 are 75 lb./cu.ft. for the fine aggregate and 55 lb./cu.ft. for the coarse aggregate.

(b) Good Workability

The smooth, spherical nature of coated clay and shale aggregate particles promotes good workability whereas aggregate particles with sharp corners make a harsh concrete mix that is difficult to work around reinforcing bars, tending to give a honeycomb structure.

(c) Low Absorption

An aggregate with a high water absorption, unless it has been pre-soaked, tends to dehydrate the cement which has a harmful effect on the setting of the concrete. Coated aggregates generally have a lower absorption than other aggregates because of the coating over the cellular interior.

(d) Uniform Size Gradation

The product must be composed of aggregate particles of a range of sizes with sufficient fine material to permit working the mix around forms and reinforcing bars. The grading prescribed may be referred to under A.S.T.M. specifications, designations C130-42.

(e) Chemical Inertness

A lightweight aggregate should not contain chemical impurities which might react with the cement or reinforcing materials with deleterious effects.

TEST METHODS

The equipment used for the laboratory evaluation of clays and shales for lightweight aggregate consisted of a small jaw crusher, screens, a gas-fired stationary furnace (capable of up to 2700°F), a drying oven, a 5" x 5' gas-fired rotary kiln, a bulk density container, a balance sensitive to one gram, and crushing strength apparatus.

Preparatory to testing, all samples were reduced in size to $-\frac{1}{8}'' + \frac{1}{4}''$. Samples that were not coarse enough or were too soft to stand crushing were pelletized in a small cement mixer, dried and screened to the above size range. Because of the short length of the rotary kiln, all samples were dried overnight in an oven maintained at 100°C to drive off the mechanically held moisture and thus prevent decrepitation when subjected to rapid heat.

Stationary Furnace Tests

Small amounts of each sample were tested first in the stationary furnace at various temperatures and heating times. These tests facilitated the elimination of materials obviously not suited to coated aggregate manufacture and the selection of the most promising ones for testing in the rotary kiln.

By firing the materials at various retention times and temperatures, it is possible to predict the relative length of vitrification

range of each material and to observe the relative amount of bloating. If a material shows little surface fusion with a dull appearance when well bloated, indications are favourable for trial in the rotary kiln. On the other hand if, on increasing the temperature and firing time, the material is not bloated until the surface shows a high degree of fusion (glassy appearance) indications are that it has a short vitrification range, and will give sticking and agglomerating trouble in the rotary kiln. Materials with a very narrow vitrification range are thus eliminated from further testing but materials having intermediate properties in this respect must be tested in the rotary kiln before any conclusions can be drawn.

Stationary furnace tests permit the screening out of materials that are poor bloomers and those that are, for economical reasons, too refractory. For the purposes of this investigation all materials that failed to show any bloating when fired in the stationary furnace at 2400°F for five minutes were classed as too refractory.

These tests also facilitate the elimination of materials that are extremely non-uniform in composition. Many materials especially those laid down under shallow water conditions contain varying amounts of the fluxes or refractory constituents. In coal-mine shales, non-uniformity is frequently caused by varying amounts of free carbon. Depending upon their extent these variations may mean the elimination of the material as a possible raw material.

As a result of the stationary furnace tests, materials that had good bloating properties with a reasonably good vitrification range, which were not too refractory, and which showed reasonable uniformity were selected for rotary kiln tests.

Rotary Kiln Tests

The selected dried materials were processed in a 5" x 5' gas-fired, rotary kiln. Although the kiln had variable pitch and speed, all materials were processed under the same retention time conditions to give a total retention time of about six minutes. The temperature for each run was kept as close as possible to the maximum temperature permissible for each material without having agglomeration of the charge. In general, this is the temperature at which commercial kilns producing coated aggregate operate. It is possible to produce the same result at a lower temperature with an increased retention time but only at a great sacrifice of the volume of material handled.

It should not be assumed that the products made in the 5" x 5' rotary kiln in this investigation are the best obtainable. In view of the number of samples covered and the limited amount of each, it was impossible to experiment with each sample to determine the best operating conditions. The small scale rotary kiln tests carried on in this investigation merely indicated which materials have the best possibilities for commercial rotary kiln coated aggregate.

The determining factor in whether or not a good bloating material is suited to coated aggregate manufacture is the degree of sticking and agglomeration of the particles when bloating. This property can be determined quite satisfactorily in the small kiln.

Based on the results of the stationary furnace and rotary kiln tests the materials were classified into five groups, as follows*:-

1. Materials considered suitable for coated aggregate production.

* The materials from British Columbia are classified in the summary table on page 21.

2. Materials which are good bloomers but which are not considered suitable for coated aggregate production because of their relatively narrow vitrification ranges and resultant sticking and agglomerating characteristics.
3. Materials which are poor bloomers.
4. Materials which are too refractory.
5. Materials which are non-uniform and which are a combination of two or more of the above classifications.

For anyone interested in the production of sinter aggregate in the rotary kiln the logical materials for experimental work, of those collected, would be those listed in Groups 1 and 2 above. Since a high bloating material is not desirable for sintering machine treatment, the possible raw materials for this type of aggregate are those listed in Group 3 above.

In connection with the materials classified in table form as having good possibilities for coated aggregate manufacture, it should be remembered that this classification is based only on the quality of product. Other factors which are of decided economic importance such as amount of material available, nearness to market, and availability of fuel are discussed if known, under the test results for each material.

It must also be kept in mind that this investigation is concerned only with the use of materials in their natural state. It is quite possible that chemical beneficiation would convert some of the unsuitable into suitable materials. Again, many materials classed as too non-uniform might prove quite suitable if finely ground and pelletized before firing. Such treatment, of course, would increase the cost of production.

Determination of Physical Properties

Three physical properties of the aggregate were measured, namely the bulk density, the crushing strength, and the volume expansion.

The bulk density was determined in a machined metal container of 1/30 cubic foot capacity on the product crushed to -3/8 inch + 8 mesh. The standard jiggling procedure as specified in A.S.T.M. designation C29-42 was followed. This size range (-3/8 inch + 8 mesh) approximates that specified in A.S.T.M. specifications, designation C130-42, and should have a bulk density value of less than 55 lb./cu.ft. to be acceptable.

The test used to determine the crushing strength was patterned on that carried out in other laboratories. The apparatus consisted of a steel cylinder, 2 inches inside diameter and 6 inches deep, into which the aggregate crushed to -3/8 inch + 8 mesh was poured without any tamping to a depth of $2\frac{1}{2}$ inches. A steel plunger, 1-31/32 inches in diameter, was used to apply pressure to the aggregate in a Carver Hydraulic Press and the amount necessary to give a compaction of 1 inch was noted. This was then converted to lb./sq. inch.

The true value of this test has not been determined. It should, however, provide a rough method of rating a product if the result is considered along with the weight of the product. Since weight and strength vary directly, the crushing strength-to-weight ratio gives a better method of evaluation.

The volume expansion of the product was determined simply by measuring the volume of the feed before firing and the product after firing, and by calculating the percentage increase. The volume expansion of a material affects the economy of the operation because the higher the volume expansion, the less the amount of feed material required to give the same volume of product.

It should be kept in mind that the mere expansion of a clay or shale does not necessarily mean that it will make a good concrete aggregate. Considerable test work must be done on any one material to determine the maximum allowable expansion necessary to give a product of the required strength. Neither is there any substitute for actual concrete tests in evaluating the product.

RELATION OF CHEMICAL PROPERTIES TO THE BLOATING
OF CLAYS AND SHALES

Review of Previous Work

T.E. Jackson⁽¹⁾ considered it possible that bloating of clays might be due to the evolution of oxygen as the ferric oxide passed into the ferrous oxide on combination with the silicates.

Orton and Staley⁽²⁾ thought that if Jackson's theory were correct all bloating clays would contain ferric oxide and should, therefore, bloat at the same temperature. They found, however, that clays bloated at different temperatures, and moreover, that many clays which contained iron did not bloat. They considered the cause of gas evolution to be chiefly the dissociation of sulphides and sulphates by silicic acid, which becomes increasingly active as the temperature rises and appropriates the bases formerly combined with the sulphur. They considered that the sulphur came out of solution as sulphur dioxide and that this gas was responsible for the bloating. They also recognized that sulphur did not oxidize to sulphur dioxide and escape until after the carbon had been oxidized. In many cases, especially if the firing was rapid, by the time the carbon was oxidized the clay had become too dense to allow the sulphur dioxide to escape and bloating resulted. They treated bloating as an undesirable quality and concluded

that it could be avoided by applying a deliberate and complete oxidation treatment, while the clay remained porous, to remove the carbon and sulphur.

Wilson⁽³⁾ considered that the gases which caused bloating when the clay or shale had reached the vitrified condition might have consisted of entrapped air, steam, sulphur dioxide and trioxide, carbon dioxide or monoxide, oxygen or hydrocarbons, absorbed during firing. He treated bloating as an undesirable quality of some clays and shales, and observed that it took place to a greater degree in the fine-grained, dense materials. He regarded expansion caused by entrapped gases in a semi-viscous body as due to two causes:

- 1) Improper oxidation resulting from insufficient heating time at temperatures below the vitrification range, where the gases were chiefly formed from the carbon, sulphur, and carbonates.

- 2) Decomposition of contained material during and above the vitrification temperature, the most common material being calcium sulphate which produced sulphur dioxide or trioxide.

Bleininger and Montgomery⁽⁴⁾ stated that if at any time the evolution of gaseous matter was rapid enough to produce pressure within the clay, then bloating was certain to take place and a vesicular structure would be formed. They recognized that both the physical constitution of the clay i.e., compactness and fine grain, as well as the mode of shaping are of as great, if not greater, importance than the amount of constituents present which form gases.

The United States Emergency Fleet Corporation⁽⁵⁾ which developed lightweight aggregate during World War I for use in the construction of concrete ships found that the clay or shale should be rich in compounds of

metallic oxides, carbon, sulphur, sodium, potassium, or other equivalent compounds, some of which, when the material is subjected to heat, will either act as a flux or give off gas.

Experiments by Jackson⁽⁶⁾ showed that not all the sulphur was evolved at low temperatures but that complex compounds of sulphur such as "ferrous sulpho-silicates" were formed. Jackson observed that sulphur is not retained at high temperatures without the presence of iron oxide in the clay. He believed that the bloating of clay was due to only that sulphur retained at high temperatures with iron and silica in the complex compounds.

Sullivan, Austin and Rogers⁽⁷⁾ when experimenting with making expanded clay building units found that, for most clays, best results were obtained when the kiln atmosphere was slightly on the reducing side. They also found that in general, high lime clays had a short bloating range and low lime clays, a longer one.

Austin, Nunes and Sullivan⁽⁸⁾ heated various clays in a tube furnace and determined quantitatively the gases evolved during bloating. They also determined the effects on bloating of variations in heating rates, rate of air flow, and the atmosphere. These investigators found that carbon dioxide, sulphur dioxide, and water were evolved at the bloating temperature. They believed that, since most carbonates decompose at low temperatures, the carbon dioxide was formed by the oxidation of the elemental carbon that remained in the clay, by reduction of the ferric oxide. They suggested that the sulphur dioxide might be evolved from the decomposition of residual calcium or manganese sulphate or intermediate compounds formed during the firing. The water evolved was considered to have come from some mineral other than clay as clay loses its crystal

lattice structure at a temperature below the bloating temperature. In general, the evolution of gases from clays varied inversely with the rate of heating, and directly with the air flow. It was shown that good bloating took place in a nitrogen atmosphere which indicated that the oxidation must come from within the clay rather than from a reaction with the atmosphere.

Conley, Wilson and Klinefelter⁽⁹⁾ made an extensive study of the availability of raw materials, methods for producing lightweight aggregate, and of causes of bloating. Their work indicated that various compounds of iron, alkali, and alkaline earths furnish the fluxes and gases necessary to bring about bloating. Using this assumption various admixtures of such compounds were added to non-bloaters and to poor bloaters with good results in some cases. They found that the results varied decidedly depending upon the clay to which the admix was made, and that each clay required a separate study. These authors attempted to correlate the bloating properties with chemical analyses, and from their work concluded that chemical analyses were only of partial value as they did not indicate the mineral form of the impurities. They observed that the mineral form of the impurities in the clay was the key to whether a clay or shale would bloat or not.

Charles M. Riley⁽¹⁰⁾ stated the two conditions necessary for bloating as follows:

- 1) "Enough of the material must fuse to fill the pore spaces so that gases being formed will be trapped. The fused material must, of course, be viscous enough so that the gas does not escape by bubbling through it."

2) "Some mineral or combination of minerals must be present that will dissociate and liberate a gas at the time when the mass of clay has fused to a viscous melt."

He classified materials as bloaters and non-bloaters and by plotting the chemical analyses on a composition diagram, was able to show that one condition of bloating could be defined i.e., the condition of proper viscosity at the bloating temperature. By adding pyrite, hematite, and dolomite to non-bloating mixtures, and by bringing the composition into the area defined on the composition diagram, Riley showed that these minerals could produce the gases necessary for bloating. It was also discovered that many igneous rocks whose compositions fell within the area of bloating on the composition diagram bloated well when ground and cast into briquettes. Riley supported the earlier contentions of Jackson⁽¹⁾ and thought the principal reason for bloating was the evolution of oxygen during the dissociation of Fe_2O_3 . He also recognized that pyrite probably dissociated to give sulphur dioxide at high temperatures and that dolomite probably formed intermediate compounds with the other constituents which retained some of the carbon dioxide until dissociating at the bloating temperature.

APPLICATION OF CHEMICAL ANALYSES
TO PROBLEM OF PRODUCING COATED AGGREGATE

As this investigation was concerned only with the highest grade of aggregate i.e., coated aggregate, the differences between materials found suitable for coated aggregate production and those that were not, were of more interest than the differences between non-bloating and bloating clays. Many materials proved to be excellent bloaters yet were found to be unsuitable for coated aggregate because of their narrow vitrification ranges,

and sticking and agglomerating qualities. Following stationary furnace and rotary kiln tests all materials tested were classified into one of five groups previously mentioned under Test Methods.

Chemical analyses were secured of representative materials from each of the classifications except the non-uniform materials. Not included in the chemical analyses plotted were materials that had an excessively high combustible carbon content such as shown by many coal mine shales. Small amounts of carbon are probably most beneficial to bloating but excessive amounts mask the normal reactions taking place and in the short heating time given the materials of high carbon content, only a thin surface coating of the particles showed any oxidation or bloating.

Some of the materials classed as poor bloomers would very probably be good bloomers or be found suitable for coated aggregate manufacture if the heating time were long enough to remove some of the excess carbon. The effect on bloating when excess carbon was removed by prolonged preheating, before subjection to bloating tests, is illustrated in Figure I. The decided improvement in the interior structure of the particles is not shown. When a material, high in combustible carbon is not preheated, the product expands by the swelling of the combustibles rather than by bloating. With prolonged preheat treatment and removal of carbon, a bloated cellular structure and a lighter product are developed. For these reasons shales high in combustible carbon were not considered to be representative of their classification as poor bloomers.

The conditions necessary for a clay or shale to be suitable for the production of a coated aggregate are as follows:

- 1) The material must contain a compound that will dissociate or form intermediate compounds that will dissociate, with the formation of a gas or

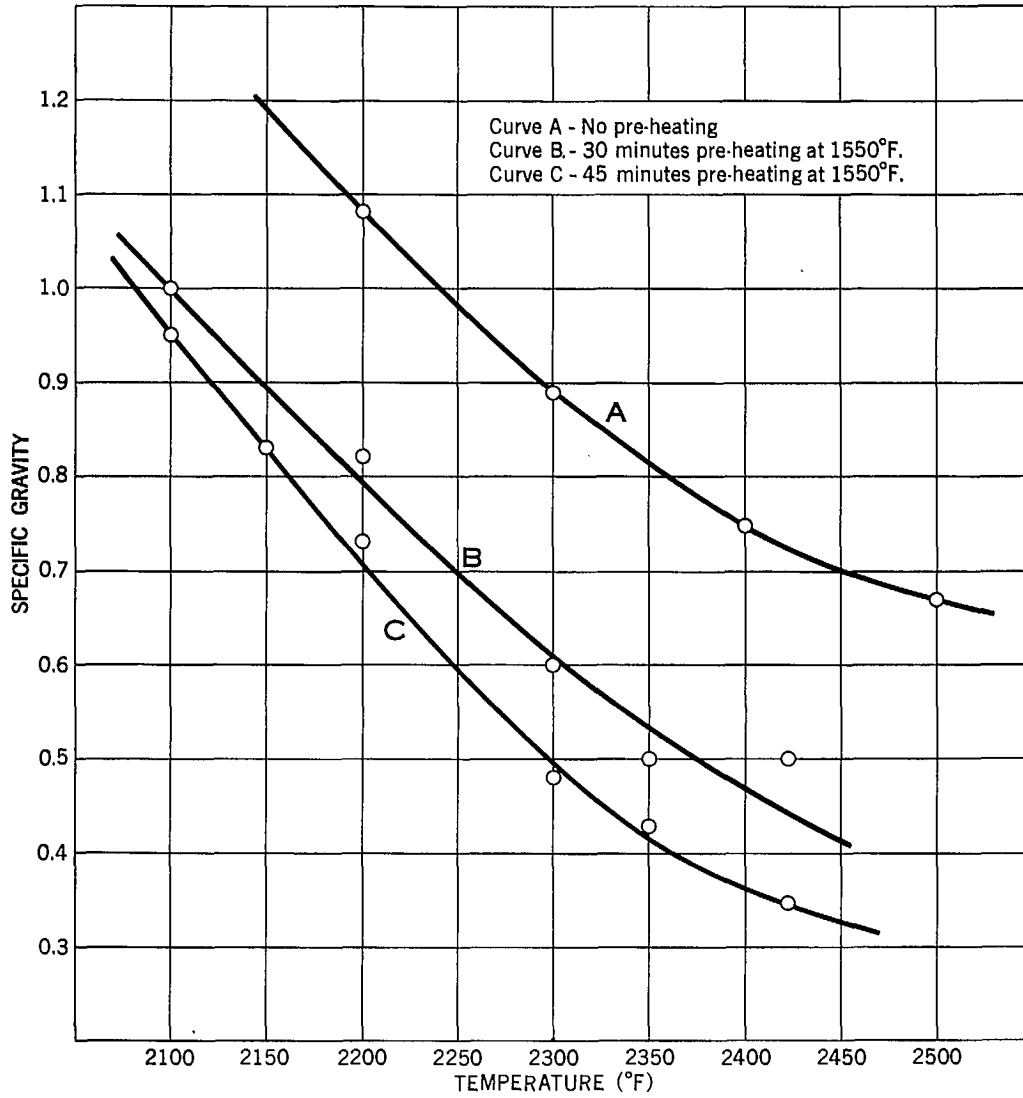


Figure 1 - Effect of preheating on the specific gravity of bloated specimens of shale high in combustible carbon.

gases at a temperature at which the material is in the pyroplastic condition.

2) The material when in the pyroplastic condition must have a high viscosity so that the released gases will be trapped, and so that the surface tension of the particles is great enough to draw each particle mass together and minimize agglomeration of the particles into a clinker.

3) The material must have a wide vitrification range to allow easy temperature control below the temperature at which sticking and agglomerating become excessive.

Previous work has shown that the chemical analysis of a material is of no value in determining whether the required gas-forming compound is present or not. However, in this investigation most materials showed some evidence of gas release or bloating with the exception of the refractory materials, a large number of which would show some bloating if the temperature were carried high enough. Other investigators have shown that a fraction of one per cent of a gas-forming compound is all that is required for good bloating of a clay or shale. In view of this it is probable that Condition 1 is not as important a determining factor as the conditions of high viscosity and wide vitrification range.

The composition diagram shown in Figure 2 with alumina, silica, and total fluxes at the corners shows that the viscosity condition requires the chemical composition of a clay or shale to be within a fairly well defined area. For this diagram the volatile material and minor constituents were neglected and the analyses recalculated on the basis of 100 per cent.

The vitrification range of a clay or shale for the purposes of lightweight aggregate manufacture covers the partially fused condition and

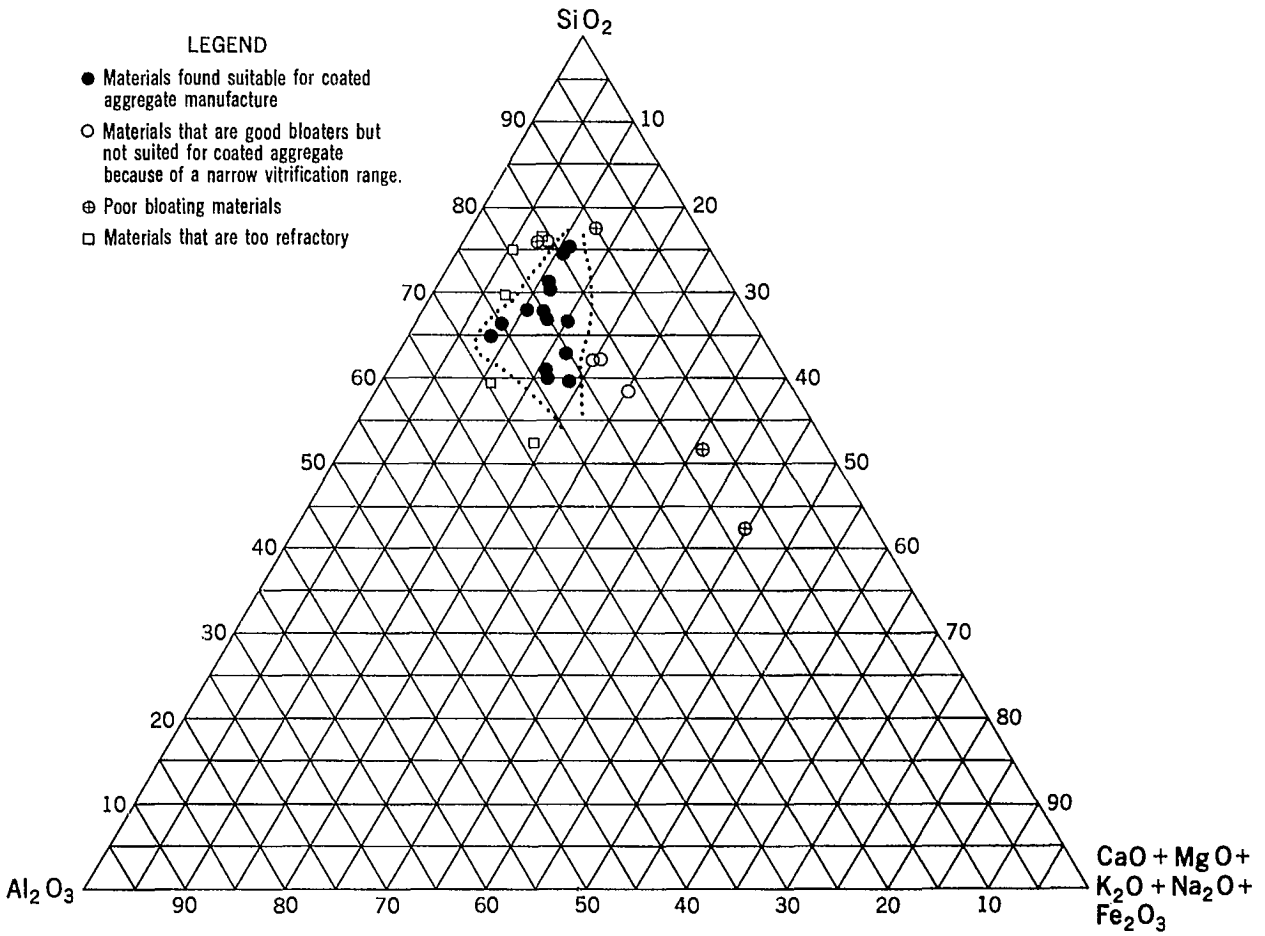


Figure 2 - Composition diagram of major oxides in clays and shales showing proportions required to produce coated aggregate. Dotted line represents approximate limits of materials suitable for coated aggregate.

is the range in temperature between the point of incipient fusion and the point at which the viscosity has decreased to unpractical working conditions. The lower limit of the vitrification range is fixed by the temperatures at which the eutectic composition of the components begins to liquefy. The upper limit is fixed by the character and quantity of the fluxes present.

The fluxes containing sodium and potassium will give a wider vitrification range than those containing calcium and magnesium because their high viscosity retards their interaction with the surrounding clay grains. Fluxes containing calcium and magnesium have a low viscosity and shorten the vitrification range. Ferric oxide is believed to be an intermediate flux. There seems reason to believe, therefore, that the vitrification range of a clay or shale should bear some relation to the proportions of the $K_2O + Na_2O$ and $CaO + MgO$ fluxes.

In Figure 3, the ratios of the $K_2O + Na_2O$ fluxes and $CaO + MgO$ fluxes have been plotted for the materials that had a wide vitrification range and were found suitable for making a coated aggregate, and for the materials that were unsuitable and had too narrow a vitrification range. It is apparent from this diagram that a material, to have a wide enough vitrification range, should have an excess of the $K_2O + Na_2O$ fluxes over the $CaO + MgO$ fluxes. With only one exception all materials found suitable for making coated aggregate in this investigation had a value of greater than 1 for the ratio of $K_2O + Na_2O$ to $CaO + MgO$. The materials with too narrow a vitrification range had a value of less than 1.

The vitrification range of a clay or shale-coated aggregate raw material has an important bearing on the size range of the feed for the rotary kiln. In most materials the extreme fine sizes start to agglomerate at a temperature below that sufficient to cause good bloating of the coarse sizes. However, if the vitrification range is wide this temperature may

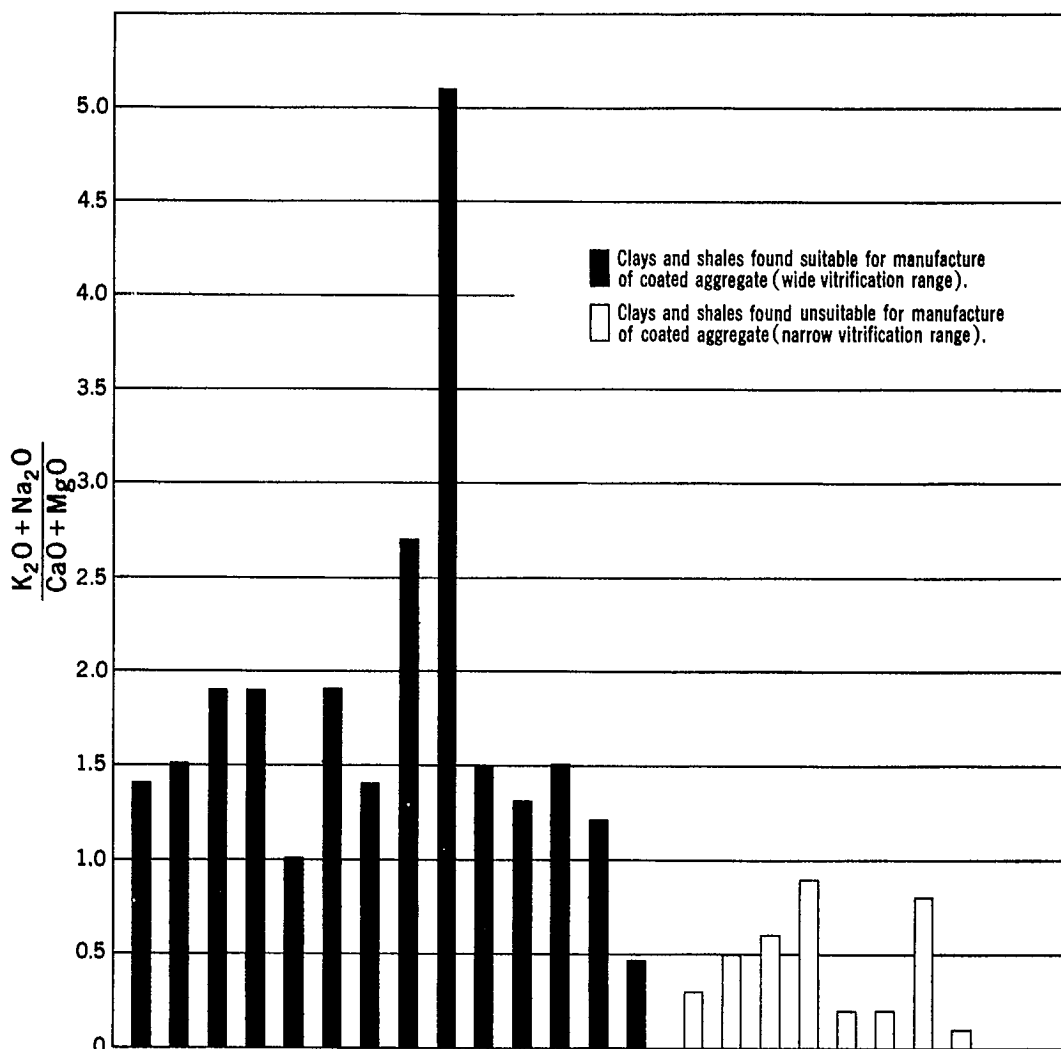


Figure 3 - Relationship of type of fluxes in clays and shales to width of vitrification range.

still be enough to allow good bloating of the coarse sizes. Otherwise, the feed has to be separated in at least two size ranges and each fired separately. In actual practice the vitrification range should be wide enough to allow bloating over a range of at least 50°F below the temperature at which sticking becomes excessive.

The chemical analysis of a clay or shale appears to be valuable for defining the two conditions necessary for producing a coated aggregate namely, viscosity and vitrification range, but is of no known value in determining whether or not the required gas-forming compound is present. A material to be suitable for the production of coated lightweight aggregate should have proportions of silica, alumina, and total fluxes as defined in the composition diagram shown in Figure 2 and an excess of the $K_2O + Na_2O$ fluxes over the $CaO + MgO$ fluxes as illustrated in Figure 3.

Figure 4

SUMMARY OF LIGHTWEIGHT AGGREGATE TEST RESULTS - BRITISH COLUMBIA

Materials having good possibilities for coated lightweight aggregate.		Materials that are good bloomers but are not considered suitable for coated aggregate because of sticking and agglomerating characteristics.		Materials that are poor bloomers.		Materials that are too refractory (show no bloating or fusion when fired in the stationary kiln at 2400°F for 5 minutes).		Materials that are not sufficiently uniform in bloating qualities.	
Location	Sample No.	Location	Sample No.	Location	Sample No.	Location	Sample No.	Location	Sample No.
Enderby	3	Quilchena	13, 15	Golden	1, 2	Quilchena	10, 11, 12	Fernie	16
Hope	61, 62	Kimberley	17	Kamloops	4, 5, 6, 7		14	Princeton	23, 29
Kilgard	66	Princeton	30, 38	Chase	8	Princeton	21, 25		31, 33
McNab Creek	74	Haney	69	Falkland	9		32, 34		36, 39
Victoria	75			Kimberley	18, 19		35, 53		40, 43
Hillbank	77, 78			Grand Forks	20		54, 55		44, 57
East Wellington	80			Princeton	22, 24		56, 58		
Gabriola Isd.	81				26, 27		59		
					28, 37	Kilgard	64, 65		
					41, 42				
					45, 46				
					47, 48				
					49, 50				
					51, 52				
					60				
				Hope	63				
				Kilgard	67				
				Bear Creek	68				
				Port Moody	70				
				Barnet	71, 72				
					73				
				Saanichton	76				
				Somenos	79				
				Campbell River	82				

CLAYS AND SHALES IN BRITISH COLUMBIA

General Distribution

British Columbia, the third largest province in Canada, has an area of approximately 364,000 square miles. Although it extends about 750 miles from north to south, 80 per cent of the population lives within 135 miles of the southern boundary.

Lightweight concrete aggregate is a relatively low priced material which cannot be transported economically more than 200 to 300 miles. This investigation was limited, therefore, to the southern mainland and the eastern coastal area of Vancouver Island mainly between Victoria and Nanaimo.

Clays (11)

Occurrences of surface clays are quite widely distributed in the areas investigated. On Vancouver Island and on some of the gulf islands they are mainly of Puyallup Interglacial age. The most common are yellowish-grey in colour and somewhat sandy. They may be 10 to 15 feet in thickness and are seldom found at elevations of more than 250 feet above sea level.

The clays on the mainland are of both Interglacial and Recent ages. A clay similar to the Puyallup Interglacial on Vancouver Island is found near the northeast shore of Howe Sound, on some islands in the Sound, and along the shore as far west as Sechelt. A blue clay occurs in places north of Burrard Inlet from Capilano to Port Moody and along the north shore of the Fraser River valley in the vicinity of Haney. A grey sandy clay occurs in the Fraser River valley in the vicinities of Ruskin, Sullivan, Port Moody, and other locations. The clay deposits of the interior are limited to isolated occurrences.

Bentonite, a clay composed chiefly of montmorillonite, occurs at several locations in the interior of the province, the largest deposits being found near Princeton and Quilchena. Other deposits are near Kamloops and Prince George.

Shales (11)

The shales on Vancouver Island and on some of the islands off the east coast are all of Cretaceous age. They are known to occur near Nanaimo, Hillbank, Duncan, and on Gabriola and Pender Islands.

Shales are not prevalent on the mainland and except for isolated deposits in the interior, they mostly occur in the lower Fraser River Valley. They are all of Tertiary age and occur at Sumas Mountain, Blue Mountain, on the south side of Burrard Inlet just east of Vancouver and along Whonnock Creek and the Stave River north of the Fraser River. Some shales also occur in conjunction with the bentonites at Princeton.

Locations, Descriptions, and Test Results

Eighty-two samples from 24 locations were tested. Of these, 10 appeared to have good possibilities as raw materials for a coated type of aggregate; 6 showed good bloating characteristics but owing to agglomeration at the bloating temperature, were not considered suitable for coated aggregate; 38 were poor bloomers; 17 were too refractory; and 11 were not sufficiently uniform.

Descriptions of the occurrences sampled and the results of the laboratory tests follow.

Golden*

A deposit of yellowish-coloured, very plastic, bentonite clay (Sample 1) occurs on the west side of Highway 1, 13½ miles north of Golden.

* Description and test work by J.G. Matthews.

It is exposed along the roadside for 300 feet. The bottom of the deposit was not reached in a 5-foot bore hole.

The sample when tested in the stationary furnace proved to have a narrow vitrification range fusing to a glassy mass with only slight indications of bloating.

A soft, green, talc schist (Sample 2) is exposed in abundance where Highway 1 crosses the Blaeberry River approximately 15 miles north of Golden. This material gave a non-uniform product in the stationary furnace. Parts were well expanded but with a high (glassy) degree of fusion while other parts showed no expansion.

Enderby*(12)

The deposit is on the east side of the Canadian Pacific Railway branch line to Sicamous, approximately one mile north of the town of Enderby. It was once worked as a brickyard by Percy A. Gorse, Salmon Arm. It consists of 4 feet of light brown, somewhat sandy, clay (Sample 3) underlain by a brownish coloured sand. Overburden is less than a foot deep. No definite information is available on the lateral extent of the deposit but it appears to be quite large.

This clay gave a well bloated product when tested in the stationary furnace and had a wide vitrification range as evidenced by the low degree of surface fusion. The fine nature of the material necessitated pelletizing before firing in the rotary kiln. The kiln operating temperature was the range 2070°F - 2110°F. Agglomeration of the charge started at 2100°F. The product crushed to -3/8 inch + 8 mesh had a bulk density of 64 lb./cu.ft. and a crushing strength for 1 inch compaction of 113 lb./sq. in., giving a crushing strength-to-weight ratio of 17. Volume expansion was

* Description and test work by J.G. Matthews.

low at only 5 per cent. The comparatively high bulk density and low volume expansion was largely due to the extreme thickness of coating on the particles. Most particles had a well bloated interior surrounded by 1/8 inch or more of unbloated material. Evidently during firing this thickness of outer surface was completely oxidized while the gases responsible for bloating were escaping. Greater compaction of the pellets would hinder the escape of gases and very likely reduce the thickness of the coating. The important point shown in the test is that the material is capable of bloating at a temperature below that at which agglomeration occurs, which gives it definite possibilities as a raw material for the manufacture of coated lightweight aggregate.

Kamloops⁽¹²⁾

High banks of a brownish silt extend for several miles along both sides of the South Thompson River in the vicinity of Kamloops. The exposed material rises up to 100 feet above the river valley. Three samples of this material (Samples 4, 5 and 6) were taken between Kamloops and Pritchard, 25 miles to the east. Tests showed that the material in all three samples has a short vitrification range accompanied by only slight bloating.

South of Kamloops on the Merritt Highway, various scattered exposures of a very plastic, green clay containing fragments of chlorite are found immediately under the topsoil. Sample 7 was taken from one of these occurrences at a point 8 miles south of Kamloops where a two-foot width of the clay is exposed on the roadside. When fired in the stationary furnace this material proved to have a narrow vitrification range giving a product at 2400°F with a high degree of fusion and only a slight amount of bloating.

Chase

A brown, sandy clay (Sample 8) is found in a highway cut 7 miles west of Chase which is 30 miles east of Kamloops. This clay is exposed to a

depth of 15 feet and a length of 250 feet along the highway and is covered by 3 feet of overburden. When tested in the stationary kiln, it proved to be a poor bloater fusing to a glass with only slight bloating.

Falkland

A grab sample (9) was taken from an inactive brick plant at Falkland, 40 miles southeast of Kamloops. When tested in the stationary kiln, this greyish-coloured surface clay showed only slight bloating and had a short firing range.

Quilchena*

A 13 $\frac{1}{2}$ -foot bed of bentonite outcrops in at least 3 locations over a distance of one mile along the Quilchena Creek Valley approximately 2 miles south of Quilchena post office. The bentonite bed dips into the valley sides at an angle of about 45° so that the amount of overburden increases rapidly. The deposit is not particularly uniform in physical appearance, some of it being massive, some well laminated, some sandy and some free from grit. Colour varies from dark brown to buff to yellowish-green. A section of the deposit was noted as follows:

Top soil	2 to 3 feet.
Shale (parts bentonitic)	3 feet.
Lignite	3 feet.
Bentonite, dark brown (Sample 15)	2 feet.
Bentonite, yellowish-green, laminated (Sample 14)	1.5 feet.
Bentonite, cream-coloured, sandy (Sample 13)	5 feet.
Bentonite, yellowish-green, laminated (Sample 12)	1.5 to 2 feet.
Bentonite, buff-coloured, massive (Sample 10)	2 feet.
Bentonite, yellowish-green, few laminations (Sample 11)	1 foot.
Lignite	8 feet.

* Description and test work by J.G. Matthews.

Samples 10, 11, 12, 14 when fired in the stationary furnace proved to be too refractory to be considered for aggregate manufacture. When fired for 5 minutes at 2400°F none of these materials showed any indications of bloating or fusing. Samples 13 and 15 both gave a well bloated product in the stationary furnace but the rotary kiln tests made on these materials gave poor products. The maximum allowable operating temperature of the kiln was 2060°F for Sample 13 and 2150°F for Sample 15 to avoid serious agglomeration of the feed. Below these temperatures there was little indication of expansion of either material.

Fernie*

There are abundant exposures of shale along Coal Creek between Fernie and the Coal Creek mines. A 10-foot width of hard black shale was sampled from an outcrop along the Coal Creek road $3\frac{1}{2}$ miles east of Fernie station (Sample 16). When tested in the stationary furnace this material proved to be non-uniform. Part of the sample bloated well but the remainder showed no bloating.

Kimberley*

Samples of sericitic argillite (Sample 17), chloritic argillite (Sample 18) and massive argillite (Sample 19) were taken from the waste rock of the Sullivan mine of The Consolidated Mining and Smelting Company of Canada Limited at Kimberley. The sericitic argillite bloated very well when fired in the stationary furnace at 2400°F but it had a narrow vitrification range indicating that it probably would give sticking trouble if attempts were made to treat it in the rotary kiln. The chloritic argillite showed only slight bloating and was almost completely fused at 2300°F when fired for 5 minutes. The massive argillite showed no bloating and a high degree of surface fusion when fired in the stationary furnace at 2400°F for 5 minutes.

* Description and test work by J.G. Matthews.

Grand Forks*

A representative sample was secured of the flood plain clay formerly utilized by Loves Brick Limited at Grand Forks, 60 miles west of Trail. The deposit appears to have a wide lateral extent. A geological section was noted as follows:

Top soil	$\frac{1}{2}$ foot
Light brown clay (Sample 20).	$2\frac{1}{2}$ feet
Fine grained silt	3 feet

When fired in the stationary furnace, this material (Sample 20) showed only slight bloating and a high degree (glassy) of surface fusion.

Princeton*

Tertiary shales of the Princeton Group outcrop abundantly in the Princeton sedimentary basin which according to Ries⁽¹³⁾ occupies an area 15 miles long by $2\frac{1}{2}$ to $4\frac{1}{2}$ miles wide. Several occurrences of shale and bentonite were sampled in this area.

Interbedded shale, coal, sandstone and bentonite outcrop on the eastern outskirts of the town of Princeton on the property of the old Princeton Collieries. The following geological section was measured.

Sand and gravel overburden	10 to 30 feet.
Reddish-brown shale (Sample 28)	3 feet.
Iron-stained, black shale (Sample 27)	12.5 feet.
Laminated, soft, grey sandstone	5 feet.
Black carbonaceous shale with 6" coal	2 feet.
Coal	4 feet.

* Description and test work by J.G. Matthews.

Hard black shale (Sample 26)	3.5 feet.
Soft grey shale (sandy)	2 feet.
Interbedded sandstone and shale	1 foot.
Laminated, soft, grey sandstone	1 foot.
Hard black shale	1 foot.
Cream-coloured bentonite (Sample 25)	1 foot.
Black carboniferous shale	1 foot.
Highly carbonaceous shale (Sample 24)	3.5 feet.
Dark grey shale, sandy towards bottom (Sample 23)	3 feet.
Black carbonaceous shale (Sample 22)	10 feet.
Concealed	±5 feet.
Coal	±10 feet.
Cream-coloured bentonite (Sample 21)	1 foot.
Coal	Not measured

The two samples of bentonite (21 and 25) when fired in the stationary furnace proved to be too refractory. Both materials showed no indications of bloating or fusing when fired at 2400°F for 5 minutes.

Stationary furnace tests on Samples 22, 24, 26, 27 and 28 proved all to be too high in carbon. In all cases, only a thin shell on the surface of the particles showed any bloating while the core consisted of a soft, black carbonaceous mass completely devoid of any bloating. The sudden short heat treatment to which the materials were subjected prevented the oxidization and removal of the excess carbon which must be removed before any bloating takes place. Prolonged pre-heat at 1550°F to remove the excess carbon would undoubtedly improve the bloating characteristics of these materials. In view of the high carbon content, none of the materials were tested in the rotary kiln.

Sample 23 proved to be non-uniform when tested in the stationary furnace. Part of the sample bloated well with a low degree of surface fusion while other particles showed no bloating. These qualities were confirmed in the rotary kiln test. Serious agglomeration of the charge started at 2000°F. Below this temperature the product formed was non-uniform and had a volume expansion of only 5 per cent.

A large bed of bentonite is exposed on the Copper Mountain railway on the south half of lot 2925S about 5 miles south of Princeton. The strike of the deposit is approximately east-west and the dip approximately 30° to the south paralleling the hillside. Samples of the bentonite as well as the underlying and overlying bentonitic shales were secured for lightweight aggregate tests. A geological section of the deposit was noted as follows:

Light brown soft, bentonitic clay (Sample 40)	6 feet.
Bentonitic sandstone	4 feet.
Light brown, soft bentonitic clay (Samples 37, 38, 39)	21 feet.
Light brown bentonitic shale (Sample 36)	1 foot.
Cream-coloured bentonite grading to light brown colour (Sample 35)	1 foot.
Yellow bentonite (Sample 34)	7 feet.
Brown bentonite containing carboniferous material (Sample 33) . .	1 foot.
Yellow bentonite (Sample 32)	7.5 feet.
Yellow bentonite with carbonaceous material (Sample 31)	0.5 feet.
Light brown bentonitic shale (Sample 30)	1 foot.
Grey bentonite sandstone	1.5 feet.
Light grey, bentonitic shale (Sample 29)	4 feet.
Light grey sandstone	Not measured.

Stationary furnace tests showed only one sample (29) worthy of rotary kiln testing. This material proved to be non-uniform in its bloating characteristics when fired in the stationary furnace although most of it was well bloated with a low degree of surface fusion. When fired in the rotary kiln, however, troublesome sticking and agglomerating began at a temperature at which there was very little bloating. The rotary kiln product was also non-uniform. Overall volume expansion was only 5 per cent.

Sample 30 bloated well in the stationary furnace but had a high degree of surface fusion. It was not tested for the latter characteristic in the rotary kiln.

Samples 32, 34 and 35 when tested in the stationary kiln proved refractory, showing no bloating and only slight fusion when fired at 2400°F for 5 minutes. Samples 31, 33 and 36 lacked sufficient uniformity to warrant testing in the rotary kiln. Sample 37 representing the lower 5 feet of soft brown bentonitic clay proved to be a poor bloater in the stationary furnace.

Sample 38 representing the bentonitic clay overlying Sample 37 gave a well bloated product in the stationary furnace when fired at 2400°F but the degree of surface fusion was considered to be too high to warrant testing in the rotary kiln.

Samples 39 and 40 behaved alike in their bloating characteristics. Both materials were non-uniform. When fired at 2400°F in the stationary furnace much of the material was well bloated but with a high degree of surface fusion. Both contained a considerable amount of material that showed no bloating characteristics at this temperature.

Large tonnages of brick red and buff-coloured shale are exposed with less than 5 feet of overburden, approximately $\frac{1}{2}$ mile west of the

Princeton-Hope highway, 10 miles southwest of Princeton. Sample 41 represented a 10-foot width of the brick red shale and Sample 42 a 20-foot width of the buff-coloured shale. When tested in the stationary furnace both materials proved to be poor bloaters and to have narrow vitrification ranges. The materials fused quickly to a glassy mass leaving a considerable amount of metallic iron.

Buff and light grey-coloured shales occur under shallow overburden in the vicinity of the mine of Taylor Burson Coal Company Limited about 5 miles southwest of Princeton. Samples 43 and 44 were grab samples of the buff and light grey-coloured shale taken on the west side of the mine. Both materials proved to be non-uniform. Sample 43 proved to be a poor bloating material in the stationary furnace. Sample 44 bloated well in part but the remainder was evidently too high in carbon and showed no bloating. Samples 45 and 46 were grab samples of buff-coloured shale overlying and underlying a seam of coal exposed in an old adit just east of the Taylor Burson mine. Stationary furnace tests showed both materials to be poor bloaters. Both were too high in carbon, as only a thin shell on the particles of each material showed slight bloating while the interior of the particles consisted of an unbloated, black mass.

Several beds of shale are exposed on the south half of lot 88 in the workings of the Taylor Burson mine. A cross section of the beds taken underground starting 10 feet beyond the seam being mined and working to the portal was noted as follows:

Shale (Sample 47)	10 feet
Coal	4 feet
Black shale (Sample 48)	5 feet
Sandstone	10 feet

Black shale (Sample 49)	5 feet
Sandy shale (Sample 50)	4 feet
Light grey, hard shale (Sample 51).	4 feet
Coal	4 feet
Massive black shale (some iron stain)(Sample 52).	11 feet
Unconsolidated overburden to portal	Not measured.

All of the above shales i.e., Samples 47 to 52 inclusive, proved to be high in carbon and because of this gave poor bloating results when fired in the stationary furnace. As with other high carbon materials, only a thin shell on the particles showed any indication of bloating while the interior consisted of a black unbloated carbonaceous core.

Large amounts of shale are exposed at the black strip mine approximately $\frac{1}{2}$ mile south of the Taylor Burson mine. The shale overlying the coal has a thickness of at least 30 feet. Sample 53, a grab sample of this material, proved to be quite refractory. When fired at 2400°F in the stationary furnace there were no indications of bloating and only a slight amount of fusion.

A large deposit of bentonite owned by Princeton Properties Limited outcrops at mileage 1 on the Copper Mountain railway. A bentonite bed believed to be the same deposit is exposed approximately one mile distant on the line of strike on the north side of the upper Allenby tailings dump. At mileage 1 the bentonite, when formerly opened underground had a thickness of 15 feet but surface sampling during the investigation showed only a width of 6.5 feet, the weight of the overlying beds evidently having pinched the exposure. A geological section of the deposit was noted as follows:

Concealed	0 - 50 feet
Interbedded sandstone and shale . . .	12 feet
Bentonite varying from yellow to brown colour (Sample 57)	1 foot
Massive yellow bentonite (Sample 56) . .	3 feet
Yellow- brown bentonite (Sample 55) . . .	1.5 feet
Massive yellow bentonite (Sample 54) . .	1 foot
Lignitic shale (2") grading to brown, sandy bentonitic shale.	2.5 feet
Soft, grey weathering sandstone	4 feet
Reddish-brown carbonaceous shale (parts sandy)	5 feet
Interbedded grey weathering, soft sandstone and brown carbonaceous shale	5 feet
Massive grey weathering sandstone. . . .	25 feet

A geological section measured of the bentonite exposed at the upper Allenby tailings dump was as follows:

Reworked, dirty bentonite containing glacial pebbles	0 - 3.5 feet
Yellow bentonite with dark grey laminations (Sample 59)	1 foot
Massive yellow bentonite (Sample 58) . . .	1 foot
Lignitic shale (2") grading to light grey, sandy bentonitic shale	2 feet
Light brown bentonitic shale	4 feet
Fairly massive, grey weathering sandstone	Not measured

All of the above bentonite samples with the exception of Sample 57 proved to be too refractory, showing no indications of bloating or fusing

when fired at 2400°F for 5 minutes in the stationary furnace. Sample 57 proved to be non-uniform. Part of the sample was well bloated but with a high degree of surface fusion when fired at 2400°F while the remainder showed no bloating.

A sample of the tailings (Sample 60) from the upper Allenby tailings dump was secured and tested with unfavourable results. This material proved to be a poor bloater showing only slight bloating with a high degree of surface fusion (glassy) when fired at 2400°F in the stationary furnace for 5 minutes.

Hope

Three samples of material were submitted from the vicinity of Hope, 120 miles east of Vancouver. The location, however, is rather unfavourable being 12 miles from the nearest road.

Samples 61 and 62 were mainly black shale but contained some grey sandstone. The shale appears to be quite extensive, one outcrop having an exposure of 40 feet by 25 feet. Both samples of shale bloated very well when fired in the rotary kiln. The sandstone however did not bloat. Sample 62 expanded 100 per cent when fired at 2020°F to 2050°F. The product had a bulk density of 39 lb./cu.ft. and a crushing strength of 1900 lb./sq.in. Sample 61 produced a product having a bulk density of 35 lb./cu.ft. and a crushing strength of 1150 lb./sq.in. when fired at 2000°F to 2070°F. The expansion was 115 per cent.

Sample 63 was a fine grained basic lava which did not bloat but fused to a glass when fired at 2300°F.

Kilgard

An extensive series of shales occurs at the southwest extremity of Sumas Mountain about 50 miles east of Vancouver. The shales which are

of Tertiary age are interbedded with sandstones and conglomerates. Four samples of shale from this area were tested.

Samples 64 and 65 were from the property of Clayburn Company Limited. Sample 64 was a red shale and Sample 65, a buff shale. Both materials were too refractory to be used as lightweight aggregate. When tested in the Remmey kiln, fusion began only when a temperature of 2600°F was used.

Sample 66 was a grab sample from the plant of Fraser Valley Brick Company Limited which produces a dry press face brick from a black and brown mottled concretionary shale. The deposit which is 15 feet in depth is on the western slope of Sumas Mountain. When tested in the rotary kiln approximately 50 per cent of the material did not bloat while the remainder bloated very well. The overall volume expansion was 40 per cent when fired at a temperature of 2020°F to 2040°F. The aggregate had a bulk density of 50 lb./cu.ft. and a crushing strength for one inch compaction of 2700 lb./sq.in. Despite the fact that only half of the shale has bloating qualities, the product appears to be low enough in weight to give a satisfactory lightweight aggregate.

A sample of brown shale from Abbotsford about 5 miles west of Kilgard was submitted for testing. This sample (67) apparently was from quite an extensive deposit. The shale proved to be a poor bloater as no bloating occurred below the agglomerating temperature.

Bear Creek

The Bear Creek Brick Company in the Surrey district 10 miles southeast of New Westminster uses a blue clay in the production of brick. The deposit is opened to a depth of 15 feet. In the stationary kiln test, this clay (Sample 68) fused without any signs of bloating. Thus it would not be suitable for lightweight aggregate.

Haney

Raw material from a 50-foot deposit of clay adjacent to the plant is used in the production of structural and drain tile by Port Haney Brick Company, Limited. The clay tested was the mixture of the blue and brown clay used in the plant. When fired in the rotary kiln at from 1970°F to 2000°F this clay (Sample 69) expanded only 10 per cent. The particles began to expand fairly well just at the agglomerating temperature which was 2000°F. Below that the bloating was very slight. This would indicate that this clay would probably not be suitable for a coated aggregate but should produce a good sintered product. The product from the test, a portion of which was not bloated, had a bulk density of 54 lb./cu.ft. and a crushing strength of 2900 lb./sq.in.

Port Moody

A deposit of grey, sandy, Pleistocene clay occurs 3 miles east of Port Moody which is 10 miles east of Vancouver and near the eastern end of Burrard Inlet. Two inactive brick plants were formerly operated side by side on the deposit. Sample 70 was taken from a 7-foot face of the deposit. In the stationary kiln tests this material showed no bloating before it fused at 2300°F.

Barnet

Mainland Clay Products Limited uses a friable shale for making brick at Kask's Corner near Barnet, 5 miles east of Vancouver on the southern shore of Burrard Inlet. The deposit has been opened to a depth of 15 feet and a length of 100 feet. The northern end of this north-south face has been somewhat weathered.

Sample 71 was of the weathered portion and Sample 72 from the unweathered portion of the face. Neither sample showed any bloating below the temperature where each became fused to a glass.

Thirty feet below the shale exposure, just above the railway track, a dense, fine-grained clay (Sample 73) outcrops to a depth of 8 feet. This material bloated only slightly below the fusion temperature and thus would be unsuitable for the production of lightweight aggregate.

McNab Creek

A black slate (Sample 74) is being quarried near the village of McNab Creek on the western shore of Howe Sound northwest of Vancouver. This material is used by Richmix Clays Limited, Vancouver, for the production of roofing granules. It is also used by B.C. Clay Products Limited, Vancouver for making flower pots.

The slate expanded 65 per cent when fired at 2050°F to 2100°F in the rotary kiln. It did not give rounded particles but exfoliated, giving a rather angular shape. The product has a bulk density of 38 lb./cu.ft. and had a crushing strength of 1910 lb./sq.in. Because of its rather open structure, the absorption would probably be high but otherwise it has quite good possibilities for a coated lightweight aggregate.

Victoria

A 25-foot deposit of rather stoney surface clay is the source material used by Baker Brick & Tile Company Limited of Victoria in making brick, tile and flower pots. A fairly light aggregate was produced from this clay (Sample 75) when fired in the rotary kiln at 2000°F to 2020°F. It had an expansion of 35 per cent but bloated in rather an odd manner. Gases formed near the surface apparently escaped when bloating occurred in the interior of the particles and the surface cracked allowing a blister-like formation to emerge. The interior of the particles seemed quite well bloated but the particles generally retained their angular shape. The bulk density of the aggregate was 46 lb./cu.ft. and the

crushing strength was 1110 lb./sq.in. These properties indicate that this material has possibilities for the production of coated lightweight aggregate.

Saanichton

Brick and drain tile are produced from a greyish surface clay (Sample 76) by Bazan Bay Brick and Tile Company Limited near Saanichton, 12 miles north of Victoria. This material has a short vitrification range as it did not bloat below the fusion temperature when fired in the rotary kiln.

Hillbank (12)

A Cretaceous shale of the Haslam formation occurs near Hillbank, 8 miles south of Duncan on Vancouver Island. This 20-foot deposit of shale which appears to be quite extensive is used by the Cowichan Metallic Brick Limited in the production of brick. The upper 4 feet of the deposit is slightly weathered. Samples of that material (Sample 77) and of the lower unweathered shale (Sample 78) were taken.

A well bloated product was obtained from each of these samples. Both well rounded and slightly angular particles resulted. Sample 77 expanded 100 per cent giving an aggregate of 30 lb./cu.ft. bulk density and 1600 lb./sq.in. crushing strength. The firing temperature was 1990°F. to 2030°F. Sample 78 was fired at 2000°F to 2030°F. The expansion was 130 per cent; the bulk density was 29 lb./cu.ft., and the crushing strength, 1750 lb./sq.in.

Somenos

Two brick plants were operated at one time near Somenos 4 miles from Duncan although there is no evidence of their existence now. A grab sample of grey surface clay (Sample 79) from the approximate location of

one of these plants proved to be a non-bloater. When tested in the stationary kiln this clay did not bloat below the temperature at which fusion took place.

East Wellington(12)

Mountain Brick and Tile Company at one time produced brick from a deposit of the Nanaimo series of Cretaceous shale at East Wellington, 4 miles from Nanaimo on the eastern coast of Vancouver Island. Sample 80 was taken from a cut through this deposit. The extent of the deposit is not known but 8 feet of shale was exposed in the cut and overlain by 6 feet of overburden. This shale bloated 145 per cent when fired at 1950°F to 2000°F in the rotary kiln. The particles expanded very well but retained an angular shape. The bulk density of the aggregate was 30 lb./cu.ft. and the crushing strength for one inch compaction was 1110 lb./sq.in. This shale shows considerable promise for a coated lightweight aggregate.

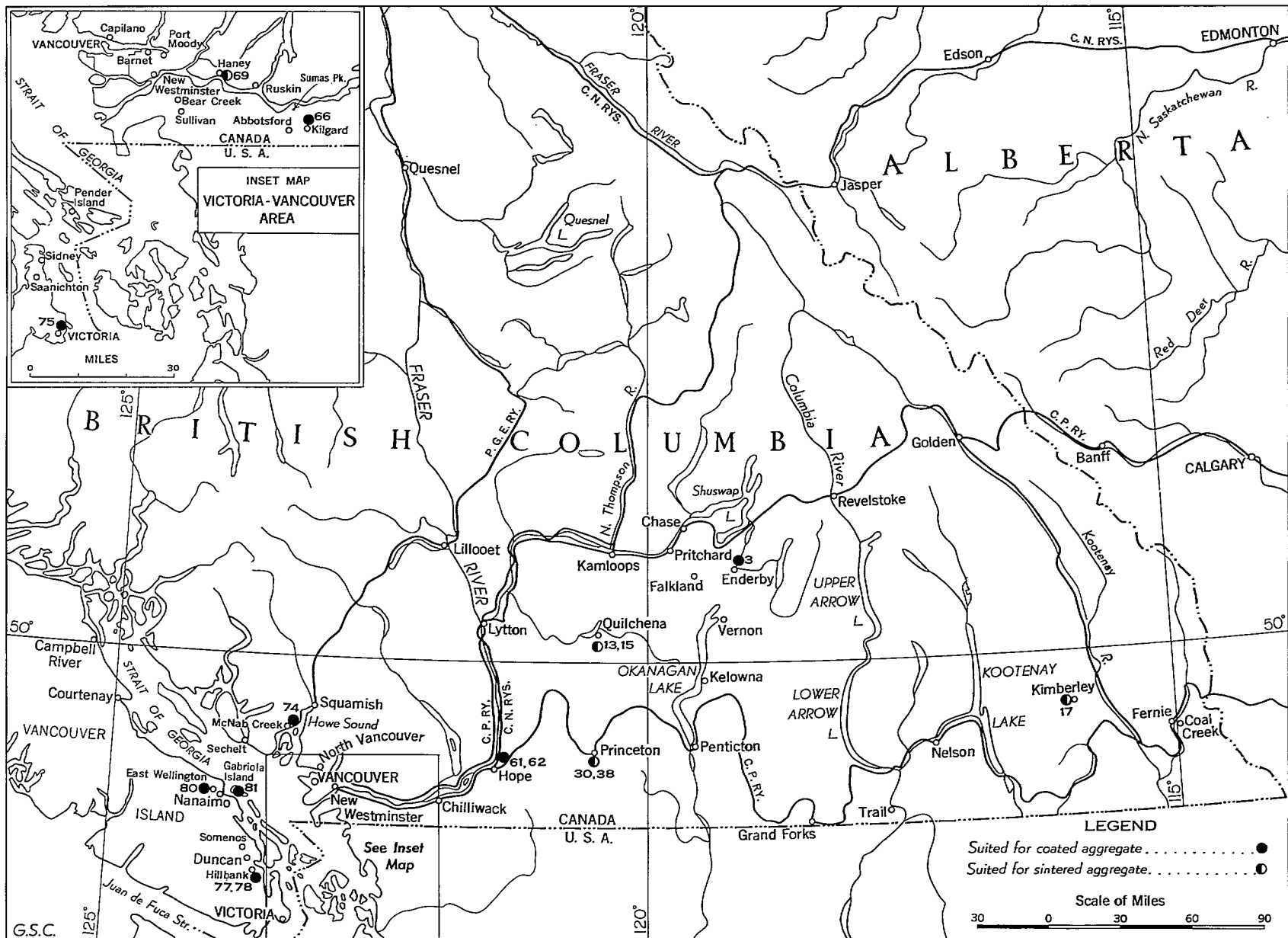
Gabriola Island

A deposit of the Northumberland formation Cretaceous shale was formerly worked by Evans Coleman and Evans Limited for the production of brick, 5 miles south of the Nanaimo ferry landing. This shale (Sample 81) also shows promise as a raw material suitable for coated lightweight aggregate production. The expansion was only 10 per cent but the quite well rounded particles had a bulk density of 48 lb./cu.ft. and a crushing strength of 4100 lb./sq.in.

Campbell River

Sample 82 which was submitted for testing was a fine grained grey clay from Campbell River, about 100 miles north of Nanaimo on the east coast of Vancouver Island. It had a short vitrification range as it did not bloat below the temperature at which fusion occurred.

* * * * *



Map of Southern British Columbia showing approximate locations of clays and shales suitable for coated aggregate and those unsuitable for coated aggregate due to agglomeration.

REFERENCES

1. Jackson, T.E.: Discussion of the paper, Changes in Color of Clays on Ignition in Clayware Kilns, by Arthur Hopwood, Trans.Ceram.Soc. (England), 1903, pp. 37-43.
2. Orton, E., and Staley, H.: A Study of Chemical Status of the Carbon, Iron and Sulphur in Clays During Various Stages of Burning; Third Rept., National Brick Manufacturers Association (1909).
3. Wilson, H.: Ceramics - Clay Technology; McCraw-Hill Book Co. Inc., New York, 1927, 296 pp.
4. Bleininger, A.V. and Montgomery, E.T.: Effect of Over-Firing upon the Structure of Clays; Nat.Bur. of Standards, T.P. 22 (1913), 23 pp.
5. History and Properties of Lightweight Aggregates; Eng. News Record (1919) 82, 802.
6. Jackson, F.G.: Oxidation of Ceramic Ware during Firing: II, Decomposition of Various Compounds of Iron with Sulphur under Simulated Kiln Conditions; Jour. Am. Ceram. Soc. Vol. 7, pp. 223-237, 1924.
7. Sullivan, J.D., Austin, C.R., and Rogers, E.J.: Expanded Clay Products; A.I.M.E. Tech. Pub. 1485.
8. Austin, C.R., Nunes, J.L., and Sullivan, J.D.: Basic Factors Involved in Bloating of Clays; A.I.M.E. Tech. Pub. 1486.
9. Conley, J.E., Wilson, H., Klinefelter, T.A., et al: Production of Lightweight Concrete Aggregates from Clays, Shales, Slates and Other Materials; U.S. Bur. of Mines Rept. of Investigations, No. 4401, 121 pp. 1948.
10. Riley, C.M.: Relation of Chemical Properties to the Bloating of Clays; Jour.Am. Ceram. Soc., Vol. 34, 4 pp. 121-128 (1951).
11. Cummings, J.M., and McCammon, J.W.: Clays and Shale Deposits of British Columbia; B.C. Dept. of Mines Bull.No. 30, 64 pp. (1952).
12. Ries, H., and Keele, J.: Clay and Shale Deposits of the Western Provinces, Part 1, G.S.C.Memoir 24E, 221 pp. (1912).
13. Ries, H.: Clays and Shale Deposits of the Western Provinces, Part III, G.S.C. Memoir 47, 66 pp. (1914).

